Standard Title Page - Report on Federally Funded Project

1. Report No. FHWA/VTRC 05-R26	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Latex-Modified Concrete Overlay Containing Type K Cement		5. Report Date April 2005 6. Performing Organization Code
7. Author(s) Michael M. Sprinkel, P.E.		8. Performing Organization Report No. VTRC 05-R26
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. 73039
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation, 1401 E. Broad Street, Richmond, VA 23219 FHWA, P.O. Box 10249, Richmond, VA 23240		13. Type of Report and Period Covered Final 7/1/03 thru 06/30/04 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Hydraulic cement concrete overlays are usually placed on bridges to reduce the infiltration of water and chloride ions and to improve skid resistance, ride quality, and surface appearance. Constructed in accordance with prescription specifications, some overlays have performed well for more than 30 years whereas others have cracked and delaminated before the overlay was opened to traffic. Shrinkage of the concrete is the most common cause of cracking in overlays. The use of Type K (expansive) cement should increase the probability that concrete overlays with minimal cracks will be constructed.

This report describes the Virginia Department of Transportation's first experience with the use of Type K cement for the construction of a latex-modified concrete overlay. One lane of the overlay was constructed with traditional Type I/II cement, and the other lane with Type K cement. With the exception of the cement, the requirements for the overlays were the same. The evaluation of the overlays included measurements for slump, temperature, air content, compressive strength, permeability to chloride ion, shrinkage, and bond strength. As expected, the shrinkage of the concrete containing Type K cement was much less than that of the concrete containing Type I/II cement. Other properties were similar.

The use of Type K cement is estimated to increase the cost of the concrete approximately 2.6 percent, or about $1/yd^2 for an overlay 1.5 in thick. This is much less than the cost to seal the shrinkage cracks in an overlay: $10/yd^2. Greater savings can also come from the longer service life of a crack-free overlay. To gain more experience, the Virginia Department of Transportation should construct additional latex-modified concrete overlays using Type K cement.

17 Key Words Overlays, Type K cement, shrinkage, cracks, concrete, bridge, deck, bond, strength, permeability, corrosion	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 24	22. Price

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

FINAL REPORT

LATEX-MODIFIED CONCRETE OVERLAY CONTAINING TYPE K CEMENT

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Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

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

Charlottesville, Virginia

April 2005
VTRC 05-R26

DISCLAIMER

ABSTRACT

Hydraulic cement concrete overlays are usually placed on bridges to reduce the infiltration of water and chloride ions and to improve skid resistance, ride quality, and surface appearance. Constructed in accordance with prescription specifications, some overlays have performed well for more than 30 years whereas others have cracked and delaminated before the overlay was opened to traffic. Shrinkage of the concrete is the most common cause of cracking in overlays. The use of Type K (expansive) cement should increase the probability that concrete overlays with minimal cracks will be constructed.

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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 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 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. The use of Type K (expansive) cement should increase the probability that concrete overlays with minimal cracks and longer service life will be constructed.

Bond Strength of Overlays

Experience has shown that obtaining overlays with high bond strengths is often a problem.[2-4] Major overlays have delaminated over large areas before ever being opened to traffic. Others have delaminated prematurely under traffic because of low bond strengths. Surface preparation is generally considered the main factor that affects bond strength. Adequate surface preparation is usually achieved by cleaning the surface to remove anything that can interfere with the bonding and curing of the overlay.

Milling is the most economical way to remove concrete down to the level of the reinforcement. Unfortunately, the impact heads on milling machines typically fracture the surface left in place. The fractures are just below the bond interface between the deck and the overlay. The fractures reduce the strength of the bond between the overlay and the deck. When concrete decks are milled prior to an overlay being placed, the bond strength of the overlay is usually controlled by the fractured concrete surface. The milled surface can be shotblasted or hydroblasted to remove some of the damaged concrete. Bond strengths increase as the damaged concrete is removed, but it is usually not practical to remove all the damaged concrete. A variety of types and sizes of milling machines is available, and research needs to be done to relate the equipment and procedural aspects of milling to damage so that equipment and procedures that will do minimal damage can be identified or developed. It is reasonable to expect that the smaller impact heads on micromilling machines cause fewer fractures.

Shotblasting is one of the practical ways to prepare concrete surfaces to achieve high bond strengths. The shotblaster abrades the deck surface with shot and vacuums up the shot and concrete cuttings. The shot does not leave fractures in the prepared concrete surface. The speed and number of passes of the shotblaster that will provide for adequate bond strength are determined with bond tests. By monitoring the speed and number of passes of the shotblaster, the cleaning operation is controlled. The shotblaster typically removes up to 1/8 in of the surface, and larger shotblasters can remove up to 1/4 in of the surface. Hydrodemolition can also be used to prepare concrete surfaces. It may be slower and more expensive than shot blasting, but provides two benefits: hydrodemolition can remove concrete to any depth and the concrete left in place is typically saturated near the surface.

Cracks in Overlays

Minimizing or eliminating cracks in overlays is often a problem. Low-permeability concretes bleed very little and are prone to plastic shrinkage cracking. Good concrete placement practices and curing practices must be exercised to minimize such cracks. Autogenous shrinkage and drying shrinkage can also contribute to the incidence and severity of cracking in overlays. In addition, creep and shrinkage in new bridges and reflective cracking in older bridges can cause cracks in an overlay. The incidence and severity of cracking likely increase with an increase in the shrinkage of the concrete. Overlays are rarely free of cracks. Figure 1 shows shrinkage cracks in an overlay placed on a deck. The use of Type K (expansive) cement, which expands during the moist curing period, should increase the probability that concrete overlays with minimal cracks will be constructed and thereby have a longer service life than those that crack.

