VTRC
Virginia Transportation
Research Council

Performance of Bridge Deck Overlays in Virginia: Phase I: State of Overlays

http://www.virginiadot.org/vtrc/main/online_reports/pdf/17-r17.pdf

SOUNDAR S.G. BALAKUMARAN, Ph.D.
Research Scientist
Virginia Transportation Research Council

RICHARD E. WEYERS, Ph.D., P.E.
Professor Emeritus
Department of Civil and Environmental Engineering
Virginia Polytechnic Institute and State University

MICHAEL C. BROWN, Ph.D., P.E.
Senior Supervising Engineer
Parsons Brinckerhoff

Final Report VTRC 17-R17

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginiadot.org

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 17-R17	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Performance of Bridge Deck Overlays in Virginia: Phase I: State of Overlays		5. Report Date: May 2017 6. Performing Organization Code:
7. Author(s): Soundar S.G. Balakumaran, Ph.D., Richard E. Weyers, Ph.D., P.E., and Michael C. Brown, Ph.D., P.E.		8. Performing Organization Report No.: VTRC 17-R17
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 105230
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:
15. Supplementary Notes:		

16. Abstract:

Maintaining the existing transportation infrastructure is a major concern of the Virginia Department of Transportation (VDOT). The increased user travel costs, safety concerns, and financial burdens involved in replacing deteriorating decks are reasons for finding appropriate rehabilitation actions that can safely extend the service life of structures.

Virginia has been a leader in employing overlays as a rehabilitation method for bridge decks. VDOT's Manual of the Structure and Bridge Division contains guidance for the decision-making process related to maintenance and repair of structures. Yet there is a need to update the guidelines based on contemporary experience and the knowledge gained through technological advances.

This report presents and discusses the preliminary findings of Phase I of a multi-phase study to determine the performance of bridge deck overlays in Virginia. Phase I focused on obtaining information regarding the experiences of VDOT's nine districts with regard to their use of different kinds of overlays and the factors that influence which overlays are used. In addition, VDOT's bridge inventory was analyzed to gain an understanding of the types of overlay systems used in Virginia.

The overlay types identified to be the most commonly used by the nine VDOT districts were latex-modified concrete, epoxy concrete, silica fume concrete, very-early-strength latex-modified concrete, and hot-mix asphalt concrete with a water-resistant membrane. From interviews, wide ranges in service life, even for the same overlay type, were found in every VDOT district. The performance of overlays, irrespective of the type, was highly dependent on the construction workmanship and the attention paid to the crucial details. Another commonly observed influential factor was the degree of deck damage (i.e., deterioration) that existed when the overlay was installed; the higher the pre-overlay deck damage, the worse the performance of the overlay.

The study recommends that a Phase II study be conducted that will involve an investigation of the overlays for bridges in VDOT's bridge inventory, including a review of inspection reports and a field survey of a selected number of bridge decks. The study further recommends that factors identified in the Phase I study, such as age of overlays, traffic volume, and salt usage, be taken into account when the bridges are selected. The results will support appropriate modifications to the bridge maintenance guidelines as they pertain to deck overlays in VDOT's Manual of the Structure and Bridge Division.

17 Key Words: Overlays, bridge deck, deck protection systems, inventory, latex modified concrete overlay, thin epoxy overlay, very early strength LMC, asphalt overlay, service life extension	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.		
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 42	22. Price:

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

FINAL REPORT

PERFORMANCE OF BRIDGE DECK OVERLAYS IN VIRGINIA: PHASE I: STATE OF OVERLAYS

Soundar S.G. Balakumaran, Ph.D.
Research Scientist
Virginia Transportation Research Council

Richard E. Weyers, Ph.D., P.E.
Professor Emeritus
Department of Civil and Environmental Engineering
Virginia Polytechnic Institute and State University

Michael C. Brown, Ph.D., P.E.
Senior Supervising Engineer
Parsons Brinckerhoff

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

May 2017
VTRC 17-R17

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

ABSTRACT

Maintaining the existing transportation infrastructure is a major concern of the Virginia Department of Transportation (VDOT). The increased user travel costs, safety concerns, and financial burdens involved in replacing deteriorating decks are reasons for finding appropriate rehabilitation actions that can safely extend the service life of structures.

Virginia has been a leader in employing overlays as a rehabilitation method for bridge decks. VDOT's *Manual of the Structure and Bridge Division* contains guidance for the decision-making process related to maintenance and repair of structures. Yet there is a need to update the guidelines based on contemporary experience and the knowledge gained through technological advances.

This report presents and discusses the preliminary findings of Phase I of a multi-phase study to determine the performance of bridge deck overlays in Virginia. Phase I focused on obtaining information regarding the experiences of VDOT's nine districts with regard to their use of different kinds of overlays and the factors that influence which overlays are used. In addition, VDOT's bridge inventory was analyzed to gain an understanding of the types of overlay systems used in Virginia.

The overlay types identified to be the most commonly used by the nine VDOT districts were latex-modified concrete, epoxy concrete, silica fume concrete, very-early-strength latex-modified concrete, and hot-mix asphalt concrete with a water-resistant membrane. From interviews, wide ranges in service life, even for the same overlay type, were found in every VDOT district. The performance of overlays, irrespective of the type, was highly dependent on the construction workmanship and the attention paid to the crucial details. Another commonly observed influential factor was the degree of deck damage (i.e., deterioration) that existed when the overlay was installed; the higher the pre-overlay deck damage, the worse the performance of the overlay.

The study recommends that a Phase II study be conducted that will involve an investigation of the overlays for bridges in VDOT's bridge inventory, including a review of inspection reports and a field survey of a selected number of bridge decks. The study further recommends that factors identified in the Phase I study, such as age of overlays, traffic volume, and salt usage, be taken into account when the bridges are selected. The results will support appropriate modifications to the bridge maintenance guidelines as they pertain to deck overlays in VDOT's *Manual of the Structure and Bridge Division.*

FINAL REPORT

PERFORMANCE OF BRIDGE DECK OVERLAYS IN VIRGINIA: PHASE I: STATE OF OVERLAYS

Soundar S.G. Balakumaran, Ph.D.
Research Scientist
Virginia Transportation Research Council

Richard E. Weyers, Ph.D., P.E.
Professor Emeritus
Department of Civil and Environmental Engineering
Virginia Polytechnic Institute and State University

Michael C. Brown, Ph.D., P.E.
Senior Supervising Engineer
Parsons Brinckerhoff

INTRODUCTION

The construction of the U.S. Interstate System began in the late 1950s. In the early 1960s, bridge decks were spalling on the newly constructed bridges within as little as 5 years after being opened to traffic in the northern U.S. climates. In the same era, a "bare pavement" policy was instituted to maintain traffic throughout the winter months, which involved keeping the pavements clear of ice and snow throughout the winter using plowing, deicing, etc.; a result was a quadruple increase in the usage of chloride-bearing deicing salts during winter maintenance activities.

In the mid-1960s, research studies were initiated to identify the cause of the observed rapid rate of deterioration of concrete bridge decks. These studies were joint efforts among the U.S. Bureau of Public Roads (now the Federal Highway Administration [FHWA]), the Portland Cement Association, and select state highway departments. The primary cause of the observed deterioration was determined to be chloride-induced corrosion of the reinforcing steel. Recommendations were made to (1) reduce the water-to-cement ratio of the concrete, thereby reducing the rate of chloride penetration; (2) increase the cover concrete over the reinforcing steel (FHWA, 1976); and (3) improve the deck drainage to reduce the time the chloride-laden melt water was in contact with the deck surface concrete. Although implementation of these recommendations significantly increased the time from construction to patching and subsequent overlaying, overlaying was eventually required.

This report presents and discusses the preliminary findings of Phase I of a multi-phase study as a first step toward determining the performance of bridge deck overlays in Virginia. Phase I focused on obtaining information regarding the experiences of the nine districts of the Virginia Department of Transportation (VDOT) with regard to the use of different kinds of overlays and the factors that influence which overlays are used. As a way to complement the information gained from the districts, VDOT's bridge inventory (VDOT, 2015b) was analyzed with the use of AASHTOware BrM (Bridge Management Software) for the types of overlays used on VDOT bridges. In addition, findings from studies on overlays since the study under the Strategic Highway Research Program (SHRP) in 1993 (Weyers 1993) were compiled to add valuable information regarding the current research on the performance of bridge deck overlays.

Problem Statement

Overlays have been used with increasing frequency because of their effectiveness in extending the service life of bridge decks. The several types of overlays used in Virginia have varying degrees of efficiency. Making decisions regarding the type of overlay for a particular bridge generally depends on the urgency of the preservation need, the feasible scheduling and duration of traffic control, and the required level of service life extension. VDOT's *Manual of the Structure and Bridge Division,* specifically Chapter 32, "Maintenance and Repair," in Part 2 of the manual (VDOT, 2015a), lacks sufficient guidelines for deciding which type of first generation overlay and, moreover, second generation overlay system should be used.

The base concrete removal technique, quantity of contaminated base material removed, surface preparation technique followed prior to overlaying, and quality of operations are some of the factors that will affect the durability of the rehabilitation. It is essential to study the overlay systems and construction methods used in Virginia and their relative effectiveness in terms of service life extension and life cycle costs so that guidelines can be developed based on objective information and documented experience.

The first step in achieving an effective plan to study concrete bridge deck overlay systems used by VDOT is to conduct a search and analysis of pertinent databases to gain a preliminary understanding of the extent of use and relative performance of different bridge deck overlay systems in Virginia. This will facilitate the selection of subsets of VDOT bridge decks for more detailed study, with consideration of the list of parameters that primarily affect the service life performance of bridge deck overlays.

PURPOSE AND SCOPE

The purpose of this study was to identify the types of bridge deck overlays used by the VDOT districts and the extent of their use previously and currently to support a detailed Phase II study of the performance of bridge deck overlays in Virginia.

The scope of the study was limited to a literature review, an analysis of Virginia bridge databases, and interviews of personnel of the nine VDOT district bridge offices with regard to their use of particular overlays.

METHODS

Three tasks were performed to achieve the study objectives:

1. Conduct a literature review of the service life performance and factors that influence the use of bridge deck overlays since the publication of the 1993 report on this topic under SHRP (Weyers et al., 1993).

2. Search Virginia bridge databases to identify the number, composition, and age of overlaid bridges and their corresponding deck overlays.

3. Interview personnel of the nine VDOT district bridge offices to identify specific overlay practices.

Task 1: Literature Review

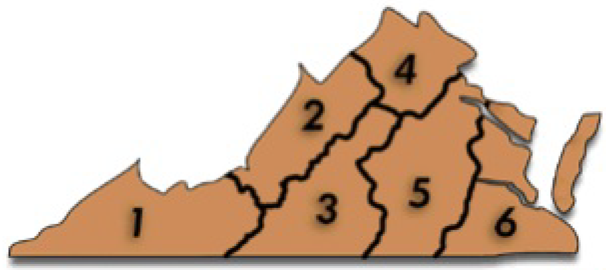
The literature related to service life performance and factors that influence the use of bridge deck overlays for the period 1993 to 2014 was identified. The literature search included peer-reviewed research conference papers and technical reports as identified from TRID, RiP, WorldCat, National Technical Reports Library, Civil Engineering Abstracts, Compendex, Web of Science, Mechanical and Transportation Engineering Abstracts, Proquest Dissertations and Theses, and ASCE Library. The Google State DOT Search Engine was also used to search research reports and documents from state departments of transportation (DOTs) describing practice related to bridge deck overlays.

