CHLORIDE INTRUSION INTO BRIDGE DECKS OVERLAID WITH LATEX MODIFIED CONCRETE

March 1996

by

Michael D. Sock
Senior Civil Engineer

Research
Technology
Development

RHODE ISLAND DEPARTMENT OF TRANSPORTATION

Mr. William F. Bundy, Director

Mr. James R. Capaldi, Chief Engineer

Mr. Colin A. Franco, Managing Engineer, R&TD

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EXECUTIVE SUMMARY

In 1992, with overlay work ongoing on the Jamestown-Verrazano Bridge, RIDOT's Chief Engineer decided that issues related to bridge deck overlays, specifically latex modified concrete (which is relatively expensive) warranted a study of their effectiveness and durability. This undertaking was delegated to the newly formed Research and Technology Development (R&TD) Section, which proceeded to plan the strategy to carry out the study. LMC overlaid as well as non-overlaid full depth portland cement concrete bridge decks were included. We looked for archive data (ages, deck and overlay thicknesses, etc.) to get a life-span perspective of the bridge decks. Bridges were selected for testing based on the availability of data, deck ages and access for retrieval of the cores. Interstate highway bridges were not selected because of their heavy traffic volumes. Site assessment, evaluations and core retrievals were undertaken as a cooperative effort with the RIDOT Materials Section. The laboratory phase was conducted by the R&TD Section. The data and conclusions were discussed and analyzed by the R&TD Section technical staff.

This project strongly indicates that an LMC overlay is effective in mitigating the ingress of chlorides into the deck. However, as the application of an LMC is a specialized and expensive operation, the economics would appear to make it an option to be used only in special circumstances.

A special commendation should go to the principal investigator (Mr. Michael D. Sock) and the staffs of the R&TD and Materials Sections for a job well done.

Colin A. Franco, P.E.
Managing Engineer
Research and Technology Development
Rhode Island Department of Transportation

ABSTRACT

This field study compared the resistance to chloride intrusion of latex modified concrete overlaid decks to that of full depth portland cement concrete decks. The relative conditions of the two systems were also examined. The test results paralleled those expected. The chloride levels at the first rebar mat were lower on the decks with a latex modified overlay, but the chloride levels in the overlay were comparable to those in the unmodified concrete at the same depth. The rapid chloride permeability results were generally in the normal range for the latex modified and unmodified concrete. In addition, an opportunity presented itself to study a deck overlaid with microsilica modified concrete. The permeability of the microsilica modified overlays averaged a little higher than expected. The overall condition seemed to be acceptable on both systems.

INTRODUCTION

The State of Rhode Island has been using latex modified concrete (LMC) as a bridge deck overlay material for nearly twenty years, on a project specific basis. The primary justification has been the belief that LMC, in addition to having good qualities as a wearing surface, acts as a barrier to chloride ion bearing water. It was therefore used to provide additional protection for the reinforcing steel in the deck concrete.

As these overlays have been in service for a significant portion of their fifty year design life, it was decided to perform tests to compare chloride levels in the deck concrete in LMC overlaid bridges to the levels in full depth concrete decks. In addition to the chloride intrusion testing, permeability tests were performed on two cores from several of the bridges, per AASHTO T 277.

Selection of the bridges was accomplished with information provided by Bridge Engineering and Bridge Maintenance. Bridges were chosen based on the age of the wearing surface (often the age of the structure) and the wearing surface type (LMC or PCC)[1]. Asphalt overlaid decks were not included in the study. The ages of the wearing surfaces selected fell into three groups: One year, approximately ten years and fifteen to twenty years. With the exception of one bridge, #250, the wearing surface was the same age as the deck.

The Union Avenue Bridge was included because it is the first microsilica overlay in the state. It provided only limited information, as it has been in place for only one year. The I-95 bridges were not tested due to the difficulty in securing the necessary traffic control.

1 PCC - Portland Cement Concrete; LMC - Latex Modified Concrete; MS - Microsilica

Table 1 - LIST OF TESTED BRIDGES

BRIDGE NO.	BRIDGE NAME	WEARING SURFACE TYPE	WEARING SURFACE AGE	NO. OF CORES TAKEN
800	Jamestown-Verazzano	LMC	1	3
824	Yawgoo Mill Pond	LMC	9	9
250	Sakonnet River (RT. 24N, southern approach)	LMC	14	5
798	Douglas Pike Ramp South	LMC	17	5
840	Main Street	LMC	17	5
775	Atwells Avenue	LMC	18	5
865	Martin Luther King	PCC	6	5
928	Smith Street RR	PCC	12	5
929	Orms Street RR	PCC	13	5
925	Union Avenue RR	MS	1	5

SURVEY, SAMPLING, INSPECTION AND TEST PROCEDURE

A standardized procedure was followed from bridge to bridge. An initial visual inspection was performed on each bridge, prior to the cores being taken. Just prior to the coring, a more detailed examination and survey was performed of the deck and other elements of the structure, where possible. The length from abutment to abutment was measured and this distance was used to determine the locations of the coring. If a significant transverse incline was noted, the testing was performed on the lower side of the deck. Cores, 9.5 centimeters in diameter, were taken near the midspans of the bridges, at spacings determined by the length of the structure. Where possible, cores were taken in the wheelpaths, but the need to maintain traffic flow generally restricted coring to the area of the gutter[2] . A Covermeter was employed to determine the cover over the rebar to avoid damaging the reinforcing mat.

- Visual inspections included examination of wear of pavement surface, crack type and size location, condition of expansion and construction joints and condition of sealant at curbing. Where possible, the substructure was also inspected for cracks and efflorescence.

- Chain dragging was performed on the Orms Street Railroad and Atwells Avenue Bridges. Noise from the traffic flow on the other bridges prevented the use of the chain drag. Hammer soundings were made on all the bridges at the joints and at specific crack locations.

- Half cell potentials could not be measured on any of the bridges, because the reinforcing steel in most cases was epoxy-coated, preventing the necessary electrical conduction through the mat. The LMC overlays may also have interfered with the readings, due to their impermeability and the subsequent effect on conductivity.

- Powdered concrete samples were taken radially from the cores, using a drill press, at the required depth. For the full depth portland cement concrete cores, samples were taken at intervals of two and one-half centimeters from the top, down to seven and one-half centimeters if the cores were of sufficient length. These samples were used to generate profiles of chloride intrusion, tested in accordance with AASHTO T 260 - "Sampling and Testing for Total Chlorides in Concrete and Concrete Raw Materials". For the LMC overlay cores, one sample was taken in the LMC, the other in the deck concrete. The chloride levels in the concrete and LMC were then tested for chloride content. Samples at intervals were also taken from selected LMC cores to generate profiles.

- Permeability test were run on selected cores, in accordance with AASHTO T 277 - "Rapid Determination of the Chloride Permeability of Concrete".

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As the curbline is usually where the highest concentrations of chlorides occur (because runoff generally collects in the gutter), this is an acceptable compromise.

VISUAL INSPECTION RESULTS

The visual inspections were performed to get a sense for the condition of the wearing surface in order to aid in the selection of bridges to be tested and to determine the nature of the testing that might be required. More detailed examinations at the time of the coring were used to aid in analyzing the chloride intrusion results. Some observations were included as being of general interest.

1) Sakonnet River, Rt. 24S (No. 250, LMC - 14 years) - The LMC is only placed on the approach spans, not on the main spans. On the northern approach, there was severe cracking and numerous patches. The southern approach was in a condition similar to the northern, but not as severe. There was also cracking in the transverse construction joints.

2) Sakonnet River, Rt. 24N (No. 250, LMC - 14 years) - The LMC is only placed on the approach spans, not on the main spans. There were no patches. On the southern approach: There was significant cracking, most of which were about three-quarters of a millimeter in width. A number of the cracks appeared to be above longitudinal oriented rebar. The remainder of the cracks were random. Three of the cores exposed rebar when removed. There was no rust visible on the steel. On two of the three cores, the bond to the steel was sufficient such that there were traces of steel on the concrete[3]. On all five cores, some aggregate separated at the mortar/aggregate interface, with no fracturing of the stone. The construction joint sealant had failed in most locations and in many cases, the joints were completely open. The expansion joint had a large amount of debris over the joint seal, making it impossible to determine its condition. There was substantial wear of the tines in the wheel paths and there were depressions in the wearing surface, apparently dating back to the LMC placement. The deck had significant vertical movement under traffic loading, especially when heavy vehicles passed over the structure.

3) Civic Center Interchange Ramps (Nos. 579 through 585, 848 and 849, multiple spans on steel beams, LMC - 7 years) - Only a windshield examination was possible. However, the wearing surface seemed to be in generally good condition, although there was some gouging of the tines.

4) Weaver Hill Road, I-95S (No. 586, single span on steel beams, LMC - 13 years) - The tines were worn and there was some cracking in the tines. There were several patches and most patches were cracked around their perimeter. There was deterioration and spalls of the south backwall and the approach.

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[3] Evidenced by rust that appeared on the concrete after several days

5) Weaver Hill Road, I-95N (No. 586, single span on steel beams, LMC - 13 years) - There was block and longitudinal cracking. There was a large patch, cracked around the perimeter. The joints had extensive spalling along their length, with heavy patching.

6) Robin Hollow Road, I-95S (No. 588, single span on steel beams, LMC - 13 years) - There were areas of random cracking, with some transverse cracking having a three to four foot spacing.

7) Robin Hollow Road, I-95N (No. 588, single span on steel beams, LMC - 13 years) - There was map and longitudinal cracking. The headwalls were cracked, with extensive asphalt patching.

8) Ten Rod Road, I-95S (No. 591, single span on steel beams, LMC - 13 years) - There are transverse and diagonal cracks, many at three to four foot spacing. The southern backwall had failed[4]. The longitudinal construction joint between the travel lanes had cracked and there was a delamination at the northern end.

9) Ten Rod Road, I-95N (No. 591, single span on steel beams, LMC - 13 years) - The longitudinal joint between the travel lanes was cracked. There were also several longitudinal cracks. There were numerous patches, including patches on patches. The southern backwall was also patched.

10) Tefft Hill Road, I-95S (No. 592, LMC - 13 years) - There was a failure of the northern backwall (probably the original). The tines were widely spaced, with wide grooves.

11) Tefft Hill Road, I-95S (No. 592, LMC - 13 years) - The southern joint had failed and was patched with asphalt. - 10 years

12) Baker Pines, I-95S (No. 593, LMC - 13 years) - There were numerous patches, with at least five different patching materials used. There were many patches on patches. There were also cracks in the patches. There was deterioration of the northern backwall. Note: The approaches were also tined. I-95N: There were numerous patches, of different materials (including asphalt), with patches within patches.

13) Atwells Avenue (No. 775, three spans on steel beams, LMC- 18 years) - There was wear of the riding surface (tines) but otherwise it was in visually excellent

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[4] The backwall and the approach were patched together.

condition. Some fine cracks were visible when the surface was wet. There was a delamination of the overlay adjacent to the joints at both abutments (west bound); on the east joint, it extended from one meter from the curb out to three meters and on the west joint, it extended from one-half meter to one and one-half meters from the curb.

14) Douglas Pike Ramp North, Rt. 7 (No. 797, single span on steel beams, LMC - 17 years) - There was wear of the riding surface (tines) but otherwise it was in visually excellent condition.

15) Douglas Pike Ramp South, I-295 (No. 798, single span on steel beams), LMC - 17 years) - There was wear of the tines, with the tines almost completely worn away at the centerline. The overlay was in generally good condition. The expansion joint was in good condition, with some wear and damage near the middle of the joint[5]; however, the seal was intact. There was failure of the joint sealant where the expansion joint met the curb. There was also some failure of the joint sealant under the curb and of the mortar between curb stones. Hammer sounding indicated delamination near the expansion joint, but a core taken at that location was removed intact. The delamination may have been at the level that the core separated. The parapet wall had extensive cracking through the cross-section at intervals of approximately a third of a meter. There were spalls around surface voids. There was wear of the coating, with loss around distressed areas (cracks, spalls).

16) Jamestown-Verazzano Bridge (No. 800, multiple structural types, LMC - 1 year) The overlay on the main span (the only section of the bridge inspected) was in good condition.

17) Yawgoo Mill Pond Bridge (No. 824, four spans on steel beams, LMC - 9 years) [Note: A more detailed examination was possible for this bridge due to the low traffic volume and the accessibility of the substructure] - The overlay had some wearing of the tines and cracking was evident in many of the tine grooves. There were two large snaking transverse cracks extending from the curb on the west bound side of the bridge; the cracks were filled with sand and appeared to follow a groove on the surface. There was a long crack extending from the eastern expansion joint, in the east bound lane. There was at least one new crack[6]. A spall was noted on the centerline near the midpoint of the bridge. There was significant failure of the curbing joint sealant and three curb sections were cracked, with one grouted. There were also several skid marks in the east bound

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5 Gouging of the steel and the rubber seal.

6 Hairline, no sign of sand in the crack, sharp edge.

lane. The expansion joints were in good shape, although they were covered with sand. Delaminations were found in the LMC adjacent to the expansion joints, discontinuously along the joints. A core taken at the location of one delamination fractured into several pieces when removal was attempted. There were cracks in the asphalt pavement on the approach sections, parallel to and eight inches away from each expansion joint. There was cracking of the parapet walls, through the cross-section, with efflorescence visible in some of the cracks. There was also failure of the wall joint sealant. There was a spall of the deck concrete near the east abutment, where the concrete was in contact with a diaphragm running between two beams (second and third from the north).

Substructure - The steel was completely rusted[7]. There did not appear to be significant section loss. The three pier systems showed no signs of distress, although close inspection was possible for only one set of piers and not for any of the pier caps. The under side of the deck was free from staining and efflorescence. There were no water stains visible on the abutments, indicating the joint seals are intact.

18) Main Ave. Bridge (No. 840, single span on steel beams, dual bridge, LMC - 17 years) - There was wear of the tines in the wheel paths and cracks in the tine grooves. There was a delamination adjacent to the west joint (expansion), starting at one and one-third meters from the east bound curb and ending at three meters. The worst area was between one and one-third meters and two meters and a core was taken in the middle of that section. It separated at the LMC/deck interface, when removed. There was severe cracking of the backwall at the west joint (fixed), with a patched area starting at two and one-half meters from the east bound curb and ending at four and one-third meters. The patch was also severely cracked, with some loss of material at the edges of the joint. The patch also showed signs of delamination, although no pieces were loose enough to be shifted by hand.

Substructure - There was some efflorescence at the construction joints. Water stains on the western abutment wall indicated failure of the expansion joint seal.

19) Martin Luther King Bridge, Francis Street, Northbound (No. 864, three spans on steel beams, full depth PCC - 6 years) - The overlay was in generally good condition, although some cracking was evident.

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7 Most likely weathering steel.

Martin Luther King Bridge, Francis Street, Southbound (No. 865, three spans on steel beams, full depth PCC - 6 years) - The overlay was in generally good condition, although some cracking was evident. There were some transverse cracks at the midspan, with spacings varying from one to four feet. The cracks were mostly hairline. A core taken through a crack struck rebar, but the crack was not over the rebar. The rebar cover averaged about five centimeters.

20) Union Ave. Railroad Bridge (No. 925, MS - 1 year) - Excellent condition.

21) Smith Street Railroad Bridge (No. 928, single span on steel beams, PCC - 14 years) - The overlay was in generally good condition, with heavy wear of the surface.

22) Orms Street Railroad Bridge[8] (No. 929, PCC - 13 years) - The overlay was in generally good condition, with some cracking evident. There was a delamination adjacent to the east joint (east bound), extending from one meter from the curb, out to two and one-third meters.

General Comments: The tines on most bridges were worn, especially on those with an older overlay. Many of the overlays had cracks and these varied from transverse to longitudinal to diagonal. The southern bridges (on I-95) were in the poorest condition. Note: Not all of the bridges listed here have had cores taken.

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8 This bridge, while wide enough for two lanes of traffic in both directions, has only one effective lane midway from curb to centerline, unless traffic is heavy.

TABLE 2 - LOCATION OF CORES

BRIDGE NO.	CORE NO.	REFERENCE POINT	LONGITUDINAL DISTANCE FROM REFERENCE (m)	DISTANCE FROM CURB (m)	REMARKS
250	1	expansion joint at middle of southern approach	18	1.3	hit rebar; clean separation of some aggregate
	2		34	1.3	hit rebar; clean separation of some aggregate
	3		50	1.3	hit rebar; clean separation of some aggregate; core taken 20 cm from crack with rust stain
	4		70	1.3	clean separation of some aggregate
	5		88	1.3	clean separation of some aggregate
775	1	east joint, west bound	35	0.3	
	2		40	0.3	separation at LMC/ PCC interface
	3		42	0.5	
	4		48	0.7	
	5		53	0.7	
798	1	north joint (exp.)	6	0.8	
	2		12	0.8	
	3		18	0.8	
	4		24	0.8	
	5	@ exp. joint	0.3	1.2	
800	1	from old bridge, three vertical beams east of midspan [a]	0	0.7	partial separation at LMC/PCC interface
	2		9.9	0.7	partial separation. at LMC/PCC interface
	3		18.5	0.7	partial separation at LMC/PCC interface

BRIDGE NO.	CORE NO.	REFERENCE POINT	LONGITUDINAL DISTANCE FROM REFERENCE (m)	DISTANCE FROM CURB (m)	REMARKS
824	1	west exp. joint, east bound	107	2.0	through crack, cut rebar
	2		99	0.7	
	3		99	2.0	
	4		99	3.3	
	5		99	5.5	separation at LMC/PCC interface
	6		38	0.7	separation at LMC/PCC interface
	7	west exp. joint, west bound	54	0.7	cut rebar
	8		84	0.7	
	9		@ east joint	0.7	fractured when removed
840	1	west joint (exp.), east bound	8	0.7	
	2		12	0.7	
	3		15	0.7	
	4		19	0.7	
	5		@ west joint	2.0	separation at LMC/PCC interface
865	1	north exp. joint, south bound	20	0.5	cut rebar
	2		26	0.5	cut rebar
	3		29	0.5	thru crack, cut rebar
	4		32	0.5	
	5		38	0.5	
925	1	west exp. joint, east bound	5	0.3	
	2		8	0.5	
	3		11	0.5	separation at MS/PCC interface
	4		10	0.5	exposed rebar
	5		14	0.5	
928	1	west joint, east bound	15	0.3	
	2		18	0.7	
	3		22	0.7	
	4		20	2.0	through crack
	5		24	1.0	exposed rebar

BRIDGE NO.	CORE NO.	REFERENCE POINT	LONGITUDINAL DISTANCE FROM REFERENCE (m)	DISTANCE FROM CURB (m)	REMARKS
929	1	west exp. joint, east bound	15	0.3	
	2		18	0.7	
	3		22	0.7	
	4		20	2.0	through crack
	5		24	1.0	exposed rebar

Note a: No reference was available on the structure; a rough position was made relative to the old bridge adjacent, which was in use prior to completion of #800.

TEST RESULTS AND ANALYSIS

Table 3 - CHLORIDE TEST RESULTS

SAMPLE NUMBER (BRIDGE NO. - CORE NO.)	THICKNESS OF OVERLAY (cm)	CORE THICKNESS (cm)	SAMPLE DEPTH (cm)	KILOGRAMS CHLORIDE PER CUBIC METER OF CONCRETE	MATERIAL
250-1	3.2	5.5	1.9	4.6	LMC
			5.1	1.7	PCC
250-4	3.8	5.0	2.2	1.4	LMC
			5.7	1.1	PCC
250-5	4.8	6.0	1.9	2.1	LMC
			5.7	1.2	PCC
775 - 1	2.9	7.0	1.9	0.5	LMC
			5.1	0.1	PCC
775 - 5	3.2	9.0	1.9	1.5	LMC
			6.0	0.1	PCC
798 - 1	4.1	10.0	2.5	4.4	LMC
			8.3	0.3	PCC
798 - 3	3.8	10.0	2.5	4.6	LMC
			7.0	0.1	PCC
798 - 4	3.8	10.0	2.5	3.4	LMC
			7.5	0.1	PCC
800 - 1	7.3	9.0	3.8	0.1	LMC
			9.0	0.1	PCC
800- 2	7.0	8.5	3.8	0.1	LMC
			8.5	0.1	PCC
800 - 3	8.6	9.0	3.9	0.1	LMC
			8.8	0.1	PCC
824 - 1	3.5	10.0	1.9	3.5	LMC
			8.3	0.1	PCC
824 - 3	3.5	12.0	1.9	2.3	LMC
			9.5	0.1	PCC
824 - 4	3.5	10.0	1.9	3.0	LMC
			7.5	0.1	PCC

SAMPLE NUMBER (BRIDGE NO. - CORE NO.)	THICKNESS OF OVERLAY (cm)	CORE THICKNESS (cm)	SAMPLE DEPTH (cm)	KILOGRAMS CHLORIDE PER CUBIC METER OF CONCRETE	MATERIAL
824 - 5	4.5	10.6	2.5	3.5	LMC
			8.3	0.1	PCC
824 - 6	4.1	10.0	1.9	1.0	LMC
			7.5	0.1	PCC
824 - 7	2.2	10.0	1.9	3.0	LMC
			7.5	0.1	PCC
840 - 1	3.8	10.3	2.5	3.2	LMC
			6.7	1.0	PCC
840 - 4	4.1	10.3	2.2	3.9	LMC
			6.7	0.2	PCC
865 - 2	N/A	6.3[a]	1.6	3.0	PCC
			3.2	1.0	
865 - 3, side A[b]	N/A	5.6	3.2	3.2	PCC
865 - 3, side B[b]	N/A	5.6	3.2	1.0	
865 - 5	N/A	6.3	1.9	0.7	PCC
			3.8	0.3	
925 - 1	5.1	9.0	3.2	0.1	MS
			7.5	0.1	PCC
925 - 2	6.0	10.0	2.9	0.4	MS
			8.0	0.2	PCC
925 - 3	4.8	6.0	4.4	0.2	MS
928 - 2	N/A	9.3	2.5	3.2	PCC
			5.1	1.8	
			7.5	0.3	
928 - 4	N/A	9.0	2.5	3.6	PCC
			5.1	1.4	
			7.5	0.6	
929 - 2	N/A	11.3	2.9	3.2	PCC
			5.7	1.4	
			8.6	0.5	
929 - 3	N/A	12.0 [c]	3.4	0.3	PCC
929 - 4, side A[b]	N/A	11.3	3.8	3.2	PCC

SAMPLE NUMBER (BRIDGE NO. - CORE NO.)	THICKNESS OF OVERLAY (cm)	CORE THICKNESS (cm)	SAMPLE DEPTH (cm)	KILOGRAMS CHLORIDE PER CUBIC METER OF CONCRETE	MATERIAL
929 - 4, side A[b]	N/A	11.3	7.5	1.4	PCC
929 - 4, side B[b]	N/A	11.3	3.8	3.7	PCC
929 - 4, side B[b]	N/A	11.3	7.5	2.2	PCC
929-5	N/A	11.3	1.9	4.2	PCC
			3.4	2.0	
			5.7	0.5	

General note: Sample depth refers to the distance from the top of the core to the *center* of the drilled hole. The actual sample contains material from the adjacent depths and varies with the diameter of the drill bit (different bits were used, depending on the thickness of the layer to be sampled).

Note a: Depth of rebar approx. 5 cm.

Note b: Cored through crack and samples taken from either side of crack.

Note c: Only one sample taken for determination of chloride content; specimen to be used for permeability test (which requires that the top 5 cm. of core is intact).

TABLE 4 - PERMEABILITY TEST RESULTS
AASHTO T 277

SAMPLE NUMBER (Bridge no. - Core No.)	PERMEABILITY RESULT (Coulombs)	MATERIAL[a]
775-3	644	LMC
775-4	159	LMC
798-2	41	LMC
798-5	518	LMC
840-2	120	LMC
840-3	35 [b]	LMC
865-1	2523	PCC
865-4	1994	PCC
928-1	1663	PCC
928-3	2927	PCC
929-1	404	PCC
929-3	1488	PCC
925-4	1120	MS
925-5	1507	MS

General Note: Per AASHTO T 277, very low permeability is 100-1000 coulombs, low is 1000-2000, moderate is 2000-4000 and anything above 4000 is very high. Any result below 100 is considered negligible

Note a: The AASHTO method calls for specimen thicknesses of 5.08 cm. Since the samples are taken from field cores, when taken from decks with a nominal 3.18 cm thick LMC overlay, the specimens listed as LMC have approximately 2.5 - 3.8 cm thickness of LMC; the remainder is the PCC of the deck.

Note b: The current passing through this specimen never rose above 1.8 mA, which is below the resolution of the automated testing apparatus used. However, since this is far down into the range of negligible permeability, an approximation based on occasional readings is provided for information. Any result below 100 coulombs indicates near total impermeability, relatively speaking.

TABLE 5 - PROFILE OF CHLORIDE INTRUSION IN SELECTED CORES FROM LMC OVERLAID BRIDGE DECKS

SAMPLE NO. (Bridge no. - Core No.)[a]	THICKNESS OF OVERLAY (cm)	CORE THICKNESS (cm)	DEPTH OF SAMPLE (cm)[b]	CHLORIDE CONTENT (kg/m^3)	MATERIAL
775-5	3.2	9.0	0.5	4.3	LMC
			1.5	2.2	
			2.5	1.1	
			3.5	0.2	PCC
			6.0	0.1	
798-1	4.1	10.0	1.0	7.4	LMC
			1.5	5.5	
			3.0	3.8	
			5.0	0.5	PCC
			8.0	0.2	
			8.3	0.3	
798-3	3.8	10.0	0.8	7.9	LMC
			1.8	5.5	
			2.5	4.6	
			4.6	0.7	PCC
			7.0	0.1	
824-3	3.5	12.0	1.0	1.7	LMC
			1.7	0.5[c]	
			2.5	0.2	
			4.1	0.1	PCC
			9.5	0.1	
824-4	3.5	10.0	0.6	5.3	LMC
			1.7	2.3[c]	
			2.8	1.4	
			3.8	1.0	PCC
			7.5	0.1	
824-6	4.1	10.0	0.9	3.4	LMC
			1.7	1.9[c]	
			2.8	1.1	
824-6	4.1	10.0	5.7	0.2	PCC

SAMPLE NO. (Bridge no. - Core No.)[a]	THICKNESS OF OVERLAY (cm)	CORE THICKNESS (cm)	DEPTH OF SAMPLE (cm)[b]	CHLORIDE CONTENT (kg/m^3)	MATERIAL
			7.5	0.1	

Note a: The cores were selected to obtain a range of chloride intrusion levels in the LMC.

Note b: The depth of the sample is measured from the top of the core (averaged between the crest and valleys of the tines) to the center of the sample hole drilled radially into the core. Three small holes (six to eight tenths of a centimeter in diameter) were drilled at each depth and the material removed was mixed to form a single sample.

Note c: At the 1.7 cm. depth for the cores from bridge number 824, there is a discrepancy between the numbers obtained in the profiling and the values obtained at 1.9 cm. that were originally obtained when testing for chloride intrusion levels. Both sets of values are believed to accurately represent the chloride ion content in the samples and it is not understood why there is a difference. However, it does not substantially alter the pattern of the data.

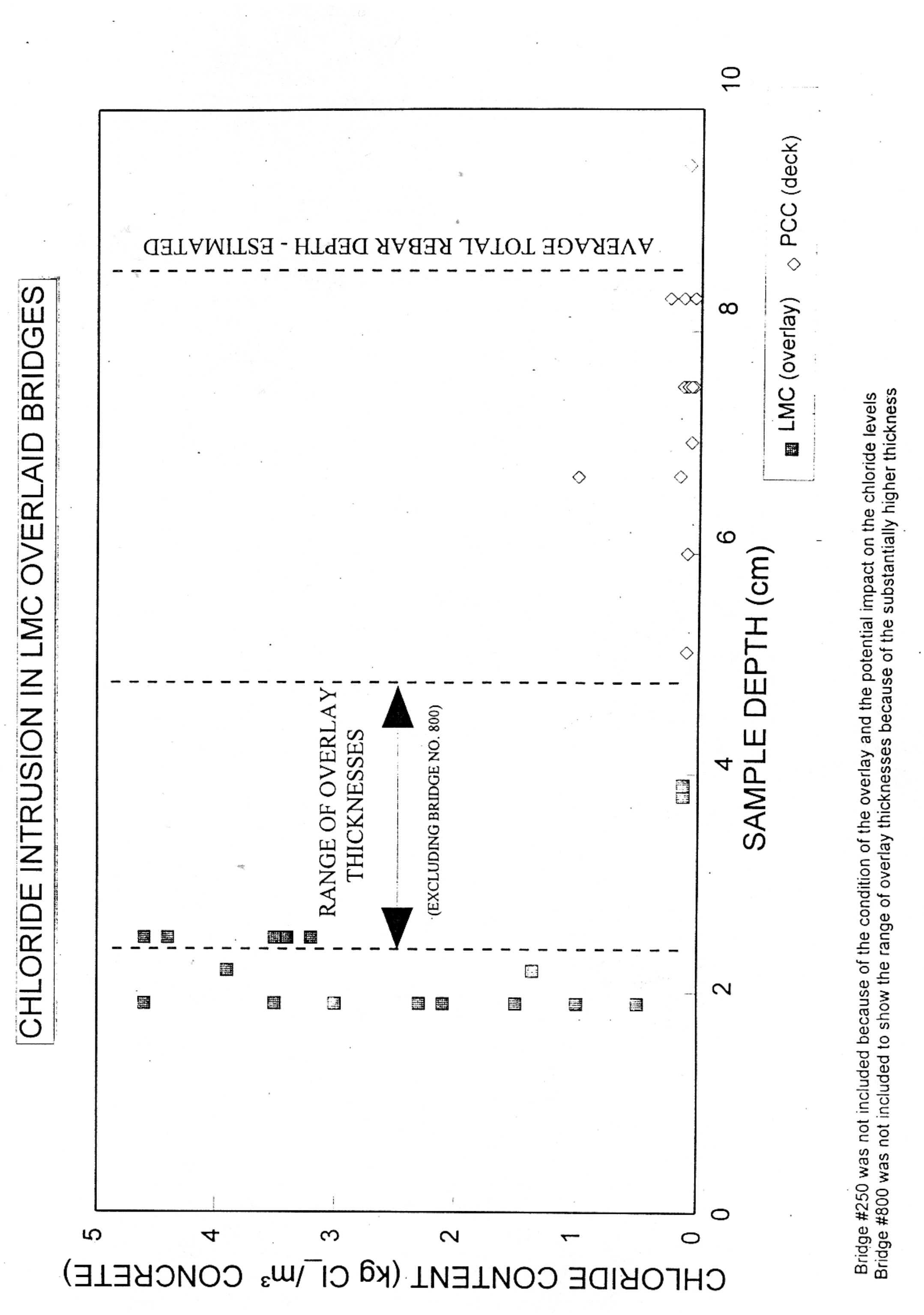

Figure 1 - Chloride Intrusion in LMC Overlaid Bridges

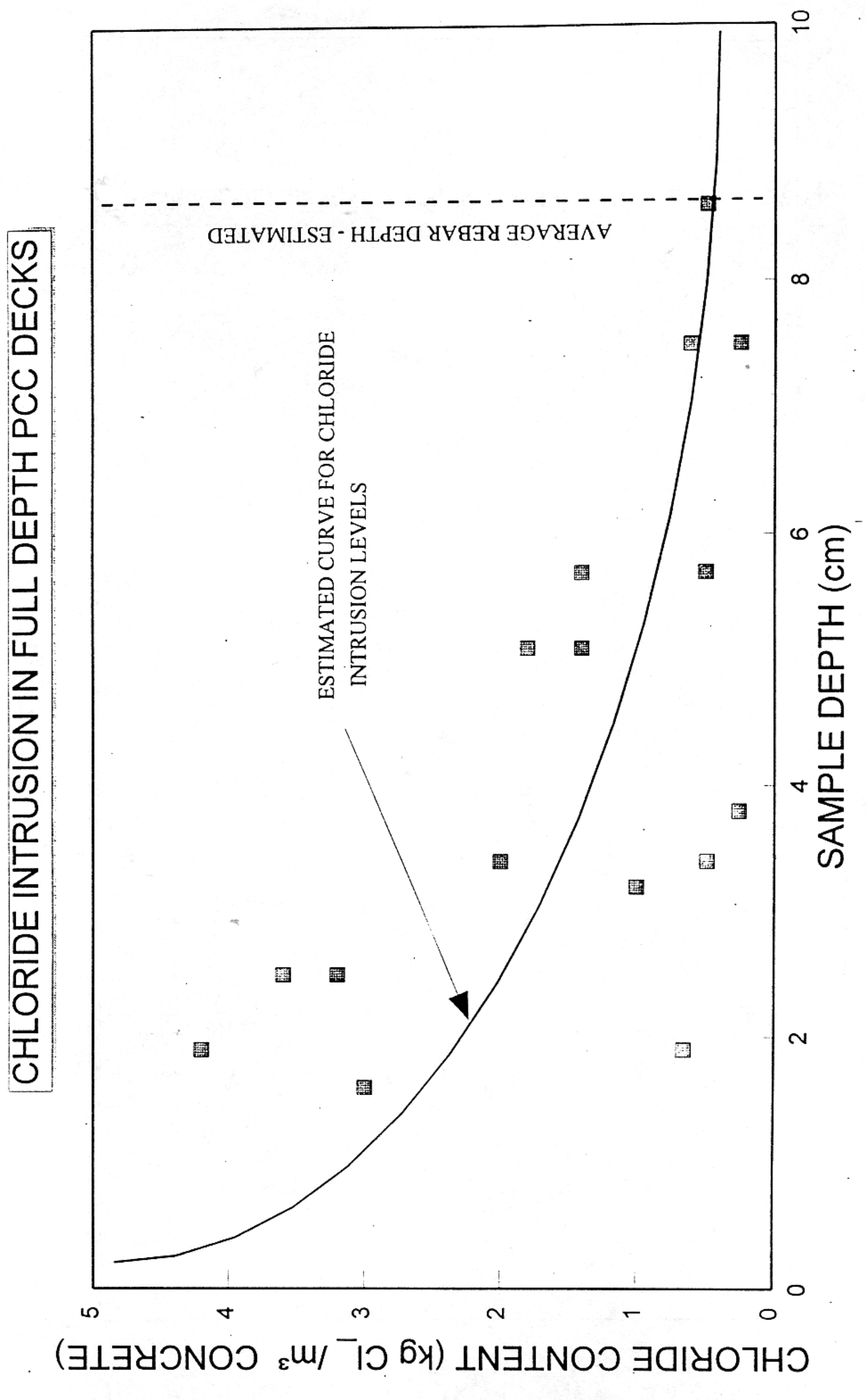

Figure 2 - Chloride Intrusion in Full Depth PCC Decks

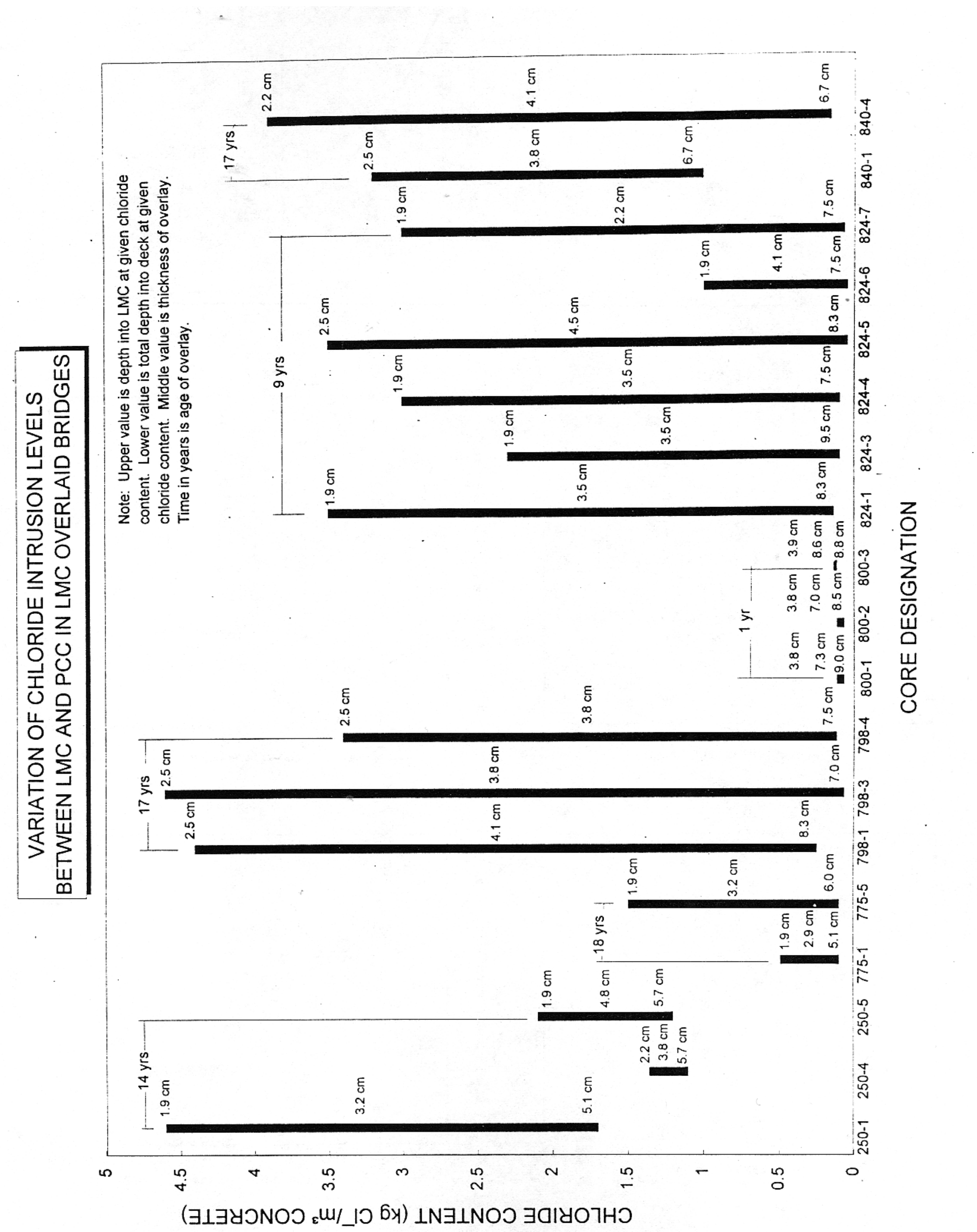

Figure 3 - Variation in Chloride Intrusion Levels Between LMC and PCC in LMC Overlaid Bridges

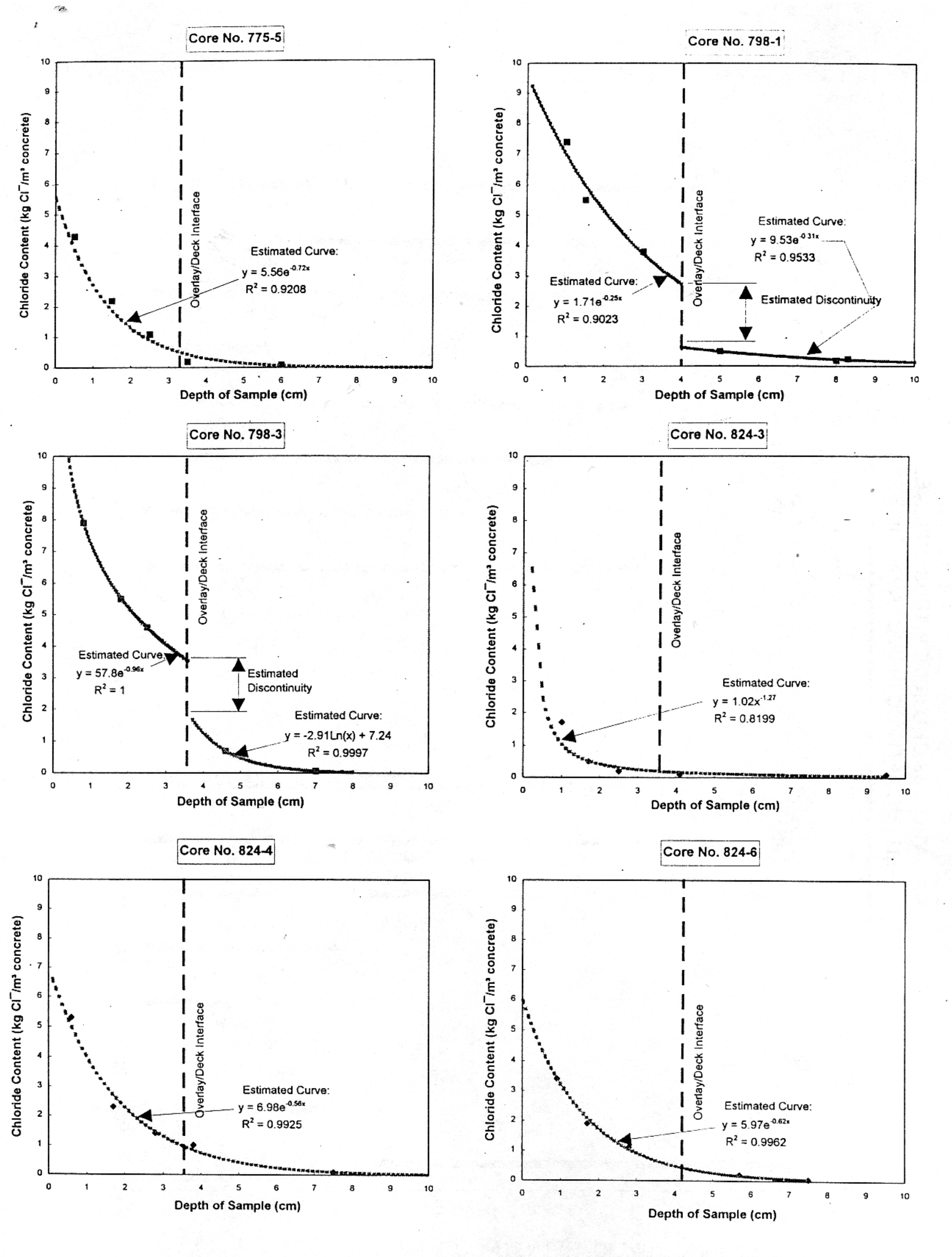

Figure 4 - Profile of Chloride Intrusion in LMC Overlaid Bridge Decks

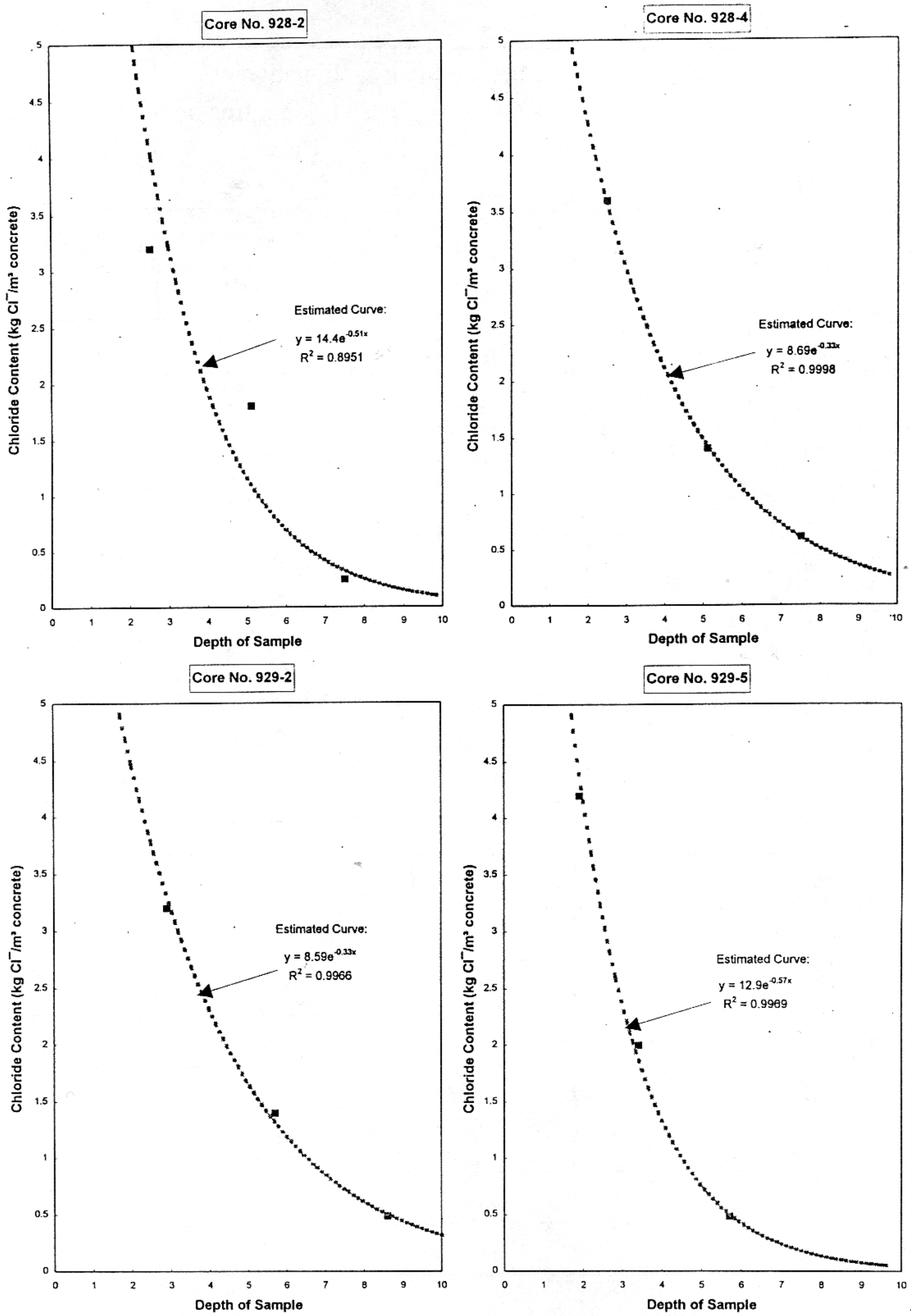

Figure 5 - Profile of Chloride Intrusion in PCC Full Depth Bridge Decks

Table 6 - Area Under the Chloride Intrusion Curves

SAMPLE NO. (Bridge no. - Core No.)	Material	Minimum Depth (cm)[a]	Maximum Depth (cm)[a]	Equation of Chloride Intrusion Curve[b]	Chloride Content per m^2 in Depth Range (kg/m^2)[c]
775-5	LMC	0	3.2	$5.56e^{-0.72x}$	6.92
	PCC	3.2	10	$5.56e^{-0.72x}$	0.75
798-1	LMC	0	4.1	$9.53e^{-0.31x}$	22.01
	PCC	4.1	10	$1.71e^{-0.25x}$	1.91
798-3	LMC	0	3.8	$-2.98 \ln(x) + 7.24$	23.73
	PCC	3.8	10	$57.8e^{-0.96x}$	1.57
824-3	LMC	0	3.5	$1.02x^{-1.27}$	5.52[d]
	PCC	3.5	10	$1.02x^{-1.27}$	0.67
824-4	LMC	0	3.5	$6.98e^{-0.56x}$	10.71
	PCC	3.5	10	$6.98e^{-0.56x}$	1.71
824-6	LMC	0	4.1	$5.97e^{-0.62x}$	8.84
	PCC	4.1	10	$5.97e^{-0.62x}$	0.73
928-2	PCC	0	3.8	$14.4e^{-0.51x}$	24.32
	PCC	3.8	10	$14.4e^{-0.51x}$	3.99
928-4	PCC	0	3.8	$8.69e^{-0.35x}$	18.12
	PCC	3.8	10	$8.69e^{-0.35x}$	5.64
929-2	PCC	0	3.8	$8.59e^{-0.33x}$	18.62
	PCC	3.8	10	$8.59e^{-0.33x}$	6.49
929-5	PCC	0	3.8	$12.9e^{-0.57x}$	20.09
	PCC	3.8	10	$12.9e^{-0.57x}$	2.53

General Note: The equations shown above are the ones shown in the plots in Figures 5 & 6. The curves were generated using the trendline function in Microsoft Excel v5.0c for the scatterplots shown. The equations were also generated using the trendline function for the curves. Most of the curves use the natural log function, which generally is quite good at describing the chloride distribution in concrete. It is possible that different forms of the equations might be more accurate in describing the distribution, but the high correlation values indicate that the ones used are adequate for the purpose intended. In two cases, other equation forms were used when the natural log gave unrealistic results (chloride contents below zero in the range considered). The use of these equations should pose no problem for the sake of this comparison; the curves correspond to the data points sufficiently to find an reasonably accurate value for the area under the curve. The areas under the curves were calculated by integration using MathCAD v3.1 for Windows.

Note a: The minimum and maximum depths are measured relative to the top of the core and are used as the lower and upper limits on the integration for the area under the curve. For the 775, 798 and 824 series of cores, the values between 0 and 10 centimeters represents the thickness of the overlay. For the 928 and 929 series of cores, the value of 3.8 centimeters is an average of the overlay thicknesses for the LMC overlays (excepting bridge no. 800 and one core from no. 824, which were considered atypical). Calculating the chloride content separately for the overlay and the deck concrete shows the relative effectiveness of the protection afforded by the overlay and a comparable thickness of unmodified concrete. 10 centimeters seemed an acceptable upper limit, given the thickness of the cores and the general placement of the rebar.

Note b: As stated in the general note above, the equations were taken from the trendline function in MS Excel. For cores 798-1 and 798-3, two curves and, subsequently, two equations were generated for each of the two sets of data points. This is due to the apparent discontinuity of the data for these two cores and is meant to represent the discontinuity more accurately than a single curve could.

Note c: The values in this column indicate the chloride ion content per square meter for the depth range used to perform the integration.

Note d: For core no. 824-3, in the range 0 to 3.5 centimeters, a lower limit of 0.05 was used in the integration. As can be seen when the equation is integrated, the calculation of the lower limit at zero gives a value of infinity and this is obviously not a reasonable value (the highest value would be that for a block of pure chloride ions). Calculations were performed at various values approaching zero and 0.05 seemed to be a reasonable value based on a visual examination of the area under the curve.

CONCLUSIONS AND RECOMMENDATIONS

From the data received from testing the samples, there appear to be three factors that affect the intrusion of chlorides into the deck concrete, especially for the long term. These factors are generally well known, although the data allows for some quantification.

The most significant factor seems to be the integrity of the concrete. If the concrete is cracked to any depth or has an excessive void structure, the presence of chloride ions is increased. Any methods employed to protect the steel by reducing intrusion will be mitigated if cracks or voids bypass them[9]. Bridge no. 250 has significant levels of chloride at the reinforcing mat level; it had significant cracking of the overlay directly over the rebar. The rust stains at one crack site on that bridge indicate that significant corrosion may already have occurred and may be contributing to or even be causing the cracking.

It has long been known that depth of cover using dense, sound concrete, can reduce intrusion at the level of the rebar mat. The accumulated data seems to indicate that to maintain the total chloride level below the corrosion threshold[10] for the tested decks over fifteen years old, total cover depth, including any cementitious overlays, of at least nine centimeters was required. Typically, at that depth, the total chloride ion content was no more than sixth-tenths of a kilogram per cubic meter of concrete[11] and was generally significantly less than that. Note that bridge number 865 has significant levels of chloride near the rebar after six years, with a cover depth of only five to eight centimeters.

Finally, the presence of a latex overlay seems to reduce the chloride concentration to near baseline levels at the top rebar mat. One unexpected result was the determination that the chloride levels in the LMC was comparable to that in the normal portland cement concrete at a depth of one inch for each. This was true even though the chloride levels in the deck concrete in the same cores were very low. This may be due to the large number of voids visible in the latex overlays. The latex is subject to foaming when agitated and this would certainly be a factor when the concrete is being mixed. This foaming could cause voids during curing. Another factor may be the manufacturer's recommended use of a slurry spread onto the deck before the placement of the overlay. This would provide an additional barrier, one more impermeable than the LMC.

9 Although the use of corrosion inhibitors may slow down the effects of chlorides, the constant influx of chlorides would rapidly neutralize the chemical components of the inhibitor.

10 Eight-tenths of a kilograms of chloride per cubic meter of concrete (0.20 percent of cement content), per Synthesis of Highway Practice Report Number 57 - "Durability of Concrete Bridge Decks", p. 16, National Cooperative Highway Research Program, Transportation Research Board (National Research Council), May 1979, Washington, D.C. Note that the value is based on testing in FHWA labs on concrete with a 658 pound cement factor and considers insoluble chlorides, although these are not believed to influence corrosion. Only soluble chlorides are believed to be capable of reacting with the steel; the report gives the corrosion threshhold for soluble chlorides as six-tenths of a kilogram of chloride per cubic meter of concrete (0.15 percent of a cement content of 658 pounds) and estimates soluble to be 75 to 80 percent of insoluble chlorides.

11 See Table 3

However, even if the chlorides could eventually pass through the LMC and the slurry[12], the normal aging of the deck concrete should render it fairly resistant by that time. It has been suggested that the LMC may act as a trap, allowing large amounts of chloride ions into the overlay, but preventing it from penetrating through to the deck. However, the chloride levels in bridge no. 250 show that any advantages created by the overlay or the bonding slurry are completely neutralized if adequate, sound cover over the rebar is not provided.

The profiling that was performed on selected cores (see figure 4) from LMC overlaid decks indicates that depending on the way the overlay was placed, either case noted above[13] may occur. Bridges number 775 and 824 appear to have had the chloride intrusion reduced steadily through the overlay, implying the trap effect. Bridge number 798 shows a sharp drop at the level of the LMC/PCC interface, implying a barrier effect[14]. Based on the chloride levels from number 798, it is possible that both effects are occurring. The other cores show that the LMC can cause a drop of at least 4 kg Cl^{-}/m^3 of concrete through three to four centimeters of an LMC overlay. If this is a limit to the inhibiting (trap) effect of the LMC, any additional protection may be caused by a barrier effect when the chloride levels in the top of the overlay are higher than 4 kg Cl^{-}/m^3 of concrete[15]. The analysis of the area under the estimated chloride intrusion curves confirm that although the amount of chloride in the LMC is often comparable with that in the PCC at the same depth, the LMC provides better protection at the rebar level. The chloride contents average one-fourth as much for the decks with a LMC overlay compared to the full depth PCC decks.[16] A comparison of the ratios of chloride content in the first depth range to that of the second depth range shows that, on average, the ratio between the two for the LMC cores is double that of the PCC.[17] This indicates a much higher percentage of the chlorides entering the concrete are passing through towards the rebar level in the full depth PCC.

The permeability testing for the remaining cores shows a marked difference between the LMC cores and the PCC cores, with an average of 253 coulombs for the LMC, 1314 for the MS and 1833 for the PCC. The two highest results for the LMC are in the very low range and the other results are negligible or nearly so. Three of the PCC cores tested in the low range and two tested in the moderate range. The sixth PCC specimen was in the very low range. That the specimens were field cores may have lowered their permeability; the wearing surface of the concrete may have been exposed to oil and other substances that would act to inhibit water penetration[18]. Conversely, that the cores have been exposed to chlorides and possibly other ions would increase

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12

13 This seems unlikely, however, given that it has not after nearly twenty years on some bridges.

14 The LMC acting as a trap or the slurry acting as a barrier

15 Chloride intrusion levels normally follow an exponentially decreasing curve as a function of concrete depth; the curves for number 798 show a substantial discontinuity in the expected shape of the curve; the curve shown for core number 928-2 in figure 5 is atypical.

16 As they are in the cores from number 798.

17 1.22 kg^{-}/m^2 of concrete over the depth range compared to 4.66 kg^{-}/m^2 of concrete.

18 The LMC cores had an average ratio of 10.4:1 (range of 6.26:1 to 15.1:1), compared to the full depth PCC which had an average ratio of 5.03:1 (range of 2.87:1 to 7.94:1). Note that the ranges of the ratios overlap.

Much like a treatment of linseed oil.

the baseline current levels, increasing the overall permeability value[19]. Despite these possible effects, the pattern clearly shows that latex modified concrete is much less permeable than unmodified concrete. This agrees with the chloride testing results. The two MS specimens that were included for comparison had results in the low range; this is expected, as the percent of microsilica used was 6.5%[20].

Given that many of the bridges that we have sampled are nearly twenty years old and do not have any visible signs of severe distress, including corrosion of the rebar[21], the use of a full depth concrete deck (no overlay) may be sufficient to protect the steel to the time when the unmodified concrete becomes relatively impermeable. This assumes that the cover over the top mat is at least nine centimeters. However, for the highest degree of long term protection, an LMC overlay is the better choice. Almost invariably, when the latex modifier is used, the chloride level has remained at baseline levels at the rebar. This does not take into account the difficulty in placing and properly curing concrete modified with latex. As noted above, if the concrete is cracked or delaminated, a direct passage is provided for the chlorides, which would increase the levels near the steel. The use of LMC, therefore, requires strict quality control. The use of an unmodified concrete overlay with a latex bonding slurry might also be considered, as a compromise solution. The permeability of laboratory-prepared samples could be tested to give an indicator of the effectiveness of the system. Adhesion tests would also have to be performed to insure that adequate bonding occurs.

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19 The AASHTO T 277 permeability test measures the effective electrical resistance of the concrete. Water acts as an electrolyte, reducing the resistance. Chloride and other ions in the concrete reduce it further. Because the test method forces chloride ions into the concrete, potentially increasing current over the length of the test, generally to some maximum, a higher baseline means a higher average current. This in turn means a higher charge passing through the concrete, i.e., the coulomb reading.

20 Microsilica can be used to replace as much as 15% of the cement in a mix, although typically no more than 10% is used and even that much can make the mix stiff and difficult to place.

21 With the exception of bridge number 250, where the deck may be significantly older than the LMC overlay.

ACKNOWLEDGMENTS

Bridge Deck Coring .... C. Cinquegrana [M]
K. Adamo [M]
E. Alves [M]
A. Chiaverini [M]
S. Donahue [M]
S. Quintin [R]
R. Recchia [M]
D. Williams [M]

Bridge Core Hole Repair .... K. Adamo
M. Follari [I]
O. Kolaware [I]

Coring Coordination .... J. Bak [M]
C. Cinquegrana

Half Cell Potential Testing .... J. Fera [R]
S. Quintin

Chloride Sampling .... S. Quintin

Chloride Sample Testing .... J. Walsh [R]
C. Corrente [R]
S. Quintin

Cutting of Permeability Specimens .... I. Frament [R]
A. Ringgold [R]

Permeability Testing .... M. Byrne [M]
S. Quintin

Chloride Results Analysis .... J. Walsh

Report Review .... C. Franco [R]
F. Manning [R]
J. Lima [R]
J. Walsh

I would like to acknowledge the assistance of Joseph Boardman and Richard Snow of RIDOT Bridge Maintenance and Bridge Engineering, respectively, in determining which bridges had a LMC overlay and details such as the ages of the overlays. I would also like to acknowledge the assistance of the Construction Section and the Maintenance Division for providing additional traffic control when required.

Key: [I] - RIDOT summer intern, [M] - RIDOT Materials Section, [R] - RIDOT Research and Technology Development

APPENDIX A - MIX DESIGNS

The following mix designs are typical of those used for Rhode Island Department of Transportation bridge construction projects ten to twenty years ago (the LMC mix design was also used for the overlay on bridge no. 800):

MIX - LATEX MODIFIED CONCRETE OVERLAY

COMPONENT	QUANTITY
Cement	658 lbs./cy
Coarse Aggregate ($^3/_8$ in.)	1120 lbs./cy
Fine Aggregate	1584 lbs./cy
Water	157 lbs./cy
Latex (50% water by weight)	24.5 gal/cy (205.8 lbs./cy)
Air Content	4 -7 %
Slump	3-7 in.
Compressive Strength (28 day)	3500 psi

MIX - CLASS AA (AE) FOR BRIDGE DECKS

COMPONENT	QUANTITY
Cement	564 lbs./cy
Coarse Aggregate (1 $^3/_8$ in.)	1963 lbs./cy
Fine Aggregate	1032 lbs./cy
Water	300 lbs./cy
Air Content	4.5 + 1 %
Slump	1-2 in.
Compressive Strength (28 day)	3000 psi

The following mix designs were used on bridge no. 925:

MIX - CLASS XX (AE) FOR BRIDGE DECKS

COMPONENT	QUANTITY
Cement	658 lbs./cy
Coarse Aggregate ($^3/_4$ in.)	1700 lbs./cy
Fine Aggregate	1250 lbs./cy
Water	289 lbs./cy
Air Content	6.0% ±1
Slump	1-3 in.
Compressive Strength (28 day)	4000 psi

MIX - MICROSILICA MODIFIED OVERLAY

COMPONENT	QUANTITY
Cement	611 lbs./cy
Microsilica	40 lbs./cy
Coarse aggregate ($^1/_2$ in. max)	1400 lbs./cy
Fine aggregate	1600 lbs./cy
Polyfiber	2 lbs./cy
Water	259.9 lbs./cy
Air content	4-7%
Slump	4-8 in.
Compressive Strength (28 day)	5000 psi

The following is a typical mix used for bridge no. 800:

MIX - 5085D (BRIDGE DECK)

COMPONENT	QUANTITY
Cement	705 lbs./cy
$^3/_4$ inch blend	1078 lbs./cy
$^1/_2$ inch blend	718 lbs./cy
Sand	1086 lbs./cy
Water	268 lbs./cy
Air content	5-7%
Slump	2-4 in.
Compressive Strength (28 day)	5000 psi