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research report

Condition of Concrete Overlays on Route 60 Over Lynnhaven Inlet After 10 Years

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16. Abstract:

In 1996, 16 high performance concrete overlays were placed on two 28-span bridges on Route 60 over the Lynnhaven Inlet in Virginia Beach, Virginia. Thirteen concrete mixtures included a variety of combinations of silica fume (SF), fly ash, slag, latex, corrosion-inhibiting admixtures, a shrinkage-reducing admixture, and fibers; one overlay was constructed with a thickness of only 0.75 in (19 mm), and spans were overlaid with and without topical treatments of two corrosion inhibitors. With the exception of one of the overlay systems, the overlays were required to have a minimum thickness of 1.25 in (32 mm). Another overlay system had a variable thickness ranging from 1.25 to 0.75 in (32 to 19 mm) to provide good ride quality. The demonstration was designed to show that many different combinations of materials can be used for overlays.

The overlays were last evaluated in the fall of 1999 after 3 years in service. The objective of this research was to determine the condition of the overlays at 10 years of age. The results indicated that all overlays have performed well with the exception of most of the areas adjacent to joints. Many of these areas were replaced by the original contractor and replaced again by the City of Virginia Beach.

The overlays were ranked with respect to permeability, chloride content, and cost. The 7% SF overlay on the eastbound lane had the lowest permeability, and the 7% SF overlay on the westbound lane had the highest permeability. The overall best performing overlay was the latex-modified concrete (LMC) overlay, which had the second lowest permeability and chloride diffusion constant and the lowest chloride ion content. Overlays containing fibers and the LMC overlay were estimated to have the highest cost, and the 40% slag overlay was estimated to have the lowest cost.

Although the overlays performed differently with respect to permeability to chloride ion and chloride intrusion, all of the overlays can provide good skid resistance and protection against intrusion by chloride ions and can be an economical technique for extending the life of hydraulic cement concrete decks. The Virginia Department of Transportation should continue to extend the life of bridge decks using LMC and should consider using overlays containing combinations of SF, fly ash, and slag as evaluated in this study when justified based on the cost-benefit analysis for a project.

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FINAL REPORT

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

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

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ABSTRACT

In 1996, 16 high performance concrete overlays were placed on two 28-span bridges on Route 60 over the Lynnhaven Inlet in Virginia Beach, Virginia. Thirteen concrete mixtures included a variety of combinations of silica fume (SF), fly ash, slag, latex, corrosion-inhibiting admixtures, a shrinkage-reducing admixture, and fibers; one overlay was constructed with a thickness of only 0.75 in (19 mm), and spans were overlaid with and without topical treatments of two corrosion inhibitors. With the exception of one of the overlay systems, the overlays were required to have a minimum thickness of 1.25 in (32 mm). Another overlay system had a variable thickness ranging from 1.25 to 0.75 in (32 to 19 mm) to provide good ride quality. The demonstration was designed to show that many different combinations of materials can be used for overlays.

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The overlays were ranked with respect to permeability, chloride content, and cost. The 7% SF overlay on the eastbound lane had the lowest permeability, and the 7% SF overlay on the westbound lane had the highest permeability. The overall best performing overlay was the latex-modified concrete (LMC) overlay, which had the second lowest permeability and chloride diffusion constant and the lowest chloride ion content. Overlays containing fibers and the LMC overlay were estimated to have the highest cost, and the 40% slag overlay was estimated to have the lowest cost.

Although the overlays performed differently with respect to permeability to chloride ion and chloride intrusion, all of the overlays can provide good skid resistance and protection against intrusion by chloride ions and can be an economical technique for extending the life of hydraulic cement concrete decks. The Virginia Department of Transportation should continue to extend the life of bridge decks using LMC and should consider using overlays containing combinations of SF, fly ash, and slag as evaluated in this study when justified based on the cost-benefit analysis for a project.

FINAL REPORT

CONDITION OF CONCRETE OVERLAYS ON ROUTE 60 OVER LYNNHAVEN INLET AFTER 10 YEARS

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INTRODUCTION

Hydraulic cement concrete (HCC) overlays are usually placed on bridge decks to reduce the infiltration of water and chloride ions and to improve the skid resistance, ride quality, drainage, and appearance of the surface. Constructed in accordance with prescription specifications,[1] some overlays have performed well for more than 30 years whereas others have cracked and delaminated before the overlay was opened to traffic. High performance concrete (HPC) overlays have high bond strengths and minimal cracks and should perform well for more than 30 years. Constructing a high-quality HPC overlay requires that appropriate decisions be made with respect to the selection and use of surface preparation equipment and procedures, mixture proportions that provide for low permeability and shrinkage, and placement and curing procedures.[2]

The service life of an overlay is usually controlled by the quality of the bond between the overlay and the deck. The life of a well-bonded overlay is usually controlled by the time it takes for chlorides to reach the reinforcement in the deck and cause corrosion-induced spalling. The rate of chloride penetration is a function of the permeability of the overlay, the number and size of the cracks in the overlay, and drainage. Cracking in the overlay typically increases with an increase in the shrinkage of the overlay. Shrinkage also contributes to the stress on the bond interface and therefore can contribute to delamination. Skid resistance, ride quality, and surface appearance rarely control the life of an HCC overlay. It is reasonable to expect that the service life of an overlay will increase with an increase in bond strength and a decrease in permeability, shrinkage, and the incidence of cracking. HPC overlays should be designed to have high bond strength, low permeability to chloride ion, low shrinkage, minimal cracks, and good surface characteristics.

Concrete overlays that have an established history of use and acceptance in Virginia include latex-modified concrete (LMC) overlays (since 1969) and 7% silica fume (SF) overlays (since 1987). Evaluations indicate that these overlays can provide skid resistance and protection against intrusion by chloride ions and are an economical technique for extending the life of HCC decks.

In 1996, 16 HPC overlays were placed on two 28-span bridges on Route 60 over the Lynnhaven Inlet in Virginia Beach, Virginia.[3, 4] The construction was funded with 20% Virginia Department of Transportation (VDOT) maintenance funds and 80% special federal funds in accordance with ISTEA, Section 6005, specifically designated to demonstrate overlay technologies. ISTEA funds were used to evaluate the overlays. The demonstration was designed to show that many different combinations of materials could be used for overlays. The overlays were last evaluated in the fall of 1999 after 3 years in service.

A site location map for the two bridges is shown in Figure 1, and a photograph of the bridges is provided in Figure 2.[5] Initially, the westbound bridge (westbound lane [WBL]) was overlaid while traffic used the eastbound bridge (eastbound lane [EBL]). Then, traffic was detoured to the WBL while the EBL was overlaid.

The installation included 13 concrete mixtures, an overlay with a thickness of only 0.75 in (19 mm), and spans with and without topical treatments of two corrosion inhibitors for a total of 16 overlays. The overlay systems are identified in Figure 1 as follows:

Overlay System A: 7% SF
Overlay System B: 5% SF and 35% S
Overlay System C: 5% SF and 15% Class F FA
Overlay System D: 15% LMC
Overlay System E: 13% SF and 15% FA
Overlay System F: 13% SF and 15% FA placed 0.75 in (19 mm) thick
Overlay System G: 7% SF and Rheocrete corrosion-inhibiting admixture (CIA) (RCI)
Overlay System H: 7% SF, Armatec CIA (ACI), ACI topical treatment (A)
Overlay System H*: 7% SF and ACI
Overlay System I: 7% SF, Darex CIA (DCI), and Postrite (P) topical treatment
Overlay System I*: 7% SF and DCI
Overlay System J: 40% S
Overlay System K: 7% SF and shrinkage-reducing admixture (CQI)
Overlay System L: 7% SF and polyolefin fibers (POF)
Overlay System M: 7% SF and steel fibers (STF)
Overlay System N: 7% SF and polypropylene fibers (PPF).

