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16. Abstract

This interim report presents the results after 5 years of a study undertaken to evaluate multiple layer polymer concrete overlays over a 10-year period. The report indicates that an overlay of low permeability and high skid resistance can be successfully installed by a contractor or by state or federal labor forces with a minimum of disruption to traffic. With one exception, the initial condition of the 10 overlays that have been evaluated since 1981 was good to excellent from the standpoint of permeability, skid resistance, and bond, although some overlays were better than others. Also, with one exception, the overlays 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. Although evaluations made at 3 years and 5 years of age showed a continuing decrease in skid number and bond strength and an increase in permeability, three overlays near Williamsburg had an acceptable skid number and permeability at 5 years of age, but these overlays can be expected to delaminate further at an age of 5 to 10 years because the concrete surface was not properly prepared prior to placing the overlays. Multiple layer polymer overlays constructed in accordance with the special provision of March 1987, can be assumed to have a useful life of 10 years and to provide an economical alternative for extending the life of decks for which maintenance should be done during off-peak traffic periods.

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SI CONVERSION FACTORS

To Convert From	To	Multiply By

Length:

in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344

Area:

in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
acre (a)	Hectares	4.046 856 E-01

Volume:

oz	m^3	2.957 353 E-05
pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01

NOTE: 1m^3 = 1,000 L

Volume per Unit Time:

ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05

Mass:

oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02

Mass per Unit Volume:

lb/yd^2	kg/m^2	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01

Velocity: (Includes Speed)

ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00

Force Per Unit Area:

lbf/in^2 or psi	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01

Viscosity:

cS_t	m^2/s	1.000 000 E-06
P	Pa·s	1.000 000 E-01

Temperature: (°F-32)^5/9 = °C

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EVALUATION OF THE CONSTRUCTION AND PERFORMANCE OF MULTIPLE LAYER POLYMER CONCRETE OVERLAYS

Interim Report No. 2
Condition of the Overlays After Five Years in Service

by

Michael M. Sprinkel
Research Scientist

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

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(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
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Charlottesville, Virginia

May 1987
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SUMMARY

This interim report presents the results after 5 years of a study undertaken to evaluate multiple layer polymer concrete overlays over a 10-year period. The report indicates that an overlay of low permeability and high skid resistance can be successfully installed by a contractor or by state or federal labor forces with a minimum of disruption to traffic. With one exception, the initial condition of the 10 overlays that have been evaluated since 1981 was good to excellent from the standpoint of permeability, skid resistance, and bond, although some overlays were better than others. Also, with one exception, the overlays 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. Although evaluations made at 3 years and 5 years of age showed a continuing decrease in skid number and bond strength and an increase in permeability, three overlays near Williamsburg had an acceptable skid number and permeability at 5 years of age, but these overlays can be expected to delaminate further at an age of 5 to 10 years because the concrete surface was not properly prepared prior to placing the overlays and because moisture, temperature change, and traffic deteriorate the bond interface. Multiple layer polymer overlays constructed in accordance with the special provision of March 1987, can be assumed to have a useful life of 10 years and to provide an economical alternative for extending the life of decks for which maintenance should be done during off-peak traffic periods.

EVALUATION OF THE CONSTRUCTION AND PERFORMANCE OF MULTIPLE LAYER POLYMER CONCRETE OVERLAYS

Interim Report No. 2
Condition of the Overlays After Five Years in Service

by

Michael M. Sprinkel
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INTRODUCTION

Multiple layer polymer concrete (PC) overlays have been installed on portland cement concrete bridge decks in Virginia and several other states during the past nine years(1,2,3,4,5,6,7). The overlay consists of three or four layers of resin and clean, dry, angular-grained silica sand applied to the top of a portland cement concrete deck to provide a 0.4-to 0.5-in thick, relatively impermeable, skid resistant wearing surface(8). Typically, the initiated and promoted resin is sprayed uniformly over the surface of the deck (Figure 1), and before it gels (10 to 20 minutes), it is covered with an excessive amount of broadcasted fine aggregate (Figure 2). Usually, within the first hour, a layer cures sufficiently to permit vacuuming the excess aggregate preparatory to placing a subsequent layer. The PC overlay has the advantage over other deck protective systems that it can be constructed in stages during off-peak traffic periods: a lane can be closed and shotblasted (Figure 3), one layer of resin and aggregate applied one day or night, and the subsequent layers on the next day or night.

The installation of PC overlays on five bridges on I-64 near Williamsburg, Virginia, in 1981; a sixth bridge near Vienna, Virginia (Beulah Road bridge), in 1982; a seventh bridge near Columbia, Tennessee (Big Swan Creek bridge), in 1983; and on eleven bridges in the Culpeper and Suffolk Districts of Virginia in 1985 has demonstrated that an overlay of low permeability and high skid resistance can be successfully installed by a contractor or by state or federal labor forces with a minimum of disruption to traffic, and at a reasonable cost. General information on these overlays is shown in Tables A-1 and A-2 of Appendix A. The initial condition of the overlays was observed to be excellent from the standpoint of permeability, skid resistance, and bond, although some overlays were better than others.

With two exceptions, the resins used were clear, low viscosity, highly resilent, general purpose, unsaturated polyester styrene resins designed for applications requiring resistance to wear and high impacts. U.S.S. Chemical's blend LB183 was used on four bridges near Williamsburg and the

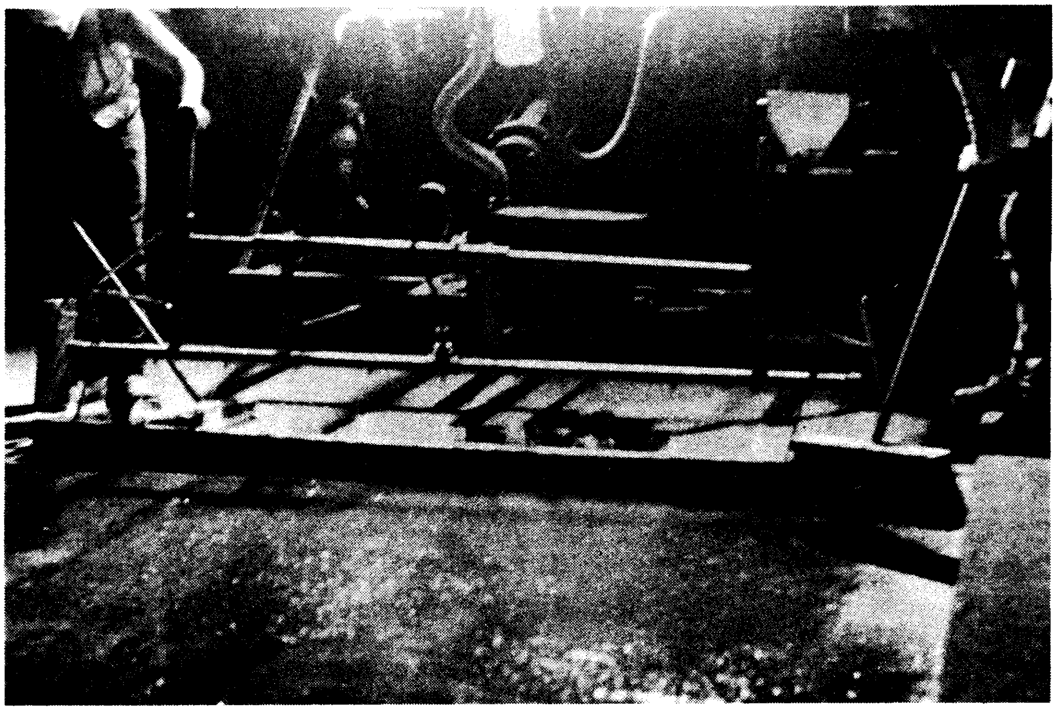

Figure 1. Polyester resin is sprayed and brushed onto a concrete deck (I-64 WBL over Hampton Roads) the same night the deck was shotblasted.

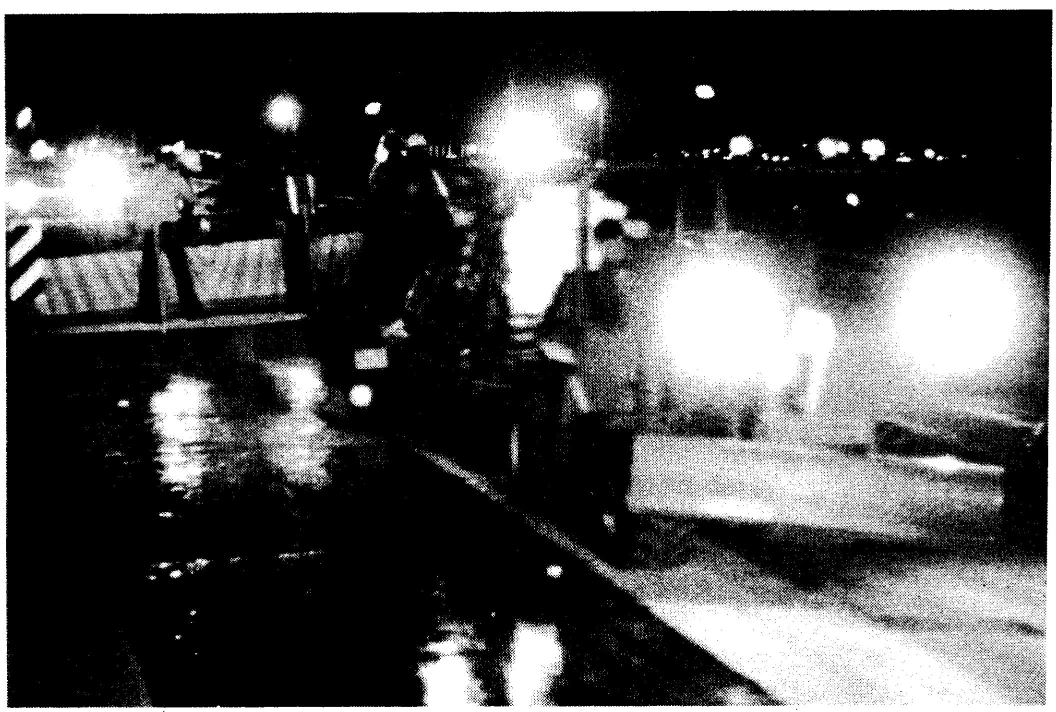

Figure 2. Silica aggregate is broadcast onto the freshly placed resin using Dural's wing spreader.

Figure 3. Shotblast equipment can clean deck at rate of 12 yd^2/min. Smaller unit removes paint lines on bridge over Rivanna River.

northbound lane of the Beulah Road bridge; Reichhold Chemical's blend Polylite 90-570 was used on the southbound lane of the Beulah Road bridge and on 10.5 of the structures overlaid in 1985; and Dural International's blend 317 was used used on the Big Swan Creek bridge. The resin for the first course contained 1% of the Union Carbide A-174 coupling Agent and 1% of Surfynol S440 wetting agent to enhance the bond strength and reduce surface tension. The second, third, and fourth courses contained 0.5% of Union Carbide A-174 coupling agent and 0.5% of Surfynol S440 wetting agent. A methyl methacrylate (MMA) resin was used on bridge W-1 near Williamsburg, and Dow Chemical's XU40047 polyester amide alkyd resin was used on the passing lane of the EBL over the Rivanna River. Although higher rates were used prior to 1986, the resins are currently applied at the following rates: layer 1--1.75 lb/yd^2, layer 2--2.25 lb/yd^2, and layer 3--2.75 lb/yd^2.

Two initiators were used: (1) 60% methylethylketone peroxide (MEKP) ($C_4H_8O_2$) in dimethyl phthalate and (2) 40% benzoyl per oxide dispersion (BPO-40) (only used on bridges near Williamsburg), equal to Reichhold Chemical's formulation 46-742. Also, two promoters were used: (1) an approximately 6% active cobalt in naphtha (CoN), and (2) N, N dimethyl aniline (DMA) ($(C_6H_4N)CH_3)_2$ (only used on bridges near Williamsburg).

The aggregate was a clean, dry (less than 1% moisture), angular-grained silica sand, free from dirt, clay, asphalt, and other organic materials and having a gradation as reported in Table 1.

TABLE 1

Gradation of Aggregate Used in Overlays

Layers	Grading	Percent Passing Indicated U.S. Sieve No. 8 Sieve	No. 12 Sieve	No. 16 Sieve	No. 20 Sieve	No. 30 Sieve	No. 100 Sieve
3 & 4	A	95-100	---	Max. 15	Max. 5	Max. 2	Max. 1
1 & 2	D	---	95-100	30-70	Max. 10	Max. 3	Max. 1

Prior to the placement of the first layer of polymer and after all major spalls had been repaired, the decks were shotblasted with a machine that recycles the steel shot, collects concrete cuttings, and rapidly provides at low cost and with little or no environmental impact a completely cleaned deck. The equipment cleans the deck at a rate of 100 to 720 yd^2/hr, depending on the size of the unit(2,3,5,6,7). It does not fracture the aggregate or paste as is common when jackhammers or scarification equipment are used(9). Also, it cleans more efficiently and completely than sandblasting equipment.

PURPOSE AND SCOPE

The purpose of this report is to describe the performance of all of the overlays on the bridges near Williamsburg after 3 years of service, the three bridges in the eastbound lane near Williamsburg after 5 years of service, the southbound lane of the Beulah Road bridge after 4 years of service, and a 200 ft section of the eastbound lane of the Rivanna River bridge (I-64 over Rivanna River in Albemarle County) after 1 year in service. This report also describes improvements in specifications, equipment, and installation procedures based on data collected by project inspectors and on observations made during one or more visits to the job sites during the installations in 1985 and 1986.

The first part of the report provides a brief summary of the installations in 1985 and 1986. The second part describes performance based on the data collected on the bond between the overlay and the deck concrete, and attempts to answer the question how long will the overlay stay down. The third part describes performance based on the protection provided by the overlays in preventing the infiltration of water and salt, thereby preventing corrosion of the reinforcing steel and extending the life of the decks. The fourth part describes performance based on the skid resistance and wear of the overlays. Part 5 shows the effects of the tensile properties of binders on performance, and Part 6 shows the effects of additives and primers on bond strength. Part 7 discusses implementation based on the finding that the environment affects the bond strength, permeability, skid number, and wear.

SUMMARY OF OVERLAY INSTALLATIONS IN 1985 AND 1986

As can be seen from Table A-1, 33,655 yd^2 of polymer overlay were placed in 1985. A polyester styrene resin prescribed by the special provision for polymer overlays was used in all overlays placed in 1985. The resin was promoted with Cobalt Naphthenate, and methyl ethyl ketone peroxide (MEKP) was added just prior to application of the resin. The resin was sanded with an excess amount of silica sand as prescribed by the special provision. Data on placement temperature, resin application rates, dosages of initiator, and gel times for some installations are shown in Table A-2. Highlights of the installations follow.

I-64 Over the Rivanna River

The resin and aggregate were placed with the equipment that had been used in 1981 to construct the overlays near Williamsburg. Although the equipment has been modified slightly, the description provided in the first interim report is adequate(3).

The contractor was allowed to close a lane between sunrise and sunset. He had planned to install the overlay in 2 to 3 weeks, but because of problems with his resin distribution equipment and shotblast equipment the installation took 60 days. The problem with the resin distribution equipment was that the initiator pump would not inject a uniform quantity of MEKP and thus portions of the resin were under-initiated. The contractor had used BPO40 initiator in 1981. The resin with the low initiator content would not gel in the time prescribed by the special provision and had to be removed. The contractor was able to confine the uncured areas to the first few feet of spray by injecting more initiator than would be required if proper mixing were achieved. Polyethylene and sand were placed on the surface below the spray bar to collect the first few feet of spray.

Two large Mike Swain shotblast units from Rustin, Louisiana, were able to shotblast the deck at a rate of up to 12 yd^2/min (Figure 3). However, the unit would not remove the paint stripes and would not clean the surface within 6 in of the parapet. The contractor rented a small shotblast unit that was supposed to clean a 9-in wide strip to handle the edge work and the paint stripes. However, the unit never worked properly and caused major delays. The contractor eventually used sandblast equipment to clean the edges and a small grinder to remove the paint lines.

Dow Chemical supplied the resin for the passing lane of the EBL. The resin was different from the 92-339 resin supplied by Reichhold Chemicals, which was used on 75% of the project, in that it contained 37% polyester-amide alkyd and 15% vinyl reactive plasticizer. Also, 0.1% Di-methyl-p-toluidine was added to accelerate the cure. In addition, it was necessary to add sufficient initiator to achieve a gel time of less than 10 minutes to obtain a cure on the deck that would allow the excess sand to be removed one hour after application.

I-64 Over Hampton Roads

Prior to placing the overlays at Hampton Roads, the contractor installed a Dow Chemical constant-flow cam pump that eliminated the problem with the under-initiated areas on the deck. Also, the contractor sandblasted the edges, applied a 6-in wide layer of polymer and sand along the edges, and removed the pavement markings prior to mobilizing for the overlay installation. Mike Swain shotblast units were used. The contractor placed the 5,500 yd^2 of PC required for the WBL in 10 nights and the 13,334 yd^2 required for the EBL in 17 nights (Figure 4). The contractor was allowed to close the lane only from 8:00 p.m. to 5:00 a.m., Monday through Thursday. The operations were so well-organized that the contractor constructed the overlay on the EBL at an average rate of 157 yd^2/hr (based on a 5-hour installation period).

