LATEX MODIFIED PORTLAND CEMENT OVERLAYS: AN ANALYSIS OF SAMPLES REMOVED FROM A BRIDGE DECK

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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SUMMARY

This report describes an evaluation of the latex modified mortar overlay on the Route 85 (NBL) bridge over the Roanoke River. While the performance of the overlay has been generally satisfactory, corings and chloride analyses indicate the possibility of future distress beyond the cracking that has been noted to date. The problems associated with the overlay have not resulted from the nature of the latex modified mortar nor from a failure of bond between the material and the original deck. Instead, the results suggest that the deterioration is due to the use of an insufficient thickness of overlay in conjunction with the inadequate preparation of an original deck that had been previously subjected to chloride penetration.

Based on the evaluation of several cores taken from the deck it cannot be recommended that thin layers of this material be used as a long-term solution for bridge deck deterioration problems where the decks have experienced prior corrosion of the reinforcing steel from chloride attack.

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BACKGROUND

Because of insufficient cover over the reinforcing steel on the interstate Route 85 bridges over the Roanoke River, the decks were treated with overlays in August 1969. To evaluate the performance of promising new materials, the NBL bridge decks were treated with a Dow-SM-100 latex modified portland cement overlay at an average thickness of 3/4 in. This material is simply applied to the deck after adequate surface preparation.

Inspection of the NBL decks in the fall of 1971 revealed extremely fine pattern cracking when the deck surfaces were damp.[1] The cracking was barely visible when the surface was dry. As a result, it was deemed desirable to obtain core samples from some typical cracked and non-cracked areas to determine whether the cracking was confined to the overlay material or had developed from the original deck below.

It was recommended in the earlier report that widespread use of the latex modified mortar await the outcome of evaluations of sample cores and future performance inspections.[1]

This report presents the findings from both petrographic and chloride analyses of the core samples removed from several spans of the bridge. The results of recent performance inspections are also given.

LATEX MODIFIED PORTLAND CEMENT

The NBL of the Roanoke River bridge is composed of eleven 70-foot spans and has a 29-foot roadway. All of the spans are covered with the Dow latex modified portland cement material, which was applied in compliance with the specifications and procedures recommended by the product developer and supplier.[2]

The Dow SM-100 material is a film forming polymer emulsion designed to upgrade the physical properties of bonded portland cement overlays. Latex modified mortars are produced by adding 3.5 gallons of the latex material for each bag of portland cement used in a mortar mix. The Dow Company literature indicates that the modified composition is more flexible, more impermeable to water, less susceptible to chemical attack, and more resistant to abrasion than is a regular portland cement mortar.(3) In addition, microscopic studies by Isenburg et al. have indicated that latex modified mortar overlays have greater bond to concrete than do mortar overlays without the latex additive.(4)

DESCRIPTION OF TEST CORES AND DECK CRACKING

Eight 4-in. diameter cores were taken from the bridge decks. With reference to the south end of the bridge, 5 cores were taken from the first span, 1 from the third, and 2 from the fifth. Six of the cores were taken from areas where the overlay was cracked, while the remaining 2 cores were taken from uncracked areas in spans 1 and 5.

As can be noted from Table 1, all of the cores taken at cracked locations showed the cracking to be generally over a reinforcing steel bar. Neither of the 2 cores taken at uncracked locations intercepted the reinforcing steel.

Table 1. Description of 4-in. Diameter Concrete Cores Removed From the NBL of Route 85 Over the Roanoke River

Span & Sample*	Vertical Cracking	Remarks
1-1	One transverse crack, parallel to and over top reinforcing steel	Horizontal break just above steel
1-2	One transverse crack, parallel to and over top reinforcing steel	Horizontal break just above steel
1-3	One longitudinal crack -- roughly parallel to longitudinal reinforcing steel	None
1-4	None	Core taken adjacent to longitudinal crack but in an uncracked area
2-1	Very small, irregular longitudinal crack over longitudinal steel	None
3-1	One transverse crack, parallel to and over top reinforcing steel	Core broke just above steel (only top portion above steel removed)
5-1	Two unconnected transverse cracks, parallel to and over top reinforcing steel	Horizontal break just above steel
5-2	None	Core taken in an uncracked area

* First number indicates span and second number the core from that span.

Typical surface cracking in the deck at the time the cores were taken is shown in Figure 1. As can be noted, the crack patterns can be easily detected as water evaporates from the wetted deck surface. The cracking is generally more extensive in the transverse direction, but shorter length longitudinal cracking, propagating outward from the transverse cracks, is prevalent also. The longitudinal cracking usually appears more random and of shorter length than the transverse cracking, but often intersects adjacent transverse cracks. The general cracking pattern could be described as a fine pattern type cracking as defined and illustrated in the ACI guide for concrete condition surveys.(5) A typical core showing a transverse crack associated with and approximately over a reinforcing steel bar is shown in Figure 2. A core taken at a longitudinal crack location is shown in Figure 3. It can be noted that in the latter case the crack is also over a steel bar.

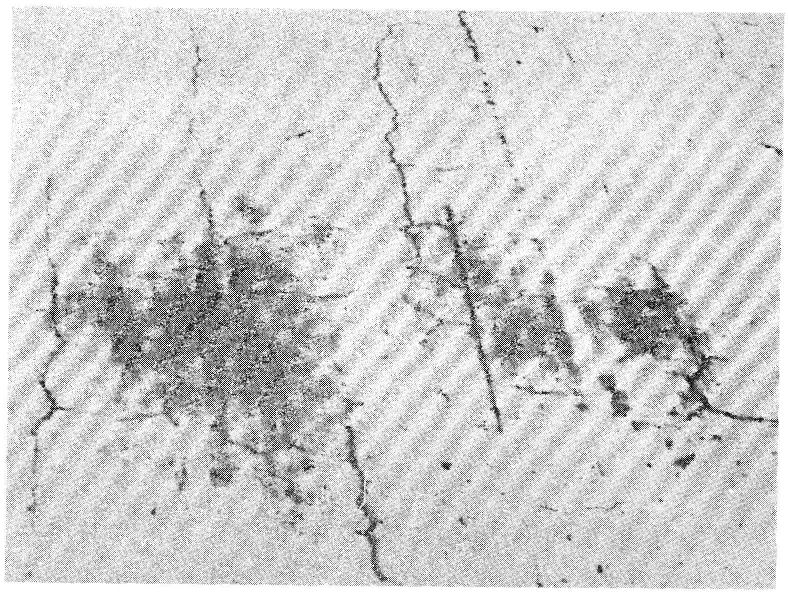

Figure 1. Typical cracking in the latex modified mortar overlay. Note that the deck is damp, which makes the cracks easily discernible.

RESULTS

Petrographic Evaluation

The concrete cores were prepared for petrographic evaluation by the procedures shown in Table 2. Two of the cores, 1-4 and 5-2, were used for air void determinations with the results tabulated in Table 3.

Figure 2. Transverse cracking in a concrete core with latex mortar overlay. Arrow on top of core denotes direction of traffic.

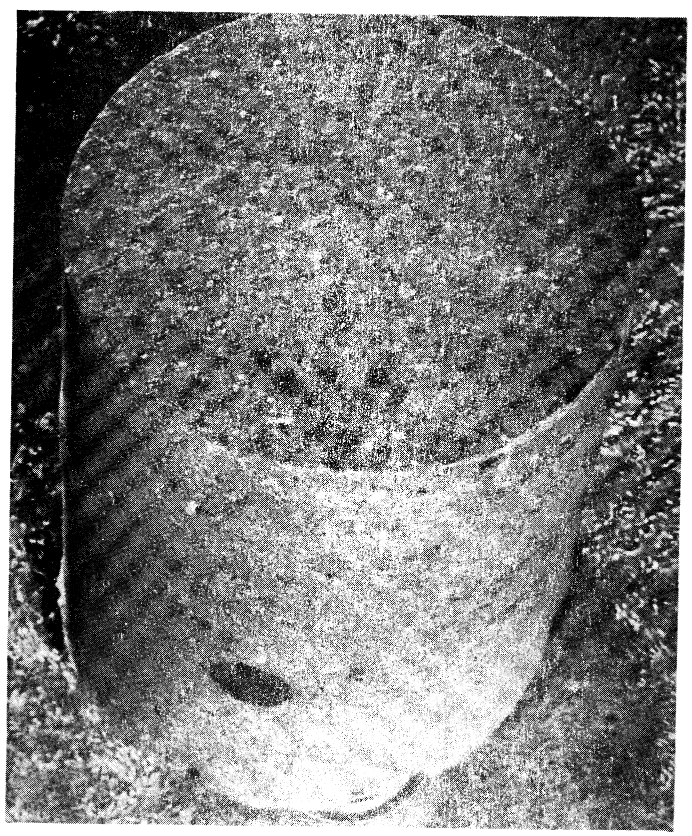

Figure 3. Longitudinal cracking in a concrete core with latex mortar overlay. Arrow on top of core denotes direction of traffic.

Table 2. Preparation Procedures

Core	Surface Cracking	Fine Ground Vertical Surface for Low Power Microscopic Examination	Fine Ground Horizontal Surfaces for Air Void Analysis	Thin Sections 0.03 mm Thick for High Power Microscopic Evaluation
1-1	Yes	X		
1-2	Yes	X		
1-3	Yes	X		
1-4	No		X	X
2-1	Yes	X		
3-1	Yes	X		
5-1	Yes	X		
5-2	No		X	X

Table 3. Results of the Air Void Analyses

(50 in. linear traverse for each determination)

Core		No. of Voids	% of Voids	Specific Surface
1-4	Latex Mortar	145	5.7	203
	PC Concrete	331	4.9	540
5-2	Latex Mortar	160	8.0	160
	PC Concrete	428	4.9	699

As indicated in Table 3, the PC concrete is sufficiently protected against freeze-thaw deterioration by entrained air. As opposed to the PC Concrete, the latex mortar contains fewer but larger voids. While such a void system would not be acceptable for PC concrete, the size and distribution of the air voids required for freeze-thaw protection of the latex mortar are not known. No freeze-thaw type deterioration of the latex modified mortar overlay has been observed in the field.

Four major types of cracking were observed in the cores:

1. The vertical pattern cracking as shown in Figure 1 and on the surface of the cores (Figures 2 and 3). It occurs over the steel and roughly parallel thereto, and extends through the latex modified portland cement to the just-below-the-bond weakness zone illustrated in Figure 4. It may or may not extend further into the PC concrete. Longitudinal cracking of this type occurs in Cores 1-3 and 2-1; transverse cracking in Cores 1-1, 1-2, 3-1 and 5-1.

A minor variant observed in Core 1-3 is fine vertical cracks parallel to the general pattern cracking, which appear to begin at the below-the-bond weakness zone and goes upward toward, but not reaching, the surface.

2. Major horizontal cracking occurring at the level of the top steel and associated with corrosion of the steel (see Figure 2). This occurs in Cores 1-1, 1-2, 3-1 and 5-1 which are the ones with the transverse vertical cracking.

3. The below-the-bond weakness zone (Figure 4) was detectable in all the samples, including those taken from Cores 1-4 and 5-2 representing uncracked areas. In the cores exhibiting pattern cracking this zone is sometimes as widely cracked and more easily seen than the vertical system. In less deteriorated samples, it exists as a discontinuous series of voids and short cracks. At the bond between the latex mortar and the portland cement concrete, the PC concrete is carbonated to a depth of 0.5 - 4 mm (Figure 5). The zone of weakness occurs just below the carbonation zone. The latex mortar is firmly bonded to the carbonated paste and apparently as well bonded to the aggregate as to the paste. No explanation for the zone of weakness is advanced. It certainly is more advanced in areas of pattern cracking which are associated with the steel. The heavy layer of carbonation may indicate that the weakness is due to some form of surface deterioration which occurred before the application of the latex mortar overlay.

4. Vertical cracking within the PC concrete. This is one of three types:

   a. Cracking which connects the below-the-bond weakness and the pattern cracking to the corroded steel. This is easily seen in 1-1 and probably existing but not seen in 3-1 and 5-1.

   b. Cracking which apparently begins at the below-the-bond weakness and extends downward but cannot be traced to the steel. This cracking is usually associated with the pattern cracking.

   c. Vertical cracks extending up from the steel which cannot be traced to connect with any other cracking. This exists in Core 1-3 which was taken at a longitudinal deck crack location.

In summary, of the eight cores the four (1-1, 1-2, 3-1 and 5-1) that exhibited transverse pattern cracking were also cracked and separated at the steel due to corrosion. In only one of these, (1-1), was it possible to definitely trace the cracking to the steel. In 3-1 and 5-1, no definite connection could be made although the cracking on the core surface was generally above a steel bar.

Two cores exhibited longitudinal vertical cracking. One of these (1-3) showed cracking rising from the steel but not connected to any other cracks. The other, (2-1), showed no internal vertical cracks. Three cores, (1-2, 1-3 and 2-1), showed vertical pattern cracking of the latex mortar which did not extend below the carbonation and weakness zone.

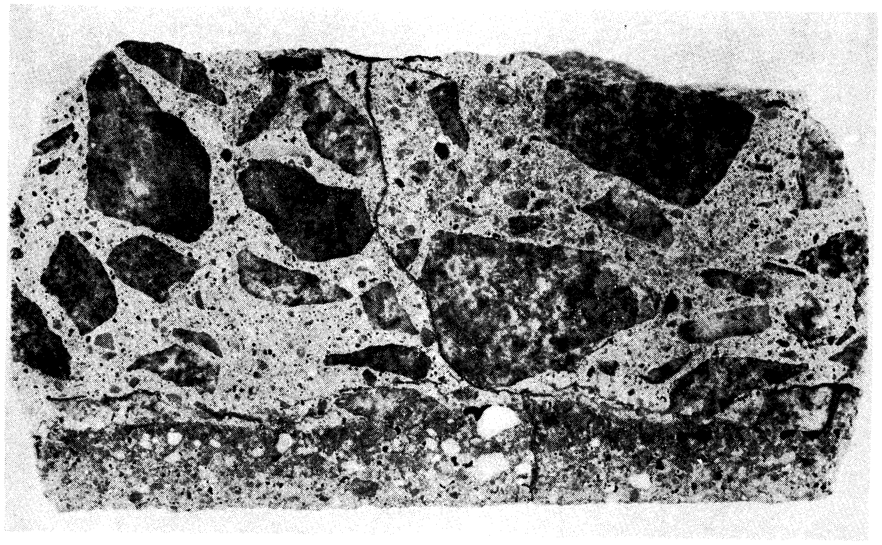

Figure 4. Section of core showing transverse cracking in the latex mortar overlay and the original concrete. A horizontal crack just below the bond line can be detected in the photograph.

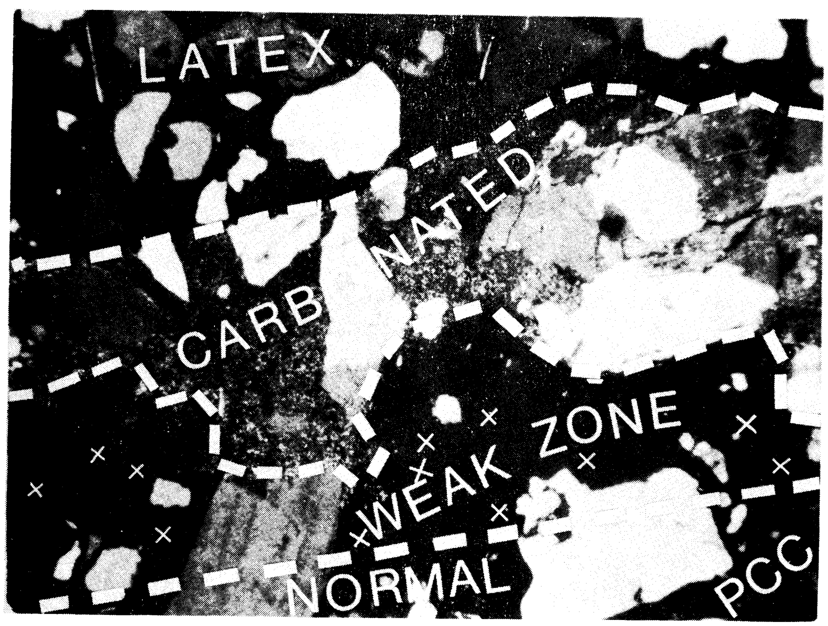

Figure 5. Thin section of bond area of core 5-2 showing latex mortar, carbonated zone, zone of weakness below the carbonated zone and normal PCC. The small x's indicate irregularly shaped voids. (50x, crossed polarizens.)

All cores showed the just-below-the-bond weakness zone; even those with no surface cracking but the latex mortar was strongly bonded to the carbonated surface of the deck concrete. There was no cracking or zone of weakness found at the bond line itself.

Interpretation

The configuration of the cracking in the samples suggests that the lower vertical cracks in the original concrete began before the overlay was installed, and that they resulted from corrosion of the reinforcing steel. The effects of corrosion of the steel can be seen in the existence of the weakened horizontal plane at the top of the steel, as shown in Figure 2, in the 4 cores with transverse cracks in the overlay. Breakage of the concrete occurred at the level of the steel during coring on only these 4 cores. The discontinuity between the vertical cracks in the original concrete and those in the overlay tends to indicate that continued steel corrosion is not the sole cause of the overlay cracking. Instead, a combination of causes is suggested. First, it seems possible that the horizontal failure of the weak layer below the bond, and perhaps some of the vertical cracks in the overlay, was caused by shearing stresses through the depth of the slab. There was evidence that the vertical crack progressed through the overlay from the horizontal crack to the surface. Secondly, cracks propagating from the reinforcing steel indicate that expansive products resulting from steel corrosion caused part of the distress that is reflected through the overlay to the surface. Corrosion of the reinforcing steel will probably continue for reasons discussed below.

Chloride Analysis

Portions of 7 of the 8 cores taken from the bridge deck were submitted to the Research Division of the FHWA for determination of the chloride contents of both the latex mortar and the original concrete. It should be noted that prior to placement of the latex mortar overlay, the bridge deck had been in service for several winters and had been subjected to deicer salts. Consequently, chloride ions would have been present in the upper region of the original concrete deck before the overlay was placed.

Chloride content determinations have become important in recent years because of the relationship between chloride induced corrosion of the reinforcing steel and subsequent deterioration of concrete bridge decks. It has been reported that the quantity of chloride required to initiate corrosion of the reinforcing steel in concrete is approximately 1.3 pounds of chloride ions per cubic yard of concrete (330 parts chloride ions per million in concrete).[6,7]

Since the thickness of the overlay was variable, chloride determinations were made at only one level below the surface on some samples and at two levels on others. It can be noted from the results, shown in Table 4, that even at the thicker (approximately 1 inch) regions of the overlay the chloride content exceeded the threshold value for corrosion of 1.3 pounds per yd^3 in all cases. For the 3 samples that included chloride determinations at two levels below the top surface of the latex mortar overlay, 2 showed decreasing amounts of chloride with depth whereas one showed a slight increase.

Due to the increase in chloride with depth in the 1 sample, the original concrete was tested to determine its content. As indicated in Table 4, the chloride content of this sample at a 1 1/2-in. depth was 4.5 lb/yd^3. Although no conclusions can be drawn from the original concrete chloride content, it is possible that some of this original chloride could have leeched upward and caused the slight increase with depth in the 1 latex mortar sample. In addition, the chloride content from this sample suggests that more of the original concrete should have been removed to reduce corrosion. This is substantiated by the appearance of corrosion on the steel in the cores. Current practice would require the removel of contaminated concrete to a level below the steel.

Table 4. Chloride Content of Cores From the NBL of I-85 Over the Roanoke River

Span & Sample Number	Thickness of Overlay (in.)	Depth Below Top Surface (in.)	Chloride in Sample (%)	Chloride Content (lbs/yd^3)*
LATEX MODIFIED MORTAR OVERLAY				
1-1	$\frac{3}{8}$	0-$\frac{3}{8}$	0.095	3.7
1-2	1	0-$\frac{1}{2}$ $\frac{1}{2}$-1	0.117 0.085	4.6 3.3
1-4	5/16	0-5/16	0.146	5.7
2-1	7/16	0-7/16	0.126	4.9
3-1	1	0-$\frac{1}{2}$ $\frac{1}{2}$-1	0.138 0.103	5.4 4.0
5-1	1	0-$\frac{1}{2}$ $\frac{1}{2}$-1	0.169 0.181	6.6 7.1
5-2	$\frac{3}{8}$	0-$\frac{3}{8}$	0.163	6.4
ORIGINAL DECK CONCRETE				
5-1	—	1-1$\frac{1}{2}$	0.115	4.5

*Calculations based on a concrete weight of 145 lbs/ft^3.

In general, the data in Table 4 indicate that chlorides will penetrate the latex mortar overlay in much the same way as it will regular portland cement concrete. Since the reinforcing steel in many areas of the original concrete was only $\frac{1}{2}$ in. from the surface, the average $\frac{3}{4}$ in. thickness of overlay - only $\frac{3}{8}$ in. in many areas - would not protect the steel from further corrosion. These data would suggest, therefore, that continued reinforcing steel corrosion can be expected, and it will probably lead to deterioration in some areas of the deck.

Performance Inspections

Visual inspections of the bridge deck were conducted in October 1975 to evaluate the performance of the overlay with respect to the cracking distress reported earlier.[1] As compared to four years earlier, the cracking appears more apparent and more extensive in many areas of the deck (see Figure 6 as compared with Figure 1).

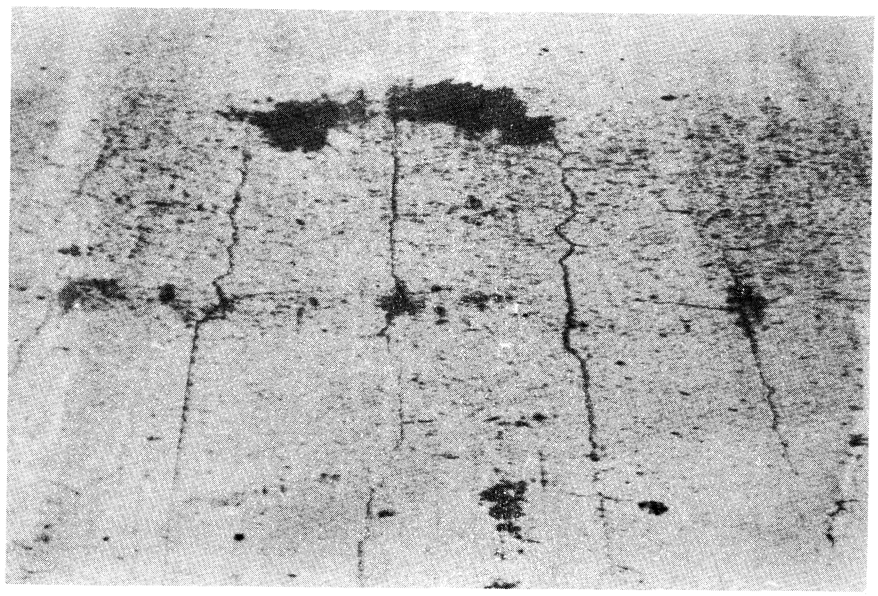

Figure 6. Recent cracking above transverse reinforcing steel in span 5. Hairline longitudinal cracking can be detected also.

The horizontal cracking observed in the sample cores, as discussed earlier, suggests the possibility of future delamination problems. Consequently, some randomly selected cracked areas were sounded with a hammer. Although no areas of total disintegration and spalling of the overlay have been found within a span to date, a small area of delamination has occurred in span 8. In this particular instance the delamination has developed in an area in which the transverse and longitudinal cracking intersects. An additional small area has spalled off adjacent to an expansion joint. It appears likely that other areas of delamination will occur as the cracking grows more severe.

CONCLUSIONS

The results of the petrographic and chloride analyses of the sample cores in addition to the performance inspections of the bridge decks appear to support the following conclusions:

1. All of the cores taken from cracked areas of the deck showed a zone of weakness with attendant cracking just below the bond zone between the latex mortar overlay and the original deck. If more of the original concrete had been removed before applying the overlay this zone of weakness may have been avoided. A delamination noted during a recent performance inspection indicates that the horizontal and vertical cracking will lead to deck deterioration problems.

2. Much of the cracking observed in the deck was located directly above the reinforcing steel, which indicates that continuing corrosion of the steel was a factor in causing much of the distress observed.

3. The results of the chloride analysis of the latex modified mortar overlay indicate that thin layers of this material, on the order of $\frac{3}{8}$ in. to 1 in. thick, will not prevent chloride penetration. Thus, reinforcing steel that remains relatively close (less than 2 in. cover) to the surface even after including the overlay thickness can be expected to experience further chloride attack.

4. Chlorides remaining in the original concrete decks subsequent to placing the latex mortar overlay can be expected to continue corroding the steel along with the chlorides from deicer salts penetrating the latex mortar overlay. Consequently, overlays applied with such attendant conditions can be expected to eventually crack and delaminate from the original concrete.

5. A thin latex modified portland cement mortar overlay applied to a bridge deck which has been subjected to chlorides and has had reinforcing steel corrosion does not appear to offer a long-term solution to deck deterioration problems.

RECOMMENDATION

While the latex modified portland cement mortar overlay has performed reasonably well on the I-85 bridge during the last six years, it does not appear to constitute a method for preventing deck deterioration over the long-term when applied to bridge decks in a manner such as that described herein. Therefore, it cannot be recommended that thin layers of this material be used for bridge deck maintenance purposes in situations where the decks have experienced corrosion of the reinforcing steel caused by chloride contents in excess of 1.3 lbs/yd^3 of concrete at the level of the reinforcing steel. The overlay is subject to distress from continuing corrosion of the reinforcement unless the contaminated concrete surrounding the steel is removed. Also, a thin overlay like that used on the study bridge cannot function as an effective barrier to the further intrusion of chlorides into the deck.

A study under way in which this material has been used in thicker layers on new two-course bridge deck construction will provide information on the performance of the material under conditions different from those included in the study reported here.

1542

ACKNOWLEDGMENTS

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1541

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1546