POLYMER CONCRETE OVERLAY ON THE BIG SWAN CREEK BRIDGE

Interim Report No. 1 -- Installation and
Initial Condition of Overlay

by

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SUMMARY

The installation of a thin polymer concrete overlay on the Big Swan Creek Bridge provides further evidence that an overlay of low permeability can be soundly bonded to a concrete bridge deck by maintenance forces with a minimum of disruption to traffic. A discussion of when to specify a thin polymer concrete overlay is appended to the report.

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INTRODUCTION

This report has resulted from an agreement between the Federal Highway Administration (FHWA) Demonstration Projects Division and the Virginia Department of Highways and Transportation to construct and evaluate a thin polymer concrete (PC) overlay on a six-span bridge located on the Natchez Trace Parkway and spanning Big Swan Creek near Hohenwald, Tennessee.(1) The project is being conducted under FHWA Demonstration Project No. 51, Bridge Deck Repair and Maintenance, which is directed to extending the service life of bridge decks.

The Big Swan Creek Bridge is approximately 20 years old and has not been subjected to deicing salts. In April 1983, deterioration of the deck resulting from the reaction of the chert aggregate with the alkali in the cement in the presence of water, together with the failure to attain sufficient entrained air in the concrete, had resulted in a poor riding surface that was corrected by removing the poor concrete, patching, and installing a 1.5 in. (3.8 cm) portland cement concrete overlay. The portland cement concrete overlay was installed on the northbound lane on April 12 and on the southbound lane on April 20. The overlay on the southbound lane cracked as a result of shear tearing during screeding and plastic shrinkage. On June 6, 7, 8, and 9, a PC overlay was installed to restore grade, provide a skid resistant wearing surface, and provide a waterproof membrane, as well as to provide an opportunity to evaluate the installation and performance of a PC overlay constructed with polyester resin 317. The overlay differs from other PC overlays being evaluated by the author[2, 3], in that the resin was supplied by a different distributor; the overlay was placed on portland cement concrete that was relatively new, less than 2 months old; and the geometry of the bridge was extreme in that the transverse slope and the longitudinal grade exceeded 10%.

PURPOSE

The purposes of this report are to describe the construction of the PC overlay and the condition of the bridge deck before and after the installation of the overlay, to project a service life for the overlay, and to extend the knowledge concerning the potential of thin PC overlays for extending the service life of bridge decks.

INSTALLATION OF PC OVERLAY

Materials

Monomers-Polyester Resin

The resin was a clear, low viscosity, highly resilient, general purpose, unsaturated polyester resin with a viscosity of 200 cP. (0.2 Pa.s.) at 73°F. (23°C.) and a density of 9.08 lb./gal. (1088 kg./m.^{3}). The resin was supplied by Dural International as Dural 317 and was similar to Reichhold Chemical's blend Polylite 90-570. The first course contained 1% Union Carbide A-174 coupling agent and 1% Surfynol S440 wetting agent to enhance the bond strength and reduce surface tension. The second, third, fourth, and fifth courses contained 0.5% Union Carbide A-174 coupling agent and 0.5% Surfynol S440 wetting agent.

Initiator

The initiator was 60% methyl ethyl ketone peroxide (MEKP) $C_4H_8O_2$ in dimethyl phthalate with approximately 9% active oxygen and a specific gravity of 1.15 at 77°F. (25°C.). It was in a liquid state with a water white color, a flash point (Cleveland open cup) of about 180°F. (82°C.), and a mildly thermal decomposition point (rapid rise) at 320°F. (160°C.).

Promoter

The promoter was approximately 6% active cobalt in naphtha (CoN). In a liquid state it is bluish red and has a flash point at or above 121°F. (49°C.) and a density of 7.5 lb./gal. (899 kg./m.^{3}).

Coupling Agent

The coupling agent was a gama-methacryloxpropyltri-methoxysilane equal to Union Carbide's formulation A-174.

Wetting Agent

The wetting agent was Surfynol S440 manufactured by Air Products and Chemicals,.Inc.

Aggregate

The aggregate was a clean, dry (less than 1% moisture), angular-grained silica sand free of dirt, clay, asphalt, and other organic materials and having a gradation similar to that reported in Table 1. The aggregate was supplied by Whitehead Brothers Company of East Hanover, New Jersey.

Table 1

Gradation of Sand, Percent Passing Indicated U. S. Sieve

Grading	Layers	8	12	16	20	30
A (#2)	3, 4 & 5	99.9	59.3	12.1	2.1	0.9
D (#1)	1 & 2	100.0	98.5	58.8	6.9	0.6

Equipment

The polymer distribution equipment and aggregate spreader were built for the Implementation Division of the FHWA by the Brookhaven National Laboratory.

Distribution Equipment

The resin distribution equipment was mounted on skids, which allowed it to be placed on a dump truck provided by the U. S. Park Service. It consisted of a generator, air compressor, two water-cooled pumps, a kenex static mixer, a spray bar, and the necessary piping to allow resins from two 55-gal. (0.21-m.^{3}) drums to be pumped simultaneously to the spray bar (see top of Figure 1). Resin containing CoN was pumped from one drum at the same rate that resin containing MEKP was pumped from the other one. The resins from the two drums were mixed in a static mixer before they entered the spray bar.

Aggregate Spreader

The aggregate spreader is shown in the bottom of Figure 1. It consists of a truck connected to a flatbed trailer equipped with a hopper, motor, an auger to move the aggregate from the hopper into the trough, and a rotating drum to dispense the aggregate from the bottom of the trough and deposit it over a maximum width of 12 ft. (3.7 m.).