With the exception of Overlay System F, overlays were required to have a minimum thickness of 1.25 in (32 mm). In addition, Overlay System E had a variable thickness that ranged from 1.25 to 0.75 in (32 to 19 mm) to provide good ride quality.

PURPOSE AND SCOPE

Previous reports documented the following tasks using the outside travel lane of at least one deck span with each of the 16 overlays:

1. Evaluate conditions of each deck prior to placement of the overlays.
2. Document the specifications used for each installation.
3. Document the installation of each overlay.
4. Evaluate the initial condition of each overlay.
5. Evaluate the condition of each overlay annually.
6. Evaluate the final condition of each overlay in 1999.
7. Prepare a final report for the Federal Highway Administration after 3 years.

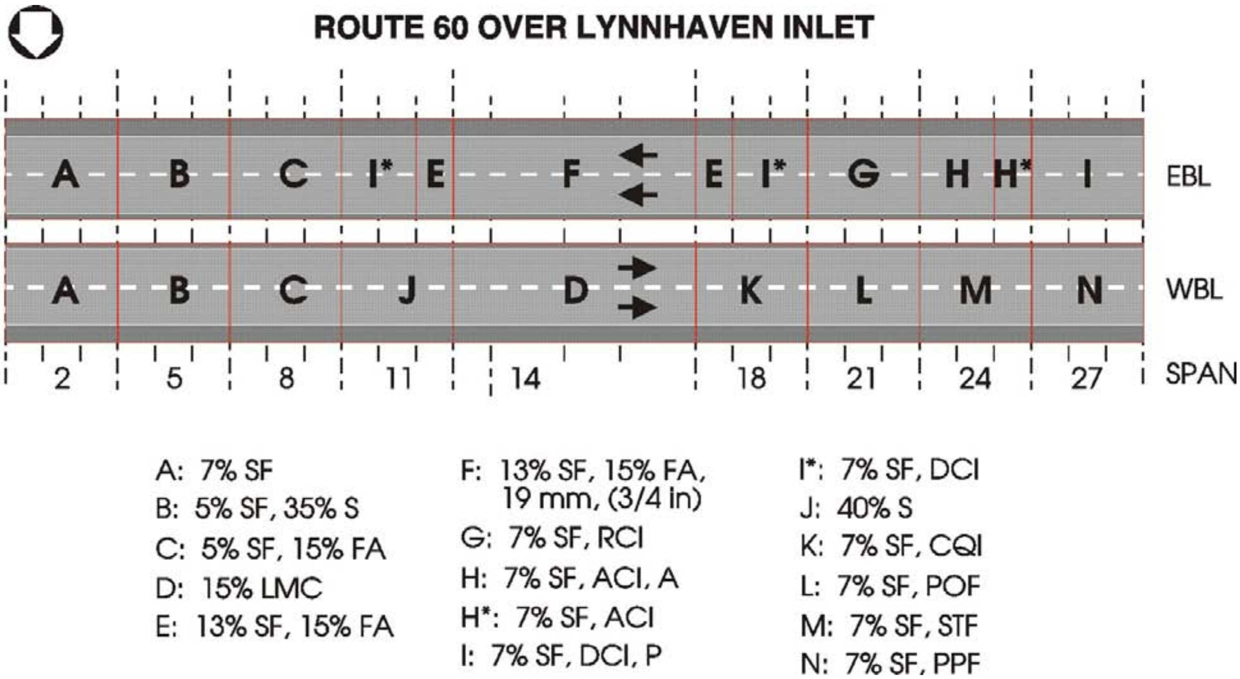

Figure 1. Plan View for Overlays on Two 28-Span Bridges on Route 60 Over Lynnhaven Inlet. EBL = eastbound lane; WBL = westbound lane; SF = silica fume; S = slag; FA = fly ash; LMC = latex-modified concrete; RCI = Rheocrete corrosion-inhibiting admixture (CIA); ACI = Armatec CIA; A = ACI topical treatment, DCI = Darex CIA, P = Postrite; CQI = shrinkage-reducing admixture, POF = polyolefin fibers, STF = steel fibers, PPF = polypropylene fibers.

Figure 2. North Elevation of Lynnhaven Bridge[5]

Tasks 1 through 5 were covered in the interim report.[3] Tasks 6 and 7 were covered in the final report.[4]

The current study was conducted to document the condition of the overlays after 10 years. Where available, information for more than one span and for the inside lane was included in the evaluation of each overlay.

METHODS

Evaluations of the overlays at 10 years were based on an assessment of how well they were bonded to the deck, how well they were providing a skid-resistant surface, how well they were protecting the deck from the infiltration of chloride ion and corrosion, and their cost-effectiveness.

As shown in Figure 1, the bridges were overlaid with 21 test sections. The outside lane of one span with each of the overlay mixtures on both decks was evaluated as follows:

1. visual survey and recording of all cracks, delaminations, spalls, and patches (all spans)
2. skid resistance (VDOT trailer test)
3. electrical half-cell potentials (ASTM C 876)
4. three tensile bond strength tests (Virginia Test Method [VTM] 92 modified for the laboratory)
5. two permeability tests on the top 2 in of the overlay and deck (AASHTO T 277)
6. three chloride ion content determinations at 4 depths within the top 2 in of the deck (AASHTO T 260).

The tests in 2006 were done near the locations of tests done in 1996 and 1999.

Crack, Delamination, Spall, and Patch Measurements

Crack, spall, and patch measurements were recorded on an 8.5-in by 11-in sheet of paper designated for each span surveyed. A chain drag of the deck was used to indicate areas that were delaminated (0 bond strength). A survey of the deck for delaminations, spalls, and patches provides an indication of bond strengths that were not high enough to prevent failure because of stress caused by shrinkage, traffic, temperature change, moisture, and cycles of freezing and thawing. Scaling (erosion of the paste) changes the appearance of the surface by exposing the coarse aggregate but is typically not a problem unless it is medium to heavy, which results in a loss of the saw-cut grooves and a reduction in the thickness of the concrete cover.

Skid Resistance Tests

Skid resistance was measured with a skid test trailer pulled at 40 mph. Tests were done with a treaded tire (ASTM E501) or a bald tire (ASTM E524). Results are reported based on the average of three tests. The treaded tire test provides a good indication of microtexture, and the bald tire test provides a good indication of macrotexture. Asphalt and concrete pavements and bridge decks typically have skid numbers between 30 and 50, which are considered acceptable to good.

Half-cell Potential Measurements

Protection against corrosion is indicated by electrical half-cell potential measurements (ASTM C 876). Readings were taken on a 5-ft grid and were interpreted as follows:

- *0 to –0.19 Vcse:* 90% probability of no corrosion
- *–0.20 to –0.35 Vcse:* uncertain as to corrosion
- *Vsce more negative than –0.35:* 90% probability of corrosion.

Tensile Bond Strength Tests

A modified version of VTM 92 was used to provide an indication of how well the overlays were bonded to the base concrete. Typically, three cores 2.25 in in diameter and approximately 4 in long were tested for each overlay. The cores were drilled through the overlay and base concrete and taken to the laboratory for testing. In the laboratory, the cores were saw cut parallel with and approximately 1 in above and below the plane of the bond interface. The machined surfaces of two pipe caps were bonded to the saw cut surfaces of each core with an epoxy. Two hooks were connected to the threaded pipe caps, and the hooks and core were pulled in tension using a universal testing machine. Cores were loaded at the rate of 1,200 lb/min, and the failure load and failure location were recorded.