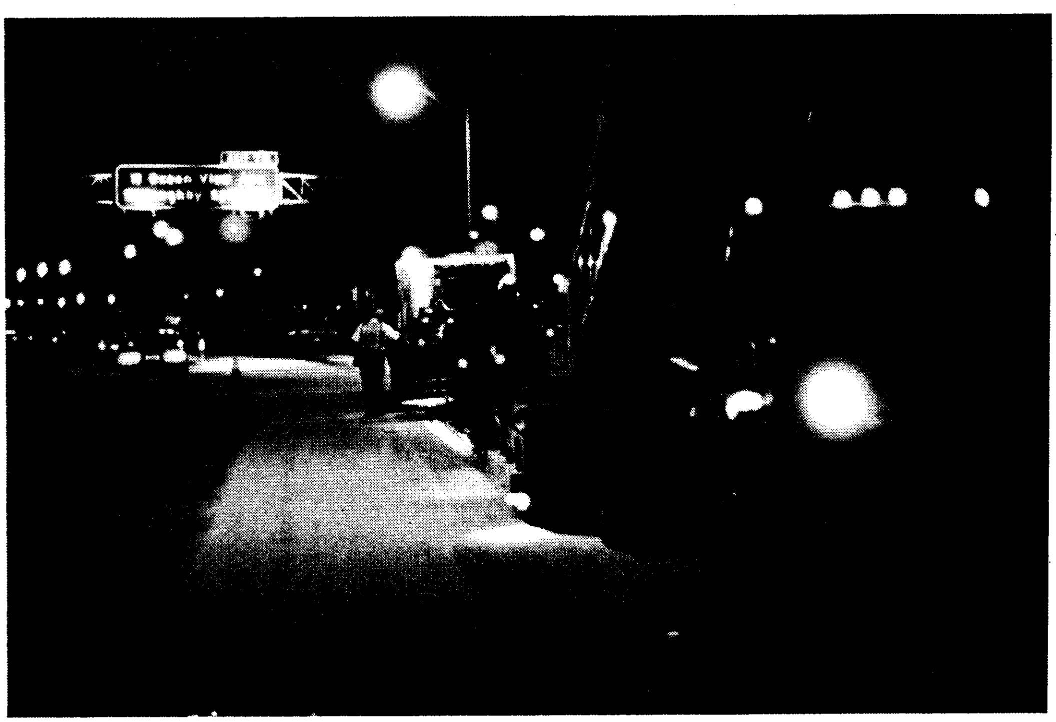

Figure 4. Polyester resin and aggregate applied at night (I-64 EBL over Hampton Roads).

Unfortunately, approximately 2% of the overlay delaminated in November; cores were removed to determine the cause of the premature failure. A modified version of the ACI 503R tensile bond test was used in the lab to develop a relationship between bond strength between the resin and aggregate and the degree of cleaning of the surface of the cores. It was concluded from the tests conducted on the cores that the most likely cause of the delaminations was a failure of the contractor to properly prepare the surface of some spans. Special cleaning was required on the WBL because of the heavy contamination from 28 years of heavy traffic and saltings and the application of a 18% solids-penetrating epoxy sealer in 1983, which tended to seal the pores of the concrete thereby interferring with the cure of the polyester resin and reducing its bond strength. As a result of this experience, the special provision was modified in 1986 to require the use of the ACI 503R pull-off test to measure the potential bond strength of the shotblasted surface before placing the first layer of resin.

I-95 Ramp Over 495

The contractor used Duracal neat to patch the deck prior to placing the PC overlay. The overlay was installed at night. Because of the small size of the deck, a TurboBlast shotblast unit that cleaned a 20-in wide path at about 2 yd^2/min was used to clean the deck, and shovels were used to broadcast the aggregate into the resin by hand. The resin was applied with a spray bar. The overlay was installed over a period of three months because the contractor was using his equipment to apply overlays on three other bridges. The only problem to occur was the stripping of the aggregate from the first layer of resin applied over the Duracal patches. It is believed that the resin ran off the patches because they were slightly higher than the surrounding surface and there was insufficient resin to bond the sand. The surface of the patches was covered with another first layer on a subsequent night prior to applying a second layer of resin and aggregate to the deck.

Three Bridges Over Rte. 50

The personnel, procedures, and equipment used to construct the PC overlay on the I-95 ramp over 495 were also used to construct the overlays on these three bridges, except that the resin used in the 195 yd^2 of overlay on the frontage road over Rte. 50 was mixed in 5-gallon pails and applied with a squeegee and broom (Figure 5). The only problem encountered on these bridges was the removal of the paint stripes and turning arrows. The contractor resorted to soaking the turning arrows with methylene chloride. Also, the contractor could not properly spray the resin when the temperature was below 50°F, and it was necessary to use a squeegee to get proper coverage at the lower temperatures. All activities were conducted at night.

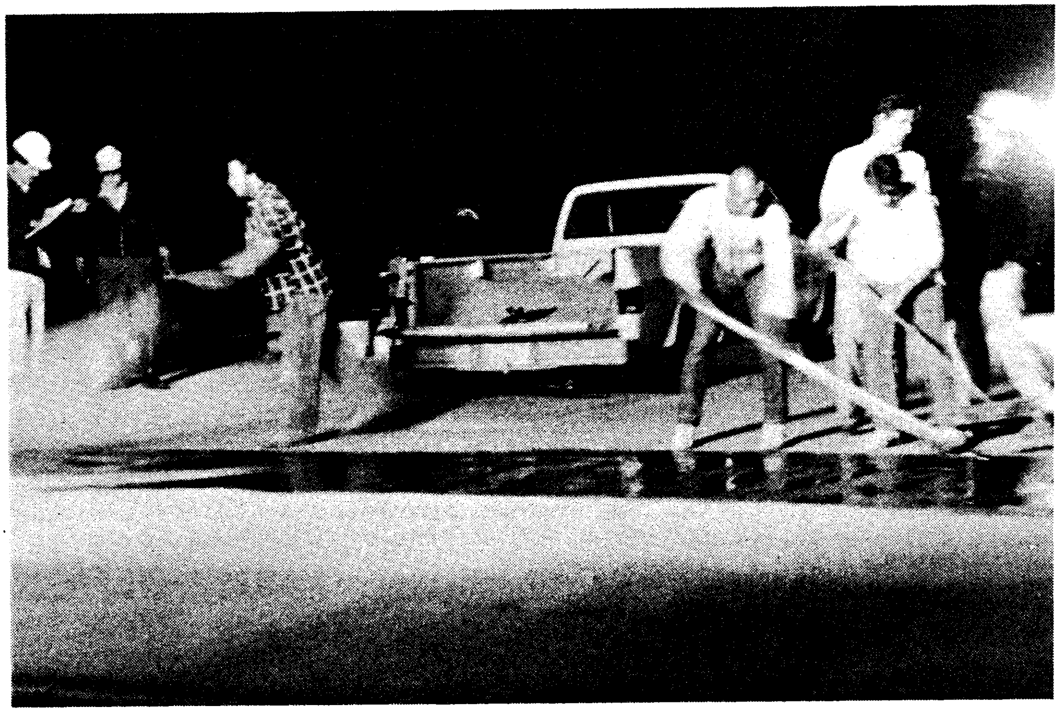

Figure 5. Hand application of resin and aggregate (frontage road over Rte. 50).

Rte. 123 Over I-95 and Rte. 620 Over I-495

The PC overlays on these three bridges were the first to be constructed by Jewell Painting, Inc. The contractor used a Blastrac shotblast unit to clean the surface of the bridges on Rte. 123 and contracted the cleaning of the bridge on Rte. 620 to TurboBlast. Both pieces of equipment cleaned a 20-in wide path at a rate of about 2 yd^2/min. Sandblasting was used to clean along the edges. The resin was applied with a Venus high-volume pump, two initiator pumps, and a Chopper Gun with a maximum output of 30 lb/min (Figure 6). A Venus digital resin meter was used to monitor the application rate, and the resin was supplied to the pump from a 4-compartment, 8,500 gallon Fruehauf tank wagon. Marks were placed at 10-ft intervals along the length of the deck to aid the operator of the spray gun in applying the resin at the proper rate. A strip of plywood was pulled behind the tank wagon to catch the overspray and to provide an area of application of uniform width.

The aggregate was applied with sandblasting equipment that included a pneumatic tank wagon loaded with aggregate, an Ingersoll-Rand 750 CFM air compressor, and a hose and nozzle (Figure 7). The volume of aggregate applied was increased and the pressure on the system decreased relative to that used for sandblasting. The nozzle was directed upward at an angle of about 60°, and the aggregate fell under the force of gravity into the resin. The contractor had loaded the tank wagon with aggregate at the Morie Sand and Gravel Plant in New Jersey. The sand application method produced an aesthetically pleasing surface, and the only disadvantage of the method was the dust caused by blowing the aggregate into the air. The overlays were applied to all three bridges in only 15 days.

Figure 6. Spray gun application of resin (Rte. 123 over I-95).

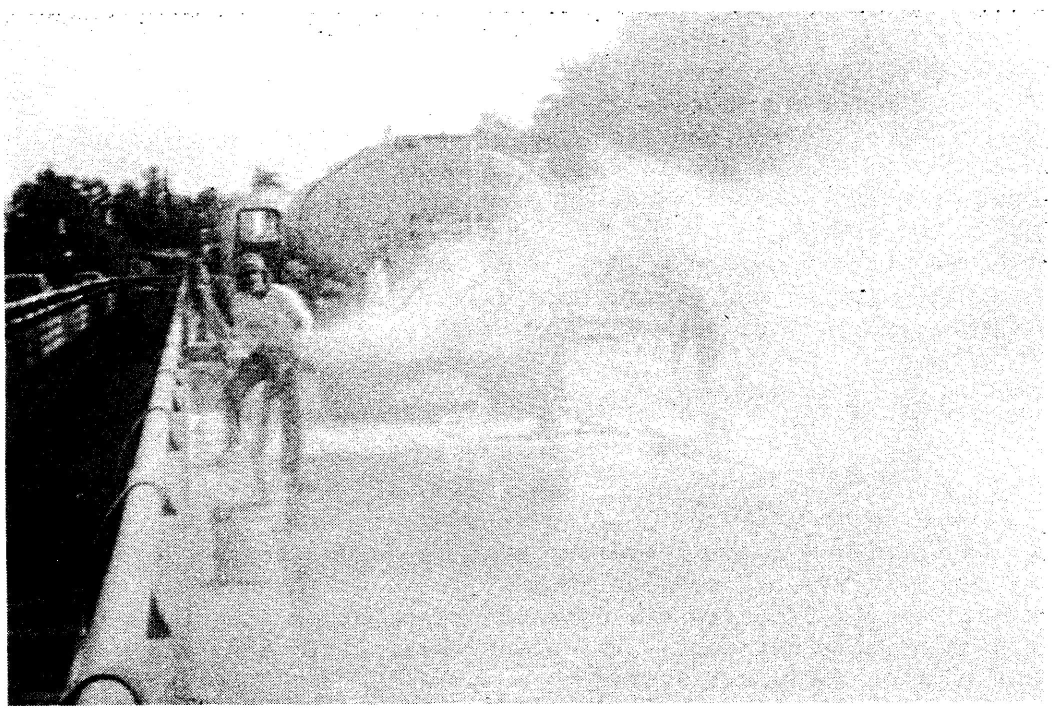

Figure 7. Aggregate is blown into air with sandblasting equipment (Rte. 123 over I-95).

The contractor failed several demonstration tests before his application method and equipment were refined so that an acceptable overlay could be constructed. Initially, he had the sand delivered by tractor trailer and pumped sand into his tank truck. Prior to the demonstration test, he pumped the sand from the tank truck to an 8-ton blast pot. The sand was pumped from the blast pot to a fertilizer spreader that dropped it into the resin. The problem with this procedure was that the handling of the sand abraided it and changed its gradation so that it did not meet the specification. For example, samples taken on August 5 showed 11.6% of grade D sand passing the No. 30 sieve, and 14.1% of grade A sand passing the No. 20 sieve, both of which exceeded the 1% maximum permitted by the special provision. The fine material coated the surface of the resin and prevented the penetration of the coarse material. The contractor discontinued the use of the spreader and tried blowing the sand into the air, but because of the high percentage of fine material the air quality in the vicinity of the application was made unacceptable.

The contractor also had problems with areas of the overlay that would not cure. He was able to eliminate the problem by increasing the quantity of initiator to the levels reported in Table A-2. The higher quantity of initiator was obtained by adding a second initiator pump to the system.

Installations in 1986

Contracts were awarded in 1986 to Dural International for PC overlays on 3 bridges: I-64 WBL over Hampton Roads, Rte. 360 over Dan River, and Rte. 7 WBL over Shenandoah River. The special provision was revised prior to advertising these contracts to require the contractor to install 3 layers rather than 4 and to use the ACI 503R tensile adhesion test to insure that his deck preparation procedure would provide for a minimum tensile bond strength of 250 psi (see Appendices B and C). Less than 1,000 yd^2 of PC overlay were placed in 1986 because the contractor was involved in patching two of the bridges and developing his overlay installation equipment and because he had problems obtaining the required tensile bond strength.

BOND STRENGTH

Obviously, a polymer overlay must be bonded to the deck surface to seal the concrete and provide skid resistance. Bond strength test methods include the ACI 503R tensile adhesion test, other direct tension tests, and the guillotine shear test. The slant shear (ASTM 882) was not used in this study because it is not suited to measure the bond strength of cores. The factors affecting bond strength include surface condition prior to application, adhesive strength of polymer, shrinkage stress, thermal stress, and flexural stress. Thermal stress is discussed in detail in reference 10.

Tensile Bond (Rupture) Strength

Figure 8 shows the ACI 503R tensile test apparatus. The test includes drilling through the overlay to separate a 2-in diameter circular portion, bonding a pipe cap to the surface, and pulling the overlay from the concrete deck (see Appendix C). Test results are reported as tensile bond strengths. However, for an adhesive failure the bond strength is equal to the rupture strength and for a failure in the overlay or base concrete the bond strength is greater than the rupture strength.

The test was first used to obtain data for this study in 1984. Prior to 1984, tensile bond strengths were determined in the laboratory by pulling the overlays from 1 in diameter cores(2). In 1986 it was observed that more consistent results could be obtained by modifying the ACI 503R equipment as follows:

1) Drill through overlay with 2.5-in diameter (2.2-in inside diameter) diamond tipped core barrel rather than a 2-in diameter carbide-tipped impact barrel to minimize damage to the overlay and to minimize the chance of getting the epoxy used to bond the cap to the surface, outside of the circular test area.

2) Modify the pipe plug and hook by drilling a 0.625-in diameter hole in the plug and placing a beveled nut on the end of the 0.5-in diameter hook. The modification reduces the chance of applying an eccentric load to the circular test area.

3) Substitute a pipe section having a diameter of 6-in so that it is easier to connect the cap, hook, and dynamometer.

According to the American Concrete Institute a tensile bond strength ≧100 psi is required for satisfactory performance(11). Our experience indicates a reasonable standard deviation for the average of 3 tests conducted with ACI 503R equipment as modified in 1986 is 40 psi, which implies that an average bond strength ≧220 psi is required for satisfactory performance. The standard deviation of 40 psi is based on the observation that a research technician exhibited an average standard deviation for 13 test locations (3 tests per location) of 33 psi and a contractors technician exhibited an average standard deviation for 14 test locations (3 tests per location) of 50 psi.

Figure 9 shows the tensile bond strength data that was collected for overlays placed on Interstate 64 near Williamsburg(3). The bond strength decreased with age for both binders. At 5 years the average bond strength was 128 psi for the LB183 and 113 psi for the MMA. Based on a standard deviation of 40 psi, parts of the overlays should be delaminating at 5 years.

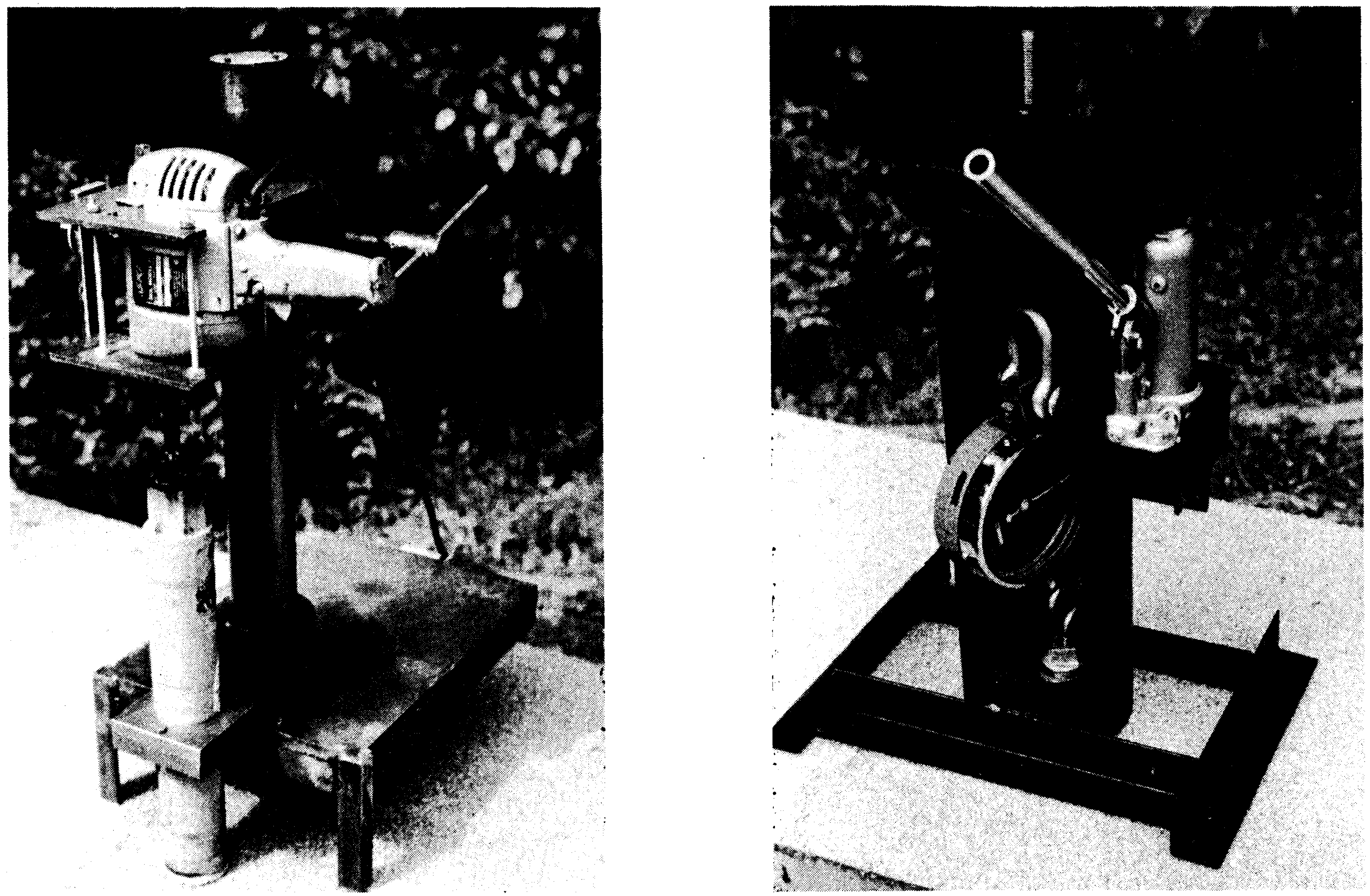

Figure 8. Apparatus used for ACI 503R Surface Adhesion Test.

