EVALUATION OF THE CONSTRUCTION AND PERFORMANCE OF POLYMER CONCRETE OVERLAYS ON FIVE BRIDGES

Interim Report No. 1

"Construction and Condition of the Overlays Initially and After One Year in Service"

by

Michael M. Sprinkel
Research Scientist

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

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

February 1983
VHTRC 83-R29

1804

CONCRETE RESEARCH ADVISORY COMMITTEE

A. D. NEWMAN, Chairman, Pavement Management Engineer, Maintenance Division, VDH&T

T. R. BLACKBURN, District Materials Engineer, VDH&T

C. L. CHAMBERS, Division Structural Engineer, FHWA

W. R. DAVIDSON, District Engineer, VDH&T

E. ESTES, Chairman of Civil Engineering Technology, Old Dominion University

J. E. GALLOWAY, JR., Asst. Materials Engineer, VDH&T

J. G. HALL, District Materials Engineer, VDH&T

F. C. MCCORMICK, Department of Civil Engineering, U. Va.

J. G. G. MCGEE, Construction Control Engineer, VDH&T

W. T. RAMEY, District Bridge Engineer, VDH&T

M. M. SPRINKEL, Research Scientist, VH&TRC

R. E. STEELE, Materials Division, VDH&T

J. F. J. VOLGYI, JR., Bridge Design Engineer, VDH&T

BRIDGE RESEARCH ADVISORY COMMITTEE

L. L. MISENHEIMER, Chairman, District Bridge Engineer, VDH&T

J. E. ANDREWS, Bridge Design Engineer Supervisor, VDH&T

F. L. BURROUGHS, Construction Engineer, Central Office

C. L. CHAMBERS, Division Structural Engineer, FHWA

M. H. HILTON, Senior Research Scientist, VH&TRC

H. L. KINNIER, Consultant, VH&TRC

J. G. G. MCGEE, Construction Control Engineer, VDH&T

M. F. MENEFEE, JR., Structural Steel Engineer, VDH&T

R. H. MORECOCK, District Bridge Engineer, VDH&T

C. A. NASH, JR., District Engineer, VDH&T

F. L. PREWOZNIK, District Bridge Engineer, VDH&T

W. L. SELLARS, District Bridge Engineer, VDH&T

F. G. SUTHERLAND, Bridge Engineer, VDH&T

C. P. WILLIAMS, District Materials Engineer, VDH&T

SUMMARY

The installation of thin polymer concrete overlays on five bridges on I-64 near Williamsburg, Virginia, has demonstrated that an overlay of low permeability and high skid resistance can be successfully installed by a contractor with a minimum of disruption to traffic of approximately eight hours per lane. The initial condition of the overlays was excellent from the standpoint of permeability, skid resistance, and bond, although some overlays were better than others. All were in good to excellent condition after one year in service, but the permeability had increased and the bond strength and skid resistance had decreased significantly. Based on the data collected during the first year it is projected that the overlays constructed with LB183 resin will have a useful service life of at least five years and that the MMA overlay will fail in less time.

EVALUATION OF THE CONSTRUCTION AND PERFORMANCE OF POLYMER CONCRETE OVERLAYS ON FIVE BRIDGES

Interim Report No. 1

"Construction and Condition of the Overlays Initially and After One Year in Service"

by

Michael M. Sprinkel
Research Scientist

INTRODUCTION

Thin polymer concrete (PC) overlays have been installed on portland cement concrete bridge decks in several states during the past four years.(1) This type of overlay was developed by the Brookhaven National Laboratory for the Implementation Division of the Office of Development of the Federal Highway Administration as a protective system for bridge decks.(2) It consists of four layers of resin and clean, dry, angular-grained silica sand applied to the top of a portland cement concrete deck to provide a 0.5 in. (1.3 cm) thick, relatively impermeable, skid resistant wearing surface. Typically, the initiated and promoted resin is sprayed uniformly over the surface of the deck and, before it gels, is covered by fine aggregate broadcast over it as shown in Figures 1 and 2. Following polymerization, the excess aggregate is removed with a vacuum device prior to the placement of a subsequent layer. The principal advantage of the overlay over other protective systems is that it is a reasonably priced system that can be installed by state forces or a contractor without the removal of a large amount of concrete and with minimal disruption to traffic, approximately 8 hr. per lane for a 250-ft. (76 m) bridge — 4 hr. for deck preparation and 1 hr. per layer to install the polymer.

PURPOSE AND SCOPE

The purpose of this study is to evaluate the construction and the performance after 1, 3, 5, 7, and 10 years of five polymer concrete overlays placed on I-64 near Williamsburg in 1981.(3) The evaluation requires a determination of the initial condition of the bridge decks, a documentation of the installation of the overlays, and determinations of the condition of the decks after the overlays were installed and after 1, 3, 5, 7, and 10 years of service life.

1808

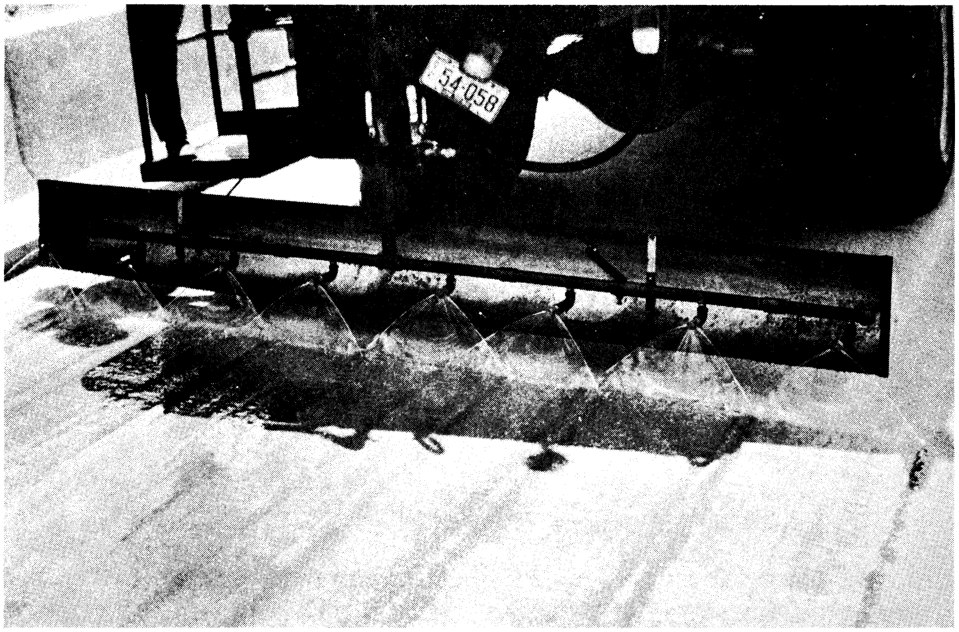

Figure 1. Polyester resin is sprayed over deck surface.

Figure 2. Silica aggregate is broadcast over resin.

The specific objectives are (1) to evaluate the procedures recommended in FHWA-TS-78-225, "Polymer Concrete Overlays, Interim User Manual — Method B"; (2) to determine the bonding characteristics, resistance to chloride penetration, and skid resistance of the overlays; and (3) to determine the effect of the overlays on the rate of corrosion of the reinforcing steel in the concrete.

This report presents the results of the evaluation of the construction and the condition of the overlays after 1 year.

In addition to the five bridges that were overlaid with the polymer concrete, four others were selected as controls — bridges 4, 5, 6 and 7, as shown in Figure 3. In the EBL bridges 1, 2, and 3 received polymer overlays, 4 was selected as a control bridge to represent an exposed concrete deck, and 5 was selected as a control bridge to represent a concrete deck covered with a waterproofing membrane of rubberized asphalt and a bituminous concrete overlay. In the WBL bridges 6, 7, 8, and 9 are similar to bridges 5, 4, 3 and 2, respectively.

CONSTRUCTION OF PC OVERLAYS

Materials

The following information on materials was taken from a Virginia Department of Highways and Transportation special provision for PC overlays which accurately describes the materials used in the construction of the overlays near Williamsburg.(4)

Monomer-1 Polyester Resin

The resin used on bridges 2, 3, 8, and 9 was U. S. S. Chemical's blend LB802-6, which is the promoted version of LB183-13. It is a clear, low viscosity, highly resilient, general purpose, unsaturated polyester resin with a viscosity of 100 to 150 cP (0.1 to 0.15 Pa s) at 77°F. (25° C) and a density of 9.08 lb./gal. (1088 kg/m^3). It is designed for applications requiring resistance to wear and high impacts. The first course contained 1% Union Carbides' A-174 coupling agent gamamethacryloxypropyltrimethoxysilane, which has a density of 8.45 lb./gal. (1013 kg/m^3) and 1% Air Products and Chemicals', Inc., Surfynol S440 wetting agent, which has a density of 8.2 lb./gal. (983 kg/m^3), to enhance the bond strength and reduce surface tension. The second, third, and fourth courses contained 0.5% Union Carbide A-174 coupling agent and 0.5% Surfynol S440 wetting agent.