Failures can occur in the base concrete, the bond interface, the overlay, the epoxy used to bond the caps to the core, and a combination of these locations. A 100% failure in the bond interface provides a true indication of bond strength. Failures at other locations indicate that the bond strength is greater than the failure load. However, for practical purposes, failures in the base concrete or overlay provide an indication of the degree to which the overlay is anchored and are considered as indicating bond strength. When a failure occurs in the epoxy, the result may be discarded if it is lower than the average of the other results or included if it is the same or higher. An epoxy failure should be a rare occurrence.

Bond strength test results may be qualified as follows:

- *≥300 psi*, excellent
- *250 to 299 psi*, very good
- *200 to 249 psi*, good
- *100 to 199 psi*, fair
- *0 to 99 psi*, poor.[4]

Permeability Tests

Protection against the infiltration of chloride ion was evaluated based on deck surveys and mapping of cracks and tests of two or three cores for permeability to chloride ion (AASHTO T 277). Permeability test results were based on tests of a 2-in-thick slice cut from the top of 4-in-diameter cores and were typically the average of tests on two or three cores. Results are expressed as follows:

- *>4000 coulombs*, high
- *2000-4000 coulombs,* moderate
- *1000-2000 coulombs,* low
- *100-1000 coulombs*, very low
- *<100 coulombs*, negligible.

Chloride Ion Content Tests

Protection against corrosion is also indicated by the chloride ion content at the level of the reinforcing steel. Chloride ion contents of 1.3 pcy or greater are sufficient to cause corrosion. Samples were taken and analyzed in accordance with AASHTO T 260. Most state departments of transportation use 2 pcy as the threshold for decisions. Low-permeability overlays are designed to reduce the rate of chloride ion penetration into decks to extend the life. The chloride ion content at various levels in the overlays was determined to provide an indication of how well the overlays are preventing the penetration of the chloride ion.

Cost

Cost-effectiveness is typically based on life cycle costs. Unfortunately, it is difficult to obtain representative costs for demonstration projects because of the unique nature and small size of typical projects. Relative comparisons of the costs of traffic control, construction, materials, and mobilization for various overlay systems can provide an indication of relative cost-effectiveness. This project compared the relative cost of materials based on estimates.

RESULTS

Cracks

Prior to placement of the overlays, with the exception of the center spans (13-16), which are on steel beams, the decks were free of cracks and patches. Span 14 in the WBL had 322 ft of cracks that were oriented transverse to traffic, and Span 14 in the EBL had 69 ft.

Tables 1 and 2 show the data for cracks, delaminations, spalls, patches, and surface scaling obtained in 1999 and 2006. In 2006, the most cracking was observed for Overlay System

Table 1. Cracks, Delaminations, Spalls, and Patches in 1999 and 2006, Westbound Lane

Span	1999 WBL					2006 WBTL				
	Cracks (ft)	Delaminations (ft^2)	Spalling (ft^2)	Patches (ft^2)		Cracks (ft)	Delaminations (ft^2)	Spalling (ft^2)	Scaling	Patches (ft^2) Outside
				Inside	Outside					
1	2.0	0.0	0.0	16.3	16.3	18	0.0	0.0	L	19
2	3.0	0.9	0.0	27.0	27.0	9	1	0.0	L	28
3	0.5	0.3	0.0	33.0	33.0	3	0.0	0.0	L	33
4	0.0	0.0	0.0	35.8	35.8	10	2	0.0	N	37
5	1.5	1.5	0.5	40.1	40.1	6	1.5	0.5	N	33
6	38.5	0.0	0.0	53.1	53.1	13	1	0.0	N	55
7	7.0	4.0	4.0	10.8	9.2	5	3	0.0	N	24
8	6.0	1.5	0.0	0.0	0.0	5	0.5	0.0	N	0.0
9	3.5	1.5	0.0	16.3	0.7	12	1	0.0	N	1
10	8.5	0.0	0.0	32.5	35.0	15[1]	0.0	0.0	M	32
11	3.5	3.0	0.0	36.8	52.0	9[2]	1.5	0.0	M	48
12	8.5	0.1	0.0	17.0	32.5	8[2]	1.5	0.0	M	32
13	18.0	0.4	0.0	21.1	20.5	10	0.0	0.0	N	20.5
14	3.5	0.0	0.0	7.6	7.6	8	0.5	0.0	N	13
15	2.3	0.0	0.0	0.0	0.0	2	0.0	0.0	N	3
16	3.5	1.5	0.0	6.5	6.5	60	0.0	0.0	N	7
17	0.5	1.5	0.0	13.0	13.0	61	3	0.0	M	23
18	1.3	0.0	0.0	0.0	0.0	60[2]	0.0	0.0	M	0.0
19	4.5	0.7	0.0	0.0	1.9	18[3]	0.0	0.0	M	2
20	5.7	0.0	0.0	3.5	3.0	4	1	0.0	H	3
21	7.0	0.0	0.0	23.6	21.6	8	10	0.0	H	30
22	3.0	3.4	0.0	19.5	21.5	0.0	7	1	H	22
23	6.5	1.6	0.0	0.5	0.8	0.0	2	0.0	M	2.5
24	0.5	1.5	0.0	0.0	0.0	1	3	0.0	N	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	2	0.0	N	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N	0.0
28	0.0	0.0	0.0	0.0	0.0	20	1	0.0	N	0.0

L = light surface scaling, N = negligible scaling, M = medium surface scaling, H = heavy surface scaling.
[1]Hairline random shrinkage cracking approximately 5 ft per ft^2.
[2]Hairline random shrinkage cracking approximately 3 ft per ft^2.
[3]Hairline random shrinkage cracking approximately 12 ft per ft^2.

Table 2. Cracks, Delaminations, Spalls, and Patches in 1999 and 2006, Eastbound Lane

Span	1999 EBL					2006 EBTL				
	Cracks (ft)	Delaminations (ft^2)	Spalling (ft^2)	Patches (ft^2)		Cracks (ft)	Delaminations (ft^2)	Spalling (ft^2)	Scaling	Patches (ft^2) Outside
				Inside	Outside					
1	66.5	8.0	3.6	2.9	4.0	14	0.0	0.0	L	22
2	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	L	0.0
3	1.3	0.0	0.5	8.8	2.5	0.0	0.0	0.0	L	0.0
4	16.0	12.0	5.3	15.8	3.0	12	4	0.0	N	25
5	1.7	1.5	7.2	13.3	8.0	13	0.0	0.0	N	36
6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N	0.0
7	4.3	0.0	0.0	11.0	25.0	14	0.0	0.0	N	30
8	0.0	0.0	0.0	5.0	19.5	0.0	0.0	0.0	N	20
9	0.8	0.0	0.0	13.0	0.0	18	0.0	0.0	N	0.0
10	3.7	4.5	0.0	9.0	13.0	12	0.0	0.0	L	18
11	3.7	5.0	0.0	14.0	12.0	6.25	2.5	0.0	L	45
12	0.0	0.5	1.3	11.9	11.0	3	3	0.0	N	20
13	0.0	0.0	0.0	41.3	20.2	0.0	0.0	0.0	N	22
14	148.8	0.0	0.2	40.5	28.0	76	0.0	0.0	N	20
15	2.3	0.0	0.0	2.4	12.4	4.25	0.0	0.0	N	25
16	0.0	0.0	0.0	0.0	0.0	6.5	1.5	4.5	N	21
17	2.5	0.0	2.5	4.4	17.8	2.5	3	0.0	N	7.3
18	7.0	3.0	8.0	19.5	0.0	10	0.0	0.0	L	24
19	2.5	0.0	5.0	0.0	3.3	6.3	0.0	0.0	L	18
20	2.5	0.0	0.2	23.7	21.8	0.5	1	0.0	L	17
21	3.3	1.5	0.8	44.3	45.2	23	3	0.0	L	24
22	5.3	0.0	0.0	73.6	44.1	0.0	0.0	0.0	L	40.5
23	7.0	0.0	0.0	27.4	17.1	0.0	0.0	0.0	L	13.5
24	2.0	0.0	0.0	58.8	39.2	2	4	0.0	L	39
25	8.0	0.5	0.0	29.2	32.5	18	0.0	0.0	L	46
26	3.0	0.0	0.0	22.2	17.1	0.0	0.0	0.0	L	11
27	5.3	5.3	1.0	23.3	11.3	6	0.0	0.0	L	39
28	3.5	2.0	0.0	8.2	13.8	6	0.0	0.0	L	19