Deck Preparation Equipment

A "Blastrac" environmental surface preparer was used to shotblast the deck surface prior to placing the first layer of resin. The equipment recycles the steel shot, collects concrete cuttings, and rapidly provides, at low cost and with little or no environmental damage, a completely cleaned deck surface. Petrographic examinations of the vertically cut and finely lapped interior surface of two cores taken from the bridge confirmed that the equipment cleaned the concrete surface without causing large fractures in the aggregate or paste of the base concrete. Jackhammers and scarification equipment typically leave large fractures when they are used to remove the upper portion of a concrete deck.(4)

Vacuum

A self-propelled, sweeper-broom type Tennant machine was used to remove excess sand from the surface approximately 1 hour after the resin mixture had gelled.

Labor

The overlay was installed by personnel from the Federal Highway Administration, the U. S. Park Service, Brookhaven Laboratories and the Virginia Department of Highways and Transportation. The shotblast equipment was operated by personnel from the manufacturer, Wheelabrator-Frye, Inc.

The resin distribution equipment was operated by a driver, a pump operator, a man on foot with a stopwatch to assist in maintaining the desired rate of application and one man who

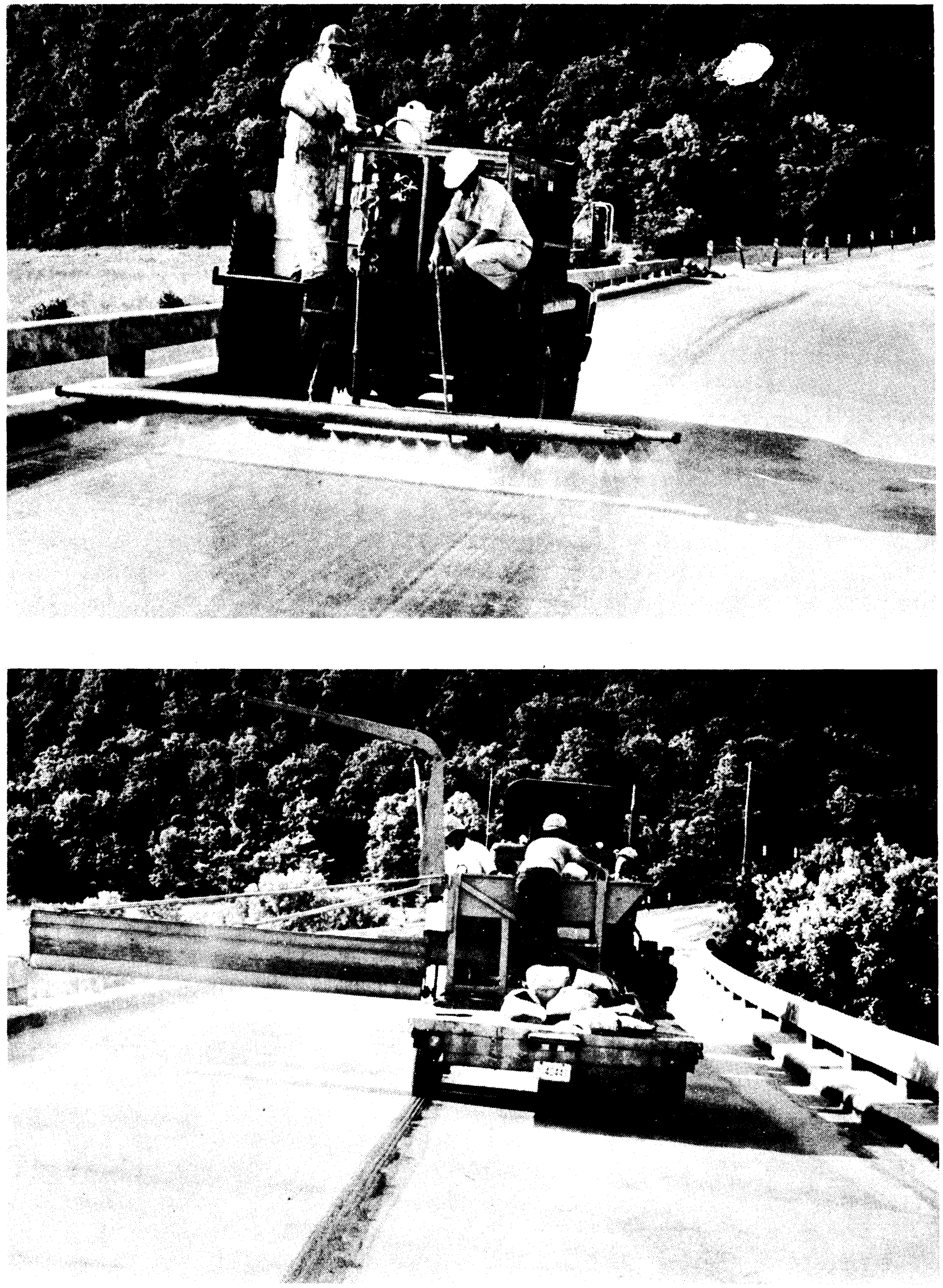

Figure 1. Application of resin and aggregate.

secured a 1.7-oz. (50-ml.) sample of resin from the spray bar at the beginning, the middle, and the end of each resin application and noted the average gel time.

The aggregate spreader was operated by a driver, a spreader operator and several men who emptied 100-lb. (444-N) bags of sand into the hopper. Also, several men were required for the hand application of sand.

The vacuum truck was operated by one man.

Assessment of Installation

The southbound lane was shotblasted on June 6 between 10:00 a.m. and 1:00 p.m. and the northbound lane on June 7 between 9:00 a.m. and 2:00 p.m. The cleaning rates were 156 yd.^{2}/hr. (130 m.^{2}/hr.) and 93 yd.^{2}/hr. (78 m.^{2}/hr.)., respectively. Less time was required to clean the southbound lane because it had been well cleaned, particularly the two northernmost spans, on May 17. The overlay installation was cancelled on May 18 due to rain and rescheduled for June 6. A machine that cleaned a 20 in. (51 cm) wide path was used in June, because use of a machine cleaning a 14 in. (36 cm) wide path in May had required 10 hours to clean the southbound lane, which allowed too little time for application of the resin on the same day.

A few days prior to the scheduled placement of the overlay in May, the coupling and wetting agents were added to all of the drums and the CoN was added to half of them. Just prior to placing the resin, the MEKP was added to one of the drums that did not contain CoN and the ingredients in this drum and the one with CoN were each mixed for 15 minutes.

The resin mixture was sprayed over a 14 ft. (4.3 m.) wide by 300 ft. (91.4 m.) long lane. The truck was moved forward at a speed calculated to provide an application of up to 2.0 lb./yd.^{2} (1.1 kg./m.^{2}) which was the maximum that could be obtained with two drums of resin. Although an application of 2.0 lb./yd.^{2} (1.1 kg./m.^{2}) for the first layer and 2.75 lb./yd.^{2} (1.5 kg./m.^{2}) for subsequent layers had been used on other bridges, this application would have been too great for the Swan Creek Bridge because of the $>$10% slope of the deck surface. Consequently, five layers of resin and aggregate were placed on the bridge rather than the usual four.

The auger and drum on the aggregate spreader could be rotated at several speeds but it was necessary to adjust the forward motion of the truck to the maximum output of the spreader to provide an aggregate application rate of approximately 10 lb./yd.^{2} (5.4 kg./m.^{2}), which would provide a slight excess of aggregate in the resin. Since the hopper would hold only 2,500 lb. (11.1 kN.) of sand, it was necessary to carry an additional supply and recharge the hopper as needed to apply an excess over the 467 yd.^{2} (390 m.^{2}) of surface area in each lane. Sand was placed by hand along a 2 ft. (0.6 m.) wide strip along the curb side of the 12 ft. (3.7 m.) strip covered by the spreader.

The installation got off to a slow start because of the inexperience of some of the personnel and problems with the resin distribution equipment. The spray nozzles of the resin distribution equipment continued to plug during the first two days. With time, placement procedures were improved, and on the last day two layers were placed on each lane. The sand application equipment was not well suited for the 14 ft. (4.3 m.) wide lane, and equipment with a variable width capability should be developed so that sand does not have to be placed by hand. Despite these problems, the overlay was properly installed with minimal disruption to traffic.

Composition of the Overlay

Information collected during and subsequent to the installation of the overlay is shown in Tables 2 and 3. Table 2 shows that the average resin application rate was 8.6 lb./yd.^{2} (4.6 kg./m.^{2}), which is only 14% less than the 10 lb./yd.^{2} (5.4 kg./m.^{2}) that could have been achieved in five applications. The aggregate application was adequate and provided an aggregate to resin ratio in excess of the 5 to 1 considered desirable for minimizing shrinkage and thermal stresses. The thicknesses of the overlay shown in Table 3 are based on measurements of cores taken from the deck and are in agreement with the application data shown in Table 2.

Gel times ranged from 14 to 18 minutes, with an average of 16 minutes, which is similar to the author's experience with resins LB183 and 90-570. The dosages of MEKP and CoN were 1.26% and 0.5%, respectively, by weight of resin.

Table 2

Composition of Overlay

Lane	Layer	Install. Date	Resin, lb./yd.^{2}	Sand, lb./yd.^{2}	Temperature, °F Air	Deck	Resin	Sand	Gel Time, Min.
Southbound	1*	6	1.56	12.86	76	80	--	84	18
"	2*	7	1.50	16.07	75	78	82	76	16
"	3	8	1.84	8.57	82	85	81	74	14
"	4	9	1.72	10.71	82	81	76	68	16
"	5	9	1.97	10.71	87	90	78	70	15
"	All*		8.59	58.92	80	83	79	74	16
Northbound	1	7	1.63	15.00	78	82	81	82	17
"	2	8	1.53	9.64	80	83	75	69	14
"	3	8	1.77	8.57	80	84	80	73	15
"	4	9	1.86	10.71	82	80	74	68	17
"	5	9	1.82	8.57	86	86	79	71	14
"	All		8.61	52.49	81	83	78	73	15

* The data are for spans 5 and 6 at the north end of the bridge. The total resin and sand application rates for spans 1 and 2 were 8.62 lb./yd.^{2} (4.65 kg.m.^{2}) and 52.49 lb./yd.^{2} (28.3 kg./m.^{2}), respectively, and for spans 3 and 4, 10.93 lb./yd.^{2} (5.9 kg./m.^{2}) and 78.21 lb./yd.^{2} (42.2 kg./m.^{2}), respectively.

0.54 kg./m.^{2} = 1 lb./yd.^{2}

°C. = (°F. -32)/1.8

Table 3

Thickness of Overlay, in.

Lane	Span 1	2	3	4	5	6	Avg.
Southbound	0.44	0.42	0.58	0.46	0.41	0.36	0.46
Northbound	--	0.40	0.43	0.51	0.37	0.48	0.44

2.54 cm. = 1.0 in.

CONDITION OF DECK BEFORE AND AFTER OVERLAY

Half-Cell Potentials

Copper sulfate half-cell potentials (ASTM C876-77) were measured by the FHWA over the entire deck surface on May 14, 1983, and the results are shown in Table 4. The half-cell data imply that there was greater than a 90% probability that no corrosion was occurring in 99.3% of the steel, which is reasonable since no deicing salts had been applied to the bridge.

Table 4

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

≤ 0.20	0.20 to 0.35	≥ 0.35
99.3	0.7	0

Delamination

A delam-tech was used by the FHWA to find areas of delamination. No delaminations were found prior to placing the PC overlay, with the exception of small areas in the vicinity of the two expansion joints that had been blocked out by the contractor to facilitate installation of the expansion devices. These delaminations were removed when the expansion joints were installed. No delaminations were noted one week after the PC overlay was installed.

Significant Cracks

Numerous random cracks were noted in spans 2, 3, and 4 of the southbound lane prior to placing the PC overlay. The cracks seem to have been caused by a combination of screed tearing, which was magnified by the steep grade of the surface, and plastic shrinkage. The cracks are probably not moving cracks and, therefore, will not contribute to cracking in the overlay. No significant moving cracks were noted.

