COMPARATIVE EVALUATION OF CONCRETE SEALERS AND MULTIPLE LAYER POLYMER CONCRETE OVERLAYS

Interim Report No. 1

by

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(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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SUMMARY

The report presents comparisons of initial evaluations of several concrete sealers and multiple layer polymer concrete overlays. The sealers evaluated included a solvent-dispersed epoxy, a water-dispersed epoxy, a silane, and a high molecular weight methacrylate. The multiple layer polymer overlays evaluated were constructed with two polyester resins and silica sand, two flexible epoxies and basalt aggregate, and three EP5-LV epoxies and silica sand. The report presents information on the permeability to chloride ion, the bond strength between the overlay and the base concrete, the skid number, and the cost of the sealers and overlays.

The data collected to date indicate that penetrating sealers can usually be applied with a lane-closure time of less than 24 hours and can provide some protection against the infiltration of chloride ions at a low initial cost. Unfortunately, the sealers usually reduce the skid number, and their use will have to be restricted to bridge decks that have a high skid number, such as those with grooves made by tining or sawcutting. Of course, the sealers can be used to reduce the permeability to chloride ions of concrete components other than the deck.

A high molecular weight methacrylate healer sealer covered with silica sand provided acceptable skid resistance and filled the cracks in a deck to a depth of about 0.5 in, depending on the width of the cracks.

A multiple layer polymer overlay designated by the VDOT as class-I waterproofing provides more protection against the infiltration of chloride ions than do the sealers, but the time required for installation is usually more than 24 hours, and the initial cost is usually more than twice as much. These overlays will usually increase the skid number of decks with low skid numbers. Unfortunately, the skid number of the overlay decreases with age, and depending on the traffic, may decrease to an unacceptable level in two to four years. The class-I waterproofing exhibited a high bond strength and low permeability to chloride ions after four years in service. Bridge engineers agreed to stop the use of class-I waterproofing in 1986 because of the low skid numbers.

Multiple layer polymer overlays constructed with polyester resin are similar to class-I waterproofing. Their initial cost is somewhat greater, because they are usually constructed in three or four layers rather than the two used for the class-I waterproofing and because the binder application rate is greater than that used for class-I waterproofing. The polyester overlays have an advantage over class-I waterproofing in that they can be installed in stages and thus allow lane closures to be restricted to off-peak traffic periods. Also, multiple layer polymer overlays constructed with polyester resin should maintain an acceptable skid number for 10 years. Initial evaluations of

multiple layer polymer overlays constructed with two flexible epoxies and basalt aggregate also look encouraging.

One hundred cycles of temperature change had little effect on the sealers, class-I waterproofing, and the flexible multiple layer epoxy overlays. The polyester overlays, particularly those constructed with brittle resins, showed an increase in permeability and a decrease in bond strength after being subjected to 100 or more cycles of temperature change. A 300-cycle test may provide more definitive results.

The performance of the sealers and multiple layer polymer overlays will have to be evaluated for at least five years to allow for an accurate assessment of life-cycle costs.

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INTRODUCTION

Sealers and overlays are usually applied to portland cement concrete bridge decks to reduce the infiltration of water and chloride ions into the concrete (1, 2, 3, 4). Sealers usually reduce the permeability of the concrete surface by coating the surface with a water-repelling material or by filling the cracks and voids in the concrete. Overlays reduce the infiltration of water and chloride ions into concrete by providing a layer of low-permeability material above the concrete. Overlays are also placed on bridge decks to improve the skid resistance, the ride quality, and the appearance of the surface.

Decks that are likely candidates for a sealer or an overlay are those with a concrete cover over the rebar that has a permeability in excess of 2,000 Coulombs (AASHTO T-277), a clear cover over the rebar of less that 2 in, a cover that is not properly air entrained, a cover that is extensively cracked (particularly decks that were constructed without epoxy coated reinforcement) and those that have been patched or need extensive patching. Decks that exhibit a bald tire skid number (ASTM E524) ≤ 20 at 40 mph, that are poorly drained, or that have poor ride quality are also candidates for overlays.

The market is flooded with sealer and overlay systems for bridge decks. The costs and benefits of these deck protective-systems vary greatly. The objective of this report is to present information on the permeability to chloride ion, the bond strength between the overlay and the base concrete, the skid number, the cost, and the service life of several sealer and polymer overlay systems. The information will help bridge and maintenance engineers make cost-effective decisions on maintaining and extending the service life of bridge decks.

WORK PLAN AND METHODOLOGY

The objectives of this study required that an effort be made to complete the tasks described below.

Task 1

To collect data that reflects the condition of the travel lane and shoulder of one or more spans of the bridges prior to placing the protective system to be evaluated. Data included:

(a) electrical half-cell potentials (ASTM C876-77),

(b) chloride content at the level of the reinforcing steel (AASHTO T260), and

(c) skid numbers at 40 mph with treaded tires (ASTM E501-76) and bald tires (ASTM C524-76).

Task 2

To collect data that reflects the condition of the same spans measured in Task 1 immediately after the protective systems were applied. Activities included:

(a) Taking electrical resistance measurements (ASTM D3633).

(b) Removing one 4-in diameter core from each span, and subjecting the top 2 in and the next 2 in of the core to a rapid permeability test (AASHTO T277).

(c) Measuring skid numbers at 40 mph based on the average of three tests with bald tires and three with treaded tires.

(d) Removing one 2.75-in diameter core from each span that has an overlay and subjecting the cores to a shear test.

(e) Removing one 2.75-in diameter core from each span that has an overlay and subjecting the cores to 100 cycles of temperature change, with each cycle ranging from 100°F to 0°F and applied at the rate of 3 cycles per day, and subsequently subjecting it to a shear test.

(f) Repeating task 2b except that prior to the permeability test the cores were subjected to 100 cycles of temperature change as in task 2e.

Task 3

To prepare an interim report that compares the initial condition of the decks with the sealers and overlays.

Task 4

To collect data that reflects the performance of the sealers and overlays after 1 year in service. Activities a, b, c, and d listed under Task 2 are to be repeated.

Task 5

To collect data that reflects the performance of the sealers and overlays after three years of service life. Activities a, b, c, and d listed under Task 2 are to be repeated.

Task 6

To prepare a final report that will reflect the performance of the sealers and overlays.

Since it was not practical to schedule the installation of all the sealer and overlay systems in the same construction season and because some promising systems were added to the study after the study was initiated, the report contains results through Task 3 for some systems through Task 4 for some, and through Task 5 for some.

The first section of the report provides a brief summary of the sealer and overlay systems under evaluation. The second part covers the bond between the overlays and the deck concrete and attempts to answer the question, How long will the overlays stay down, based on the data collected for the decks under study? The third part deals with the protection provided by the overlays and sealers in preventing the infiltration of water and salt and the consequent corrosion of the reinforcing steel. The fourth part covers the skid resistance of the overlays and sealers. Implementation of the findings is discussed in section five.

SEALER AND OVERLAY SYSTEMS

Multiple layer polymer concrete overlays consist of two or more layers of a polymer binder and a graded angular-grained aggregate (5, 6). Typical binders are polyester styrene, epoxy, methylmethacrylate, and vinyl ester. The deck is shotblasted prior to placing the first layer.

Concrete sealers may be classified as hydrophobic, water-blocking, and integral (3,7). Hydrophobic (water-repellent) sealers include stearates, silicones, and silanes (7). These sealers typically coat or chemically combine with the surface of the concrete to provide a water-repellent surface. Water-blocking sealers include linseed oil, mineral gums, acrylics, methyl-methacrylates, urethanes, and epoxies (7). These sealers fill the voids in the concrete and block out water and salt. Integral sealers include admixtures and silicates (7). These sealers typically allow the concrete to be placed at a lower water-to-cement ratio or chemically react within the concrete to produce a concrete that is less permeable to water. The reader should review references 3 and 7 for more information on concrete sealers.

Many studies have been done on integral sealers such as high-range water reducing and latex admixtures; therefore, the integral classification of sealers is beyond the scope of this report. Three water-blocking sealers are included in the study -- a solvent dispersed epoxy, a water dispersed epoxy, and a high molecular weight methacrylate. A silane was selected for study to represent the hydrophobic sealers.

The following information on the materials and installation procedures specified for the sealer and overlay systems was taken from VDOT specifications and special provisions, literature provided by the manufacturers of the systems, and other reference material. Further details can be found in the Appendices.

Multiple Layer Polyester Concrete Overlays

Multiple layer polyester concrete overlays have been installed on portland cement concrete bridge decks in Virginia and several other states during the past nine years (8). 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. Typically, the initiated and promoted polyester resin is sprayed uniformly over the surface of the deck (Figure 1) and before it gels (10 to 20 minutes), is covered to excess with broadcasted fine aggregate (Figure 2). Usually, within the first hour, a layer cures sufficiently to permit vacuuming the excess aggregate preparatory to placing a

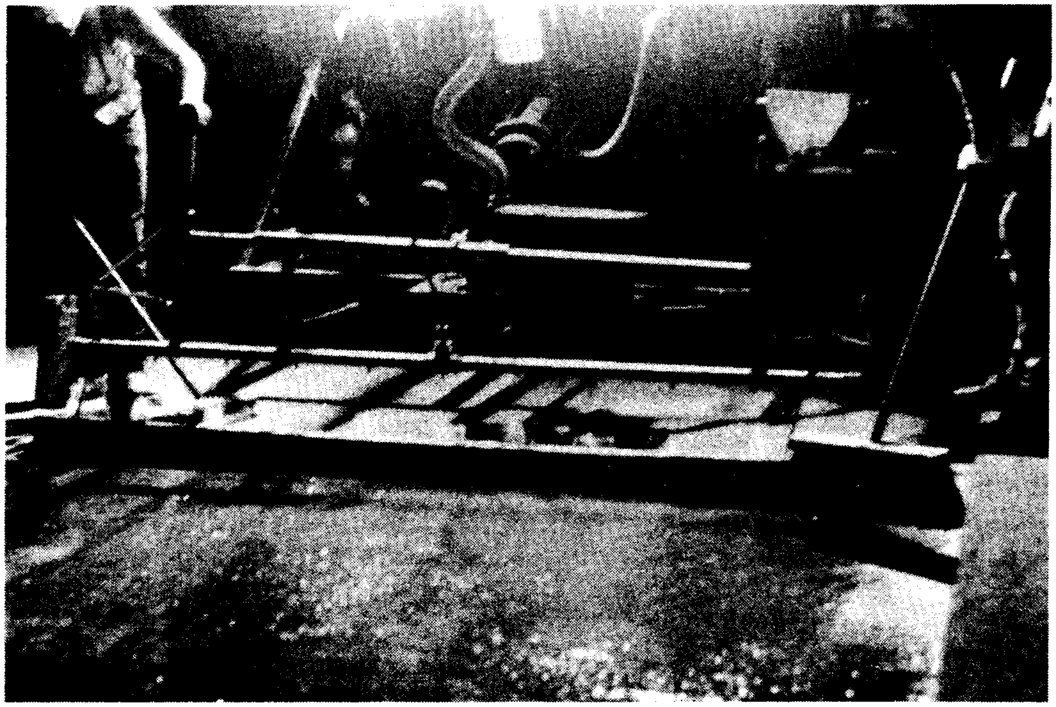

Figure 1. Polyester resin is sprayed and brushed onto a concrete deck (I-64 WBL over Hampton Roads) the same night the deck was shotblasted.

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

subsequent layer. The polyester concrete overlay has an advantage over other deck protective systems in that it can be constructed in stages during off-peak traffic periods. The first layer of resin and aggregate can be applied to a lane that has been closed and shotblasted (Figure 3), and after a minimum of three hours of cure, the lane can be opened to traffic. Subsequent layers can be placed on the next day or night off-peak traffic period. The Virginia Department of Transportation's special provision for multiple layer polyester and epoxy polymer overlays is shown in Appendix A.

Multiple Layer Epoxy Concrete Overlays

The 1986 special provision for multiple layer polymer concrete overlays was revised in 1987 to include two epoxy overlay systems as alternates to the polyester overlay (See Appendix A). The epoxy overlay systems are marketed under the trade names, Flexolith and Flexogrid. Multiple layer overlays constructed with these binders differ from the polyester overlays in that two layers are prescribed rather than three, the binder is an epoxy rather than a polyester, and the aggregates are special grades of either crushed basalt (Flexolith) or crushed basalt and granite (Flexogrid) rather than the grade A and D silica sand. The aggregates have a gradation similar to that of grade A silica sand. The overlays differ from VDOT class-I water proofing in that the epoxy application rates are greater, the epoxies have a higher tensile elongation (ASTM D638), and the aggregate is coarser. Information on the properties of these materials is shown in Appendix B.