Permeability of Overlays

Obtaining overlay concretes with low permeability is typically not a problem.[5] Use of latex or pozzolans and slag, as supplemental cementitious materials, and good concreting practices easily provide for overlay concretes with low permeability.

Figure 1. Shrinkage Cracks in Overlay Placed on Deck

Skid Resistance, Ride Quality, Drainage, and Surface Appearance of Overlays

Obtaining overlays with good skid resistance, ride quality, drainage, and surface appearance is typically not a problem. These properties are easily achieved with good construction practices, and the grooves that are saw cut into the hardened concrete surface ensure good skid resistance. The Virginia Department of Transportation (VDOT) has recently implemented the use of a ride specification for bridge decks that should be applicable to overlays.[6]

VDOT's Specification for Latex-Modified Hydraulic Cement Concrete Overlays

VDOT's requirements for latex-modified hydraulic cement concrete (LMC) overlays are specified in Section 412 of *Road and Bridge Specifications.*[1] The requirements are as follows:

- *Air content:* 3 to 7 percent
- *Slump*: 4 to 6 in
- *Maximum water to cement ratio by weight:* 0.40
- *Minimum cement content:* 658 lb/yd^3
- *Design minimum laboratory compressive strength at 28 days:* 3,500 psi.

VDOT's requirements for the cement used in LMC overlays are included in Section 217 of *Road and Bridge Specifications.*[1] The specifications require the use of a blend of mineral admixtures and Type I or II portland cement. However, the specifications are flawed because the required blend has never been used in LMC overlays. LMC overlays have been typically constructed with Type II or Type I/II portland cement since the first overlay was done in Virginia in 1969. LMC overlays have also been constructed with Type III cement when it was necessary to place traffic on the overlay after only 24 hours of cure.[7] In recent years, an increasing number of LMC overlays have been constructed with Rapid-Set cement so that traffic could be placed on the overlay after only 3 hours of cure.[8] VDOT's *Road and Bridge Specifications* do not have requirements for Rapid Set cement, and its use has been covered by a special provision. Likewise, *Road and Bridge Specifications* does not have requirements for Type K cement, and its use in this project was by a work order. The cement was supplied by CTS Cement Manufacturing Corp. The company also supplies an admixture (Komponent) that can be added to Type I/II portland cement to provide the equivalent of Type K cement. The advantage of using Komponent is that Type I/II cement is readily available locally and the cost to ship Komponent is less than the cost to ship Type K cement.

Bond Strength

Since bond strength is the most significant factor in the life of an overlay, VDOT is working to develop and implement requirements. A recent project, which was VDOT's first project with a performance specification for an overlay, had a lower quality limit for bond strength (ACI 503R-93)[9,10] of 150 psi at 28 days. The bond strength between the overlay concrete and the existing concrete was the average of tests on three 2-to-4-in-diameter cores cut and tested by the engineer from each sublot. The cores were cut and tested after the overlay had exceeded the design compressive strength, after the curing of the overlay was complete, and prior to the overlay being opened to traffic. The cores were cut 1 in into the existing concrete to isolate the overlay concrete. Locations for each test were randomly determined by the engineer. Tests that resulted in a failure in the base concrete at a depth of 1/4 in or more over greater than 50 percent of the test area and a test value of less than 150 psi were assigned a value of 150 psi when the average was computed. When more than 50 percent of the tests result in a failure in the base concrete at a depth of 1/4 in or more over more than 50 percent of the test area and a test value of less than 150 psi, the percent within limits is the greater of 55 or the calculated value.

Delaminations

Overlays delaminate when the stresses on the bond interface exceed the strength of the bond between the overlay and the deck. Although the VDOT specification for LMC overlays does not specifically require delaminated overlay to be replaced, delaminated overlay is considered unacceptable and not worthy of payment. The total surface area of a new overlay is typically tested for delaminations using the chain drag test (ASTM D 4580-86).[11] Typically, delaminated areas are replaced by the contractor at no additional cost to the owner.

Pattern Cracking

VDOT does not have a requirement regarding pattern cracks in overlays. Since cracks reduce the protection provided by the overlay and may affect bond strength, VDOT is working to develop and implement requirements. A recent project required that overlay concrete for any given sublot in which the cracks were within 1 in of the bond interface be removed.[9] If the engineer elects to accept the concrete, the contractor is compensated at 50% of the contract unit price for the HCC specified. Cracks that are not within 1 inch of the bond interface must be filled with a gravity fill polymer in accordance with VDOT's Special Provision for Gravity Fill Polymer Crack Sealing.[12]

Linear Cracking

VDOT does not have a requirement regarding linear cracks. Since cracks reduce the protection provided by the overlay and may affect bond strength, VDOT is working to develop and implement requirements. A recent project required that overlay concrete for any given sublot in which the cracks were within 1 in of the bond interface or in which the frequency of cracking exceeded 0.12 ft/ft^2 be removed.[9] If the engineer elects to accept the concrete, the contractor is compensated at 50% of the contract unit price for the HCC specified. Cracks that are not within 1 in of the bond interface and in which the frequency of cracking is less than or equal to 0.12 ft/ft^2 must be filled with a gravity fill polymer in accordance with VDOT's Special Provision for Gravity Fill Polymer Crack Sealing.[12]

Shrinkage

VDOT does not have a requirement regarding the shrinkage of LMC or other concrete used in overlays (ASTM C 157).[13] The implementation of a requirement should reduce the incidence of cracking in overlays.