Task 2: Search of Virginia Bridge Databases

Virginia has a variety of climate zones from Appalachian Mountains, to Coastal, to Piedmont flatlands. In addition, Virginia has widely different traffic conditions from Northern Virginia with one of the nation's highest traffic volumes, to Hampton Roads with seasonal traffic, to rural areas with less travelled roads. This makes Virginia's infrastructure a demanding one to preserve and maintain. Figure 1 shows the state divided into six climate zones based on climatic conditions and environmental exposure and salt usage (Williamson et al., 2007).

VDOT's nine districts (Figure 2) cover a wide range of environmental and traffic conditions, from very high deicing salt applications and traffic volumes in Northern Virginia, to very low deicing salt applications and very high seasonal traffic in Hampton Roads, to high deicing salt applications in moderate traffic in the Southwest.

VDOT's bridge inventory (VDOT, 2015b) was searched using AASHTOware BrM to identify characteristics of bridge systems and overlays in VDOT's nine districts.



Zone#	Environmental Zone Description	Notation	Salt Usage (kg-Cl-/lane-km)
1	Southwestern Mountain	SM	688
2	Central Mountain	CM	671
3	Western Piedmont	WP	220
4	Northern	N	4369
5	Eastern Piedmont	EP	530
6	Tidewater	TW	225

Figure 1. Virginia Climate Zones With Deicing Salt Usage

Figure 2. VDOT's Nine Districts

Task 3: Interviews of Personnel in VDOT District Bridge Offices

Table 1 presents the questionnaire used to interview personnel of the nine VDOT district bridge offices who were directly involved in maintaining bridges in their respective district. The questionnaire was developed to identify the types of overlays in use and the factors that might influence overlay service life performance. The factors used in developing the questionnaire were historical overlay conditions, traffic levels, corresponding superstructure type(s), deck condition-assessment techniques, and selection and construction of overlays. These factors were selected based on observation and assumptions related to the performance of overlays. Although there might be other factors that can influence the service life of overlays, the scope of this study was restricted to these factors. The questionnaire was purposely developed with overlaps and redundancy.

Table 1. Interview Questions for VDOT District Bridge Office Personnel

No.	Category	Interview Questions
1	Overlay Usage	Of the following overlay types, which are the most used overlay types in your district? • Epoxy concrete (EC) • Latex modified concrete (LMC) • Silica fume concrete (SF) • Very early strength latex modified concrete (VESLMC) • Low slump dense concrete (LSD) • Asphalt with a membrane (HMAM) • Asphalt without a membrane (HMA)
2	Overlay Usage	Why are these overlay types the most used?
3	Overlay Usage	Where are the most used overlay types used? Low volume rural roads, secondary urban roads, primary urban roads, interstate roads?
4	Overlay Usage	Are certain types of overlays used on specific superstructure types as: adjacent box beams or slabs, spread box beams, concrete prestressed I-beams, steel beams?
5	Overlay Selection	Do you have a formal or informal procedure for selecting an overlay type to be used?
6	Overlay Selection	What are your criteria for selecting an overlay type to be used?
7	Overlay Selection	What is the basis for determining when bridge decks are to be overlaid, other than budget issues?
8	Overlay Performance	Of the overlays used in your District, what is the range of years when first repairs are required?
9	Overlay Performance	Of the overlays used in your District, what is the range of years when an overlay had to be replaced?
10	Construction Procedure	Have you or do you plan to use milling-hydro demolition to remove the cover concrete prior to overlaying a deck?
11	Construction Procedure	Have you used or do you plan on using milling- hydro demolition to remove the concrete to below the top reinforcing steel prior to placing an overlay?
12	Formalities	What is the average budget of an overlay? Did the budget play a part in selection of that overlay type?
13	Formalities	What involvement does the bridge team have in overlay construction as opposed to the construction team?
14	Formalities	Who is involved in the inspection of overlays? State or contractors?

Interview invitations along with the questionnaire in Table 1 were sent to the district structure and bridge engineer of each of the nine VDOT districts requesting their participation in an in-person interview. They were also requested to share the invitation with the in-house experts on bridge deck overlays.

RESULTS AND DISCUSSION

Literature Review

Background

In the late 1960s, bridge deck preservation overlay systems were developed. Initial systems included low-slump dense concrete (LSDC), latex-modified concrete (LMC), and hot-mix asphalt (HMA) concrete with a water-resistant membrane (HMAM). Virginia’s first use of an LMC overlay was in 1969 on a bridge deck that had been constructed with insufficient cover concrete. LMC overlays continue to be used in Virginia today.

Virginia began to experiment with thin polymer concrete overlays in the early 1980s as a maintenance protection system to prevent further chloride ingress into concrete bridge decks. Polymer systems included multiple-layer, premixed, and slurry methods (Sprinkel et al., 1993). Having first tried epoxy in 1985, VDOT has exclusively used multiple-layer epoxy concrete (EC) for thin polymer overlays since 1990. Thin polymer overlays were developed by Virginia as a rapidly applied protective maintenance system. The multiple-layer epoxy system installation includes shot blasting the concrete deck surface and then applying a layer of epoxy that is then covered with an aggregate and an additional layer of epoxy and aggregate for skid resistance. The overlay thickness is generally about 1/4 in. Any chloride that is already in the concrete is locked in, but it continues to penetrate toward the reinforcing steel at a slower rate. Ingress of additional chloride is blocked by the thin polymer overlay so long as it is intact and adhered to the deck surface.

In the late 1980s, Virginia began to use microsilica (silica fume [SF]) concrete overlays in place of LMC overlays. During a brief period, SF concrete overlays were used almost exclusively. They are still used today, but at a lower frequency, and have been replaced mostly by LMC overlays.

Virginia again led an effort in the development of very-early-strength LMC (VESLMC) overlays to reduce construction time and, thus, the interruption in traffic flow. VESLMC overlays first used Type III portland cement, which was subsequently replaced with Rapid Set cement. Rapid Set cement is presently used in the construction of VESLMC overlay systems, which are generally 1¼ to 1¾ in thick. Typical construction consists of milling off about ½ in of the concrete deck surface, patching spalled and delaminated areas, and placing the VESLMC overlay. Chloride remaining in the deck concrete continues to penetrate to the depth of the reinforcing steel at a rate that depends on factors such as concrete quality and moisture content. However, more recent overlay installation procedures generally follow the recommendations of Weyers et al. (1993) in their SHRP report to remove more of the chloride-contaminated concrete. One Virginia method of removing concrete highly contaminated by chloride is by milling about 1¾ in of the surface concrete, removing an additional nominal ½ in by hydro-demolition, and removing any remaining unsound concrete using hand tools.

SHRP Project C-103 culminated in a series of reports. In *Concrete Bridge Protection, Repair, and Rehabilitation Relative to Reinforcement Corrosion: A Methods Application Manual* (Weyers et al., 1993), service lives of bridge deck overlay systems were estimated. The service lives of LSDC, LMC, and HMAM overlays were estimated at 22 to 26, 22 to 26, and 10 to 15 years, respectively. The authors found that service life was limited by the extent and quantity of chloride left in the deck concrete. In *Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques: Rapid Concrete Bridge Deck Protection, Repair and Rehabilitation* (Sprinkel et al., 1993), the service life of EC overlays was estimated at 10 to 25 years and was found to be a function of average daily traffic (ADT): 10 years for ADT greater than 50,000 vehicles per day; 15 years for ADT of 25,000 to 50,000 vehicles per day; and 25 years for ADT less than 25,000 vehicles per day.

In *Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques. Service Life Estimates* (Weyers et al., 1994), the post-installation rate of chloride penetration to deeper concrete depths under both hydraulic cement and polymer concrete overlays was determined. For LMC and LSDC overlays, further chloride ingress into the overlay concrete combines with the chloride left in place in the deck concrete and results in a smooth continuous diffusion curve at an overlay age of about 15 years. For epoxy overlays, the deck surface concrete chloride concentration continues to decrease and the chloride concentration at deeper depths increases as the system approaches uniform chloride distribution equilibrium. Thus, properties controlling the service life of epoxy overlays, in addition to traffic, are reduction in permeability (i.e., exclusion of further chloride ingress) and the extent and quantity of chloride left in place when the overlay was placed.

Before overlaying, surface preparation of the existing concrete deck or base concrete is performed to increase the bond strength between the new and existing layers. With the exception of thin-bonded epoxy overlays, all overlays require removal of base concrete to a certain depth, which depends on the level of chloride contamination and reinforcement corrosion and dead load or vertical profile constraints. Impact head milling is the most economical concrete removal technique used in Virginia (Sprinkel, 2004); however, it can result in fractures below the milled surface and vibrations throughout the structure. Hydro-demolition is a relatively expensive technique used for the same purpose; however, this method does not cause fractures below the surface or vibrations.

Presently, overlay service life estimates from the SHRP C-103 study remain definitive, as little additional work appears to have been conducted in the last 20 years on this topic. In addition, little to no effort has been expended to assess the condition of and make recommendations regarding first generation overlays beyond their service life (e.g., should a second generation overlay be recommended or should the deck continue to be repaired and then replaced?).

Databases with historical conditions of bridge structures exist to assist in decision-making about future maintenance activities. The National Bridge Inventory (NBI) is a database compiled by Federal Highway Administration (FHWA) using data supplied by the state departments of transportation (DOTs). This database consists of information on structure location, geometry, superstructure type, materials, deck protection systems, condition ratings, and other related data for all structures recognized as bridges (generally defined as highway crossings of 20 ft or more in span).

The AASHTO Pontis (now called AASHTOware BM) bridge management software, which supports the collection and recording of element-level condition ratings of bridge components, was developed to assist recordkeeping and prediction of future maintenance activities. Element-level condition records have been maintained since 1996 in Virginia, although the quality of information may have evolved over that time. Data recorded prior to 2003 may be less reliable than data that are more recent. Biannual bridge inspection records present historical information on the type of deck wearing surface and quantities (by square feet for decks) in each of the five condition states. It is important to note that under the Pontis Commonly Recognized (CoRe) elements framework, whereas other elements under the Pontis element-level inspection are documented according to the portions of the total element quantity in each applicable condition, bridge deck condition is reported as the entire deck area in a single “average” condition. Implementation of a newer generation of National Bridge Element definitions to be used within AASHTOware BM will rectify this shortcoming in the future.

Laboratory personnel in VDOT’s Materials Division evaluate materials used in the construction of bridge components and maintain records of the results along with associated contract identification information. Identifying the contracts related to the overlaying can help in gathering information on cost and the source(s) of construction materials. Such information may facilitate classification and selection of bridges for consequent field investigations.