1810

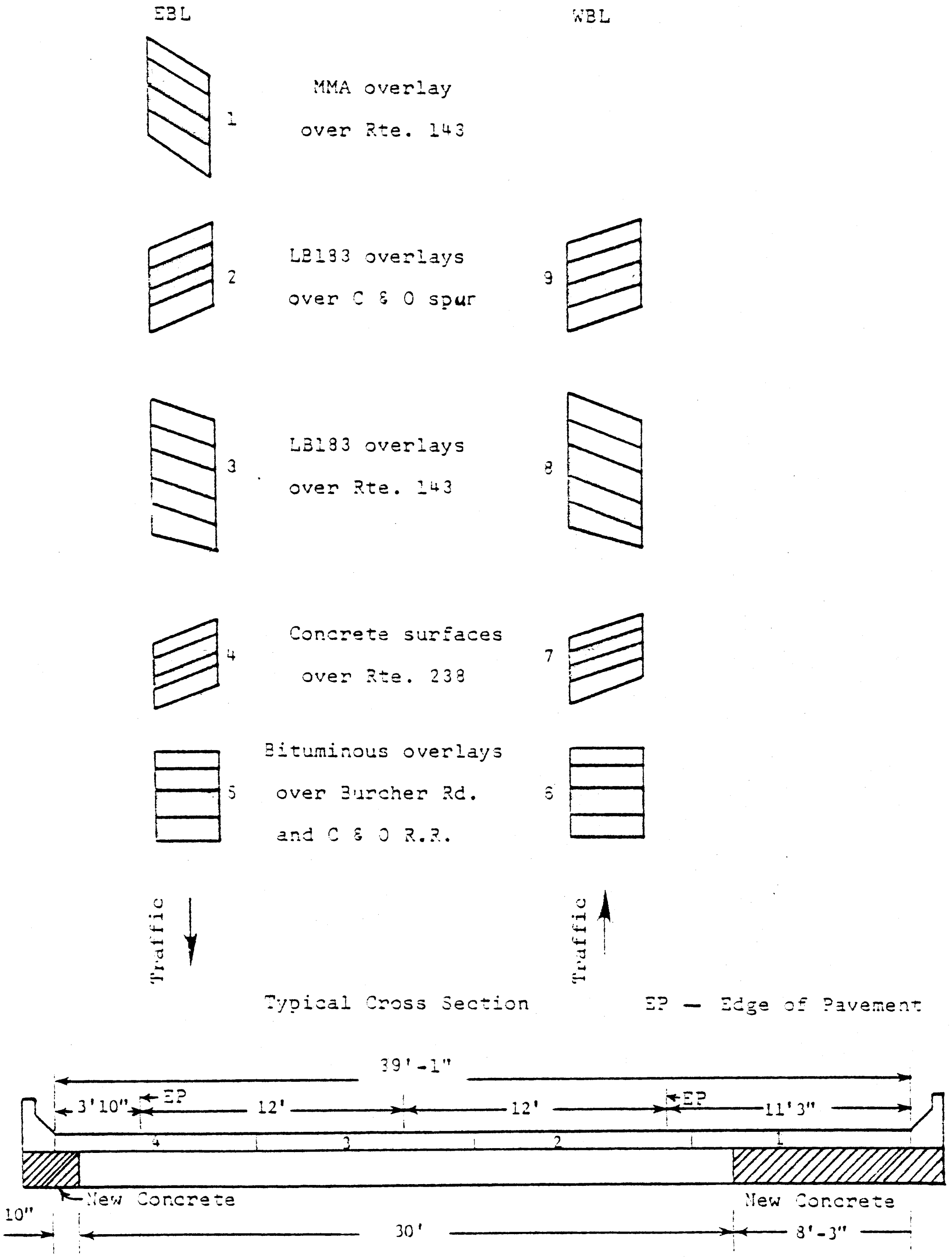

Figure 3. Locations and typical cross section of study bridges. 2.54 cm = 1 in., 0.305 m = 1 ft.

Initiator-1

The initiator used with monomer-1 was Reichhold Chemical's Formulation 46-742, which is a 40% dispersion of benzoyl peroxide (BPO-40) in a plasticizer. BPO-40 has a density of 10 lb./gal. (1198 kg/m^3). The contractor elected to dilute the BPO-40 with one part styrene to 8 parts BPO-40 so that it could be pumped. The BPO-40 was added to the resin at a dosage of 2% to 6%.

Promoter-1

The promoter used with monomer-1 was N, N, Dimethyl Aniline (DMA) $C_6H_4N(CH_3)2$. The DMA had a maximum monomethyl aniline content of 0.5% and a density of 8 lb./gal. (959 kg/m^3). A dosage of DMA of 0.37% by weight of resin was added by U. S. S. Chemicals prior to shipping the resin. A dosage of 0.063% was added by the contractor prior to pumping the resin.

Monomer-2 — Methyl Methacrylate (MMA)

The resin used on bridge 1 was 63% MMA, DuPont's H-205, and 37% PMMA, DuPont's methacrylate bonding agent EP 4160. The MMA has a density of 7.82 lb./gal. (937 kg/m^3) prior to the addition of the PMMA powder. All courses contained 1% A-174 and 0.5% Surfynol S440 with the exception that the tack coat contained 1% Surfynol S440. The contractor mixed the PMMA with the MMA approximately 2 weeks prior to placing the overlay.

Initiator-2

The initiator used with monomer-2 was the same as the one used with monomer-1.

Promoter-2

The promoter used with monomer-2 was N, N-Dimethyl-P-Toluidine (DMT) $C_9H_{13}N$. The DMT had a purity of 98%, a melting point of 76°F. (24° C), a boiling point of 365° F. (185° C), and a density of 7.6 lb./gal. (911 kg/m^3). It was added at a dosage of 0.5% by weight of monomer.

Tack Coat-2

A tack coat consisting of 83% MMA, 15% PMMA, 1% Surfynol S440, and 1% A-174, was brushed into the concrete deck surface prior to placing the first layer of monomer-2 and aggregate.

1812

Cleaning Agent

The distribution system was flushed with methylene chloride after each use to remove the resin and additives before polymerization could occur.

Aggregate

The aggregate was a clean, dry (less than 1% moisture), angular-grained silica sand free of dirt, clay, asphalt and other organic materials, and having a gradation as reported in Table 1. The aggregate was purchased in bulk quantities from the Morie Sand Company of Mauricetown, New Jersey.

Table 1

Gradation of Sand Used in Overlays

Grading	Layers	Percent Passing Indicated U. S. Sieve				
		8	12	16	20	30
A	3 & 4	97.6	52.5	10.6	2.2	1.0
D	1 & 2	100.0	98.9	52.4	7.6	1.9

NOTE: Results based on tests of one sample of each grading taken from each of 5 bridges.

Equipment

Demonstration Test

The polymer distribution equipment and aggregate spreader were prepared by the contractor, "Concrete Repair Specialists" of Lynchburg, Virginia. Demonstration tests were conducted on May 21 and 22 and June 3, 1981, to ensure that the distribution equipment and sand spreader were functioning prior to moving it to the bridge. Three days of demonstration tests were required because the contractor experienced problems with the pumping of the resin, the application of the aggregate, and the gelling of the polyester resin. For example, it was necessary to install a viton-coated stator in the pump because the standard bunna-n coating reacted with the resin. Also, the resin would not gel until the dosage of initiator was increased to about twice that required by the specifications. Finally, once it was established that the application of an excess of aggregate would not retard the gel of the resin, the application of the aggregate was found to be an art that the crew became better at with experience.

Distribution Equipment

The resin distribution equipment consisted of a flatbed truck carrying a 300-gal. (1.14 m^3) tank that held the mixture of promoted resin, wetting agent, and coupling agent; a 30-gal. (0.11 m^3) tank that held the initiator; two pumps; a static mixer; a 10-ft. (3.1 m) spray bar with 8 nozzles; and the necessary piping to allow for the circulation and distribution to the spray bar of promoted resin and initiator (see Figure 4). The pumps circulated the promoted resin and initiator with two closed loops until two valves were opened and two valves were closed to allow the two ingredients to enter the static mixing box above the spray bar. The equipment was calibrated at the beginning of each work day by noting the time required to fill containers of a known volume with resin and initiator. It was found that a resin flow rate of about 25.0 gpm (1.6×10^{-3} m^3/s) and an initiator flow rate of about 1.1 gpm (6.9×10^{-5} m^3/s), were desirable. The spray bar was extremely adjustable as it could be moved up and down, left to right, and rotated to accommodate a skew. The maximum width of application that could be obtained with the spray bar was 11 ft. (3.4 m). Also, the nozzles could be removed to facilitate cleaning or to provide an application width of less than 11 ft. (3.4 m). A pan was attached along the axis of the spray bar. It was secured on the front of the spray bar during the resin applications and then dropped below the bar to catch the methylene chloride poured through the mixing box and spray bar to clean the system.