L = light surface scaling, N = negligible scaling, M = medium surface scaling, H = heavy surface scaling.

F (13% SF and 15% FA) on Span 14 of the EBL. Most of the 76 ft of cracking could be attributed to reflective cracking since 69 ft of cracking was observed prior to placement of the overlay. Overlay System F is thin and has the highest binder content and, therefore, would be expected to crack the most. The cracking in 2006 was less than in 1999 because the data for 2006 were for the travel lane and the data for 1999 were for both lanes. In 2006, the second worst cracking occurred in Overlay System D (LMC) on Span 16 and Overlay System K (7% SF and CQI) on Spans 17 and 18 of the WBL. Most of the cracking in Overlay System D on the steel spans was reflective cracking from the cracks in the deck. On the positive side, only 8 ft of cracking was observed on Span 14 of the WBL. Prior to placement of the overlay, 332 ft of cracking was recorded. Evidently, the LMC overlay used on Span 14 was able to bridge the 322 ft of cracking observed prior to placement. This overlay had the lowest modules of elasticity of the overlay systems used and would be expected to have the most crack-bridging capability. The cracking in Overlay System K was longitudinal in the left wheel path, for which the cause is not known. Most of the other linear cracking in the overlays was in the patches used to replace the overlay along the joints. Hairline random shrinkage cracking was observed in Overlay System J (40% S) on Spans 10, 11, and 12 and Overlay System K on Spans 18 and 19 in the WBL. The shrinkage cracking was likely caused by insufficient curing. Evidently, a 3-day wet burlap cure was not adequate. Overall, the cracking performance of the overlays was excellent.

Delaminations, Spalls, and Patches

Considerable patching was done in the vicinity of the joints on both bridges between 1996 and 1999.[4] The overlay delaminated and spalled on each side of many of the joints on the WBL because the joints were not properly prepared for the overlay placement. No filler material was placed in the joint, and the finisher placed a notch in the surface of the freshly placed overlay to control contraction cracking. Unfortunately, when the spans expanded with an increase in temperature, the overlay delaminated within 2 ft on each side of the joint because no expansion material was in the joint area. The overlay in the vicinity of most joints had to be removed, formed properly, and placed again. The overlay delaminated on each side of most of the joints on the EBL because the form material was not compressible and because it was not removed in a timely fashion. The overlay was recast one or more times in the vicinity of most joints on both bridges because incorrect forming and form removal techniques were used. The 7% SF mixture (Overlay System A) was used for the overlay repairs. A silicone joint material was placed in each joint following the saw-cutting operation. Patching has not yet been required other than adjacent to the joints.

Delaminations and spalls in the WBL in 1999 and 2006 are noted in Table 1. Delaminations and spalls in the EBL in 1999 and 2006 are noted in Table 2. Between 1996 and 1999, areas of delamination adjacent to the joints ranged from 0 to 12 ft^2 and in 2006 ranged from 0 to 10 ft^2. A chain drag of the overlays in 1999 revealed no delaminations except those adjacent to the joints. In 2006, only 3 ft^2 of delamination (Spans 4 and 25 WBL) and 4.5 ft^2 of spall (Span 16 EBL) was not located in the vicinity of the joints. With these minor exceptions, delaminations, spalls, and patches were in the vicinity of the joints. With the exception of the area along the joints, the performance of the overlays has been excellent with respect to not delaminating and spalling and needing to be patched.

Surface Scaling

The air content of the concretes was high enough to prevent scaling.[3] Table 1 indicates that heavy surface scaling was observed for Overlay System L (7% SF and POF) on Spans 20, 21, and 22 WBL. Evidently, the excess water that was placed on the surface to aid the finishing operation because of the poor workability of the concrete caused by the fibers caused the scaling. The excess water likely ran onto Span 23 from Span 22. Overlay System M (7% SF and STF) was used on Spans 23, 24, and 25, but only Span 23 had medium scaling. Medium scaling was observed for Overlay Systems J (40% S) and K (7% SF and CQI) in the WBL. Light scaling was observed for Overlay Systems A (7% SF), G (7% SF and RCI), H (7% SF and ACI), and I (7% SF and DCI). Negligible scaling was observed for Overlay Systems B (5% SF and 35% S), C (5% SF and 15% FA), D (LMC), E and F (13% SF and 15% FA), M (7% SF and STF), and N (7% SF and PPF). Scaling performance was acceptable for most of the overlays.

Skid Resistance

The results of the skid tests conducted in December 1996, November 1999, and August 2008 with a skid trailer are shown in Table 3. Although the data for 2008 represent 12 years in service, there is no reason to expect different numbers for 2006. The tests were conducted on the outside lane of the overlays. All overlay concretes provided excellent skid resistance. Saw-cut grooves 0.13 in wide, 0.13 in deep, and spaced 0.75 in apart yielded the excellent skid numbers.

Electrical Half-cell Potentials

Electrical half-cell potentials were measured (ASTM C 876) on a 4-ft (1.2-m) grid over the outside shoulder and travel lane prior to placement of the overlays in 1996, in November 1999, and in October 2006. The data reported in Table 4 as the percentage of readings in each range show a 90% or greater probability that corrosion is occurring (potentials more negative than –0.35 Vcse) in small areas of eight spans prior to the overlays being placed, a small area of Span 14 after the overlays were placed, and no areas after 10 years in service. There is a 90% or greater probability that corrosion is not occurring (potentials less negative than –0.20 Vcse) after 10 years in service. The overlays have halted the corrosion that was occurring prior to placement of the overlays and prevented further corrosion after 10 years in service.