Permeability

VDOT's requirement for maximum permeability is 1000 coulombs (AASHTO T 277) at 28 days when tested using accelerated curing procedures described here.[14] The permeability is the average of tests on two 4-in by 8-in cylinders cast, cured, and tested by the engineer from each placement. Two-inch-thick samples are cut from the center of each cylinder for testing. Except for LMC, cylinders are moist cured for the first week in a moist room at 73 F and in saturated limewater at 100 F for the next 3 weeks. LMC cylinders are moist cured for the first 2 days and air cured for the next 5 days in the lab at 73 F. The cylinders are air cured in an oven at 100 F for the next 3 weeks. The accelerated curing provides permeability values at 28 days that are comparable to those that will be obtained at 90 days to 1 year in the in-place overlay concrete. Recently, the requirements were changed to allow conductivity tests rather than permeability tests to be conducted.[15] If the specimens fail the conductivity test, permeability tests are done.

Freeze-Thaw Tests

The Virginia Transportation Research Council (VTRC) conducts tests to determine resistance to freezing and thawing in accordance with ASTM C666, Procedure A, with the exception that a 3 percent sodium chloride solution, rather than water, is used around the beams.[16] In addition, the tests are initiated at 28 days of age rather than at 2 weeks. The beams are subjected to 300 cycles of freezing and thawing. Beams fail if the weight loss exceeds 7 percent, the surface rating is greater than 3 percent, or the durability factor is less than 60 percent. The test is routinely done by VTRC for VDOT, and the results are used to prevent some concrete products from being accepted for use. However, products that fail the test have been used when they have a record of acceptable field performance. Typically, LMC does not pass the test because it does not contain entrained air.[5] A failure to pass the test has not been a concern with LMC because more than 30 years of field performance has not revealed any problem with the freeze-thaw performance of LMC overlays.

Latex Suppliers

Historically, latex for overlays has been supplied to VDOT by three companies (Dow Chemical, Reichhold Chemical, and BASF). In 2002, the latex divisions of Dow Chemical and Reichhold Chemical merged into Dow Reichhold. BASF and Dow Reichhold now supply the latex for overlays.

PURPOSE AND SCOPE

The purpose of this study was to evaluate VDOT's first experience with the use of Type K cement in an LMC overlay.

METHODS

LMC overlay mixtures with Type I/II and Type K cement were prepared and tested in the concrete laboratory prior to and after the overlays were constructed in the field.[17, 18]

Dow Reichhold latex was used in the first set of mixtures prepared in the lab because the contractor planned to use Dow Reichhold latex in the bridge overlays. Two Type I/II cements were evaluated to provide an indication of differences in performance between cements of the same type. A mixture with Type K cement and a mixture with part Type I/II cement and sufficient Type K additive to provide a shrinkage similar to that of a mixture with all Type K cement were also evaluated. The first set of mixtures included four batches:

1. Roanoke Type I/II cement typically used by the contractor

2. Holcim Type I/II cement supplied by Holcim U.S. Inc. (Holly Hill, South Carolina)

3. Type K cement supplied by CTS Cement Manufacturing Corp. (Cypress, California)

4. Komponent additive supplied by CTS Cement Manufacturing Corp., and Roanoke Type I/II cement supplied by Titan America (Troutville, Virginia).

BASF latex was used in the second set of mixtures prepared in the laboratory since it was thought it might be used in future overlays. Mixtures were prepared with Roanoke Type I/II and Type III cements, Type K cement, and Rapid Set cement. Mixtures were prepared with Type III and Rapid Set cements because VTRC had not evaluated concrete made with these cements and BASF latex. The second set of mixtures included four batches:

1. Roanoke Type I/II cement typically used by the contractor

2. Roanoke Type III cement

3. Type K cement supplied by CTS Cement Manufacturing Corp.

4. Rapid Set cement supposed by CTS Cement Manufacturing Corp.

The evaluations of the overlay mixtures prepared in the lab and placed in the field were based on the preparation and testing of specimens for slump, air content, compressive strength, and permeability to chloride ion as described in the "Introduction" section. The temperature of the concrete was also measured. Lab mixtures were also tested for shrinkage. The second set of lab mixtures was also tested for resistance to cycles of freezing and thawing. The overlays were also checked for bond strength, delaminations, and cracks as described in the "Introduction" section.

RESULTS AND DISCUSSION

Laboratory Mixtures

Mixture Proportions

Table 1 shows the mixture proportions for Set 1 evaluated in the concrete laboratory at VTRC. The ingredients were the same with the exception of the four cement combinations.

Table 1. Mixture Proportions for Set 1 with Dow Reichhold Latex

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke Type I/II**	**Holcim Type I/II**	**CTS Type K**	**Roanoke Type I/II and CTS Komponent**
Cement, lb	658	658	658	551.5
Komponent, lb	0	0	0	106.5
Air, %	5	5	5	5
Coarse Aggregate, lb[a]	1485	1485	1485	1485
Fine Aggregate, lb	1666	1666	1666	1666
Latex, lb	209	209	209	209
Water, lb	147	147	147	147
Water to Cement Ratio	0.39	0.39	0.39	0.39

[a]Coarse aggregate was 50/50 blend of No. 4 and 3/8-in aggregate.

Table 2 shows the mixture proportions for Set 2 with BASF latex evaluated in the concrete laboratory at VTRC. The ingredients were the same with the exception of the four cement combinations. In addition, less fine aggregate was used with Batch 4 because Rapid Set cement is less dense than the other cements.

Table 2. Mixture Proportions for Set 2 with BASF Styrofan 1186 Latex

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke Type I/II**	**Roanoke Type III**	**CTS Type K**	**CTS Rapid Set**
Cement, lb	658	658	658	658
Air, %	5	5	5	5
Coarse Aggregate, lb [a]	1485	1485	1485	1485
Fine Aggregate, lb	1666	1666	1666	1541
Latex, lb	209	209	209	209
Water, lb	147	147	147	147
Water to Cement Ratio	0.39	0.39	0.39	0.39

[a]Coarse aggregate was 50/50 blend of No. 4 and 3/8-in aggregate.

Properties of the Plastic Concrete

Table 3 shows the properties of the plastic concrete batched for Set 1. The air content of the batch with Holcim cement was too high, causing the unit weight to be low. The other data are ordinary.

Table 3. Plastic Properties of Set 1

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke Type I/II**	**Holcim Type I/II**	**CTS Type K**	**Roanoke Type I/II and CTS Komponent**
Mix Date	1-29-04	1-29-04	1-29-04	1-29-04
Air Temperature, F	71	71	71	71
Relative Humidity, %	45	45	45	45
Slump, in	8.25	8.5	7	6.5
Unit Weight, pcf	142.8	128.4	140.8	141.6
Air Content, %	5.4	16	7	6.1
Concrete Temperature, F	74	74	74	75

Table 4 shows the properties of the plastic concrete batched for Set 2. The data are ordinary.

Table 4. Plastic Properties of Set 2

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke Type I/II**	**Roanoke Type III**	**CTS Type K**	**CTS Rapid Set**
Mix Date	8-3-04	8-3-04	8-3-04	8-3-04
Air Temperature, F	71	71	71	71
Relative Humidity, %	63	63	63	60
Slump, in	8.0	5.2	5.5	7.25
Unit Weight, pcf	144.8	145.2	144.4	146.0
Air Content, %	3.9	4.3	4.3	3.3
Concrete Temperature, F	73	75	76	76

Compressive Strength

Table 5 shows the compressive strength test results for Set 1. The Holcim cement batch did not meet the 28-day strength requirement of 3,500 psi. The other data are ordinary.

Table 6 shows the compressive strength test results for Set 2. The Rapid Set concrete had the strength needed for traffic at 3 hours. The other data are ordinary.

Table 5. Compressive Strength of Set 1, psi

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke Type I/II**	**Holcim Type I/II**	**CTS Type K**	**Roanoke Type I/II and CTS Komponent**
1 day moist	2610	1440	1180	2030
7 day moist	3760	2530	2910	3600
2 day moist + 5 day air	4190	2860	3470	4280
28 day moist	4480	2580	3990	4650
2 day moist + 26 day air	4900	3250	5020	5680
2 day moist + 363 day air	6940	4530	6270	7330

Table 6. Compressive Strength of Set 2, psi

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke I/II**	**Roanoke III**	**Type K**	**Rapid Set**
3 hr moist	-	-	-	3510
4 hr moist	-	-	-	3810
5 hr moist	-	-	-	4070
1 day moist	2380	3280	1680	5440
7 day moist	4160	5020	3440	-
2 day moist + 5 day air	4640	5330	4220	6290
28 day moist	5230	5750	5410	6400
2 day moist + 26 day air	5710	6240	5880	6710
2 day moist + 363 day air	-	-	-	-

Shrinkage

Since shrinkage can be the most significant cause of cracking, specimens were prepared and measured for length change in accordance with ASTM C157. Six specimens were prepared from each of the four batches of concrete. Three were moist cured for 2 days, which is typical for an LMC overlay placed in the field, and three were moist cured for 28 days, which is typical for concretes other than LMC cured in the lab. The results for Set 1 are shown in Figure 2. Beams from the mixtures with Type K cement and Komponent expanded the most when moist cured for 28 days. The length at 112 days was greater than the original length. These results indicate that moist curing an overlay with these mixtures for 28 days could cause a failure of the overlay because of the stress on the bond caused by the restrained expansion of the overlay—the opposite of the situation in which shrinkage is high and a failure of the overlay is caused by the stress on the bond caused by the restrained contraction of the overlay.

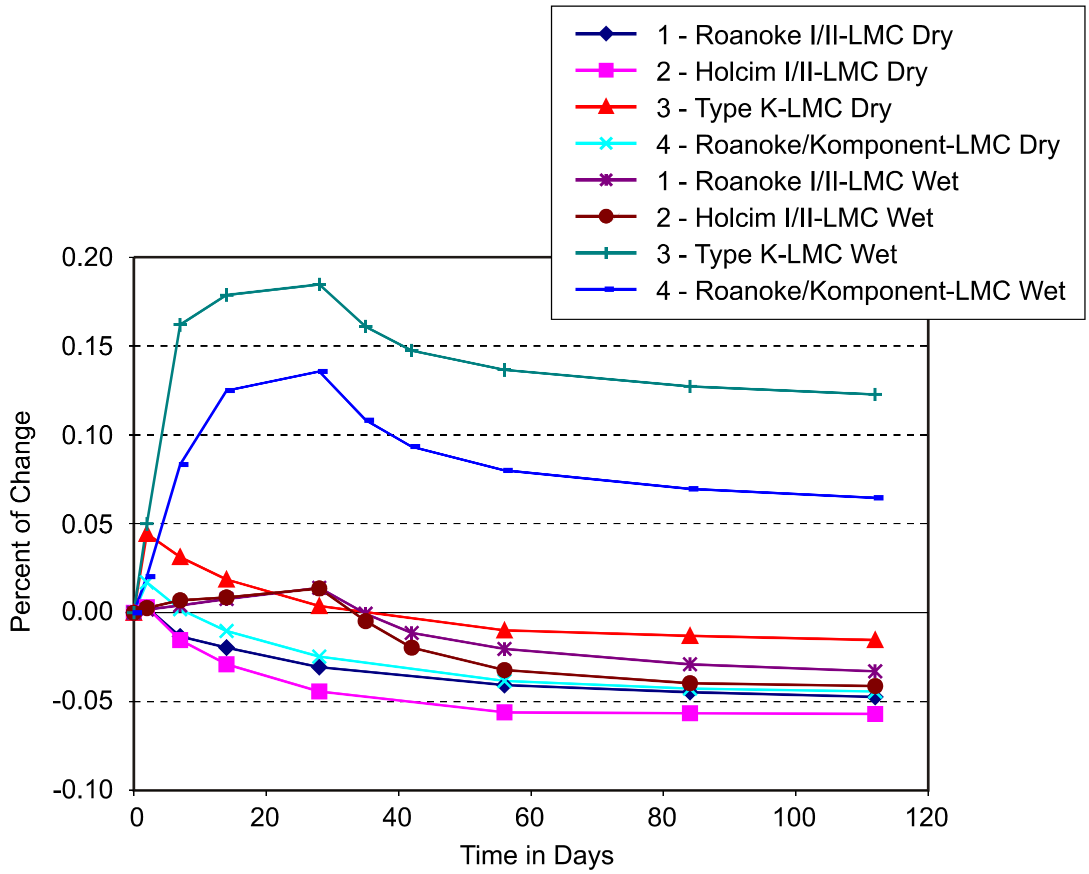

Figure 2. Length Change Results for LMC with Dow Reichhold Latex

The lowest shrinkage at 112 days was for the beams from the mixture with Type K cement and the 2-day moist cure. Beams from mixtures with Type I/II cement moist cured for 28 days showed the next lowest shrinkage. The shrinkage of the beams from the mixtures with Type I/II cement moist cured only 28 days was approximately 0.035 percent, which is low compared to the 0.055 percent that had been reported.[4] It is not clear why the length change of the mixture with Komponent was not as low as that for the beams from the mixture with Type K cement. As expected, the greatest length change was for the beams from the mixtures with Type I/II cement moist cured for 2 days as is typically done in the field. It is clear from the length change data that an overlay with the mixture with Type K cement moist cured for 2 days would be the least likely to crack.

The data for beams prepared for Set 2 with the BASF latex are shown in Figure 3. The results are similar to those shown in Figure 2 with the exception that the beams from the mixtures with Rapid Set cement had very low shrinkage, comparable to that of beams from mixtures with Type K cement when moist cured for 2 and 28 days. Evidently the 28-day cure had no effect on the beams from the mixtures prepared with Rapid Set cement.

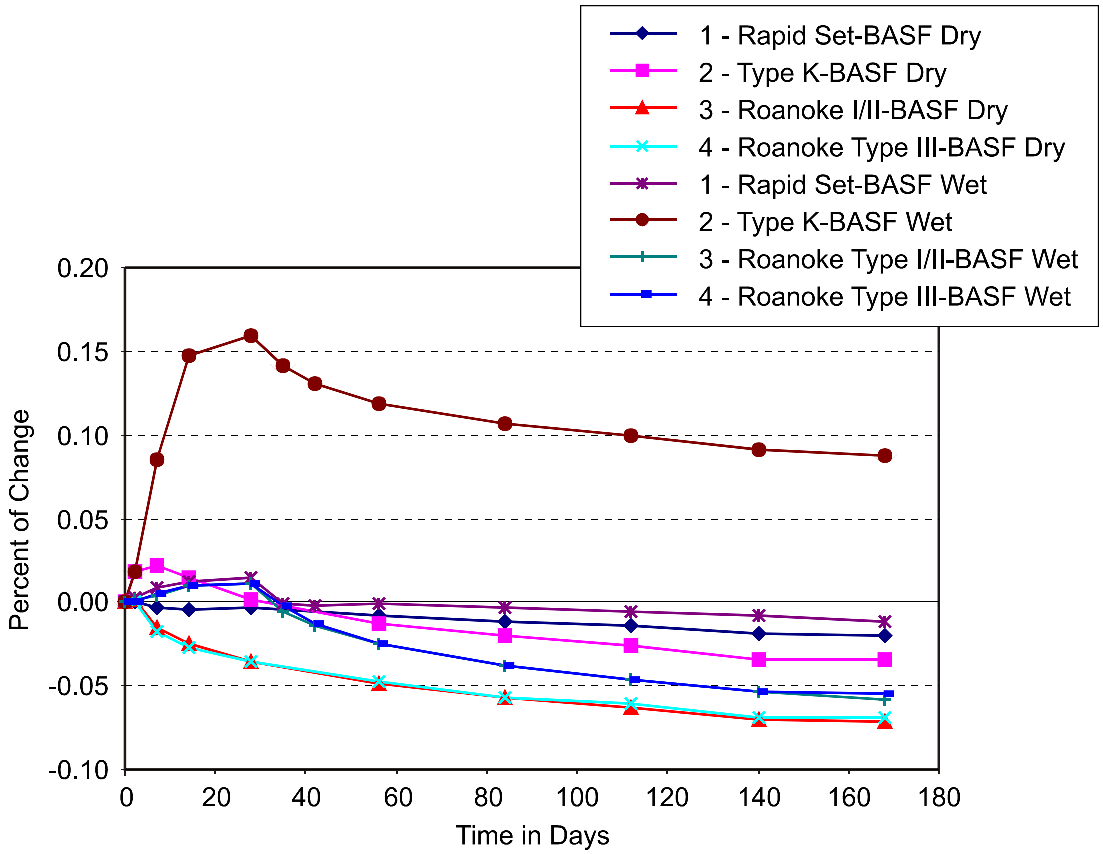

Figure 3. Length Change Results for LMC with BASF Latex

Permeability to Chloride Ion

Table 7 shows the permeability test results for Set 1. The permeability of the mixture with Roanoke Type I/II cement was slightly higher than the 1,000 coulomb maximum at 28 days but not high enough to cause concern. When tested at 1 year, the permeability for the two mixtures with Type I/II cement was very low and that for the two mixtures with Type K cement was negligible.

Table 7. Permeability of Set 1, coulombs

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke I/II**	**Holcim I/II**	**CTS Type K**	**Roanoke & CTS Komponent**
28 day 2 day moist + 26 day air	1726	2034	1222	1225
28 day 2 day moist + 5 day air + 21 day 100 F dry	1048	680	871	754
356 day 2 day moist + 354 day air	195	578	64	96

Table 8 shows the permeability test results for Set 2. As with the Dow Reichhold latex, the mixture with Roanoke Type I/II cement and BASF latex had a permeability that was slightly higher than the 1000 coulomb maximum at 28 days but not high enough to cause concern. The 28-day accelerated permeability for the mixture with Rapid Set was already negligible.

Table 8. Permeability of Set 2, coulombs

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke I/II**	**Roanoke III**	**Type K**	**Rapid Set**
28 day 2 day moist + 26 day air	1885	1458	835	268
28 day 2 day moist + 5 day air + 21 day 100 F dry	1014	844	321	33
356 day 2 day moist + 354 day air	-	-	-	-

Freeze-Thaw Tests

Tests for resistance to cycles of freezing and thawing were not performed for the concrete mixtures in Set 1 because the quantity of material was not adequate. In addition, it was considered the least important of the tests. Table 9 shows the freeze-thaw test results for the Set 2 mixtures that contained BASF latex. These results should provide an indication of the results that would have been obtained with the Dow Reichhold latex. Since latex from both suppliers comply with the VDOT specification for latex, the source of the latex should not be a factor in the freeze-thaw performance of the concrete.[1] All four mixtures in Set 2 failed the test. Pictures of the failed beams are shown in Figures 4 through 7. Beams made with Rapid Set cement performed the best.

Table 9. Freeze-Thaw Performance with BASF Latex

Batch	**1**	**2**	**3**	**4**
Cement	**Roanoke I/II**	**Roanoke III**	**CTS Type K**	**Rapid Set**
Weight change, %	64.12[a]	34.06[a]	29.68[a]	13.25[a]
Surface rating	5.00[a]	4.88[a]	5.00[a]	2.29
Durability factor	0[a]	0[a]	0[a]	50[a]

[a]Failed test.

Figure 4. Beams with Roanoke Type I/II Cement

Figure 5. Beams with Roanoke Type III Cement

Figure 6. Beams with CTS Type K Cement

Figure 7. Beams with CTS Rapid Set Cement

Field Mixtures

The overlays were placed on the three-span bridge on Route 221 over Beaver Creek approximately 7 miles east of Floyd, Virginia (Project 0221-031-1023, SR02). The standard LMC overlay was constructed on the westbound lane May 14, 2004, in accordance with VDOT's *Road and Bridge Specifications* using Type I/II cement. [1] The eastbound lane was constructed in accordance with the specification with the exception that Type K cement was substituted for Type I/II cement. The LMC overlay with Type K cement was placed on June 14, 2004, by work order at an added cost to VDOT of $1,337.94. The mixture proportions used in the overlay are shown in Table 1.

Type A milling to remove the top 0.5 in of the old surface was a pay item. Following the milling, concrete was removed from areas requiring patching and patches were constructed with the same concrete mixture used in the overlay. Prior to placing the overlay, patches were shotblasted along with the rest of the deck. Surface preparation by shotblasting was included in the overlay price. The entire deck was wetted and covered with polyethylene following the shotblasting. The polyethylene was removed and the deck wetted again as needed to provide a saturated surface dry deck ahead of the overlay placement. Following placement of the overlay concrete, the surface was immediately covered with wet burlap and polyethylene. The wet cure was maintained for 48 hours. Prior to opening the overlay to traffic, grooves were saw cut into the surface in the transverse direction to provide a skid-resistant surface.

Slump and Air Content

Results for slump and air content for the two overlay placements are shown in Table 10. The slumps were within the requirement of 4 to 6 in. The air contents (ASTM C 231) were within the required 3.0 to 7.0 percent range.[19] Results are from one test by the engineer per lane.

Table 10. Results for Slump and Air Content

Lane	Cement	Slump, in	Air, %
Westbound	Type I/II	4.0	5.0
Eastbound	Type K	4.0	5.5

Compressive Strength

The design compressive strength (ASTM C 39) at 28 days was 3,500 psi. The strengths in Table 11 were the average of tests on three 4-in by 8-in cylinders cast, cured, and tested by the engineer from each lane. [20]

Table 11. Results for Compressive Strength at 28 days, psi

Lane	Cement	Strength, psi
Westbound	Type I/II	5870
Eastbound	Type K	5620

Bond Strength

The tensile bond strength between the overlay concrete and the existing concrete was the average of tests on six 2.25-in-diameter cores taken from each overlay and tested in the VTRC lab using a modified version of ACI 503R-93.[8] The modification was that the tests were performed in the lab with a pipe cap bonded to the top and bottom of each core. The bottoms of the cores were saw cut perpendicular to the axis to provide a flat surface to which to bond the cap. The cores were taken on November 9, 2004, and tested in the lab on November 12. The core diameter was 2.25 in, and the core depth was approximately 4 in. The tensile bond strength test results are shown in Table 12. The average values for the six tests for each lane were very good and similar (292 psi for Type I/II and 281 psi for Type K). The values are indicative of the strength of the old base concrete placed in 1936. Figure 8 is a diagram showing the locations of the core. Core holes were patched with a rapid-setting HCC patching material.

Table 12. Tensile Bond Strength, Failure Location, and Overlay Thickness at Test Locations

Material Name	Sample No.	Sample Diameter, in	Overlay Thickness, in	Load, lb	Bond Strength, lb	Failure Area (%)		
						Overlay	Bond	Base
Westbound Type I/II	2	2.25	2	980	245	Epoxy failure		
	Redo 2	2.25	2	1732	435			100
	3	2.25	2.375	838	210	15		85
	4	2.25	1.75	853	215			100
	5	2.25	1.875	1540	385	10	90	
	6	2.25	1.5	764	190			100
	8	2.25	2.25	1260	315			100
	Avg.	2.25	1.96	1165	292	4	15	81
Eastbound Type K	9	2.25	2.25	842	210			100
	11	2.25	1.75	980	245			100
	12	2.25	1.5	1424	360			100
	13	2.25	2.125	1264	320			100
	14	2.25	1.75	990	250			100
	15	2.25	2.25	840	210	Epoxy failure		
	Redo 15	2.25	2.25	1200	300			100
	Avg.	2.25	1.94	1117	281	0	0	100

Delaminations

The total surface area was checked for delaminations using the chain drag (ASTM D 4580-86). No delaminations were found.

Pattern Cracking

None was found.

Linear Cracking

One transverse crack approximately 3 ft long was found in Span 3 of the westbound lane approximately 1 ft 8.5 in from the joint with Span 2 and next to the centerline between the lanes. The crack likely reflected from the edge of the half-depth concrete removal that was done next to the joints. No cracks were found in the eastbound lane with Type K cement.

Permeability

The VDOT requirement for maximum permeability was 1000 coulombs (AASHTO T 277) at 28 days. The permeability of the cast samples is the average of tests on 2-in-thick slices cut from two 4- by 8-in cylinders cast, cured, and tested by the engineer using the accelerated procedure described in the "Introduction" section. The permeability of the core samples is the average of tests on 2-in-thick slices cut from the top of two 4-in-diameter cores taken from each lane (Cores 1, 7, 10, and 16) on November 9, 2004, at overlay ages of 6 and 7 months. Tests were also done on 2-in-thick slices cut from the 68-year-old base concrete of two 4-in-diameter cores taken from each lane. The results are shown in Table 13. As would be expected, the results for the cores are similar to the results for the field-prepared specimens and the VTRC lab-prepared specimens tested at 28 days. The results for the base of Cores 7 and 10 were medium and for Core 16 were high. The value for Core 1 was similar (868 coulombs) to that for the LMC overlay and is likely a value for the LMC overlay concrete that was used to patch the deck as the overlay was placed. It is not likely a value for the old deck concrete. Figure 8 provides a diagram showing the core locations.

Table 13. Results for Permeability

Lane	Cement	Cast samples: Permeability, coulombs	Cores, overlay: Permeability, coulombs	Cores, base: Permeability, coulombs
Westbound	Type I/II	856 (28 days)	996 (7 months)	868, 3536 (68 years)
Eastbound	Type K	494 (28 days)	669 (6 months)	3112, 5564 (68 years)

Cost

The eastbound lane of the overlay was constructed in accordance with VDOT specifications with the exception that Type K cement was substituted for Type I/II cement by a work order at an added cost to VDOT of $1,337.94. Type K cement for the job cost $80 per ton ($3.76 per bag) more than Type I/II. For the 8 yd^3 of LMC required for the overlay on each lane, 56 bags of cement were required at an additional cost of $210.56 for the Type K cement. An additional cost of $600 was required to ship the Type K cement, and $527.38 was required for labor for handling and loading the Type K cement. The resulting total extra cost per bag for the Type K cement was $23.89. At a bid cost for LMC with Type I/II cement of $1,000/$yd^3$, the extra cost for LMC with Type K cement was $9,337.94/8,000 = 1.167, approximately 17 percent higher.

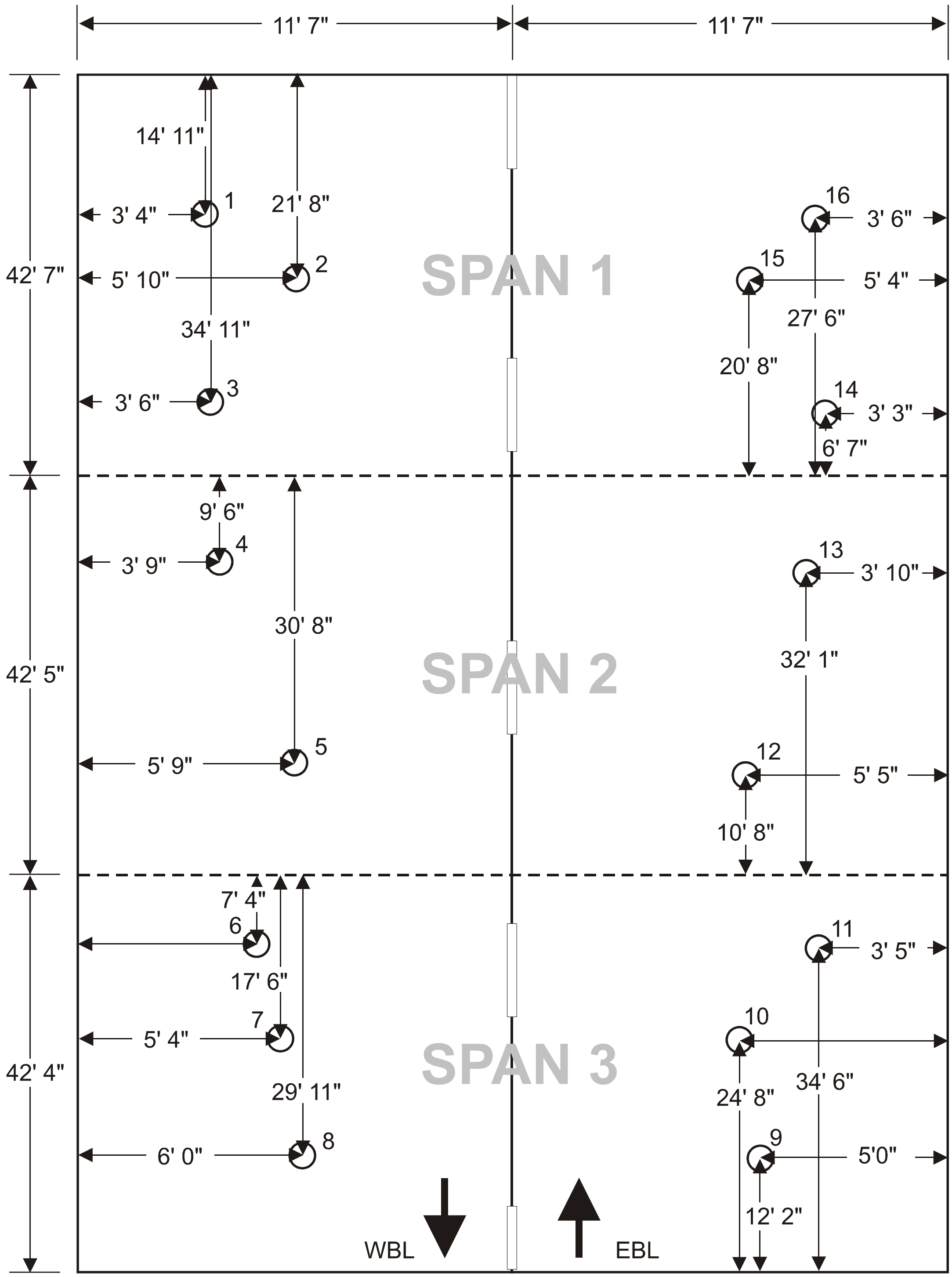

Figure 8. Locations of Cores

For future jobs, assuming Type K is standard and available (at no extra charge for shipping and loading the mixer), the added cost will be approximately \$8210.56/8000 = 1.026 = 2.6 percent. A typical overlay is 1.5-in thick and costs \$41.67/yd^2 when the LMC costs \$1,000/yd^3. Therefore, a typical LMC overlay with Type K cement will cost an additional

\$1.08/yd^2 (\$41.67 x 0.026). The cost to treat the cracks in an overlay is approximately \$10/yd^2. The potential savings are much greater when you consider that the total cost of a typical overlay is \$130/yd^2 when the cost of traffic control and miscellaneous costs associated with construction are included.

CONCLUSIONS

- Concrete containing Type K cement shrinks much less than concrete containing Type I/II cement.
- Concrete containing Type K cement complies with VDOT's specifications regarding air content and has high compressive strength, low permeability, and good bond strength.
- The use of the Type K cement is estimated to increase the cost of a concrete overlay approximately 2.6 percent, or about \$1/yd^2, for a 1.5-in-thick overlay. This is much less than the cost of about \$10/yd^2 to seal shrinkage cracks in an overlay. Greater savings can come from the longer service life of a crack-free overlay.

RECOMMENDATIONS

1. VDOT should use Type K cement for the construction of additional LMC overlays.
2. VDOT should also try the use of Type K cement with other bridge overlay materials.

COSTS AND BENEFITS ASSESSMENT

VDOT spends approximately \$2.9 million per year on concrete overlays for bridges. Assuming that half of the overlays constructed without Type K cement have shrinkage cracks and assuming that VDOT pays to replace 10 percent immediately, pays to treat the cracks in 15 percent, and accepts a reduced service life for 25 percent, VDOT can save approximately \$600,000 per year by using Type K cement in bridge overlays.

ACKNOWLEDGMENTS

The LMC Type K overlay constructed and evaluated in this project is the first of its kind. The work would not have been done without the initiative of Bob Milliron of Lanford Brothers Construction. Mr. Milliron encouraged VDOT to use Type K cement on one of the two lanes of the bridge to see the potential benefits of less cracking. Lanford Brothers constructed the overlay. David Lee and Nancy Widgen of the Salem District supported the effort and the work

order required to do the experimental overlay. Billy Boothe of the Salem District monitored the construction and testing of the overlay and specimens. VTRC technicians Michael Burton, Bill Ordel, and Andy Mills conducted the tests on the concrete specimens. This project is a good example of VDOT and industry working together to improve technology.

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