Thin Polymer Overlays

Polymer concrete overlays are thin layers used over concrete bridge decks to reduce the ingress of chloride and moisture and to increase skid resistance. Since these overlays are thin and follow the contours of the existing substrate, they typically do not prominently alter the drainage patterns, improve ride quality, or increase the cross-section geometry (Sprinkel et al., 1993). The polymers are formulated to cure rapidly for quick construction and require less labor and specialized equipment than a rigid overlay (Wilson and Henley, 1995). They are best suited for dry warm temperatures (Wilson and Henley, 1995). Being thin compared to the other overlay systems, these do not add significant dead load (Sprinkel et al., 1993). The mentioned factors may be used in deciding if a structure will be a candidate for a thin polymer overlay rather than a rigid overlay.

Virginia has tried a number of thin polymer overlay materials and has been using epoxy polymer overlays for a majority of decks recently. The type of epoxy formulated for overlaying purposes is specified as EP-5 and it is defined as a low-modulus patching, sealing, and overlay adhesive with an elongation of at least 10% (VDOT, 2007). When epoxy is used as a penetrating sealer and as a repair method for non-rigid cracks, low-viscosity type EP-5 is used.

The Washington State DOT has been using epoxy and methyl methacrylate (MMA) thin overlays since the mid-1980s as an alternative to rigid concrete overlays. MMA overlays were found to retain friction resistance after 9 years of service, whereas epoxy overlays lose their friction resistance in 5 to 7 years of service; however, epoxy overlays showed better bond strength compared to MMA overlays (Wilson and Henley, 1995). In a study conducted on different kinds of polymer overlays for the Utah DOT, epoxy-based overlays were found to be the best performing; although silicon-based overlays did not crack, they did not provide wearing protection for the deck (Guthrie et al., 2005).

Good Candidates

Epoxy polymer overlays will perform well only if the bridge decks on which they are installed are in decent condition prior to the overlaying. If the decks need patching on more than 5% of the deck surface area, the overlay will perform well for only a few years (Harper, 2007). Thus, care should be taken in selecting decks on which to place thin polymer overlays. Weyers et al. (1993) suggested the following criteria for choosing thin polymer overlays for rehabilitation action:

- The cover concrete is not critically contaminated with chlorides, which is typically taken to mean no more than 1 to 2 lb/yd^3 of concrete.

- The cover concrete over the reinforcing bars has a permeability greater than 2000 coulombs (AASHTO T 277) (American Association of State Highway and Transportation Officials, 2011).

- The clear cover over the reinforcing bar is less than 2 in (*5* cm).

- The cover concrete is extensively cracked, if cracks are not active (AASHTO-AGC-ARTBA Task Force 34, 1995).

- The bald tire skid number (ASTM E524) (ASTM, 2008) is less than 2.0 at 40 mph (64 km/h).

- The overlay can be used as a protection method for new decks (AASHTO-AGC-ARTBA Task Force 34, 1995).

Bad Candidates

Bridge decks with certain conditions will not make good candidates for thin polymer overlays (Weyers et al., 1993). A different rehabilitation approach such as placing a rigid concrete overlay or replacing the deck should be considered if the deck has any of the following conditions:

- corrosion-induced delaminations and spalls
- cover concrete that is critically chloride-contaminated
- half-cell potentials more negative than -250 mV CSE
- unsound concrete, when tensile rupture strength is less than 150 psi (1.0 MPa)
- poor drainage pattern
- poor ride quality, except if slurry and premixed overlays are used.

It is a concern that active concrete cracks can reflect through thin polymer overlays, thereby compromising the resistance to moisture penetration. Sprinkel (2003) recommended that large cracks be filled ahead of time with gravity fill polymer. However, Carter (1993) concluded that extreme cold, superstructure flexibility, and live load deflection can make crack repairs useless.

Construction Procedure

The polymer resin can typically be applied by spray, roller, brush, or squeegee (AASHTO-AGC-ARTBA Task Force 34, 1995; Weyers et al., 1993). Within a few minutes, a gap-graded aggregate is broadcast over the layer of resin. According to Fowler and Whitney (2012), the aggregate grading should meet the requirements set forth in AASHTO guide specifications. Typically, the aggregates subjected to wear would be silica or basalt (Weyers et al., 1993) and have a Mohs scale hardness of 7 (Fowler and Whitney, 2012). After about an hour, the excess unbonded aggregate is removed by use of a physical method such as sweeping. For a multiple-layered overlay, the process is repeated. Typically, a single layer of overlay will be around $^{1}/_{8}$ in (~3 mm) thick. Polymers are generally hydrophobic until they are completely cured (Wilson and Henley, 1995); this requires that the decks be dry during the construction.

Three types of thin polymer overlay constructions are typically followed (Weyers et al., 1993):

1. *Multiple-layer:* two or more layers of polymer and gap-graded, dry angular-grained aggregate

2. *Slurry:* a polymer-aggregate slurry spread with gauge rakes and covered with fine aggregate

3. *Premixed:* a premixed polymer concrete mixture consolidated and struck off with a vibratory screed.

Multiple-layer overlays follow the contours of the bridge deck. Thus, those decks that have good riding quality are good candidates for multiple-layer overlays. Those decks that have many surface irregularities are good candidates for slurry and premixed thin overlays (Sprinkel, 2003).

The most commonly used binders for thin polymer overlays are epoxy, polyester styrene, and methacrylate. The polymer binders are typically two-component systems, where one component contains the resin and the other contains the curing agent or the initiator (Weyers et al., 1993). Deck friction can be improved by grooving the concrete or broadcasting more aggregates on the surface (AASHTO-AGC-ARTBA Task Force 34, 1995).

Performance Specifications

AASHTO-AGC-ARTBA Task Force 34 (1995) recommended the following specifications to ensure a good quality polymer overlay:

- bond strength with substrate > 500 psi (>3.4 MPa) (VDOT, 2000)

- compressive strength of overlay > 5,000 psi (34.5 MPa) (ASTM C579) (ASTM, 2012a)

- tensile strength of polymer binder from 2,000 psi to 5,000 psi (13.8 to 34.5 MPa) (ASTM D638) (ASTM, 2010)

- permeability < 200 coulombs (ASTM C1202) (ASTM, 2012b)

- friction resistance.

Problems Encountered During Construction

Ease of installation is one of the major factors that can affect the preference for a particular type of overlay among contractors and transportation agencies. An overlay method that has an overly complicated or a highly sensitive installation process may not have a reliably long service life, given the opportunities for errors. Contractors have encountered the following problems during the placement of thin polymer overlays (Fowler and Whitney, 2012):

- Weather affects the overlay, e.g., rain or high or low temperatures.

- Cure times of resin are too slow to allow opening to traffic as required by the contract.

- Plans indicate less than material quantities required.

- Day or night temperatures affect the work time and volume of materials.

- Decks are often badly deteriorated. Some DOTs assume that a polyester premixed overlay can restore a badly deteriorated deck when an overlay 18 to 150 mm (0.75 to 6 in) thick is needed to restore ride quality; the inevitable deterioration of the overlay is usually blamed on the contractor.

- Excessive moisture in the deck reduces bond strength.

Recommendations for Selecting Contractors

It is common knowledge that the quality of overlays will depend on the quality of construction. Thus, it becomes important to select the right kind of contractor. Fowler and Whitney (2012) suggested the following points regarding contractor selection.

- Bidders should be prequalified based on experience with thin polymer overlays.

- A representative of the resin manufacturer should be present, especially if a warranty is required.

- Repairs should be made using compatible polymer patching materials supplied or specified by the manufacturer, which eliminates paying for traffic control twice and having to build in an extra 28 to 56 days to let the patches cure, dry, and outgas.

- Diamond-grinding should be specified for very rough decks to save on the cost of shot blasting and to minimize resin consumption.

- A mandatory 4-hour curing period is too long in hot weather; 1 hour is often enough and can be verified by the impact hammer and/or screwdriver test; peak exotherm or maturity might also work to confirm the curing, especially for thicker overlays.

- Specifications requiring airless spray application for high-molecular-weight methacrylate sealers and primers should be eliminated because of the difficulty in keeping the spray guns calibrated. Often by the time the problem is discovered, considerable improperly mixed resin has been applied.

- Thin polymer overlay applications are best restricted to warm and dry periods.

- Warranties for 5 years should be required.

Recommendations From Material Suppliers

In a survey of material suppliers, the following recommendations were made to improve the quality of thin polymer overlays (Fowler and Whitney, 2012):

- Technical representatives should be trained.

- A manufacturer's representative should be on site to oversee the work.

- The deck should be in good condition.

- The deck should be clean and dry.

- The deck cleaning texture should be specified as International Concrete Repair Institute's concrete surface profile No. 7, but No. 6 can be accepted.

- Multiple-layer thin polymer overlays should be used for epoxy systems.

- Aggregate should have a Mohs hardness of 7.

- For polyester systems specifications, have contractors make an investment in volumetric mixers with readouts and plural components, paving machines with automatic grade control, and shot-blasting equipment.

- Specifications should require experience with thin polymer overlays.

Service Life

The service life of thin polymer overlays is an important factor to be considered, since the life cycle cost of this rehabilitation depends on it. With longer life, there is significant savings for transportation agencies in terms of maintenance costs and for the public in terms of free-flowing traffic. Wilson and Henley (1995) reported that most polymer concrete overlays would require application of additional polymer material at 5 to 10 year intervals, depending on the type and volume of traffic. The service life extensions provided by Weyers et al. (1993) for different types of polymer concrete overlays through projections of data from field evaluations are shown in Table 2.

Table 2. Service Life of Overlay Types Based on Traffic Volumes

Polymer Type	ADT < 5,000 (years)	5,000 < ADT < 25,000 (years)	25,000 < ADT < 50,000 (years)	ADT > 50,000 (years)
Multiple-Layer Epoxy	25	25	15	10
Multiple-Layer Epoxy-Urethane	25	15	--	--
Methacrylate Slurry	18	7	5	3

Data from Weyers et al. (1993).

The service life extension offered by polymer overlays was one of the questions in the surveys conducted by Krauss et al. (2009) of state transportation agencies; the authors found that polymer overlays could last from 1 to 35 years, with a mean range of 9 to 18 years. According to the authors, the mean range of service life was calculated by separately averaging the reported low-end and high-end values of service life estimates provided by the surveyed states (P. Krauss, personal communication). A case study concluded that when applied properly, the epoxy polymer overlay could last for 15 years or more with high skid resistance and low permeability (Pfeifer and Kowalski, 1999).

Failure Causes

A survey conducted on the performance of overlays found that the primary reasons for failure of epoxy overlays were cracking, delamination, and inadequate surface preparation (Guthrie et al., 2005). Reasons behind failures of thin polymer overlays were obtained through surveys and interviews with state transportation agencies (Fowler and Whitney, 2012) and included the following:

- poor deck condition (in many cases)
- repaired areas not sufficiently dry and/or not roughened
- inadequate surface preparation
- cool damp weather during installation
- deck too damp at time of overlay installation
- construction problems
- inadequate quality control
- use of snow chains.

Rigid Concrete Overlays

Rigid overlays, or hydraulic cement concrete overlays, are placed on bridge decks to reduce the infiltration of moisture and chloride and to improve ride quality and skid resistance. These rigid overlays are placed with internal and surface vibration and then struck off with a mechanical screed (Weyers et al., 1993). These bonded overlays become structural components of the deck and add structural capacity (Krauss et al., 2009). Portland cement concrete, LMC, SF concrete, and LSDC are the common types of rigid overlays used for bridge deck rehabilitation (Weyers et al., 1993). However, LMC and SF concrete overlays are the most commonly used overlays in Virginia. Thus, this discussion is primarily about those overlays.