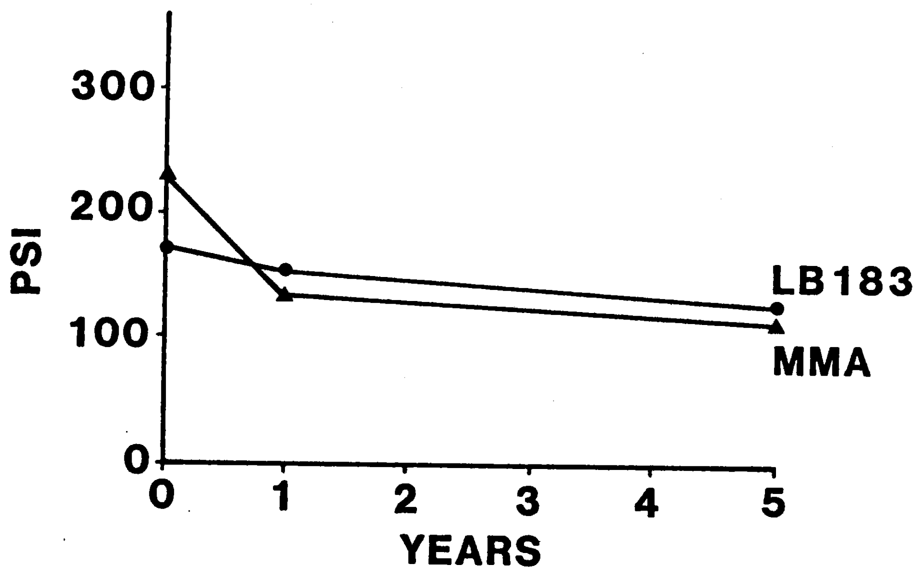

Figure 9. Tensile bond strength vs age, Williamsburg.

Figure 10 shows the bond strength data for two polyester overlays placed on the Beulah Road bridge in 1982(2). The LB183 is the same brittle polyester placed near Williamsburg. It has a tensile elongation (ASTM D638) of 8%. The 90-570 is a flexible polyester which has a tensile elongation of 49%. At 4 years the average tensile bond strength of the 90-570 overlay was 223 psi, which is indicative of satisfactory performance. At 4 years the average tensile bond strength of the LB183 overlay was 167 psi, which indicates portions of the overlay have a bond strength of less than 100 psi.

Figure 11 shows the data for the brittle polyester LB183 near Williamsburg and on Beulah Road. Note that the initial bond strength was much higher on Beulah Road. Traffic was allowed on the shotblasted surfaces near Williamsburg before the overlays were placed. At both locations the bond strength has decreased with age.

Table 2 shows the average bond strength at 5 years for the shoulder, the right wheel path of the travel lane, and the left wheel path of the passing lane for the bridges near Williamsburg. The LB183 polyester exhibited the lowest strength in the travel lane, as would be expected. It's not known why the shoulder of the bridge with the MMA overlay exhibited a low value.

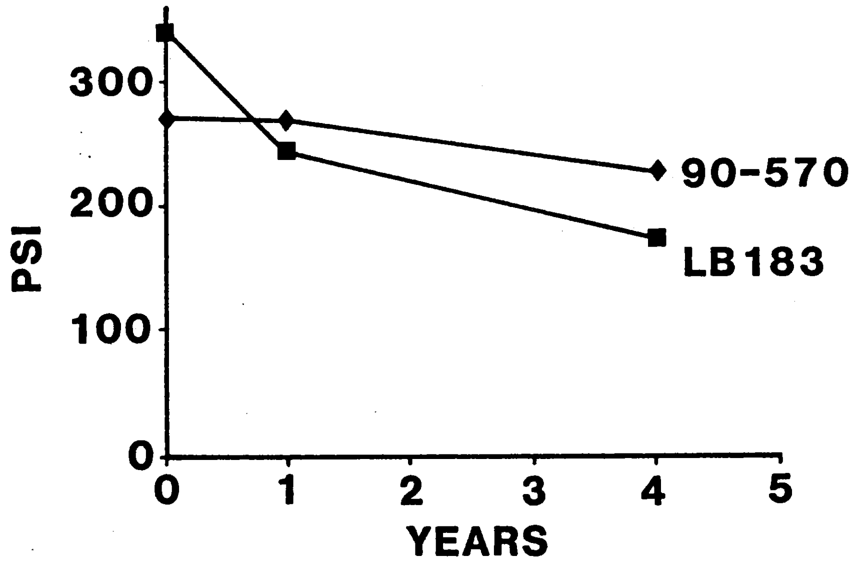

Figure 10. Tensile bond strength vs age, Beulah Road.

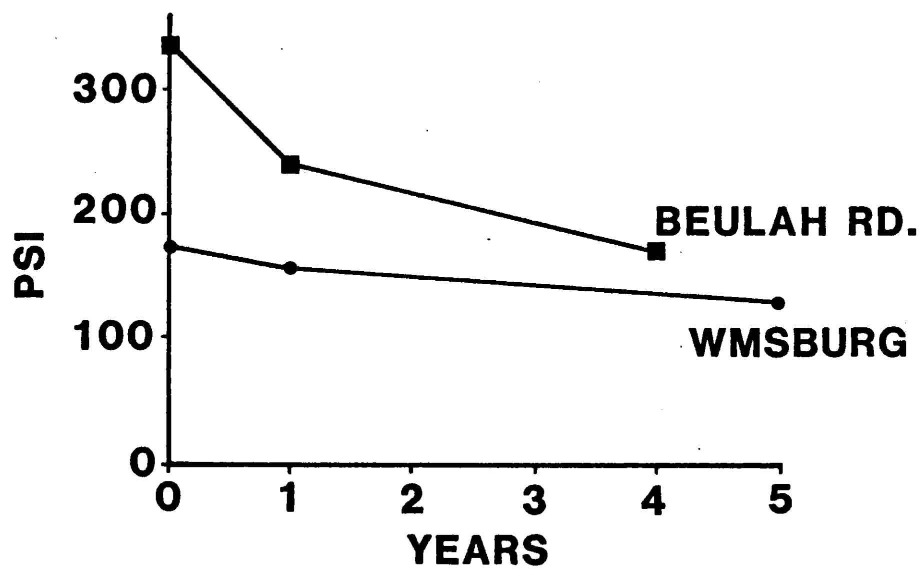

Figure 11. Tensile bond strength vs age, LB183.

TABLE 2

Average Tensile Bond Strength After
5 Years, psi (30,000 ADT)

	S.	T.L.	P.L.
MMA	89	101	149
LB183	141	93	151

Table A-3 shows the tensile bond strength data that has been collected since 1981. Typically, the bond strength at early age is greater than reported because the rupture usually occurs in the base concrete. At later ages the overlays are more likely to fail in adhesion or very near the bond interface. However, the XU40047 overlay on I-64 over the Rivanna River exhibited a very low bond strength (with mostly adhesive type failure) initially and after 1 year; it should delaminate within 3 years. On the other hand, an EP5-LV epoxy overlay installed on bridge 4 near Williamsburg in 1984 was found to have a tensile bond strength after 2 years of 350 psi.

It is obvious that the environment has caused a decrease in tensile bond strength; that overlays constructed with some resins have been affected more than others; that one should anticipate some delamination in 10 years of service.

Shear Bond Strength

Figure 12 shows the guillotine shear apparatus that was used to collect the shear bond strength data. A test value was determined by placing a 2.75-in diameter core into the base, placing the top part of the apparatus over the overlay, and subjecting the apparatus to a compressive force which shears the overlay from the base concrete. A value for the shear strength of the base concrete was determined by directing the shear force through the base concrete approximately 2.5 in below the interface. The loading was applied at the rate of 10,000 lb/min. According to Felt, shear bond strengths ≧200 psi are adequate for good performance(12).

Figure 13 shows the shear bond strength data for the bridges near Williamsburg. At 5 years the average bond strength of the LB183 overlays was 200 psi and the bond strength of the MMA overlay was 155 psi. Obviously, 50% of the LB183 overlays and more than 50% of the MMA overlay has less than adequate bond. The environment has caused a significant decrease in the shear bond strength over the 5-year period.

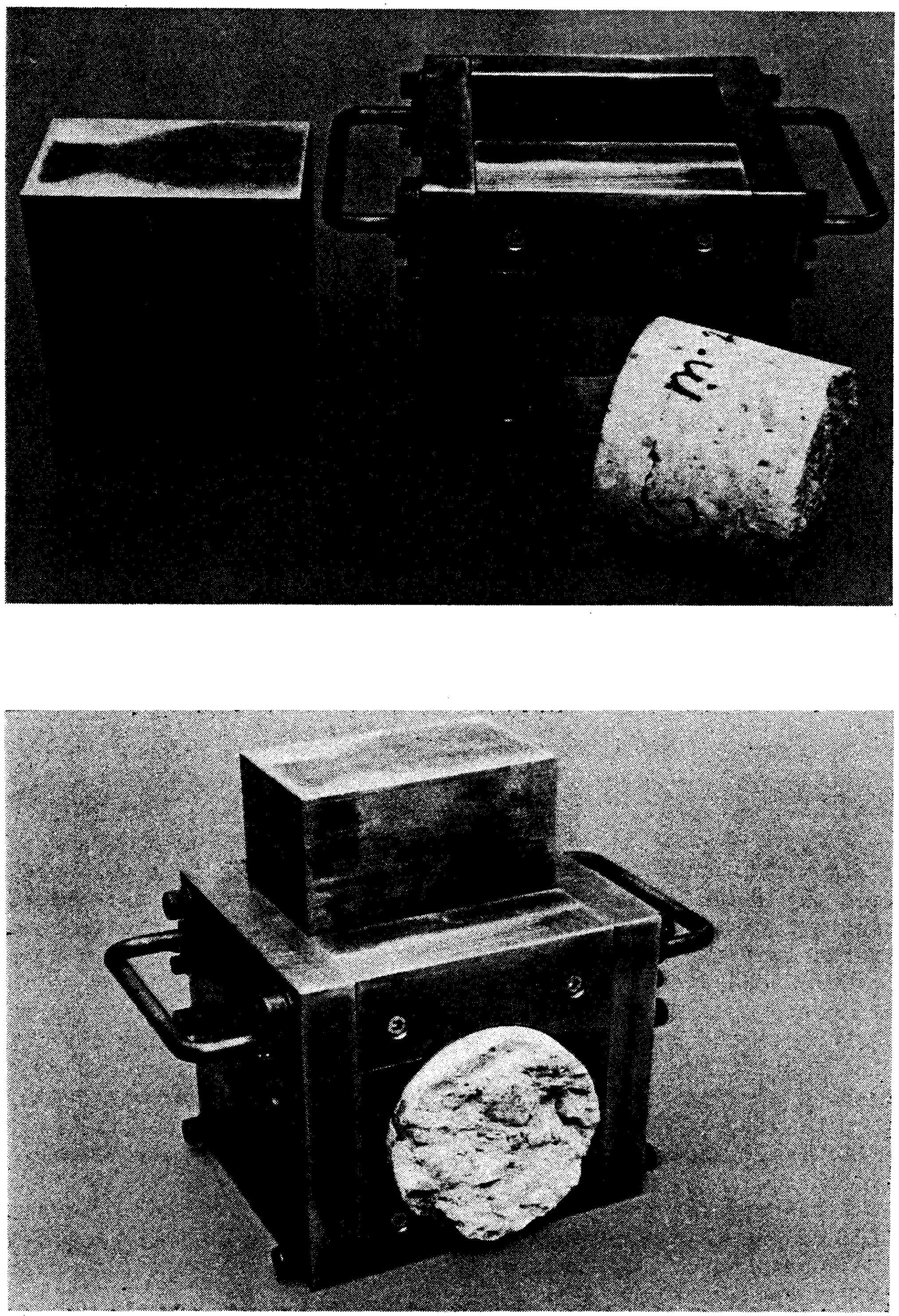

Figure 12. Apparatus used to subject cores to shear.

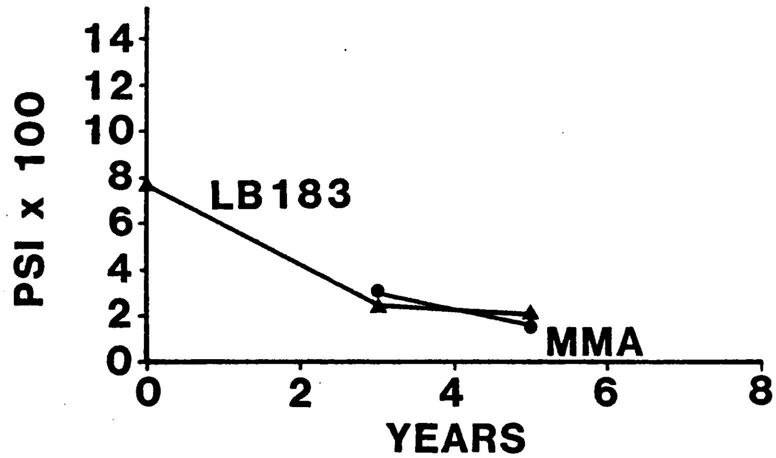

Figure 13. Shear bond strength vs age, Williamsburg.

Figure 14 shows the shear bond strength as a function of age (the solid line) and the number of thermal cycles (the dashed line) for the LB183 overlays near Williamsburg. One thermal cycle consists of cooling a specimen to 0°F, heating it to 100°F, and cooling it to room temperature at the rate of 3 cycles/day. After 100 thermal cycles the bond strength was 228 psi which was approximately equal to the strength at 4 years.

Whereas the thermal cycling test predicted the bond strength at 4 years of the LB183 overlays near Williamsburg, Figure 15 shows that it failed to predict the bond strength on Beulah Road. Evidently, something other than thermal stress caused the drop in bond strength on Beulah Road.

Figure 16 shows that the thermal cycling test did an excellent job of predicting the performance of the flexible polyester 90-570 through 3 years and 75 thermal cycles. The drop in bond strength at 4 years may have been caused by the 90-570 polymer losing most of its flexibility after 3 years. Whereas the polyester remained flexible during the short-term thermal cycling test, the polyester that was in service became brittle after 3 years. The environment caused the decrease in flexibility.

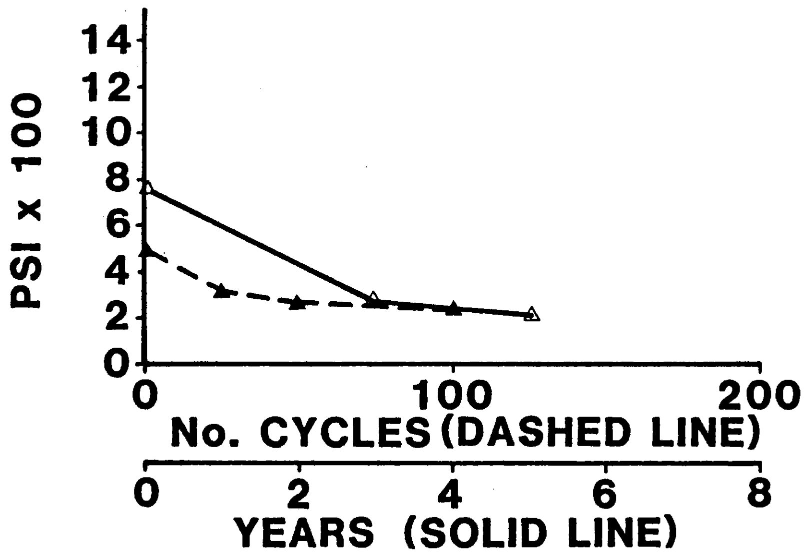

Figure 14. Shear bond strength vs age and number of thermal cycles, LB183 - Williamsburg.

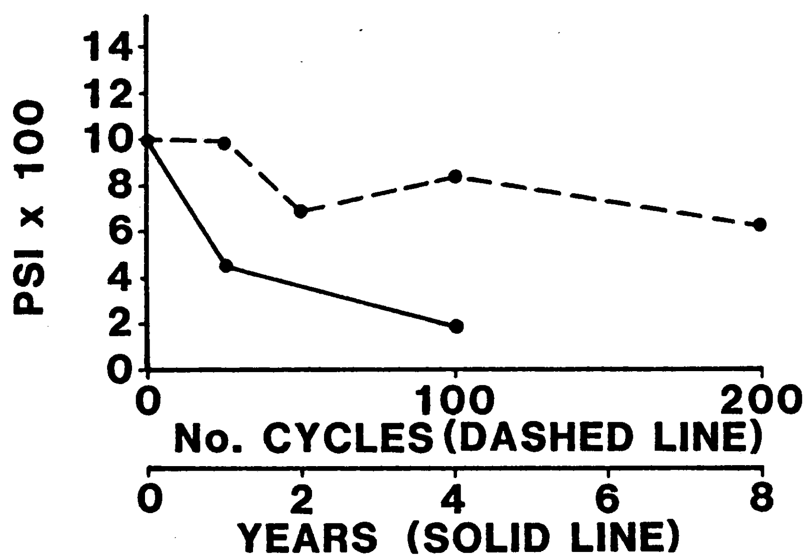

Figure 15. Shear bond strength vs age and number of thermal cycles, LB183 - Beulah Road.