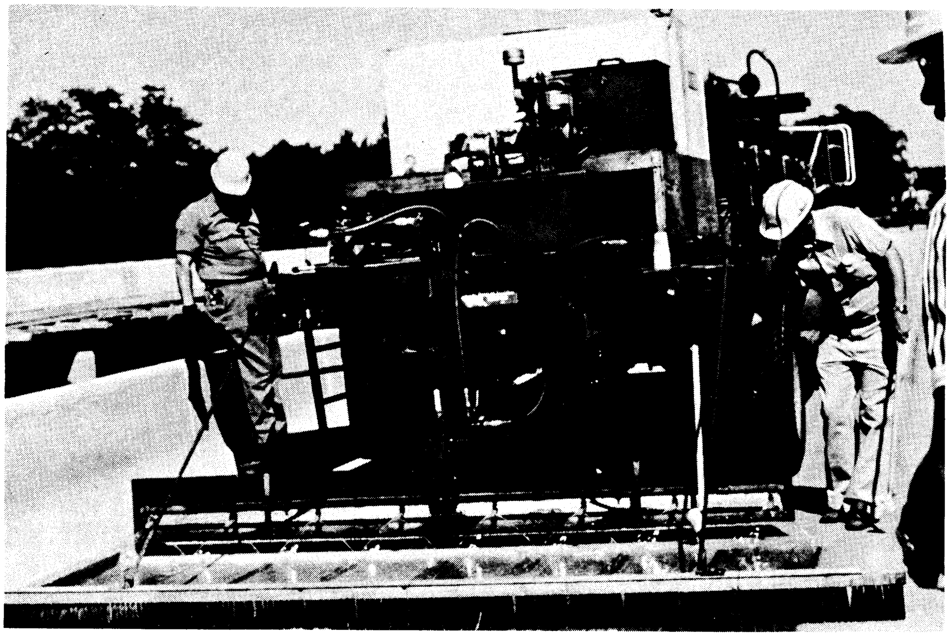

Figure 4. Resin application equipment.

Since the bridges were 39 ft. (11.9 m) wide, the resin was sprayed over one of the four placement lanes that varied in width from 7 (2.1 m) to 11 ft. (3.4 m). By altering the width of the application it was possible to divide the 39 ft. (11.9 m) width into four placement lanes, as shown in figure 3, and to overlap the joints between placement lanes with a subsequent layer. The truck was moved forward at a speed that provided an application rate of 2.0 lb./yd.^{2} (1.1 kg/m^2) for the first course and 2.75 lb./yd.^{2} (1.5 kg/m^2) for the subsequent courses.

Aggregate Application Equipment

The aggregate application equipment was shown earlier in Figure 2. It consisted of a 10-ton (89 kN) dump truck that pushed an aggregate spreader as it was backed over the freshly placed resin. Two cranks were installed on the tailgate of the truck so that a proper flow of aggregate could be obtained between the elevated bed and the spreader. The spreader placed aggregate over a maximum width of 10 ft. (3.1 m). Therefore, it was necessary to apply the aggregate by hand along the sides when the resin was sprayed over a width greater than 10 ft. (3.1 m). The gate on the spreader was adjustable, and with considerable experience the proper combination of truck speed and gate adjustment was obtained. A wooden block was used to block part of the opening when an application width of less than 10 ft. (3.1 m) was desired. A front-end loader was used to fill the dump truck with aggregate stored in bulk at the Virginia Department of Highways and Transportation's Skiffs Creek Area Headquarters located near the bridges.

Shotblaster

Prior to placement of the first layer of polymer and after all major spalls had been repaired, the deck surface was cleaned with steel shot impinged upon the deck with equipment supplied by Porta-Shot Blast, a Division of the Nelco Manufacturing Company located in Chesapeake, Virginia. The equipment, which is similar to that shown in figure 5, collects the steel shot and the latience removed from the surface and provides a more uniform and completely cleaned deck surface than is generally achieved with sandblasting.

The shotblaster cleaned the 1,508-yd.^{2} (1260 m^2) surface of the largest bridge in one workday while traffic was maintained in one traffic lane. However, it was necessary to use sandblasting to clean a strip about 6 in. (15 cm) wide along the edge of each parapet, which required several hours but could be done along with the shotblasting.

Figure 5. Shotblasting equipment similar to that used on the bridges near Williamsburg.

Roller

A pneumatic-tired roller was used to compact the aggregate into the freshly placed polymer mixture before the mixture gelled. The roller was self-propelled and applied 200 lb./in. (350 N/cm) of rolling width (see Figure 6).

Vacuum

A self-propelled, sweeper-broom type vacuum truck was used to remove excess aggregate from the surface approximately 1 hour after the resin had gelled (see Figure 7). Approximately 20 minutes were required to remove the excess aggregate from two placement lanes.

Labor

The resin distribution equipment was operated by a driver, one man who controlled the spray bar and the pumps, and a man on foot with a stopwatch to assist in maintaining a proper speed.

The aggregate distribution equipment was operated by a driver and two men who maintained a proper flow of aggregate from the truck through the spreader and onto the resin.

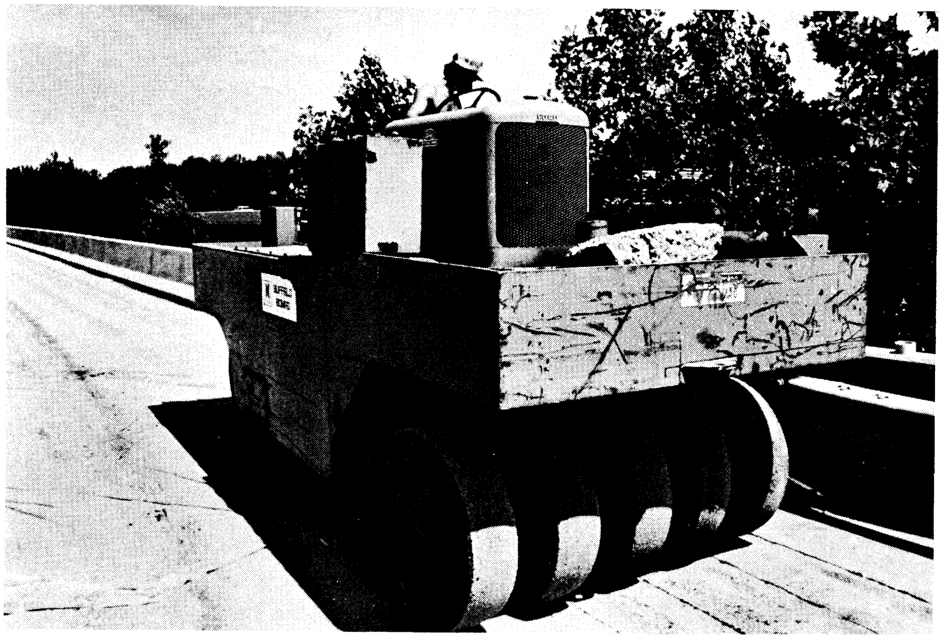

Figure 6. Pneumatic tire roller compacts aggregate and resin.

Figure 7. Sweeper-broom type vacuum truck removes excess aggregate.

A seventh man operated the roller. One man from the Materials Division of the Virginia Department of Highways and Transportation secured a 1.7-oz. (50-ml) sample of resin from the spray bar at three locations for each of the applications and recorded the gel times.

One man who had earlier helped distribute the aggregate operated the vacuum truck.

Two men from the Research Council maintained two 1-yd.^{2} (0.84 m^2) sampling devices at the end of each application lane to provide an indication of the rate at which the resin and aggregate were being applied. Another indication was obtained by measuring the depth of the resin in the holding tank before and after a layer was applied. The initiator concentration was also determined by measuring the depth of the initiator in the holding tank before and after a layer was applied. The depth measurements were made by the man who drove the distribution equipment.

Composition of the Overlays

Information on the composition of the five overlays is shown in Table 2. It can be seen that there were some significant differences between the installations that should affect the performance of the overlays. For example, traffic was allowed on the shotblasted surfaces from 1 to 16 days prior to the installation of the overlays. Traffic can contaminate the surface and if it does, the contamination should affect the relative strength of the bond between the overlays and the old surface. The temperature of the latter at the time of placement ranged from 64°F. (18° C) to 101° F. (38° C). Overlays placed at the higher temperatures would be subjected to a greater thermal stress when cooled during the winter and should deteriorate more rapidly.(5)

In general, the application rate for the four layers of resin, based on the stick reading taken on the resin holding tank, was not significantly different for the overlays and was in compliance with the Virginia Department of Highways and Transportation's specification. However, all of the bridges except bridge 2 and the passing lane of bridge 1 received less than the 52 lb./yd.^{2} (28 kg/m^2) of sand specified. Also, the rate at which it was applied was significantly different for some of the overlays and thus caused a difference in the sand-to-resin ratio between the bridges. The lower the sand-to-resin ratio, the greater is the thermal stress induced by a change in temperature.(5) A sand-to-resin ratio in excess of 4 is needed to minimize the effects of thermal stress.(5) The overlays on bridges 3 and 8 should deteriorate more rapidly due to thermal stress than those on bridges 9 and 2, because the former were constructed at a higher temperature and with a lower sand-to-resin ratio.

Table 2

Composition of Overlays

	Bridge	Deck Surface	Lane[a]	1981 Placement Date	Time since Shotblasting, Days	Concrete Temp., °F	Resin[b] lb./yd.^{2}	Sand[c] lb./yd.^{2}	Sand/Resin	Gel Time[d] Min.	Overlay[e] Thickness, in.	Overlay[e] Void Content, %
	8	LB183	T	6/10[f]	2	92	11.6	44.5	3.8	15	.56	13.2
	8	"	P	6/25	16	101	9.9	37.2	3.8	11	.58	11.9
	3	"	P	6/30	1	86	9.3	38.0	4.1	18	.55	12.8
	3	"	T	7/07[g]	2	93	10.2	33.2	3.3	12	.51	11.7
	9	"	T	8/13	3	86	10.8	43.1	4.0	12	.57	6.9
	9	"	P	8/18	7	83	10.5	41.9	4.0	10	.56	8.3
	2	"	P	8/25	1	80	10.4	55.3	5.3	11	.50	4.8
	2	"	T	8/26	8	79	10.5	54.2	5.2	10	.53	12.6
	1	MMA	T	9/23	2	64	10.2	48.3	4.7	11	.38	15.1
	1	MMA	P	9/24	3	68	10.0	70.4	7.0	12	.34	27.5
Average	All				5	83	10.3	46.6	4.5	12	.51	12.3
	LB183				5	88	10.4	43.4	4.2	12	.54	10.5
	MMA				3	66	10.1	59.4	5.9	12	.37	19.2
Specified	Min.				1	60	9.3	52.0	4.6	--	--	--
	Max.				3	90	11.3	84.0	9.1	--	--	--

[a] T represents the average of the two placement lanes which covered the right shoulder and the right two-thirds of the travel lane. P represents the average of the two placement lanes which covered the left shoulder, the passing lane and the left third of the travel lane.

[b] Based on stick readings of holding tank.

[c] Based on one sample per lane per layer.

[d] Average of 3 samples per lane per layer.

[e] Based on two cores from lane T and one from lane P.

[f] Layer 4 placed on 6/23 and again on 6/24.

[g] Layer 1 placed on 7/01

°C = (°F−32)/1.8; 0.54 kg/m^2 = 1 lb./yd.^{2}; 2.54 cm = 1 in.

The average gel time was several minutes longer for the applications on the passing lane on bridge 3 and the travel lane on bridge 8 than for the other applications, but it is believed that this will not have a significant effect on performance. The contractor had adjusted the dosage of initiator from day-to-day to achieve a target gel time of 10 to 15 minutes. Figure 8 shows the relationship between gel time and dosage of BPO-40 for several temperatures based on the data collected during the field installations and in the lab. Since a larger dosage of initiator was required in the field than in the lab, it can be speculated that more efficient mixing was achieved in the lab using a hand-operated stirring tool than was achieved with the static mixing box in the field.

The thicknesses of the four polyester resin overlays were about the same and close to the 0.5 in. (1.3 cm) anticipated. On the other hand, the thickness of the MMA overlay was significantly less than anticipated, even though the resin application rate was acceptable and the aggregate application rate was heavy. It is believed that the MMA overlay was thin because the resin has a lower viscosity and evaporates faster than the polyester resin. An evaporation test conducted in the laboratory at 72°F.(22°C) showed that 11% of the MMA resin evaporated as compared to only 2% of the polyester resin during the 10 to 15 minutes required for the resin to gel.

Petrographic examinations of the vertical face of the overlay on three 4-in (10 cm) diameter cores taken from each bridge revealed some differences in the void contents of the overlays. The highest void contents were found for the MMA overlay. Bridges 9 and 2 exhibited the lowest void contents. The lower void contents should provide a lower permeability.

Based on the data in Table 2, it is anticipated that bridges 9 and 2 will perform the best because they will be subjected to the lowest thermal stress and because they have the lowest void content.

Assessment of Construction of Overlays

Overall the construction of the overlays with both resins was reasonably successful. The resin distribution equipment worked extremely well, and after gaining experience the contractor was able to apply a uniform layer of resin. The sand application equipment was adequate, but it was found that the application of the aggregate with this equipment was an art and, therefore, improved as the personnel gained experience.

1820

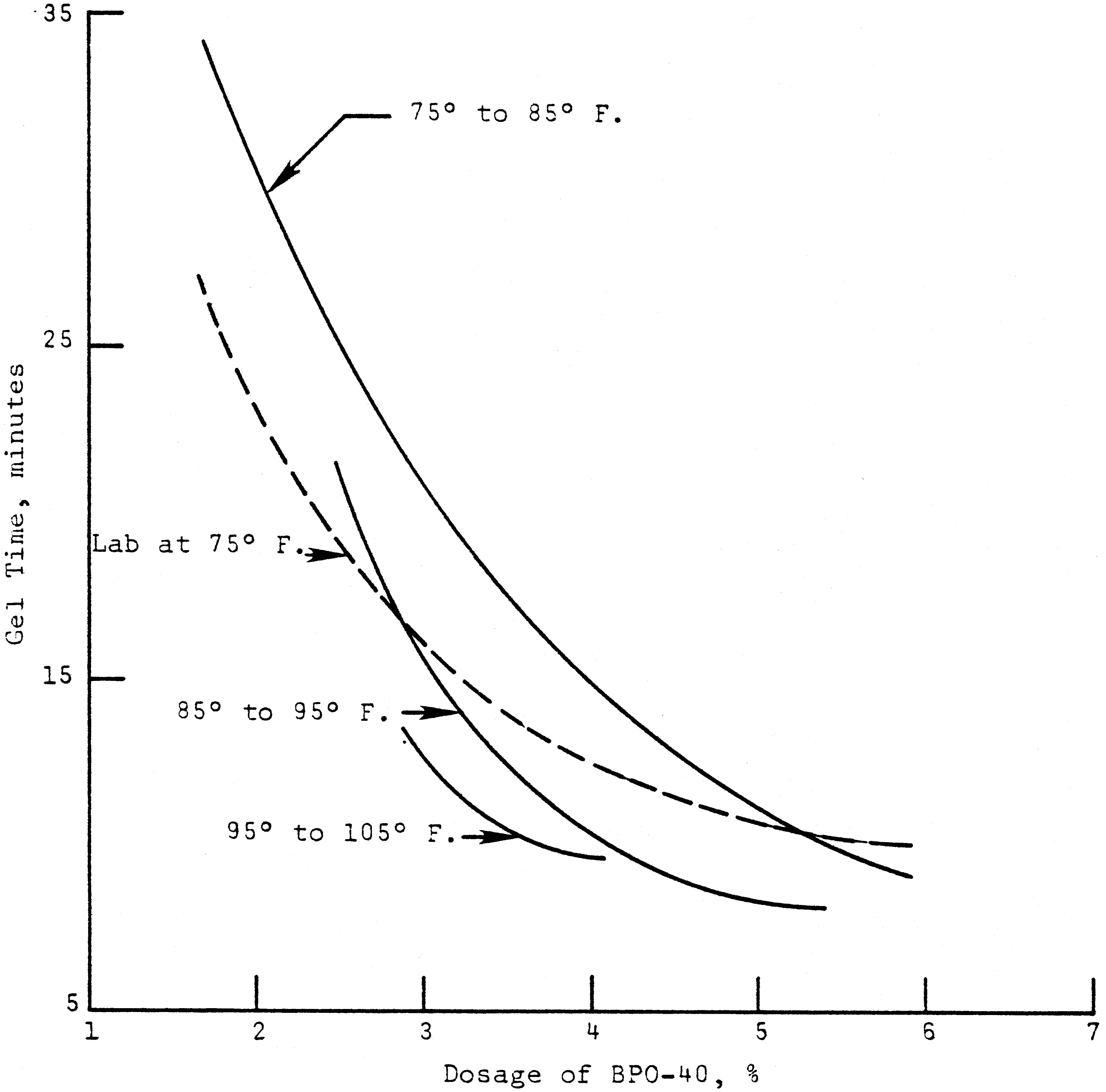

Figure 8. Gel time as a function of dosage of BPO-40 for several temperature ranges. Dosage DMA = 0.43%. °C = (°F - 32)/1.8

The MMA resin was much more difficult to apply than the polyester resin; it smelled worse because of the higher rate of evaporation, it required the application of a tack coat by hand, and it was more prone to stopping up the distribution equipment. Also, the MMA overlay was rougher because it was more prone to tracking during construction and the cost was much higher, \$54/yd.^{2} (\$65/m^2) as compared to \$41/yd.^{2} (\$49/m^2) for the polyester overlay.

CONDITION OF BRIDGE DECKS BEFORE AND IMMEDIATELY AFTER OVERLAY AND 1 YEAR AFTERWARDS

Chloride Ion Content

A chloride ion content in excess of 1.3 lb./yd.^{3} (0.77 kg/m^3) at the level of the reinforcing steel can cause the steel to corrode in the presence of oxygen and moisture.(6) Table 3 shows the approximate depth of cover over the top mat of reinforcing steel based on pacometer readings taken on a 10 ft. (3.1 m) grid spacing on the nine bridges under study. Table 4 shows the chloride content of a concrete sample obtained at each of four levels at each of three locations on the nine bridges under study except that no samples were taken from the shoulder area of bridges 4 and 7 because these bridges were not widened. The shoulder area of the other bridges contained concrete that had been placed several months prior to the installation of the overlays. All other concrete in the study bridges was approximately 20 years old. It can be seen from Table 4 that although there was sufficient chloride in the top 0.5 in. (1.3 cm) of the 20-year-old concrete in most of the study decks to cause corrosion, the data in Table 3 indicate that chloride had not migrated to the level of the rebar in sufficient quantity to cause corrosion. Of the bridges that received the polymer overlays only 1, 2, and 9 had more than 1.3 lb./yd.^{3} (0.77 kg/m^3) at the 1/2 in. (1.3 cm) to 1 in. (2.54 cm) level, and only bridge 1 had more than 1.3 lb./yd.^{3} (0.77 kg/m^3) at the 1 in. (2.54 cm) to 1½ in.(3.8 cm) level. It is interesting to note the large amount of chloride in the shoulder area (new concrete) of bridges 1 and 5. The concrete in the shoulder of bridge 5 had been in service for one winter but the concrete in the shoulder of bridge number 1 was only 2 months old and had not received deicing salt. It can be concluded from the data in Tables 3 and 4 that additional chloride could initiate corrosion and, therefore, it is anticipated that the installation of the PC overlays will prevent the infiltration of additional chloride and thereby extend the service life of the bridges.

Table 3

Cover Over Reinforcing Steel

Bridge	Percent of Total Number of Readings at Indicated Level			
	< 1.5 in.	1.5 — 1.9 in.	2.0 — 2.4 in.	> 2.5 in.
1	8	11	26	55
2	2	20	36	42
3	5	8	47	40
4	10	10	53	27
5	0	2	19	79
6	0	0	1	99
7	4	36	33	27
8	8	12	40	40
9	8	18	51	23
Avg.	5	13	34	48

2.54 cm = 1 in.

Table 4

Chloride, Cl$^-$, Content
lb./yd.^{3}

Bridge	Sample Location	Depth, in.			
		1/8 — 1/2 in.	1/2 — 1 in.	1 — 1½ in.	1½ — 2 in.
1	Shoulder	1.08	1.04	0.61	0.80
2	"	0.40	0.27	0.39	0.12
3	"	0.72	0.28	0.26	0.12
5	"	2.03	1.20	0.26	0.01
6	"	0.67	0.45	0.29	0.25
8	"	0.40	0.24	0.16	0.41
9	"	0.34	0.25	0.29	0.38
1	Traffic Lane	8.08	2.58	1.70	0.32
2	"	5.89	2.77	0.84	0.34
3	"	1.80	0.43	0.15	0.23
4	"	7.86	0.78	0.17	0.12
5	"	3.74	4.36	2.95	4.16
6	"	3.66	3.53	1.85	1.18
7	"	1.05	0.53	0.15	0.07
8	"	3.25	0.65	0.16	0.12
9	"	4.65	2.03	0.42	0.16
1	Passing Lane	1.99	1.85	1.09	0.63
2	"	2.60	1.16	0.12	0.48
3	"	0.78	0.33	0.19	0.26
4	"	0.56	0.33	0.19	0.21
5	"	4.85	2.63	1.83	1.94
6	"	3.01	3.53	2.39	2.07
7	"	1.35	0.53	0.10	0.26
8	"	1.43	0.74	0.22	0.15
9	"	1.95	0.80	0.14	0.26

NOTE: Results based on test of 1 sample at each depth.

0.59 kg/m^3 = 1 lb./yd.^{3}

2.54 cm = 1.0 in.

No corrosion-induced spalling or delamination was noted on the nine bridges. Note was made of the amount of surface scaling and cracking on the bridges. On the average, the 20-year-old concrete in the decks exhibited 25% light, 15% light to medium, 5% medium, and 5% heavy scaling. Bridges 3 and 8 were observed to be more heavily scaled than the others. Also, bridge 3 and, to a lesser degree, bridge 8 contained many transverse cracks typically spaced at 4- to 5-ft. (1.2 — 1.5 m) intervals in the skewed end areas and further apart elsewhere. Only a few transverse cracks were noted in the other bridges. Longitudinal cracks were noted at the construction joints in all the bridges except 4 and 7, which were not widened. These cracks can be significant if they reflect through the PC overlay.

Half-Cell Potentials

Copper sulfate half-cell potentials (ASTM C876-77) were measured at grid points spaced 5 ft. (1.5 m) apart over two or three spans of each of the nine bridges. The results of measurements made in 1981 prior to the construction of the overlays and again in 1982 after 1 year of service life are shown in Table 5. No measurements could be made through the impermeable PC overlays immediately after they were installed, but after 1 year the overlays had cracked enough to allow the electrical current to pass.

It can be seen in Table 5 that in both 1981 and 1982 the majority of the readings were less negative than -0.20 volt, which implies that for the deck area covered by these readings there was a 90% probability that no corrosion was occurring. No conclusion can be drawn as to the probability of corrosion for the area represented by the readings found to be between -0.20 and -0.35 volt. Only 6% or less of the reading were found to be in this range in 1981 but a higher percentage was found in 1982, 20% for bridge 1. Of greatest significance is the percentage of readings more negative than the -0.35 volt that implies a 90% probability of corrosion. With the exception of bridge 5, only 1% or less of the readings were found in this range in 1981 and 1982. Ten percent of the readings taken on bridge 5 were more negative than -0.35 volt in 1982. However, the readings for bridge 5 may not provide an accurate indication of corrosion since they were taken through a bituminous overlay and rubberized asphalt membrane. Based on the half-cell data collected in 1981 and 1982, no conclusions can be drawn as to whether or not the PC overlays were retarding or preventing corrosion of the steel.

Delamination

A delam-tech was used to find areas of delamination in two or three spans of the bridges in 1982. No areas of delamination were found to have occurred during the first year of service life.

1824

Since no delaminations were found, an effort was made to determine if the strength of the bond interface between the PC overlays and the base concrete had deteriorated during the first year. An indication of the strength of the bond interface is provided by the data in Table 6.

Shear Strength of Bond

The shear strength data shown in Table 6 are based on direct shear tests of one or more 4 in. diameter cores removed from each bridge in 1981. Two shear tests were performed on each core that contained a PC overlay. The shearing force was directed through the bond interface for the first test and through the base concrete approximately 2.5 in. (6.4 cm) below the bond interface in the second test. The shearing load was applied at the rate of 10,000 lb./min. (44.5 kN/min.).

It can be seen that the average shear strength of the new base concrete in the shoulder area was 923 lb./in.^{2} (6.36 MPa) and that of the 20-year-old concrete 690 lb./in.^{2} (4.76 MPa). Of the bridges that received the PC overlays, the lowest shear strengths were found for bridges 8 and 9, which would suggest that these two bridges would be the most likely to experience a shear failure of the base concrete. The average strength of the bond interface of the LB183 overlays was 763 lb./in.^{2} (5.26 MPa), which is greater than that of the base concrete. Only bridge 3 showed a bond interface strength less than that of the base concrete. Unfortunately, no cores were obtained in 1982 for the shear test.

Tensile Strength of Bond

The tensile strength of the bond interface was determined for 1-in. (2.5 cm) diameter cores removed from the bridges in 1981 and 1982. A load rate of 5,000 lb./min. (22.2 kN/min.) was used in an attempt to pull the overlay from the base concrete. It can be seen from the data in Table 6 that the average tensile strength of the 1 in. (2.5 cm) diameter cores in 1981 was between 143 and 230 lb./in.^{2} (0.986 and 1.59 MPa). The strength of cores removed from the bridges in 1982 were typically lower, which suggested that a deterioration in strength of the bond interface had occurred during the first year of service life. The MMA overlay exhibited the most loss in strength, 40%. The data representing the number of failures of the indicated types suggest that in 1981 the tensile strength of the bond interface was about equal to the strengths of the base concrete and the overlay, since 46% of the failures were at the bond interface. In 1982, 78% of the failures were in the bond interface.

Table 5

Electrical Half-Cell Potentials, Percentage of Total Number of Readings

		Range, (-Volts CSE)					
	Deck	<0.20		0.20 to 0.35		>0.35	
Bridge	Surface	81	82	81	82	81	82
1	MMA	94	79	6	20	0	1
2	LB183	98	96	1	4	1	0
3	LB183	98	86	2	14	0	0
4	Concrete	98	94	1	6	1	0
5	Bituminous	96	77	3	13	1	10
6	Bituminous	99	--	0	--	1	--
7	Concrete	100	--	0	--	0	--
8	LB183	95	93	5	7	0	0
9	LB183	94	100	6	0	0	0

Table 6

Bond Strength Data

		1981 Shear Strength, lb./in.^{2}			Tensile Strength							
					1981				1982			
		Concrete		Bond	Strength,	No. Failures of Indicated Type			Strength	No. Failures of Indicated Type		
Bridge	Deck Surface	New	Old	Interface	lb./in.^{2}	Polymer	Bond	Concrete	lb./in.^{2}	Polymer	Bond	Concrete
1	MMA	1,404	921	--	230	0	2	2	139	0	3	0
2	LB183	838	774	1,125	171	0	1	1	157	1	4	0
3	LB183	1,124	730	469	143	0	2	0	105	0	5	0
4	Concrete	--	597	--	--	-	-	-	--	-	-	-
5	Bituminous	660	565	--	--	-	-	-	--	-	-	-
6	Bituminous	744	--	--	--	-	-	-	--	-	-	-
7	Concrete	--	848	--	--	-	-	-	--	-	-	-
8	LB183	832	541	776	191	2	0	0	152	1	2	3
9	LB183	860	541	681	195	0	1	2	211	0	4	0
Avg.	LB183	923[a]	690[a]	763	175	1	1	1	156	1	4	1

---

[a] All bridges

6.89 kPa = 1 lb./in.^{2}

The most significant points to be made from the data in Table 6 are that the strength of the bond interface was generally good at the time the PC overlays were constructed and that the strength of the bond interface decreased during the first year. It will be interesting to see if the differences in bond strengths between the bridges will have an effect on the service life.

Skid Resistance

Skid numbers were determined from test at 40 mph (64 km/hr) in the travel lane and passing lane of each bridge in 1980 prior to the installation of the PC overlays, in 1981 after they were installed, and in 1982 after 1 year of service life. The numbers were determined with a treaded tire (ASTM E501-76) and a smooth tire (ASTM E524-76).

The skid test results shown in Table 7 indicate that the bridges yielded similar skid numbers in 1980 with the unexplained exception that the bridges with the bituminous overlays exhibited a relatively high number when tested with the smooth tire. Immediately after the PC overlays were installed, the overlaid bridges exhibited skid numbers at least 30% greater than those of the control bridges when tested with the treaded tire and 100% greater when tested with the smooth tire. Tests conducted after 1 year of service life indicated that the bridges with the PC overlays yielded a skid number at least 10% greater with the treaded tire and 60% greater with the smooth tire. Clearly, the installation of the PC overlays has resulted in a major improvement in skid resistance, but a significant portion of the improvement was lost during the first year. A projection of the trends represented by the data in Table 7 suggests that the skid numbers for the bridges with the PC overlays will be similar to that of the control bridges after 5 years of service life.

Rutting in Wheel Paths

A 12-ft. (3.7 m) straightedge was used to measure rutting in the wheel paths. Measurements were made at 10-ft. (3.1 m) intervals along the length of two or three spans of each bridge in both traffic lanes. Readings obtained after 1 year of service life were subtracted from readings obtained immediately after the overlays were installed to gain an indication of the rutting that occurred in the first year. The results, which are shown in Table 8, indicate that on the average less than 1/32 in. (0.8 mm) of rutting occurred during the first year. The MMA overlay and the exposed concrete rutted the least and the LB183 and bituminous overlays the most.

Table 7

Skid Numbers at 40 MPH (64 km/hr.)

Bridge No.	Deck Surface	Treaded Tire Travel Lane 80	81	82	Treaded Tire Passing Lane 80	81	82	Smooth Tire Travel Lane 80	81	82	Smooth Tire Passing Lane 80	81	82
1	MMA	46	59	53	49	60	54	26	56	38	22	54	43
2	LB183	46	64	58	51	63	57	24	63	46	22	62	46
3	LB183	45	63	57	53	58	61	25	62	43	33	60	50
4	Concrete	46	43	48	50	46	51	27	27	24	24	24	23
5	Bituminous	45	43	42	44	43	44	41	27	23	41	25	20
6	Bituminous	46	49	45	44	47	49	41	25	20	44	30	20
7	Concrete	47	47	51	50	48	52	30	27	28	24	28	26
8	LB183	46	59	55	48	64	55	25	58	42	23	64	45
9	LB183	47	62	56	52	61	59	23	60	44	24	60	50
Avg.	LB183	46	62	56.5	51	61.5	58	24	61	44	25.5	61.5	48

Table 8

Rutting in Wheel Paths During First Year, 1/32 in., (0.8 mm)

Bridge	Passing Lane Left	Passing Lane Right	Traffic Lane Left	Traffic Lane Right	Average
1-MMA	0.0	0.4	0.1	0.2	0.2
2-LB183	1.8	0.1	0.6	0.3	0.7
3-LB183	0.8	0.0	(0.9)*	0.8	0.2
4-Concrete	0.1	0.0	0.7	0.5	0.3
5-Bituminous	0.8	0.6	0.6	1.1	0.8
8-LB183	0.3	1.1	0.2	0.0	0.4
9-LB183	0.3	1.7	0.9	0.5	0.9
Avg.-LB183	0.8	0.7	0.2	0.4	0.5

---

* Relatively higher in wheel path because high area next to wheel path wore during first year.

Ride Quality

Tests were made with the Mays meter and rolling straightedge to evaluate the ride quality of the PC overlays as reflected by inches of roughness and percent of deck out of level. It was found that the ride quality of the bridges that received the LB183 overlays did not change. On the other hand, the rolling straightedge indicated that for bridge 1 the percentage of the deck area out of level by more than ± 1/8 in. in 10 ft. (3.2 mm in 3.1 m) increased by a factor of 3 as a result of the installation of the MMA overlay.

Electrical Resistivity

Electrical resistivity measurements (ASTM D3633-77) were made on 5 ft. (1.5 m) grid points immediately following the installation of the PC overlays and in 1982 after 1 year of service life. The results, which are reported in Table 9, indicate that a majority of the original readings for the PC in 1981 were in the good to excellent range whereas the majority of the readings taken at the same locations in 1982 were in the poor to fair range. The data in Table 9 clearly indicate that the overlays had cracked enough during the first year to allow water to penetrate the surface at a majority of the points where the readings were taken. Therefore, it would be expected that the permeability had increased significantly during the first year in service.

The greatest amount of cracking, as illustrated in Figure 9, had occurred in bridge 1, which received the MMA overlay. Readings taken on this deck in 1982 were comparable to those for an exposed concrete surface. A wide range of results were obtained for bridges 5 and 6, which were overlaid with a rubberized asphalt membrane and bituminous concrete, and these readings should be viewed with caution as it is possible to get misleading results if water is present in the bituminous concrete.

Permeability

A rapid permeability test recently developed by the Portland Cement Association for the FHWA was used to determine the permeability to chloride ion of 4 in. (10 cm) diameter cores removed from the bridges.(7) The results are shown in Table 10. An average permeability of 6,467 coulombs was determined for the base concrete based on tests of cores obtained from bridges 1, 2 and 6. The permeability of the concrete in bridges 4 and 7 was significantly lower for reasons that are unknown at this time.

Table 9

Electrical Resistivity, Percentage of Total Number of Readings

		Range of Electrical Resistivity, ohm/ft.^{2}							
	Deck	Poor $<10^4$		Fair 10^4 to $<10^6$		Good 10^6 to 10^8		Excellent $>10^8$	
Bridge	Surface	81	82	81	82	81	82	81	82
1	MMA	0	100	23	0	11	0	66	0
2	LB183	0	24	4	73	1	3	95	0
3	LB183	0	38	12	55	16	7	72	0
4	Concrete	91	100	9	0	0	0	0	0
5	Bituminous	4	24	36	34	13	9	47	33
6	Bituminous	1		29		25		45	
7	Concrete	100		0		0		0	
8	LB183	0	44	9	26	53	30	38	0
9	LB183	0	46	5	52	9	2	86	0
Avg.	LB183	0	38	7	52	20	10	73	0

10.8 ohm/m^2 = 1. ohm/ft.^{2}.

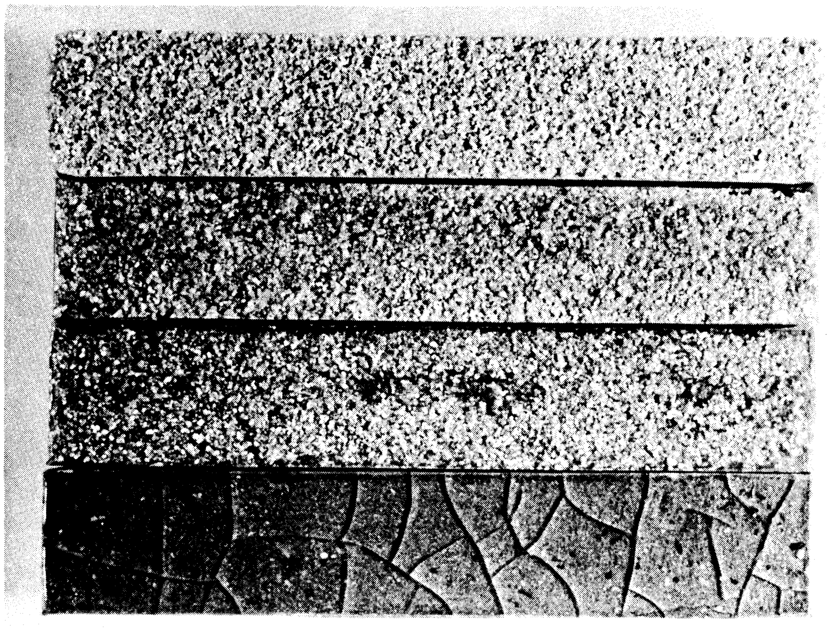

Figure 9. Top view of bonded PC overlays prepared with MMA and aggregate application rates of 0, 14, 28, and 56 lb./yd.^{2}, from bottom to top of figure. Cracks in the specimen with no aggregate are obvious after 1 thermal cycle (0.54 kg/m^2 = 1 lb./yd.^{2}).

1830

Table 10

Permeability Data, Coulombs

Bridge	Deck Surface	Year 1981[a]	 1982
1	Concrete[b]	6974	—
2	Concrete[b]	6109	—
1	MMA	216	1331
2	LB183	12	384
3	LB183	167	3607
4	Concrete	3100	—
5	Bituminous[c]	69	—
6	Bituminous[d]	6349	—
7	Concrete	2494	—
8	LB183	200	747
9	LB183	37	370
Avg.	LB183	62	787
Avg.	Concrete 1, 2, 6	6467	—

[a] Average of three specimens, one each from shoulder, traffic and passing lane.

[b] Base concrete prior to overlay.

[c] Concrete after removing bituminous overlay.

[d] Concrete after removing bituminous overlay and rubberized asphalt membrane.

The permeability of the cores with the PC overlays were significantly lower than those of the cores from the control bridges, except for bridge 5, which was tested with the rubberized asphalt waterproofing membrane in place. However, the average permeability of the PC overlays was significantly higher for the cores taken in 1982 as compared to 1981. The higher permeability in 1982 agrees with the electrical resistivity measurements, which indicated that the overlays had cracked during the first year in service. It is believed that the cracks were caused by shrinkage, the reflection of cracks from the base concrete, and by thermally-induced stress.(5)

Figure 10 shows the effect of cycles of temperature change on the permeability of the PC overlays, the base concrete and a protective overlay consisting of an 1.25 in. (3.2 cm) layer of latex-modified concrete. For each cycle the temperature was made to vary from 10°F. (-12° C) to 100° F. (38° C) at the rate of 3 cycles per day. The thermal cycles did not significantly change the permeability of the base concrete or the latex-modified concrete overlay. The permeability of the cores with the PC overlays increased with an increase in the number of thermal cycles. For example, the MMA exhibited a permeability of 216 coulombs at 0 cycles, and the permeability increased to 1,560 and 2,067 coulombs at 51 and 102 cycles, respectively. After 1 year in service the permeability was 1,331, which suggests that approximately 40 thermal cycles are equivalent to the forces causing change during that year.

The average permeability of the cores with the LB183 overlays taken from four bridges was 62 coulombs at 0 cycles and 658 and 942 coulombs after 51 and 102 cycles, respectively. The 787 coulombs recorded after one year in service suggest that approximately 70 thermal cycles are equivalent to the first year deterioration. A projection of the curves in Figure 10 would suggest that the permeability of the LB183 overlays will be less than that of the base concrete for at least 5 years and that the permeability of the MMA overlay will equal that of the base concrete in less than 5 years.

Figure 11 provides an indication of the effect of the concrete deck temperature at the time the overlays were installed and the effect of the sand application rate on the permeability of the overlays constructed with LB183 resin based on 12 cores obtained from the four bridges in 1981 and 13 in 1982. It can be seen that the initial permeability and the permeability after 1 year of service life increased as the placement temperature increased and as the sand application rate decreased. It would appear that the lowest permeability can be obtained by placing the PC overlays at the lower temperatures and by sanding the resin to an excess.

1832

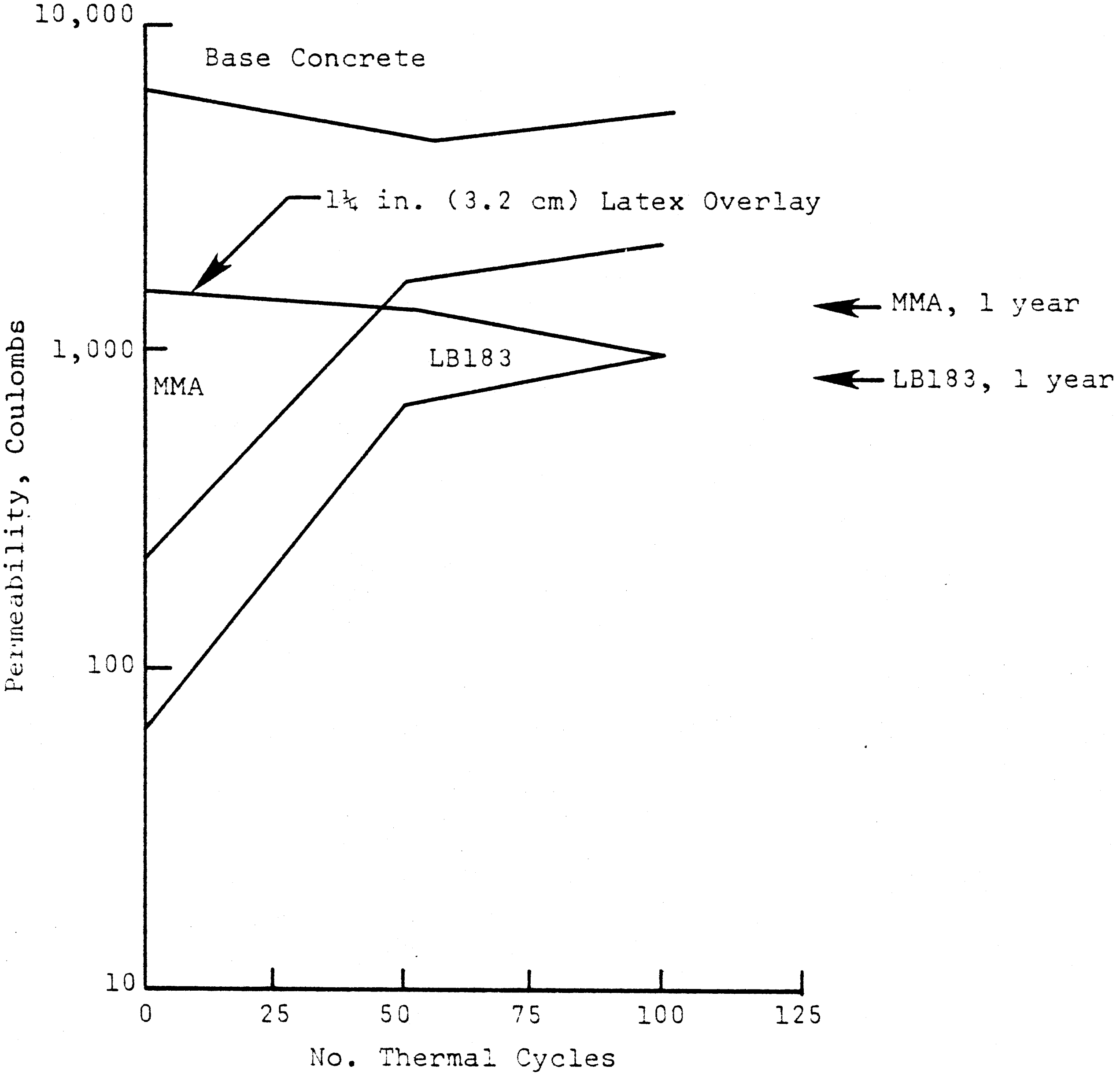

Figure 10. Permeability to chloride ion of PC overlays as a function of number of thermal cycles.

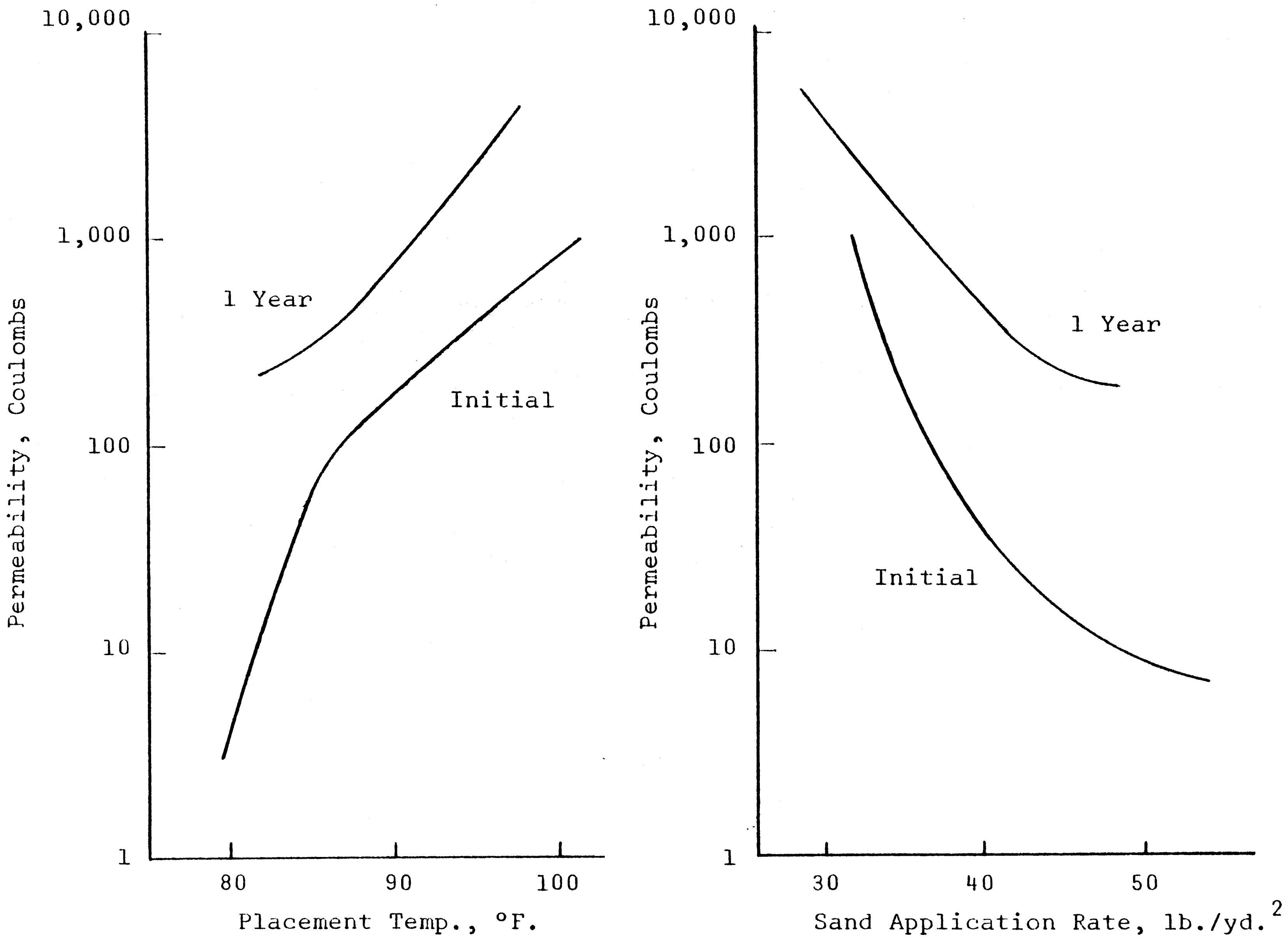

Figure 11. Effect of placement temperature and sand application rate on permeability.
°C = (°F - 32)/1.8; 0.54 kg/m^2 = 1 lb./yd.^{2}

1824

Rate of Corrosion Based on Corrosometer Probes

Six corrosometer probes were installed in bridges 2, 3, and 5 prior to placement of the overlays. The probes were precast into a 2 in. x 3 in. x 11 in. (5.1 cm x 7.6 cm x 27.9 cm) concrete specimen containing 15 lb./yd.^{3} (8.9 kg/m^3) of chloride ion. Three probes were installed in the right wheel path and three along the right parapet in one span of each bridge. The probes were placed so as to have the same elevation as the top mat of reinforcing steel. It was hoped that the overlays would keep out moisture so that the probes would not corrode even in the presence of 15 lb./yd.^{3} (8.9 kg/m^3) of chloride ion.

Table 11 shows the average corrosion rate in mils (2.5 nm) per year at the time the overlays were placed and on December 8, 1982, for the six probes in each bridge. No conclusions can be drawn at this time. The rate of corrosion for bridge 5, which has a rubberized asphalt membrane was higher in December than when the bituminous overlay was placed. Though bridges 2 and 3 both have LB183 overlays, the rate of corrosion was higher in 2 and lower in 3 in December as compared to the rate at the time the overlays were installed.

Table 11

Rate of Corrosion, Mils/Yr.

	Bridge No. and Surface Type		
	2	3	5
Date	LB183	LB183	Bituminous
1981	0.45	5.14	0.93
12/8/82	1.86	3.83	2.00

2.5 nm = 1 mil

Assessment of Condition of PC Overlays

Prior to the installation of the PC overlays the decks were in sound condition, the steel was not corroding, and there was no corrosion-induced delamination. Chloride contents were high in some bridges, but below levels necessary to cause corrosion in the steel.

The deck surfaces were properly prepared and the PC overlays were initially soundly bonded to the base concretes. The overlays are providing a wearing surface of low permeability and high skid resistance following 1 year in service. The MMA overlay has deteriorated more than the LB183 overlays, and it will be interesting to monitor the performance of these overlays over the coming years as they are subjected to wear, reflective cracking, and thermally-induced stress.

EVALUATION OF PROCEDURES IN USER MANUAL

One objective of this research was to evaluate the procedures recommended in FHWA-TS-78-225, "Polymer Concrete Overlays, Interim User Manual — Method B". Based on the experience gained from the construction and evaluation of the five PC overlays located near Williamsburg and a sixth PC overlay installed by maintenance forces near the Dulles Airport,(8) it can be concluded that most of the procedures in the user's manual are acceptable. However, the following changes are recommended.

1. The following statement should be added to Section 1.2. "The overlay will not prevent the corrosion of steel when sufficient chloride is present in the vicinity of the steel to cause corrosion."

2. The recommended compaction of the aggregate into the monomer in Section 1.3 should be omitted. The mechanical compacting of the aggregate is unnecessary, can cause an excess of voids in the overlay, and has the potential to damage the overlay.

3. Section 1.3 should be changed to indicate an overlay of four layers is approximately 0.5 to 0.6 in. (1.3 to 1.5 cm) thick and weighs about 5 to 6 lb./ft.^{2} (239 to 287 N/m^2).

4. Section 2.0 should be changed to indicate that shotblasting is required for cleaning the surface of the deck. The following statements should be added to Section 2.0. "The shotblasted surface should be covered with at least one layer of polymer before it is opened to traffic. Subsequent layers can be placed on an uncontaminated surface at a later date. When feasible, the fourth layer should be placed at least

one day after the first layer is placed so that shrinkage and reflection cracks can be filled with resin."

5. Polylite 90-570 should be added to Section 3.1. Also, Section 3.1 should indicate that the first course shall contain 1% A-174 coupling agent and 1% S440 wetting agent, and subsequent courses should contain 0.5% of each additive.

6. Section 3.3 should be modified to include the following statement. "The concentration of initiator and promoter should be adjusted as necessary to obtain a working time of 10 to 20 minutes as determined by the observation of a 1.7 oz. (50 ml) sample of resin that does not contain aggregate."

7. Section 3.3.2 should be changed to indicate that the initiator should be mixed thoroughly with the monomer. The experience with mechanized distribution equipment in the present study indicates that the initiator does not have to be mixed with the monomer for 3 minutes.

8. Section 4.0 should be changed to indicate "angular-grained" silica sand.

9. The gradations in Section 4.0 should be as follows:

	Percent Passing Indicated U.S. Sieve Size				
Sieve Size	8	12	16	20	30
Layers 1 & 2	—	95-100	20-55	5-10	Max. 1
Layers 3 & 4	95-100	40-55	5-15	Max. 1	—

10. The paragraph dealing with compaction should be omitted from Section 5.0.

11. The monomer application rates in Section 5.0 should be changed to 2.0 ± 0.25 lb./yd.^{2} (1.1 ± 0.14 kg/m^2) for layer 1 and 2.75 ± 0.25 lb./yd.^{2} (1.5 ± 0.14 kg/m^2) for layers 2, 3, and 4. The aggregate application rate should be changed to 17 ± lb./yd.^{2} (9.2 ± kg/m^2) with a note to cover the resin completely.

12. The MEKP concentrations for the polyester resin shown in Table 1 should be increased to 1.5% for mix 1 and 1.0% for mix 2, so that a work time of 10 to 20 minutes can be obtained.

13. Figure 1 should be modified so that work times greater than 20 minutes are not shown.

14. Figure 5 should be omitted.

15. Other chemicals and suppliers should be added to Appendix A.

    Polyester Resin —U.S.S. Chemicals

    Initiator, BPO-40 —Reichhold Chemicals

CONCLUSIONS

1. The installation of thin polymer concrete overlays on five bridges on I-64 near Williamsburg demonstrates that PC overlays of low permeability and high skid resistance can be successfully installed by a contractor with a minimum of disruption to traffic — approximately 8 hr. per lane.

2. The initial condition of the overlays was excellent from the standpoint of permeability, skid resistance, and bond, although some overlays were better than others.

3. All the overlays were in good to excellent condition after 1 year in service, but the permeability increased and the bond strength and skid resistance decreased significantly during the first year.

4. Based on the data collected during the first year it is projected that the polyester overlays constructed with LB183 resin will have a useful service life of at least 5 years and that the MMA overlay will fail in less time.

ACKNOWLEDGEMENTS

The contributions of many persons to this project are gratefully acknowledged.

Significant technical contributions concerning the installation of the overlay were provided by Milton Collins of the Cooperative Construction Company, the subcontractor who installed the overlays; Richard Steele of the Virginia Department of Highways and Transportation's Materials Division; John Bartholomew and, more recently, Thomas Larkin of the Office of Implementation of the FHWA; Charles Chambers of the FHWA; and Jack Fontanna of the Brookhaven National Laboratory. Assistance in planning was provided by the members of the Council's Bridge and Concrete Research Advisory Committees.

Assistance with the collection of data was provided by the subcontractor's work crew, personnel from the Materials Division at Elko, personnel from the Williamsburg Residency, skid test personnel from the Lynchburg District, and the technicians and several temporarily employed students in the Concrete and Bridge Group of the Council.

Arlene Fewell handled the secretarial responsibilities and the Report Section under Harry Craft, edited and reproduced this report.

The study is being conducted under the direction of Howard Newlon and with the administrative guidance and support of Harry Brown.

The study is being financed with HPR funds as a Type A study.

1840

REFERENCES

1. "Applications of Polymer Concrete", Publication SP-69, American Concrete Institute, Detroit, Michigan, 1981, pp. 21-43.

2. "Polymer Concrete Overlays, Interim Users Manual — Method B", U. S. Department of Transportation Washington, D. C., FHWA-TS-78-225, February 1978.

3. Sprinkel, Michael M., "Working Plan — Evaluation of the Construction and Performance of Polymer Concrete Overlays on Seven Bridges", VHTRC 80-WP4, Virginia Highway and Transportation Research Council, Charlottesville, Virginia.

4. "Special Provision for Polymer Concrete Overlay", Virginia Department of Highways & Transportation, Richmond, Virginia, April 1981.

5. Sprinkel, Michael M., "Thermal Compatibility of Thin Polymer Concrete Overlays", paper presented at the Annual Meeting of the Transportation Research Board, Washington, D. C., January 1983.

6. "Durability of Concrete Bridge Decks", NCHRP 57, Transportation Research Board, Washington, D. C., May 1979.

7. Whiting, D., "Rapid Determination of the Chloride Permeability of Concrete", FHWA-RD-81/119, August 1981.

8. Sprinkel, Michael M., "Polymer Concrete Overlay on Beulah Road Bridge", VHTRC 83-R28, February 1983.