Construction Procedure

The following steps for constructing rigid concrete overlays were presented by Weyers et al. (1993):

1. Scarify and remove unsound concrete by milling or hydro-demolition.
2. Remove concrete dust by grit blasting or shot blasting.
3. Saturate the milled deck with water 12 hours prior to the overlaying.
4. Place the overlay on saturated surface dry substrate.
5. Allow sufficient time for curing, depending on the cement used.

For overlays with a thickness less than 2 in, No. 7 and No. 8 coarse aggregates are typically used in the concrete mixture and for overlays with a thickness greater than or equal to 2 in, No. 57 coarse aggregate is also used (Weyers et al., 1993).

If the chloride contamination is found only above the top reinforcement mat, the concrete above the top reinforcement mat is removed by milling. The overlay will be placed. However, if the chloride contamination has proceeded to the top reinforcement depth and even below the top reinforcement mat, then concrete removal will proceed approximately 1 in below the top reinforcement mat. It is important not to damage the bottom reinforcement mat or surrounding concrete since the structural integrity of the deck would be in peril (Krauss et al., 2009).

Hydro-demolition is a method of removing concrete using high-pressure water jets, which has several advantages over conventional milling including removing concrete between reinforcing bars (Sohanghpurwala, 2006). Recently, hydro-demolition has been used on some projects in Virginia to get below the top reinforcement mat and has been considered an efficient alternative method to milling despite the higher cost and environmental precautions necessary to handle the excess wastewater from the process.

Limitations

Rigid overlays may increase the dead load on a bridge, thus increasing the stress carried by the structure. In addition, these overlays should not be used on decks with concrete that is susceptible to alkali-aggregate reactions (Weyers et al., 1993). Both LMC and SF concrete overlays can be placed and cured within 56 hours. VESLMC overlays can be placed and opened for traffic within 8 hours but may shrink more than conventional bridge deck concrete (Weyers et al., 1993). VESLMC overlays shrink less than other overlays (Sprinkel, 1998).

When sufficient chloride-contaminated substrate concrete is not removed before the overlays are applied, the corrosion process will simply proceed inside the concrete, undermining the value of the rehabilitation process.

Candidacy

Selecting the appropriate overlay type, such as high early strength, very early strength, etc., for a particular bridge deck depends on several factors (Krauss et al., 2009), primarily the following:

- traffic constraints on construction closures
- dead load/clearance (for truss structures) restrictions
- drainage and slope corrections needed
- previous deck overlays and repairs
- costs
- contractor and DOT experience.

Service Life

Since the overlaying with rigid concrete is typically performed after a bridge deck has undergone a higher degree of deterioration than for thin overlays, these overlays are considered an alternative to full deck replacement and are expected to extend the life of the deck for many years before any major rehabilitation action will be required.

Weyers et al. (1993) projected the following service lives of rigid overlays from field data:

- *LMC overlays:* 22 to 26 years
- *SF concrete overlays:* 22 to 26 years.

However, an overlay service life is also dependent on the environmental exposure conditions and salt usage. A survey of transportation agencies on the service life ranges of rigid overlays gave the following service life ranges (Krauss et al., 2009):

- *High-performance concrete overlays:* 10 to 40 years; mean range, 16 to 29 years
- *LSDC overlays:* 10 to 45 years; mean range, 16 to 32 years
- *LMC overlays:* 10 to 50 years; mean range, 14 to 29 years.

Latex-Modified Concrete (LMC) Overlays

LMC is a portland cement concrete in which an admixture of styrene butadiene latex particles suspended in water is used to replace a portion of the water (Sprinkel, 1998). It has been claimed that LMC increases flexibility, decreases permeability, and increases resistance to chemical attacks (Hilton et al., 1975). This type of concrete overlay has been used in Virginia since 1969 (Sprinkel, 1998).

Advantages

In an extensive field study of 16 different overlay systems, it was concluded that LMC overlays were the best overall performing overlay type, since they showed the second-lowest permeability and chloride diffusion coefficients and the lowest chloride concentration after 10 years of service (Sprinkel, 2009). In a study in which curling, delaminations, and tensile bond strengths were compared for different high-performance overlays, LMC overlays were recommended as good performing overlays (Ray et al., 2008). Ozyildirim (1996) observed in a 4-year study that LMC overlay had very low permeability, low chloride ingress, satisfactory compressive strength, and higher flexural strength.

Disadvantages

A study on high-performance overlays showed that the freeze-thaw durability of LMC overlay materials under standard tests was low; however, the low permeability prevented water saturation such that the overlays showed fewer problems in the field (Ozyildirim, 1996). The following were listed as the disadvantages of the LMC overlays in a study by Krauss et al. (2009):

- need for specialized equipment
- need for contractor experience
- construction quality that is sensitive to weather conditions.

Very-Early-Strength Latex-Modified Concrete (VESLMC) Overlays

In a number of situations, bridge decks cannot be closed for rehabilitation for extended periods because of constraining factors such as high traffic volume, long detour lengths, and too few travel lanes to support phased construction. Even when the rehabilitation is performed during off-peak traffic hours, the strength gain of standard LMC overlays and other available overlays may be slow. A need was identified for an overlay that could develop strength sufficiently rapidly for the structures to be opened quickly to traffic. Several quick-setting concrete mixtures have been used (Sprinkel, 1988, 1998) to reduce concrete setting time and increase the rate of strength gain. All of these quick-setting concretes are referred to as rapid-set concretes in this report.

Specially blended Rapid Set cement was used instead of typical Type I/II cement in LMC overlays (Sprinkel, 1998). Typically, LMC overlays would require 1 or 2 days of deck closure, although sometimes for as little as 8 hours. A VESLMC overlay system was developed that allowed the deck to be opened for traffic within 3 hours of placement (Sprinkel, 1998).

Advantages

Use of VESLMC overlays reduces inconvenience to the public; allows overnight installation when traffic is minimal; and provides low-permeability, high-strength concrete protection for the substrate (Sprinkel, 1998).

Disadvantages

VESLMC overlays are more susceptible to construction errors because of the short time available for construction and even shorter time for the curing process (Weyers et al., 1993).

Plastic shrinkage cracking has been reported in VESLMC overlays (Wenzlick, 2006). Yun and Choi (2014) observed that initial map cracking developed into wider visible cracks within a week. The problem was attributed to delay in the curing process because of time taken for concrete tining. The authors recommended the following: use concrete with the lowest early strength possible; use a low amount of very-early-strength cement; maintain a low hydration temperature; use the minimum necessary cement paste volumes; and prevent restraint to promote free shrinkage to reduce the cracking. Wenzlick (2006) observed a bonding problem when the substrate concrete did not have a rough texture. Moist curing is essential for reducing the risk of shrinkage cracking.

Silica Fume (SF) Concrete Overlays

SF is a mineral admixture used in concrete as a substitute for a portion of the cement. SF has a significantly smaller particle size compared to cement and has been proven to reduce appreciably the permeability of concrete to moisture and chlorides. Thus, a concrete overlay with SF, substituted at typically 7% by weight of cement, was developed for use as a rehabilitation procedure. The cost of a SF concrete overlay is comparable to that of an LMC overlay in Virginia. The bond between SF concrete and normal concrete substrates was found to be better than the bond strength of LMC overlays (Ozyildirim, 1993).

Advantages

The main advantage of the SF concrete overlay is the ease of installation. No special equipment or extensive contractor experience is necessary for placing an SF concrete overlay. SF concrete overlays show satisfactory strength gain, higher bond strength, very low permeability, low chloride ingress, and good freeze-thaw durability (Ozyildirim, 1996). Properly designed SF concrete overlays can be opened for traffic within 24 hours of placement (Sprinkel, 2000). Shear bond strengths were found to be higher for 7% SF concrete than for LMC (Sprinkel, 2000).

Limitations

Because of the greater need of water for hydration, there is a chance that an SF concrete may crack if the curing process is not performed well (Ozyildirim, 1993; Sprinkel, 2000). In a study on curling, delamination from substrate, and tensile bond strength of different overlays, SF concrete without a shrinkage-reducing admixture performed less satisfactorily than SF concrete with a shrinkage-reducing admixture (Ray et al., 2008). Ozyildirim (1996) found the flexural strength of SF concrete to be lower than that of LMC, thus increasing its tendency to crack on a flexible superstructure.

Asphalt Concrete Overlays With Waterproof Membrane (HMAM Overlays)

Asphalt concrete is a very permeable material. Thus, when water penetration resistance is needed, a waterproof membrane is used to form an HMAM overlay. Given the low cost and ease of installation, HMAM overlays are preferred over other types of overlays. However, the inability to inspect the deck and the relatively short service life are disadvantages. Two primary types of waterproofing are preformed membranes and constructed-in-place (liquid) membranes (Russell, 2012). Virginia allows the use of both types of membranes (VDOT, 2007), but the preformed membranes are more commonly used. Distlehorst (2009) found HMAM overlays to be the most cost-effective alternative. However, the deterioration of the membrane will allow moisture to enter through the permeable asphalt concrete on top, and the concrete surface will trap it. This results in corrosion damage of steel reinforcement (Sohanghpurwala, 2006).

Construction Procedure

Weyers et al. (1993) described the construction procedure for HMAM overlays as follows:

- The deck surface should be dry.
- Concrete patches should be allowed to cure for a minimum of 14 days.
- Primer should be applied to the surface and allowed to dry to a tack-free condition.
- Preformed membrane should be rolled onto the surface, and the edges should be sealed with a mastic or polyurethane sealer.
- Within 2 days of membrane application, the HMAM overlay should be applied.

Membrane Specifications

In a synthesis report, Russell (2012) specified the following to be the properties expected from an ideal waterproof membrane:

- impermeable to water
- good adhesion to the deck
- good adhesion to the protective riding surface
- tolerant of deck surface roughness
- resistant to traffic before application of the riding surface
- capable of bridging cracks in the concrete deck or opening joints between adjacent precast members
- safe to apply and with low volatile emissions
- able to withstand high and low temperatures
- can be applied over a wide range of temperatures

- extended service life of 50 to 100 years.

Advantages

Krauss et al. (2009) listed the following as advantages of HMAM overlays:

- low cost
- ease of installation
- quick installation
- improved rideability of the surface
- can be used on questionable decks
- use is proven.

Sohangpurwala (2006) specified the following as advantages of HMAM overlays:

- Membranes can be applied relatively rapidly, including application of the HMA wearing surface.

- Membranes can bridge and prevent reflection of most moving concrete cracks because of their elastic nature.

- The HMA wearing surface can provide a good riding surface.

- Membranes can be applicable to almost any deck geometry.

Disadvantages

Krauss et al. (2009) listed the following as disadvantages of HMAM overlays:

- installation or other problems resulting in water and/or chlorides being trapped underneath the membrane

- underlying deck cannot be seen or inspected and effectiveness of membrane is unknown

- short life

- dead load

- difficulty of removal

- need for timely maintenance

- thickness needs to be sufficient so that traffic does not pull the asphalt concrete off the surface

- shoving of the membrane over time.

Sohangpurwala (2006) listed the following as disadvantages of HMAM overlays:

- The service life of the membrane may be limited by the wearing surface when exposed to heavy traffic.