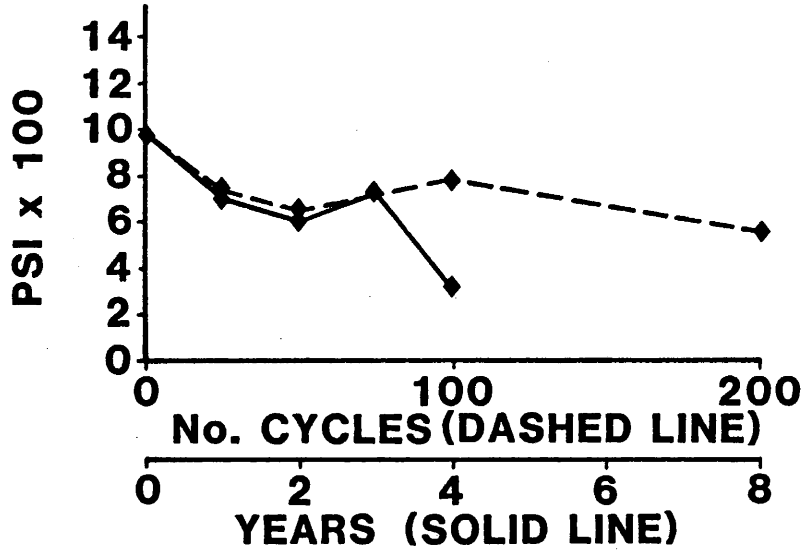

Figure 16. Shear bond strength vs age and number of thermal cycles, 90-570 - Beulah Road.

The average shear bond strengths for the overlays near Williamsburg are shown in Table 3. The lowest bond strengths were found in the travel lane for both resins. The strengths are lower in the travel lane probably because of the higher volume of traffic in the travel lane which caused more contamination of the shotblasted surface prior to placing the overlay and more flexural stress on the overlay.

TABLE 3

Average Shear Bond Strength After 5 Years, psi
(30,000 ADT)

	S.	T.L.	P.L.
MMA	172	101	192
LB183	220	162	218

Table A-4 shows the shear bond strength data that has been collected since 1981. It was encouraging to note that 44% of the test results for the LB183 overlays near Williamsburg and 100% of the results for the 90-570 overlay on Beulah Road and the 93-339 overlay over the Rivanna River were greater than 200 psi. Unfortunately, only 20% of the results for the MMA overlay and 0% of the results for the XU40047 overlay were greater than 200 psi. By comparison it was found that an EP5-LV epoxy overlay installed in 1981 near Williamsburg exhibited an average shear bond strength of 494 psi after 4 years(13).

It is obvious that the environment has caused a reduction in shear bond strength; that overlays constructed with some resins have been affected more than others; that one should anticipate some delamination in 10 years of service. Also, a thermal cycling test can be used to simulate environmentally produced thermal stress and to predict bond strength.

Delamination

The overlays placed near Williamsburg in 1981 are gradually delaminnating as predicted in the first interim report on this project(3). In September 1986 the following surface areas had delaminated: bridge 1 (MMA) 7%; bridge 2 - 15%; bridge 3 - 13%; bridge 8 - 50%; and bridge 9 - 1%. No delaminations were noted in 1986 in the SBL of the Beulah Road bridge or the EBL of the bridge over the Rivanna River. Because high tensile and shear bond strengths were obtained at some locations on the overlays near Williamsburg, it can be anticipated that portions of the overlays will remain bonded for longer than 10 years.

PROTECTION PROVIDED BY OVERLAYS

Polymer overlays are usually placed on bridge decks to protect the concrete from the infiltration of water and chloride ion, which can cause frreze-thaw damage to the concrete and corrosion of the reinforcement. An indication of the protection provided by the overlays is based on the rapid permeability test, the electrical resistivity test, the half-cell potential test, and the measurement of the rate of corrosion of probes in the concrete.

Rapid Permeability Test

A rapid permeability test (AASHTO T-277) was used to measure the permeability to chloride ions of 4-in diameter cores taken from the bridge decks. The results were reported in Coulombs, which have the following relationship to permeability.

Coulombs		Permeabiilty
>4000	-	High
2000 - 4000	-	Moderate
1000 - 2000	-	Low
100 - 1000	-	Very low
<100	-	Negligible

Factors affecting permeability include shrinkage stress, thermal stress, and flexural stress.

Figure 17 shows permeability as a function of age (solid line) and the number of thermal cycles (dashed line) for the MMA overlay. The thermal cycling test predicted a rapid increase in permeability for the brittle MMA overlay. In service, the permeability increased significantly the first year and leveled off to 1,630 Coulombs at 5 years, which is lower than the 4,000 typically obtained for bridge deck concrete.

Figure 18 shows the two curves for the LB183 brittle overlays near Williamsburg. The thermal cycling test predicts the permeability at 100 cycles and 1 1/3 years in service. At 5 years the permeability is 1,500 Coulombs, which is about the same as that of the MMA overlay.

Figure 19 shows that the two curves for the LB183 resin used on Beulah Road do not agree at 1 and 2 years, but they meet at 4 years and 300 cycles. The permeability at 4 years was 1,656 Coulombs, which was about the same as the permeability of the overlays near Williamsburg at 5 years.

The two curves for the flexible 90-570 polyester are shown in Figure 20. The thermal cycling test predicted the permeability of the overlay throughout the 4 years and 300 cycles. At 4 years the permeability was 706 Coulombs which is <u>very low</u> and similar to the permeability of a latex modified concrete overlay.

Figure 21 shows the two curves for the 317 resin used on the bridge over Big Swan Creek. The resin is similar to the 92-339 resin used on the bridges over the Rivanna River. The permeability at 2 years was 794 Coulombs.

The average permeabilities for the overlays near Williamsburg are shown in Table 4. The highest permeabilities were found in the travel lane and the lowest on the shoulder.

TABLE 4

Average Permeability After 5 Years, Coulombs
(30,000 ADT)

	S.	T.L.	P.L.
MMA	863	2,354	1,673
LB183	668	2,070	1,763

Table A-5 shows the permeability data that has been collected since 1981. By comparison it was observed that an EP5-LV epoxy overlay near Williamsburg exhibited a permeability of 402 Coulombs at 4 years of age(13).

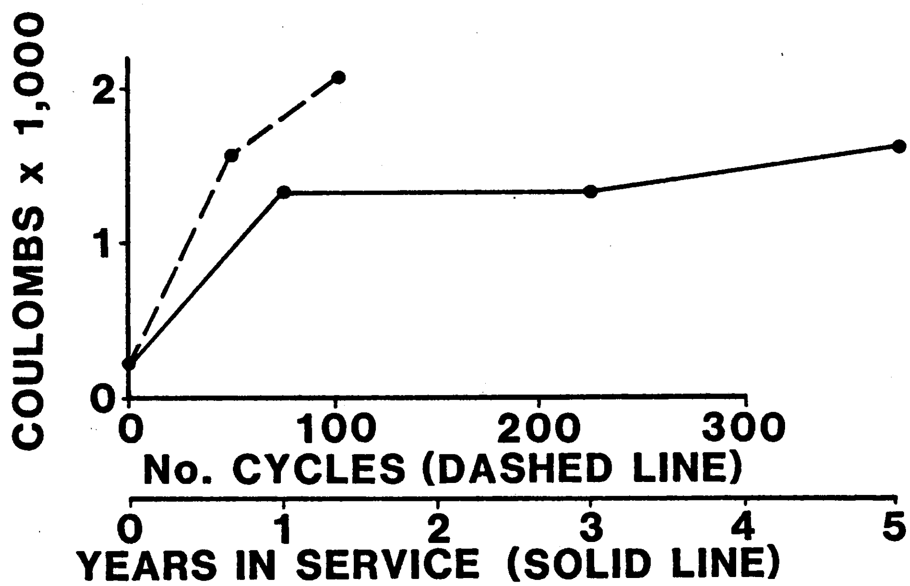

Figure 17. Permeability of chloride ions vs age and number thermal cycles, MMA.

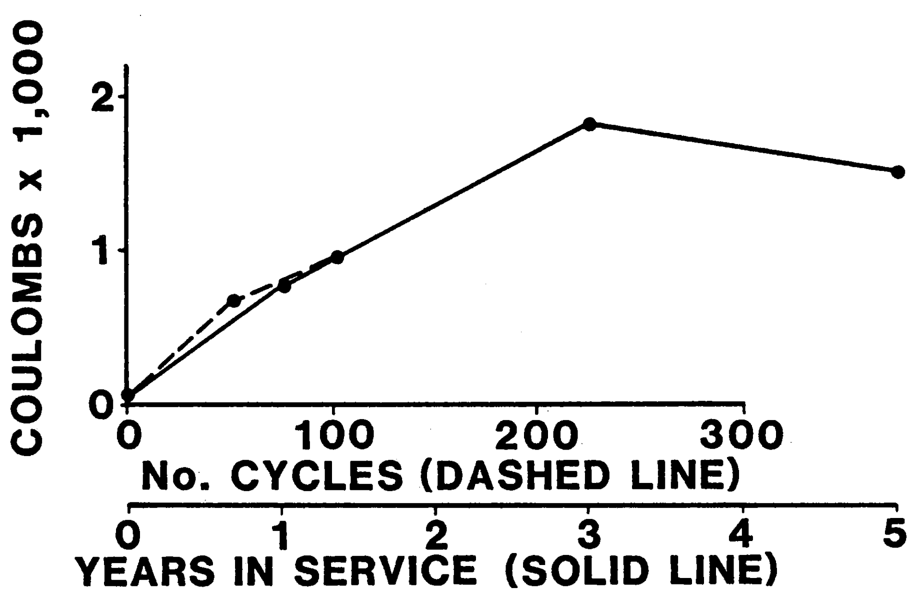

Figure 18. Permeability of chloride ions vs age and thermal cycles, LB183 - Williamsburg.

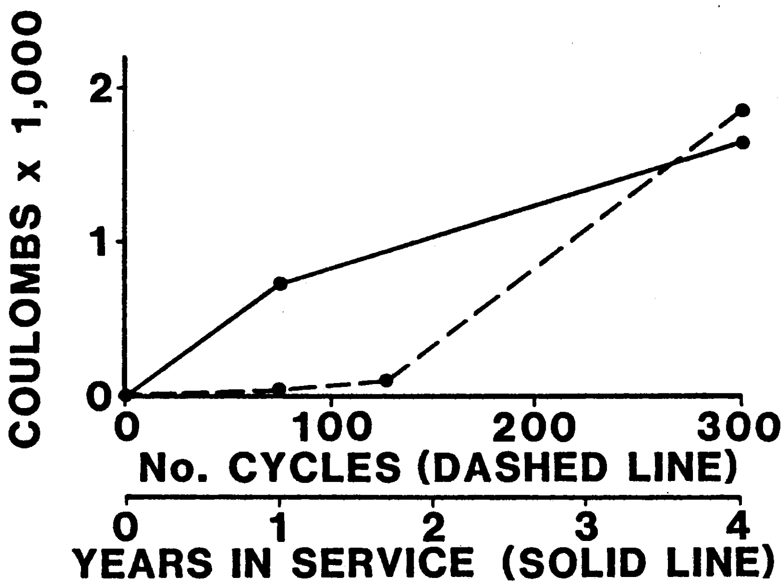

Figure 19. Permeability of chloride ions vs age and number thermal cycles, LB183 - Beulah Road.

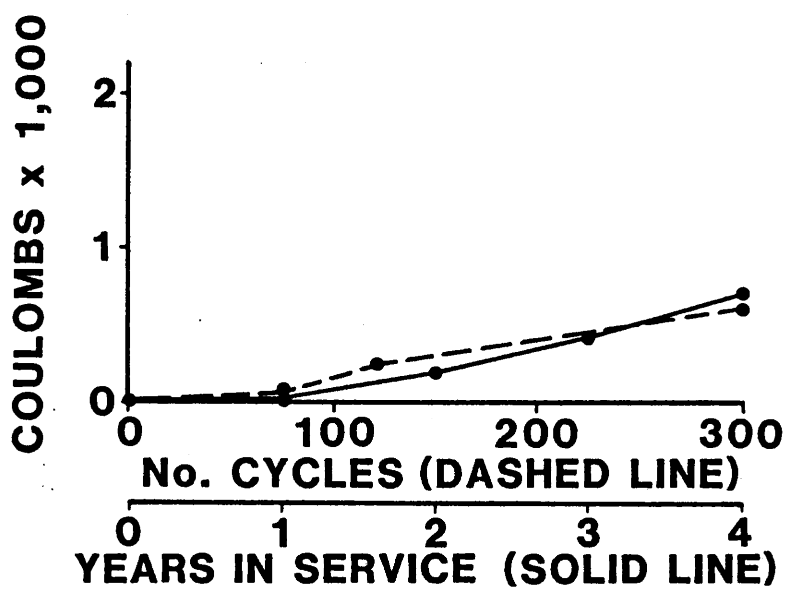

Figure 20. Permeability of chloride ions vs age and number thermal cycles, 90-570.

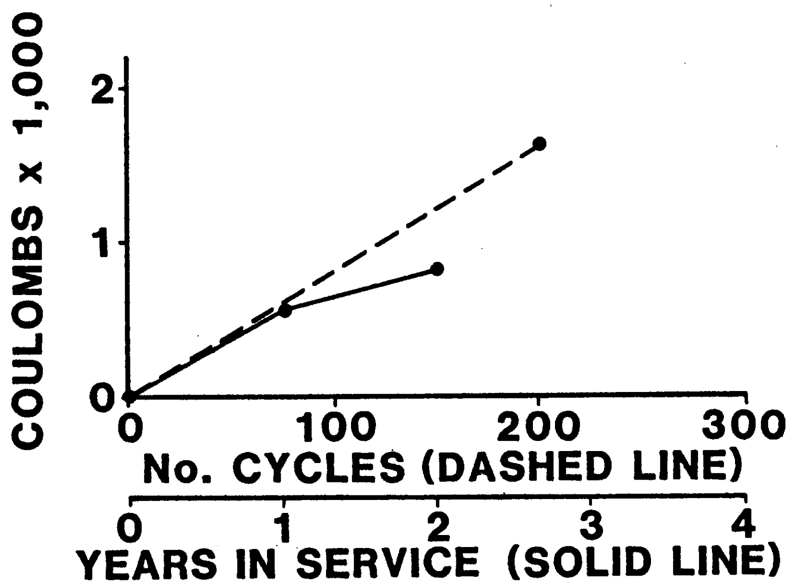

Figure 21. Permeability of chloride ions vs age and number thermal cycles, 317.

It is obvious from the data that the environment has caused an increase in permeability, and that the permeability of overlays constructed with some resins has been affected more than others. Also, specimens can be subjected to a thermal cycling test and subsequently tested for permeability to provide an indication of the permeability to be expected in service at a later age. Epoxy and flexible polyester overlays exhibit the lowest permeabilities at later ages.

Electrical Resistivity

The electrical resistivity test (ASTM D 3633) provides a good indication of the extent of microcracking in an overlay. A low reading is indicative of a microcrack at the test location. The crack allows water to penetrate the overlay and lower the resistance in the electrical circuit. Data collected since 1981 is shown in Table A-6. It is obvious from the data that with the exception of the 90-570 overlay, which was not cracked significantly until evaluated at an age of 3 years, overlays constructed with any resin were extensively cracked in 1 year or less as indicated by the fact that most readings were in the poor to fair range. However, the cracks cannot be seen without the aid of magnification, and based on the permeability data, the cracked overlays are providing protection against the infiltration of chloride ion.

Half-Cell Potentials

Table A-7 shows the cooper sulfate half-cell potential data (ASTM C 876). The data indicate that there was greater than 90% probability that no corrosion was occurring in the steel represented by the readings of <0.20 volts, which is the range of the majority of the readings. It is important that the half-cell potentials have not changed significantly over the 5-year evaluation period; this supports the theory that the PC overlays can extend the time to corrosion if applied prior to the on-set of corrosion.

Rate of Corrosion Based on Corrosometer Probe

Table A-8 shows typical data collected for the rate of corrosion of the corrosometer probes. The rate of corrosion of the probes in all three bridges continued to decrease. The data do not reflect a difference in the rate of corrosion for the probes in the decks with the polymer overlays vis-a-vis the deck with the S5 bituminous overlay.

SKID NUMBER AND WEAR

Skid Numbers

Polymer concrete overlays have been placed on bridge decks to increase the skid number of decks constructed with polishing aggregate. A good indication of skid resistance is provided by the ASTM (E524-76) bald tire test.

An overlay which wears excessively in the wheel paths may loose its protective properties and its skid resistance. An indication of wear is provided by comparing measurements of rutting in the wheel paths and measurements of the thickness of the overlays immediately after the overlay was placed and at later ages.

Tables A-9A and A-9B show the results of skid tests (ASTM E501-76 and E524-76) conducted at 40 mph. The minimum acceptable value for a treaded tire is 37 and that for a bald tire is 20. The factors that affect the skid number and wear are the hardness of and shape of aggregates, gradation of aggregate, aggregate content of polymer, adhesive strength of polymer, traffic volume, and tire characteristics.

Figure 22 shows the 5 years of bald-tire skid test data for the overlays near Williamsburg. Prior to placing the overlays the skid number was about 25. The new overlays exhibited numbers of about 60. The numbers dropped significantly the first year and leveled off. At 5 years the average numbers were 38 for the MMA overlay and 39 for the LB183 overlays.

Figure 23 compares the bald-tire skid numbers for the overlays constructed with the LB183 brittle polyester and an EP5-LV epoxy. The epoxy overlays exhibited an average skid number of 21 at 2 years. Another EP5-LV overlay near Williamsburg exhibited a number of 19 at 4 years(13). It is believed the epoxy overlays exhibited a low number at 2 years because the overlays were constructed with less resin and a finer sand than was used for the polyester overlays and because the flexibility of the epoxy increased the first year. Last year three epoxy overlays were constructed using the resin application rates and the gradation of aggregates used for polyester overlays. It is anticipated that these epoxy overlays will maintain a higher skid number.