Electrical Resistivity

On June 13, four days after the PC overlay was installed, electrical resistivity measurements (ASTM D3633-77) were made by the FHWA over the entire deck surface, and the results are reported in Table 5. All of the low readings were measured along the curbs, and may have resulted from the water used in the test coming into direct contact with the unprotected concrete curb. If the readings along the curb are eliminated, the resistivity of the overlay is excellent, indicating that no shrinkage nor reflective cracks had formed.

Table 5

Electrical Resistivity Measurements, Percentage of Total Number of Readings

Age, wk.	Range of Electrical Resistivity, Ohms/ft.^{2}			
	Poor $<10^4$	Fair 10^4 to $<10^6$	Good 10^6 to 10^8	Excellent $>10^8$
-3	100	0	0	0
1	0	41*	1	58

* All the low readings were taken along curbs and may have resulted from the water making direct contact with concrete on curb.

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

Permeability

A rapid permeability test recently developed by the Portland Cement Association for the FHWA was used to determine the permeability to chloride ion of 4-in. (10-cm.) diameter cores removed from the bridge.(5) From the results shown in Table 6, which are based on single specimens or the average of two, it can be seen that the permeability of the old base concrete was very high. The 1.5 in. (3.8-cm.) thick overlay exhibited a much lower permeability, and that of the PC overlay was almost 0.

Table 6

Permeability to Chloride Ion of 4 in. (10 cm.)
Diameter Cores, Coulombs

Lane	Concrete Base	Concrete Overlay	PC Overlay	
Southbound	6,521[a]	2,709	0.06[a]	---
Northbound	10,640[a]	2,948[a]	0.03	1,596[b]

[a]One specimen.

[b]After 200 thermal cycles.

Because it was known that low temperatures could produce contraction cracks in the overlay, two cores were subjected to 200 cycles of temperature change in air in which the temperature fluctuated from 0°F. (-18°C.) to 100°F. (38°C.) at a rate of 3 cycles per day. The effect of the cycles of temperature change was to increase the permeability to 1,596 coulombs. The increase in permeability is believed to have resulted from thermal stresses. While it is not known how many years of service the 200 cycles represent, it can be seen that after being subjected to this number the permeability of the overlay was less than that of the concrete it is bonded to. The performance of the 317 resin is almost identical to the performance of the 90-570 resin used in a project on Beulah Road.(2)

Shear Strength

To obtain an indication of the shear strength of the portland cement concrete and PC overlay composites, cores were subjected to two tests. In the first test, the shear force was directed through the bond interface; for the second, it was directed through the concrete approximately 1.0 in. (2.5 cm.) below the bond interface to gain an indication of the shear strength of the portland cement concrete overlay. Prior to the tests, the cores were subjected to from 0 to 200 thermal cycles applied as previously described.

A plot of the shear strength of the cores as a function of the number of thermal cycles is shown in Figure 2 for fifteen 2.75 in. (7.0 cm.) diameter cores removed from the bridge one week after it was overlaid. From the figure it