- The HMA overlay is a nonstructural component of the deck slab, adding to the dead load without increasing structural capacity.

- The system is not suitable for grades in excess of 4% because the bond capacity is limited and shoving and debonding can occur under traffic.

Service Life

Because of their permeability and the fact that they can hold moisture, HMAM overlays have not been shown to be a durable deck protection method. The predicted service life of these overlays is about 10 to 15 years (Weyers et al., 1993). Krauss et al. (2009), from their survey of transportation agencies, reported that the service life ranges from 3 to 40 years, with a mean range of 12 to 19 years. A study of the efficiency of waterproofing membranes in extending the life of bridge decks found that a polypropylene fabric membrane extended the life of a structure by 10 to 15 years on a high ADT route (Distlehorst, 2009). In another study, the membranes had to be removed or replaced after about 10 years or less (Sohanghpurwala, 2006).

Task 2: Search of Virginia Bridge Databases

Number of Overlaid Bridge Decks

According to VDOT's bridge inventory, there were 13,650 bridges in Virginia as of April 24, 2013. The numbers presented in the remainder of this report were current as of April 24, 2013, and were extracted from the inventory using AASHTOware BrM. Table 3 shows the total number of bridges; total number overlaid; and percent overlaid on interstate, primary, secondary, and other roadways obtained by filtering of the inventory. Tables 3 through 15 present the results of an analysis of the bridges in the inventory for information relevant to this study.

As shown in Table 3**,** most of the bridges overlaid were on secondary roadways and the fewest were on interstates. Whereas more than 50% of the interstate bridges had been overlaid, only about 31% of the secondary roadway bridge decks had been overlaid.

Table 4 presents the percentage and ranking of bridges in the nine VDOT districts relative to total bridges. The bridges are also separated by interstate, primary, and secondary roadways. Table 4 also illustrates the complexity the VDOT districts have in maintaining their bridges. Whereas the Bristol District ranks No. 1 for number of total bridges, it also ranks No. 1 for primary and secondary roadway bridges but No. 5 for interstate bridges. By contrast, the Fredericksburg District ranks No. 9 for total number of bridges and No. 8, No. 9, and No. 9 for interstate, primary, and secondary roadway bridges, respectively. Between these two districts, the Hampton Roads District ranks No. 6 in total number of bridges but No. 1 in interstate and No. 6 and No. 8 in primary and secondary roadway bridges, respectively.

It is important to note that the percentage of bridges in each type of roadway within a district may not reflect maintenance needs relative to this study and as a whole; square footage of deck area may be a better characterizing parameter than number of bridges.

Table 3. VDOT Bridges and Overlays by Roadway Type

Roadway Type	Total Bridges	Overlaid Decks	% Bridges Overlaid
Interstate	1,409	745	53
Primary	3,530	1,698	48
Secondary	7,685	2,354	31
Other	1,026	24	4
Total	13,650	4,821	35

Table 4. Percentage of Bridges in VDOT Districts Ranked by Roadway Classification

	Total		Interstate		Primary		Secondary	
District	% Bridges	Rank	% Bridges	Rank	% Bridges	Rank	% Bridges	Rank
Bristol	19%	1	10%	5	16%	1	22%	1
Salem	15%	3	8%	6	14%	4	18%	3
Lynchburg	9%	5	0%	9	11%	5	10%	4
Richmond	12%	4	20%	2	15%	2	9%	5
Hampton Roads	9%	6	24%	1	10%	6	4%	8
Fredericksburg	3%	9	2%	8	4%	9	3%	9
Culpeper	8%	8	5%	7	7%	8	9%	6
Staunton	17%	2	15%	4	15%	3	18%	2
Northern Virginia	8%	7	16%	3	8%	7	7%	7

Tables 5 through 15 address the age component of bridges in Virginia. Bridge age was separated into 10-year increments beginning with bridges built or rebuilt prior to 1950 and then in the 1950s, 1960s, 1970s, 1980s, 1990s, 2000s, and 2010s. Table 5 presents the bridges maintained by VDOT, separated into 10-year increments. Table 5 shows a marked increase in the number of bridges built at the peak of interstate construction, the 1960s through the 1980s; more than 40% of bridges maintained by VDOT were built during this period. The typical bridge design life was 50 years before the 1980s. More than 26% of VDOT bridges are older than 50 years. Typically at present, a newly designed bridge is anticipated to have a service life of 75 years (FHWA, 2011) and the structure usually requires a major rehabilitation at between 30 and 40 years (Balakumaran et al., 2013). About 15% of VDOT bridges are older than 75 years, and more than 45% are older than 35 years.

Table 6 presents the VDOT-maintained bridges and the average general condition rating (GCR) of the decks that have been overlaid, separated by construction era. Table 6 shows a reduction in the number of overlaid bridges built beginning in the 1980s, where the 1980s bridges yet to be overlaid and the 1970s bridges yet to be overlaid were 65% and 57%, respectively. Presently, the bridges built after 1980 can be as old as 35 years of age. The average deck GCR for the structures separated by age shows a clear decrease, as expected, with age. The average GCR of overlaid decks shows a slight increase for decks built since 1970.

However, for some structures, the year built or GCR was not available. It is not possible to conclude anything from the GCR values, since the ages of the overlays themselves are not known.

Table 5. Bridges by VDOT District and Construction Era

District	Pre- 1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total
Bristol	505	79	241	276	481	471	269	144	2,466
Salem	463	78	264	303	264	305	295	145	2,117
Lynchburg	243	61	164	214	118	151	183	104	1,238
Richmond	102	85	230	288	273	269	255	64	1,566
Hampton Roads	87	84	185	217	270	274	110	57	1,284
Fredericksburg	49	42	63	45	66	62	58	54	439
Culpeper	222	47	77	162	145	182	136	64	1,035
Staunton	498	118	265	413	364	238	231	79	2,206
Northern Virginia	74	17	80	131	192	374	238	193	1,299
Total	2,243	611	1,569	2,049	2,173	2,326	1,775	904	13,650
Percent	16%	4%	11%	15%	16%	17%	13%	7%	

Table 6. Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	842	171	231	213	236	113	93	52	1,951	5.99
Asphalt Overlay/Membrane	51	22	34	85	154	186	203	105	840	6.86
Thin Overlay	22	79	251	397	142	86	34	4	1,015	6.34
Rigid Overlay	49	55	147	179	232	233	96	24	1,015	6.09
Total Overlays	964	327	663	874	764	618	426	185	4,821	6.32
Total Statewide Structures	2,243	611	1,569	2,049	2,173	2,326	1,775	904	13,650	6.49
GCR—Overlaid Decks	5.97	5.87	6.11	6.58	6.74	6.91	7.36	8.21	6.32	
GCR—All Decks	5.99	5.94	6.27	6.32	6.40	6.70	7.20	8.14	6.47	
% Overlaid	43%	54%	42%	43%	35%	27%	24%	20%	35%	

GCR = average general condition rating.

Typically, the bridge decks overlaid with HMA and HMAM overlays are on low-volume roadways. Thin overlays and rigid overlays are placed on reinforced concrete decks on roadways with higher traffic volumes. Of the total overlaid bridge decks, about 60% have HMA overlays and about 40% have thin or rigid overlays. The average deck GCR for the overlay types did not exhibit clear patterns.

Of the 13,650 VDOT-maintained bridges, 4,821 (35%) have an overlay. In addition, more than 58% of the bridges with a deck overlay are older than 35 years of age.

Tables 7 through 15 present the overlaid bridge decks by overlay type and bridge construction era in each of the nine VDOT districts with the average deck GCR values.

Table 16 summarizes these tables as percent of structures overlaid separated by asphalt, asphalt with membrane, thin overlays, and rigid overlays for each of the nine VDOT districts.

Table 7. Bristol District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	179	30	74	55	66	18	21	25	468	6.21
Asphalt Overlay/Membrane	5	1	3	3	9	4	21	19	65	7.26
Thin Overlay	1	1	3	4	18	8	2	0	37	6.30
Rigid Overlay	0	6	24	29	64	72	12	2	209	5.46
Total Overlays	185	38	104	91	157	102	56	46	779	6.31
Total Structures	505	79	241	276	481	471	269	144	2,466	6.28
% Structures Overlaid	37%	48%	43%	33%	33%	22%	21%	32%	32%	

GCR = average general condition rating.

Table 8. Salem District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	172	18	34	23	16	8	9	8	288	5.99
Asphalt Overlay/Membrane	3	1	0	2	3	2	8	3	22	7.09
Thin Overlay	4	12	36	59	18	11	3	0	143	6.64
Rigid Overlay	12	14	26	34	46	39	26	1	198	6.05
Total Overlays	191	45	96	118	83	60	46	12	651	6.44
Total Structures	463	78	264	303	264	305	295	145	2,117	6.59
% Structures Overlaid	41%	58%	36%	39%	31%	20%	16%	8%	31%	

GCR = average general condition rating.

Table 9. Lynchburg District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	88	8	17	20	12	14	17	8	184	6.50
Asphalt Overlay/Membrane	4	0	2	7	9	10	18	12	62	7.00
Thin Overlay	1	1	0	6	6	3	3	0	20	*6.70*
Rigid Overlay	1	7	9	41	11	13	12	10	104	6.31
Total Overlays	94	16	28	74	38	40	50	30	370	6.63
Total Structures	243	61	164	214	118	151	183	104	1,238	6.57
% Structures Overlaid	39%	26%	17%	35%	32%	26%	27%	29%	30%	

GCR = average general condition rating.

Table 10. Richmond District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	51	39	16	31	26	16	8	5	192	5.59
Asphalt Overlay/Membrane	1	2	0	18	22	23	14	13	93	6.28
Thin Overlay	0	0	2	4	2	4	4	0	16	5.69
Rigid Overlay	0	0	3	1	2	23	25	2	56	6.23
Total Overlays	52	41	21	54	52	66	51	20	357	5.95
Total Structures	102	85	230	288	273	269	255	64	1,566	6.25
% Structures Overlaid	51%	48%	9%	19%	19%	25%	20%	31%	23%	

GCR = average general condition rating.

Table 11. Hampton Roads District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	7	2	10	2	1	2	0	0	24	5.92
Asphalt Overlay/Membrane	4	6	9	9	20	10	4	0	62	6.31
Thin Overlay	6	29	71	80	48	12	3	0	249	6.13
Rigid Overlay	0	5	21	12	16	25	2	1	82	6.20
Total Overlays	17	42	111	103	85	49	9	1	417	6.14
Total Structures	87	84	185	217	270	274	110	57	1,284	6.38
% Structures Overlaid	20%	50%	60%	47%	31%	18%	8%	2%	32%	

GCR = average general condition rating.

Table 12. Fredericksburg District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	25	16	13	3	3	1	1	0	62	5.69
Asphalt Overlay/Membrane	3	0	3	0	2	2	2	1	13	6.38
Thin Overlay	0	1	1	1	0	0	0	0	3	6.33
Rigid Overlay	1	5	10	4	14	3	4	2	43	6.28
Total Overlays	29	22	27	8	19	6	7	3	121	6.17
Total Structures	49	42	63	45	66	62	58	54	439	6.54
% Structures Overlaid	59%	52%	43%	18%	29%	10%	12%	6%	28%	

GCR = average general condition rating.