Figure 24 compares the bald-tire skid numbers for the overlays constructed with the flexible 90-570 polyester and the EP5-LV epoxy. The 90-570 overlay exhibits an acceptable skid number of 38 at 3 years. It is obvious that new polymer overlays exhibit a high skid number, the number drops rapidly the first year, and with the exception of the epoxy overlays, the number gradually drops to 35 to 40 at 5 years. It is anticipated that the MMA and polyester overlays will maintain acceptable skid numbers for 10 years.

Rutting in Wheel Paths

A 12-ft straightedge, which is shown in Figure 25, was used to measure rutting in the wheel paths. The device, which is placed between the centerline and edge of pavement, has 6 scales spaced 2 ft apart. Measurements are made by depressing the six scales until they touch the surface of the deck and recording the readings. The rutting in a wheel path is computed by subtracting the reading on the scale located in the center of the wheel path from the average of the readings for the two adjacent scales. Measurements were made at 10-ft intervals along the length of the bridges. The values reported in Table A-10 were computed by subtracting the rutting value at the indicated year from the value obtained immediately after the installation of the overlay. It is obvious from the data, which shows an average 5 year rut for the MMA and LB183 overlays of 0.03 in, that rutting is not a problem.

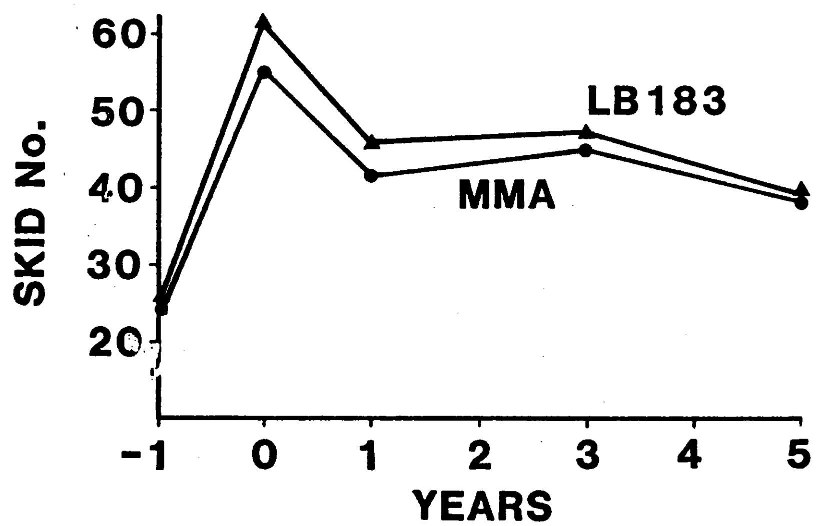

Figure 22. Skid number at 40 mph vs time ASTM E524 Bald Tire, Williamsburg.

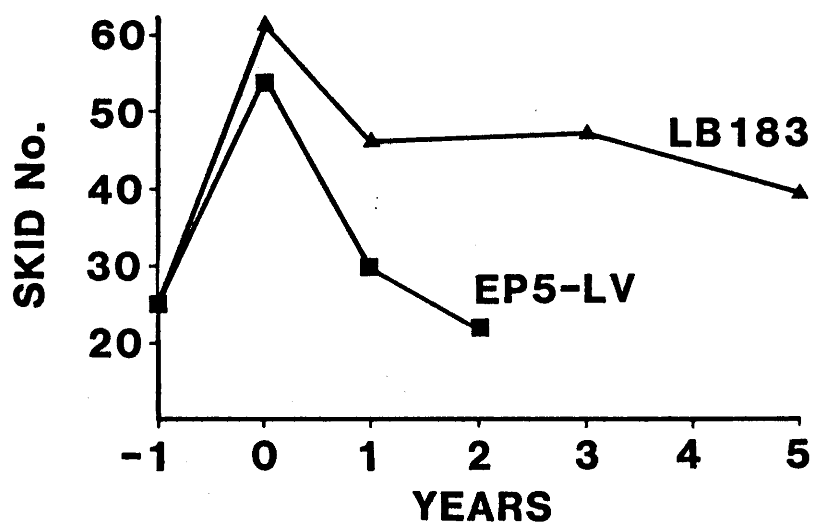

Figure 23. Skid number at 40 mph vs time ASTM E524 Bald Tire, Williamsburg.

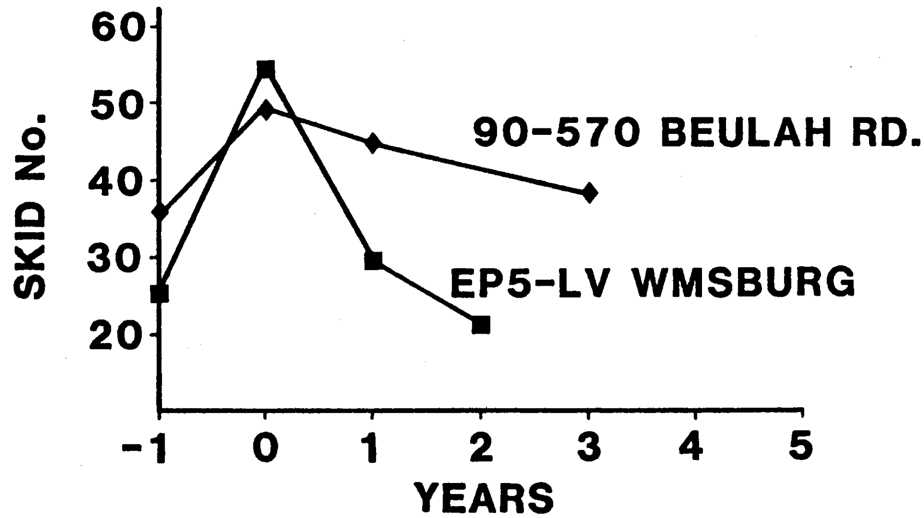

Figure 24. Skid number at 40 mph vs time ASTM E524 Bald Tire.

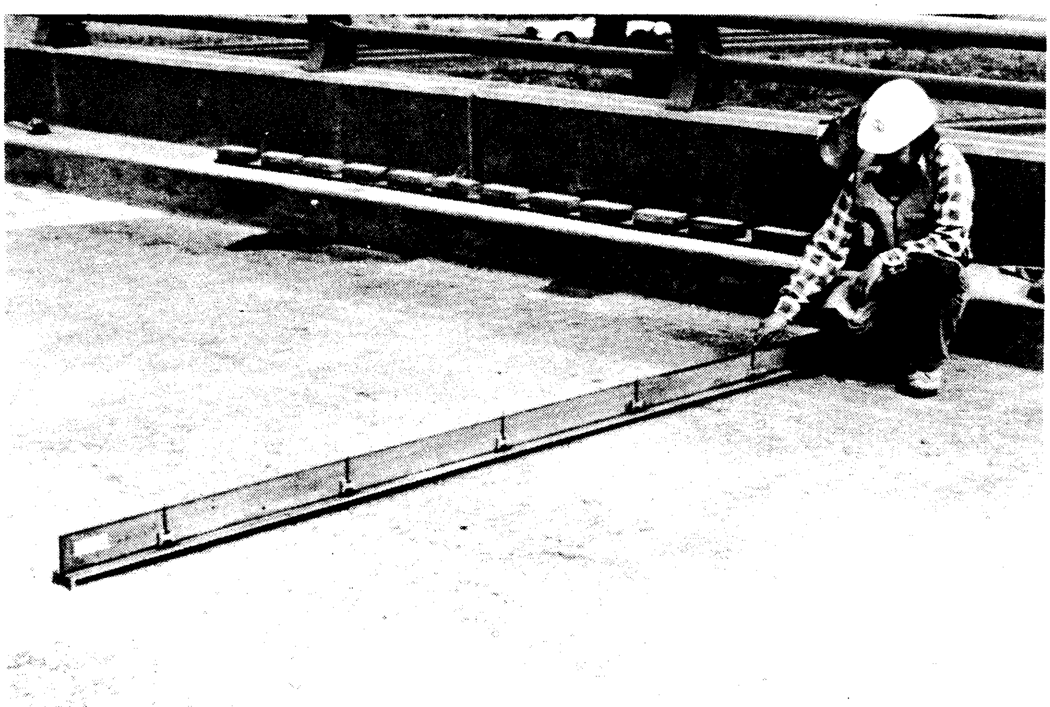

Figure 25. Straightedge used to measure rutting.

Wear

The average 5-year wear for the overlays near Williamsburg is shown in Table 5. The values were computed by subtracting the thickness of the overlays on cores removed in 1986 from the thickness of the overlays on cores removed in 1981. Typically, the most wear has occurred in the travel lane and the least wear on the shoulder. The most wear occurred with the LB183 polyester in the travel lane. At a wear rate of 0.10 in in 5 years, the 0.50-in overlay should wear away in 25 years. A wear rate of 0.10 in in 5 years for 30,000 ADT is equal to 0.007 in/yr/10,000 ADT, which is 23% of the wear rate of 0.03 in/yr/10,000 ADT reported for latex modified concrete overlays(14).

TABLE 5

Average 5-Year Wear, In.
(30,000 ADT)

	S.	T.L.	P.L.
MMA	.01	.05	.06
LB183	.04	.10	.04

Clearly, the environment has caused a reduction in skid number and in the thickness of the overlays over the 5-year study period. However, the overlays will likely delaminate before they wear through or exhibit an unacceptable skid number.

TENSILE PROPERTIES OF BINDERS

It has been illustrated that the bond strength and the protection provided by the overlay constructed with the 90-570 resin were better than those of the overlays constructed with LB183 resin. For example, the shear and tensile strengths of the bond interface deteriorated much more for the latter than for the former during the first year of service life. Also, the resistivity of the LB183 overlay decreased and the permeability increased significantly during the first year of service life, whereas the 90-570 overlay exhibited good resistivity after 2 years and low permeability after 4 years. Since both products are polyester resins, it was thought necessary to determine the physical properties of the two products that led to the superior performance of one over the other.

The most obvious difference between the two products was determined using ASTM D638-80, "Standard Test Method for Tensile Properties of Plastics." The results of tests conducted in accordance with this procedure are shown in Table A-11. It is obvious that the LB183 resin has a higher tensile strength and modulus of elasticity and a much lower elongation than the 90-570. Since the LB183 elongates only 8.3%, it is more likely to crack when subjected to shrinkage, reflective cracking, or thermal stress than is the 90-570. The more flexible 90-570 is able to elongate and accommodate the tensile stresses and thereby provide an overlay of high resistivity and low permeability. The 90-570, 92-339, and 317 resins should be less prone to cracking than LB183, MMA, and EP5-LV epoxy. Flexolith and Flexogrid, epoxy overlay systems with high elongations, are under study at this time(13). Based on the data in Table A-11, it is reasonable to conclude that a resin should have a minimum elongation of 20% to minimize the formation of cracks and thereby ensure better protection. A specification requiring 20% to 40% elongation seems reasonable.

Figure 26 shows the tensile elongation data as a function of time for the EP5-LV epoxy and the 90-570 flexible polyester. The flexibility of the epoxy has increased the first year, which may have caused the decrease in skid number. The 90-570 polyester has become brittle at 3 years, which may explain the sudden drop in bond strength at 4 years. Clearly, the stability of polymers needs to be improved.

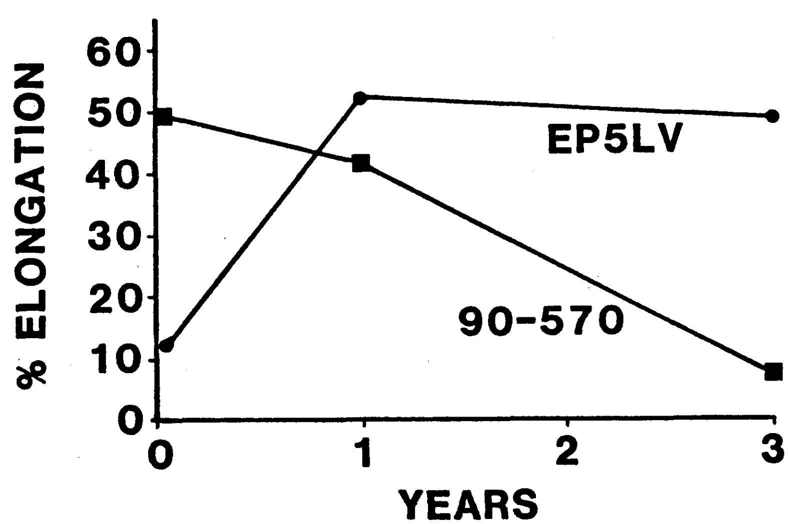

Figure 26. Tensile elongation of resins vs age ASTM D638.

EFFECTS OF ADDITIVES AND PRIMERS ON BOND STRENGTH

Since the principal mode of failure of a polymer overlay is a failure of the bond between the overlay and the base concrete, a series of laboratory tests were conducted to see if an improvement in bond strength could be obtained by mixing additives with the resin, priming the concrete surface, or by varying the condition of the concrete surface.

Table A-12 shows the results of a modified version of the ACI 503R tensile test conducted on one-layer overlays placed on the saw cut surfaces of slices of 4-in by 8-in cylinders of concrete having three different 28-day compressive strengths. The overlays were constructed with silica sand and 317 resin with 1% S440 and 1% A174, unless noted otherwise. Also, two high molecular weight methacrylate (HMWM) primers (PCM 200 and PCM 1100) were applied to the surface of some specimens 1 hour prior to applying the 317 resin. A later set of tests were conducted on slices of 4-in by 8-in cylinders of Duracal mortar (1 part Duracal and 1 part sand) and Duracal concrete (1 part Duracal, 1 part sand, 1 part pea gravel), typical of that used to patch bridge decks. The data in Table A-12 show that acceptable bond strengths were obtained for all conditions except that in which the penetrating sealer was applied 24 hours prior to the application of the overlay. The strength of the base concrete affected the tensile bond (rupture) strength, and as would be expected, lower strength concretes caused lower tensile bond (rupture) strengths. It is obvious that acceptable bond strengths can be obtained without the aid of additives or primers.

Table 6 shows the results of guillotine shear bond strength tests conducted on four-layer overlays placed on the saw cut surfaces of slices of 4-in by 8-in cores taken from a concrete pavement approximately 20 years old. The overlays were constructed with silica sand and 317 resin with 1% S440 and 1% A174, unless noted otherwise. For comparison, PCM200 and PCM 1100 were each applied to the surface of 20% of the specimens, grooves 0.125-in wide by 0.125-in deep spaced 0.5 in apart were cut into the surface of 20% of the specimens, and the S440 and A174 were omitted from the resin used on 20% of the specimens. Twenty percent of the specimens (triplicates of 5 test conditions = 15 specimens) were stored in the laboratory for about 1 year prior to being subjected to the shear bond tests described earlier. Forty percent of the specimens were subjected to the thermal cycling test described earlier (15 specimens were subjected to 100 cycles and 15 to 300 cycles) and forty percent were subjected to the ASTM C666 Procedure A freezing and thawing test, with 2% NaCl added to the test water, prior to being subjected to the shear bond test at an age of about 1 year. The data in Table 6 is discouraging because four of the five average initial bond strengths were lower than the 600 psi minimum usually obtained with acceptable polymer overlays. However, the data does reflect certain trends in performance that are useful.

TABLE 6

Shear Bond Strength Data for Five Test Conditions and Two Test Methods

Test Condition	Test: Cycles:	Shear Bond Strength, lb/in^2 None 0	Thermal Cycles 100	Thermal Cycles 300	ASTM C666 100	ASTM C666 300
No A174 No S440		564	413	266	269	126
PCM 200 Primer		506	507	533	580	307
PCM 1100 Primer		417	464	378	344	215
Grooves in Surface		621	712	641	513	342
Control 317		430	532	445	335	124

Figures 27 and 28 show the shear bond strengths at 100 cycles and 300 cycles as a percent of the bond strengths at 0 cycles for the 5 test conditions and the two test procedures. Figures 29 and 30 show the percentages of the failure areas that occur at the bond interface between the overlay and the base concrete for the 5 test conditions and the two test procedures.

Figures 27-30 show that the ASTM C666 test causes a more rapid deterioration in bond strength than the thermal cycling test. Figures 27 and 29 show that adequate bond strength and a low percentage of interface failure can be obtained through 300 thermal cycles without the use of HMWM primers or grooving the surface. However, the S440 and A174 additives seem to provide for better bond strength through 300 thermal cycles than can be obtained without the additives.

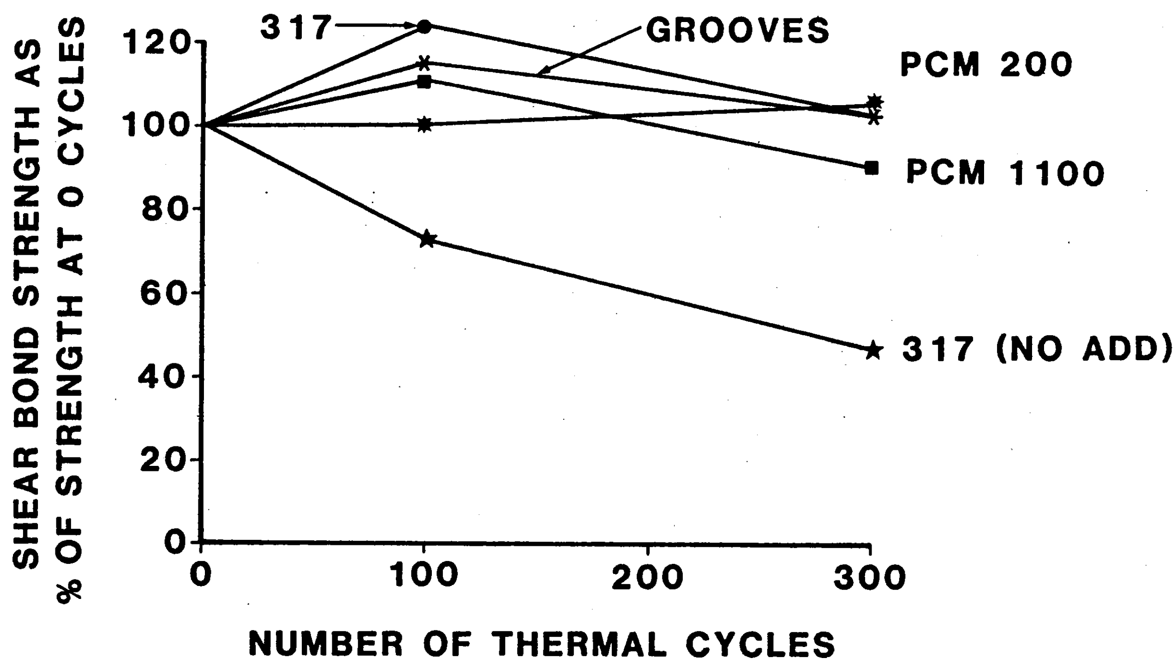

Figure 27. Shear bond strength vs thermal cycles.

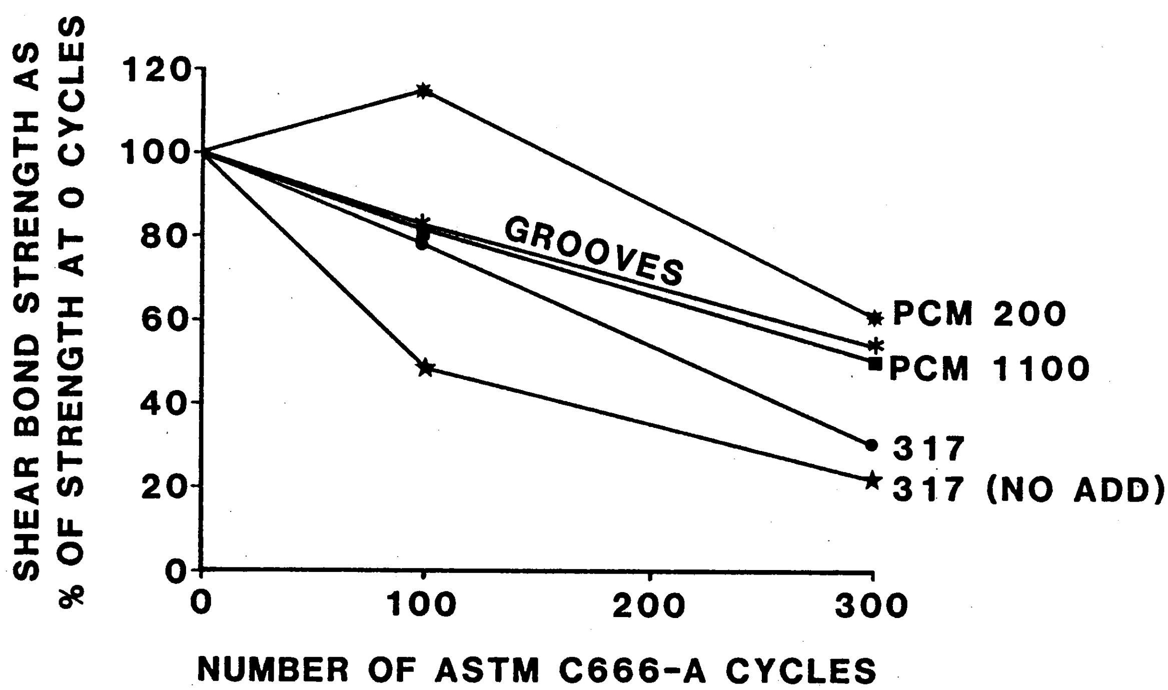

Figure 28. Shear bond strength vs ASTM C666-A cycles.

1704

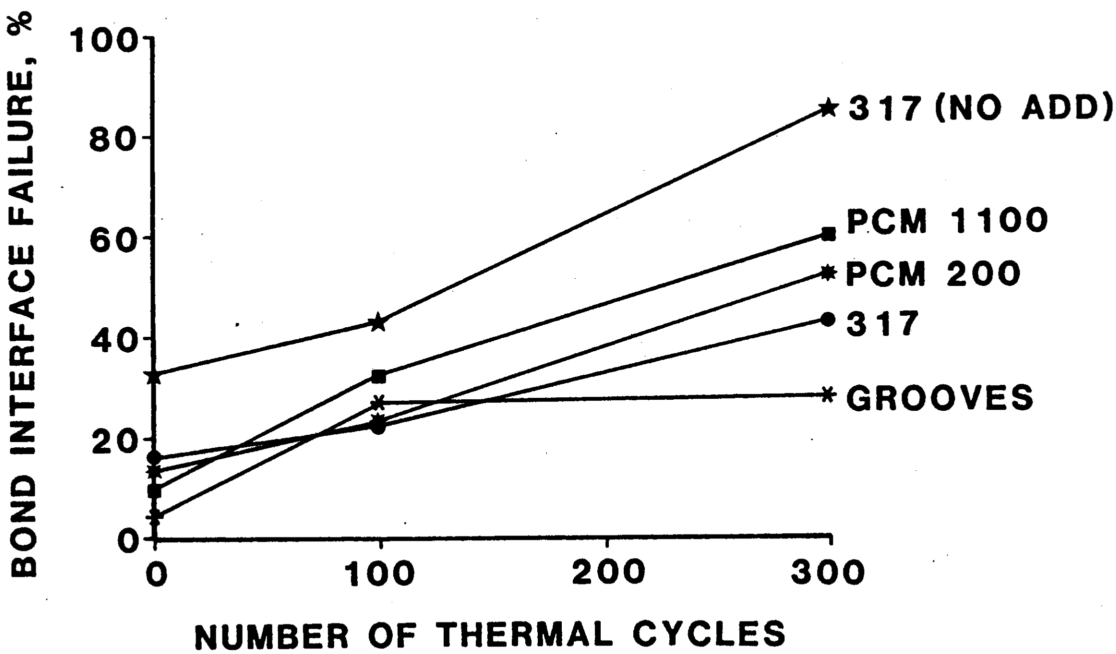

Figure 29. Bond interface failure, % vs thermal cycles.

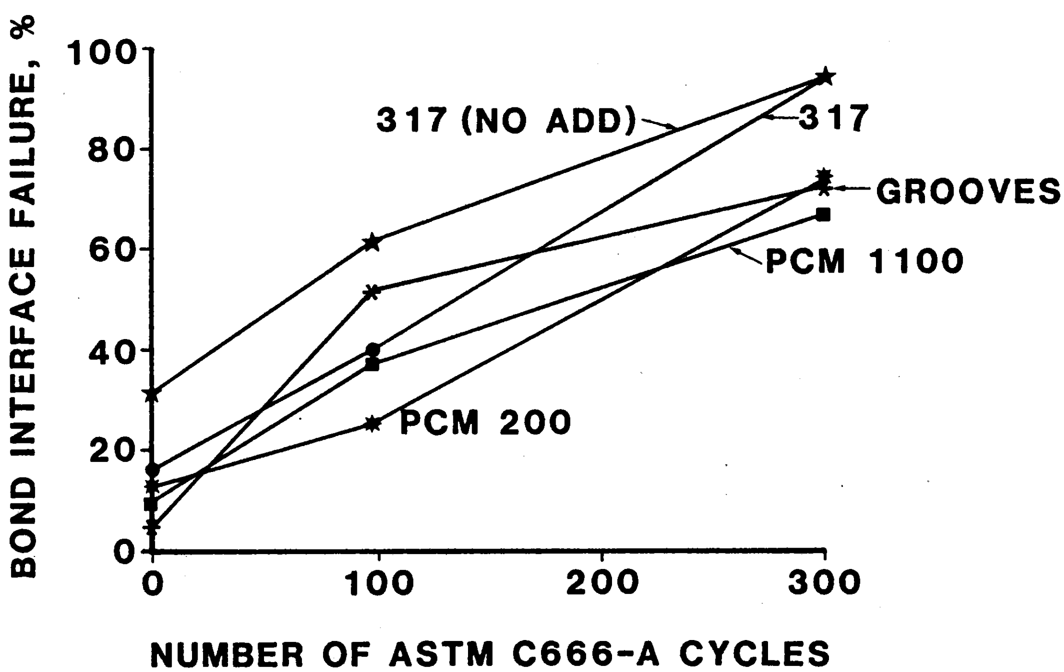

Figure 30. Bond interface failure, % vs ASTM C666-A cycles.

On the other hand, Figures 28 and 30 indicate that after 300 cycles of freezing and thawing in water, a higher bond strength and a lower percent of bond interface failure was obtained for the specimens with the HMWM primers and the grooves in the surface. It would appear that the use of HMWM primers or grooving the surface could be justified on overlays that will be subjected to freezing and thawing in a saturated condition in the presence of salt. However, under these conditions an overlay other than a polyester should probably be specified because (as shown in Table 6) after 300 cycles the bond strength for the best specimens (grooved surface) is only 342 psi and because (as shown in Figure 30) the percent of failure at the bond interface for the best specimens (PCM 1100 primer) is 67%. Except for poorly drained areas of a bridge deck that allow the concrete to become saturated and remain saturated for extended periods, cost-effective bond strengths can be obtained with a polyester resin equal to 317 which contains 1% S440 and 1% A174. A service life of less than 10 years can be expected when polymer overlays are used on poorly drained slabs on or below grade.

IMPLEMENTATION OF FINDINGS

Polymer Overlays Most Likely to Give Optimum Performance

Based on the data collected over the 5-year study, it appears that the polymer overlays most likely to give optimum performance will initially have a high bond strength (≧700 psi in shear and ≧250 psi in tension), skid number (≧45 with bald tire), tensile elongation of binder of 20% to 50% (ASTM D638), low shrinkage (≦0.2%), aggregates with ≧90% gradation between nos. 8 and 20 sieves, and aggregates with MOHS' scale hardness ≧7.

Laboratory Tests to Predict Performance

It appears that a reasonably accurate indication of the performance to be obtained from an overlay material can be determined by measuring the initial condition of specimens of bridge deck concrete and overlay material. The specimens should be tested for permeability (AASHTO T-277), shear bond strength (guillotine), and tensile bond strength (ACI 503R). A second set of specimens should be tested for permeability, shear bond strength, and tensile bond strength after being subjected to 200 thermal cycles as described in this report or 300 freeze thaw cycles (ASTM C666). The permeability of a potentially successful material initially should be ≦100 Coulombs. The permeability after the 200 thermal cycles should be ≦1500 Coulombs. The initial guillotine shear bond strength should be ≧700 psi or greater than the shear strength of the base concrete and should not decrease ≧50% after 200 thermal cycles. The initial tensile bond strength should be ≧250 psi or greater than the tensile strength of the base concrete and should not decrease ≧50% after 200 thermal cycles. Similar limits could be applied to the freezing and thawing test. However, polymer overlays should not be used under conditions that are simulated by this test. In addition, specimens could be subjected to wear tests (ASTM E-660) and skid tests (ASTM E-303).

When to Use Polymer Overlays

When first constructed, polymer overlays provide low permeability, high skid numbers and high bond strengths. In addition, joint replacement costs are less than when thicker overlays are used. Of course the problem is that the environment causes a reduction in bond strength, a reduction in skid number, and an increase in permeability. The polymer binders and aggregates being recommended for use today will provide overlays which can function for 10 years. Hopefully, demonstration projects sponsored by FHWA will lead to the development of binders and aggregates that will provide a longer service life(15). The decision to use a polymer overlay should be based on a life-cycle cost comparison with other protective systems assuming a life of 10 years. Additional incentive to use a polymer overlay would come from an assessment of traffic conditions. A polymer overlay can be justified when it is highly desirable to install a protective system during off-peak traffic periods so as to reduce inconvenience to the motorist. A reduced service life can be expected when polymer overlays are used on concretes that can become saturated and remain saturated for extended periods, such as poorly drained slabs on or below grade.

CONCLUSIONS

1. The installation of multiple layer polymer concrete overlays on portland cement concrete bridge decks since 1981 has demonstrated that overlays of low permeability and high skid resistance can be successfully installed by a contractor or by state or federal labor forces, with a minimum of disruption to traffic.

2. The initial condition of the overlays has been excellent from the standpoint of permeability, skid resistance, and bond, although some overlays have been better than others, particularly with respect to bond strength.

3. Overlays constructed with all resins have exhibited a decrease in bond strengths and skid numbers and an increase in permeability with age.

4. All overlays have an acceptable skid number and permeability after 5 years in service.

5. The overlays will delaminate before they wear through or exhibit an unacceptable skid number.

6. Parts of some overlays are delaminating after 5 years primarily because the initial bond strengths were low because the concrete surfaces were not properly cleaned. The XU40047 overlay had a low bond strength initially probably because of a curing problem.

7. Half-cell potentials have not changed significantly over the 5-year evaluation period; this supports the theory that PC overlays can extend the time to corrosion if applied prior to the on-set of corrosion.

8. The MMA overlay is not performing any better than the LB183 overlays and future use of MMA overlays would not likely be justified because of the higher cost of the MMA.

9. The majority of the MMA and LB183 overlays near Williamsburg should delaminate within a 10-year life, but 92-339 overlays that are installed in accordance with the special provision of March 1987 (see Appendix B) can be assumed to have a useful service life of 10 years.

10. A service life of less than 10 years can be expected when polymer overlays are placed on concretes that can become and remain saturated for extended periods, such as poorly drained slabs on or below grade.

11. A good indication of the performance to be expected from a PC overlay can be obtained by (1) measuring the tensile elongation of the neat resin (ASTM D 638), (2)testing specimens with PC overlays for permeability to chloride ions (AASHTO T-277), and (3) measuring bond

strength in shear (guillotine) and direct tension (ACI 503R) after subjecting the specimens to a thermal cycling test. The tensile adhesion test prescribed by ACI 503R provides a good indication of surface adhesion and should be used prior to placing an overlay to ensure that proper surface preparation techniques are being used.

12. To develop the full potential of PC overlays, industry, government, and academia must continue to work together to refine the materials, installation techniques, and test methods.

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APPENDIX A

Data on Multiple-layer PC Overlays Constructed in Virginia and at Swan Creek, Tennessee

TABLE A-1

General Information

Bridge No.	Location	Str. No.	Resin	Resin Supplier	Contractor	Date of Inst.	Contract Quantity, yd^2	Cost, $\$/yd^2$
-	Rte. 629 over Cowpasture River	6030	LB183	USS Chem.	Charles W. Barger	10/80	250±	-
W-8	I-64 over Rte. 143, WBL	2807	LB183	USS Chem.	Luke Const./ Con.Repair Specialists	6/81	1,508	41.00
W-3	EBL	2806	LB183	"	"	6/81	1,508	41.00
W-9	I-64 over C&O, WBL	2001	LB183	"	"	8/81	1,074	41.00
W-2	I-64 EBL	2000	LB183	"	"	8/81	1,156	41.00
W-1	I-64 over 143, EBL	2002	MMA	DuPont	"	9/81	1,088	54.00
BRN	Rte. 675 over Dulles Airport Road, NBL	6232	LB183	USS Chem.	VDHT, FHWA, FAA	5/82	600	12.00 (Matls.only)
BRS	SBL	6232	90-570	Reichhold Chem.	"	5/82	600	12.00 (Matls.only)
RRET	I-64 over Rivanna River, TL EBL	2047	92-339	Reichhold Chem.	Marvin V. Templeton & Sons, Inc./Polymer Systems	4,5, 6/85	2,359	25.50
RREP	PL EBL	2047	XU40047	Dow Chem.	"	4,5/85	2,358	25.50
RRW	I-64 WBL	2048	92-339	Reichhold Chem.	"	4,5,6/85	4,944	25.50
HRW	I-64 over Hampton Roads, WBL	2900	92-339	"	"	7,8/85	5,500	28.75
HRE	EBL	2866	92-339	"	"	7,8,9/ 85	13,334	28.75
-	I-95 SBL Ramp over I-495	2025	92-339	"	Marboro Const.Co./ Polymer Sys.	9,10,11/ 85	741	57.00
-	Rte. 123 over I-95, NBL	1072	92-339	"	Jewell Painting, Inc.	10/85	1,005	34.00
-	SBL	1071	92-339	"	"	10/85	714	34.00
-	Rte. 620 over 495, WBL	6212	92-339	"	"	10/85	1,425	36.00
-	Rte. 7 over Rte. 50, EBL	1035	92-339	"	Dural Int.	10,11/85	587	34.00
-	WBL	1043	92-339	"	"	10,11/85	493	34.00
-	Frontage Rd over Rte. 50	1042	92-339	"	"	10,11/85	195	34.00

TABLE A-2

Installation Data for PC Overlays

Bridge No	Average Surface Temp.,°F	Average Resin App. Rate, lb/yd^2	Average MEKP Dosage, %	Average Gel Time, min.
W-8	97 (86)*	10.7 (1.7)	3.2 (3.3)**	13 (16)
W-3	90 (80)	10.0 (1.9)	3.6 (4.0)**	15 (18)
W-9	85 (74)	10.7 (2.2)	4.5 (4.2)**	11 (16)
W-2	80 (75)	10.5 (2.2)	5.2 (4.8)**	11 (15)
W-1	66 (61)	10.1 (2.1)	3.0 (3.8)**	12 (13)
BRN	77 (74)	11.5 (2.6)	1.2 (1.2)	16 (15)
BRS	81 (81)	10.7 (2.3)	1.2 (1.2)	18 (18)
RRET	97 (85)	10.5 (2.2)	2.3 (2.9)	12 (19)
RREP	88 (93)	9.9 (1.9)	2.4 (2.9)	8 (6)
RRW (TL)	99 (103)	10.3 (2.2)	2.3 (2.6)	12 (12)
RRW (PL)	103 (100)	10.1 (2.4)	2.1 (2.2)	14 (11)
HRW	78 (80)	9.6 (1.9)	2.2 (2.2)	10 (11)
HRE	77 (76)	9.8 (1.8)	2.3 (2.4)	10 (11)
Rte. 123 NBL	71 (71)	10.1 (1.7)	2.1 (2.0)	15 (14)
Rte. 123 SBL	70 (72)	10.4 (1.7)	2.2 (2.0)	13 (15)
Rte. 620	59 (65)	10.5 (2.0)	2.5 (2.5)	20 (14)
I-95 RAMP	55 (68)	11.2 (2.0)	-- --	14 (11)
Front Road over Rte. 50	62 (52)	-- (1.8)	-- --	17 (18)

* Numbers in parentheses are data for first layer

** BPO-40

TABLE A-3

Tensile Test Results, lb/in^2

Bridge	Deck Surface	81	82	83	84	85	86
W-Avg.	LB183	175	156	--	--	--	128
BRN	LB183	--	337	241	--	--	167
BRS	90-570	--	268	266	--	134	223
RRET	92-339	--	--	--	--	353	308
TS-1	92-339	--	--	--	--	241	--
TS-2	92-339	--	--	--	--	287	--
TS-2	XU-40047	--	--	--	--	218	--
RREP	XU40047	--	--	--	--	90	29
HRW	92-339	--	--	--	--	175	--
HRE	92-339	--	--	--	--	220	--
W-4	EP5-LV	--	--	--	--	--	350

TABLE A-4

Shear Bond Strength

Bridge	Deck Surface	1981 Shear Bond Strength, lb/in² Concrete New[a]	1981 Concrete Old	1981 Bond Interface New and Old	1982 Shear Bond Strength, lb/in² Concrete Old	1982 Bond Interface Old	1983 Shear Bond Strength, lb/in² Concrete New	1983 Concrete Old	1983 Bond Interface New	1983 Bond Interface Old	1984 Shear Bond Strength, lb/in² Concrete New	1984 Concrete Old	1984 Bond Interface New	1984 Bond Interface Old	1985 Shear Bond Strength, lb/in² Concrete New	1985 Concrete Old	1985 Bond Interface New	1985 Bond Interface Old	1986 Shear Bond Strength, lb/in² Concrete New	1986 Concrete Old	1986 Bond Interface New	1986 Bond Interface Old
W-1	MMA	1404	921	-	-	-	-	-	-	-	838	774	335	271	-	-	-	-	1061	931	172	147
W-2	LB183	838	774	1125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1027	918	290	144
W-3	LB183	1124	730	469	-	-	-	-	-	-	470	573	222	187	-	-	-	-	1368	675	264	218
W-4	Concrete	-	597	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W-5	Bituminous	660	565	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W-6	Bituminous	774	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W-7	Concrete	-	884	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W-8	LB183	832	541	776	-	-	-	-	-	-	1046	808	678	137	-	-	-	-	-	-	-	-
W-9	LB183	860	541	681	-	-	-	-	-	-	1245	794	84	282	-	-	-	-	1504	853	106	209
W-Avg.	LB183	923	690	763	-	-	-	-	-	-	920	725	328	202	-	-	-	-	1300	815	220	190
BR	90-570	-	-	-	812	972	-	823	-	730	-	763	-	602	-	950	-	734	-	787	-	320
BR	LB183	-	-	-	804	1001	-	838	-	436	-	-	-	-	-	-	-	-	-	984	-	172
SC	317	-	-	-	-	-	1386	-	1168	-	-	-	769	-	1392	-	910	-	-	-	-	-
RREB	92-339	-	-	-	-	-	-	-	-	-	-	-	-	-	-	980	-	793	-	823	-	514
RREB	XU40047	-	-	-	-	-	-	-	-	-	-	-	-	-	-	771	-	582	-	791	-	86
HRW	92-339	-	-	-	-	-	-	-	-	-	-	-	-	-	-	794	-	519	-	-	-	-
HRE	92-339	-	-	-	-	-	-	-	-	-	-	-	-	-	-	695	-	750	-	-	-	-

[a] Concrete was placed the same year the overlay was placed.

TABLE A-5

Permeability, Coulombs

ridge	Deck Surface	1981	1982	1983	1984	1985	1986
-1	Concrete[a]	6974	-	-	-	-	7230
-2	Concrete[a]	6109	-	-	-	-	5738
-1	MMA	216	1331	-	1339	-	1630
-2	LB183	12	384	-	-	-	1105
-3	LB183	167	3607	-	3252	-	1895
-4	Concrete	3100	-	-	-	-	-
-5	Bituminous[b]	69	-	-	-	-	-
-6	Bituminous[c]	6349	-	-	-	-	-
-7	Concrete	2494	-	-	-	-	-
-8	LB183	200	747	-	1892	-	-
-9	LB183	37	370	-	962	-	-
-Avg.	LB183	62	787	-	1809	-	1500
-Avg.	Concrete 1,2,6	6467	-	-	-	-	6198
R	90-570	-	1	1	187	412	706
R	LB183	-	3	713	-	-	1656
R-90-570	Concrete	-	2124	-	-	4303	-
R-LB183	Concrete	-	2308	-	-	-	4788
C	317	-	-	0	513	794	-
C	Concrete	-	-	2787	-	-	-
R-92-339		-	-	-	-	29	322
R-XU40047		-	-	-	-	92	2047
R-92-339	Concrete	-	-	-	-	7378	-
R-XU40047	Concrete	-		-	-	6986	5865

Base concrete prior to overlay.

Concrete after removing bituminous overlay.

Concrete after removing bituminous overlay and rubberized asphalt membrane.

TABLE A-6

Electrical Resistivity, Percentage of Total Number of Readings

Range of Electrical Resistivity, ohm/ft^2

Bridge	Deck Surface	Poor $<10^4$						Fair 10^4 to $<10^6$						Good 10^6 to 10^8						Excellent $>10^8$					
		81	82	83	84	85	86	81	82	83	84	85	86	81	82	83	84	85	86	81	82	83	84	85	86
1	MMA	0	100	–	99	–	2	23	0	–	1	–	98	11	0	–	0	–	0	0	66	0	–	0	0
2	LB183	0	24	–	100	–	6	4	73	–	0	–	94	1	3	–	0	–	0	95	0	–	0	–	0
3	LB183	0	38	–	85	–	0	12	55	–	15	–	100	16	7	–	0	–	0	72	0	–	0	–	0
4	Concrete	91	100	–	100	–	–	9	0	–	0	–	–	0	0	–	0	–	–	0	0	–	0	–	–
5	Bituminous	4	24	–	2	–	0	36	34	–	73	–	68	13	9	–	14	–	16	47	33	–	11	–	16
6	Bituminous	1	0	–	0	–	–	29	0	–	58	–	–	25	0	–	26	–	–	45	0	–	16	–	–
7	Concrete	100	0	–	90	–	–	0	0	–	10	–	–	0	0	–	0	–	–	0	0	–	0	–	–
8	LB183	0	44	–	78	–	–	9	26	–	22	–	–	53	30	–	0	–	–	38	0	–	0	–	–
9	LB183	0	46	–	97	–	–	5	52	–	3	–	–	9	2	–	0	–	–	86	0	–	0	–	–
Avg.	LB183	0	38	–	90	–	3	7	52	–	10	–	97	20	10	–	0	–	0	73	0	–	0	–	0
BR	90-570	–	1	0	0	0	–	–	2	11	15	95	–	–	13	78	84	5	–	–	84	11	1	0	–
BR	LB183	–	0	2	–	–	–	–	6	80	–	–	–	–	15	17	–	–	–	–	79	1	–	–	–
SC	317	–	–	0	31	100	–	–	–	41	34	0	–	–	–	1	35	0	–	–	–	58	0	0	–
RR	92-339	–	–	–	–	0	0	–	–	–	–	2	100	–	–	–	–	4	0	–	–	–	–	94	0
RR	XU40047	–	–	–	–	0	0	–	–	–	–	0	100	–	–	–	–	6	0	–	–	–	–	94	0

10.8 ohm/m^2 = 1.0 ohm/ft^2

TABLE A-7

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

Bridge	Deck Surface	Range (-Volts CSE) <0.20 81	82	83	84	85	86	0.20 to 0.35 81	82	83	84	85	86	>0.35 81	82	83	84	85	86
W-1	MMA	94	79	-	92	-	90	6	20	-	8	-	10	0	1	-	0	-	0
W-2	LB183	98	96	-	97	-	99	1	4	-	3	-	1	1	0	-	0	-	0
W-3	LB183	98	86	-	98	-	97	2	14	-	2	-	3	0	0	-	0	-	0
W-4	Concrete	98	94	-	97	-	-	1	6	-	3	-	-	1	0	-	0	-	-
W-5	Bituminous	96	77	-	71	-	79	3	13	-	27	-	21	1	10	-	2	-	0
W-6	Bituminous	99	-	-	97	-	-	0	-	-	3	-	-	1	-	-	0	-	-
W-7	Concrete	100	-	-	100	-	-	0	-	-	0	-	-	0	-	-	0	-	-
W-8	LB183	95	93	-	95	-	-	5	7	-	5	-	-	0	0	-	0	-	-
W-9	LB183	94	100	-	99	-	-	6	0	-	1	-	-	0	0	-	0	-	-
BR	90-570	--	100	100	-	93	-	-	0	0	-	7	-	-	0	0	-	0	-
BR	LB183	-	100	99	-	-	-	-	0	1	-	-	-	-	0	0	-	-	-
SC	317	-	-	99	-	99	-	-	-	1	-	1	-	-	-	0	-	0	-
RR	92-339	-	-	-	-	-	71	-	-	-	-	-	29	-	-	-	-	-	0
RR	XU40047	-	-	-	-	-	49	-	-	-	-	-	45	-	-	-	-	-	6

TABLE A-8

Rate of Corrosion, Mils/Yr.

Date	Bridge Number and Surface Type 2 LB183	 3 LB183	 5 Bituminous
4/09/81	---	1.65	0.93[a]
7/07/81	0.00	5.14[a]	2.64
8/24/81	0.45[a]	---	---
9/22/81	0.69	5.39	3.28[b]
12/02/81	1.37	5.55[b]	3.19
12/08/82	1.86[b]	3.83	2.00
6/24/83	1.70	3.11	1.59
7/16/84	1.41	2.22	1.12
12/19/85	1.18	1.56	0.73
7/1/86	1.05	1.41	0.63

[a] Overlay installed

[b] Maximum rate

TABLE A-9-A

Skid Numbers for Tests at 40 MPH, 1980-1986

		Treaded Tire													
	Deck	Travel Lane							Passing Lane						
Bridge	Surface	80	81	82	83	84	85	86	80	81	82	83	84	85	86
W-1	MMA	46	59	53	--	45	--	46	49	60	54	--	49	--	49
W-2	LB183	46	64	58	--	45	--	46	51	63	57	--	52	--	47
W-3	LB183	45	63	57	--	46	--	44	53	58	61	--	54	--	49
W-4	Concrete	46	43	48	--	63[a]	45	40	50	46	51	--	65[a]	--	45
W-5	Bituminous	45	43	42	--	39	--	41	44	43	44	--	45	--	44
W-6	Bituminous	46	49	45	--	41	--	--	44	47	49	--	47	--	--
W-7	Concrete	47	47	51	--	58[a]	46	--	50	48	52	--	66[a]	--	--
W-8	LB183	46	59	55	--	48	--	--	48	64	55	--	54	--	--
W-9	LB183	47	62	56	--	47	--	--	52	61	59	--	55	--	--
W-Avg.	LB183	46	62	56	--	46	--	--	51	62	58	--	54	--	--
BR	90-570	--	--	55	56	--	49	--	--	--	--	--	--	--	--
BR	LB183	--	--	53	58	--	--	--	--	--	--	--	--	--	--
RR	92-339	--	--	--	--	--	62	54	--	--	--	--	--	--	--
RR	XU40047	--	--	--	--	--	--	--	--	--	--	--	--	64	57
HRW	92-339	--	--	--	--	--	43	--	--	--	--	--	--	42	--
HRE	92-339	--	--	--	--	--	47	--	--	--	--	--	--	48	--

[a] EP5-LV epoxy overlay installed in 1984.

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TABLE A-9-B

Skid Numbers for Tests at 40 MPH, 1980-1986

		Bald Tire													
		Travel Lane							Passing Lane						
Bridge	Deck Surface	80	81	82	83	84	85	86	80	81	82	83	84	85	86
W-1	MMA	26	56	38	--	42	--	37	22	54	43	--	48	--	40
W-2	LB183	24	63	46	--	43	--	32	22	62	46	--	50	--	41
W-3	LB183	25	62	43	--	41	--	40	33	60	50	--	52	--	43
W-4	Concrete	27	27	24	--	52[a]	28	20	24	24	23	--	60[a]	--	22
W-5	Bituminous	41	27	23	--	28	--	28	41	25	20	--	32	--	25
W-6	Bituminous	41	25	20	--	24	--	--	44	30	20	--	36	--	--
W-7	Concrete	30	27	28	--	46[a]	30	--	24	28	26	--	58[a]	--	--
W-8	LB183	25	58	42	--	44	--	--	23	64	45	--	52	--	--
W-9	LB183	23	60	44	--	41	--	--	24	60	50	--	53	--	--
W-Avg.	LB183	24	61	44	--	42	--	--	26	61	48	--	52	--	--
BR	90-570	--	--	49	45	--	38	--	--	--	--	--	--	--	--
BR	LB183	--	--	47	49	--	--	--	--	--	--	--	--	--	--
RR	92-339	--	--	--	--	--	56	50	--	--	--	--	--	--	--
RR	XU40047	--	--	--	--	--	--	--	--	--	--	--	--	59	50
HRW	92-339	--	--	--	--	--	42	--	--	--	--	--	--	40	--
HRE	92-339	--	--	--	--	--	45	--	--	--	--	--	--	45	--

[a] EP5-LV epoxy overlay installed in 1984.

TABLE A-10

Rutting in Wheel Paths, 1/32 in

Bridge	Deck Surface	Year	Passing Lane Left	Passing Lane Right	Traffic Lane Left	Traffic Lane Right	Average
W-1	MMA	1982	0.0	0.4	0.1	0.2	0.2
		1984	(0.4)[a]	0.4	0.0	0.1	0.0
		1986	1.0	0.8	0.8	1.2	0.9
W-2	LB183	1982	1.8	0.1	0.6	0.3	0.7
		1984	1.8	0.1	(0.1)	0.5	0.6
		1986	1.9	(0.2)	0.5	0.6	0.7
W-3	LB183	1982	0.8	0.0	(0.9)	0.8	0.2
		1984	0.8	0.6	(0.2)	0.7	0.5
		1986	1.0	3.1	0.1	0.8	1.2
W-4	Concrete	1982	0.1	0.0	0.7	0.5	0.3
		1984	0.0	(0.1)	1.4	0.6	0.5
W-5	Bituminous	1982	0.8	0.6	0.6	1.1	0.8
		1984	0.6	0.4	0.8	1.3	0.8
		1986	1.4	0.3	1.2	1.7	1.2
W-6	Bituminous	1982	---	---	---	---	---
		1984	0.7	0.3	0.7	1.2	0.7
W-7	Concrete	1982	---	---	---	---	--
		1984	(0.9)	1.1	(0.8)	(0.8)	(0.4)
W-8	LB183	1982	0.3	1.1	0.2	0.0	0.4
		1984	0.6	2.7	(1.2)	1.2	0.8
W-9	LB183	1982	0.3	1.7	0.9	0.5	0.9
		1984	0.3	0.1	0.8	1.4	0.7
W-Avg.	LB183	1982	0.8	0.7	0.2	0.4	0.5
		1984	0.9	0.9	(0.2)	1.0	0.7
		1986	1.4	1.5	0.3	0.7	1.0
BRS	90-570	1983	---	---	(0.1)	(0.3)	(0.2)
		1985	---	---	(0.0)	(0.4)	(0.2)
BRN	LB183	1983	---	---	(0.2)	(0.3)	(0.2)
RRET	92-339	1986	---	---	(0.4)	1.6	0.6
RREP	XU40047	1986	(0.4)	(0.8)	---	---	(0.6)

[a] Relatively higher in wheel path.

TABLE A-11

Tensile Properties of Resins (ASTM D 638)

Resin	Age	Tensile Strength, lb/in^2		Elongation at Break, %		Young's Modulus, lb/in^{2}x10^4	
		x	s	x	s	x	s
LB183	1 wk	5089	1928	8.0	3.8	7.81	0.91
"	1 yr	4270	972	5.9	1.9	7.45	0.72
	3 yr	2828	995	4.8	1.4	5.79	0.41
90-570	1 wk	2836	373	49.2	11.4	3.52	0.21
"	1 yr	2586	157	41.3	7.0	3.04	0.91
	3 yr	1669	243	6.0	2.7	3.71	1.57
MMA	1 wk	1427	525	2.3	0.4	6.29	1.39
"	1 yr	1410	267	2.3	0.2	6.04	0.94
	3 yr	896	603	2.0	0.5	4.13	1.94
317	1 wk	2858	301	23.3	8.1	4.69	0.99
EP5LV	1 wk	4797	626	12.5	1.2	6.60	1.56
"	1 yr	760	29	52.2	5.1	0.87	0.04
	3 yr	732	30	48.9	6.1	0.86	0.21
Flexogrid	1 wk	1489	179	89.9	13.9	0.57	0.01
"	1 yr	1406	-	49.0	-	1.42	-
Flexolith	1 wk	3888	307	21.8	10.6	6.11	1.00
92-339	1 wk	3728	156	23.4	4.7	4.86	0.76
92-339 HR	1 wk	3727	63	23.9	11.4	5.19	0.52
XU40047	1 wk	2570	67	28.8	5.5	3.47	0.22
IX215	1 wk	2670	34	30.2	1.7	3.96	0.18
XU40047 PM	1 wk	3636	457	4.0	0.8	9.04	0.61

Source: Data supplied by Richard Steele, Materials Engineer, Virginia Department of Transportation.

TABLE A-12

Effect of Additives, Primers, and Surface Condition on Tensile Bond Strength and Failure Condition

			Base Concrete 28-Day Compressive Strength, lb/in²								
			7350			5450			2200		
Test Condition	No. Spec.	Average Strength, lb/in²	Strength, lb/in²	Failure, % base	Failure, % bond	Strength, lb/in²	Failure, % base	Failure, % bond	Strength, lb/in²	Failure, % base	Failure, % bond
No A174 No S440	4,7,4	308	369	32	30	315	6	24	239	68	25
Control	3,6,4	310	355	37	19	330	40	18	244	76	18
E-bond sealer	3,6,3	159	179	11	87	149	12	88	149	8	90
Saturated at test	3,3,3	241	258	18	50	265	33	25	200	92	5
Damp at overlay	0,3,0	--	--	--	--	291	23	53	--	--	--
PCM 200 primer	4,4,4	306	321	29	16	388	45	7	210	47	8
PCM 1100 primer	4,4,4	302	327	30	10	328	69	12	252	96	3
PCM 200 primer No A174 No S440	4,4,4	345	364	2	14	422	35	12	248	84	15
PCM 1100 primer No A174 No S440	3,3,3	335	353	0	0	329	7	3	322	100	0

NOTE: These data were developed by George Kelsey to partially satisfy his requirements for Materials Science Laboratory Course MS-692. Tests were conducted on one-layer overlays placed on the saw cut surfaces of slices of 4-in by 8-in cylinders of concrete having three different 28-day compressive strengths. The overlays were constructed with silica sand and 317 resin with 1% S440 and 1% A174 unless noted otherwise.

			Duracal Patching Material 24 Hour Compressive Strength, lb/in²					
			(Duracal/Sand) 4445			(Duracal/Sand/ C.A.) 3490		
Control	3,2	264	258	80	20	270	73	27
PCM1100 primer	3,3	266	261	83	17	271	58	38

NOTE: These data are based on tests conducted on slices of 4-in by 8-in cylinders of Duracal patching material.

APPENDIX B

Special Provision for Polymer Concrete Overlays

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
POLYMER CONCRETE OVERLAY

March 24, 1987

I. DESCRIPTION -

This work shall consist of furnishing and applying thin polymer concrete overlays on designated bridge structures in accordance with this specification and in reasonably close conformity with the lines, grades and details shown on the plans or established by the Engineer.

II. DEFINITION OF TERMS -

A. Monomer as used herein is a low viscosity, liquid organic material from which a polymer is made.

B. Polymers are hard glassy solids commonly called plastics.

C. Polymerization is a chemical process by which a monomer is converted to a polymer.

D. Inhibitors are materials that are added to monomers to prevent polymerization from occurring during shipping and storage.

E. Initiators are chemical materials that are required to start the polymerization process.

F. Promoters are chemicals used to accelerate the polymerization process.

III. MATERIALS -

A. Polyester Overlay Materials:

1. Monomers Polyester Resin -

A clear, low viscosity, highly resilient, general purpose, unsaturated polyester resin designed for applications requiring toughness and high impact and shall have a viscosity of 100 to 200 cP at 77°F (25°C) using Spindle 1 at 60 RPM on a Brookfield Model LVT viscometer, a tensile elongation of 20-40% (ASTM D638) and, equal to Reichhold Chemicals, Inc. blend Polylite 90-570. The first course shall contain 1% of Union Carbide A-174 coupling agent and 1% of Surfynol S440 wetting agent to enhance bond strength and to reduce surface tension. The second and third courses shall contain a minimum of 0.5% of Union Carbide A-174 coupling agent and a minimum of 0.5% of Surfynol S440 wetting agent.

2. Initiators -

a. Methyl Ethyl Ketone Peroxide (MEKP) $C_4H_8O_2$ and BPO-40 shall consist of a 60% MEKP in dimethyl phthalate with approximately 9% active oxygen and with a Specific Gravity of 1.15 at 64°F (18°C), shall be in a liquid state with a water white color, with a flash point (Cleveland Open Cup) of above 180°F (82°C) and with a mildly thermal decomposition point (rapid rise) at 302°F (150°C).

b. 40% Benzoyl Peroxide Dispersion (BPO-40) shall be either Reichhold Chemicals, Inc. formulation 46-742, or Witco Chemical's formulation BZQ-40.

3. Promoters -

(a) N,N, Dimethyl Aniline (DMA) $C_6H_4N(CH_3)_2$ shall have a technical grade freezing point of 35.8°F (2.1°C), a percentage purity of 98.9 mole, a maximum monomethyl aniline content of 0.5%, a density of 8 lb./gal. (0.96 g/cc), a refractive index of 1.5581.

(b) Cobalt Naphthenate (CoN) shall contain approximately 6% active cobalt in naphtha, shall be in a liquid state with a bluish red color, with a flash point at or above 121°F (49°C), and with a density of 7.5 lb./gal. (0.90 g/cc).

4. Aggregate Materials shall consist of clean, dry with less than 1% moisture, angular grained silica sand and shall be free from dirt, clay, asphalt and other organic materials. Except as otherwise approved by the Engineer, silica sand shall conform to the following gradation for the grading specified:

Grading	No.8 Sieve	No.12 Sieve	No.16 Sieve	No.20 Sieve	No.30 Sieve	No.100 Sieve
A	95 - 100	——	Max. 15	Max. 5	Max. 2	Max. 1
D	——	95 - 100	30 - 70	Max. 10	Max. 3	Max. 1

Note: Numbers indicate percent passing U.S. Standard Sieve Series.

B. Epoxy Overlay Materials:

1. Epoxy Resins -

Low viscosity, low-modulus two component epoxy resin equal to Dural Flexolith as prescribed by Dural data sheet FL-685 or Polycarb Flexogrid as prescribed by data sheet 04-317/R-5.

2. Aggregate Materials shall be equal to Dural "Basalt" or polycarb Mark 371 crushed stone.

IV. INITIATOR-PROMOTER FORMULATIONS -

A. Polyester Resin:

Property	Mix No.1	Mix No.2	Mix No.3
Temperature range, °F	65 - 75	75 - 90	65 - 90
**Initiator Concentration, percent of monomer by weight	1.2% MEKP	0.6% MEKP	2.5% BPO-40
Promoter Concentration, percent of monomer by weight	0.5% CoN	0.25% CoN	0.3% DMA

** The quantity of initiator is affected by mixing efficiency and temperature, and may vary from day to day. The quantity of initiator shall be determined at the beginning of each day. Gel time should be between 10 and 20 minutes when tested using a container which will produce a depth of approximately 1 to 1½ inches when filled with 50 ml of resin.

Ungelled portion of overlay course represented by a test Gel which has not gelled within 30 minutes shall be removed immediately and replaced at no additional cost to the Department.

V. CONSTRUCTION METHODS -

A. Safety Provisions:

Personnel shall be thoroughly trained in the safe handling of materials in accordance with the Manufacturer's recommendations.

B. Storage of Materials:

Information pertaining to the safe practices for the storage, handling and disposal of the materials and to their explosive and flammability characteristics, health hazards and the recommended fire fighting equipment shall be obtained from the manufactures and posted at storage areas. All required fire fighting equipment shall be kept readily accessible at storage areas. A copy of such information shall be provided to the Engineer.

In addition:

1. Monomers -

   Monomers shall be stored in an area separate from the areas in which the initiator is stored. Sufficient ventilation shall be maintained in the storage area to prevent the hazardous buildup of monomer vapor concentration in the storage air space.

2. Initiators -

   The MEKP and BPO-40 initiators shall be stored in a cool place away from the monomer and promoter storage area.

3. Promoters -

   Storage of the promoters DMA and CoN shall be in a cool place away from the initiator storage area.

C. Surface Preparation:

Before placement of the polymer concrete overlay, the entire deck surface shall be cleaned by shotblasting and other means to remove asphaltic material, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar and other potentially detrimental materials, which may interfere with the bonding or curing of the overlay. Acceptable cleaning is usually achieved by significantly changing the color of the concrete and mortar and beginning to expose coarse aggregate particles. Mortar which is sound and soundly bonded to the coarse aggregate must have open pores due to cleaning to be considered adequate for bond. Areas of asphalt larger than one inch in diameter, or smaller areas spaced less than six inches apart, shall be removed. Traffic paint lines shall be considered clean when the concrete has exposed aggregate showing through the paint stripe. A vacuum cleaner shall be used to remove all dust and other loose material..

Prior to placing the first course, the contractor shall use the test method prescribed in ACI 503R - Appendix A of the ACI Manual of Concrete Practice to determine the cleaning practice (size of shot, flow of shot, forward speed of shotblast machine, and number of passes) necessary to provide a tensile bond strength greater than or equal to 250 psi or a failure area, at a depth of ¼ in. or more into the base concrete, greater than 50% of the test area. A test result shall be the average of three tests on a test patch of approximately 1 ft x 3 ft, consisting of two courses. One test result must be obtained for each span or 200 yd which ever is the smaller area. The engineer will designate the location of the test patches. The cleaning practice will be approved if one passing test result is obtained from each test area.

If the cleaning practice is not acceptable, the contractor must make the necessary afjustments and test all test areas at no additional cost to the Department until satisfactory test results are obtained.

If the engineer determines that an approved cleaning practice has changed prior to the completion of the job, the contractor must return to the approved cleaning practice and reclean the suspect areas or verify through tests at no additional cost to the Department that the practice is acceptable.

All patching and cleaning operations shall be inspected and approved prior to placing each layer of the overlay. Any contamination of the deck or to intermediate courses, after initial cleaning, shall be removed. Subjecting any overlay course to traffic for more than seven days, without other evidence of contamination, shall be considered as having contaminated the surface. The first course shall be applied following the cleaning and prior to opening the area to traffic. Subsequent courses shall be placed as soon as practicable.

There shall be no visible moisture present on the surface of the concrete at the time of application of the polymer concrete overlay. Compressed air may be used to dry the surface of the deck.

D. Equipment:

The Contractor's equipment shall consist of no less than a polymer distribution system, fine aggregate spreader, broom and sweeper broom or vacuum truck, and a source of lighting if work will be performed at night. The distribution system or distributor shall accurately blend the monomer and initiator/promoter, and shall uniformly and accurately apply the polymer materials at the specified rate to the bridge deck in such a manner as to cover approximately 100% of the work area. The fine aggregate spreader shall be propelled in such a manner as to uniformly and accurately apply the dry silica sand to cover 100% of the polymer material. The sweeper broom or vacuum truck shall be self-propelled.

With the approval of the Engineer, the Contractor's equipment may consist of calibrated containers, a paddle type mixer, squeegees, rollers and brooms, which are suitable for mixing the resin and applying the resin and aggregate in accordance with the manufacture's recommendations.

E. Application of Polymer Concrete Overlays:

The handling, mixing and addition of promoters, initiators and monomers shall be performed in a safe manner to achieve the desired results in accordance with the manufacturer's recommendations as approved or directed by the Engineer. Polymer concrete overlay materials shall not be placed when weather or surface conditions are such that the material cannot be properly handled, placed and cured within the specified requirements of traffic control.

1. Polyester Overlays -

The polymer concrete overlay shall be applied in 3 separate courses in accordance with the following rate of application; the total of the 3 applications shall not be less than 6.25 lbs. per square yard.

Course	Polymer Rate (Lb./S.Y.)	Silica Sand (Lb./S.Y.)*
1	1.75 $\pm$ 0.25	Grading D; 17 $\pm$
2	2.25 $\pm$ 0.25	Grading A; 17 $\pm$
3	2.75 $\pm$ 0.25	Grading A; 17 $\pm$

* Application of sand shall be of sufficient quantity to completely cover the polymer.

After the polymer mixture has been prepared for the polymer concrete overlay, it shall be immediately and uniformly applied to the surface of the bridge deck. The first course polymer mixture shall be broomed into the deck surface immediately following application. The temperature of the bridge deck surface shall be above 40°F. The dry silica sand shall be applied in such a manner as to cover the polymer mixture completely within 5 minutes. First course applications which do not receive enough sand prior to gel shall be removed and replaced. Second and third courses insufficiently sanded may be left in place, but will require additional applications before opening to traffic. The polymer concrete overlay shall be cured at least one hour, or until brooming or vacuuming can be performed without tearing or otherwise damaging the surface and no traffic or equipment shall be permitted on the overlay surface during the curing period. After the curing period, all loose silica sand shall be removed by brooming or vacuuming and the next overlay course applied to completion.

Unless otherwise specified the polymer concrete overlay courses shall be applied over the expansion joints of the bridge deck. The expansion joints shall be provided with a bond breaker. Prior to opening any application to traffic, the overlay shall be removed over each joint by removal of tape, bond breakers, or by scoring the overlay prior to gelling, or by saw cutting after cure.

The Contractor shall plan and prosecute the work so as to provide a minimum of 3 hours cure prior to opening that section to public or construction traffic, unless otherwise permitted. Night operations, or other times of slow curing, the minimum time shall be increased to 4 hours cure prior to opening to traffic.

In the event the Contractor's operation damages or mars the polymer concrete overlay course(s), the Contractor shall remove the damaged area(s) by saw-cutting in rectangular sections to the top of the concrete deck surface and shall replace the various courses in accordance with the Specifications in a manner acceptable to the Engineer at no additional cost to the Department.

In the event the Contractor's method of operation or polymer mixture is outside the limitations provided herein, the overlay as placed will be removed to the satisfaction of the Engineer.

2. <u>Epoxy Overlays</u> -

The epoxy overlay shall be applied as prescribed by Section V. E. I. <u>Polyester Overlays</u> with the exception that the epoxy overlay shall be applied in 2 separate courses in accordance with the following rate of application, the total of the 2 applications shall not be less than 4.75 lbs per square yard.

Course	Epoxy Rate (lb./S.Y.)	Aggregate (lb./S/Y/)*
1	2.00 ± 0.25	10±
2	3.00 ± 0.25	14±

* Application of aggregate shall be of sufficient quantity to completely cover the epoxy.

VI. **METHOD OF MEASUREMENT** -

Polymer concrete overlay will be measured in square yards of bridge deck surface for the type specified, complete-in-place.

Repairing of the deck and removing bituminous overlay will be measured and paid for in accordance with Section 416 of the Specifications.

VII. **BASIS OF PAYMENT** -

Polymer concrete overlay will be paid for at the contract unit price per square yard, which price shall be full compensation for deck preparation, and testing for furnishing and applying polymer concrete overlay courses, for all safety precautions, for any necessary repairs, for saw-cutting expansion joints, and for all materials, labor, tools, equipment and incidentals necessary to complete the work.

Payment will be made under:

PAY ITEM	PAY UNIT
Polymer Concrete Overlay	Square Yard

APPENDIX C

ACI 503R Test Procedure

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Figure C-1. Resin applied for first layer of 1 ft by 3 ft test patch.

Figure C-2. Aggregate broadcast onto resin.

Figure C-3. Drilling through the overlay to separate a 2.2 in diameter circular portion.

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Figure C-4. Bonding a pipe cap to the surface.

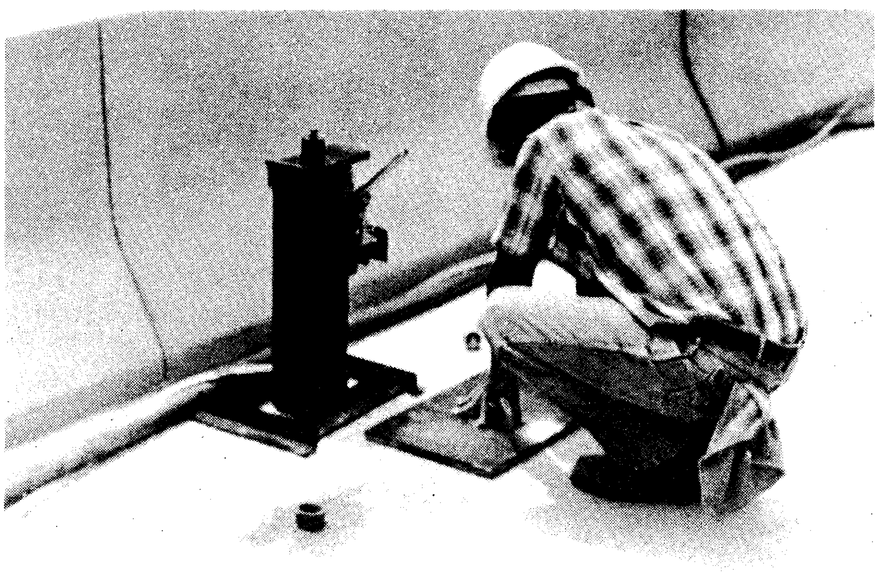

Figure C-5. Template used to center pull-off device over pipe cap.

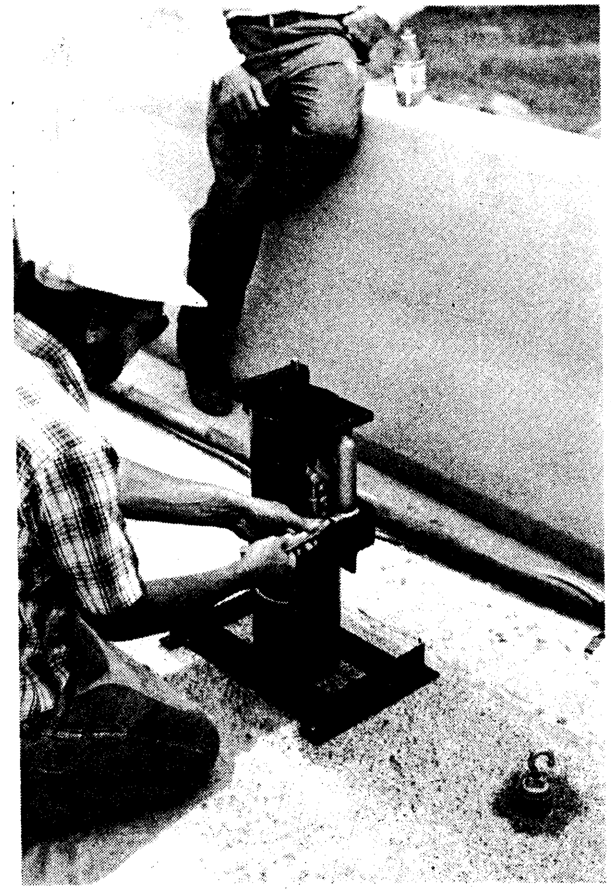

Figure C-6. Pull-off device in position for test.