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

An experimental overlay was placed on Route 17 (EM-15) by the Suffolk District bridge maintenance crew in the fall of 1986. The overlay was constructed with two layers of EP5-LV epoxy and grades A and D silica sands as prescribed by the special provision for polymer overlays. The application rates were 1.8 lb/yd^2 for layer 1, and 2.7 lb/yd^2 for layer 2. Overlays constructed with Flexolith and Flexogrid epoxies are similar to the experimental EP5-LV overlay (EM-15), except that the Flexolith and Flexogrid epoxies have a greater tensile elongation and the aggregates differ.

Class-I Waterproofing

The VDOT class-I waterproofing has been used on bridge decks since the late sixties (1). The overlay currently consists of two layers of EP5-LV epoxy and silica sand applied to the top of a portland cement concrete bridge deck to provide a 0.2-in thick, relatively impermeable, skid-resistant wearing surface. Typically, the epoxy is mixed in a 5- to 20-gallon container and applied to the deck with a squeegee or paint roller (Figure 4), and before it gels, is covered to excess with broadcasted fine aggregate. Although the VDOT class-I waterproofing (EP5-LV overlays) can be considered a multiple layer polymer overlay, they are classified separately for this report because the resin application rates are lower, the EP5-LV epoxy resin has a lower tensile elongation (ASTM D638), and the aggregate is finer than specified by the special provision for multiple layer polymer overlays (Appendix A).

Figure 4. Epoxy resin applied to deck surface with squeegee.

Class-I Waterproofing - 1982 Specification

Class-I waterproofing is defined in section 421.02 of the 1982 edition of the VDOT Road and Bridge Specifications. The specification prescribes class-I waterproofing as a first layer of epoxy applied at the rate of 1 gallon per 50 ft^2 and a second layer applied approximately four hours later at the rate of 1 gallon per 75 ft^2. Grade A aggregate as prescribed in Table II-19 of Section 254.06 is applied in excess to layer 2 (See Appendix C).

Class-I Waterproofing - 1984 Amended Specification

Sections 421.02(e)3 and 254.06 were amended on August 6, 1984, to improve the specifications. The amended section 421.02(e)3 (shown in Appendix C) requires that the first layer of epoxy be applied at the rate of 1 gallon per 75 ft^2 and the second layer at the rate of 1 gallon per 50 ft^2. The amended section also requires that both layers be sanded to excess. The amended section 254.06 allows the use of a sand that passes a #2 sieve analysis where not more than 25% passed through a #30 sieve. The sand is finer than a grade A sand (See Appendix C, Table II-19), which has a maximum of 3% passing through the #30 sieve.

Penetrating Sealers

Four penetrating sealers were evaluated. One was an 18% solids solvent-dispersed epoxy, E-bond 120, supplied by E-bond; one was a 50% solids water-dispersed epoxy, Horsey-set, supplied by Robson Downes; one was a silane, Chem-Trete BSM 40, supplied by Dynamit Nobel of America; and one was a high molecular weight methacrylate, supplied by Rohm and Haas.

The VDOT special provision for penetrating sealers is shown in Appendix D. The physical properties of the sealers are shown in Appendix E.

Sealer and Overlay Installations Under Evaluation

Table 1 provides general information on the bridge deck installations that are under evaluation. Bridges W-2 and W-3 received LB183 polyester overlays in 1981 (details of the installations can be found in reference 9). Bridges BRN and BRS received polyester overlays in 1982 (details can be found in reference 10). LB183 polyester was placed on BRN and 90-570 polyester on BRS. Bridge RRET received a 92-339 polyester overlay in the travel lane in 1985 (details can be found in reference 8).

TABLE 1

General Information

Bridge No.	Location	Structure	Deck Surface	Material Supplier	Contractor	Date Syst. Inst.	Contract Quantity, Yd^2	Cost, \$/yd.^{2}
W-3	I-64 over Rte. 143, EBL, Newport News	2806	LB183	USS Chem.	Luke Const./ Con. Repair Specialists	6/81	1,508	41.00
W-2	I-64 EBL James City	2000	LB183	USS Chem.	Luke Const./ Con. Repair Specialists	8/81	1,156	41.00
BRN	Rte. 675 over Dulles Airport, NBL, Fairfax	6232	LB183	USS Chem.	VDHT, FHWA, FAA	5/82	600	12.00 (Matls. only)
BRS	SBL, Fairfax	6232	90-570	Reichhold Chem.	VDHT, FHWA, FAA	5/82	600	12.00 (Matls. only)
RRET	I-64 over Rivanna River, EBL, Albemarle	2047	92-339	Reichhold Chem.	Marvin V. Templeton	4,5,6/85	2,359	25.50
FL-3	Rte. 613, Rte. 50, Fairfax	6111	100% solids, high elongation, epoxy sand overlay	Dural Int.	Dural Int.	6/86	271	34.00
FG	Rte. 3 over Rapidan River EBL, Orange	---	100% solids, high elongation, epoxy sand overlay	Poly-Carb. Inc.	English Construction Company	7/87	275	---
EM-15	Rte. 17 over Bennetts Creek SBL, Suffolk	1813	EP5-LV epoxy overlay	Futura Adhesive, Inc.	Suffolk Bridge Crew	10/86	119	---
7E	I-64 EBL, N&SRR, Norfolk	2833	100% solids EP5-LV epoxy sand overlay	E-bond	Century Conc. Ser. Inc. Va. Beach	8/84	32,959	10.35

8E	I-64 WBL, N&SRR, Norfolk	2834	100% solids EP5-LV epoxy sand overlay	E-bond	Century Conc. Ser. Inc. Va. Beach	8/84	32,959	10.35
E4	I-64 EBL, Rte. 238 Newport News	2809 (2208)[a]	EP5-LV epoxy sand overlay	Fox	Crowder Const. Co. Va. Beach	7/84	2,844	14.00
E7	I-64 WBL, Rte. 238 Newport News	2808 (2209)[a]	EP5-LV epoxy sand overlay	Fox	Crowder Const. Co. Va. Beach	7/84	2,844	14.00
17E	I-64 WBL, Rte. 17 Newport News	2200	EP5-LV epoxy sand overlay	---	Suffolk Bridge Crew	9/81	1,294	---
5	I-64 EBL, Rte. 13, Norfolk	2829	18% solids Epoxy penet. sealer	E-bond	Century Concrete Services, Inc., Va. Beach	11/83	16,417	5.05
6	I-64 WBL, Rte. 13, Norfolk	2830	18% solids	E-bond	Century Concrete Services, Inc. Va. Beach	11/83	16,417	5.05
HS	I-264 EBL, N&W RR, Chesapeake	2529	Water disp. epoxy penet. sealer	Robson Downes Assoc.	Jewell Painting, Inc.	6/85	8,330	8.50
CT	Rte. 161 NBL, North Run, Henrico	1021	Silane penet. sealer	Dynamit Nobel of America	Marks-Runions, Inc.	1985	249	7.40
HMWM	Rte. 601 Polecat Creek, Caroline Co.	6005	High mole-cular, weight methacrylate 1100, 1500	Rohm and Haas	Fredericks-burg Bridge Crew	6/86	59	---

[a] Current structure number.

Bridge FL-3 was overlaid with three layers of Flexolith and basalt aggregate in 1986. The eastern most span of the EBL of bridge FG was overlaid with two layers of Flexogrid and basalt aggregate in 1987. The southern most span of the SBL of bridge EM-15 was overlaid in 1986 with two layers of EP5-LV epoxy and sand as prescribed by the 1987 special provision for polymer overlays. Bridges 7E, 8E, E4, and E7 were overlaid in 1984 with class-I waterproofing in accordance with the VDOT road and bridge specification as amended in 1984. Bridge 17E was overlaid in 1981 with class-I waterproofing as prescribed by the 1982 VDOT road and bridge specifications.

Bridges 5 and 6 were sprayed with an 18% solids solvent-dispersed penetrating epoxy sealer in 1983. A water-dispersed epoxy sealer was applied to bridge HS with a squeegee in 1985. A silane sealer was applied to bridge CT in 1985. Rohm and Haas PCM 1100 and Monomer 1500 high molecular weight methacrylates were applied with a squeegee to two half spans of bridge HMWM in 1986 (See Figure 5).

Prior to applying the E-bond penetrating epoxy the decks were sandblasted to remove oils and contaminates that might interfere with the penetration and curing of the epoxy. The deck was shotblasted prior to applying the Horsey-set. The Chem-Trete was applied to a new concrete deck prior to opening the deck to traffic. No cleaning was required. The deck was blasted with compressed air to remove loose material prior to applying the high molecular weight methacrylate.

Approximately 20 to 30 minutes after the deck on Rte 601 was flooded with the high molecular weight methacrylate and prior to the gellation of the monomers, the deck was covered with an excess of grade A sand (See Appendix C, Table II-19) to provide a good skid number. Class-I waterproofing was applied to all other areas of the deck. The high modecular weight methacrylate and the class-I waterproofing were opened to traffic at the end of each work day.

Subsequent to the deck application on Rte 601, high molecular weight methacrylate monomers 1540 (HMWM-HM) and 1680 (HMWM-LM) were applied to several cracks in a deck on I-81 (NBL) over the New River. Approximately 30 minutes after the application, sand was applied to soak up the excess monomer. The sand and monomer filled the grooves in the surface. Figure 6 shows the average crack width and the average crack width filled with HMWM-LM versus depth. Figure 6 is based on the averages of measurements made on eleven vertical, polished, cracked surfaces (11). Figure 6 shows that on the average the most complete filling of the cracks was obtained within 0.5 in of the deck surface. On two other bridges, large cracks were filled with monomer 1500 from a squeeze bottle. Approximately 30 minutes after the application, sand was applied to soak up the excess monomer and a stiff bristle broom was used to remove the sand. The procedure partially filled and sealed the cracks and retained the tined texture of the concrete deck surface.

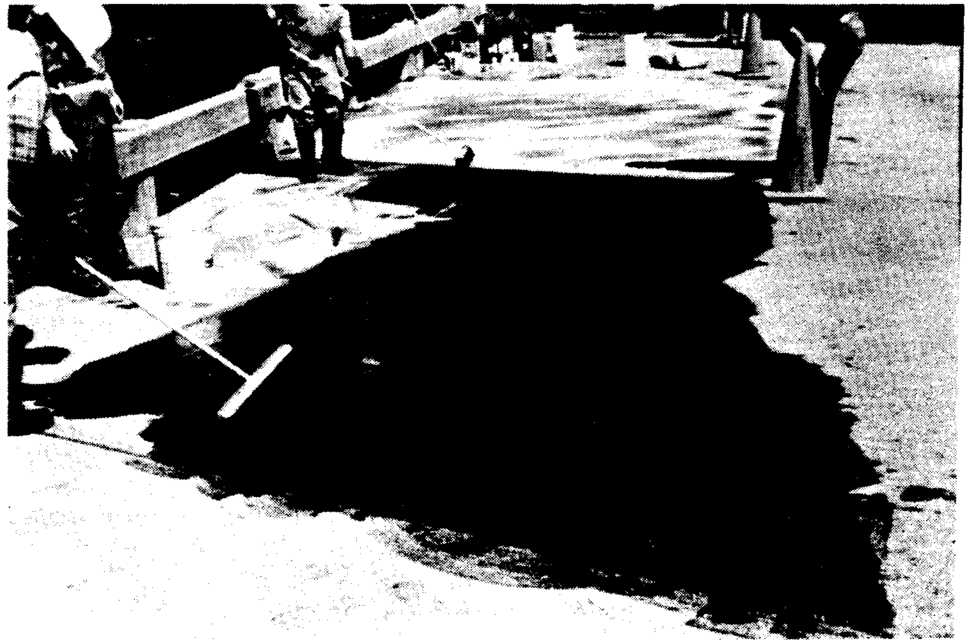

Figure 5. Healer sealer applied to deck surface with broom.

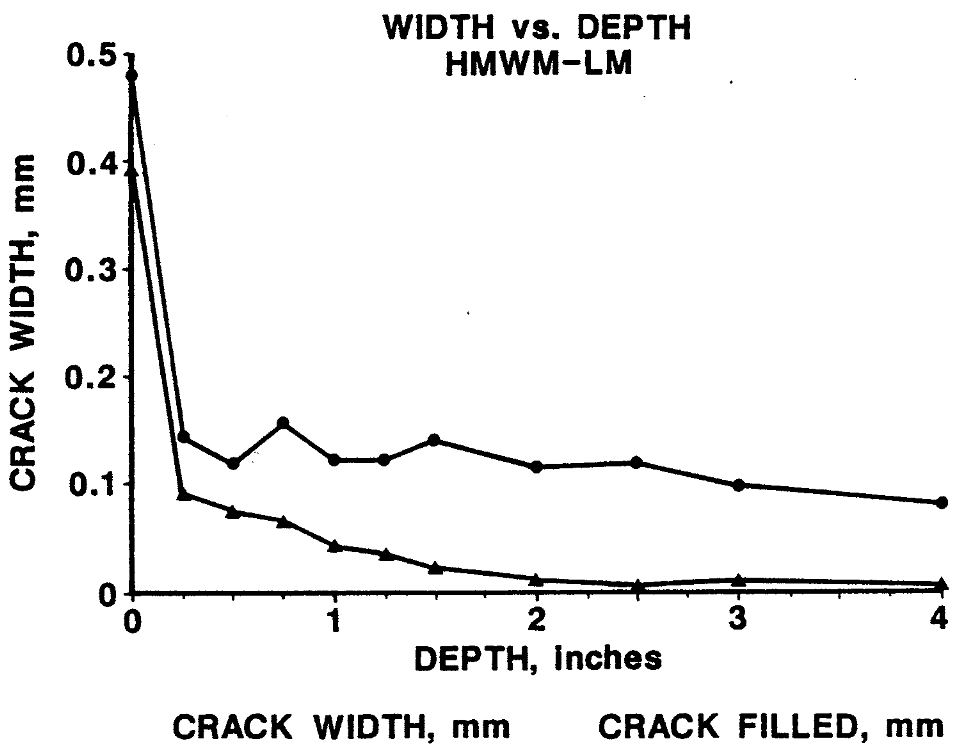

Figure 6. Average crack width filled with high molecular weight methacrylate, I81 over New River.

The study was initiated to compare the cost-effectiveness of multiple layer polyester overlays (bridges W-2, W-3, BRN, BRS, RRET) with class-I waterproofing (bridges 7E and 8E) and an 18% solids penetrating epoxy sealer (bridges 5 and 6). Bridges E4 and E7 were added to provide another contractor and supplier for class-I waterproofing. Bridge 17E was added so that the class-I waterproofing prescribed by the 1982 specification could be compared with the specification as amended in 1984 and to provide skid numbers for an overlay constructed the same year as the first polyester overlays. Bridge EM-15 was added to the study to see if the EP5-LV epoxy used in class-I waterproofing could provide an acceptable skid number for a longer period if the overlay was constructed in accordance with the 1987 special provision for polymer overlays. Bridges FL and FG were added to the study as epoxy alternatives to the polyester. Bridges HS and CT were added because it was believed that a water-dispersed epoxy or a silane might perform as well or better than a solvent-dispersed epoxy. Bridge HMWM was added to the study because some decks only need to have the cracks healed and sealed. Chloride content data for some of the bridges is shown in Table 2. The details of the evaluations of these systems follow.

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 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.

Tensile Bond Strength

The ACI 503R tensile adhesion test can be used to measure the bond strength in tension between an overlay and the base concrete. The test includes drilling through the overlay to separate a circular portion, bonding a pipe cap to the surface, and pulling the overlay from the concrete deck. 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 (10). In 1986 it was observed that more consistent results could be obtained by modifying the ACI 503R equipment as follows (8).

TABLE 2

Chloride, Cl^-, Content, lb/yd^3

Bridge No.	Str. No.	Span	Depth Top Rebar, in	Depth Sample, in	Chloride Content,[a] lb/yd^3
5	2829	A	3.2	2.0 - 2.5	0.09
5	2829	B	1.9	2.0 - 2.5	0.14
5	2829	C	1.9	2.0 - 2.5	0.82
6	2830	A	3.2	2.0 - 2.5	0.09
6	2830	B	3.0	2.0 - 2.5	1.50
6	2830	C	3.0	2.0 - 2.5	0.23
7E	2833	A	1.2	1.5 - 2.0	0.25
7E	2833	B	1.7	1.5 - 2.0	0.16
7E	2833	C	1.7	1.5 - 2.0	0.25
8E	2834	A	2.0	1.5 - 2.0	0.10
8E	2834	B	1.4	1.5 - 2.0	0.12
8E	2834	C	2.0	1.5 - 2.0	0.13
E4	2809	B	2.3	1.5 - 2.0	0.12
E4	2809	C	1.7	---	---
E7	2808	B	2.1	1.5 - 2.0	0.07
E7	2808	C	2.4	---	
17E		A	---	---	1.40
17E		B	---	---	2.15
17E		C	---	---	0.66
HS	2529	A	---	---	0.21
HS	2529	B	---	---	0.46
HS	2529	C	---	---	0.40
CT		A	---	1.75 - 2.25	0.09

[a] Results based on test of one sample.

1. Drill through the overlay with a 2.25-in (inside diameter) diamond-tipped core barrel rather than a 2-in (inside 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 a 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 (12). Our experience indicates that a reasonable standard deviation for the average of three tests is 40 psi, which implies that an average bond strength of 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.

Table 3 shows the tensile rupture strengths that have been obtained since 1981. The initial strengths obtained from the LB183 overlays near Williamsburg were low because traffic was allowed on the shotblasted surfaces prior to placing the overlays. The initial strengths for all the other overlays exceed the 250 psi minimum strength required by the special provision for polymer overlays (See Appendix A).

TABLE 3

Tensile Rupture Strengths, lb/in^2

Bridge	Deck Surface	81	82	83	84	85	86	87
W-Avg	LB183	175	156	--	--	--	128	--
BRN	LB183	--	337	241	--	--	167	140
BRS	90-570	--	268	266	--	134	223	168
RRET	92-339	--	--	--	--	353	308	--
FL-3	Flexolith	--	--	--	--	--	--	136
FL-2	Flexolith	--	--	--	--	--	281	149
FG	Flexogrid	--	--	--	--	--	--	276
EM-15	EP5-LV	--	--	--	--	--	341	401
E4	EP5-LV	--	--	--	--	--	350	--
HMWM	High molecular weight methacrylate	--	--	--	--	--	--	294

Figure 7 shows the bond strength data for two polyester overlays placed on the Beulah Road bridge in 1982 and epoxy overlays FG, FL-2, and EM-15 (8). The LB183 resin applied to BRN is the same brittle polyester placed near Williamsburg. It has a tensile elongation (ASTM D638) of 8%. The 90-570 resin applied to BRS is a flexible polyester that has a tensile elongation of 49%. At 5 years, the average tensile bond strength of the 90-570 overlay was 168 psi, which is fair. At 5 years, the average tensile bond strength of the LB183 overlay was 140 psi. The two-layer epoxy overlay (FG) installed in 1987 had a tensile bond strength of 276 psi. The two-layer epoxy overlays (FL-2 and EM-15) installed in 1986 were found to have initial tensile bond strengths of 281 and 341 psi respectively, and strengths after 1 year of 149 and 401 psi respectively. An EP5-LV epoxy overlay installed on bridge E4 near Williamsburg in 1984 was found to have a tensile bond strength after 2 years of 350 psi. The data suggest that equivalent tensile bond strengths can be obtained with epoxy and polyester overlays; however, they are not conclusive because of the differences between the installations. The epoxy overlays were applied by hand; the polyester overlays were applied with mechanical equipment. The Flexolith epoxy and the Flexogrid epoxy were placed on concrete having an age of less than 1 year, whereas the other overlay installations were on older

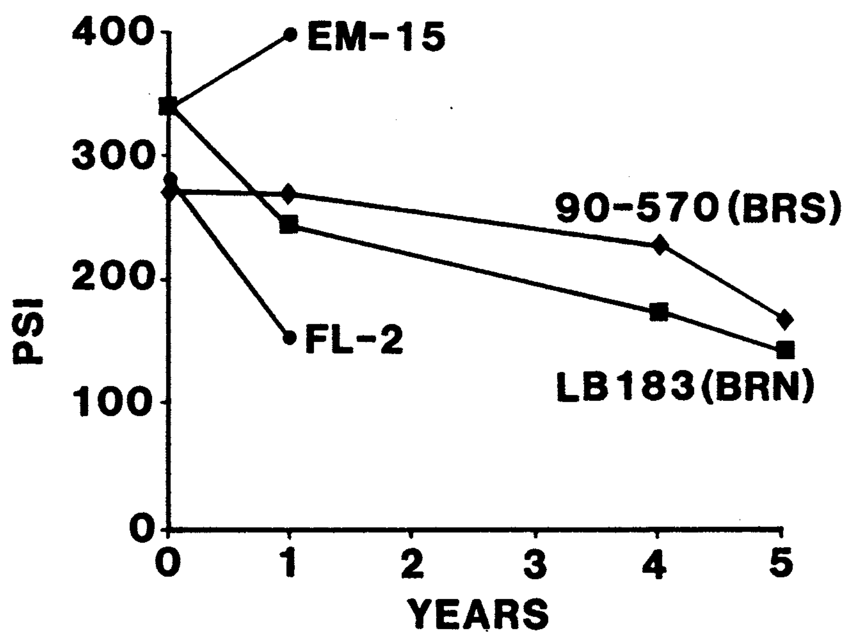

Figure 7. Tensile bond strength vs age.

concretes that had been opened to traffic for many years. Although the polyester overlays will likely delaminate in 10 years, there is insufficient data to forecast the time to delamination of the epoxy overlays.

Shear Bond Strength

Figure 8 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 that shears the overlay from the base concrete. Because the overlays on bridges 7E, 8E, E4, E7, 17E were only approximately .12-in thick, it was necessary to apply a layer of epoxy about .25-in thick to the tops of the cores to provide sufficient thickness in the overlay to allow it to be sheared from the base. 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 (13).

Table 4 shows the shear bond strength data for the bridges under study. Typically, the bond interface data are based on the average of tests on three cores and the base concrete data are based on the average of tests on two cores. It was encouraging to note that all the test results for the epoxy overlays were greater than 200 psi. Also, after five years, 44% of the test results for the LB183 overlays near Williamsburg and 100% of the results for the 90-570 overlay on the Beulah Road Bridge were greater than 200 psi.

Table 5 shows the bond strengths based on tests of cores that have been subjected to 100 thermal cycles. 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 three cycles/day. Although the polyester overlays showed significantly lower bond strengths after the thermal cycling test, all values were above 200 psi. The bond strengths of the class-I waterproofing and the Flexogrid and Flexolith overlays were not significantly changed by the thermal cycles.

Figure 9 shows the shear bond strength data for the bridges near Williamsburg. At five years, the average bond strength of the LB183 overlays was 200 psi. At four years, the bond strength of the class-I waterproofing on 17E was 494 psi. The environment has caused a greater decrease in the shear bond strength of the LB183 than the epoxy.

Figure 10 shows the shear bond strength as a function of age (the solid line) and the number of thermal cycles (the dashed line) for the

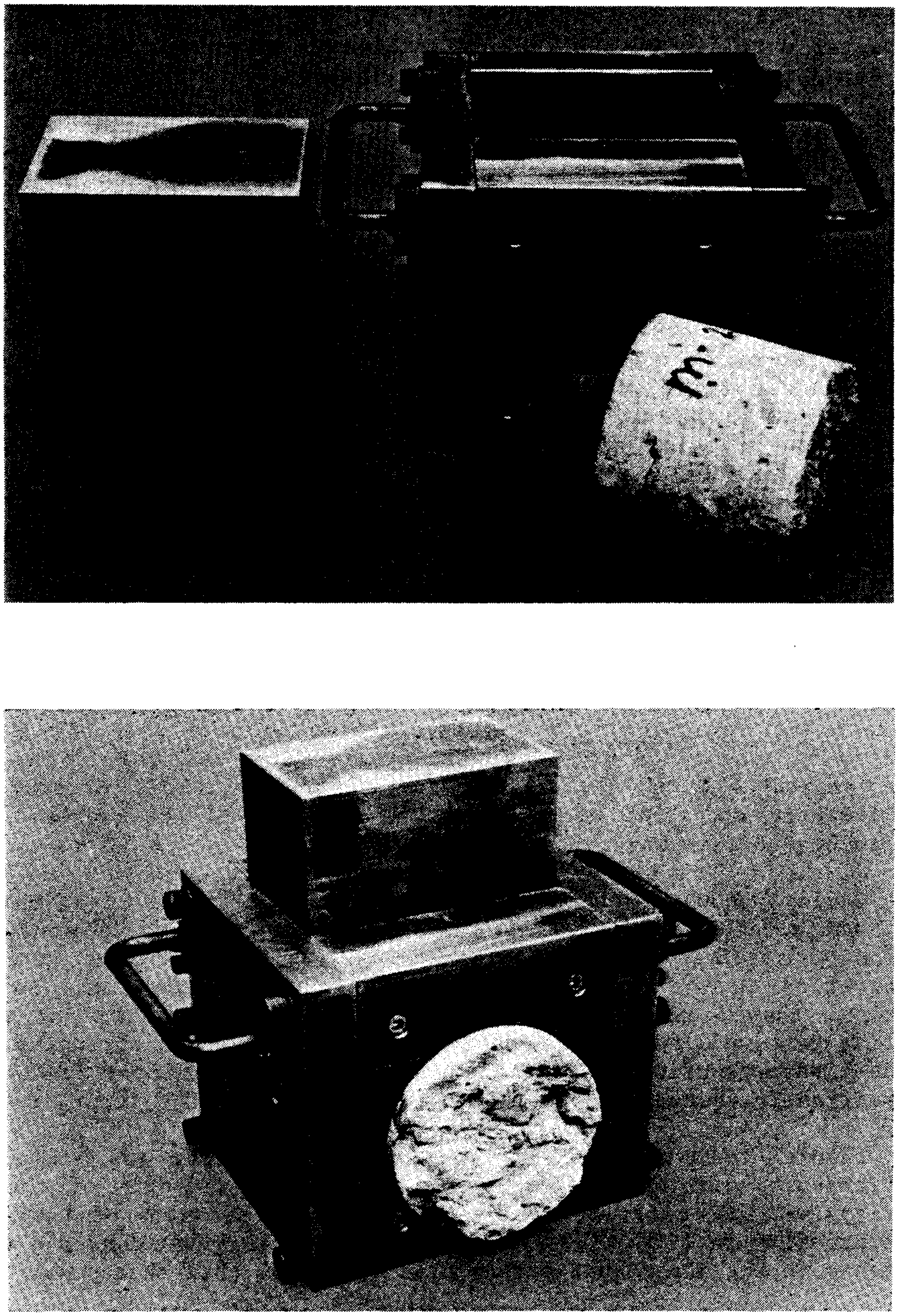

Figure 8. Apparatus used to subject cores to shear.

TABLE 4

Shear Bond Strength

Bridge	Deck Surface	1981 Shear Bond Strength, lb/in² Concrete New	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	1987 Shear Bond Strength, lb/in² Concrete New	1987 Concrete Old	1987 Bond Interface New	1987 Bond Interface Old
W-2	LB183	838	774	1125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1027	918	290	144	-	-	-	-
W-3	LB183	1124	730	469	-	-	-	-	-	-	470	573	222	187	-	-	-	-	1368	675	264	218	-	-	-	-
BRS	90-570	-	-	-	812	972	-	823	-	730	-	763	-	602	-	950	-	734	-	787	-	320	-	960	-	308
BRN	LB183	-	-	-	804	1001	-	838	-	436	-	-	-	-	-	-	-	-	-	984	-	172	-	1064	-	285
RRET	92-339	-	-	-	-	-	-	-	-	-	-	-	-	-	-	980	-	793	-	823	-	514	-	-	-	-
FL-3	Flexolith	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1040	-	701	-	855	-	664	-
FG	Flexogrid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1085	-	680	-
EM-15	EP5-LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	928	-	486
7E	EP5-LV	-	-	-	-	-	-	-	-	-	-	839	-	439	-	585	-	492	-	-	-	-	-	-	-	-
8E	EP5-LV	-	-	-	-	-	-	-	-	-	-	906	-	572	-	970	-	437	-	-	-	-	-	-	-	-
E4	EP5-LV	-	-	-	-	-	-	-	-	-	-	401	-	615	-	694	-	537	-	-	-	-	-	-	-	-
E7	EP5-LV	-	-	-	-	-	-	-	-	-	-	594	-	563	-	669	-	387	-	-	-	-	-	-	-	-
17E	EP5-LV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	865	-	494	-	-	-	-	-	-	-	-

New concrete is concrete placed same year as overlay.

Old concrete is concrete that was at least one year old prior to placing overlay.

TABLE 5

Permeability and Bond Strength of Cores after 100 Thermal Cycles

Bridge No.	Deck Surface	Permeability, Coulombs	Shear Bond Strength, lb/in^2
W-Avg	LB183	950	228
BRN	LB183	72[a]	609[b]
BRS	90-570	221[a]	544[b]
RRET	92-339	996[b]	620[b]
FL-3	Flexolith	115	649
FG	Flexogrid	48	769
EM-15	EP5-LV	384	---
7E	EP5-LV E Bond	117	570
8E	EP5-LV E Bond	37	558
E4	EP5-LV-Fox	429	502
E7	EP5-LV-Fox	434	573
5	Penet. Sealer-E Bond	2,060	---
6	Penet. Sealer-E Bond	2,132	---
HS	Water disp. epoxy penet. sealer	1,536	---
CT	Silane penet.	3,794	---
HMWM	High molecular Weight Methacrylate	1,242	---

[a]125 cycles

[b]200 cycles

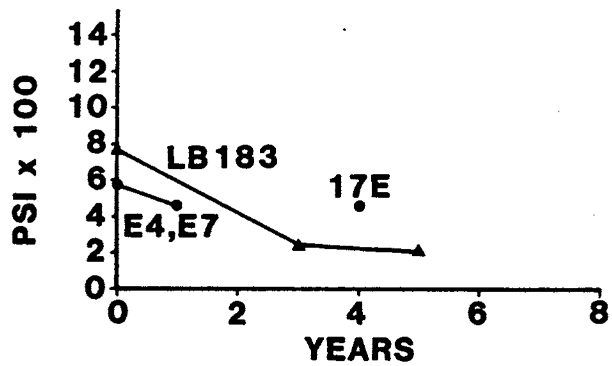

Figure 9. Shear bond strength vs age.

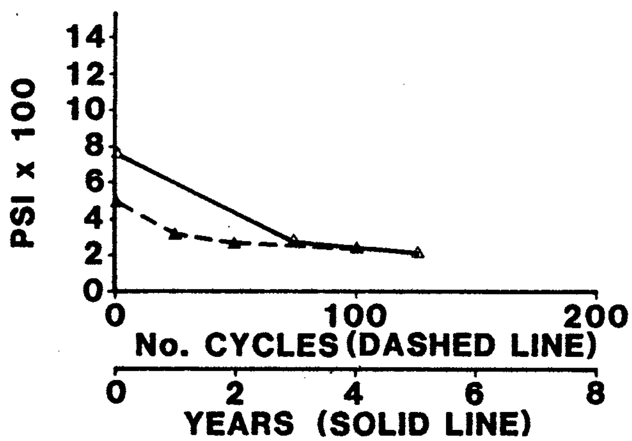

Figure 10. Shear bond strength vs age and number of thermal cycles-LB183 Williamsburg.

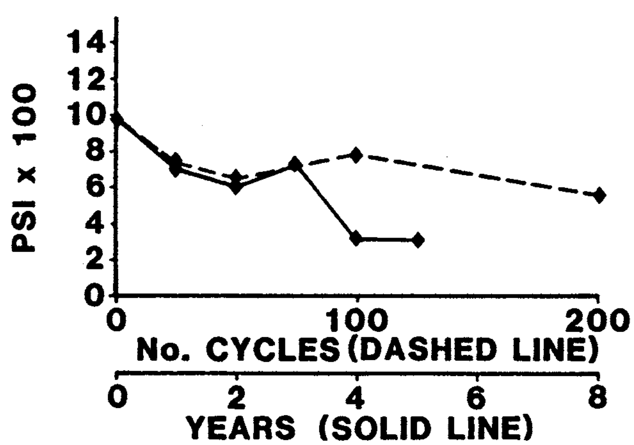

Figure 11. Shear bond strength vs age and number of thermal cycles, 90-570 Beulah Road.

LB183 overlays near Williamsburg. After 100 thermal cycles the bond strength was 228 psi, which was approximately equal to the strength at four years.

Figure 11 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. Although the polyester remained flexible during the short-term thermal cycling test, the polyester that was in service became brittle after three years (8).

It is obvious that the environment has caused a reduction in shear bond strength of polyester overlays, that overlays constructed with some resins have been affected more than others, and that one should anticipate some delamination within 10 years of service. Also, a thermal cycling test can be used to simulate environmentally produced thermal stress and to predict bond strength. Although the data are not sufficient to predict the time to delamination of the class-I waterproofing, the Flexogrid, or the Flexolith, the high value for bridge 17E suggests that the overlays will be bonded for longer than 10 years.

PROTECTION PROVIDED BY OVERLAYS

Concrete sealers and polymer overlays are usually placed on bridge decks to protect the concrete from the infiltration of water and chloride ions, which can cause freezing and thawing damage to the concrete and corrosion of the reinforcement. An indication of the protection provided by the sealers and overlays is based on the rapid permeability test (AASHTO T-277), the electrical resistivity test (ASTM D 3633), and the half cell potential data (ASTM C876).

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	Permeability
> 4000	High
2000 - 4000	Moderate
1000 - 2000	Low
100 - 1000	Very Low
< 100	Negligible

Table 6 shows the permeability test results for cores taken from the bridges with the protective systems under evaluation. Typically, the results for the top 2 in are based on the average of three cores, and the results for the base are based on the average of slices taken from two cores 2 in to 4 in from the top. On occasion, because of the problems associated with obtaining three good cores from a deck, results for the top 2 in are based on tests of two cores, and the results for the base are based on one slice.

The data in Table 6 show that all 2-in slices with the protective systems exhibited a lower permeability than the 2-in slices of base concrete. Negligible permeabilities were obtained for the new multiple layer polymer overlay systems on bridges W-2, BRS, BRN, RR, FL-3, FL-2, FG, and EM-15 and the class-I waterproofing on E7. Very low permeabilities were obtained for the new class-I waterproofing on bridges 7E, 8E, E4 and probably 17E (the only value available is from an age of 4 years) and for the water dispersed epoxy on bridge HS. Low permeabilities were obtained for the penetrating sealer on bridge 6 and the high molecular weight methacrylate healer sealer on bridge HMWM. Moderate permeabilities were obtained for the penetrating sealer used on bridge 5 and the silane used on bridge CT.

After one year in service, the only systems to exhibit a negligible permeability were the 90-570 polyester on BRS and the class-I waterproofing on bridges 7E and 8E. Most of the systems exhibited very low permeabilities after one year in service. However, the permeability of the water-dispersed epoxy on bridge HS was in the low range after one year and the permeabilities of the silane on bridge CT and the brittle polyester on bridge W-3 were in the moderate range after one year.

The lowest permeability after four years in service was exhibited by the class-I waterproofing on bridge 17E (402 Coulombs) and the lowest

TABLE 6

Permeability, Coulombs

Bridge No.	Deck Surface	1981 Top 2 in	1981 Base Concrete	1982 Top 2 in	1982 Base Concrete	1983 Top 2 in	1983 Base Concrete	1984 Top 2 in	1984 Base Concrete	1985 Top 2 in	1985 Base Concrete	1986 Top 2 in	1986 Base Concrete	1987 Top 2 in	1987 Base Concrete
W-2	LB183	12*	6,109	384	-	-	-	-	-	-	-	1,105	5,738	-	-
W-3	LB183	167*	-	3,607	-	-	-	3,252	-	-	-	1,895	-	-	-
BRS	90-570	-	-	1*	2,124	1	-	187	-	412	4,303	706	-	760	5,370
BRN	LB183	-	-	3*	2,308	713	-	-	-	-	-	1,656	4,788	2,253	6,492
RR ET	92-339	-	-	-	-	-	-	-	-	29*	7,378	322	-	-	-
FL-3	Flexolith	-	-	-	-	-	-	-	-	-	-	0*	2,957	8	2,952
FL-2	Flexolith	-	-	-	-	-	-	-	-	-	-	74*	2,120	-	-
FG	Flexogrid	-	-	-	-	-	-	-	-	-	-	-	-	24*	2,507
EM-15	EP5-LV	-	-	-	-	-	-	-	-	-	-	97*	-	191	5,502
7E	EP5-LV E Bond	-	-	-	-	-	-	244*	6,381	75	3,561	-	-	-	-
8E	EP5-LV E Bond	-	-	-	-	-	-	103*	6,869	76	6,164	-	-	-	-
E4	EP5-LV - Fox	-	3,100	-	-	-	-	608*	-	629	3,602	-	-	-	-
E7	EP5-LV - Fox	-	2,494	-	-	-	-	76*	-	256	5,396	-	-	-	-
17E	EP5-LV	-*	-	-	-	-	-	-	-	402	3,750	-	-	-	-
5	Pene. Sealer-E Bond	-	-	-	-	-	-	2,408*	9,517	1,495	3,135	-	-	-	-
6	Pene. Sealer-E Bond	-	-	-	-	-	-	1,744*	4,585	1,752	5,111	-	-	-	-
HS	Water disp. epoxy penet. sealer	-	-	-	-	-	-	-	-	961*	2,922	1,710	5,030	-	-
CT	Silane penet. sealer	-	-	-	-	-	-	-	-	3,385*	4,933	2,510	5,624	-	-
HMWM	High molecular wt. methacrylate	-	-	-	-	-	-	-	-	-	-	1,281*	5,123	1,301	7,189

*Protective system installed.

permeability after five years was exhibited by the 90-570 polyester used on bridge BRS (760 Coulombs). Both values were in the very low range.

Table 5 shows the permeability of specimens that have been subjected to 100 thermal cycles. The class-I waterproofing on bridge 8E, the Flexogrid on Bridge FG, and the LB183 polyester used on bridge BRN were the only systems to exhibit a negligible permeability after 100 cycles. After 100 cycles, very low permeabilities were exhibited by the multiple layer polymer overlays on bridges W-2, W-3, BRS, FL-3, EM-15, and the class-I waterproofing on bridges 7E, E4, and E7. Low permeabilities were exhibited by the water-dispersed epoxy on bridge HS and the methacrylate on bridge HMWM. Moderate permeabilities were exhibited by the penetrating epoxy on bridges 5 and 6 and the silane on bridge CT.

Figure 12 shows permeability as a function of age (solid line) and the number of thermal cycles (dashed line) for the LB183 resin used on Beulah Road. The two curves do not agree at one and two years, but they meet at four years and 300 cycles. The permeability at five years was 2,253 Coulombs. The curves suggest that the specimens should be subjected to 300 cycles prior to testing.

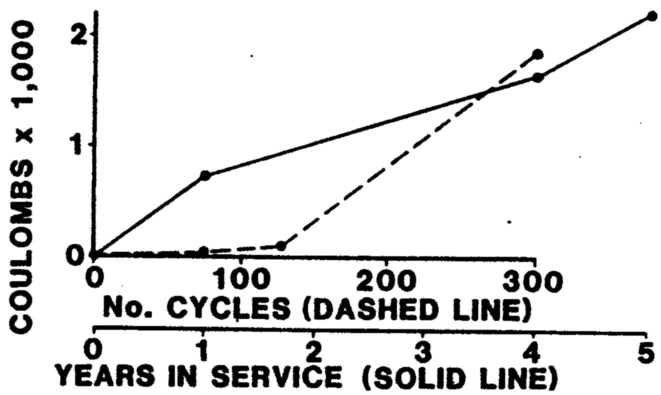

Figure 12. Permeability of chloride ions vs age and number thermal cycles, LB183 Beulah Road.

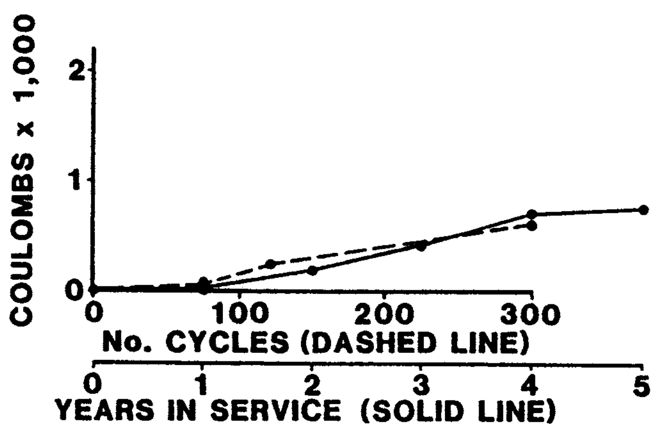

Figure 13. Permeability of chloride ions vs age and number thermal cycles 90-570.

The two curves for the flexible 90-570 polyester are shown in Figure 13. The thermal cycling test predicted the permeability of the overlay throughout the four years and 300 cycles. At five years the permeability was 760 Coulombs, which is very low and similar to the permeability of a latex modified concrete overlay.

The data in Tables 5 and 6 and Figures 12 and 13 suggest that 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. Brittle polyester overlays show the greatest increase in permeability with age and thermal cycles. The permeabilities of the penetrating sealers and class-I waterproofing were not increased significantly by 100 thermal cycles.

Electrical Resistivity

The electrical resistivity test (ASTM D 3633) provides a good indication of the extent of microcracking in a sealer or overlay. A low reading is indicative of a microcrack at the test location. The crack allows water to penetrate the sealer or overlay and lower the resistance in the electrical circuit. Data collected since 1981 are shown in Table 7. It is obvious from the data that with the exception of the 90-570 overlay on bridge BRS, which was not cracked significantly until evaluated at an age of three years, multiple layer polymer overlays constructed with all resins were extensively cracked in one year or less, which is shown by the fact that most readings were in the poor to fair range. Similarly, the majority of the readings obtained for the new class-I waterproofing on bridges 7E, 8E, E4, and E7 were in the good range; however, the majority obtained in 1985 were in the fair range, which indicates that after one year in service the overlays had cracked. As anticipated, the readings for the penetrating sealers were in the fair or poor range. The microcracks that cause low readings cannot be seen without the aid of magnification, and based on the permeability data, the cracked sealers and overlays are providing protection against the infiltration of chloride ion.

Half-Cell Potentials

Table 8 shows the copper sulfate half-cell-potential data (ASTM C 876). The majority of the readings were less negative than the -0.20 volts, which indicates a 90% probability that no corrosion is occurring. No conclusion can be drawn as to the probability of corrosion for the area represented by the readings between -0.20 and -0.35 volts. Small areas on only four spans exhibited readings more negative than -0.35

TABLE 7

Electrical Resistivity, Percentage of Total Number of Readings

Range of Electrical Resistivity, ohm/ft^2

Bridge	Deck Surface	Poor < 10^4 81	82	83	84	85	86	87	Fair 10^4 to < 10^6 81	82	83	84	85	86	87	Good 10^6 to 10^8 81	82	83	84	85	86	87	Excellent > 10^8 81	82	83	84	85	86	87
W-2	LB183	0	24	-	100	-	6	-	4	73	-	0	-	94	-	1	3	-	0	-	0	-	95	0	-	0	-	0	-
W-3	LB183	0	38	-	85	-	0	-	12	55	-	15	-	100	-	16	7	-	0	-	0	-	72	0	-	0	-	0	-
BRS	90-570	-	1	0	0	0	-	-	-	2	11	15	95	-	-	-	13	78	84	5	-	-	-	84	11	1	0	-	-
BRN	LB183	-	0	2	-	-	-	-	-	6	80	-	-	-	-	-	15	17	-	-	-	-	-	79	1	-	-	-	-
RRET	92-339	-	-	-	-	0	0	-	-	-	-	-	2	100	-	-	-	-	-	4	0	-	-	-	-	-	94	0	-
FL-3	Flexolith	-	-	-	-	-	0	0	-	-	-	-	-	7	100	-	-	-	-	-	1	0	-	-	-	-	-	92	0
EM-15	EP5-LV	-	-	-	-	-	-	0	-	-	-	-	-	-	74	-	-	-	-	-	-	23	-	-	-	-	-	-	23
7E	EP5-LV	-	-	-	0	0	-	-	-	-	-	11	65	-	-	-	-	-	82	34	-	-	-	-	-	7	1	-	-
8E	EP5-LV	-	-	-	0	0	-	-	-	-	-	1	76	-	-	-	-	-	96	22	-	-	-	-	-	3	2	-	-
E4	EP5-LV	-	-	-	0	0	-	-	-	-	-	39	93	-	-	-	-	-	61	7	-	-	-	-	-	0	0	-	-
E7	EP5-LV	-	-	-	0	0	-	-	-	-	-	15	94	-	-	-	-	-	79	6	-	-	-	-	-	6	0	-	-
17E	EP5-LV	-	-	-	-	1	-	-	-	-	-	-	98	-	-	-	-	-	-	1	-	-	-	-	-	-	0	-	-
5	Pene Epoxy	-	-	-	80	0	-	-	-	-	-	20	100	-	-	-	-	-	0	0	-	-	-	-	-	0	0	-	-
6	Pene Epoxy	-	-	-	69	0	-	-	-	-	-	31	100	-	-	-	-	-	0	0	-	-	-	-	-	0	0	-	-
HS	Pene Epoxy	-	-	-	-	0	6	-	-	-	-	-	100	94	-	-	-	-	-	0	0	-	-	-	-	-	0	0	-
CT	Silane	-	-	-	-	0	0	-	-	-	-	-	100	100	-	-	-	-	-	0	0	-	-	-	-	-	0	0	-
HMWM	High molecular wt. methacrylate	-	-	-	-	-	-	0	-	-	-	-	-	-	100	-	-	-	-	-	-	0	-	-	-	-	-	-	0

TABLE 8

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

Range (-Volts CSE)

		<0.20							0.20 to 0.35							>0.35						
Bridge	Deck Surface	81	82	83	84	85	86	87	81	82	83	84	85	86	87	81	82	83	84	85	86	87
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	-
BRS	90-570	-	100	100	-	93	-	89	-	0	0	-	7	-	11	-	0	0	-	0	-	0
BRN	LB183	-	100	99	-	-	-	90	-	0	1	-	-	-	10	-	0	0	-	-	-	0
RRET	92-339	-	-	-	-	-	71	-	-	-	-	-	-	29	-	-	-	-	-	-	0	-
FL-3	Flexolith	-	-	-	-	-	2	51	-	-	-	-	-	90	43	-	-	-	-	-	8	6
EM-15	EP5-LV	-	-	-	-	-	-	93	-	-	-	-	-	-	7	-	-	-	-	-	-	0
7E	EP5-LV	-	-	75	92	85	-	-	-	-	24	8	15	-	-	-	-	1	0	0	-	-
8E	EP5-LV	-	-	82	97	93	-	-	-	-	18	3	7	-	-	-	-	0	0	0	-	-
E4	EP5-LV	-	-	-	100	91	-	-	-	-	-	0	9	-	-	-	-	-	0	0	-	-
E7	EP5-LV	-	-	-	100	98	-	-	-	-	-	0	2	-	-	-	-	-	0	0	-	-
17E	EP5-LV	-	-	-	-	63	-	-	-	-	-	-	34	-	-	-	-	-	-	3	-	-
5	Pene. Epoxy	-	-	94	95	90	-	-	-	-	6	5	10	-	-	-	-	0	0	0	-	-
6	Pene. Epoxy	-	-	59	62	65	-	-	-	-	41	36	35	-	-	-	-	0	2	0	-	-
HS	Pene. Epoxy	-	-	-	-	99	99	-	-	-	-	-	1	1	-	-	-	-	-	0	0	-
CT	Silane	-	-	-	-	83	44	-	-	-	-	-	17	44	-	-	-	-	-	0	12	-
HMWM	High molecular weight methacrylate	-	-	-	-	-	-	28	-	-	-	-	-	-	70	-	-	-	-	-	-	2

volts. It is important that the half-cell potentials have not changed significantly over the evaluation period; this supports the theory that the sealers and overlays can extend the time to the onset of corrosion if applied prior to the onset of corrosion.

SKID NUMBER

Polymer concrete overlays have been placed on bridge decks to increase the skid number of decks constructed with polishing aggregate. Table 9 shows 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 of the overlay are hardness and shape of aggregates, gradation of aggregate, aggregate content of polymer, adhesive strength of polymer, traffic volume, and tire characteristics.

With two exceptions (bridges 17E and HS) the deck surfaces tested had adequate skid resistance following the application of the overlays or sealers. The skid numbers for the class-I waterproofing on bridges 7E, 8E, E4, and E7 had decreased significantly after one year in service. The number for bridge E4 was 20 after two years, and the overlay on bridge 17E had an unacceptable number of 19 after four years in service. Bridge HS, on which the Horsey-set penetrating sealer was applied, had an unacceptable treaded tire number and a low bald tire number initially, but the numbers were higher after one year because of the wear in the wheel paths that removed some of the sealer. The higher value for permeability after one year for bridge HS reported in Table 6 also provides an indication that some of the sealer was worn from the surface. Although the application of the penetrating epoxies to bridges 5 and 6 reduced the skid number, the numbers are acceptable because the surfaces had been grooved to provide the drainage necessary to obtain a good skid number. The numbers for bridge CT were also high because of the grooves in the surface. The data indicate that the application of a sealer reduces the skid number, so their use should be restricted to decks with a high skid number, such as those with a grooved surface.

Figure 14 compares the bald tire skid numbers for the overlays constructed with the LB183 brittle polyester (bridges W-2 and W-3) and an EP5-LV epoxy (bridge E4). The class-I waterproofing on bridge E4 exhibited a skid number of 20 in the left wheel path of the travel lane at two years. The class-I waterproofing on bridge 17E near Williamsburg exhibited a number of 19 at four years. It is believed the class-I waterproofing exhibited a low number at two 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 (8). It is anticipated that the multiple layer epoxy

TABLE 9

Skid Numbers at 40 mph, Taken in Travel Lane

Bridge No.	Deck Surface	Treaded Tire 81	82	83	84	85	86	87	Bald Tire 81	82	83	84	85	86	87
W-2	LB183	64*	58	-	45	-	46	-	63	46	-	43	-	32	-
W-3	LB183	63*	57	-	46	-	44	-	62	43	-	41	-	40	-
BRS	90-570	-	55*	56	-	49	-	42	-	49	45	-	38	-	27
BRN	LB183	-	53*	58	-	-	-	41	-	47	49	-	-	-	29
RRET	92-339	-	-	-	-	62*	54	-	-	-	-	-	56	50	-
FL-2	Flexolith	-	-	-	-	-	58*	48	-	-	-	-	-	56	47
FG	Flexogrid	-	-	-	-	-	-	71	-	-	-	-	-	-	63
EM-15	EP5-LV	-	-	-	-	-	49*	50	-	-	-	-	-	39	35
7E	EP5-LV	-	-	43	58*	45	-	-	-	-	26	41	31	-	-
8E	EP5-LV	-	-	36	56*	45	-	-	-	-	20	42	29	-	-
E4	EP5-LV	-	-	48	63*	45	40	-	-	-	24	52	28	20	-
E7	EP5-LV	-	-	51	58*	46	-	-	-	-	28	46	30	-	-
17E	EP5-LV	-*	-	-	-	32	-	-	-	-	-	-	19	-	-
5	Pene. Epoxy	-	-	52	47*	45	-	44	-	-	50	43	42	-	45
6	Pene. Epoxy	-	-	54	45*	44	-	46	-	-	52	47	46	-	45
HS	Pene. Epoxy	-	-	-	-	36*	51	-	-	-	-	-	23	34	-
CT	Silane	-	-	-	-	48*	51	-	-	-	-	-	42	46	-
HMWM	Methacrylate	-	-	-	-	-	68*	56	-	-	-	-	-	42	40

*Protective system installed.

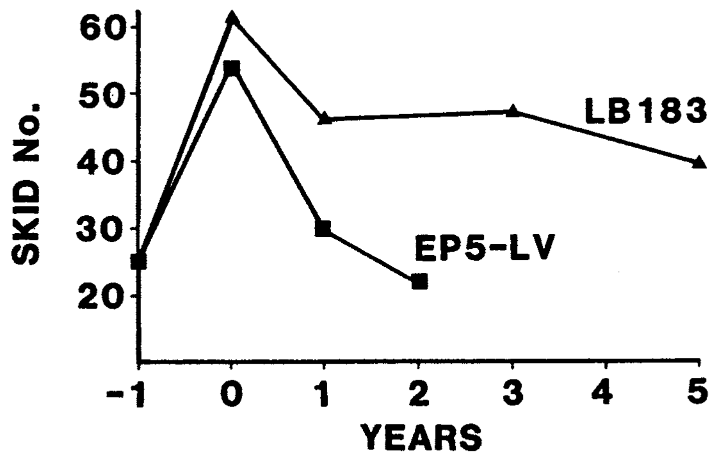

Figure 14. Skid number at 40 mph vs time ASTM E524 Bald Tire - Williamsburg.

overlays on bridges FL-3, FG, and EM-15, which were constructed using the resin application rates and the gradation of aggregates used for polyester overlays, will maintain a higher skid number than those with class-I waterproofing. The multiple layer polyester overlays on bridges W-2 and W-3 have maintained a high skid number for five years.

A recent Synthesis indicates that seventeen agencies have used epoxy to prepare skid-resistant roadways; but only two have continued the practice, and only one indicated acceptable performance (4). Reasons cited for discontinuing the use of these overlays include wear, debonding, polishing, lost aggregate, and high cost. The experience in Virginia with class-I waterproofing is in agreement with that of the other 16 agencies, with the exception that debonding and high cost have not been a major problem. In the fall of 1986, bridge engineers in Virginia agreed to terminate the use of class-I waterproofing except when an asphalt overlay is applied for skid resistance.

IMPLEMENTATION OF FINDINGS

The data collected to date indicate that penetrating sealers can usually be applied with a lane closure time of less than 24 hours and can provide some protection against the infiltration of chloride ions at a low first cost. Unfortunately, the sealers usually reduce the skid number and their use will have to be restricted to bridge decks that have a high skid number, such as those with grooves made by tining or saw cutting. Of course, the sealers can be used to reduce the permeability to chloride ions of concrete components other than the deck. Also, as an alternative to applying an overlay, grooves can be cut into the deck and a penetrating sealer subsequently applied.

A high molecular weight methacrylate healer sealer provided acceptable skid resistance and filled the cracks in a deck to a depth of about 0.5 in depending on the width of the crack.

A multiple layer polymer overlay designated by the VDOT as class-I waterproofing provides more protection against the infiltration of chloride ions than do the sealers; but the time required for installation is longer (usually more than 24 hours), and the initial cost is usually more than twice as much. The overlays will usually increase the skid number of decks with low skid numbers. Unfortunately, the skid number of the overlay decreases with age, and depending on the traffic, may drop to an unacceptable level after two to four years. The class-I waterproofing exhibited a high bond strength and low permeability to chloride ions after four years in service. Bridge engineers agreed to stop the use of class-I waterproofing in 1986 because of the low skid numbers. It is recommended that no further evaluations be made of bridges 7E, 8E, E4, E7, and 17E since these kinds of overlays are no longer used.

Multiple layer polymer overlays constructed with polyester resin are similar to class-I waterproofing. Their initial cost is somewhat greater because they are usually constructed in three or four layers rather than the two used for class-I waterproofing and because the binder application rate is greater than that used for class-I waterproofing. The polyester overlays have an advantage over class-I waterproofing in that they can be installed in stages and thus allow lane closures to be restricted to off-peak traffic periods. Also, multiple layer polymer overlays constructed with polyester resin should maintain an acceptable skid number for 10 years. Initial evaluations of a multiple layer polymer overlays constructed with two flexible epoxies and basalt aggregate also look encouraging. Evaluations of the multiple layer epoxy overlays on bridges FL-3, FG, and EM-15 should be continued.

One hundred cycles of temperature change had little effect on the sealers, the class-I waterproofing, and the flexible epoxy overlays tested. The polyester overlays, particularly those constructed with brittle resins, showed an increase in permeability and decrease in bond strength after being subjected to 100 or more cycles of temperature change. A 300-cycle test may provide more definitive results.

The performance of the sealers and multiple layer polymer overlays will have to be evaluated for at least five years to allow for an accurate assessment of life-cycle costs.

The (AASHTO T-277) rapid permeability test can be used to provide a relative indication of the protection provided by a concrete sealer. Also, 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. The permeability initially should be ≦100 Coulombs. The permeability after 200 thermal cycles should be ≦1500 Coulombs. The initial shear bond strength should be ≧700 psi and should not decrease ≧50% after 200 thermal cycles. The initial tensile bond strength should be ≧250 psi and should not decrease ≧50% after 200 thermal cycles. Similar limits could be applied to the freezing and thawing test (ASTM C666-A); 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). However, small-scale field installations tested in accordance with ASTM E524-76 may provide a more realistic indication of skid numbers.

It is anticipated that demonstration projects sponsored by FHWA will lead to further development and refinement of concrete sealers and polymer overlays (14).

CONCLUSIONS

1. Penetrating sealers can provide some protection (low permeability) against the infiltration of chloride ions at a low initial cost.

2. The application of penetrating sealers causes a reduction in the skid number; consequently, the applications should be restricted to bridge decks that have a high skid number, such as those with grooves made by tining or saw cutting, or to other bridge components such as pier caps.

3. Traffic wears the sealer from the surface.

4. Class-I waterproofing provides excellent protection (very low permeability) against the infiltration of chloride ions at a reasonable initial cost.

5. High bond strengths can be maintained with class-I waterproofing.

6. Class-I waterproofing should not be used as the final riding surface on bridge decks because the skid number can be unacceptable at an age of 2 to 4 years.

7. Multiple layer polymer concrete overlays constructed with a flexible polyester resin such as 92-339 provide good skid numbers and low permeability to chloride ions after 5 years in service.

8. The bond strength of multiple layer polyester overlays decreases with age, and the overlays constructed with a resin such as 92-339 will likely delaminate in approximately 10 years.

9. Multiple layer polymer concrete overlays constructed with a flexible epoxy and Basalt aggregate were in excellent condition initially from the standpoint of permeability, skid resistance, and bond strength.

10. The rapid permeability test (AASHTO T277) can be used to provide a relative indication of the protection provided by a concrete sealer or overlay.

11. A good indication of the performance to be expected from a multiple layer polyester overlay can be obtained by measuring the tensile elongation of the neat resin (ASTM D 638) and by testing specimens with PC overlays for permeability to chloride ions (AASHTO T 277) and bond strength in shear and direct tension 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. The performance of the concrete sealers and polymer overlays must be evaluated for at least 5 years to provide a reasonable indication of service life and life-cycle cost.

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APPENDIX A

SPECIAL PROVISION FOR POLYMER OVERLAYS (1987)

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 ± 0.25	Grading D; 17 $\pm$
2	2.25 ± 0.25	Grading A; 17 $\pm$
3	2.75 ± 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. Epoxy Overlays -

The epoxy overlay shall be applied as prescribed by Section V. E. I. Polyester Overlays 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 B

PROPERTIES OF MATERIALS USED IN MULTIPLE LAYER POLYMER CONCRETE OVERLAYS (92-339, FLEXOLITH, FLEXOGRID)

APPENDIX B

PROPERTIES OF MATERIALS USED IN MULTIPLE LAYER POLYMER CONCRETE OVERLAYS (92-339, FLEXOLITH, FLEXOGRID)

Properties @ 75°F

Binder	92-339[a]	Flexolith[b]	Flexogrid[c]
Color Part A	Purple Clear	Amber	Amber
Part B	Water White	Amber	Amber
Mixing Ratio A:B	50:1(±)	2:1	2:1
Min. Mix Temp., °F	60	50	25
Percent Solid	100	100	100
Shelf Life, months	> 3	---	24
Specific Gravity	1.05 - 1.22	1.08	1.08
Flash Point, °F	89	466	N/A
Mixed Viscosity, cps	150 - 200	700-1,000	2000-2500
Pot Life, min.	10-20	15 - 30	8 - 10
Tack Free Time, hrs.	0.5-1	3 - 4	0.5 - 0.7
Initial Cure, hrs.	3	5	2 - 3
Tensile Strength, psi	2,800-3,800	2,500-3,500	2,700
Tensile Elongation, %	20 - 50	> 30	35 - 45
Tensile Modulus, psi X 10^4	3 - 5	9 - 13	7 - 8
Compressive Strength, psi	7,000-8,000	>7,000	7,000-9,000
Compressive Modulus, psi X 10^6	1.2 - 2.6	0.1 - 0.14	---
Aggregate	Silica	Basalt	Basalt, Granite
Aggregate,[d] 4	100	100	100
Percent 8	95-100	34	59
Passing 12	---	3	9
U.S. 16	Max. 15	< 1	< 1
Standard 20	Max. 5	< 1	< 1
Sieve 30	Max. 2	< 1	< 1
Series 100	Max. 1	< 1	< 1

a) Product Bulletin - Polylite Polyester Resin 32-040 Reichhold Chemicals, Inc., Jacksonville, Florida.

b) Data Sheet FL-685, Dural International, Deer Park, New York.

c) Data Sheets 04-317/R-5, Mark 371 Glacial Gravel, Poly-Carb, Inc., Cleveland, Ohio.

d) Based on special provision for Grade A aggregate for 92-339 and analysis of samples of aggregate supplied for use with Flexolith and Flexogrid.

APPENDIX C

VIRGINIA DEPARTMENT OF TRANSPORTATION ROAD AND BRIDGE SPECIFICATIONS FOR CLASS I WATERPROOFING

VIRGINIA

Department of Highways and Transportation

Road and Bridge Specifications

JULY 1, 1982

COMMONWEALTH OF VIRGINIA
Richmond
1982

SECTION 421–WATERPROOFING

Sec. 421.01 Description–This work shall consist of furnishing and applying a waterproofing membrane on concrete bridge decks to be surfaced with bituminous materials or on other surfaces as shown on the plans.

Unless otherwise specified, Class II waterproofing shall be used for bridge decks and the work shall include surfacing with the material specified on the plans.

Sec. 421.02 Class I Waterproofing–

(a) **Description:** This work shall consist of furnishing and applying a two coat epoxy resin system in accordance with the plans and these specifications.

(b) **Materials:** Epoxy resin compounds and aggregates for surface application shall conform to Section 254. Epoxy resin shall be Type EP-5, LV.

(c) **Equipment:** Containers, tools and mechanical equipment shall be free of solvents, loose material and deposits of hardened material.

(d) **Temperature:** Epoxy resin shall not be applied when the concrete surface or the ambient air temperature is below 50°F unless otherwise specified in the manufacturers instructions,

(e) **Work:** The work shall be performed in 4 distinct continuous operations as follows:

1. **Surface Preparations** shall conform to Section 404.21(c)1.

2. **Mixing** shall conform to Section 404.21(c)2.

   The specified content of Component B (epoxy hardening agent) shall be mixed thoroughly with the specified content of Component A (epoxy resin) in strict compliance with the manufacturer's instructions. No solvents or other materials shall be added to the mixture.

3. **Application**–The first coat of epoxy resin shall be applied at a rate of one gallon per 50 square feet. After the first coat has cured for approximately 4 hours, the second coat of epoxy resin shall be applied at the rate of one gallon per 75 square feet. The sand shall be applied to the surface of the second coat of the wet epoxy compound within the pot life of the compound at a rate sufficient to cover the surface, but no less than 11 pounds per square yard. After curing, unbonded sand shall be broomed from the surface and may be reused if uncontaminated.

   At the edges of the waterproofing system and at any point where it is punctured by such appurtenances as drains or pipes, suitable provisions shall be made to prevent water from getting between the waterproofing and the waterproofed surface.

   Unless otherwise specified or shown on the plans, the waterproofing system shall be extended as follows: 1 inch up faces of curbs; continuously across abutment backwalls and a minimum of 6 inches down the backs of backwalls; a minimum of 12 inches onto approach slabs where they are used; continuously across all joints.

   When applied to prestressed concrete slab and box beam members for new construction, the application shall be made at the prestressing plant. Joints and damaged areas shall be waterproofed after erection.

4. **Curing** time shall conform to the manufacturer's recommendation. During this time all traffic, both pedestrian and vehicular, shall be barred from freshly placed surfaces.

SECTION 254–EPOXY RESIN SYSTEMS

Sec. 254.01 Description–Epoxy resin systems shall be the type required in the contract and shall conform to the requirements herein.

Sec. 254.02 Detail Requirements–

(a) **Epoxy Resin** materials shall conform to the applicable requirements of Table II-16. II-17 and II-18 for the type specified.

(b) **Infrared Spectrum** for each component shall essentially match that of the standard infrared spectrum for the particular component as specified in AASHTO T237, Sections 4 and 5.

Sec. 254.03 Epoxy Systems–Epoxy, Types EP-1, EP-2 and CTE, shall be aminopolyamide base epoxies for sealing, bonding or patching dry construction materials. Aggregates used with these systems must be oven dry (completely free of moisture). All surfaces on which these systems are placed shall be clean, dry, sound; free from rust, grease, waxes, impregnations and disintegrated materials.

Epoxy, Type EP-1, shall be a low viscosity 100 percent solids system, and shall not contain fillers, pigment or solvent. When used in patching mortar, it shall be mixed with five to seven parts by weight of grading B sand conforming to Table II-19. When used for filling dry potholes, it shall be mixed with sand and No. 8 aggregate.

Epoxy, Type EP-2, shall be an epoxy, Type EP-1 with approximately 30 to 40 percent inert finely ground filler added. When used in mortar or epoxy concrete, it shall be mixed with three parts by weight of aggregate.

Epoxy, Type CTE, shall be a coal tar modified epoxy resin and may be used to seal hydraulic cement concrete surfaces.

Epoxy, Type EP-3B and EP-3T, shall be 100 percent reactive high-build coatings designed as a two-coat-minimum system for the protection of concrete exposed to splash zones and tidal water. Epoxy, Type EP-3B, shall be the prime or base coat and Epoxy, Type EP-3T, shall be the finish or top coat.

Epoxy, Types EP-4, EP-5 and EP-6, shall be moisture-insensitive systems designed for structural bonding, sealing and grouting of dry, damp, or wet structural material free of standing water. Mortar shall be prepared by mixing 3¼ parts by volume of loose oven dry sand to one part of premixed Epoxy, Type EP-4 or EP-5; however, Epoxy, Type EP-6, shall be mixed on a one to one ratio. Mortars shall be mixed to a uniform consistency.

Epoxy, Type EP-4, shall be a high modulus, rigid, general purpose adhesive with tensile elongation of 1 to 3 percent. Unless otherwise specified, Epoxy, Type EP-4, low viscosity, shall be used to seal rigid cracks.

Epoxy, Type EP-5, shall be a low modulus patching, sealing and overlay adhesive with a minimum elongation of 10 percent, Epoxy, Type EP-5, used as a penetrating sealer and for repairing non-rigid cracks, shall be of a low viscosity.

Epoxy, Type EP-6, shall be a low modulus, non-sagging, flexible adhesive with a minimum elongation of 5 percent. Unless otherwise specified, Epoxy Type EP-6 shall be used for bonding or repairing damp and underwater surfaces where a non-sagging, low modulus material is required.

Other specially formulated epoxy systems not listed in this specification may be used in certain applications if approved in writing.

Sec. 254.04 Classes—The epoxy resin shall be formulated for use at specific temperatures. Three classes of systems are defined according to the range of temperatures for which they are suited. The controlling temperature shall be that of the surface of the hardened concrete to which the bonding system is applied. Where unusual curing rates are desired and upon approval of the Engineer, a class of bonding agent may be used at a temperature other than that for which it is normally intended. Class and gel temperature requirements are as follows:

Class A–for use above 60°F (16°C)
Class B–for use between 40°F and 60°F (4°C and 16°C)
Class C–for use below 40°F (4°C)

Sec. 254.05 Mixing of Epoxy—Epoxy resin shall be furnished in two components for combining immediately prior to use in accordance with the manufacturer's instructions. Component A shall contain a condensation product of epichlorohydrin with bisphenol "A", and shall conform to the requirements of Table II-16. Component B shall conform to the requirements of Tabel II-17, and shall contain one or more hardening agents which, on mixing with Component A, will cause the system to polymerize and harden in accordance with Table II-18. Thixiotropic agents used to control viscosity will be permitted as per the manufacturer's recommendations. In the event mix proportions of Components A to B exceeds 4 to 1, only complete units, as packaged by the manufacturer, shall be used.

The contents of the separate packages containing Components A and B shall be thoroughly stirred prior to use. The same paddle shall not be used to stir Component A as is used to stir Component B. Equipment and tools may be cleaned with toluene, zylol or methyl-ethyl-ketone before the adhesive has set. Component A and B shall be stored at a temperature between 65 and 80°F (18 and 27°C) for at least two hours before use. Epoxy components may be heated in hot water or by other approved method of indirect heat to bring them to the required temperature prior to mixing. Solvents and thinners shall not be used except for cleanup of equipment.

The two components shall be mixed for three to five minutes with a power drill having a paddle operating at 300-400 RPM's or other mixing equipment which will insure that no unmixed resin exists and air is not entrapped in the mixture.

When mineral fillers are specified, they shall be inert and non-settling or readily dispersible. Materials showing a permanent increase in viscosity or settling of pigments which cannot be readily dispersed with a paddle shall be replaced by the Contractor. At least 95 percent of the filler shall pass the No. 300 sieve.

Sec. 254.06 Aggregates—

Surface Application—Aggregate for surface application work shall be nonfriable, nonpolishing, clean and free from surface moisture. A silica sand, having well rounded particle shape shall be used unless otherwise approved by the Engineer. Aggregates, which will be exposed to traffic shall have a minimum Mohs' scale hardness of 7. In surface applications, the aggregate shall be applied on the epoxy surface in excess of the rate necessary to cover the surface; the aggregate shall be sprinkled or dropped vertically in such a manner that the level of epoxy mixture is not disturbed; the aggregate shall be applied within five minutes after the application of the epoxy; except, at temperatures below 70°F (21°C) a maximum of ten minutes is allowable. The grading analysis of the fine aggregate (silica sand) shall conform to Table II-19.

NOTE: Grading A aggregate may be used for sandblasting or as a non-skid surface of epoxy overlay wearing coarse. Grading B aggregate may be used for epoxy mortars or sandblasting. Grading D sand shall be used in epoxy overlays. Grading A or C sand may be used in epoxy coating when followed by an asphaltic wearing coarse. Aggregates used in epoxy mortars shall be oven dry.

Sec. 254.07 Handling and Storing Materials–The two components of the epoxy resin system shall be furnished in separate containers which are non-reactive with the materials contained therein. The size of the containers shall be such that the recommended proportions of the final mixture can be obtained by combining one container of Component A with one container of Component B. The maximum size of the container shall be 10 gallons (38 liters). When less than one complete unit is used, each component shall be measured within plus or minus 2% of the volume required. Batches of less than 6 fl. oz. (180 ml) shall be measured within plus or minus 1%.

Containers shall be identified as "Component A–Contains Epoxy Resin" and "Component B–Contains Hardener" and shall show the type, class and mixing directions. Each container shall be marked with the name of the manufacturer, the class, batch or lot number, the date of packaging, the date of shelf life expiration, pigmentation, if any, and the quantity contained therein in pounds (kg) and gallons (1). Potential hazards shall be so stated on the package in accordance with the Federal Hazardous Products Labeling Act with the following warning:

CAUTION:

Epoxies will cause dermatitis if proper precautions are not followed. Avoid contact with the skin and eyes, use gloves and protective creams on the hands. In the event of contact, wash thoroughly with soap and water. Goggles should be used to protect the eyes; however, in the event of eye contact, flush with water for ten (10) minutes and secure immediate medical attention.

Sec. 254.08 Sampling–A minimum of one random test sample of each component from each batch or lot number will be taken by the Department. The quantity of Component A required to react with one full quart of Component B will be sufficient sample for the tests specified. In order to reduce testing duplication and delays, components should be furnished in as few different batches or lots as possible.

Sec. 254.09 Certification–Shipments of less than 15 gallons (57 liters) may be accepted on certification. The Contractor shall submit a certification from the manufacturer of the epoxy resin system that

Components A and B meet the requirements of this specification. Such certification shall consist of a statement by the manufacturer, that Component A and B have been sampled and tested, and the certification shall be signed by an authorized agent of the manufacturer and shall contain actual results of tests performed in accordance with the methods described in Section 254.10.

Sec. 254.10 Methods of Testing–Testing will be performed in accordance with the following methods:

(a) Viscosity–ASTM 2393, Model LVT Brookfield Viscometer. The viscosity determination will be made at the temperature given in Section 254.04 for the Class of materials being tested.

(b) Epoxide Equivalent–ASTM D1652 and VTM-43.

(c) Volatile Content–ASTM D1259 Method B for the volatile content of the mixed system. The mixed sample will be cured 4 days at room temperature and then weighed on the previously weighed metal foil.

(d) Filler Content–VTM-43

(e) Ash Content–ASTM D482

(f) Pot Life–AASHTO T237 at the temperature given in Section 254.04 for the Class of material being tested.

(g) Tensile Strength–ASTM D638

(h) Bond Strength Test–VTM-41

(i) Compressive Strength–VTM-41

(j) Water Absorption–ASTM D570

(k) Thermal Shear Test–VTM-42

TABLE II -16
REQUIREMENTS — COMPONENT A

Type	EP-1 (PA-1)		EP-2 (PA-2)		EP-3B (PA-4B)		EP-3T (PA-4T)		EP-4(PA-6)		EP-5 (PA-7)		EP-6 (PA-8)		CTE	
Property	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Viscosity: Poises* 75°F (23.9°C)	4	8	4	10	60	130	20	60	15	30	10	20	—	—	8	30
Spindle No.	3		3		4		4		4		3		Gel		3	
Speed RPM	60		60		60		60		60		60				60	
Epoxide Equivalent	175	190	175	225	250	275	200	220	180	225	200	300	240	270	220	245

TABLE II - 17
REQUIREMENTS — COMPONENT B

Type	EP-1 (PA-1)		EP-2 (PA-2)		EP-3B(PA-4B)		EP-3T(PA-4T)		EP-4(PA-6)		EP-5(PA-7)		EP-6(PA-8)		CTE	
Property	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Viscosity: Poises* 75°F(23.9°C)	0	3	70	160	120	250	120	250	20	80	10	40	50	150	2	15
Spindle No.	1		4		4		4		4		4		4		2	
Speed RPM	60		60		12		12		60		60		30		60	

TABLE II -18
REQUIREMENTS — MIXED EPOXY SYSTEMS

Type	EP-1(PA-1)		EP-2(PA-2)		EP-3B(PA-4B)		EP-3T(PA-4T)		EP-4(PA-6)		EP-5(PA-7)		EP-6(PA-8)		CTE	
Color	Straw		Gray		Orange		Gray		Straw		Straw		Lt. Straw		Black	
Property	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Pot Life @ 75°F(23.9°C)	15	25	25	35	40	65	40	65	35	55	35	55	20	30	20	40
Tensile Strength PSI @ 75°F (23.9°C)	—	—	3,500	—	—	—	—	—	3,000	—	2,000	—	1,500	—	400	—
Tensile Elongation %@ 75°F (23.9°C)	—	—	2	5	—	—	—	—	1	3	5	15	5	15	30	—
Water Absorption Max. %	—	0.8	—	0.8	—	0.8	—	0.8	—	0.8	—	0.8	—	0.8	—	0.8
2" Cubes Compressive PSI, 24hrs. Dry Min.	7,000 (48.39 MPa)		7,000 (48.39 MPa)		—		—		6,000 (41.47 MPa)		—		—		—	
Strength PSI 48 hr. Wet Min.	8,000 (55.29 MPa)		8,000 (55.29 MPa)		—		—		7,000 (48.39 MPa)		4,000 (27.64 MPa)		4,000 (27.64 MPa)		—	
Bond Strength — Hardened Concrete to Hardened Concrete or Fresh Concrete PSI Min.	4,500 (31.10 MPa)		4,500 (31.10 MPa)		—		3,000 (20.73 MPa)		3,000 (20.73 MPa)		—		3,000 (20.73 MPa)		2,500 (17.28 MPa)	
Ash Content %	—	0.5	—	35	20	30	10	20	—	0.5	—	0.5	5	15	—	5.0
Viscosity: Poises @ 75°F (23.9°C)	0	3	15	75	40	100	40	150	20	40	10	25	—	—	6	25
Spindle No.	1		3		4		4		3		3		Gel		2	
Speed	60		60		60		60		60		60				60	
Volatile Content Max. Percent	3.0		3.0				6.0		3.0		3.0		3.0		20.0	

Note: The Lo-Mod L.V. System (EP-5) shall have a viscosity of less than 9.0 poises @ 77°F (25°C)

TABLE II-19
FINE AGGREGATE
(Silica Sand)

Amounts Finer Than Each Laboratory Sieve (Sieve Opening*), Percentage by Weight							
Grading	No. 4	No. 8	No. 16	No. 20	No. 30	No. 40	No. 100
A		Min. 100	50±10		Max. 3		Max. 1
B		Min. 100	99±1	95±5		Max. 10	Max. 1
C	Min. 100	Max. 5					Max. 1
D	Min. 100	97±3	70±10	45±10		25±10	10±5

*Numbered sieves are those of the U.S. Standard Sieve Series

VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
SPECIAL PROVISION FOR
SECTION 421 - WATERPROOFING

August 6, 1984

Section 421 of the Specifications is amended as follows:

Section 421.02(e)3, the first paragraph is replaced with the following:

Section 421.02(e)3 Application - The first coat of epoxy resin shall be applied at a rate of one gallon per 75 square feet. The sand shall be applied to the surface of the wet epoxy compound in accordance to Section 254.06, at a rate sufficient to cover the surface, but no less than 11 pounds per square yard. After curing, unbounded sand shall be broomed from the surface and may be reused if uncontaminated. After the first coat has cured for approximately 4 hours, the second coat of epoxy resin shall be applied at the rate of one gallon per 50 square feet. The sand must be applied to the second coat of epoxy in the same manner as in the first application.

VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
SPECIAL PROVISION FOR
SECTION 254 - EPOXY RESIN SYSTEMS

August 6, 1984

Section 254 of the Specifications is amended as follows:

Section 254.06: NOTE is replaced with the following:

Section 254.06 Aggregates - NOTE: Grading A aggregate may be used for sandblasting or as a non-skid surface of epoxy overlay wearing coarse. Grade B aggregate may be used for epoxy mortars or sandblasting. Grade D sand may be used in epoxy overlays. Sand which has passed a #2 sieve analysis: where not more than 25% passed through a #30 and 100% passed through a #8 sieve, may be used in epoxy overlays. Aggregates used in epoxy mortars shall be oven dry.

APPENDIX D

SPECIAL PROVISION FOR PENETRATING SEALERS

SPECIAL PROVISION FOR CONCRETE SURFACE PENETRANT SEALER

August 3, 1984

I. DESCRIPTION -

This work shall consist of furnishing and applying a water repellant concrete surface penetrant in accordance with this provision and in reasonably close conformity with the details and locations indicated on the plans. The color of the penetrant shall be clear.

Concrete surface penetrant sealer hereinafter referred to as penetrant sealer, shall be applied to entire deck area between face of parapets. Although called surface penetrant sealer, it must be completely absorbed into the concrete.

II. MATERIALS -

The penetrant sealer used in the performance of this work shall be a product as listed on the Department's current list of approved penetrating sealers; however, the Contractor may use other materials provided a certification that such material conforms to the following criteria is furnished by the manufacturer:

The penetrant sealer material shall not oxidize and shall show no appreciable change in color after 1000 hours when tested in accordance with ASTM D822; shall have excellent resistance to acids, alkalies, gasoline and mineral spirits when tested in accordance with ASTM D543; shall allow moisture vapor from the concrete interior to pass through the coating when tested in accordance with ASTM E398 or D1653; and shall reduce the absorption rate or exterior moisture into the pores of the concrete surface when tested in accordance with Federal Specification TT-C-555 B.

Such certification shall be furnished to the Engineer for approval prior to use of materials not on the current list.

III. CONSTRUCTION METHODS -

The penetrant sealer shall be applied in accordance with the manufacturer's recommendations, except as otherwise specified herein. The penetrant sealer shall not be applied until all concrete placement operations for the particular structure have been completed. All surfaces to receive the penetrant sealer shall be sandblasted to provide a clean uniform texture free of foreign substances such as oils, release agents, curing agents or efflorescence. All sandblasting residue shall be completely removed prior to application. The penetrant sealer shall not be applied when the concret surface is damp, when the concrete surface temperature is below 40°F, when the air temperature is above 90°F or between the hours of 11 A.M. and sunset.

Each container of penetrant sealer material shall be thoroughly mixed in strict compliance with the manufacturer's recommendations. Unless otherwise specified, the penetrant sealer material shall be applied in a one coat application by experienced mechanics with a squeegee, brush or roller; spray is prohibited. It shall not be thinned or reduced, except as may be specifically required by the manufacturer.

The rates of application as shown in the approved list are approximate only. Actual application rate shall be based upon a minimum of two test sections of approximately one foot square each for each structure to be treated. Such tests shall consist of applying a single coat of penetrant sealer and allowing it to dry thoroughly. The acceptable application rate shall consist of that quantity required to effect a complete and uniform absorption of a single coat at a maximum time period of 10 minutes. The surface should appear wet for 5 minutes after application, but should appear dry 10 minutes after application. In the event the absorption time of the material exceeds the 10 minute period, then the remaining unabsorbed material, including material which has ponded or filled grooves, shall be moved to a new place of application with a stiff broom. The penetrant sealer shall be considered unabsorbed if the surface of the concrete is tacky, wet, or has a shiny appearance.

IV. METHOD OF MEASUREMENT -

Accepted quantities of concrete surface penetrant sealer will be measured in square yards of completed deck surface to which it has been applied.

V. BASIS OF PAYMENT -

Concrete surface penetrant sealer will be paid for at the contract unit price per square yard, which price shall be full compensation for surface preparation and for furnishing all materials, labor, tools, equipment and incidentals necessary for the satisfactory completion of the work.

Payment will be made under:

Pay Item	Pay Unit
Concrete Surface Penetrant Sealer	Square Yard

VI. PRE-CONSTRUCTION ESTIMATE -

For bidding purposes only, the penetrant sealer application rate shall be estimated in the amount of square ft. per 1 gallon. The amount of material actually used will depend on the porosity of the concrete.

APPENDIX E

PROPERTIES OF PENETRATING SEALERS

APPENDIX E

PROPERTIES OF SEALERS

Sealer	E-bond 120[a]	Horsey-Set/ WDE[b]	Chem-Trete BSM 40[c]	Rohm & Haas High Molecular Weight Meth-acrylate[d]
Colar Part A	light amber	gray	clear	amber
Part B	dark amber	amber	none	red-violet pale yellow
Mixing Ratio A:B (Volume)	1:1	1:2	none	100:2 100:4
Percent Solid (Weight)	18	50	0	100
Shelf Life, months	24	12	12	12
Specific Gravity	0.88	1.19	0.81	1.0 - 1.1
Flash Point, °F	45°	non-flammable	70	>200
Mixed Viscosity, cps	7	700-1000	0.1	8 - 20
Pot Life, min.	360 - 480	15 - 60	infinate	20 - 45
Tack Free Time, hrs.	1	8 - 10	n/a	3 - 6
Initial Cure, hrs.[(e)]	3 - 4	10 - 24	0.25 - 2	3 - 6
Application rate, lb/yd^2				
1st Coat	0.22-0.25	0.35 - 0.6	0.4 - 0.6	0.5 - 1.0
2nd Coat	0.15	0.25 - 0.35	n/a	---

a) Personal Communication - John Robinson, Fort Lauderdale, Florida E-Bond Epoxies Inc., 5/1/87

b) "Horsey-Set/WDE Data and Specifications," Robson-Downes Associates, Inc., Oxford, Maryland, 1985.

c) Personal Communication - Ruth Gregory, Dynamit Noble of America Inc.," Rockleigh, New Jersey, 5/1/87.

d) "DOT Applications for High Molecular Weight Methacrylate Monomers," Rohm and Haas Company, Spring House, Pennsylvania, 1986.

e) Open to traffic.