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Supplementary Notes

Abstract

The results of a study undertaken to evaluate premixed polymer concrete overlays (PMPCO) over a 3-year period are presented. The PMPCO evaluated were constructed with polyester amide para resin and silica sand 1; polyester styrene resin 1 and silica sand 2; polyester styrene resin 2, basalt aggregate and coke breeze (for conductivity); polyester styrene resin 2, silica sand 3 and coke breeze; and vinyl ester styrene resin, silica sand 2, and coke breeze. The mixing of the ingredients was done with either portable concrete mixers, mortar mixers, or a continuous batching mobile concrete mixer. The overlays were struck off and consolidated with a vibrating screed or a slip form paver. The report indicates that a nonconductive PMPCO with high bond strength, low permeability, and high skid resistance can be successfully installed by a contractor and opened to traffic after only three hours of curing. The report indicates that a conductive PMPCO with high bond strength and skid resistance can be successfully installed as a secondary anode for a cathodic protection system. Also, it is shown that the special provision for a PMPCO should require the installation of test patches or test sections of overlay prior to placing the final overlay to assure that the surface preparation is adequate and the mixing, installation equipment, procedures, and materials will provide a satisfactory overlay.

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FINAL REPORT

PREMIXED POLYMER CONCRETE OVERLAYS

Michael M. Sprinkel
Research Scientist

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

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

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

March 1990
VTRC 90-R8

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ABSTRACT

The results of a study undertaken to evaluate premixed polymer concrete overlays (PMPCO) over a 3-year period are presented. The PMPCO were constructed with polyester amide para resin and silica sand 1; polyester styrene resin 1 and silica sand 2; polyester styrene resin 2, basalt aggregate, and coke breeze (for conductivity); polyester styrene resin 2, silica sand 3, and coke breeze; and vinyl ester styrene resin, silica sand 2, and coke breeze (see Table 1 of Appendix). The mixing of the ingredients was done with either portable concrete mixers, mortar mixers, or a continuous-batching mobile concrete mixer. The overlays were struck off and consolidated with a vibrating screed or a slip form paver. The report indicates that a PMPCO with high bond strength, low permeability, and high skid resistance can be successfully installed by a contractor and opened to traffic after only 3 hours of curing. Also, it is shown that the special provision for a PMPCO should require the installation of test patches or test sections of overlay prior to placing the final overlay to ensure that the surface preparation is adequate and that the mixing, installation equipment, procedures, and materials will provide a satisfactory overlay.

Evaluations done between 1986 and 1989 indicate that the initial conditions of the two overlays constructed with polyester amide resin and polyester styrene resin 2, were good from the standpoint of skid resistance (ASTM E524) and bond (ACI 503R and guillotine shear). Also, the permeability (AASHTO T277) of the overlay constructed with polyester amide para resin was negligible. On the other hand, the overlays constructed with polyester styrene resin 1 and vinyl ester resin had good skid resistance, but the tensile rupture strengths were low, largely because of inadequate surface preparation. The bond strength of the overlays constructed with polyester styrene resin 1 could not be determined because surface preparation was done with a scarifier rather than a shotblaster. The scarifier fractured the concrete, and this caused low tensile rupture strengths because of failures in the fractured concrete. Also, the permeability of the two overlays constructed with polyester styrene resin 1 ranged from low to high either because the paving equipment did not properly consolidate the mixture or because the mixture was not properly proportioned. Because of extensive delaminations and spalls, the overlay constructed with the vinyl ester styrene resin was replaced after 11 months and the two overlays constructed with polyester styrene resin 1 were replaced after 18 months.

Although evaluations made at later ages typically showed some delaminations and a decrease in bond strength, the overlays constructed with polyester amide resin and polyester styrene resin 2 exhibited tensile rupture strengths that were high. Although these overlays can be expected to delaminate further at later ages, PMPCO constructed with polyester amide para resin and silica sand 1 or polyester styrene resin 2, silica sand 3, and coke breeze or polyester styrene resin 2, basalt, and coke breeze have potential for extending the life of decks.

With the exception of the conductive overlays, which require a cure time of 24 hours or more, the PMPCO can be installed during off-peak traffic periods and opened to traffic with as little as 4 hours of cure. PMPCO can be used as an alternative to the multiple-layer polymer concrete overlay, but further evaluations should be made to determine their service life.

FINAL REPORT

PREMIXED POLYMER CONCRETE OVERLAYS

Michael M. Sprinkel
Research Scientist

INTRODUCTION

Polymer concrete overlays have been placed on bridge decks to extend the life of the decks by reducing the intrusion of water and chloride ion, which can cause the corrosion of the reinforcement, and by increasing the skid resistance of the surface (1,2). The principal advantage of the polymer concrete overlays over portland cement concrete overlays is their rapid strength development, which allows the overlay to be placed during off-peak traffic periods, thereby minimizing delays and inconvenience to the traveling public.

On older bridges, where there is sufficient chloride in the concrete to cause corrosion, and where the steel is corroding, it is unlikely that the application of a polymer overlay will stop the corrosion. On these bridges, it is usually necessary to remove the chloride contaminated concrete or to install a cathodic protection system. The use of a conductive polymer overlay as the secondary anode of a cathodic protection system has the potential to extend the life of these decks (3).

Premixed polymer concrete overlays (PMPCO) have been used extensively by the California Department of Transportation, but most other DOTs, (including Virginia) have almost exclusively used multiple-layer polymer concrete overlays. The advantages of the PMPCO relative to the multiple-layer overlay are that they require less resin, they can be applied in one layer, decks that are very irregular in contour can be brought to the desire grade more easily, and it is easier to impart conductivity to a PMPCO when cathodic protection is sought (4).

PURPOSE AND SCOPE

The purpose of this report is to describe the installation and early performance of four premixed overlay mixtures that were placed using three different methods on three bridge decks.

A brief summary of the installations is provided. Performance based on the data collected on the bond between the overlay and the deck concrete is described. The performance based on the protection provided by the non-conductive overlays in preventing the infiltration of water and salt, thereby preventing corrosion of the reinforcing steel and extending the life of the decks is described. The performance of the conductive mixtures is based on the cathodic protection system data, which provides an indication of the conductivity of the overlays. Also, the performance based on the skid resistance and wear of the overlays is described. Finally, implementation based on the evaluation of the installation and performance is discussed.

SUMMARY OF INSTALLATIONS

Table 1 of the Appendix shows the date of the installations, their locations, the mixtures, and the placement methods. All installations were on lightly traveled roads: Rte 340 (2615 ADT), Rte 99 (6455 ADT), Rte. 629 (secondary, no data). The decks were originally constructed during the following years: 1 and 2 - 1941, 3 and 4 - 1936, and 5, 6, and 7 - 1961. Therefore, considerable patching of the concrete in the decks was required prior to placing the overlays. Installations 1 and 2 were done in July 1986, and subsequent installations were done in October 1987, with the exception that installation 7 was done to replace installation 5 in September 1988. Figure 1 shows the bridge deck span layout for installations 1 and 2. Figure 2 shows the layout for installations 5, 6, and 7.

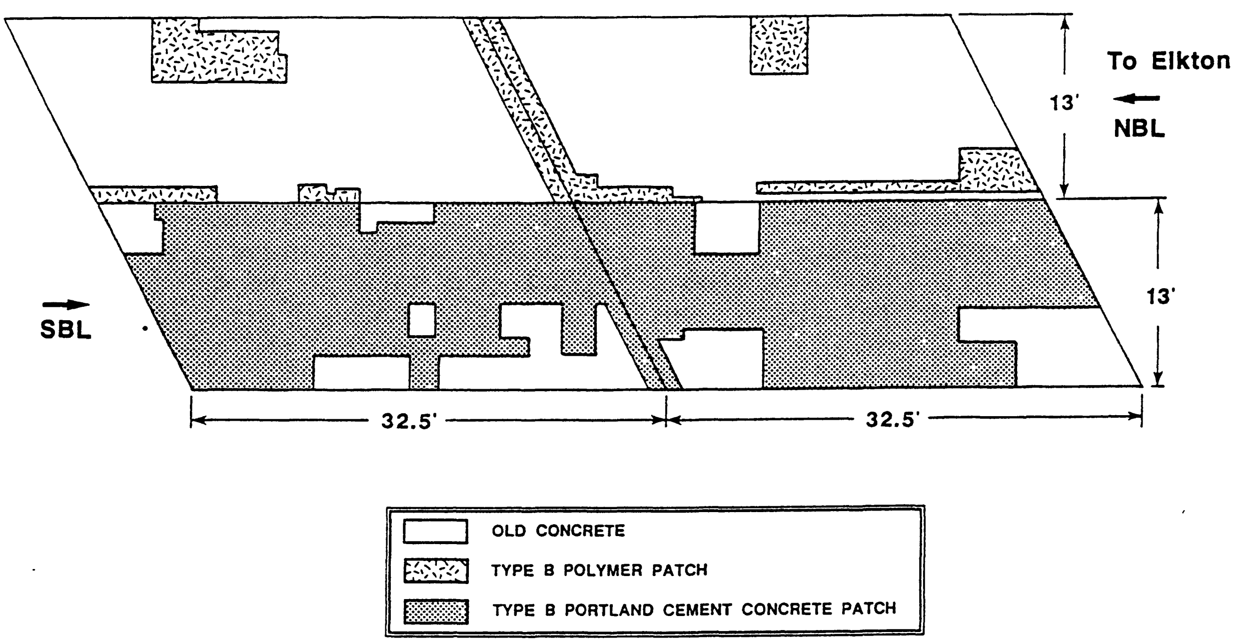

Figure 1. Bridge deck span layout for installations 1 and 2.

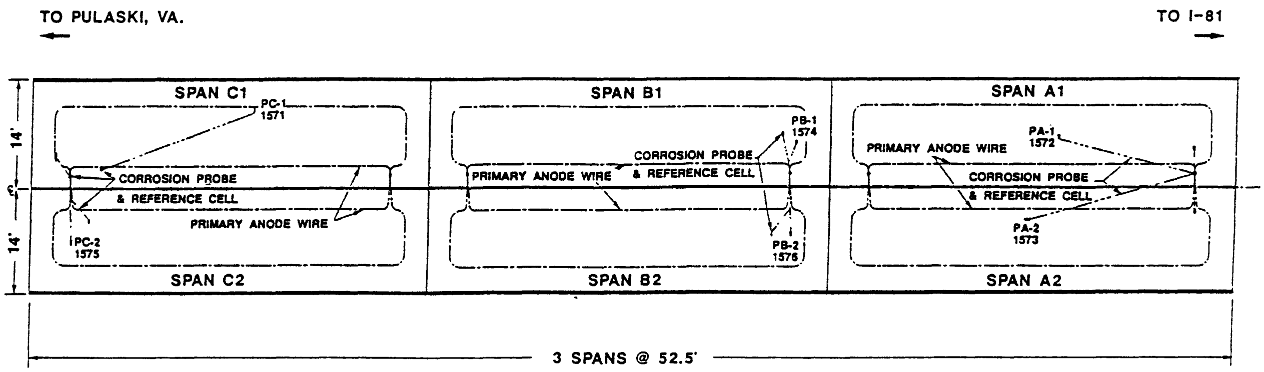

Figure 2. Bridge deck span layout for installations 5, 6, and 7 showing the locations of the conductive loops, reference cells, and corrosion rate probes in each of six zones (two zones per span).

Mixture Proportions

The mixture proportions are shown in Table 2 of the Appendix. The mixture used for installations 1 and 2 was designed and supplied by DOW Chemical U.S.A. It consisted of polyester amide para resin, carefully graded silica sand 1, and a finely ground polystyrene shrinkage compensating admixture that was blended with the silica sand. For the Type B patching (which involves removing old concrete to depth $\geq$3/4 in below the top mat of rebar) done on installation 1 (called installation 1R), the mixture was extended with 1 1/2 in maximum nominal size river gravel (50 percent retained on 3/4 in screen and 50 percent retained on 1/2 in screen).

The mixture used for installations 3 and 4 was supplied by Quality Controlled Industries (QCI). The mixture consisted of polyester styrene resin 1, graded silica sand 2, and coarse aggregate with a maximum nominal size of 3/8 in.

The mixtures used for installations 5, 6, and 7 were supplied by Brookhaven National Laboratory as part of a Federal Highway Administration (FHWA) sponsored project to design and install conductive polymer concrete overlays for the cathodic protection of bridge decks. The binder for mixture 5 was a modified vinyl ester resin, which was supplied by Ashland Chemical Company. For mixtures 6 and 7 it was polyester styrene resin 2, which was supplied by Reichhold Chemical Company. The aggregate for installations 5 and 7 consisted of 50 percent coke breeze and 50 percent silica sands 2 and 3, respectively, and for installation 6, 50 percent coke breeze and 50 percent basalt. The aggregates for mixtures 5 and 6 were precoated with 1.1 percent S440 wetting agent and 0.4 percent BZP-C50X initiator. The resin for installation 5 contained 1 percent A-174 silane coupling agent and 0.4 percent dimethyl aniline promoter. Because of the low temperature during the placement of installation 5, 0.5 percent BZP-C50X was added to the mixer. The resin for installations 6 and 7 contained 1 percent A-174 silane coupling agent and 0.4 percent cobalt naphthenate (6 percent in mineral spirits). A total of 1 to 1.3 percent MEKP was added at the mixer.

Surface Preparation

A combination of surface preparation technologies was used to prepare the old concrete surfaces prior to placing the overlays. VDOT class 1 surface preparation (which includes the removal of at least the top 1/2 in of the concrete with a scarifier) was done for installations 1, 2, 3, and 4. Class II surface preparation (which includes the removal of concrete at least 3/4 in below top mat of reinforcement) was done as required prior to patching all installations. Polyester amide para resin concrete was used to patch installation 1 just prior to placing the overlay (see Table 3 of Appendix). VDOT Class A4 portland cement concrete (4,000 psi minimum design compressive strength) was used to patch installations 2, 5, and 6 approximately 4 to 6 weeks prior to placing the overlays. A quick-setting gypsum, portland cement (Duracal), and sand mixture was used to patch installations 3 and 4 approximately 2 to 3 months prior to placing the overlays.

Sandblasting was used to prepare the final surface for installations 1, 3, and 4. Shotblasting was used to prepare the final surface for installations 2, 5, 6, and 7. The final blasting was done the same day the overlays were installed. The ACI 503R Tensile Adhesion Tests were not performed on test patches prior to placing the overlays except on installations 5 and 6. Unfortunately, these patches cured so slowly that the results were inconclusive when the patches were tested approximately 20 hr later. Special provisions for future installations should require the installation and testing of test patches using the ACI 503R Procedure to ensure that surface preparation procedures, the mixture proportions, and the placement equipment and procedures can provide a satisfactory overlay.

Application of Primer

An unprimed surface wicks the resin from the overlay and leaves voids that cause reduced bond strength. A primer seals the surface and allows the overlay to retain the proper ratio of binder to aggregate. Therefore, a primer is usually specified for PMPCO. For installations 1 and 2, a DOW Chemical one-component urethane primer (Polybond) was applied with a paint roller at the rate of 175 ft^2/gal (see Figure 3). The primer was allowed to cure for approximately 1 to 2 hours prior to placing the overlays. A QCI polyester styrene primer was sprayed onto the deck surface at the rate of

100-125 ft^2 /gal and was allowed to cure for approximately 1 to 2 hours prior to placing the overlays for installations 3 and 4 (see Figure 4). When the overlays were placed, the urethane was tack free and the polyester was gelled but sticky. No primer was used for installations 5, 6, and 7 because the primer would inhibit the conduction of current between the overlay and the base concrete. However, polyester styrene resin 2 was applied to a small strip next to the parapet for installation 7 just to see if the primer would enhance the bond strength of the overlay. The development of a conductive primer could be beneficial. Figure 5 shows one of the six continuous loops of platinum-niobium covered copper wire attached to the shotblasted surface prior to placing the conductive polymer concrete overlay on Rte. 99.

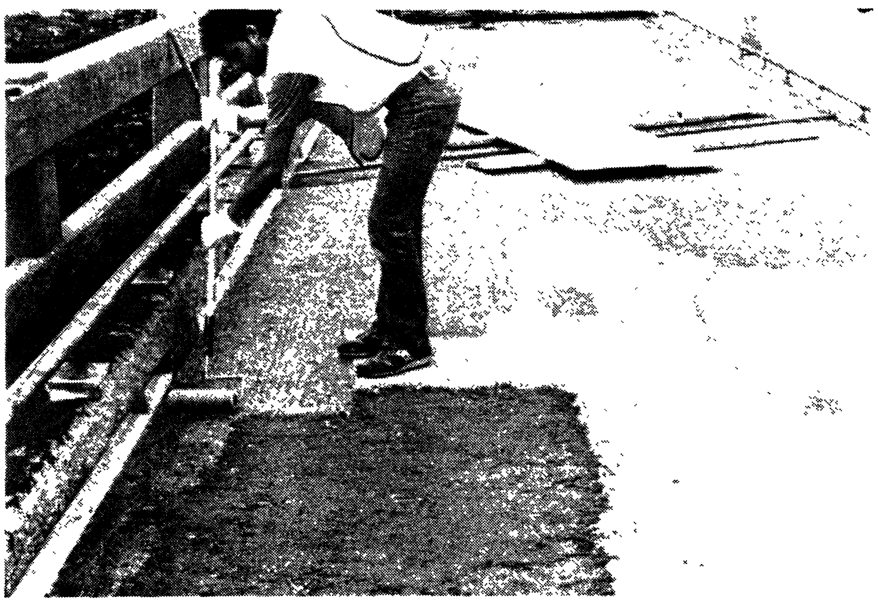

Figure 3. A one-component urethane primer is applied to the deck surface prior to placing the overlay on Rte. 340.

Figure 4. Polyester styrene primer is sprayed onto the deck surface prior to placing overlay on Rte. 629. Mobile concrete mixer in adjacent lane contains resin, initiator, and aggregates for overlay.

Figure 5. One of six continuous loops of platinum-niobium-covered copper wire attached to the shotblasted surface prior to placing the conductive polymer concrete overlay on Rte. 99.

Placement Methods

Mixing Materials

As shown in Table 1 of the Appendix, two 6 ft^3 capacity portable concrete mixers were used for installations 1 and 2, and two 4 ft^3 capacity mortar mixers were used for installations 5, 6, and 7. The aggregate was dried and bagged and delivered to the job site on pallets. The mixing was done as follows: add resin, add initiator, mix 1 minute, add aggregate, mix 3 to 5 minutes, and dump mixed material into buggy or wheelbarrow (Bobcat loader for installation 7) (see Figures 6, 7, and 8). A continuous-batching mobile concrete mixer typical of that used to batch latex-modified concrete was used for installations 3 and 4(see Figure 9). The mixer was modified for polymer concrete and calibrated by QCI.

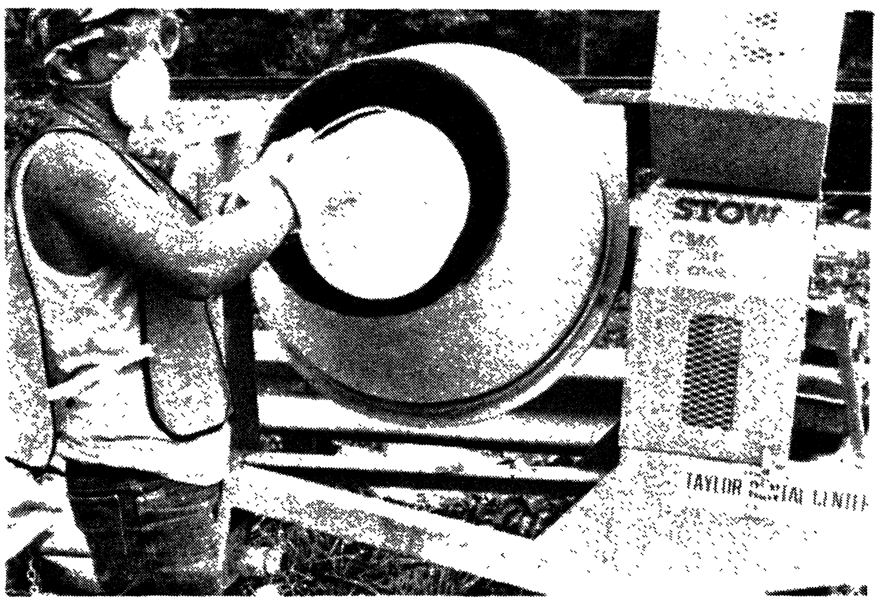

Figure 6. Polyester amide para resin is added to a concrete mixer.

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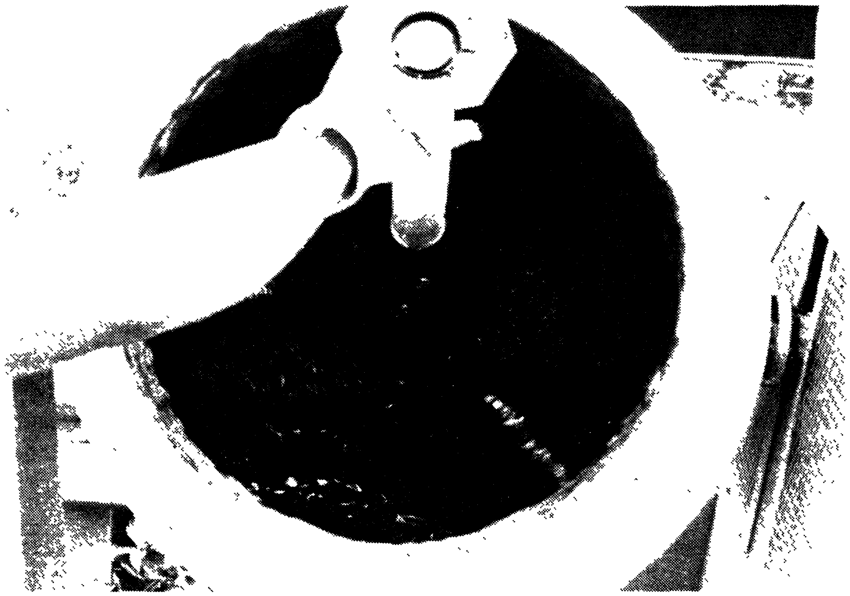

Figure 7. MEKP initiator is added to resin in a mixer.

Figure 8. DOW Chemical prepackaged aggregate is added to a concrete mixer.

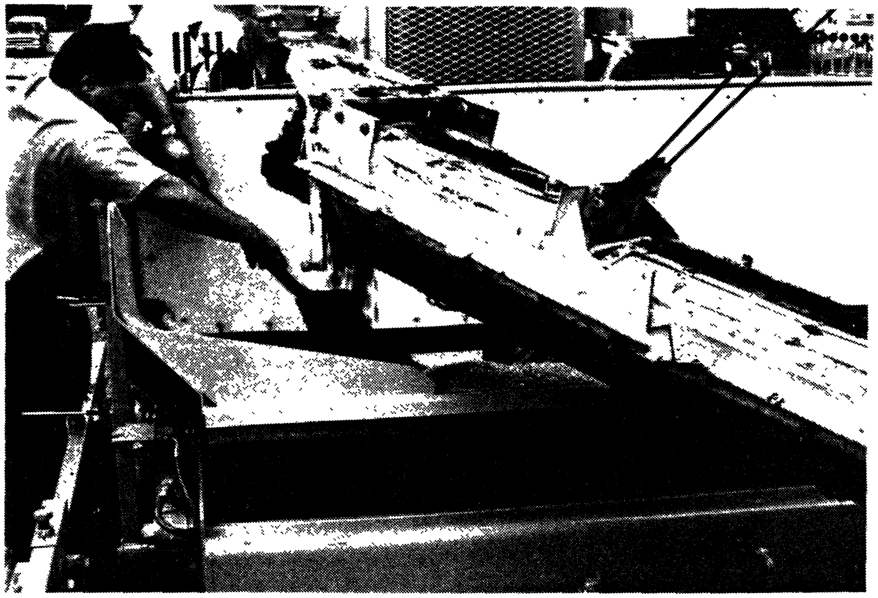

Figure 9. A mobile concrete mixer discharges polyester styrene concrete into the hopper of a slip form paver.

Placing and Consolidating the Overlay

Mixed material was dumped from the mixers into buggies that were used to transport the material to the deck surface for installations 1, 2, 5, and 6 (see Figure 10). A vibratory screed was used to consolidate, strike off, and finish the overlays (see Figures 11 and 12). Hand finishing with metallic floats was done as required.

A specially designed vibrating paver was used to consolidate, strike off, and finish the mixtures used on installations 3, 4, and 7 (see Figures 13 and 14). The paver, which was provided by QCI, paved a 12-ft-wide strip. The thickness of the overlay was controlled by adjustable skids. For installations 3 and 4, the hopper of the paver was loaded by dropping mixed material from the end of the auger of the mobile concrete mixer. For installation 7, the paver was supplied with material from a front end loader that was loaded from the portable mortar mixers (see Figure 15). A 2-ft-wide strip between the 12-ft-wide paved section and the parapet was placed by hand using metallic floats to level and finish the concrete. The floats were used elsewhere as needed to finish the surface.

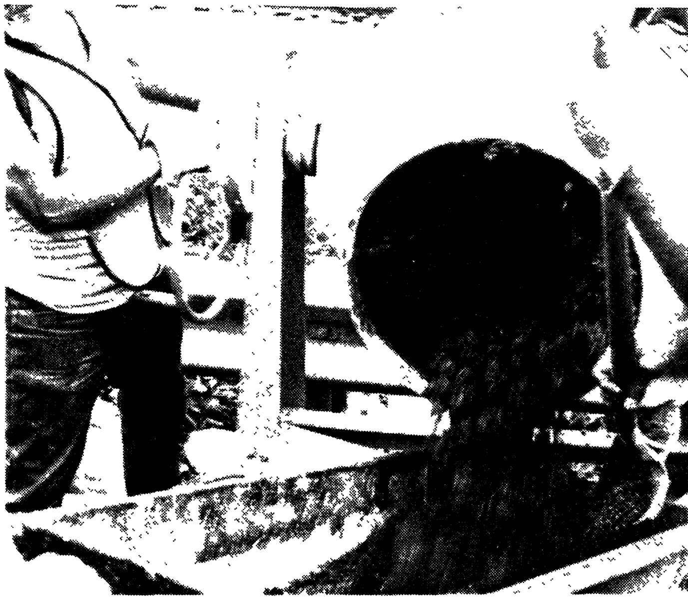

Figure 10. Polymer concrete is discharged into a buggy.

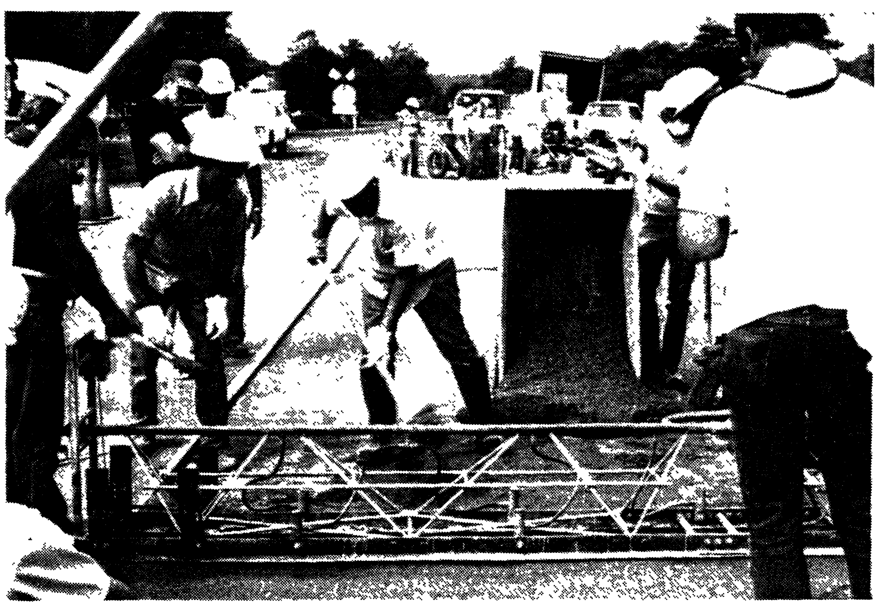

Figure 11. Polyester amide concrete is consolidated and struck off using an Allen vibrating screed.

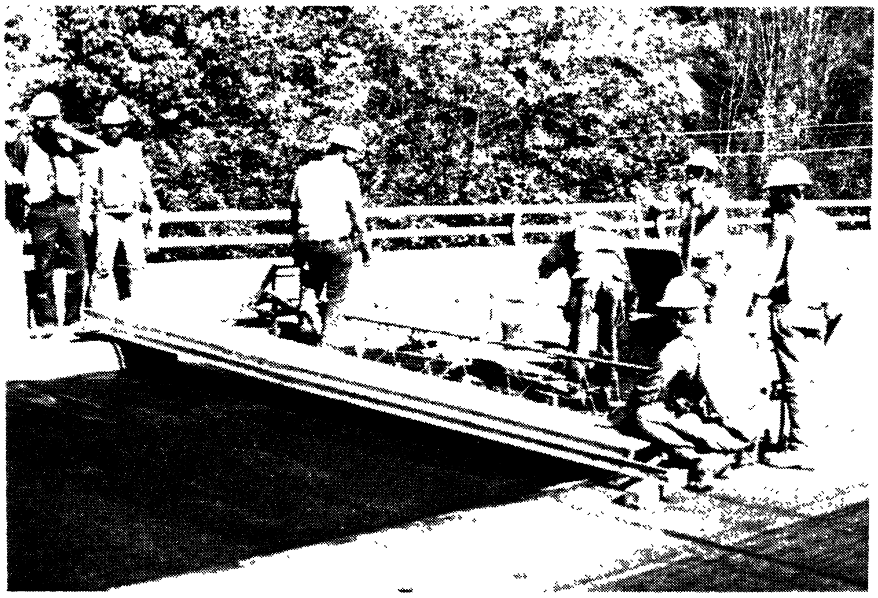

Figure 12. Conductive polyester styrene concrete is consolidated and struck off with an Allen vibrating screed.

Figure 13. A QCI slip form paver consolidates and strikes off a polyester styrene concrete overlay on Rte. 629. The edges are leveled and textured by hand.

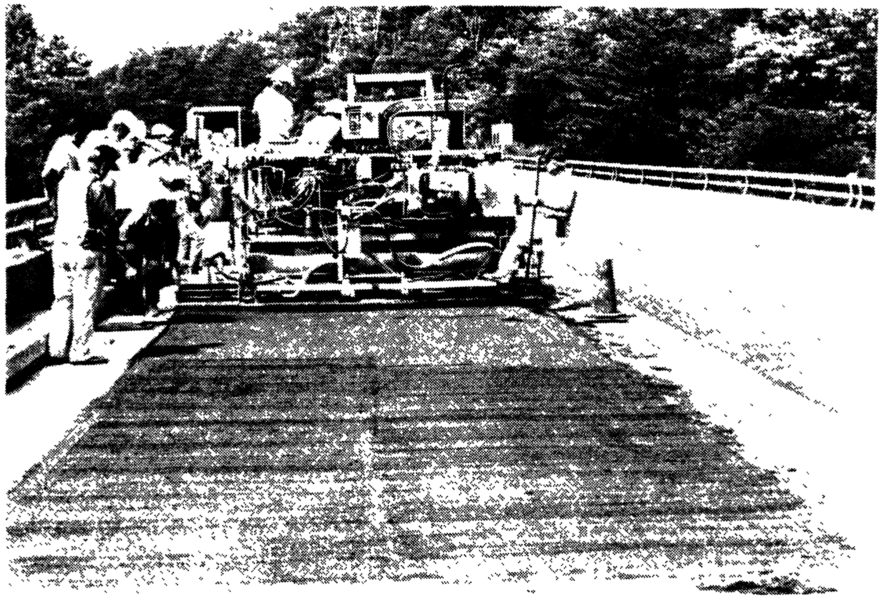

Figure 14. A QCI slip form paver consolidates and strikes off a conductive polyester styrene concrete.

Figure 15. A front end loader deposits conductive polyester styrene concrete into the hopper of a slip form paver.

Applying the Skid Resistant Texture

A grooved texture (grooves approximately 1/8 in wide by 1/8 in to 1/4 in deep spaced 3/4 in to 1 in on center) was applied to the surface immediately following the finishing operation for installations 1, 2, 5, 6, and 7. A plastic disk-type roller was used to texture the surface of installations 1 and 2; a Teflon-coated metal disk-type roller was used for installations 5 and 6; and a rake made with coated 16D nails was used to texture installation 7 (see Figures 16 and 17). The plastic disk was fabricated on a lathe from a 12 in long by 3 in diameter piece of plastic. The Teflon disk roller consisted of 1/8-in-thick Teflon discs 2 in. in diameter spaced 3/4 in apart with 1-in diameter spacers placed on a 1/2-in diameter rod 18 in long. The rake was made by driving coated 16 D nails spaced 3/4 in apart through an 18 in x 3/4 in x 1 1/2 in piece of plywood. A long handle was attached to each texturing head. Silica aggregate was broadcast onto the freshly screeded surface of installations 3 and 4 to provide a skid resistant texture.

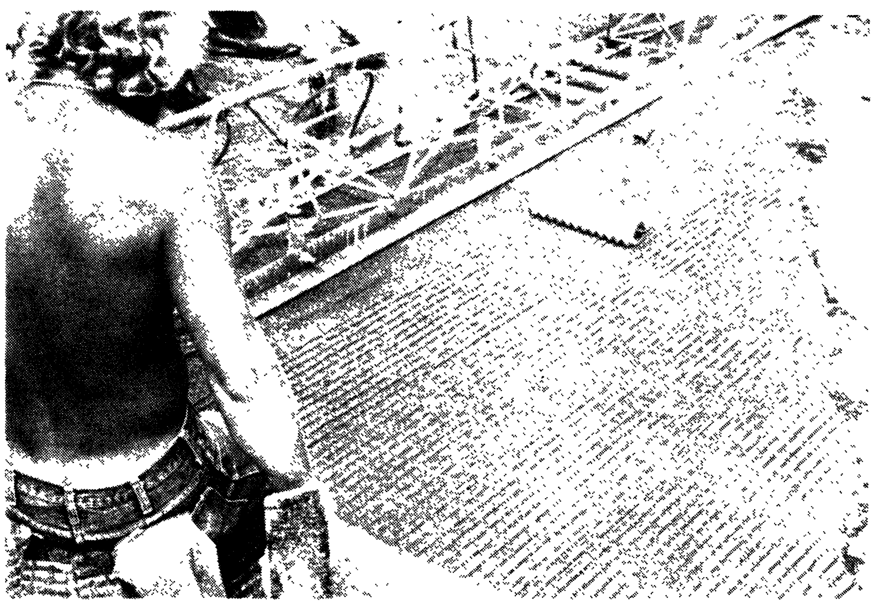

Figure 16. A plastic roller is used to place grooves in deck surface to provide good skid number.

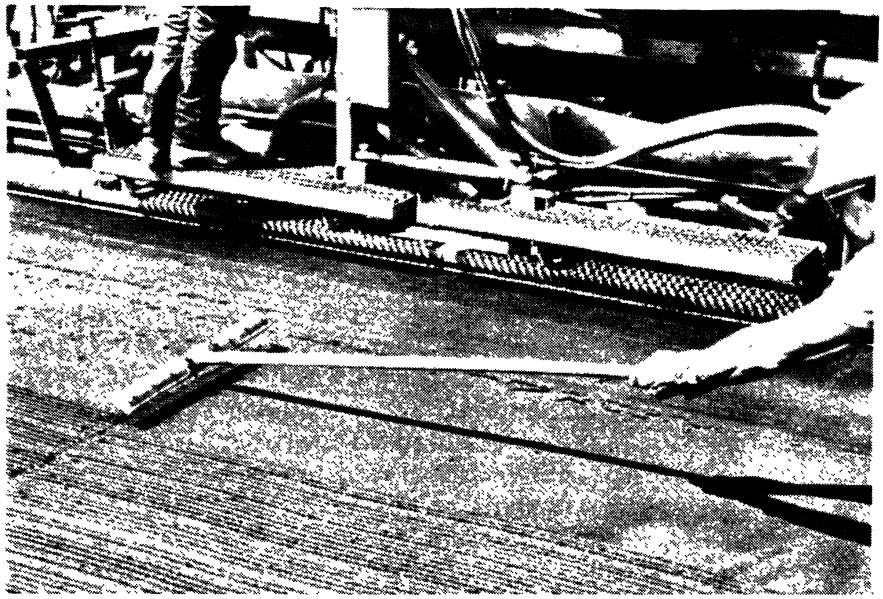

Figure 17. A tyning device is used to place grooves in surface of conductive polymer concrete overlay.

Compressive Strength

The VDOT requires that a portland cement concrete overlay have a minimum compressive strength of 3,000 psi prior to placing traffic on the overlay. The VDOT allows traffic on a multiple-layer polymer overlay after a minimum of 3 hr of cure (or longer as required at night or other times of slow cure) to obtain a minimum compressive strength of 1000 psi. Since a PMPCO is more like a structural overlay than a protective coating, the VDOT decided to require a minimum compressive strength of 3,000 psi prior to placing traffic on the overlay.

To provide an indication of the compressive strength of the mixtures as a function of age, 2-in mortar cubes and in some situations 4 in x 8 in cylinders were fabricated and tested at the job site. Tests after 24 hr of age were generally done in the laboratory at the Research Council. Tables 4a and 4b of the Appendix show the compressive strength data that was collected. Figures 18 and 19 show the strength development as a function of age. As can be seen from these figures, the early age compressive strength is a function of the mixture proportions and the temperature. Early age compressive strength decreases with a decrease in temperature and with the addition of coke breeze. Based on a requirement of a minimum strength of 3,000 psi, at temperatures above 75°F, the mixtures used for installations 1, 2, 3, and 4 could be opened to traffic in approximately 4 hr. The mixtures containing the coke breeze used for installations 5, 6, and 7 required 24 hr or more to obtain this strength. It seems reasonable that at higher placement temperatures, mixtures 5, 6, and 7 could achieve 3,000 psi in less than 24 hr.

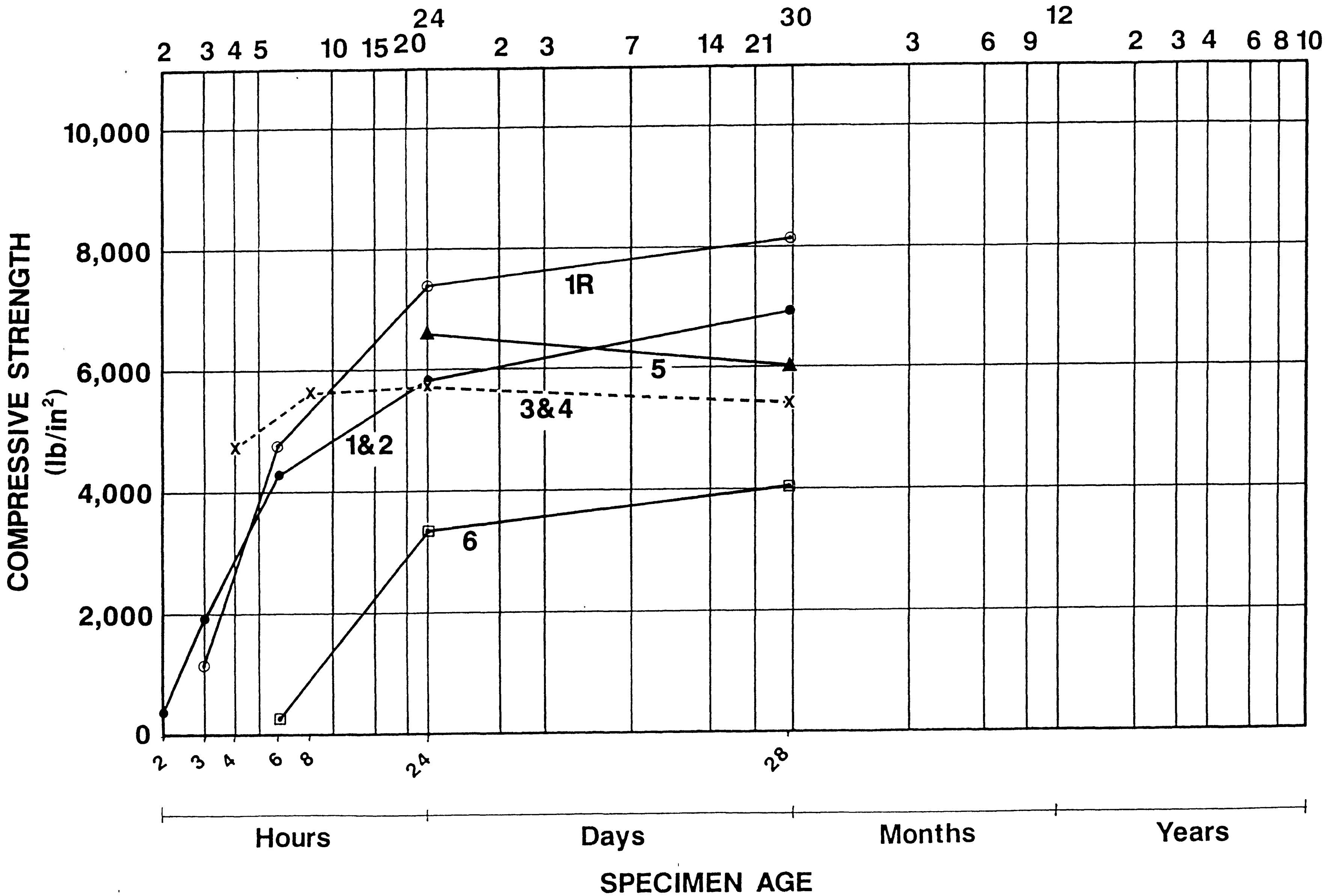

Figure 18. Compressive strength v. age for 4 in x 8 in cylinders, lb/in^2.

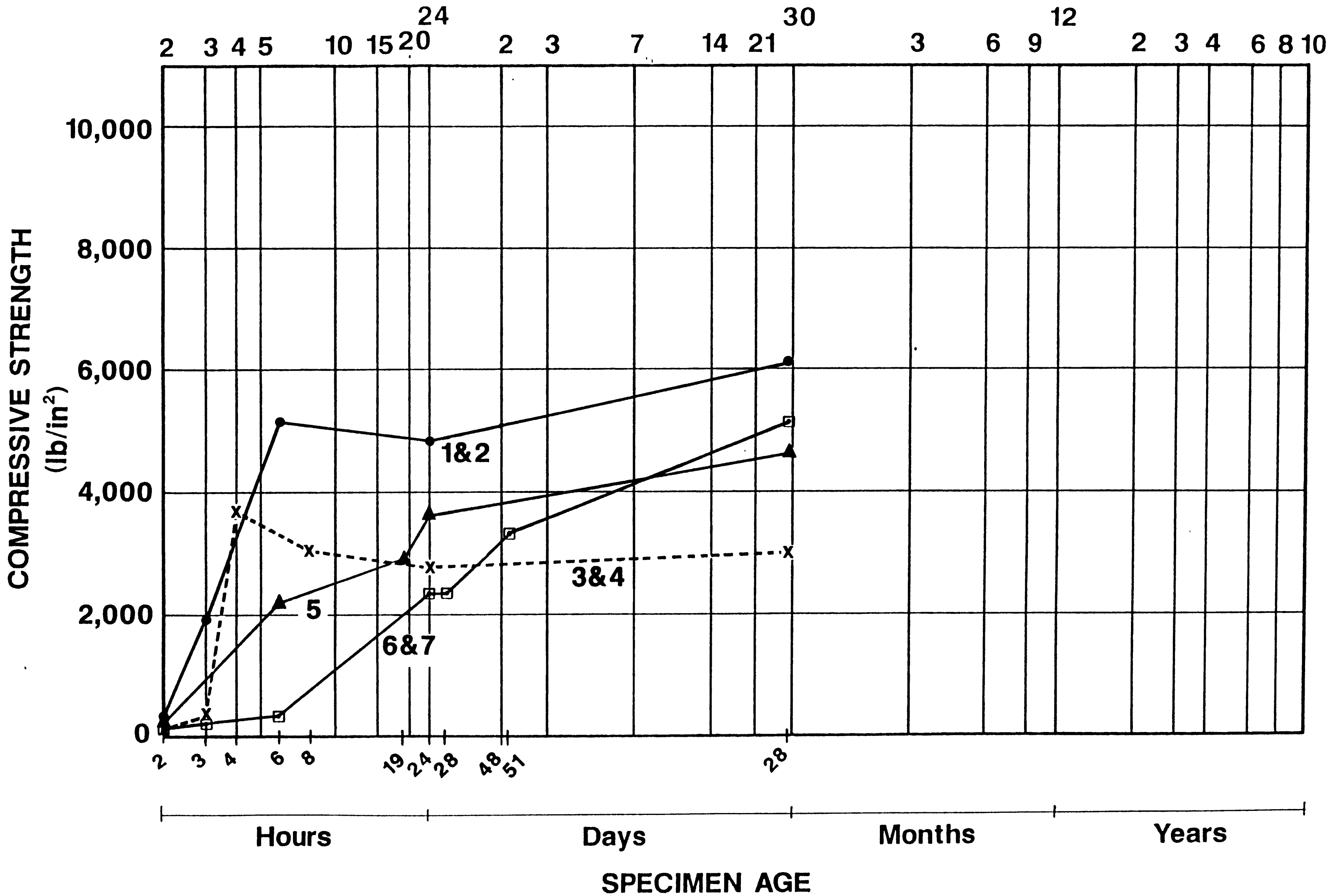

Figure 19. Compressive strength v. age for 2-in cubes, lb/in^2.

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Principal Problems with Placements

Installation 1

Cracks reflected through overlay because of shrinkage of Type B polyester amide para resin concrete patches (installation 1R) (see Figure 20).

Installations 1 and 2

Shrinkage cracks (5).

Delaminations in vicinity of cracks.

Some shrinkage compensating admixture leaked from bags during shipment and blew away during addition of aggregate to the mixer.

Installation 3

Vibrating paver not adjusted for proper grade, which caused a thick section on the east end of EBL and a thin section near the center of the lane.

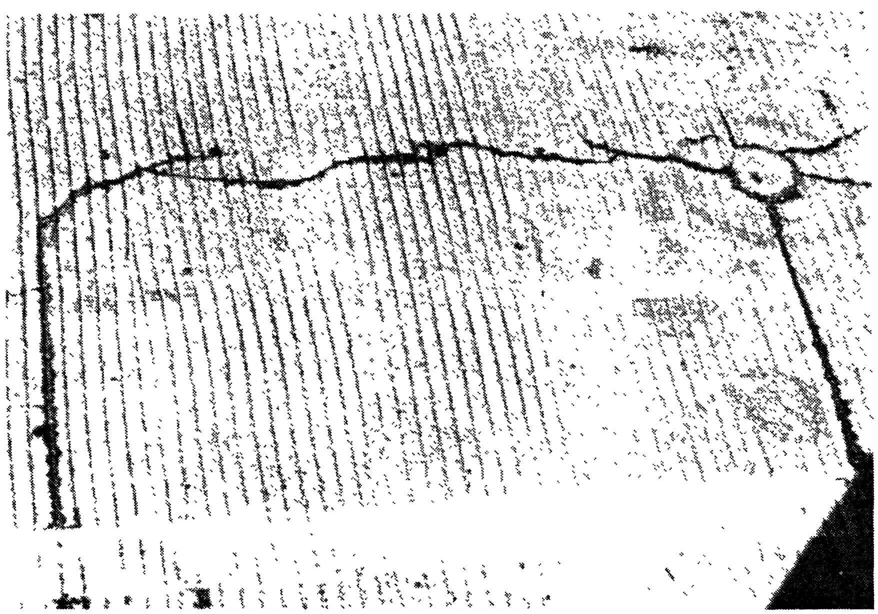

Figure 20. Cracks in PMPCO installation 1 caused by use of polymer concrete for Type B patching. The cracks in the overlay follow the perimeter of the patch. Similar cracks were noted in 1987 when polyester styrene concrete was used for Type B patching on Rte. 360 over the Dan River in Halifax County.

Installations 3 and 4

Surface preparation done with scarifier that fractured the base concrete causing low tensile rupture strengths (ACI 503R) with failures in base concrete. Evidently, scarification causes more damage to some concretes than others. A scarifier was used to prepare the surface for installations 1 and 2 and higher bond strengths were obtained than for installations 3 and 4.

The overlay was very permeable to chloride ion (AASHTO T277) because of either (1) the use of less than optimum mixture proportions or (2) a failure of the vibrating paver to properly consolidate the mixture.

The overlay was replaced after 18 months (April 1989) because of extensive delaminations and spalls, which can be attributed to the fractured base concrete and the high permeability of the overlay.

Installation 5

The vinyl ester resin stiffened rapidly as the first few yards were placed, and it was necessary to stop and clean the screed. The dosage of initiator was reduced to increase the working time. A small area of the overlay on the north end could be scraped from the surface the following day. According to Brookhaven National Laboratories, the small area was within the last 20 ft that was batched with the resin intended for use on the adjacent lane (installation 6) (see discussion below). The resin was used because the last 55-gal drum of vinyl ester styrene resin was not immediately accessible because it had been loaded on a truck behind two pallets of aggregate. The overlay was replaced after 11 months (September 1988) because of excessive delaminations and spalls. When the overlay was removed, it was obvious from the styrene odor that some sections had not completely cured.

Installation 6

The resin intended for the installation (a mixture of A457 polyester from Dural International, Derakane 8084 from DOW Chemical, U.S.A., and polystyrene dissolved in styrene monomer) could not be used because trial batches done two days earlier indicated that the mixture would not cure properly. