INTERIM REPORT

EVALUATION OF THE INSTALLATION AND INITIAL CONDITION OF LATEX-MODIFIED AND SILICA FUME CONCRETE OVERLAYS PLACED ON SIX BRIDGES IN VIRGINIA

MICHAEL M. SPRINKEL
Research Manager

CRISTOPHER MOEN
Graduate Research Assistant

V·I·R·G·I·N·I·A
VTRC
TRANSPORTATION RESEARCH COUNCIL

VIRGINIA TRANSPORTATION RESEARCH COUNCIL

Standard Title Page - Report on Federally Funded Project

1. Report No. VTRC 99-IR2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Interim Report: Evaluation of the Installation and Initial Condition of Latex-Modified and Silica Fume Concrete Overlays Placed on Six Bridges in Virginia		5. Report Date March 1999 6. Performing Organization Code
7. Author(s) Michael M. Sprinkel and Christopher Moen		8. Performing Organization Report No.
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. 00021549
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	FHWA 1504 Santa Rosa Road Richmond, VA 23239	13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Latex-modified and silica fume concrete overlays were placed on six bridges on I-95 south of Emporia, Virginia, in the fall of 1994. The construction was funded with 20 percent Virginia Department of Transportation maintenance funds and 80 percent special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial condition of the overlays and to prepare this report.

17 Key Words	18. Distribution Statement
overlay, concrete, bridge, latex, silica fume	No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	51	

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

INTERIM REPORT

EVALUATION OF THE INSTALLATION AND INITIAL CONDITION OF LATEX-MODIFIED AND SILICA FUME CONCRETE OVERLAYS PLACED ON SIX BRIDGES IN VIRGINIA

Michael Sprinkel
Research Manager

Cristopher Moen
Research Assistant

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

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

March 1999
VTRC 99-IR2

1.0 Project Introduction

1.1 Summary

Latex-modified and silica fume (SF) concrete overlays were placed on six bridges on I-95 south of Emporia, Virginia, in the fall of 1994. The construction was funded with 20 percent Virginia Department of Transportation maintenance funds and 80 percent special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial condition of the overlays and to prepare this report.

The overlays placed on the six bridges were modified by weight of cementitious material as follows:

- 7 percent SF, Bridges 1 and 4
- 10 percent methylmethacrylate LMC (MMLMC), Bridge 2
- 10 percent microlite (ML), Bridge 5
- 15 styrene butadiene LMC, Bridges 3 and 6

High early strength was achieved by:

- substituting Type III for Type II cement for the latex-modified overlay placed on Bridge 3
- increasing the cement content for the latex-modified overlay placed on Bridge 3
- increasing the Type II cement content for the SF concrete overlay placed on Bridge 4.

A site location map for the six bridges is shown in Figure 1.1. Initially, the outside shoulder and travel lane of each bridge were overlayed while traffic used the inside lane. Then, traffic was placed on the outside lane of each bridge while the inside lane and shoulder were overlayed.

1.2 Objective

The objective of this research is to evaluate bridge deck overlays placed using ISTEA Section 6005 funds.

1.3 Methodology

The objective is to be accomplished by completing the following seven tasks with regard to the outside shoulder and travel lane of the six bridges:

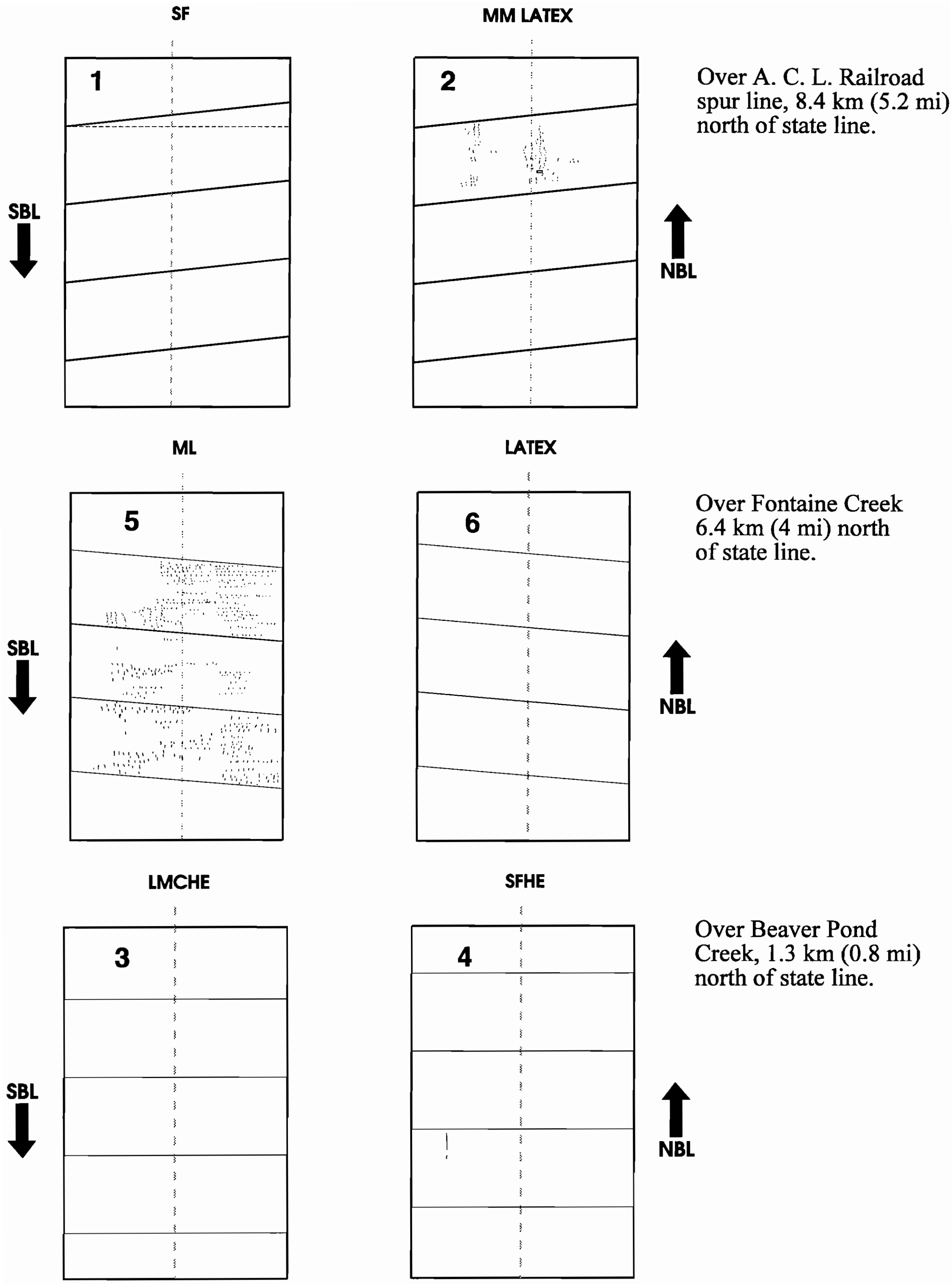


Figure 1.1 Site location map, I-95, 1.3 to 8.4 km (0.8 to 5.2 mi) north of the Virginia, North Carolina state line.

- *Task 1.* Evaluate conditions of each deck prior to placement of the overlays.
- *Task 2.* Document the specifications used for each installation.
- *Task 3.* Document the installation of each overlay.
- *Task 4.* Evaluate the initial condition of each overlay.
- *Task 5.* Evaluate the condition of each overlay annually.
- *Task 6.* Evaluate the final condition of each overlay in 1999.
- *Task 7.* Prepare and submit a draft and final report to FHWA covering Tasks 1 through 7. The report is to include an estimate of the service life and cost-effectiveness of each installation.

This report covers Tasks 1 through 4. When available, information obtained for the inside shoulder and paving lane is presented and included in the evaluation. The mixture planned for Bridge 2 was used only on the outside shoulder and travel lane of the approach slab and Spans 1 and 2 and, therefore, evaluations of the mixture were based on tests done on Spans 1 and 2.

2.0 Evaluation of Conditions Prior to Installation

2.1 Electrical Half-Cell Potentials (ASTM C876)

Electrical half-cell potential measurements (ASTM C876) were taken on a 1.2-meter grid over the outside shoulder and travel lane prior to placement of the overlays (Figure 2.1). The electrical half-cell potential data (Table 2.1) show that there is a 90 percent or greater probability that corrosion is occurring in a small percentage of the decks of Bridges 1 and 5. On the majority of the deck area of all six bridges, there is a 90 percent or greater probability that corrosion is not occurring.

Figure 2.1. Measuring electrical half-cell potentials, *foreground,* and taking chloride ion content samples, *background.*

Bridge No.	Half-Cell Potential Range, -VCSE		
	<0.20	0.2-0.35	>0.35
1	44	50	6
2	97	3	0
3	88	12	0
4	73	27	0
5	55	43	2
6	84	16	0

Table 2.1. Electrical half-cell potentials for outside lane and shoulder prior to overlay application (ASTM C876), percent. Values for each bridge are averages of three spans.

2.2 Chloride Ion Content Profiles

Chloride ion content samples were taken at five depths on each of the six bridges at the following locations:

- center of the outside shoulder (of Span 1)
- center of the right wheel path of travel lane (of Span 2)
- center of the outside travel lane (of Span 3).

All samples were taken at midspan. The chloride ion content data (Table 2.2) show that Bridges 1 and 5 have sufficient chloride ion at the top mat level of steel to cause corrosion (0.77 kg/m^3). The chloride ion data support the electrical half-cell potential data.

Depth of Samples from Surface, cm	Chloride Ion Content, kg/m^3					
	Bridge No.					
	1	2	3	4	5	6
0.64-1.27	1.31	1.14	0.66	0.47	0.72	1.04
1.27-2.54	1.45	0.70	0.48	0.39	0.83	0.78
2.54-3.81	1.43	0.51	0.37	0.28	0.87	0.65
3.81-5.08	1.63	0.42	0.31	0.19	0.74	0.49
11.43-12.70	0.55	0.04	0.26	0.07	0.34	0.05

Table 2.2. Chloride ion content data. Values are the average of three samples; one taken in the center of the shoulder of Span 1, one taken in the right wheel path of Span 2, and one taken in the center of the outside lane of Span 3. All three samples were taken at midspan.

2.3 Map of Cracks and Patches

All six bridge decks were covered with epoxy overlays, and, thus, no cracks or patches were visible. The condition of the EP5 modified epoxy concrete overlay on Bridge 2 was excellent. The epoxy and sand Class I waterproofing on the other bridges was in very poor condition. The waterproofing on the bridges was worn away over much of the traveled surface but in place over most of the shoulder areas.

2.4 Permeability to Chloride Ion (AASHTO T277)

Cores 102 mm in diameter and approximately 127 mm long were taken for chloride ion permeability tests (AASHTO T277). Three cores were taken from the following locations on each bridge:

- the center of the outside shoulder of Span 1
- the right wheel path of the outside travel lane of Span 2
- the center of the outside travel lane of Span 3.

All three samples were taken at midspan. The top 5.1 cm (2 in) (surface) and the next 5.1 cm (2 in) (base) were tested, and the results are reported in Table 2.3. The data (base value) show that the concrete in all six decks has a high permeability (>4000 coulombs). The values for the top 5.1 cm (2 in) (surface) of the cores are lower because the decks were covered with epoxy overlays in various conditions. The epoxy overlay on Bridge 2 was a modified EP5 in excellent condition and, therefore, the permeability values are negligible (<100 coulombs). The epoxy overlays on the other five bridges were old Class I waterproofing and were worn through in many places. The permeability values for the five bridges were in the very low (100-1000 coulombs) to low (1000-2000 coulombs) range.

Bridge No.	Location	Permeability, coulombs			
		Span 1	Span 2	Span 3	Avg.
1	Surface	1803.6	1557.2	338.4	1233.1
	Base	6050.7	10654.2	12848.4	9851.1
2	Surface	85.5	9.9	9.0	34.8
	Base	7124.4	8608.5	9982.8	8571.9
3	Surface	1584.9	1407.6	689.4	1227.3
	Base	6457.5	4251.6	4887.9	5199.0
4	Surface	1266.3	1073.5	651.6	997.1
	Base	11127.6	7816.5	12780.0	10574.7
5	Surface	1286.1	1566.0	984.6	1278.9
	Base	8700.3	5573.7	7000.2	7091.4
6	Surface	1122.3	1434.6	568.8	1041.9
	Base	7431.3	7077.6	9499.5	8002.8

Table 2.3. Pre-installation permeability readings.

2.5 Preinstallation Photographic Record

Color slides were used to provide a photographic record of the condition of the outside travel lane and shoulder of the decks prior to placement of the overlays. A scan of one slide taken of five of the six bridge decks is shown in Figures 2.2 through 2.6. No pictures of Bridge 5 were taken, but the deck surface condition was similar to that of Bridge 6.

Figure 2.2. Bridge 1 prior to overlay placement. The surface has been milled.

Figure 2.3. Bridge 2 prior to overlay placement. The modified EP5 epoxy overlay is in excellent condition.

Figure 2.4. Bridge 3 prior to overlay placement.

Figure 2.5. Bridge 4 prior to overlay placement. The wet spots are locations where half-cell potential measurements were taken.

Figure 2.6. Bridge 6 prior to overlay placement. The Class I waterproofing was worn off much of the travel lane.

3.0 Specifications for Installation

3.1 Site Preparation and Preoverlay Repairs

Traffic control devices and concrete barricades were installed to divert traffic to the inside lane prior to preparation of the surface of the outside lane of each bridge.

Approach slabs and decks were milled to remove the epoxy overlays and the top 13 mm (0.5 in) of the concrete (see Figure 3.1). The milled surface was chain dragged to identify delaminated areas. Concrete was removed to one half the deck thickness at three locations on Bridge 1 because a chain drag of the milled surface identified delaminations. The total area of concrete removed for patching on Bridge 1 was approximately 1.67 m^2 (2 yd^2). Concrete was removed in an area approximately one half the deck thickness by 15 cm (6 in) wide along each side of the joints on all six bridges.

Figure 3.1. Milling machine removing the top 13 mm (0.5 in) of Bridge 4.

3.2 Surface Preparation

Milled surfaces were shotblasted within 24 hours of the overlay placement to remove contaminants and open the pours in the concrete surface. Surfaces were wetted and covered with polyethylene sheeting following the shotblasting operation to achieve a saturated surface dry condition.

3.3 Overlay Technology

Table 3.1 shows the structure number and installation dates for the six overlay types.

Project Bridge No.	Structure No.	Overlay Type	Date Overlay Applied	
			OL	IL
1R*	2000	SF	9/15/94- 9/16/94	N/A
1	2000	SF	9/28/94	10/26/94
2**	2005	MMLMC	9/21/94	10/19/94
3	2003	LMC High Early Strength (LMCHE)	10/5/94	10/13/94
4	2002	Silica Fume High Early (SFHE)	10/4/94	10/12/94
5	2004	ML	9/20/94	10/21/94
6	2001	Styrene Butadiene LMC	9/27/94	10/18/94

*The first overlay placed on Bridge 1 was removed because it developed many full-depth plastic shrinkage cracks that appeared to be initiated as screed tares.
**Third span of outside lane is ML; inside lane is LMC.

Table 3.1. Overlay technology description.

3.4 Overlay Design Thickness

All overlays were designed to have a thickness of 30 mm (1.25 in) or greater.

3.5 Overlay Design Life

All overlays were designed to have a service life of 20 years or more.

3.6 Design Mixture Proportions

Table 3.2 shows the design mixture proportions for the six overlays.

Material	Bridge No.					
	1, 1R	2	3	4	5	6
Cement, kg/m^3	361	390	446	389	361	390
SF, kg/m^3	30	0	0	30	56*	0
Latex, kg/m^3	0	87	122	0	0	134
CA, kg/m^3	873	869	705	873	831	726
FA, kg/m^3	883	869	873	831	800	924
Water, kg/m^3	156	97	96	168	156	86
AE Admixture, mL/m^3	232-348	0	0	271-387	271-387	0
Retarder, mL/m^3	706-1176	0	0	760-1267	706-1176	0
Air, %	6±2	5	5	6±2	6	5
Slump, cm	10-18	10-15	10-15	10-18	10-18	10-15
w/c**	0.40	0.37	0.36	0.40	0.40	0.40

*ML (56 kg/m^3 contains 30kg/m^3 of SF).
**Water-cementitious material ratio.

Table 3.2. Design mixture proportions.

3.7 Aggregate Gradation Specification

Table 3.3 shows the design aggregate gradation specification.

Type of Aggregate	Sieve Analysis of Aggregates									
	19 mm (3/4 in)	13 mm (1/2 in)	10 mm (3/8 in)	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
CA-No.78	Min. 100	95 ± 5	60 ± 20	Max. 20	Max. 8	Max. 5	-	-	-	-
FA-Grading A	-	-	Min. 100	97± 3	90 ±10	67 ±18	42 ±17	17± 9	Max. 10	-

Table 3.3. Design sieve analysis for aggregates (Virginia Department of Transportation, *Road and Bridge Specifications,* January 1994).

3.8 Characteristics of Ingredients

Table 3.4 shows other characteristics of the concrete ingredients.

Material	Type	Source	SG	Absorption	F.M.
Cement	Type II	Blue Circle	3.15	-----	-----
SF	-----	W.R. Grace	2.20	-----	-----
ML	SF	Master Builders	0.45	-----	-----
CA	No.78 Stone	Vulcan Materials	2.72	0.40	-----
FA	Sand	Glover Materials	2.64	0.50	2.74
Latex	Styrene Butadiene	Dow Chemical	1.01	-----	-----
Latex	Methylmethacrylate	Dow Chemical	1.10	-----	-----
AE Admixture	Daravair	W.R. Grace	1.07	-----	-----
Retarder	Daratard	W.R. Grace	1.22	-----	-----

*Type III cement was used for the LMCHE overlay placed on Bridge 3.

Table 3.4. Overlay concrete ingredient characteristics.

3.9 Curing Method and Time

Table 3.5 shows curing methods and time.

Overlay Type	Description of Curing Method and Time
SF, MMLMC, ML	Wet burlap and white plastic sheeting for 3 days followed by liquid membrane curing compound
SFHE	Wet burlap and white plastic sheeting for 20 hours followed by liquid membrane curing compound
SBLMC	Wet burlap and white plastic sheeting for 48 hours
LMCHE	Wet burlap and white plastic sheeting for 24 hours

Table 3.5. Overlay curing methods and times.

3.10 Bond Strength (VTM-92)

The specification for the overlays did not require this test.

3.11 Compressive Strength (ASTM C39)

The minimum laboratory design compressive strength at 28 days for the overlays placed for the project were:

- 24.1 MPa (3500 psi) for the LMC placed on Bridges 2, 3, and 6
- 34.5 MPa (5000 psi) for the SF concrete placed on Bridges 1, 4, and 5.

The minimum laboratory design compressive strength at 24 hours was 20.7 MPa (3000 psi) for the high-early-strength overlays on Bridges 3 and 4.

3.12 Grout

For each bridge, the mortar fraction of the overlay concrete was first broomed into the prepared substrate. The coarse aggregate was discarded. A separate grout was not used.

4.0 Results of Quality Assurance Testing

4.1 Mixture Proportions

Table 4.1 shows the mixture proportions used. Characteristics of ingredients are provided in Sections 3.7 and 3.8 of this report.

Material	Bridge No.						
	1R	1	2*	3**	4	5	6**
Cement, kg/m^3	361	361	390	446	389	361	390
SF, kg/m^3	30	30	0	0	30	56***	0
Latex, kg/m^3	0	0	87	122	0	0	134
CA, kg/m^3	873	873	705	705	873	831	726
FA, kg/m^3	883	883	873	873	831	799	924
Water, kg/m^3	151	151	97	97	163	151	86
AE Admixture, mL/m^3	155	135	0	0	155	139	0
Retarder, mL/m^3	1276	1276	0	0	1361	1276	0
Air, %	4.6-7.5	6.0-13.2	3.8 -15.0+	4.0-8.2	5.5-7.8	3.0 -6.8	4.1-8.0
Slump, cm	6-21	13-18	17-19	10-17	11-15	10-18	13-20
w/c****	0.39	0.39	0.37	0.36	0.39	0.36	0.40

*Span 3 of outside lane received the same mixture used on Bridge 5, and the inside lane received the mixture used on Bridge 6.
**For mobile mixed concrete, the design mixture proportions are used because the mixer is calibrated based on those proportions
***ML (56 kg/m^3 contains 30kg/m^3 of SF).
****Water-cementitious material ratio.

Table 4.1. Overlay mixture proportions.

4.2 Aggregate Moisture Content

Table 4.2 shows the moisture content of the aggregates.

Material	Bridge No.													
	1R		1		2		3*		4		5		6*	
	OL	IL	OL	IL	OL	IL	OL	IL	OL	IL	OL	IL	OL	IL
Coarse Aggregate (No. 78 Stone)	0.47	N/A	0.41	0.8	1.0	1.0	1.0	1.0	0.47	0.2	0.4	0.7	1.0	1.0
Fine Aggregate (Sand)	2.9	N/A	5.2	3.5	5.0	5.0	5.0	5.0	4.3	3.3	3.1	3.6	5.0	5.0

* Approximate aggregate moisture content obtained from mobile mixer calibration sheets.

Table 4.2. Fine and coarse aggregate moisture contents.

4.3 Comparison of Actual Mixture Properties to Design Specifications

A comparison of the data in Tables 3.2 and 4.1 shows that, in general, the design mixture proportions were used. In some cases, the aggregate batch weights were slightly different than the design weights, the amount of water used was less than the maximum, and the admixture dosages were different from the design ranges. The mixtures satisfied the specification.

4.4 Summary of Placement Conditions

Table 4.3 is a summary of the placement conditions. It is generally accepted that plastic shrinkage cracking is likely in overlays when the evaporation rate exceeds 0.5 $kg/m^2/h$. Cracking occurred in overlays 1R, Span 3 of Bridge 2, and Bridge 5. Evaporation rates were less than 0.5 $kg/m^2/h$ in all three cases. Based on the data, there is no relationship between rate of evaporation and cracking.

4.5 Coefficients of Thermal Expansion of Deck and Overlay Concrete

Following the completion of drying shrinkage measurements described in Section 4.6, the coefficient of thermal expansion for each of the overlay concretes was determined (Table 4.4). Four of the six specimens used for length change measurement over a 32-week drying period were used to determine the coefficients. The values were obtained from measurements of four specimens of concrete placed on the outside lane of each bridge deck. The specimens were stored overnight in a temperature-controlled chamber, and the length of the specimens and temperature of the chamber were recorded. The coefficients of thermal expansion are based on measurements made at 0°C and 38°C. The highest coefficients were recorded for the mixtures that contained latex. The highest value of 21.2×10^{-6} per °C was for the LMCHE mixture used on Bridge 3. The combination of latex and additional cement is believed to have caused the higher value.

The coefficient for the deck concrete was not measured. Earlier work indicates that a value of 10.3×10^{-6} mm/mm/°C is typical of deck concrete in Virginia.[1]

Assuming 40°C temperature change and a modulus of elasticity of 28.9 GPa for the concretes, theoretical shear stresses at the bond interface would range from 2.3 MPa (330 psi) for Bridge 5 to 6.3 MPa (920 psi) for Bridge 3.[1]

Based on these stresses the overlays could delaminate because of thermal stress at times of extremely low temperatures. Thermal failures rarely occur because of creep and shrinkage and because the overlay is in tension relative to the base.

Bridge No.	Lane	Climatic Conditions	Rate of Evaporation, $kg/m^2/h$	Concrete Temp., °C	Air Temp., °C	Relative Humidity, %	Avg. Wind Speed, km/h
1R	OL	night; cool, humid	0.12	26-29	17-29	62-98	N/A
	IL	N/A	N/A	N/A	N/A	N/A	N/A
1	OL	night; cool, humid	0.12	21-26	16-18	90-98	0.0
	IL	day; cloudy, light drizzle	0.19	16-18	10-17	77-100	6.5
2	OL	evening; drizzle to hard rain	0.19	26	17	N/A	1.2
	IL	morning; cool, humid	0.06	20	10-15	87-95	2.3
3	OL	morning; cool, dry	0.19	16-24	8-29	27-90	4.4
	IL	morning; cool	0.06	19-20	18-27	83	1.1
4	OL	morning; cool, humid	0.12	18-24	10-19	60-92	1.9
	IL	morning; cool	0.19	17-24	14-20	68-78	1.3
5	OL	night; cool, humid	0.12	22-26	10-13	96-99	0.0
	IL	morning; cool	0.12	21-24	14-23	79-87	1.6
6	OL	morning; cool, humid	0.12	25-26	18-19	95-99	1.6
	IL	morning; cool	0.21	14-18	10-22	76-81	4.0

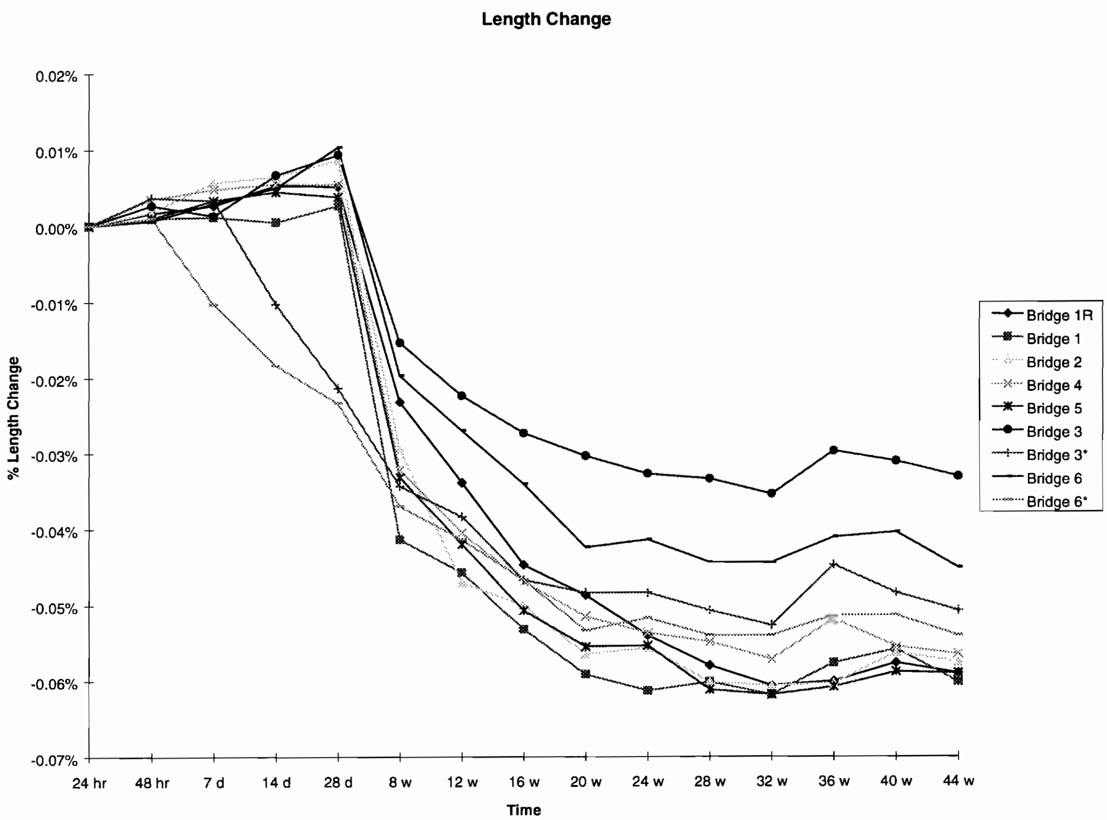
Table 4.3. Summary of placement conditions.

Bridge No.	mm/mm/°C x 10^{-6}
1R	16.7
1	15.3
2	17.7
3	21.2
4	15.6
5	14.2
6	18.3

Table 4.4. Coefficients of thermal expansion of overlay concrete.

4.6 Drying Shrinkage of Overlay Concrete

Three length change specimens were prepared from each of two samples of concrete taken during the overlay placements on the outside lane of each of the six bridges. The specimens were cured next to the bridges for approximately 20 hours, transported to the laboratory over the next 3 hours, and removed from their molds between 23 and 24 hours of age. The initial length was measured at 24 hours of age, and the specimens were placed in a moist curing room. With the exception of three specimens from Bridge 3 that were moist cured for 7 days and three from Bridge 6 that were moist cured for 48 hours, the specimens were moist cured for 28 days. Once the moist curing period was complete, specimens were moved to the laboratory and stored on racks at approximately 50 percent relative humidity. The length as a function of age is plotted in Figure 4.1. The LMCs with the 7-day and 48-hour moist curing period exhibited greater shrinkage at early age than the other concretes. This greater shrinkage was caused because the beams were allowed to dry sooner. At later ages, their shrinkage was slightly less than but not significantly different from that of the SF concretes. This can be attributed to the insignificant differences between the water-to-cementitious materials ratios for the latex-modified and SF concretes. The LMCs that were moist cured for 28 days exhibited significantly lower shrinkage than the other concretes. All of the LMCs exhibited less shrinkage after 32 weeks of drying than the SF concretes, suggesting that SF concrete is slightly more prone to cracking than LMC.



Bridge 3, 28-day moist cure set, Bridge 3*, 7-day moist cure set; Bridge 6, 28-day moist cure set, Bridge 6**, 48-hour moist cure set.

Figure 4.1. Graph of length change versus age of concrete.

4.7 Compressive Strength, MPa

Table 4.5 shows the compressive strength of the overlay concretes. The ML, MMLMC, and LMCHE concretes had the highest strengths at 24 hours of age. The LMC had significantly lower strengths at 28 days of age. The 24-hour strengths for the inside lane were generally lower than for the outside lane because of lower curing temperatures at the site.

Bridge No.	Overlay Type	24 hours		7 days		28 days		1 year
		OL	IL	OL	IL	OL	IL	OL
1R	SF	21.5	N/A	32.1	N/A	42.1	N/A	48.7
1	SF	23.5	5.8	37.3	N/A	48.9	51.44	55.4
2	MMLMC*	28.2	15.0	43.2	N/A	50.1	35.02	57.5
3	LMCHE	28.0	25.8	38.8	N/A	45.8	50.44	55.4
4	SFHE	18.2	17.8	40.5	N/A	57.1	50.58	64.3
5	ML	29.0	N/A	44.1	42.71	55.1	60.8	63.7
6	LMC	16.9	11.4	23.2	N/A	30.0	31.19	40.3

*ML used in Span 3 of outside lane, LMC used in inside lane.

Table 4.5. Compressive strength based on average of three specimens from each of two batches.

4.8 Shear Bond Strength

Table 4.6 shows the guillotine shear bond strength test results for specimens prepared at the job site during the placement of the concretes in the outside lane. The base concretes were sawn slices 5 cm (2 in) thick of the typical A4 bridge deck concrete batched in the laboratory. The slices were placed in the bottom of molds 102 mm high and overlaid with concrete at the bridge site. The results show the bond strength potential of the overlay concretes. For the ideal surface conditions used in this test, the values tend to be proportional to the compressive strength. The bond strength for the LMCHE is low and not representative of the concrete. The 28-day bond strength for the LMC is reasonable considering its lower relative compressive strength, but the 24-hour value is unrealistically high. Other values seem reasonable.

Bridge No.	Time After Placement	Avg. Bond Strength, kPa	Overlay Failure Area, %		
			Base	Bond	OL
1R	24 hr	2880	30	60	10
	28 d	5060	45	50	5
	1 yr	7100	35	35	30
1	24 h	3920	35	60	5
	28 d	5350	40	45	15
	1 yr	6890	20	35	45
2	24 hr	2600	0	55	45
	28 d	3320	5	45	50
	1 yr	3600	10	75	15
3	24 h	2110	5	85	10
	28 d	2200	15	85	0
	1 yr	2580	5	95	0
4	24 h	2760	15	70	15
	28 d	5260	35	55	10
	1 yr	7290	30	45	25
5	24 h	3770	45	45	10
	28 d	5200	45	45	10
	1 yr	7030	35	35	30
6	24 h	3340	20	65	15
	28 d	2910	30	65	5
	1 yr	4660	20	60	20

Table 4.6. Shear bond strength**.** Values are average of two specimens. All specimens are 102 mm (4 in) in diameter.

4.9 Permeability to Chloride Ion (AASHTO T277), Coulombs

Table 4.7 shows the results of tests on specimens of overlay concretes 51 mm thick by 102 mm in diameter. Samples were prepared from two batches (Z and A) for the outside lane and two batches (B and C) for the inside lane. The results are in the low to very low range at 90 days as would be expected for all of the concretes. The SF concretes have lower permeability than the LMCs.

4.10 Susceptibility to Freeze-Thaw Cycles

Table 4.8 shows the results of tests conducted in accordance with ASTM C666-Procedure A modified by the addition of 2% NaCl to the test water. Concrete was tested from the outside lane of each overlay. The best performer was MMLMC, and the worst were ML and LMC. The MMLMC and LMCHE concretes had the lowest weight loss and the least surface scaling. The test is not considered realistic for overlays because LMC overlays over 25 years old have not shown freeze-thaw damage.

Bridge No.	Overlay Type	28 days				90 days		1 year	
		OL		IL		OL		OL	
		Z	A	B	C	Z	A	Z	A
1R	SF	953	1097	N/A	N/A	788	820	986	979
1	SF	1733	1292	2325	2237	1124	1157	1282	1064
2	MMLMC*	1885	1669	1697***	2497***	1687	1357	1361	1130
3	LMCHE	1821	2854*	1889	1324**	1442	1679**	1275	525
4	SFHE	1783	1677	1264	1175	968	887	1059	945
5	ML	1337	1251	1234	1205	860	718	796	666
6	LMC	2536	2287**	2561	2202**	2014	1652**	2062	204

*Accidentally moist cured for 7 days.
**Moist cured for 48 hours.
***Inside lane is LMC.

Table 4.7. Rapid permeability test data. All values are averages of two samples.

Bridge	Weight Loss, %	Durability Factor, %	Surface Scaling
1R	2.3	95	1.3
1	4.1	68	1.8
2	0.9	96	0.6
3	1.0	57	0.7
4	2.7	93	1.3
5	5.3	38	1.7
6	24.1	55	2.6

Table 4.8. Weight loss, durability, and surface scaling performance of overlay concrete.

5.0 Evaluation of Conditions After Installation

5.1 Location of Delaminations

Bridge 2 had 0.093 m^2 (1 ft^2) of delamination. Otherwise, no delaminations were found.

5.2 Skid Tests

The results of the skid tests conducted with a trailer are shown in Table 5.1. The tests were conducted on the outside lane of the overlays. All the overlay concretes achieved acceptable skid resistance. A tined texture was placed on Bridges 3 and 4. Grooves were saw cut into the other overlays.

Bridge No.	Overlay Type	Bald Tire	Treaded Tire
1	SF	46.1	45.3
2	MMLMC	45.1	44.9
3	LMCHE	41.5	41.8
4	SFHE	51.4	51.0
5	ML	38.1	41.3
6	LMC	32.9	31.3

Table 5.1. Skid testing on travel lane.

5.3 Electrical Half-Cell Potential Results

Table 5.2 shows the results of the electrical half-cell potential tests performed prior to placement of the overlays on the outside lane and at 8 to 16 days after placement. All the results except for Bridge 5 were more negative after the overlays are placed. It is believed that this is due to the moisture in the new overlays, which improves conductivity, and to the epoxy on the surface prior to placement of the overlays, which tends to resist current flow.

5.4 Tensile Bond Strength Results

Table 5.3 shows the results of the tensile adhesion tests conducted on the outside travel lane and shoulder in accordance with a modified version of ACI 503A and VTM 92. The modification is that cores are removed from the deck and saw cut in the laboratory to provide a specimen 102 mm high with 51 mm on each side of the bond line, a pipe cap is bonded to both sawn surfaces, and the specimen is subjected to tension using a universal testing machine in the laboratory. The

Bridge No.	Prior to Overlay, -VCSE			After Overlay, -VCSE		
	<0.20	0.2-0.35	>0.35	<0.20	0.2-0.35	>0.35
1	44	50	6	2	81	17
2	97	3	0	44	50	6
3	88	12	0	81	19	0
4	73	27	0	57	43	0
5	55	43	2	80	20	0
6	84	16	0	66	34	0

Table 5.2. Electrical half-cell potentials prior to and after overlay application (ASTM C876), %.

Bridge No.	Overlay Thickness, cm	Bond Strength, kPa	Failure Area, %		
			Overlay	Bond	Base
1	3.41	1049	3	3	94
2	3.73	725	10	7	83
2C*	3.33	414	0	15	85
3	4.17	607	2	0	98
4	4.04	814	0	7	93
5	3.30	918	8	0	92
6	3.76	842	0	2	98

* Span 3 was overlaid with ML.

Table 5.3. Tensile bond strength test results. All cores are 57 mm (2.25 in) in diameter.

bond strengths are very low because the failures are predominately in the base concrete below the bond line. It is believed the failures occurred in the base concrete because of the damage done by the milling machine. The results are not representative of the bond strengths of the six overlay concretes. The overlay may fail prematurely because of the weak base to which they are bonded.

5.5 Permeability Test Results

Table 5.4 shows the results of permeability tests conducted on cores 102 mm in diameter removed from the outside lane and shoulder of the decks at an overlay age of about 8 to 16 days and tested at an age of 6 weeks. Tests were conducted on the top 51 mm (surface) and the next

Bridge No.	Location	Permeability, coulombs			
		Span 1	Span 2	Span 3	Avg.
1	Surface	1082.7	1457.1	703.4	1081.1
	Base	8182.8	14408.1	13662.5	12084.5
2	Surface	3039.3	2027.3	326.7	1797.8
	Base	13601.7	11718.9	9083.7	11468.1
3	Surface	1014.8	1826.6	2152.8	1664.7
	Base	7163.1	5884.2	5982.3	6343.2
4	Surface	707.9	961.7	776.7	815.4
	Base	9677.7	6193.8	10007.1	8626.2
5	Surface	1351.8	1050.8	1231.7	1211.4
	Base	10895.4	7324.2	N/A	9109.8
6	Surface	1261.4	1267.2	1360.4	1296.3
	Base	7182.0	7785.5	N/A	7483.8

Table 5.4. Post-installation rapid permeability test data.

51 mm (base). The results for the surface specimens are in the low to very low range, indicating that all of the overlays are providing good protection. The results for the base concretes are in the very high range, indicating the deck concretes needed a protection system.

5.6 Post-installation Photographic Record

Figures 5.1 and 5.2 show the severe case of plastic shrinkage cracking initiated by screed tares that occurred in the overlay placed on the outside lane of Bridge 1. The overlays on the approach slabs were not cracked, which suggests that a possible explanation for the cracking was the rapid cooling of the hot overlay concrete, which was placed in the evening as temperatures dropped. The concrete in the approach slabs was insulated by the subgrade. Figure 5.3 shows the excellent condition of the SF overlay in the outside lane of Bridge 1 that replaced the cracked overlay. Figure 5.4 shows the relative dark color of Span 3 of Bridge 2. Span 3, which was overlayed with ML, was full of plastic shrinkage cracks, which were later treated with high-molecular-weight methacrylate, causing the darker color. Spans 1 and 2 are in excellent condition. Figures 5.5 and 5.6 show the excellent condition of Bridges 3 and 4, the early-strength concretes that were opened to traffic at 24 hours of age. Figure 5.7 shows the ML overlay of Bridge 5, which was full of plastic shrinkage cracks that were subsequently treated with high-molecular-weight methacrylate. Figure 5.8 shows the excellent condition of the LMC overlay on Bridge 6. Cracking on the decks is illustrated in the next section.

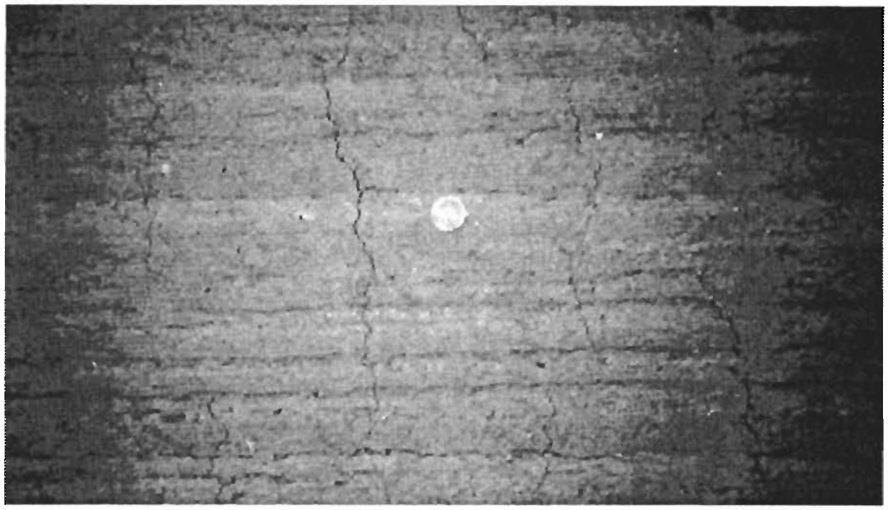


Figure 5.1. Plastic shrinkage cracking in Bridge 1R. The cracks are parallel with the axis of the rotating drums on the screed. The SF overlay was removed.

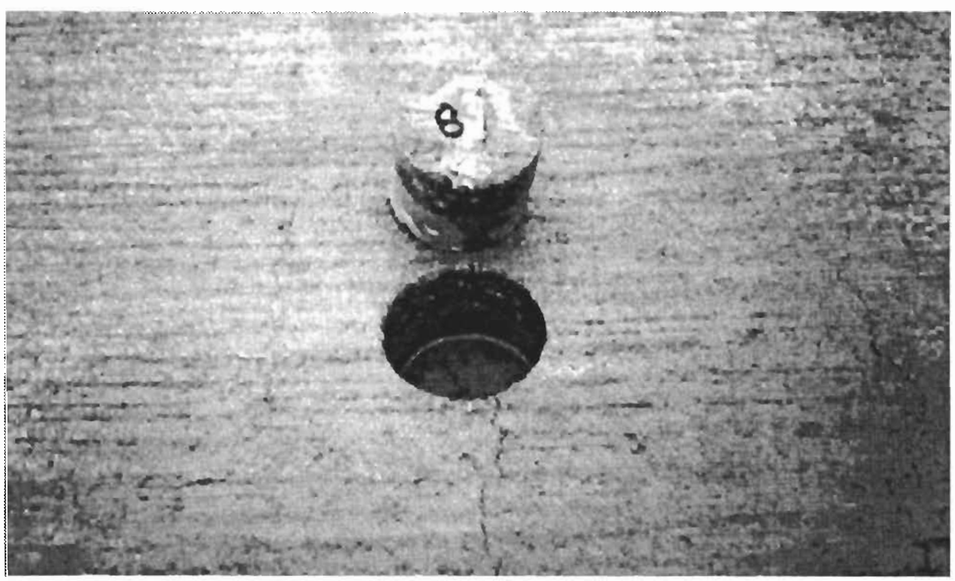


Figure 5.2. Bridge 1R after SF overlay placement. Core shows plastic shrinkage cracks are full depth.

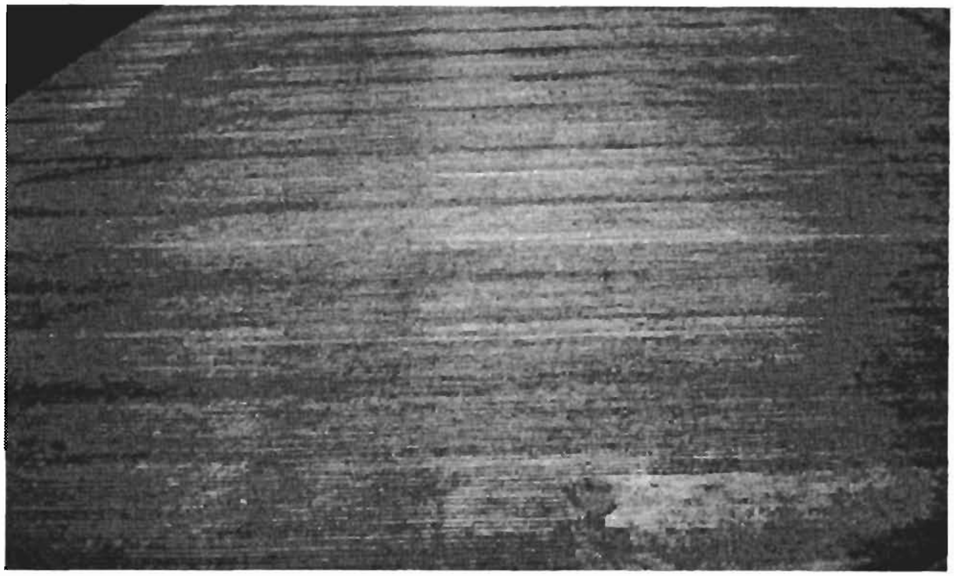


Figure 5.3. Outside lane and shoulder of Bridge 1 after SF overlay placement.

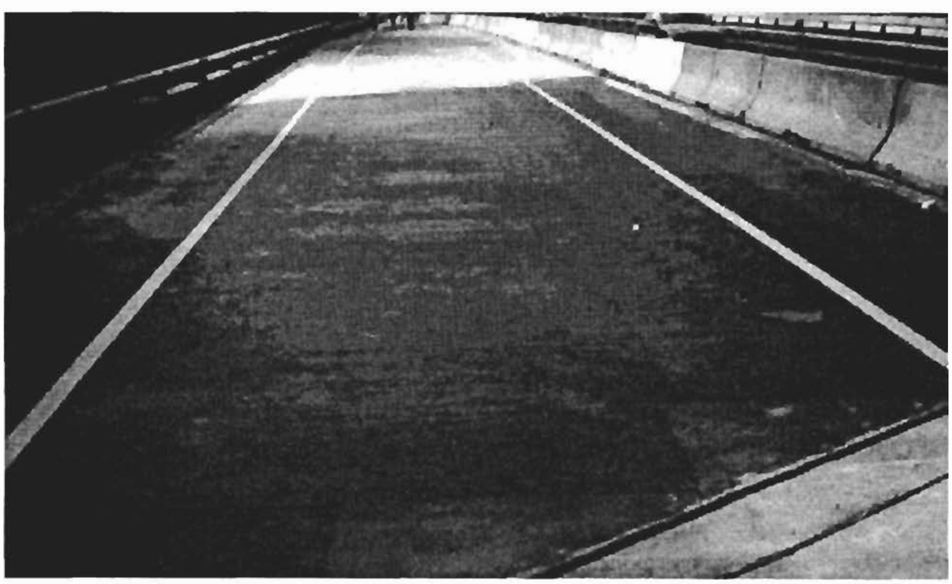


Figure 5.4. Outside lane and shoulder of Bridge 2 after MMLMC and ML overlay placement.

Figure 5.5. Outside lane and shoulder of Bridge 3 after LMCHE overlay placement.

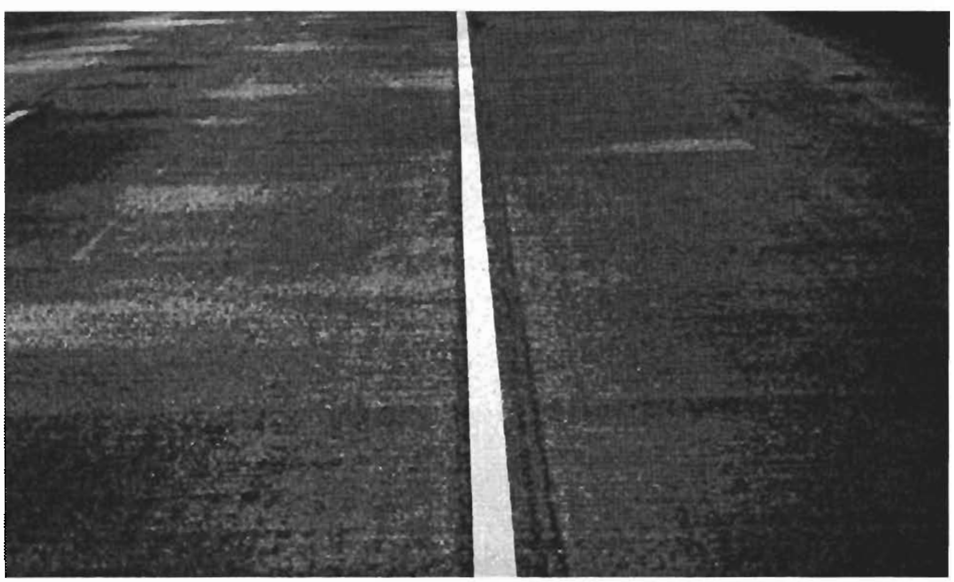


Figure 5.6. Outside lane and shoulder of Bridge 4 after SFHE overlay placement.

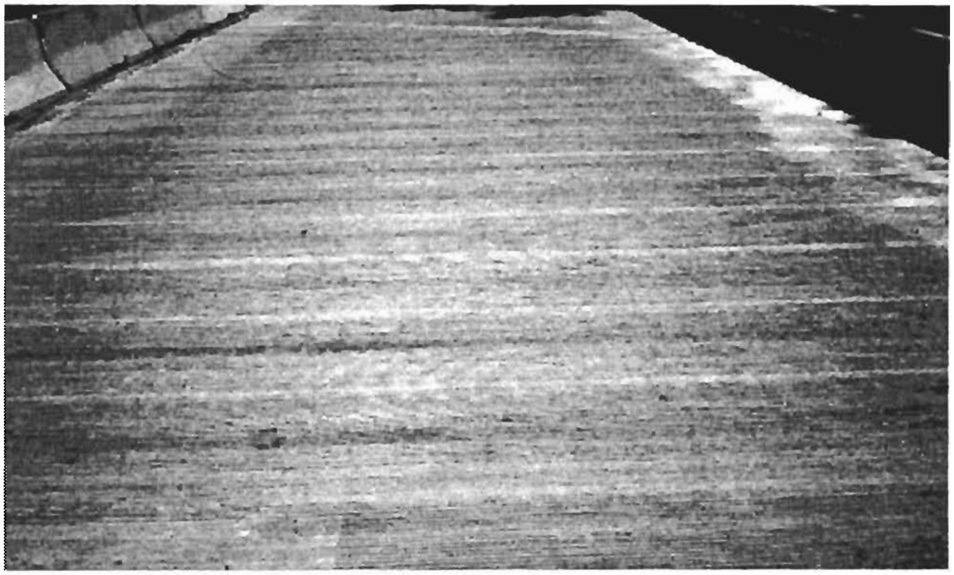


Figure 5.7. Outside lane and shoulder of Bridge 5 after ML overlay placement.

Figure 5.8. Outside lane and shoulder of Bridge 6 after LMC overlay placement.

5.7 Crack, Patch, and Test Location Map

Table 5.5 is a summary of the cracks and patches in the outside lane and shoulder of the six bridge overlays. The overlays on Bridge 1 (1R) were removed because of the plastic shrinkage cracks initiated by screed tares. The overlays on Bridge 5 and Span 3 of Bridge 2 were treated with high-molecular-weight methacrylate to seal the plastic shrinkage cracks. Only the overlays on Bridge 2 had to be patched, and the delaminated area was small. The cracks and patch are shown in Figures 5.9 through 5.15.

	Bridge No.						
	1R	1	2	3	4	5	6
Cracks	numerous plastic shrinkage	none	none*	none	3.7 m (12 ft)	numerous plastic shrinkage	none
Patches	0 m^2	0 m^2	0.093 m^2 (1 ft^2)	0 m^2	0 m^2	0 m^2	0 m^2

*Span 3 with ML had numerous plastic shrinkage cracks.

Table 5.5. Summary of cracks and patches after overlay placements.

5.8 Cost of Overlay

Cost data for the six bridge overlay installations is shown in Table 5.6. The unit costs of the concretes were slightly different because of the costs of the ingredients and the relative difficulties and ease with which the overlays can be constructed. The cost of bridge preparation and traffic control exceeds the cost of the overlays.

Bridge No.	Type of Overlay	Cost of Bridge Preparation and Traffic Control, $	Unit Cost of Concrete, $/$m^3$	m^3 of Concrete Placed	Total Cost, $
1	SF	120,293	850	62*	172,943
2	MMLMC	104,074	850	43**	140,854
3	LMCHE	81,774	948	47	125,999
4	SFHE	75,019	889	44	113,779
5	ML	93,503	900	46	134,783
6	LMC	79,376	850	43	116,101
Total Project Cost					804,459

*15 m^3 included for replaced span.
**19 m^3 MMLMC + 16 m^3 LMC + 8 m^3 ML.

Table 5.6. Cost description of project.

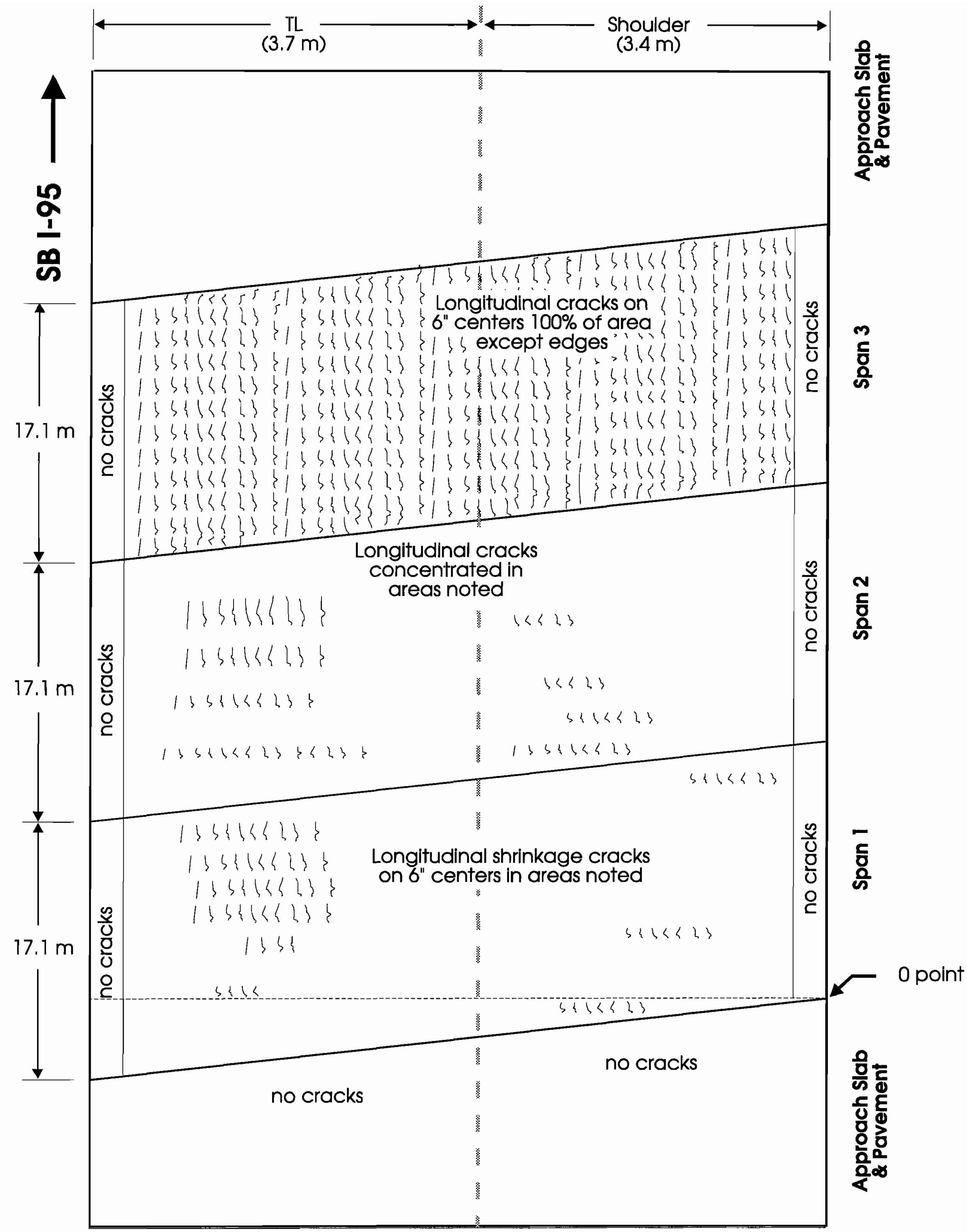


Figure 5.9. Cracks and delaminations in Bridge 1 SBL, TL and shoulder (removed).

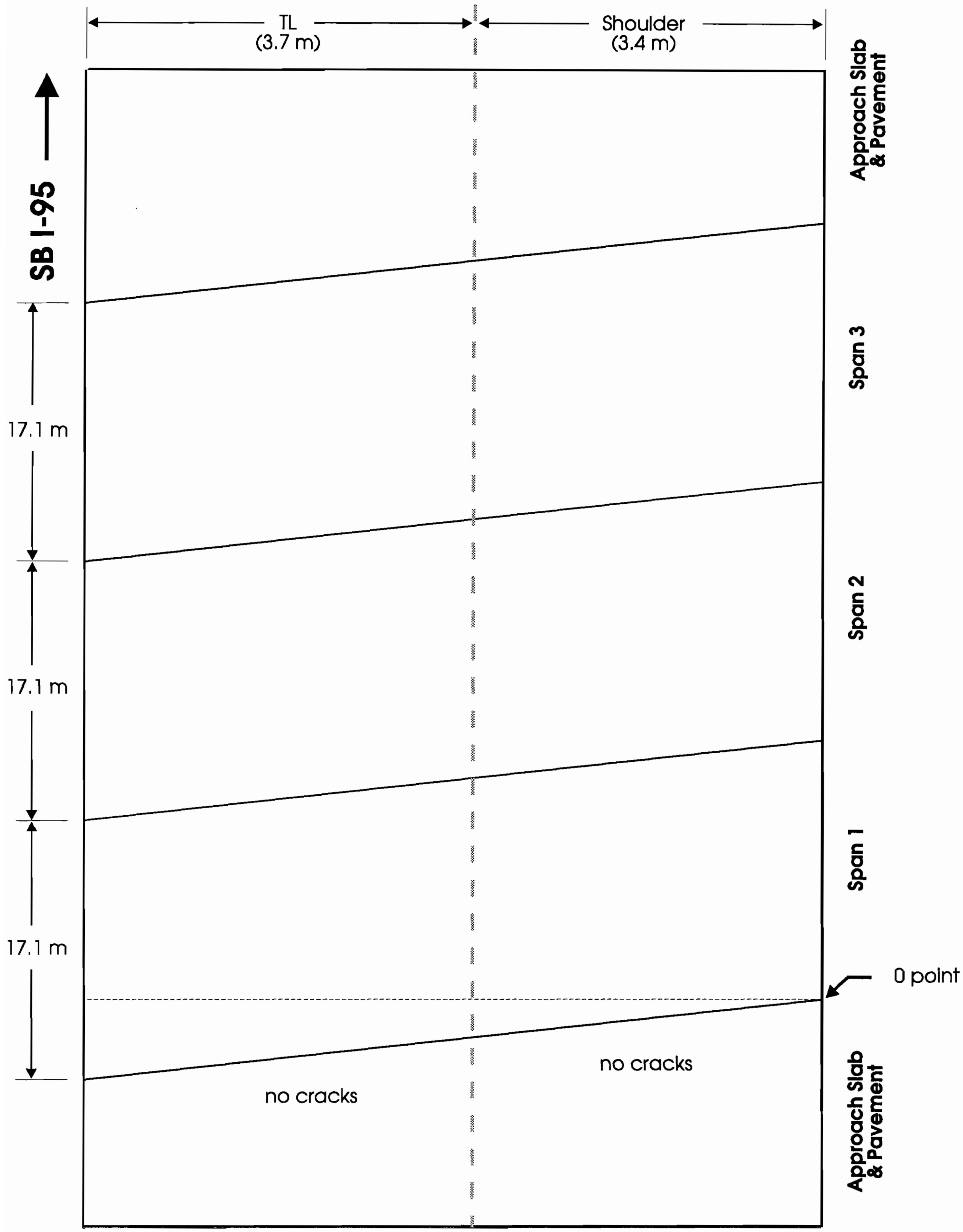


Figure 5.10. Cracks and delaminations in Bridge 1 SBL, TL and shoulder.

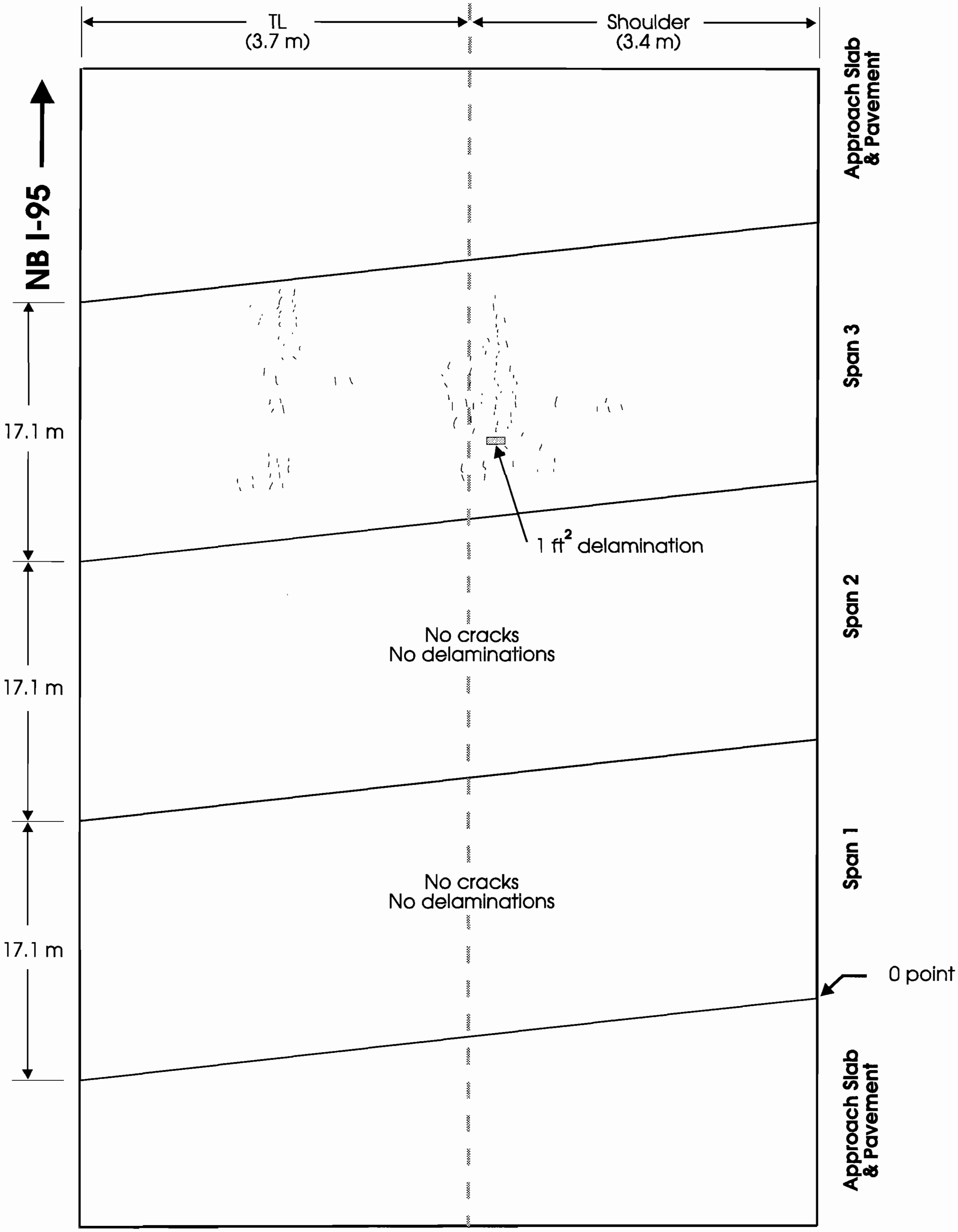


Figure 5.11. Cracks and delaminations in Bridge 2 NBL, TL and shoulder.

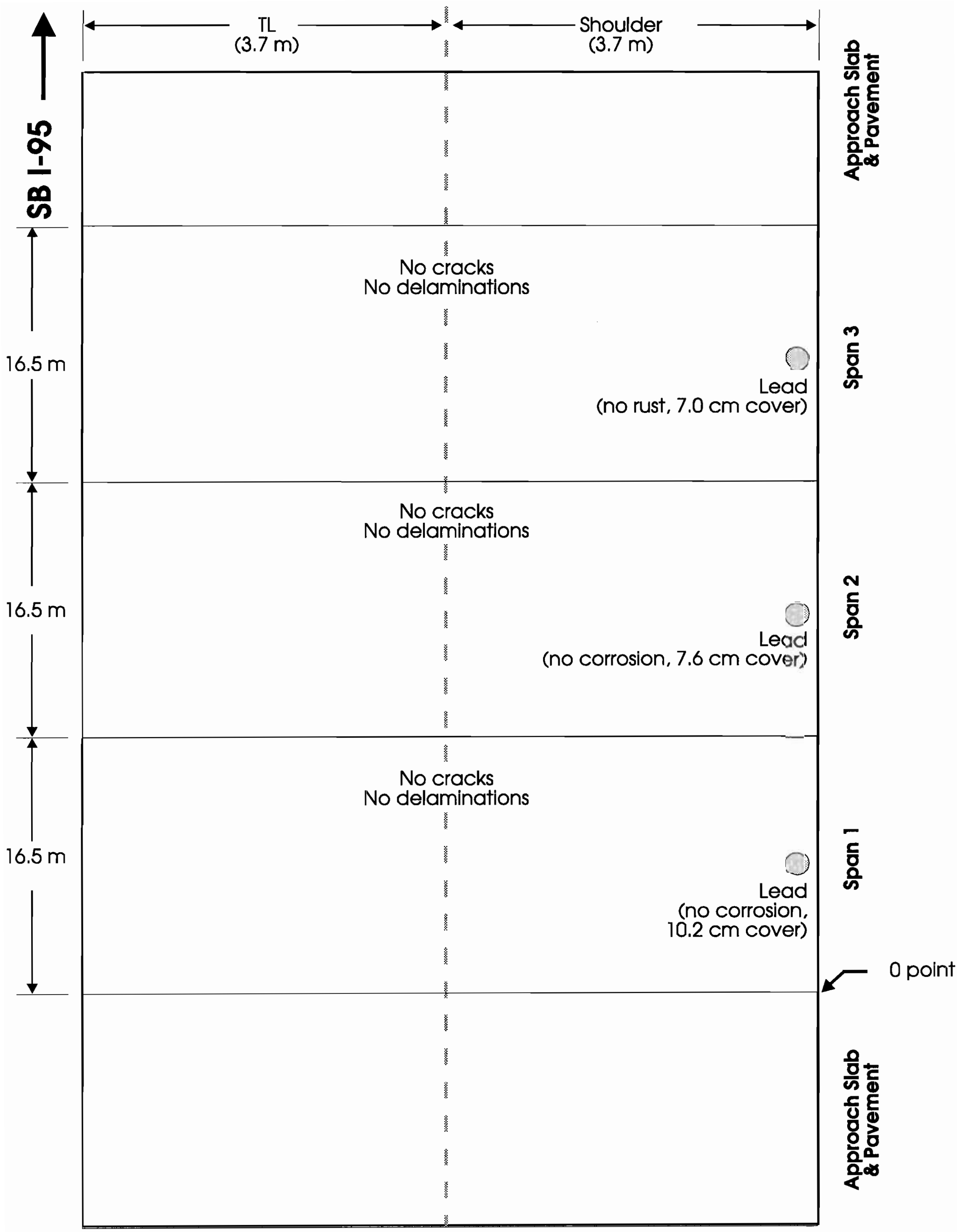


Figure 5.12. Cracks and delaminations in Bridge 3 SBL, TL and shoulder.

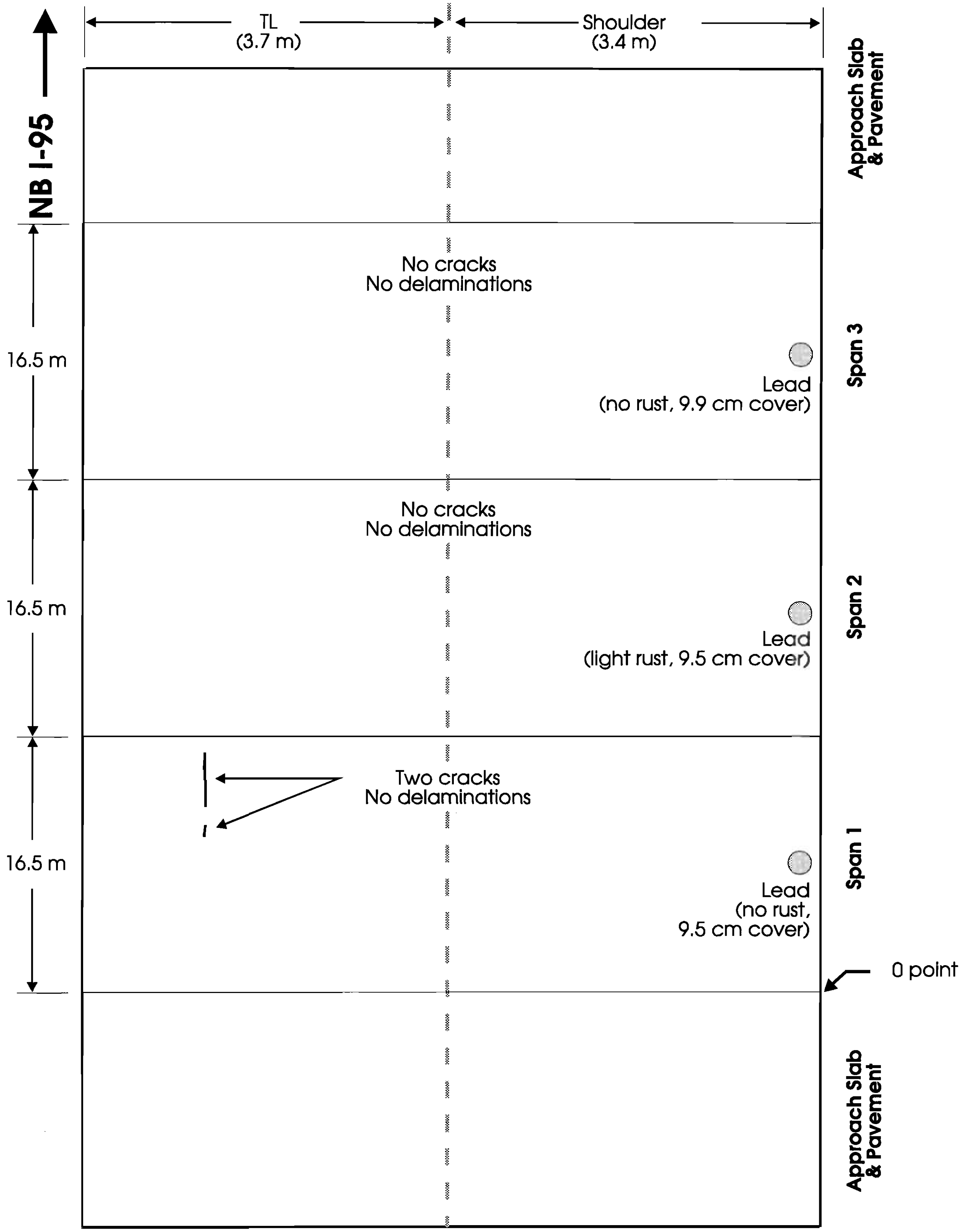


Figure 5.13. Cracks and delaminations in Bridge 4 NBL, TL and shoulder.

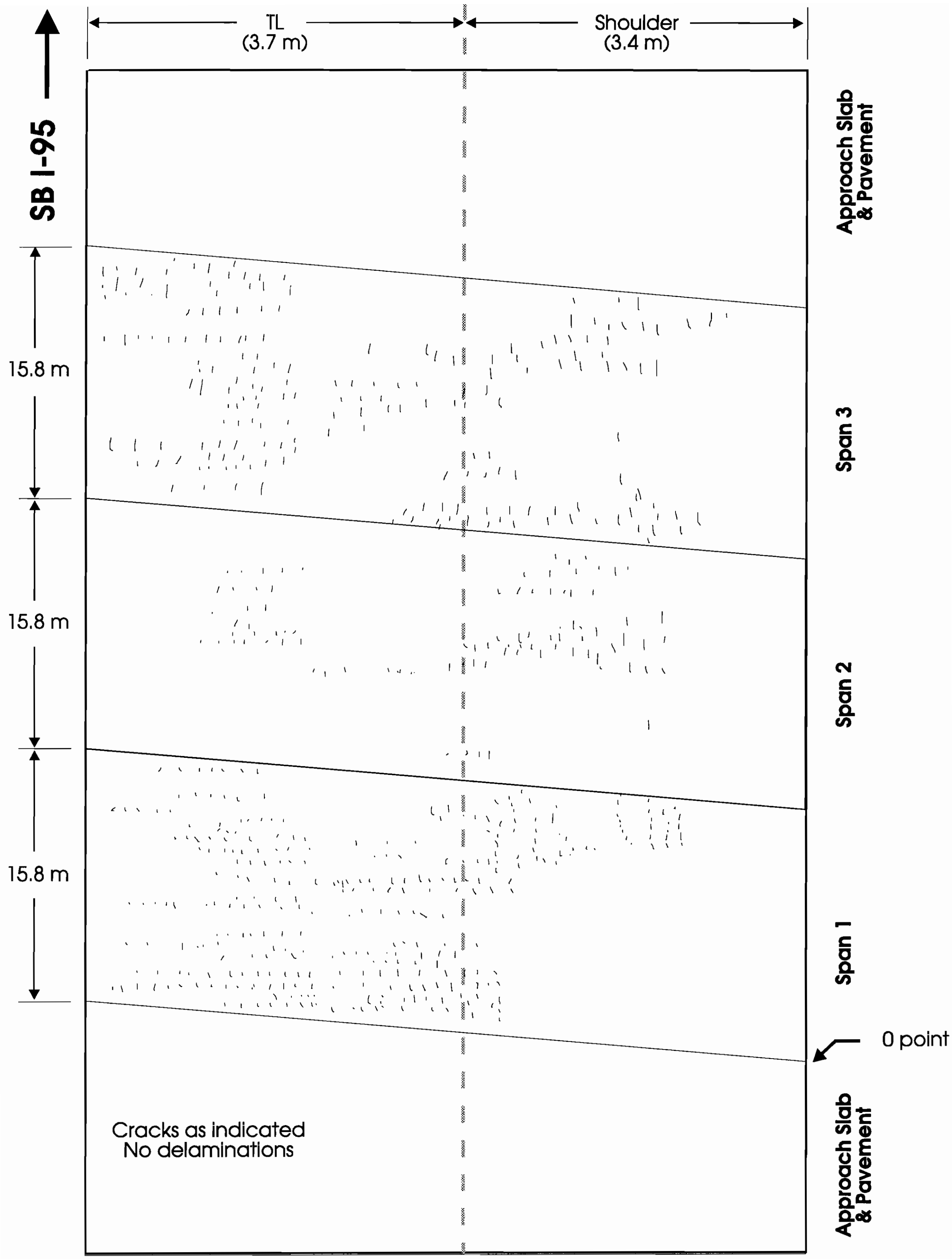


Figure 5.14. Cracks and delaminations in Bridge 5 SBL, TL and shoulder.

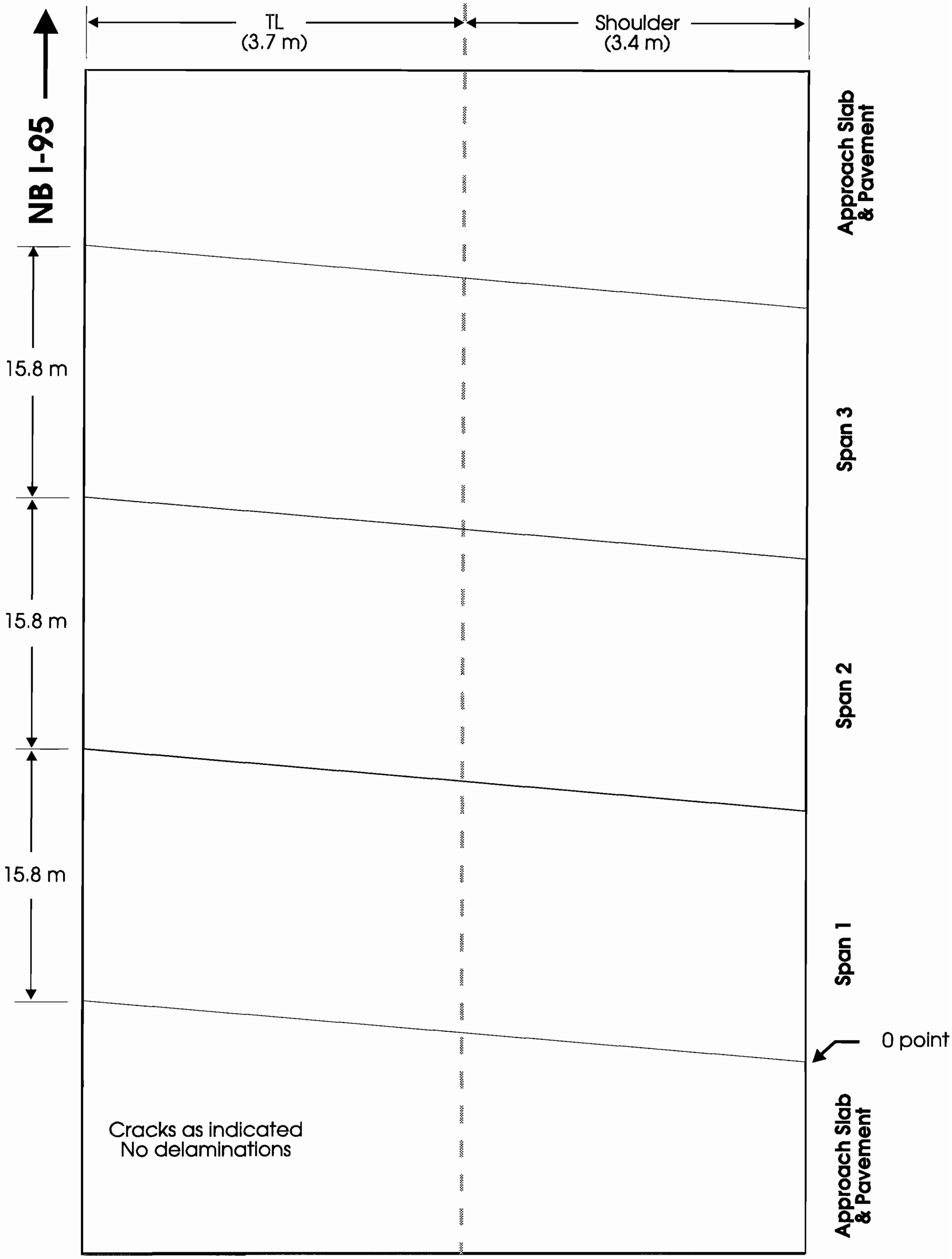


Figure 5.15. Cracks and delaminations in Bridge 6 NBL, TL and shoulder.

6.0 Conclusions

6.1 Estimate of Remaining Service Life of Overlays

Data obtained during the evaluation indicate the overlays have many properties that are similar to those of overlays that have lasted 20 years. Unfortunately, the bond strengths are lower than those of long-lasting overlays, and premature spalling may occur.

6.2 Evaluation of Cost-Effectiveness

The concretes differ slightly with respect to cost because of the differences between the cost of the ingredients and the equipment and procedures required for the installation. The cost of mobilization, traffic control, joint replacement, backwall construction, and approach slab construction exceeds the cost of the overlays.

6.3 Assessment of Project's Objectives Using Section 6005(e)7

In the spirit of the ISTEA funding, this project has demonstrated the viability of latex-modified and SF concrete overlays and identified areas for improvement.

6.4 Specific Conclusions

1. The project demonstrates that styrene butadiene LMC and MMLMC and 7 percent and ML SF concrete overlays are viable deck protective systems that can provide high bond strengths, low permeability to chloride ions, and good skid resistance.

2. The quality of the deck concrete and the quality of the surface preparation can control the life of the overlay with low-strength chloride-contaminated deck concrete and damage from milling operations causing premature spalling.

3. The latex-modified and SF concrete overlays are very susceptible to plastic shrinkage cracking, and considerable care must be exercised during placement to prevent rapid loss of moisture and rapid cooling of the concrete that can cause cracking and, therefore, reduce the effectiveness of the protection systems.

4. Properly designed styrene butadiene latex-modified and 7 percent SF concrete overlays can be opened to traffic at 24 hours of age.

5. Later age compressive strengths were similar for all materials evaluated except the standard styrene butadiene LMC, which had a lower compressive strength.

6. Shear bond strengths were higher for the 7 percent and ML SF concrete overlays.

7. Tensile bond strengths were low for all overlays because of the low strength of the old base concrete. Milling likely damaged the old concrete.

8. Seven percent and ML SF concrete and MMLMC shrink more than styrene butadiene LMC and are, therefore, slightly more prone to cracking.

9. The concretes differ slightly with respect to cost because of the difference between the cost of the ingredients and the equipment and procedures required for the installation.

10. The cost of mobilization, traffic control, joint replacement, backwall construction, and approach slab construction exceeds the cost of the overlays.

7.0 Recommendations

1. Styrene butadiene LMC and 7 percent SF concrete overlays should continue to be used as deck protective systems. MMLMC, which is not currently available, and ML concrete overlays can be used as alternatives to the standard latex-modified and SF overlays.

2. More emphasis and care should be placed on concrete removal and surface preparation.

3. An effort should be made to identify ways to reduce the cost of traffic control required to construct the overlays.

8.0 Acknowledgments

This research and 80 percent of the construction was done with ISTEA 6005 thin-bonded overlay funds provide by FHWA. Thanks go to Vasant Mistry and Roger Larson of FHWA for administering the funds.

9.0 Reference

1. Sprinkel, M.M. *Polymer Concrete Overlay on Beulah Road Bridge.* VHTRC 83-R28. Virginia Transportation Research Council, Charlottesville, 1982.

Appendix. Test Results in Detail

A.1 Electric Half-Cell Potential

Prior to Overlay					After Overlay			
	9/9/94			**Bridge 1**			**10/6/94**	
Span	**<0.20**	**0.2-0.35**	**>0.35**	I-95 SBL	Span	**<0.20**	**0.2-0.35**	**>0.35**
1	55.00%	44.17%	0.83%		1	0.00%	84.17%	15.83%
2	12.50%	73.33%	14.17%		2	0.83%	71.67%	27.50%
3	65.83%	31.67%	2.50%		3	5.83%	86.67%	7.50%
Total %	**44.44%**	**49.72%**	**5.83%**		**Total %**	**2.22%**	**80.83%**	**16.94%**
	9/10/94			**Bridge 2**			**10/5/94**	
Span	**<0.20**	**0.2-0.35**	**>0.35**	I-95 NBL	Span	**<0.20**	**0.2-0.35**	**>0.35**
1	94.17%	5.83%	0.00%		1	0.00%	82.50%	17.50%
2	96.67%	3.33%	0.00%		2	50.00%	50.00%	0.00%
3	99.17%	0.83%	0.00%		3	80.83%	19.17%	0.00%
Total %	**96.67%**	**3.33%**	**0.00%**		**Total %**	**43.61%**	**50.56%**	**5.83%**
	9/7/94			**Bridge 3**			**10/19/94**	
Span	**<0.20**	**0.2-0.35**	**>0.35**	I-95-SBL	Span	**<0.20**	**0.2-0.35**	**>0.35**
1	90.82%	9.18%	0.00%		1	79.59%	20.41%	0.00%
2	88.78%	11.22%	0.00%		2	64.29%	35.71%	0.00%
3	83.67%	16.33%	0.00%		3	97.96%	2.04%	0.00%
Total %	**87.76%**	**12.24%**	**0.00%**		**Total %**	**80.61%**	**19.39%**	**0.00%**
	9/9/94			**Bridge 4**			**10/19/94**	
Span	**<0.20**	**0.2-0.35**	**>0.35**	I-95 NBL	Span	**<0.20**	**0.2-0.35**	**>0.35**
1	75.51%	24.49%	0.00%		1	34.69%	65.31%	0.00%
2	69.39%	30.61%	0.00%		2	73.47%	26.53%	0.00%
3	73.47%	26.53%	0.00%		3	62.24%	37.76%	0.00%
Total %	**72.79%**	**27.21%**	**0.00%**		**Total %**	**56.80%**	**43.20%**	**0.00%**
	9/9/94			**Bridge 5**			**10/6/94**	
Span	**<0.20**	**0.2-0.35**	**>0.35**	I-95 SBL	Span	**<0.20**	**0.2-0.35**	**>0.35**
1	61.61%	38.39%	0.00%		1	54.46%	45.54%	0.00%
2	95.54%	4.46%	0.00%		2	91.07%	8.93%	0.00%
3	8.04%	84.82%	7.14%		3	94.64%	5.36%	0.00%
Total	**55.06%**	**42.56%**	**2.38%**		**Total %**	**80.06%**	**19.94%**	**0.00%**

	9/10/94			**Bridge 6**			**10/5/94**	
Span	**<0.20**	**0.2-0.35**	**>0.35**	I-95 NBL	Span	**<0.20**	**0.2-0.35**	**>0.35**
1	93.75%	6.25%	0.00%		1	73.21%	26.79%	0.00%
2	75.00%	25.00%	0.00%		2	67.86%	32.14%	0.00%
3	83.93%	16.07%	0.00%		3	57.14%	42.86%	0.00%
Total	**84.23%**	**15.77%**	**0.00%**		**Total**	**66.07%**	**33.93%**	**0.00%**

Table A.1. Pre- and post-installation electric half-cell potential readings.

A.2 Chloride Ion Content, lb/yd^3

Depth of Samples from Surface (in)	Bridge No.																	
	1			2			3			4			5			6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
0.25-0.5	3.23	1.88	1.52	2.58	1.73	1.45	1.55	1.4	0.41	1.53	0.28	0.58	0.62	2.17	0.86	1.51	1.9	1.9
0.5-1.0	3.15	2.12	2.08	1.49	1.58	0.47	1.56	0.7	0.18	1.5	0.12	0.33	2.06	1.75	0.39	0.98	1.67	1.29
1.0-1.5	2.96	2.53	1.73	1.36	1.13	0.08	1.18	0.62	0.09	1.17	0.09	0.19	2.57	1.72	0.1	0.61	1.54	1.15
1.5-2.0	5.01	1.96	1.26	1.17	0.9	0.06	1.03	0.4	0.13	0.85	0.03	0.09	2.19	1.4	0.15	0.22	1.52	0.74
4.5-5.0	2.27	0.46	0.05	0.04	0.11	0.06	1.15	0.13	0.04	0.09	0.13	0.11	1.65	0.07	0.00	0.06	0.09	0.11

Table A.2. Chloride content of bridge deck concrete.

A.3 Post-installation Permeability

Bridge No.	Location	Permeability, coulombs						
		Span 1		Span 2			Span 3	
		1	1'	2	2'	2BB	3	3'
1	Surface	1082.7	N/A	2035.8	878.4	N/A	894.6	512.1
	Base	8182.8	N/A	14408.1	N/A	N/A	13662.5	N/A
2	Surface	4075.2	2003.4	1814.4	1406.7	2647.8	357.3	296.1
	Base	13601.7	N/A	8584.2	N/A	14853.6	9083.7	N/A
3	Surface	972	1057.5	1832.4	1820.7	N/A	1988.1	2317.5
	Base	7163.1	N/A	5884.2	N/A	N/A	5982.3	N/A
4	Surface	767.7	648	927	996.3	N/A	801.9	751.5
	Base	9677.7	N/A	6193.8	N/A	N/A	10007.1	N/A
5	Surface	1458	1245.6	1116.9	984.6	N/A	1467.9	995.4
	Base	10895.4	N/A	7324.2	N/A	N/A	N/A	N/A
6	Surface	1396.8	1125.9	1278	1256.4	N/A	1818	902.7
	Base	7182	N/A	7076.7	8494.2	N/A	N/A	N/A

Table A.3. Post-installation chloride ion permeability for surface (top 2 in) and base (next 2 in) of each bridge deck.

A.4 Design Mixture Proportions

Material	Bridge No.					
	1, 1R	2	3	4	5	6
Cement, lb/yd^3	608	658	752	655	608	658
SF, lb/yd^3	50	0	0	50	95*	0
Latex, lb/yd^3	0	147	206	0	0	225
CA, lb/yd^3	1471	1465	1188	1471	1400	1224
FA, lb/yd^3	1489	1465	1471	1400	1348	1557
Water, gal	31.6	19.7	19.5	33.9	31.6	17.5
AE Admixture, oz/yd^3	6-9	0	0	7-10	7-10	0
Retarder, oz/yd^3	18-30	0	0	20-33	18-30	0
Air, %	6±2	5	5	6±2	6	5
Slump, in	4-7	4 -6	4-6	4-7	4-7	4-6
w/c**	0.40	0.37	0.36	0.40	0.40	0.40

*ML (95 lb/yd^3 contains 50 lb/yd^3 of SF).
**Water-cementitious material ratio.

Table A.4. Design Mixture Proportions

A.5 Actual Mixture Proportions

Material	Bridge No.						
	1R	1	2*	3*	4	5	6*
Cement, lb/yd^3	608	608	658	752	655	608	658
SF, lb/yd^3	50	50	0	0	50	95**	0
Latex,lb/yd^3	0	0	147	206	0	0	225
CA, lb/yd^3	1471	1471	1188	1188	1471	1400	1224
FA, lb/yd^3	1489	1489	1471	1471	1400	1347	1557
Water, lb/yd^3	255	255	163	163	274	255	146
AE Admixture, oz/yd^3	4	3.5	0	0	4	3.6	0
Retarder, oz/yd^3	33	33	0	0	35	33	0
Air, %	4.6-7.5	6.0-13.2	3.8 -15.0+	4.0-8.2	5.5-7.8	3.0 -6.8	4.1-8.0
Slump, in	2.5-8	5-7	6.5-7.5	4-6.5	4-6	4-7	5-8
w/c***	0.39	0.39	0.37	0.36	0.39	0.36	0.40

*For mobile mixed concrete, the design mixture proportions are used because the mixer is calibrated based on those proportions.
**ML.
*** Water-cementitious material ratio.

Table A.5. Actual overlay mix designs. Characteristics of ingredients can be found in Section 3.7 of this report.

A.6 Placement Conditions

Bridge No.	Lane	Climatic Conditions	Rate of Evaporation, $lb/ft^2/hr$	Concrete Temp., °F	Air Temp, °F	Relative Humidity, %	Avg. Wind Speed, mph
1R	OL	night; cool, humid	0.025	78-84	62-85	62-98	N/A
	IL	N/A	N/A	N/A	N/A	N/A	N/A
1	OL	night; cool, humid	0.025	70-78	60-65	90-98	0.0
	IL	day; cloudy, light drizzle	0.038	60-64	50-62	77-100	4.0
2	OL	evening; drizzle to hard rain	0.038	78-79	62	N/A	0.75
	IL	morning; cool, humid	0.013	68	50-59	87-95	1.4
3	OL	morning; cool, dry	0.038	60-76	47-84	27-90	2.7
	IL	morning; cool	0.013	65-68	64-81	83	0.67
4	OL	morning; cool, humid	0.025	64-76	50-67	60-92	1.2
	IL	morning; cool	0.038	62-75	58-68	68-78	0.8
5	OL	night; cool, humid	0.025	72-78	50-56	96-99	0.0
	IL	morning; cool	0.025	69-74	57-73	79-87	1.0
6	OL	morning; cool, humid	0.025	77-78	65-67	95-99	1.0
	IL	morning; cool	0.042	58-64	50-71	76-81	1.6

Table A.6. Summary of placement conditions.

A.7 Coefficients of Thermal Expansion

Bridge No.	in/in/°F x 10^{-6}
1R	6.2
1	5.7
2	6.6
3	7.9
4	5.8
5	5.3
6	6.8

Table A.7. Coefficients of thermal expansion of overlay concrete. Values obtained from concrete placed on outside lane of each bridge deck.

A.8 Compressive Strength

Bridge No.	Overlay Type	Compressive Strength, psi											
		24 hours				7 days		28 days				1 year	
		OL		IL		OL		OL		IL		OL	
		Z	A	B	C	Z	A	Z	A	B	C	Z	A
1R	SF	3350	2890	N/A	N/A	5040	4250	6420	5780	N/A	N/A	7370	6770
1	SF	3350	3460	930	750	5260	5540	7040	7130	7520	7390	7830	8230
2	MMLMC*	3850	4320	2640	1710	5460	7060	6580	7930	5500	4650	7450	9230
3	LMCHE	4480	3640	3450	4040	5720	5520	6660	6610	6800	7820	7790	8260
4	SFHE	2660	2610	2560	2600	5890	5860	8260	8280	7210	7450	9300	9330
5	ML	3980	4410	5990**	6390**	6300	6490	7810	8150	8480	9130	9050	9400
6	LMC	2560	2330	1620	1690	3230	3500	4130	4560	4090	4950	5480	6200

*ML used in Span 3 of outside lane, LMC used in inside lane.
**7-day compressive strength values (forgot to test at 24 hours).

Table A.8. Compressive strength of overlay concrete.

A.9 Shear Bond Strength

Batch No.	Time	Bond Strength, psi	Base	Bond	OL
1R	24	420	20	70	10
	24	450	20	70	10
	28	720	50	50	0
	28	845	35	50	15
	1 yr	910	30	35	35
	1 yr	1090	40	20	40
1RA	24	360	40	60	0
	24	440	35	50	15
	28	590	40	50	10
	28	775	50	50	0
	1 yr	1250	30	40	30
	1 yr	865	35	45	20
1	24	430	35	60	5
	24	610	35	60	5
	28	765	50	35	15
	28	770	30	50	20
	1 yr	965	25	35	40
	1 yr	1055	5	30	65

1A	24	555	30	70	0
	24	675	35	50	15
	28	790	40	45	15
	28	775	40	50	10
	1 yr	1105	30	40	30
	1 yr	870	25	30	45
2	24	225	0	40	60
	24	340	0	40	60
	28	565	0	15	80
	28	255	0	20	80
	1 yr	585	10	80	10
	1 yr	350	5	80	15
2A	24	400	0	85	15
	24	540	0	60	40
	28	635	0	60	25
	28	470	0	80	15
	1 yr	580	15	60	25
	1 yr	575	20	75	5
3	24	320	5	90	5
	24	360	10	80	10
	28	320	0	100	0
	28	320	10	90	0
	1 yr	305	5	95	0
	1 yr	60	0	100	0
3A	24	265	5	90	5
	24	275	10	75	15
	28	375	10	85	5
	28	260	35	60	5
	1 yr	475	5	90	5
	1 yr	665	10	90	0
4	24	355	20	60	20
	24	335	20	75	5
	28	785	35	40	25
	28	840	35	60	5
	1 yr	980	30	40	30
	1 yr	1085	50	35	15
4A	24	450	10	65	25
	24	460	10	85	5
	28	715	25	70	5
	28	710	50	40	10
	1 yr	1100	15	30	55
	1 yr	1060	30	65	5
5	24	680	45	50	5
	24	475	40	60	0
	28	830	50	50	0
	28	770	70	25	5
	1 yr	1100	40	20	40
	1 yr	1090	55	30	15

5A	24	510	45	50	5
	24	515	40	60	0
	28	750	30	50	20
	28	665	40	50	10
	1 yr	1020	30	45	25
	1 yr	865	20	40	40
6	24	390	20	75	5
	24	700	20	75	5
	28	505	40	60	0
	28	440	20	75	5
	1 yr	800	10	20	70
	1 yr	620	20	70	10
6A	24	430	15	50	35
	24	415	20	60	20
	28	510	35	60	5
	28	230	30	60	10
	1 yr	605	25	75	0
	1 yr	675	30	65	5

Table A.9. Shear bond strength between base concrete and overlay.

A.10 Tensile Bond Strength

2.25-in-diameter cores

Sample No.	Overlay Thickness, in	Load, lb	Bond Strength, psi	Failure Area, %		
				Overlay	Bond	Base
1A	1 24/64	710	180	0	0	100
1B	1 27/64	510	130	0	0	100
1C	1 15/64	570	145	10	10	80
2A	1 8/64	308	75	0	10	90
2B	1 39/64	366	90	5	10	85
2C	1 20/64	240	60	0	15	85
2BB	1 43/64	588	150	25	0	75
3A	1 41/64	338	85	0	0	100
3B	1 45/64	160	40	5	0	95
3C	1 36/64	556	140	0	0	100
4A	1 48/64	476	120	0	5	95
4B	1 31/64	526	130	0	5	95
4C	1 35/64	418	105	0	10	90
5A	1 8/64	404	100	15	0	85
5B	1 29/64	666	165	10	0	90
5C	1 19/64	538	135	0	0	100
6A	1 39/64	490	125	0	0	100
6B	1 36/64	604	150	0	0	100
6C	1 19/64	360	90	0	5	95

Table A.10. Tensile bond strength between base and overlay concrete.

A.11 Cost Description

Bridge No.	Type of Overlay	Cost of Bridge Preparation and Traffic Control, $	Unit Cost of Concrete, $/yd^3	yd^3 of Concrete Placed	Total Cost, $
1	SF	120,293	650	81*	172,943
2	MMLMC	104,074	650	56**	140,854
3	LMCHE	81,774	725	61	125,999
4	SFHE	75,019	680	57	113,779
5	ML	93,503	688	60	134,783
6	LMC	79,376	650	56.5	116,101
Total Project Cost					**804,459**

*20 yd^3 included for replaced span.
**25 yd^3 MMLMC + 21 yd^3 LMC + 10 yd^3 ML.

Table A.11. Cost description of project.