Table 13. Culpeper District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	81	13	10	28	40	16	4	0	192	5.73
Asphalt Overlay/Membrane	5	3	3	6	27	56	65	17	182	7.23
Thin Overlay	2	5	24	68	25	28	9	1	162	6.52
Rigid Overlay	0	4	7	6	3	1	1	1	23	6.17
Total Overlays	88	25	44	108	95	101	79	19	559	6.41
Total Structures	222	47	77	162	145	182	136	64	1,035	6.39
% Structures Overlaid	40%	53%	57%	67%	66%	55%	58%	30%	54%	

GCR = average general condition rating.

Table 14. Staunton District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	215	43	52	47	57	22	31	6	473	6.20
Asphalt Overlay/Membrane	20	9	10	28	42	49	71	33	262	7.48
Thin Overlay	8	30	99	149	23	12	10	3	334	6.91
Rigid Overlay	31	12	34	39	66	38	11	1	232	6.11
Total Overlays	274	94	195	263	188	121	123	43	1,301	6.68
Total Structures	498	118	265	413	364	238	231	79	2,206	6.62
% Structures Overlaid	55%	80%	74%	64%	52%	51%	53%	54%	59%	

GCR = average general condition rating.

Table 15. Northern Virginia District Overlaid Bridges by Construction Era

Overlay	Pre-1950	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total	Deck GCR
Asphalt Overlay	24	2	5	4	15	16	2	0	68	6.10
Asphalt Overlay/Membrane	6	0	4	12	20	30	0	7	79	6.68
Thin Overlay	0	0	15	26	2	8	0	0	51	5.86
Rigid Overlay	4	2	13	13	10	19	3	4	68	5.96
Total Overlays	34	4	37	55	47	73	5	11	266	6.15
Total Structures	74	17	80	131	192	374	238	193	1,299	6.77
% Structures Overlaid	46%	24%	46%	42%	24%	20%	2%	6%	20%	

GCR = average general condition rating.

Table 16. Summary of Bridge Deck Overlays by District and Type

District	% Total Overlaid	Asphalt	Asphalt With Membrane	Thin	Rigid
Bristol	32%	60%	8%	5%	27%
Salem	31%	45%	3%	22%	30%
Lynchburg	30%	50%	17%	5%	28%
Richmond	23%	54%	26%	4%	16%
Hampton Roads	32%	6%	15%	60%	19%
Fredericksburg	28%	51%	11%	2%	36%
Culpeper	54%	34%	33%	29%	4%
Staunton	59%	36%	20%	26%	18%
Northern Virginia	20%	25%	30%	20%	25%
Total	34%	40%	18%	19%	23%

Overlaid Surface Area

Square footage of overlaid bridge decks may better represent the usage of overlay material in Virginia rather than simply the number of bridges overlaid. This was calculated by taking the product of the roadway width and the length of the structure from VDOT's bridge inventory. Table 17 presents the total square feet and percent of overlay material on interstate, primary, and secondary roadways. As shown, rigid concrete and thin polymer overlay materials (43% and 38%, respectively) are most commonly used throughout the three roadway types. The use of rigid concrete materials range from 54% on overlaid interstate roadways to 43% on overlaid secondary roadways, whereas the usage of thin overlays ranges from 39% on overlaid interstate roadways to 22% on overlaid secondary roadways.

Asphalt, with and without a membrane, has been used very little (4% and 3%, respectively) on overlaid interstate roadways. However, their use is greater on primary (7% and 11%, respectively) and even greater on secondary roadways (15% and 22%, respectively), which represents more than 3.9 million square feet of deck area.

The usage of particular overlay materials among the nine VDOT districts is highly variable based on the surface area of deck (see Table 18**)**. Usage of asphalt without a membrane ranges from 1% in the Hampton Roads District to 19% in the Lynchburg District; in the Salem District, the usage is 1% for asphalt with a membrane, and in the Richmond District, the usage is 21%. Thin overlay usage is also highly variable based on the square footage of deck overlaid; usage ranges from 9% in the Lynchburg District to 63% in the Culpeper District. The usage of rigid overlay ranges from 13% in the Culpeper District to 64% in the Bristol District.

Table 17. Summary of Overlaid Bridge Deck Surface Area by Roadway Type

Type of Roadway	Asphalt (%)	Asphalt With Membrane (%)	Thin (%)	Rigid (%)	Total Area (ft^2)
Interstate	3	4	39	54	10,659,202
Primary[a]	11	7	45	37	11,296,923
Secondary	22	15	45	18	5,212,559
Total	11	8	38	43	27,168,684

[a]Urban bridges included.

Table 18. Summary of Overlaid Bridge Deck Surface Area by District

District	Asphalt (%)	Asphalt With Membrane (%)	Thin (%)	Rigid (%)	Total Area (ft^2)
Bristol	17	2	17	64	2,283,298
Salem	12	1	25	61	3,090,057
Lynchburg	19	8	9	63	1,479,701
Richmond	23	21	10	46	2,643,223
Hampton Roads	1	3	72	23	8,046,786
Fredericksburg	15	8	18	59	890,421
Culpeper	11	13	63	13	1,999,666
Staunton	11	8	44	37	4,986,673
Northern Virginia	9	13	34	43	1,748,858
Statewide	10	7	43	40	27,168,684

Interviews of Personnel in VDOT District Bridge Offices

Overview

Participants

Of nine in-person interviews, three had the participation of the district structure and bridge engineers themselves. Expect for one district where the district structure and bridge engineer participated, all interviews had the participation of at least one of the assistant district structure and bridge engineers. In addition, three separate interviews had the participation of bridge maintenance program managers. Further, some interviews had the participation of supervising engineers from both the structure and bridge and construction sections. Overall, the number of participants in each interviewed varied from 1 to 5.

Interview Results

Tables 19 to 23 summarize pertinent results regarding the different overlay types from the interviews with personnel from the nine district bridge offices. The thin overlay category includes overlays that are less than 1 in (~25 mm) in thickness (excluding the asphalt membranes), which include a variety of polymer overlays. Rigid overlays include LMC, SF concrete, and VESLMC overlays. Asphalt overlays were separated into two categories: HMA overlays and HMAM overlays.

The interviews resulted in the following findings:

- *EC overlays are used in all nine districts, although they have been used more extensively and for a longer time in some districts such as the Hampton Roads District.* The primary use of EC overlays is as a preventive maintenance measure to reduce the ingress rate of chloride into the deck concrete. After a number of overlays with various polymer binder types were tried, EC overlays were adopted and have been used widely in Virginia.

- *All nine districts have used LMC overlays for an extensive period, in some cases more than 30 years, and continue to use them at present.* Very few, if any, of the LMC overlays have been replaced, but some are approaching the end of their service life.

- *SF concrete overlays were most widely used over a period from 1990 to 1998 by four of the nine districts because they had lower initial cost than LMC overlays.* These four districts terminated the use of SF concrete overlays because of cracking problems. Two other districts continue the use of SF overlays because of local contractor preference.

- *LMC overlays using Type III cement had limited use where the traffic control times had to be significantly reduced.* The Type III cement was replaced with Rapid Set cement for these cases. The resulting VESLMC overlays are in an early stage of usage and are used where LMC lane closure times are too extensive.

- *Asphalt overlays:*

  HMA overlays. Three reasons existed for bridges presently having HMA-only overlays.

  1. HMA overlays were inherited from previous construction eras.

  2. Decks were paved over during roadway paving projects without the knowledge of the district bridge engineer. These will not have waterproofing membranes.

  3. HMA was used without the intent to serve a preservation or rehabilitation function for the structural deck but rather to provide an improved riding surface for a few years until funds were available to replace the deck.

  HMAM overlays. These overlays are generally used on two types of structures: prestressed adjacent box beams and prestressed adjacent slabs. Previous experience with waterproofing systems has shown poor functionality on such structures because of relative movement between the adjacent members. Recently, an improved longitudinal joint sealing system comprising a waterproof coating over a bonded fiber mesh has been successfully used. In addition, plug joints are used. Plug joints consist of a backer rod between the two structural members with a joint sealant over which a metal plate is placed and covered with flexible modified asphalt material, as shown in Figure 3.

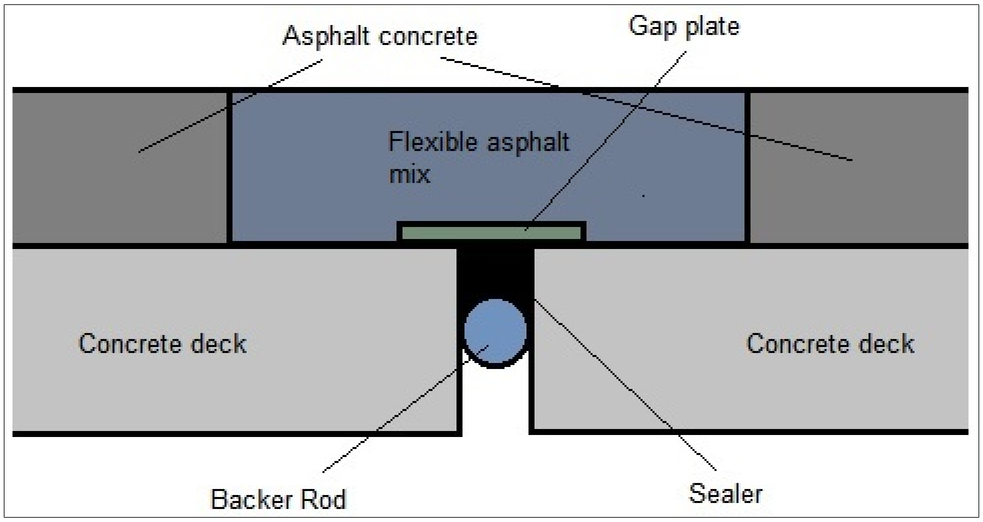


Figure 3. Plug Joint Illustration

Thin Epoxy Concrete (EC) Overlays

Table 19 presents a summary of the interview results regarding the use of EC overlays. As shown, all nine districts use EC overlays as a preventive maintenance method. The longevity of usage varies among the districts. Seven districts have a long-term experience of more than 20 years with EC overlays, and two have a relatively short history with EC overlays. Of the seven districts, the Hampton Roads, Staunton, and Culpeper districts have the longest periods of usage, almost from the inception of usage in the state. These three districts span the exposure conditions in Virginia from very high traffic and very little deicing salt usage (Hampton Roads District) to very high traffic and very high deicing salt usage (Staunton District). The remaining districts did not provide the observed service life of their overlays. The Fredericksburg District has used this overlay in only a few bridge decks and so does not have a lot of experience with it. The Northern Virginia (NOVA) District used this overlay in the 1980s and took it up again only after 2000. They did not provide an observed service life.

Table 19. Summary of Thin EC Overlays From District Interviews

Criterion	**No. of Districts**
Used recently	2
Used long-term	7
Preventive Maintenance	9
Observed Service Life Ranges (years)	
7 to 15: Salem District	
10 to 15: Richmond District	
10 to 20: Lynchburg District and Culpeper District	
20 to 22: Staunton District	
20 to 30: Hampton Roads District	
No damage since installation 8 or 9 years back: Bristol District	

Typical comments from the nine interviews were as follows:

- Used as a preventive maintenance method to reduce the ingress of chloride.