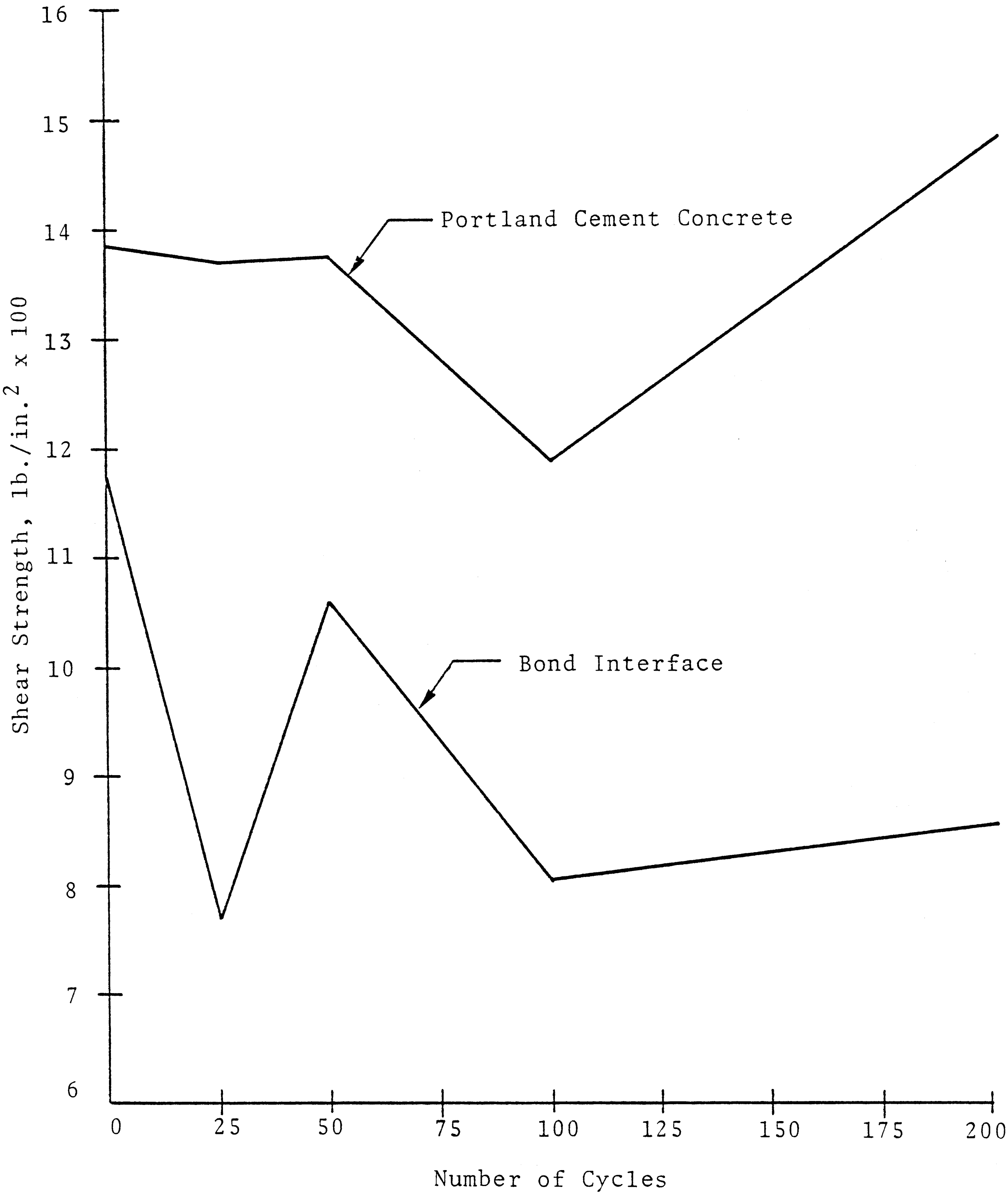

Figure 2. Shear strength as a function of number of thermal cycles. (6.89 kPa = 1 lb./in.^{2})

can be seen that, although there is a lot of variability in the results, the shear strength of the portland cement concrete was unaffected by the thermal loading. On the other hand, that of the bond between the PC overlay and the portland cement concrete decreased as the number of thermal cycles increased. The types of failure which occurred during the shear tests provided further evidence that the strength of the bond interface deteriorated when subjected to cycles of temperature change. At zero thermal cycles, 4 of 6 of the failures involved only the base concrete, whereas at 25 cycles 1 of 3 failures involved only the base concrete, and at 50 or more thermal cycles, all of the failures involved the bond interface and none involved only the base concrete. Nevertheless, the strength of the bond after 200 cycles is high and, therefore, a long service life can be expected.

Assessment of Condition of PC Overlay

Prior to the installation of the PC overlay the deck was in sound condition, the steel was not corroding, and there was no delamination. The deck surface was properly prepared and the PC overlay was soundly bonded to the concrete. The PC overlay was providing a wearing surface of low permeability following one week in service.

EXPECTED SERVICE LIFE OF PC OVERLAY

Factors

The service life of a PC overlay can be influenced by the condition of the base concrete, the strength of the bond between the PC overlay and the base concrete, wear, reflective cracking, the curing shrinkage of the overlay, and thermal stress. It was noted earlier in this report that the base concrete on the Swan Creek Bridge was in good condition and the overlay was soundly bonded to the base concrete. Therefore, these two factors would not be expected to adversely affect the service life. The same can be said about wear, because the bridge is not subjected to much traffic. (Measurements of the depths of ruts in the wheelpaths of PC overlays in Virginia that are subjected to more traffic have not indicated wear after one year of service life.) Similarly, reflective cracking is not expected to have an adverse effect, because moving cracks were not noted in the deck prior to placement of the overlay.

The extent of cracking from curing shrinkage and thermal stress can be minimized by placing an excess of aggregate in the overlay and by selecting a resin with a high tensile elongation. An excess of aggregate was used in the Swan Creek overlay and therefore, the aggregate content should not have a negative effect on the service life.

Tensile Properties of Resin

The results of tests conducted in accordance with ASTM D638-80, "Standard Test Method for Tensile Properties of Plastics," are shown in Table 7 and Figure 3. Values are reported for other resins used on bridges in Virginia as well as for the 317 resin used on the Swan Creek Bridge.(6) From Table 7 and Figure 3, it is obvious that the 317 resin has a high elongation and should perform as well as the 90-570 resin used on the Beulah Road Bridge. The 90-570 and 317 resin should be less prone to cracking than LB183, methylmethacrylate (MMA), and EP5LV epoxy. Extensive cracking has occurred in overlays constructed with LB183 and MMA.(2, 3) The EP5LV epoxy overlay system is under study at this time.(7)

Table 7

Tensile Properties of Resins

Resin	Tensile Strength, lb./in.^{2}		Elongation at Break, %		Modulus of Elasticity, lb./in.^{2a}	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
317	2858	301	23.3	8.1	4.69×10^4	0.99×10^4
LB183	5089	1928	8.0	3.8	7.81×10^4	0.91×10^4
90-570	2836	373	49.2	11.4	3.52×10^4	0.21×10^4
MMA-1[b]	1427	525	2.3	0.4	6.29×10^4	1.39×10^4
EP5LV	4797	626	12.5	1.2	6.60×10^4	1.56×10^4
MMA-2[c]	4821	262	6.7	0.0	7.19×10^4	0.58×10^4

[a] Calculated at 0.05 in./in. strain except MMA.

[b] 63% MMA and 37% PMMA.

[c] FX822, PMMA unknown.

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

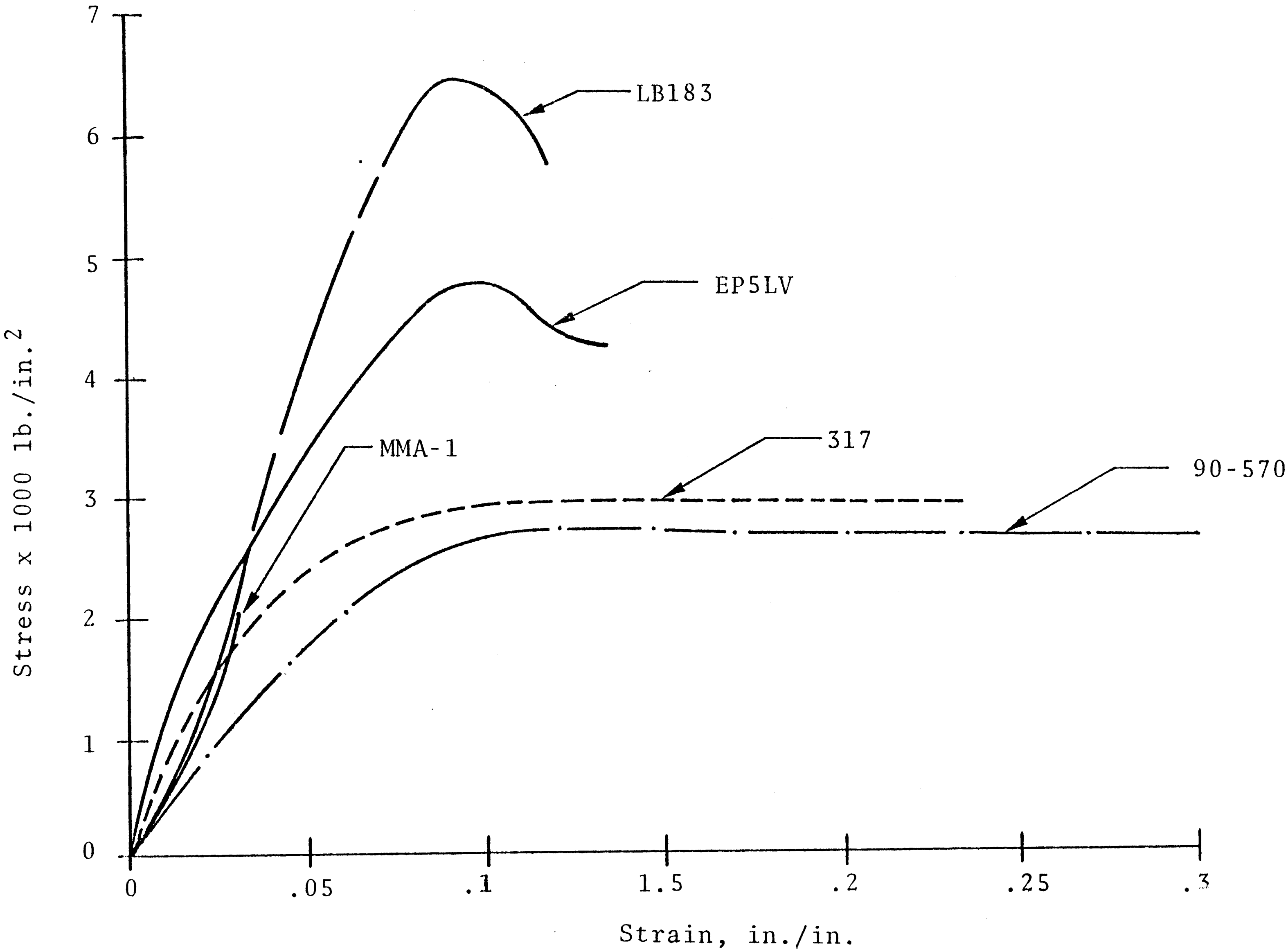

Figure 3. Stress-strain data based on average of three specimens of each resin.(6) (6.89 kPa = 1 lb./in.^{2})

Thermal Stress

When two materials of different properties are bonded together, a shearing stress develops when the composite is subjected to a change in temperature. The stress is a function of the temperature change and the coefficient of thermal expansion and moduli of elasticity of the materials. A shear failure in the vicinity of the interface can be expected if the shear stress exceeds the shear strength of either of the materials or the strength of the bond. A method for computing the theoretical stress is discussed in detail in reference 2.

Twelve 1 x 1 x 11.5 in. (2.5 x 2.5 x 29.2 cm.) specimens were prepared at the bridge site during the installation of the Swan Creek overlay for use in determining the coefficient of thermal expansion and the dynamic modulus of elasticity of resin 317 with and without aggregate. Six specimens were prepared without aggregate and six with approximately 20% resin by weight. In each group, three specimens were cast with a single filling of the molds and three were cast in eight layers.

The coefficient of thermal expansion was determined by measuring the lengths of the specimens at 0°F. (-17.8°C.), at 74°F. (23°C.) and at 140°F. (60°C.). The average values for the 74°F. (23°C.) base temperature are shown in Table 8 along with the values for similar specimens prepared with LB183 and 90-570 resins. From Table 8 it can be concluded that the 317 resin is similar to the LB183 and 90-570 resins and that a reasonable value for a polyester resin overlay sanded to excess is 16×10^{-6} in./in./°F. (9×10^{-6} cm./cm./°C.).

Table 8

Average Coefficient of Thermal Expansion, in./in./°F ($\times 10^{-6}$)

Resin	No Aggregate	Excess Aggregate
317	58.3 (3.5)[a]	16.4 (2.3)
317[b]	53.2 (5.6)	16.1 (4.1)
LB183	54.3 (---)	15.8 (---)
90-570	60.1 (---)	15.6 (---)

[a] Standard deviation

[b] Cast in 8 layers

(0.56 cm./cm./°C. = 1.0 in./in./°F.)

Values for the dynamic moduli of elasticity of the specimens as determined by ASTM C215-60 are not available but are believed to be similar to those reported for the 90-570 resin in Figure 9 of reference 2. These values are 0.3×10^6 lb./in.^{2} (2 kPa.) for an overlay with no aggregate and 1.2×10^6 lb./in.^{2} (8.3 kPa.) for an overlay constructed with an excess of aggregate. However, the greatest thermal stress occurs when the deck is subjected to the lowest temperature, and under this condition the overlay is in tension. Therefore, it is believed that another indication of the theoretical shear stress can be obtained by using the modulus of elasticity of the overlay in tension, as reported in Table 7, rather than the dynamic modulus of elasticity.

Table 9 shows values of theoretical shear stress for resins 317, 90-570, and LB183. The values are computed using the data in Tables 7 and 8 and the following equation from reference 2.

$$S = \frac{(C_p - C_c)\, E_p E_c\, \Delta T}{E_p + E_c},$$

where

S = shearing stress, lb./in.^{2} (Pa.);

C_p = coefficient of thermal expansion for PC overlay, in./in./deg. F. (cm./cm./deg. C.);

C_c = coefficient of thermal expansion for portland cement concrete, in./in./deg. F (cm./cm./deg. C.);

E_p = modulus of elasticity of PC overlay, lb./in.^{2} (Pa.);

E_c = modulus of elasticity of portland cement concrete, lb./in.^{2} (Pa.); and

ΔT = temperature change, deg. F. (C.)

For purposes of calculation, the portland cement concrete was assumed to have a C_c of 5.7×10^{-6} in.in./^{o}F. (10.3×10^{-6} mm./mm./^{o}C.) and an E_c of 4.2×10^6 lb./in.^{2} (28.9 GPa.) Since the data in Table 7 are for specimens prepared without aggregate, it was necessary to assume that a specimen with 80% aggregate by weight would have a modulus of elasticity in tension four times that of the modulus of a specimen without aggregate. The assumption is in agreement with the observed change in the dynamic modulus of elasticity with a change in aggregate content.(2)

Table 9

Theoretical Thermal Shear Stress, lb./in.^{2}

Resin	No Aggregate $\Delta T = 1^oF.$	$\Delta T = 70^oF.$	Excess Aggregate $\Delta T = 1^oF.$	$\Delta T = 70^oF.$
317	2.4	170	1.9	130
LB183	3.7	260	2.9	210
90-570	1.9	130	1.3	94

6.89 kPa = 1 lb./in.^{2}; 0.56 $^oC.$ = $1^oF.$

For an overlay with no aggregate, the theoretical stress values in Table 9 are too low to cause a shear failure based on the shear strength values shown in Figure 2. On the other hand, the values in Figure 11 of reference 2 indicate that a shear failure would occur for a $70^oF.$ ($39^oC.$) change in temperature. Therefore, the delamination of the overlays on specimens constructed in the laboratory with 90-570 resin and no aggregate provides evidence that the dynamic modulus rather than the tension modulus of elasticity of the polymer should be used to compute the theoretical shear stress caused by a change in temperature.

For an overlay constructed with an excess of aggregate, the magnitude of the thermal stress for a $70^oF.$ ($39^oC.$) change in temperature is less than the shear strength values shown in Figure 2; regardless of whether we use the theoretical stress values in Table 9, which are based on the tension modulus of the polymer, or the values in Figure 11 of reference 2, which are based on the dynamic modulus of the polymer. Therefore, the overlay on the Big Swan Creek Bridge should remain bonded for many years.

Fatigue

Table 6 indicates that the permeability of the cores with the PC overlay increased significantly as a result of being subjected to 200 cycles of temperature change. Similarly, Figure 2 indicates that the strength of the bond interface decreased as a result of the cycles of temperature change. This behavior was also noted with resins LB183, 90-570, and MMA.[2,3] The increase in permeability and the deterioration in bond strength with cycles of temperature change were caused by thermal stress. The magnitude of the stress, as shown in

Table 9 and in Figure 11 of reference 2, is not great enough to cause the bond to fail, but evidently it is great enough to fatigue the concrete and overlay composite. Consequently, the service life of the overlay is finite but difficult to predict.

Four inch (10.2 cm.) diameter concrete specimens overlaid with 90-570 resin and an excess of aggregate and subsequently subjected to 300 cycles of temperature change have not exhibited delamination.(8) Since the 317 resin is similar, it should perform as well. Certainly, the overlay on the Big Swan Creek Bridge will remain bonded and provide low permeability for more than five years, and ten years seems a reasonable expectation. It will be necessary to follow the performance of this PC overlay as well as those on the bridges in Virginia to make a more accurate projection of the service life of such an overlay.

A discussion of when to specify a thin PC overlay, taking into account possible service life, cost, discount rate, and traffic volumes, is presented in the Appendix to this report.

CONCLUSIONS

1. The thin PC overlay on the Big Swan Creek Bridge provides further evidence that an overlay of low permeability can be soundly bonded to a concrete deck by maintenance forces with a minimal disruption to traffic.

2. Laboratory tests indicate that the resin 317 used on the Big Swan Creek Bridge has a high elongation as determined by ASTM D638-80 and is similar to the resin 90-570 used on one lane of the Beulah Road Bridge in Virginia. Because of the high elongation, overlays constructed with these resins are less likely to crack than overlays constructed with LB183, MMA, and EP5LV epoxy.

3. When the cores from the overlay constructed with 317 were subjected to cycles of temperature change, the bond decreased and the permeability increased. Although a useful service life in excess of five years is virtually certain, and a life of ten years seems reasonable, it will be necessary to monitor the performance of the overlay as well as that of the overlays in Virginia to make a more accurate projection of the useful service life.

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APPENDIX

WHEN TO SPECIFY THIN POLYMER CONCRETE OVERLAYS

by

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INTRODUCTION

The principal advantage of a thin polymer concrete (PC) overlay over other bridge deck protective systems is that it can be installed with minimal lane closure time. Unfortunately, PC is basically not thermally compatible with portland cement concrete, so the useful service life of a PC overlay is limited. Based on experience to date, it is believed that a service life of 10 years can be used in comparing the economics of PC overlays with those of alternative systems.

Three cases are presented to illustrate when the use of a thin PC overlay is justified as compared to the use of a more conventional latex modified concrete overlay. The comparison is based on a consideration of the service life of the PC overlay, the volume of traffic, the discount rate, and the value of driving time. For each of the three cases it is assumed that the following conditions exist.

1. The overlay is to be placed on a 2-lane bridge on I-95, 40-ft. (12 m.) wide by 350 ft. (107 m.) long.

2. It is necessary to increase the skid resistance and curtail the infiltration of additonal chloride.

3. It is not feasible to construct a temporary bridge or detour traffic.

4. A 0.5-in. (1.3 cm.) thick PC overlay can be installed with 12 hours of lane closure time and at a cost of \$24/yd.^{2} (\$29/m.^{2}) plus the cost of traffic control with cones, and will provide acceptable service for 5 to 15 years.

5. A 1.25-in. (3.2 cm.) thick latex modified concrete overlay can be installed with 9 days of lane closure time and at a cost of $30/yd.² ($36/m.²) plus the cost for traffic control with median barriers, and will provide acceptable service for 30 years.

6. Since it is difficult to predict the relationship between interest rate and inflation over a 30-year period, calculations are made for discount rates of 0%, 5% and 10%, where the discount rate is the annual rate at which money increases in value thru investment.

CASE ONE

For case one, the peak-hour volume to capacity ratio with both lanes open is 0.30. With one lane closed, the ratio for the open lane is 0.60. Traffic flow will not be impeded by closing one lane for an extended period of time.

The cost for traffic control while the PC overlay is being installed is $1/yd.² ($1.20/m.²) and for the latex overlay $5/yd.² ($6/m.²). The present worth of the thin PC overlay at a discount rate of 0% and a service life of 10 years is $25/yd.² + $25/yd.² + $25/yd.² = $75/yd.² ($89/m.²) as compared to $35/yd.² ($42/m.²) for the latex. At a discount rate of 5% and a service life of 10 years the present worth of the PC overlay is $\$25 + (\$25) \div (1.05)^{10} + (\$25) \div (1.05)^{20} =$ $50/yd.² ($60/m.²), and at a discount rate of 10%, it is $38/yd.² ($45/m.²). As shown in Table 1, the latex overlay at $35/yd.² ($42/m.²) is the most economical alternative in case one, unless for a service life of 10 years the discount rate exceeds 12.6%, which is highly unlikely, or for a service life of 15 years the discount rate exceeded 6.3%. It seems reasonable to conclude that for case one the latex overlay is the most economical alternative, since a service life for the PC overlay in excess of 10 years and a discount rate in excess of 5% are not likely at this time.

CASE TWO

For case two, the peak-hour volume to capacity ratio is 0.6 with both lanes open and 1.0 with one lane closed. The one open lane cannot carry the peak-hour traffic volume, and a major reduction in speed and level of service occurs. The PC overlay is justified because one lane of the bridge cannot be closed during peak-hour traffic, which is necessary for the construction of the latex overlay.

For case two, the cost of traffic control for the latex is higher than in case one, because of the higher volume of traffic. A cost of $20/yd.^2$ ($24/m.^{2}) seems reasonable. The cost of traffic control for the PC overlay would be the same as in case one. The present worth of the latex overlay for the 30-year service life is $50/yd.^{2} ($60/m.^{2}) and, as can be seen in Table 1, the present worth of the PC overlay is less if the discount rate exceeds 5% for a 10-year service life and exceeds 0% for a 15-year service life. For case two, the use of the PC overlay is justified because one lane cannot be closed during peak-hour traffic to allow the construction of a latex overlay. In addition, the PC overlay can be justified on the basis of present worth when the discount rate exceeds 5% for a 10-year service life and 0% for a 15-year service life.

CASE THREE

For case three, the peak-hour volume to capacity ratio with both lanes open is 0.5 and with one lane closed is 1.0 Based on reference A-1, it is reasonable to assume that an increase in the volume to capacity ratio from 0.5 to 1.0 will cause a decrease in the average speed of the motorist from 53 mph (85 km./hr.) to 32 mph (51 km./hr.). Assuming the speed reduction affects a 10-mile (16 km.) segment of the average trip, the average time lost per vehicle is 7.4 minutes. Furthermore, assuming an average wage rate of $1 per hour per vehicle, which is extremely conservative considering today's wages, the cost of the reduction in speed to the motorist is 12 cents per trip. Assuming an average hourly traffic flow of 1,300, which is reasonable based on reference A-2, the cost to the motorist of the reduction in speed is $161 per hour. For the 12 hours of the lane closure required for the installation of the PC overlay the cost is negligible, assuming the lane closure occurs during off peak hours. For the minimum of 9 days required for the installation of the latex overlay, the cost is $15/yd.^{2} ($18/m.^{2}), assuming the delays associated with the lane closure last for 8 hours each day. The addition of the cost of travel time increases the present worth of the latex overlay to $65/yd.^{2} ($78/m.^{2}) and for a service life of 15 years the polymer overlay is more economical. For a service life of 5 or 10 years, the polymer is more economical when the discount rate exceeds 9.2% or 1.5%, respectively. For case three the PC overlay is generally the most economical alternative based on present worth if the value of travel time is taken into account.

The costs of accidents and increases in vehicle operating costs which result from a lane closure provide additional incentive to use a PC overlay. Over a 30-year period the total lane closure time required for the construction of a latex overlay with a 30-year service life is 3, 6, or 9 times greater than that required for the construction of PC overlays with useful service lives of 5, 10, or 15 years, respectively. It is reasonable to expect that the benefits from a reduction in lane closure time and, therefore, in the number of potential accidents would increase with an increase the volume of traffic and the useful service life of the PC overlay. Research is needed to quantify these benefits.

Table 1

Present Worth of Thin PC Overlay as a Function of Discount Rate and Service Life of PC Overlay, $\$/yd.^2$ ($0.84\ m.^2 = 1\ yd.^2$)

Service life of PC overlay, yrs.	Discount Rate, % 0	5	10
5	$150	$89	$62
10	75	50	38
15	50	37	31

CONCLUSIONS

1. The thin PC overlay becomes more economical relative to the latex overlay with increases in --

   a) the effective service life of the PC overlay,

   b) the volume of traffic,

   c) the discount rate, and

   d) the value of driving time.

2. In situtations where traffic volumes are low, the latex overlay will typically be the most economical alternative.

3. In situations where a lane cannot be closed during peak-hour traffic periods, the PC overlay will typically be the reasonable alternative.

4. In situations where traffic volumes are high, the service life of the PC overlays, the volume of traffic, the discount rate, and the value of driving time can be used to determine the most economical alternative.

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