Tensile Bond Strength

The tensile bond strength of an overlay is a function of the quality of the deck concrete, the quality of the surface preparation, and the quality of the overlay placement. Shot blasting was used to prepare the deck surface. Table 5 shows the results of the tensile adhesion tests conducted on the outside travel lane in accordance with a modified version of ACI 503R and VTM 92. The modifications were that cores were removed from the deck and saw cut in the laboratory to provide specimens 4 in high, pipe caps were bonded to the surfaces of the overlays and the sawn surfaces of the bases, and the specimens were subjected to tension using a universal

Table 3. Skid Test Results in 1996, 1999, and 2008

Overlay System	1996 WBL Bald Tire	1999 WBL Bald Tire	2008 WBL Bald Tire	1996 WBL Tread Tire	1999 WBL Tread Tire	2008 WBL Tread Tire	Overlay System	1996 EBL Bald Tire	1999 EBL Bald Tire	2008 EBL Bald Tire	1996 EBL Tread Tire	1999 EBL Tread Tire	2008 EBL Tread Tire
A	48	51	49	47	51	50	I	45	47	47	46	46	49
B	49	51	47	50	50	47	H	33	47	49	34	47	50
C	48	52	48	47	51	48	G	38	49	50	39	49	52
J	54	54	51	53	53	53	I*	43	48	50	43	47	50
D	42	53	48	43	54	50	F	37	46	45	39	47	52
K	39	51	51	42	51	53	I*	38	48	52	42	48	55
L	36	48	51	38	48	52	C	37	49	51	42	50	52
M	41	50	50	43	50	53	B	41	49	51	43	50	51
N	40	48	49	39	47	51	A	46	51	52	44	50	52

Table 4. Electrical Half-Cell Potentials Prior to Overlay Applications and in November 1999 (ASTM C 876)

Span	Direction	Prior to Overlay, –Vcse			November 1999, – Vcse			October 2006, – Vcse		
		<0.20	0.2-0.35	>0.35	<0.20	0.2-0.35	>0.35	<0.20	0.2-0.35	>0.35
2	WBL	96.9	3.1	0.00	100.0	0.0	0.0	98.1	1.9	0.0
	EBL	81.3	14.3	4.4	100.0	0.0	0.0	100.0	0.0	0.0
5	WBL	100.0	0.0	0.0	98.1	1.9	0.0	98.1	1.9	0.0
	EBL	98.9	1.1	0.0	100.0	0.0	0.0	98.1	1.9	0.0
8	WBL	91.8	7.1	1.0	98.1	1.9	0.0	98.1	1.9	0.0
	EBL	96.7	3.3	0.0	100.0	0.0	0.0	100.0	0.0	0.0
11	WBL	98.0	2.0	0.0	98.1	1.9	0.0	98.1	1.9	0.0
	EBL	75.8	19.8	4.4	92.3	7.7	0.0	90.4	9.6	0.0
14	WBL	86.2	11.7	2.1	43.3	54.8	1.9	89.4	10.6	0.0
	EBL	44.0	43.4	12.6	90.4	9.6	0.0	93.3	6.7	0.0
18	WBL	96.9	3.1	0.0	100.0	0.0	0.0	100.0	0.0	0.0
	EBL	81.3	15.4	3.3	96.2	3.8	0.0	98.1	1.9	0.0
21	WBL	99.0	1.0	0.0	96.2	3.8	0.0	98.1	1.9	0.0
	EBL	86.8	11.0	2.2	100.0	0.0	0.0	100.0	0.0	0.0
24	WBL	94.9	4.1	1.0	100.0	0.0	0.0	100.0	0.0	0.0
	EBL	100.0	0.0	0.0	100.0	0.0	0.0	98.1	1.9	0.0
27	WBL	98.2	1.8	0.0	100.0	0.0	0.0	100.0	0.0	0.0
	EBL	93.4	6.6	0.0	100.0	0.0	0.0	94.2	5.8	0.0

testing machine in the laboratory. After 10 years in service, the bond strengths were as follows: four eastbound (EB) spans were excellent, four EB and four westbound (WB) spans were very good, two EB and three WB spans were good, and only two WB spans were fair.

Typically, bond strengths were similar or better than in the past and failure areas were similar. Overlay System I with the Postrite treatment was the only overlay with a high percentage failure in the bond for all three evaluation periods. Overlay Systems B and C in the WBL had the only fair bond strengths after 10 years, but Overlay Systems B and C in the EBL had excellent bond strengths indicating that, overall, Overlay Systems B and C are performing similar to the other overlay systems. The majority of the failures were in the base concrete close to the bond interface, which indicates that surface preparation could have been better. However, the majority of the bond strength values were very good to excellent. In 2006, bond strengths were generally higher in the EBL than in the WBL, but since the failures were mostly in the old deck concrete, the difference in strengths can be attributed to the deck concrete and surface preparation and not to the concrete in overlay systems.

Permeability

Tables 6 and 7 show the results of permeability tests (AASHTO T 277) conducted on cores 4 in (102 mm) in diameter removed from the outside lane of the decks and tested at an age of 6 to 7 months (November 1996), 42 to 43 months (November 1999), and 10 years (October 2006). Tests were conducted on the top 2 in (51 mm) of two cores from each span with the exception that only one core was tested from the EBL in 1996. Cores from Span 24 of the WBL could not be tested because the steel fibers cause a short circuit. With two exceptions, the test results were in the low (1000 to 2000) to very low (100 to 1000) range, indicating that the overlays were providing good protection. The exceptions were Overlay System A WBL, which

Table 5. Tensile Bond Strengths

Span	WBL, 10 mo of age					EBL, 6 wk of age				
	Overlay Thickness, in	Bond Strength, psi	Failure Area, %			Overlay Thickness, in	Bond Strength, psi	Failure Area, %		
			Overlay	Bond	Base			Overlay	Bond	Base
2	1.6	305	3	29	68	1.5	230	3	40	57
5	1.6	325	3	32	65	1.6	210	5	38	57
8	1.6	265	0	0	100	1.6	240	2	30	68
11	1.4	260	20	33	47	1.7	230	3	34	63
14	1.7	260	0	25	75	1.1	240	0	35	65
18	1.6	280	10	40	50	1.5	275	5	40	55
21	1.6	265	18	58	24	1.5	220	3	17	80
24	1.9	290	20	27	53	1.7	135	0	28	72
25	-	-	-	-	-	2.0	215	2	27	71
27	1.5	315	0	17	83	1.5	145	0	57	43

Span	WBL, 11/99					EBL, 11/99				
	Overlay Thickness, in[1]	Bond Strength, psi[1]	Failure Area, %			Overlay Thickness, in[1]	Bond Strength, psi[1]	Failure Area, %		
			Overlay[1]	Bond[1]	Base[1]			Overlay[1]	Bond[1]	Base[1]
2	1.6	275	37	28	35	1.7	255	0	40	60
5	1.3	300	0	0	100	1.7	260	8	33	58
8	1.5	280	3	7	90	1.8[2]	260[2]	5[2]	28[2]	67[2]
11	1.5	300	27	23	50	1.9	290	8	18	73
14	1.6	310	3	27	70	1.2	305	2	0	98
18	1.5	245[4]	6[3]	35[3]	59[3]	1.9	265	12	10	78
21	1.5	220	35	38	27	1.4	205	5	28	67
24	1.8	250	20	8	72	1.5	200	3	32	65
25	-	-	-	-	-	1.8[4]	200[4]	0[4]	0[4]	100[4]
27	1.5	320	33	0	67	1.4	255	17	58	25

Span	WBL, 10/06					EBL, 10/06				
	Overlay Thickness, in	Bond Strength, psi	Failure Area, %			Overlay Thickness, in	Bond Strength, psi	Failure Area, %		
			Overlay	Bond	Base			Overlay	Bond	Base
2	1.7	251	63	4	33	1.6	293	0	27	73
5	1.3	174	0	0	100	1.5	353	17	33	50
8	1.6	179	0	0	100	1.5	305	7	2	91
11	1.4	255	0	0	100	1.8[2]	291[2]	12	13	75
14	1.7	271	0	5	95	1.3[2]	300[2]	2	13	85
18	1.5	263	7	25	68	1.8	333	27	13	60
21	1.5	242	17	40	43	1.2[2]	260[2]	3	25	72
24	1.8	241	0	0	100	1.5[2]	298[2]	3	72	25
25	-	-	-	-	-	1.6	222	2	15	83
27	1.5	239	0	0	100	1.5[2]	211[2]	6	81	13

[1]Average of 3 cores, except as noted.
[2]Average of 4 cores.
[3]Average of 5 cores.
[4]Average of 2 cores.

Table 6. Post-Installation Rapid Permeability Test Data for Westbound Lane

Span	WBL 96 Overlay Thick., in	WBL 96 Perm., Coulombs	WBL 99 Overlay Thick., in	WBL 99 Perm., Coulombs	WBL 06 Overlay Thick., in	WBL 06 Perm., Coulombs	Overlay System	Overlay Type
2	1.7	1082	1.8	1459	1.6	2222	A	7% SF
5	1.4	522	1.4	587	1.2	569	B	5% SF, 35% S
8	1.6	349	1.7	362	1.5	865	C	5% SF, 15% FA
11	1.4	1309	1.5	1887	1.3	1958	J	40% S
14	1.6	703	1.7	333	1.8	130	D	15% LMC
18	1.5	581	1.5	702	1.5	851	K	7% SF, CQI
21	1.6	1249	1.5	1660	1.6	1207	L	7% SF, POF
24	-	-	1.8	-	2.0	-	M	7% SF, STF
27	1.4	923	1.4	1458	1.5	1278	N	7% SF, PPF

Table 7. Post-Installation Rapid Permeability Test Data for Eastbound Lane

Span	EBL 96 Overlay Thick., in	EBL 96 Perm., Coulombs	EBL 99 Overlay Thick., in	EBL 99 Perm., Coulombs	EBL 06 Overlay Thick., in	EBL 06 Perm., Coulombs	Overlay System	Overlay Type
2	1.6	527	1.6	518	1.5	35	A	7% SF
5	1.5	422	1.7	497	1.6	516	B	5% SF,35% S
8	1.3	369	1.6	300	1.5	262	C	5% SF,15% FA
11	1.9	1418	1.9	1090	1.8	153	I*	40% S
14	1.2	193	1.2	230	1.5	155	F	15% LMC
18	1.7	1614	1.9	2347	2.0	340	I*	7% SF, DCI
21	1.7	1031	1.4	823	0.9	1579	G	7% SF, RCI
24	1.7	393	1.6	419	1.4	308	H	7% SF, ACI, A
27	1.5	1695	1.4	1395	1.4	443	I	7% SF, DCI, P

had medium permeability after 10 years, and Overlay System A EBL, which had negligible permeability after 10 years. With two exceptions, Overlay System D WBL (LMC) and Overlay System I EBL (7% SF and DCI), the permeability had not significantly changed over the 10-year evaluation period. The permeability of the LMC and 7% SF and DCI overlays had decreased with time. The only overlay system that likely could not comply with the VDOT 1500-coulomb maximum value for low-permeability overlays was Overlay System J (40% S).[6] Overlay System B (7% SF and 35% S) easily complied with the specification.

Chloride Ion Content

Following the tensile bond tests, chloride ion content samples were milled from tensile bond test core A (right wheel path) taken from each bridge span evaluated. A chloride sample was milled from each 1/8-in depth, starting at the top surface, to obtain 5 to 9 samples from each core, depending on the total thickness of the core. The results are reported in Table 8, and the profiles are shown in Figures 3 and 4.

The data in Table 8 and the profiles in Figures 3 and 4 showed there was considerable variation in the chloride content between the cores in the top 0.5 in, and many of the chloride contents were high. At depths greater than 0.5 in, six spans had chloride contents less than 1 lb/yd^3 (EBL 5 [5% SF, 35% S], 8 [5% SF, 15% FA], and 24 [7% SF, ACI, A] and WBL 5 [5% SF, 35% S], 14 [15% LMC], and 24 [7% SF, STF]). As shown in Figure 4, the lowest chloride ion contents were for WBL 14 (15% LMC) and 24 (7% SF, STF). Span 2 EBL (7% SF) had the lowest permeability but not the lowest chloride ion content. Span 14 WBL (15% LMC) had the

Table 8. Chloride Ion Content (pcy) Data for Overlays in 2006

Depth of Samples from Surface, in	Span No.									
	2		5		8		11		14	
	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL
0.000-0.125	3.440	5.899	2.182	5.112	3.887	7.594	3.131	4.439	6.239	3.568
0.125-0.250	3.195	5.723	1.070	4.062	2.520	7.232	2.964	3.436	2.223	2.001
0.250-0.375	2.321	4.928	0.749	2.116	1.421	4.209	2.962	2.358	1.301	0.865
0.375-0.500	1.453	3.501	0.747	1.069	1.018	1.919	2.303	1.327	1.260	0.507
0.500-0.625	1.028	2.896	0.904	0.711	0.949	1.472	1.929	1.152	1.222	0.385
0.625-0.750	0.720	2.395	-	0.582	1.156	1.145	1.760	0.900	1.202	0.238
0.750-0.875	-	1.931	-	0.480	-	1.082	1.655	-	-	0.247
0.875-1.000	-	1.849	-	0.516	-	0.925	-	-	-	0.359
1.000-1.125	-	1.824	-	0.905	-	0.751	-	-	-	0.819

Depth of Samples from Surface, in	Span No.							
	18		21		24		27	
	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL
0.000-0.125	2.323	4.567	2.800	8.724	9.786	2.037	3.348	3.892
0.125-0.250	2.951	5.358	2.482	4.587	6.181	1.004	3.111	2.826
0.250-0.375	3.037	4.447	1.950	2.704	3.312	0.662	2.800	2.007
0.375-0.0500	2.538	3.495	1.687	1.824	1.482	0.397	2.143	1.419
0.500-0.625	1.898	2.360	1.607	1.532	0.843	0.365	1.732	1.069
0.625-0.750	1.768	1.645	1.546	1.065	0.704	0.350	1.581	0.873
0.750-0.875	-	1.274	1.690	0.944	0.585	0.487	1.441	-
0.875-1.000	-	1.083	1.481	1.002	0.708	0.523	1.317	-
1.000-1.125	-	1.064	1.922	1.000	0.916	0.561	1.319	-

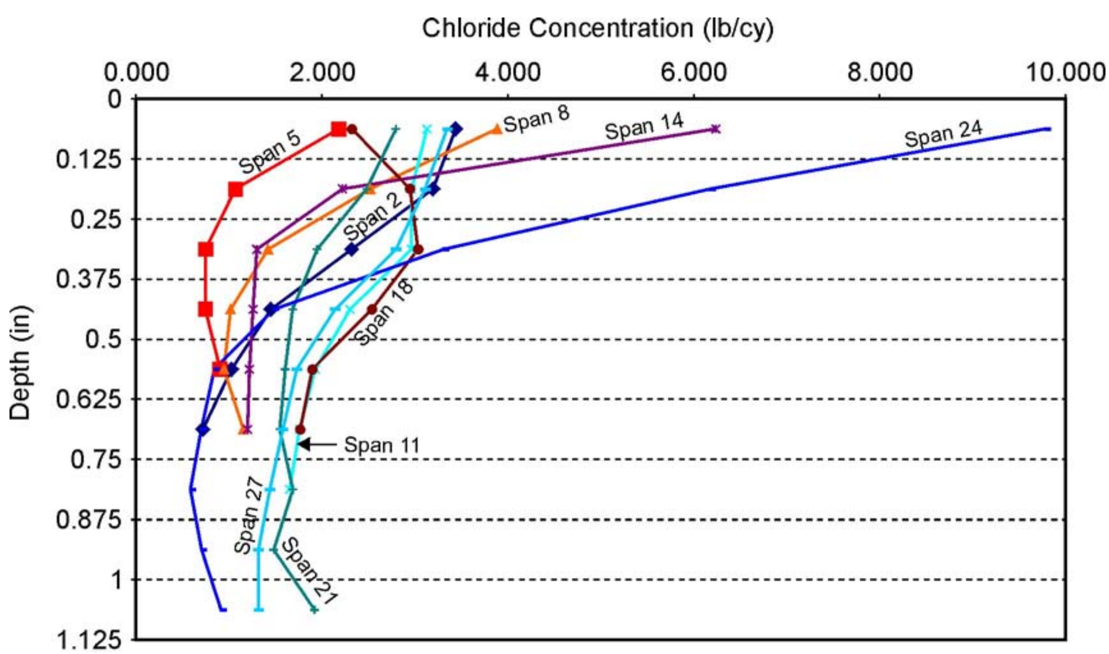

Figure 3. Chloride Profiles for Overlays in Eastbound Lane

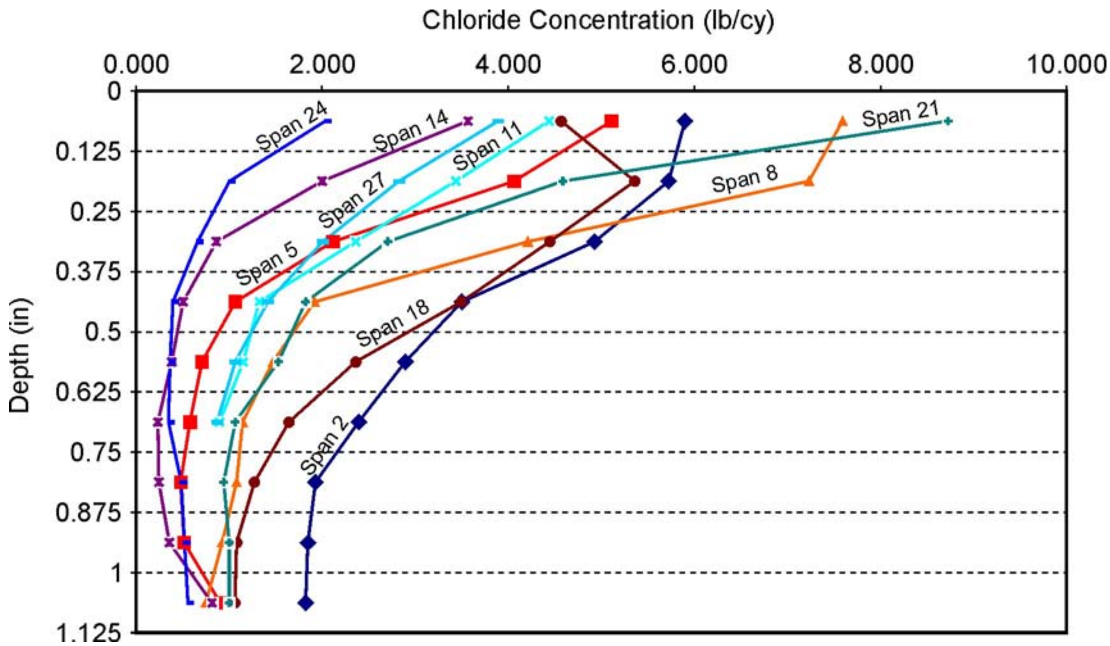

Figure 4. Chloride Profiles for Overlays in Westbound Lane

second lowest permeability and second lowest chloride ion content. Span 24 WBL with the lowest chloride content could not be tested for permeability because of the steel fibers.

Table 8 and the profiles in Figures 3 and 4 show slight increases in chloride content at the lower levels (0.5-1 in) for some of the overlays. These increases are likely the result of chloride from the surface of the deck migrating up into the overlay. Table 9 shows the chloride content data for the deck at the time the overlays were placed.[3] Values are the average of three samples taken from the outside lane; one taken in the right wheel path at the quarter point of the span; one taken in the center of the outside lane at midspan; and one taken in the left wheel path at the ¾ point. Most of the spans had 3 to 4 lb/yd^3 chloride at the surface of the deck that can migrate upward into the overlays. The principal benefit of using milling to remove 0.5 to 1.0 in of concrete from the top of the deck is to remove the chloride-contaminated concrete.

At the time the overlays were placed, there was not sufficient chloride (1.3 lb/yd^3) at the level of the top mat of reinforcement to cause corrosion in the deck under any of the overlays.[3] The chloride data and the half-cell potential data recorded 10 years later indicate that the overlays have prevented additional chloride from reaching the reinforcement and the decks have been protected from corrosion-induced spalling. After 10 years, half-cells are less negative and chlorides in the deck are likely lower because of upward migration into the overlay. The overlays should retard the further ingress of chlorides and extend the life of the structures, some more than others.

Diffusion Coefficients

Table 10 shows chloride diffusion coefficients for the overlays calculated from the chloride content data in Table 8 using Fick's first law. The higher the coefficient, the greater the rate at which chloride diffuses into the concrete.

Table 9. Chloride Ion Content (pcy) Data for 1996 When Overlays Were Installed

Depth of Samples from Surface, in	Span No.									
	2		5		8		11		14	
	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL
0.25-0.5	4.3	2.3	3.3	1.7	2.3	4.2	3.2	3.0	3.7	3.6
0.5-1.0	2.8	0.8	2.1	<0.3	1.6	1.4	1.9	1.7	2.0	1.9
1.0-1.5	2.5	<0.3	0.67	<0.3	0.5	<0.3	1.0	0.7	0.9	0.4
1.5-2.0	1.6	<0.3	0.21	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
4.5-5.0	<0.3	<0.3	<0.18	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3

Depth of Samples from Surface, in	Span No.							
	18		21		24		27	
	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL
0.25-0.5	4.5	2.1	3.8	2.4	3.1	3.0	3.2	2.5
0.5-1.0	2.0	0.5	3.1	0.6	2.1	1.6	1.3	0.9
1.0-1.5	1.3	<0.3	1.9	<0.3	0.8	0.4	0.7	<0.3
1.5-2.0	0.8	<0.3	0.72	<0.3	<0.3	<0.3	<0.3	<0.3
4.5-5.0	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3

Table 10. Diffusion Coefficients for Overlays (in^2/year)

Span	Overlay	Diffusion Coefficient	Span	Overlay	Diffusion Coefficient
E2	7% SF	0.013	W2	7% SF	0.034
E5	5% SF, 35% S	0.007	W5	5% SF, 35% S	0.006
E8	5% SF, 15% FA	0.007	W8	5% SF, 15% FA	0.009
E11	7% SF, DCI	0.067	W11	40% S	0.009
E14	13% SF, 15% FA	0.002	W14	LMC	0.003
E18	7% SF, DCI	0.019	W18	7% SF, CQI	0.015
E21	7% SF, RCI	0.087	W21	7% SF, POF	0.004
E24	7% SF, ACI, A	0.004	W24	7% SF, STF	0.004
E27	7% SF, DCI, P	0.047	W27	7% SF, PPF	0.009

DISCUSSION

Bond tests showed that the majority of the failures occurred in the base concrete close to the bond interface, which indicates that surface preparation could have been better. However, the majority of the bond strengths were very good to excellent. Good bond strength was also indicated by the performance of the overlays being excellent with respect to not delaminating and spalling and needing to be patched. Overlay System I with the Postrite treatment was the only overlay system with a high percentage of failure in the bond for all three evaluation periods. Otherwise, the overlays can be considered equal with regard to potential bond strength.

Saw-cut grooves 0.13 in wide and 0.13 in deep spaced 0.75 in apart yielded the excellent skid numbers. The overlays can be considered equal with regard to potential skid resistance.

Scaling performance was acceptable for most of the overlays. The use of Overlay Systems J, K, and L should be avoided in situations in which heavy scaling in not acceptable.

Protecting the deck from the infiltration of chloride ion and corrosion is a function of degree of cracking, permeability to chloride ion, and chloride ion infiltration. Overall, the cracking performance of the overlays was excellent. Based on half-cell potentials, the overlays have halted the little corrosion that was occurring prior to placement of the overlays and prevented further corrosion after 10 years in service.

Given that other attributes were similar with minor exceptions as mentioned, the best way to rank the overlay systems from the standpoint of deck protection is to rank them with respect to permeability to chloride ion and chloride ion content. The only overlay system that likely cannot comply with the VDOT specification of a 1500-coulomb maximum value for low-permeability overlays was Overlay System J (40% S).[6] Overlay System B (7% SF and 35% S) easily complied with the specification. The data in Table 8 and the profiles in Figures 3 and 4 showed that there was considerable variation in the chloride content in the top 0.5 in of the cores among the overlays and that many of the chloride contents were high.

Table 11 ranks the overlays from best to worst from the standpoint of permeability to chloride ion (based on the data in Tables 6 and 7), chloride ion content (based on the area to the left of the curves in Figures 3 and 4), and diffusion coefficient (based on the data in Table 10). It is not surprising that the LMC overlay, an overlay technology in use since the late 1960s, was at the top of the list. Other overlays performing almost as well as the LMC overlay included 7% SF, STF; 5% SF, 35% S; and 5% SF, 15% FA. It is interesting that the 7% SF overlay in the EBL was performing well but the 7% SF overlay in the WBL had the worst performance of all the overlays. The 7% SF, DCI overlay also had a variable performance, which is not a desirable characteristic. Regardless of the rank in Table 11, all overlays can comply with the VDOT's 1500-coulomb maximum value for low-permeability overlays except for Overlay System J (40% S). The decision as to which overlay system to use would likely be based on cost and ease of construction.

Table 11. Overlay Rank From Best (Top) to Worst Based on Permeability to Chloride Ion and Chloride Ion Content

Permeability to Chloride Ion		Chloride Ion Content		Diffusion Coefficient	
Span	**Overlay**	**Span**	**Overlay**	**Span**	**Overlay**
E2	7% SF	W14	LMC	E14	13% SF, 15% FA
W14	LMC	W24	7% SF, STF	W14	LMC
E11	7% SF, DCI	E5	5% SF, 35% S	E24	7% SF, ACI, A
E14	13% SF, 15% FA	W5	5% SF, 35% S	W21	7% SF, POF
E8	5% SF, 15% FA	E8	5% SF, 15% FA	W24	7% SF, STF
E24	7% SF, ACI, A	E14	13% SF, 15% FA	W5	5% SF, 35% S
E18	7% SF, DCI	E2	7% SF	E5	5% SF, 35% S
E27	7% SF, DCI, P	E24	7% SF, ACI, A	E8	5% SF, 15% FA
E5	5% SF, 35% S	W27	7% SF, PPF	W8	5% SF, 15% FA
W5	5% SF, 35% S	W11	40% S	W11	40% S
W18	7% SF, CQI	E21	7% SF, RCI	W27	7% SF, PPF
W8	5% SF, 15% FA	W21	7% SF, POF	E2	7% SF
W21	7% SF, POF	W8	5% SF, 15% FA	W18	7% SF, CQI
W27	7% SF, PPF	E27	7% SF, DCI, P	E18	7% SF, DCI
E21	7% SF, RCI	E11	7% SF, DCI	W2	7% SF
W11	40% S	E18	7% SF, DCI	E27	7% SF, DCI, P
W2	7% SF	W18	7% SF, CQI	E11	7% SF, DCI
-	-	W2	7% SF	E21	7% SF, RCI

CONCLUSIONS

- The HPC overlays evaluated had fair to excellent bond strengths and excellent skid resistance at 10 years of age. The overlays differed with respect to permeability to chloride ion.

- In addition to the VDOT conventional overlays of LMC and 7% SF, HPC overlays that have very low to low permeability to chloride ion and good to excellent bond strength can be constructed with a variety of combinations of SF, FA, S, latex, corrosion-inhibiting admixtures, a shrinkage-reducing admixture, and fibers.

- The overall best performing overlay was the LMC overlay, which had the second lowest permeability and chloride diffusion coefficient and the lowest chloride ion content.

- Use of Overlay Systems J, K, and L should be avoided in situations in which heavy scaling in not acceptable. These situations might include areas with poor drainage, sidewalks, and surfaces that need to have a pleasing appearance. The scaling can likely be avoided if a proper air-void system can be obtained in these overlay systems.

- Joints in overlays must be properly formed and the forms removed in a timely fashion to prevent damage to the bond interface of the overlay adjacent to the joint and subsequent spalling in a short time.

- Deck surface preparation by shot blasting can provide high bond strengths.

- Milling of the top 0.5 to 1 in of the deck surface prior to shot blasting the surface can remove chloride from older decks that when not removed can migrate upward into the overlay.

RECOMMENDATIONS

1. *VDOT's Structure & Bridge Division should continue to extend the life of bridge decks using LMC.*

2. *VDOT's Structure & Bridge Division should consider using overlays containing combinations of SF, FA, and S as evaluated in this study when a cost-benefit analysis for a project indicates that the higher cost of LMC is not justified.* Although the other overlays evaluated can be used, the higher cost associated with adding the corrosion inhibitors, fibers, and shrinkage-reducing admixture would need to be justified.

COSTS AND BENEFITS ASSESSMENT

The contractor bid \$1,200/yd^3 for all overlay systems.[3] Therefore, it was not possible to obtain an indication of the relative cost of the overlays from this study. The cost was approximately 50% greater than VDOT typically pays for conventional LMC and 7% SF concrete overlays probably because of the experimental nature of the project. Based on the relative cost of the ingredients, the researcher believes that the overlays would rank as follows from highest to lowest cost:

1. 7% SF and STF, 7% SF and POF
2. 7% SF and PPF, LMC, 7% SF and CQI
3. 7% SF and DCI, 7% SF and RCI, 7% SF and ACI
4. 13% SF and 15% FA
5. 7% SF
6. 5% SF and 35% Slag, 5% SF and 15% FA
7. 40% S.

Because of the relatively higher costs of the ingredients, the overlays with steel fibers, polyolefin fibers, and latex would be slightly more expensive, and the overlays with 40% S, 5% SF and 35% slag and the overlays with 5% SF and 15% FA would cost the least.

The majority of the cost of an overlay is the labor, equipment, mobilization, and traffic control. The material is often less than 20% of the cost, and, therefore, differences in material costs are minor when the total cost of the overlay is considered.

VDOT spends approximately $3 million per year on concrete overlays for bridges. Use of the lower cost overlays containing combinations of SF, FA, and S could save VDOT approximately 5%, or $150,000, annually. However, the performance of an overlay is governed more by the quality of the installation than the characteristics of the materials. The material characteristics can affect the quality of the installation, and spending slightly more for a material to obtain a quality installation is typically worth the extra cost on a life cycle basis.

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