- Overlay should be applied within the first 10 years of service of deck.
- Use on decks when the deck damage is less than 10% of surface area.
- Use on decks to address excessive (non-working) cracking.
- Performance is highly dependent on the contractor.
- Service life is traffic dependent, maybe even less than 10 years on interstates.
- Primary failure mode is by wearing through, instead of delaminating.
- A second EC overlay can be placed over the existing EC overlay by milling of the present overlay and replacing with a new EC overlay.

The estimated service lives range from 7 to 15 years to 20 to 30 years as influenced by traffic volumes on interstate roadways and secondary roadways, respectively. EC overlays exist in the Culpeper District that have been in service for 30 years (M. Sprinkel, personal communication). Service life performance can be related to the quality of construction and thus contractor experience. EC overlays have been replaced when they wear out by placing a new EC overlay over an existing overlay or by milling off the old and replacing it with a new EC overlay. Overlay quality can depend on construction quality and the quality of the pre-overlay deck.

Latex-Modified Concrete (LMC) Overlays

Table 20 presents a summary of the interview results regarding the use of LMC overlays. All nine districts use them generally on primary and interstate roadways. All nine districts use the results of the bridge inspection program to provide an indication when a deck needs to be overlaid. Five districts do some testing, which may include visual inspection to measure spalling, sounding (hammer and chain drag) for delaminations, and concrete sampling to measure chloride concentration at the depth of the reinforcing bar. Four districts employ the assessment guidelines set forth in Chapter 32 in Part 2 of VDOT's *Manual of the Structure and Bridge Division* (VDOT, 2015a). The assessment procedures include inspection of spalls, delaminations, reinforcing steel cover depth, corrosion potentials, chloride at depth of reinforcing bars, and compressive strength and a petrographic analysis of the deck concrete.

Service life varies with deicing salt usage and traffic volumes. The lowest estimated life of 15 to 20 years represents bridges carrying high traffic and high deicing salt usage. The highest estimated life is for bridges having very low deicing salt usage but high traffic volumes. The performance of the overlays also depends on the condition of the pre-overlay deck and contractor workmanship (M. Sprinkel, personal communication) according to observations. The Lynchburg District did not use LMC overlays because of the unavailability of local contractors with experience with LMC overlays. The Richmond District did not provide an estimation of the service life of this overlay.

Table 20. Summary of LMC Overlays From District Interviews

Criterion	No. of Districts
Usage since 1980s	9
Deck Evaluation Prior to Overlaying	
General Condition rating	9
Some testing	5
Follow Chapter 32 procedures	4
Observed Service Life Ranges (years)	
15 to 20: Bristol District	
20 to 30: Culpeper District and Staunton District	
25: Northern Virginia District	
25 to 30: Salem District	
30 to 40: Fredericksburg District	
40 to 50: Hampton Roads District	

Typical comments from the nine interviews were as follows:

- LMC is used typically when deck age is 20 years or more.
- LMC is used if deck damage by surface area is 10% to 20%.
- LMC is used if lane closure period is not limited.
- LMC is preferred on the interstates and primary roads for durability, even though lane closures may be limited.
- LMC is used as a preservative rehabilitation method to extend service life of decks.

Very-Early-Strength Latex-Modified Concrete (VESLMC) Overlays

Table 21 presents a summary of the interview results regarding the use of VESLMC overlays. This overlay was first installed on two bridge decks in 1997 (U.S. 33 over the Mattaponi River) and 1998 (Braddock Road over I-495), respectively; however, the decks were replaced within approximately 10 years because of superstructure conditions, although the overlays were performing well. Many VESLMC overlays were installed since the mid-2000s, but VDOT has only about 10 years of continuous experience since installation (M. Sprinkel, personal communication). The primary reason for using VESLMC overlays is to minimize lane closure periods in high traffic zones. As explained in the literature review, this overlay is relatively more sensitive than regular LMC overlays to various factors during construction such as weather conditions, curing, and so on. Thus, contractors have to deal with an overlay design with a low tolerance for mistakes; there is a learning curve involved for understanding concrete placing limitations and adjusting accordingly. A result of the lack of adherence to the reduced placement time and procedures has been excessive cracking in VESLMC overlays. However, some contractors have learned to adjust and produce quality VESLMC overlays. Many VESLMC overlays have no cracks: the I-64 EBL over the Rivanna River is a 5,000-ft^2 example that is 10 years old, constructed over 2 weekends in 2006 (Sprinkel, 2011).

Table 21. Summary of VESLMC Overlays From District Interviews

Criterion	No. of Districts
Usage for 1 year	1
Usage for 2 years	2
Usage for 4 years	1
Observed Service Life Ranges (years)	
Experience consistently shows good performance over 10 years with expectations of continuing good performance based on condition, though projecting specific service life beyond 10 years would be speculative at this time.	

Given the advantage of reduced lane closures, which reduce traffic control costs and public inconvenience, the use of VESLMC overlays has continued to increase since 2000 and should increase significantly in the future. The remaining districts did not provide the observed service life of their overlays.

Typical comments from the nine interviews were as follows:

- VESLMC is used where lane closure periods are limited.
- VESLMC performance has been observed to be unreliable mainly because of its sensitivity to various factors during construction. This is due to the influence of several factors including ambient temperature, humidity and so on; this overlay performs satisfactorily about 50% of the time. There are often severe cracking problems with VESLMC since the mix typically has high cement content, which leads to high shrinkage
- With a small margin of error with VESLMC, there needs to be a learning curve for the construction crew.
- VESLMC reduces traffic maintenance costs with short lane-closure durations.

Silica Fume (SF) Concrete Overlays

Table 22 presents a summary of the interview results regarding the use of SF concrete overlays. Six of the nine districts have used these overlays. However, four of the six districts (Salem, Fredericksburg, Hampton Roads, and Staunton) used SF concrete overlays only over a short period, generally between 1990 and 1998. Two districts continue the general use of SF overlays: Bristol and Lynchburg. The usage is related to contractors being given the choice to pick either an LMC or SF concrete overlay. The primary reason for the use of SF concrete overlays having been discontinued in other districts is cracking problems. In addition, an initial cost savings of SF concrete versus LMC overlays has decreased significantly in recent decades. The remaining districts did not use this overlay enough to provide the observed service life.

Table 22. Summary of SF Concrete Overlays From District Interviews

Criterion	**No. of Districts**
Usage since 1980s to present	2
Usage in 1990s	4
Deck Evaluation Prior to Overlaying	
Inspection reports	6
Observed Service Life Ranges (years)	
5 to 20: Staunton District	
15 to 20: Bristol District	
20 to 30: Lynchburg District	

Typical comments from the nine interviews were as follows:

- SF is preferred over LMC by some contractors because of simpler equipment needs.
- SF is used on primary roadways.
- SF is used if superstructure is relatively rigid like concrete superstructure rather than steel.
- Districts started to use SF overlays because it was a cost-effective alternative to LMC, but SF and LMC might be comparable in cost in the present.
- SF and LMC costs are similar.
- SF had cracking problems, so many districts went back to LMC.
- Some districts found few cracking problems with SF for which the exact reason was not known. This will need some investigation.

The explanation for the cracking in SF concrete overlays is typically poor workmanship (M. Sprinkel, personal communication).

Asphalt Overlays With a Membrane (HMAM Overlays)

Table 23 presents a summary of the interview results regarding the use of HMAM overlays. Two primary types of waterproofing are preformed membranes and constructed-in-place (liquid) membranes. Seven districts use HMAM overlays, four use joint sealing techniques with HMA overlays, and three use sheet membranes. Service lives appear to be marginal at 10 to 12 years, and as a result, some districts use EC overlays instead, where applicable. Most districts did not provide the observed service life of their overlays. Sometimes this overlay has been placed over other overlays such as an EC overlay and over the top flanges of adjacent box beams.

Table 23. Summary of HMAM Overlays From District Interviews

Criterion	No. of Districts
Waterproof coating on top surface of members, strip seal joints, plug seal joints	4
Sheet membranes (Landsaver, Rubberoid, VDOT specification SS8, Meldec 300)	3
Observed Service Life Ranges (years)	
10 to 12: Richmond District	
25 to 30: Salem District (low-traffic roads)	
First repairs in 10 to 15 years: Fredericksburg District	
10 to 15: Staunton District	

Typical comments from the nine interviews were as follows:

- Some question how well the waterproofing membrane / strip seal / plug seal approach works.
- HMAM are used primarily on low-volume roads.
- HMAM does not perform well at or close to traffic signals because of drag from the vehicles coming to a stop.
- It is important for the waterproofing to cover the entire deck instead of only over the strip joint seals. HMAM does not perform well; many HMAM overlays have been replaced with EC overlays.

HMAM overlays are mainly used on low-volume secondary roadways for prestressed adjacent box beams and adjacent slab structures as well as timber decks. Long-term use is limited to these two structure types. Waterproofing effectiveness is critical for these two prestressed structure types with unique rapid construction characteristics. The use of these two types of simply supported structures may increase, as they can be built with relatively lower cost and faster construction. Thus, the use of HMAM overlays may continue in the future.

Summary of Interview Findings

The five most commonly used overlays in Virginia and their performance from observation by district engineers are as follows:

1. *Asphalt concrete overlays* are the least durable deck protection systems because of their high permeability and their tendency to hold moisture. These overlays are mainly used on short, rural bridges with low traffic volumes. Waterproof membranes, when properly installed, can extend the protection to up to 10 years or more. However, there are concerns about the consistent performance of the waterproof membranes.

2. *EC overlays* are used as a preventive deck protection method that is typically installed on decks that have little to no deterioration. Depending on the traffic volume, the service life varies from 7 to 30 years. These overlays deteriorate by wearing away and are often well suited for a second generation EC overlay on top, either as is or after the worn layer is removed.

3. *SF concrete overlays* are durable rigid overlays when used as a rehabilitation method; however, in some instances, widespread cracking has been reported. Cracking often has been attributed to poor curing practices. The observed service life of this overlay type is up to 30 years. Only a few districts have continued the installation of SF concrete overlays because of cracking.

4. *LMC overlays* are the most commonly used rigid overlay system in Virginia. This type of overlay is used as a preservative rehabilitation method and requires specialized equipment for mixing. The observed service life was reported as high as 50 years. The requirement for lane closures for up to 3 days is a disadvantage on bridges that carry high traffic volumes.

5. *VESLMC overlays* have important applications for roads with high traffic volumes. However, the restricted time for installation may lead to construction mistakes. Extensive instances of wide cracks have been reported because of ill-timed curing practices. The learning curve for contractors can be steep. Experience with this type of overlay is limited, so the approximate service life is not known, but VDOT currently has overlays that are performing well after 10 years. Use continues to increase.

CONCLUSIONS

- *The literature review aided in developing the questions for interviews with the district personnel who are involved in decisions regarding overlay construction. The interviews helped the researchers collect both subjective and objective information regarding how the bridge deck overlays are selected, which factors influence their performance, common modes of failure, and expected service life.*

- *The five most common overlay types used by the nine VDOT districts are LMC, EC, SF concrete, VESLMC, and HMAM overlays.*

- *Wide ranges of service life, even for the same overlay types, are the case in every VDOT district.*

- *One common opinion that was repeatedly expressed by the district engineers is that the performance of overlays, irrespective of the type, is highly dependent on the construction contractor, which in turn means that the performance of overlays primarily depends on the quality of construction and the extent of attention paid to the crucial details.*

- *Another commonly observed influential factor was the degree of deck damage (i.e., deterioration) that existed when the overlay was installed; the higher the pre-overlay deck damage, the worse the performance of the overlay.*

RECOMMENDATIONS

1. *The Virginia Transportation Research Council (VTRC) and VDOT's Structure and Bridge Division should conduct a Phase II study to determine the performance of the overlays identified as the commonly used deck protective systems in this Phase 1 study. The details regarding the proposed study are as follows:*

   - VTRC and VDOT's Structure and Bridge Division should assess the service life performance of each of the five types of overlays and compare it with the observational service life presented in the Phase I study. Overlay types to be assessed are LMC, EC, SF, VESLMC, and HMAM overlays.

   - VTRC and VDOT's Structure and Bridge Division should identify the primary factors that affect the service life of the five overlay types. Wide ranges of service life for each of the overlay types, as observed by the district engineers, indicate that there are influential factors that affect the overlay performance. Deck condition, evaluation, and construction records would provide significant aids in assessing the service life performance and provide guidelines in the decision-making process to overlay again or replace the bridge deck. The following records will be useful in this analysis:

     — deck evaluation reports prior to overlay including surveys of patches, spalls, delaminations, corrosion half-cell potentials, cover depths, and chloride contents

     — construction inspection records that document the amount of concrete removed by milling or other means, patches and corresponding locations, overlay material and quantities, the contractor who performed the work, and difficulties encountered, if any

     — finalized (as-built) plans and reports of the rehabilitation.

   - VTRC and VDOT's Structure and Bridge Division should collect, compile, and analyze the performance condition of the overlaid bridge decks under service along with the data from VDOT's bridge inventory (using AASHTOware BrM) and inspection records. Study parameters should include the following:

     — overlay age
     — traffic characteristics and deicing salt use
     — available records
     — visual inspection: patches, spalls, soffit condition
     — delaminations

— corrosion half-cell potentials
— chloride contents at four depths.

BENEFITS AND IMPLEMENTATION

Benefits

As per Recommendation 1, the Phase II investigation of VDOT's bridge deck overlays through reviewing VDOT's bridge inventory (with the use of AASHTOware BrM); reviewing historical inspection reports; and visually surveying selected bridge decks will provide detailed information on the performance of the commonly used overlay types in Virginia. With historical performance data, the service life expectations of bridge deck overlays can be formulated. This information will aid in improving guidance for rehabilitation of bridge decks and improving the life-cycle cost analysis of the rehabilitative methods.

Implementation

The Phase II study described in Recommendation 1 was initiated by VTRC and VDOT's Structure and Bridge Division on November 4, 2016, and is expected to be complete April 30, 2018. The results will be used to provide appropriate modifications to the bridge maintenance guidelines that pertain to deck overlays in VDOT's *Manual of the Structure and Bridge Division.*

REFERENCES

AASHTO-AGC-ARTBA Task Force 34. *Guide Specifications for Polymer Concrete Bridge Deck Overlays.* American Association of State Highway and Transportation Officials, Washington, DC, 1995.

American Association of State Highway and Transportation Officials. *AASHTO T 277: Electrical Indication of Concrete's Ability to Resist Chloride.* Washington, DC, 2011.

ASTM International. *ASTM E524: Standard Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests.* West Conshohocken, PA, 2008.

ASTM International. *ASTM D638: Standard Test Method for Tensile Properties of Plastics.* West Conshohocken, PA, 2010.

ASTM International. *ASTM C579: Standard Test Methods for Compressive Strength of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes.* West Conshohocken, PA, 2012a.

ASTM International. *ASTM C1202: Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.* West Conshohocken, PA, 2012b.

Balakumaran, S., Weyers, R.E., and Brown, M.C. Modeling Corrosion Effects: An Examination of Chloride-Induced Deterioration of a Bridge Deck with Epoxy-Coated Reinforcement. *Concrete International,* Vol. 35, No. 2, February, 2013, pp. 47-53.

Carter, P.D. *Thin Polymer Wearing Surfaces for Preventive Maintenance of Bridge Decks.* SP 137. American Concrete Institute, Farmington Hills, MI, 1993.

Distlehorst, J. *Cost Effective Bridge Deck Reconstruction in Kansas Using High-Density Concrete Overlays and Asphalt Membrane Overlays.* FHWA-KS-07-4. Kansas Department of Transportation, Topeka, 2009.

Federal Highway Administration. *Federal-Aid Highway Program Manual.* Washington, DC, 1976.

Federal Highway Administration. *Bridge Preservation Guide—Maintaining a State of Good Repair Using Cost Effective Investment Strategies*. FHWA-HIF-11042. Washington, DC, 2011.

Fowler, D.W., and Whitney, D.W. *Long-Term Performance of Polymer Concrete for Bridge Decks.* NCHRP Synthesis 423. Transportation Research Board of the National Academies, Washington, DC, 2012.

Guthrie, W.S., Nelsen, T., and Ross, L.A. *Performance of Concrete Bridge Deck Surface Treatments: Final Report.* UT-05.05. Utah Department of Transportation, Salt Lake City, 2005.

Harper, J. *Investigations of Failures of Epoxy Polymer Overlays in Missouri.* RI06-020. Missouri Department of Transportation, Jefferson City, 2007.

Hilton, M.H., Walker, H.N., and Wallace, T.M. *Latex Modified Portland Cement Overlays: An Analysis of Samples Removed From a Bridge Deck*. VHTRC 9376-R25. Virginia Highway & Transportation Research Council. Charlottesville, 1975.

Krauss, P.D., Lawler, J.S., and Steiner, K.A. *Guidelines for Selection of Bridge Deck Overlays, Sealers, and Treatments.* NCHRP 20-07/Task 234. Transportation Research Board, Washington, DC, 2009.

Ozyildirim, H.C. *A Field Investigation of a Concrete Overlay Containing Silica Fume on Route 50 Over Opequon Creek.* VTRC 93-R15. Virginia Transportation Research Council, Charlottesville, 1993.

Ozyildirim, H.C. *A Field Investigation of Concrete Overlays Containing Latex, Silica Fume, or Pyrament Cement.* VTRC 96-R23. Virginia Transportation Research Council, Charlottesville, 1996.

Pfeifer, B.A., and Kowalski, G. *Evaluation of Thin Lift Polymer Bridge Deck Overlays on I-57 Bridges at Clifton, IL.* IL-PRR-132. Illinois Department of Transportation, Bureau of Materials and Physical Research, Springfield, 1999.

Ray, I., Davalos, J.F., and Hong, T. *Characterization of Early Age Interface Properties of High-Performance Concrete Overlay and Normal Concrete Substrate*. ASCE Aerospace Division International Conference, Long Beach, CA, 2008.

Russell, H.G. *Waterproofing Membranes for Concrete Bridge Decks.* NCHRP Synthesis 425. Transportation Research Board of the National Academies, Washington, DC, 2012.

Sohanghpurwala, A.A. *Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements.* NCHRP Report 558. Transportation Research Board of the National Academies, Washington, DC, 2006.

Sprinkel, M.M. *High Early Strength Latex Modified Concrete Overlay*. VTRC 88-R12. Virginia Transportation Research Council, Charlottesville, 1988.

Sprinkel, M.M. *Very-Early-Strength Latex-Modified Concrete Overlay*. Virginia Transportation Research Council, Charlottesville, 1998.

Sprinkel, M.M. *Evaluation of Latex-Modified and Silica Fume Concrete Overlays Placed on Six Bridges in Virginia*. VTRC 99-IR2. Virginia Transportation Research Council, Charlottesville, 2000.

Sprinkel, M.M. *Twenty-Five-Year Experience With Polymer Concrete Bridge Deck Overlays.* SP 214. American Concrete Institute, Farmington Hills, MI, 2003, pp. 51-62.

Sprinkel, M.M. *Performance Specification for High Performance Concrete Overlays on Bridges*. VTRC 05-R2. Virginia Transportation Research Council. Charlottesville, 2004.

Sprinkel, M.M. *Rapid Concrete Bridge Deck Overlays.* ACI-SP-P10. American Concrete Institute, Farmington Hills, MI, 2011.

Sprinkel, M.M., and Weyers, R.E. *Rapid Concrete Bridge Deck Protection, Repair and Rehabilitation.* SHRP S-344. Strategic Highway Research Program, National Research Council, Washington, DC, 1993.

Sprinkel, M.M., Sellars, A.R., and Weyers, R.E. *Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques: Rapid Concrete Bridge Deck Protection, Repair and*

Rehabilitation. SHRP-S-344. Strategic Highway Research Program, National Research Council, Washington, DC, 1993.

Virginia Department of Transportation, Materials Division. *Virginia Test Method 92: Testing Epoxy Concrete Overlays for Surface Preparation and Adhesion—(Physical Lab).* 2000. http://www.virginiadot.org/business/resources/Materials/bu-mat-VTMs.pdf. Accessed March 3, 2017.

Virginia Department of Transportation. *Road and Bridge Specifications*. Richmond, 2007.

Virginia Department of Transportation. *Manual of the Structure and Bridge Division.* Richmond, 2015a. http://www.virginiadot.org/business/bridge-manuals.asp. Accessed March 20, 2017.

Virginia Department of Transportation, Structure and Bridge Division. *State of the Structures and Bridges Report—Fiscal Year 2015*. Richmond, 2015b. http://www.virginiadot.org/info/resources/bridgeReports/2015-07-FY2015-State_of_the_Structures_and_Bridge_Report-Generated_2015-10-09.pdf. Accessed April 6, 2017.

Wenzlick, J.D. *Evaluation of Very High Early Strength Latex Modified Concrete Overlays.* OR06-004. Missouri Department of Transportation, Jefferson City, 2006.

Weyers, R.E., Prowell, B.D., Sprinkel, M.M., and Vorster, M. *Concrete Bridge Protection, Repair, and Rehabilitation Relative to Reinforcement Corrosion: A Methods Application Manual.* SHRP-S-360. Strategic Highway Research Program, National Research Council, Washington, DC, 1993.

Weyers, R.E., Fitch, M.G., Larsen, E.P., Al-Qadi, I.L., Chamberlin, W.P., and Hoffman P.C. *Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques. Service Life Estimates.* SHRP-S-668. Strategic Highway Research Program, National Research Council, Washington, DC, 1994.

Williamson, G., Weyers, R.E., Brown, M.C., and Sprinkel, M.M. *Bridge Deck Service Life Prediction and Cost*. VTRC 08-CR4. Virginia Transportation Research Council, Charlottesville, 2007.

Wilson, D.L., and Henley, E.H. *Thin Polymer Bridge Deck Overlays: WSDOT's Ten Year Evaluation.* WA-RD 374.1. Bridge and Structures Office, Olympia, 1995.

Yun, K., and Choi, P. Causes and Controls of Cracking at Bridge Deck Overlay With Very-Early-Strength Latex-Modified Concrete. *Construction and Building Materials*, Vol. 56, 2014, pp. 53-62.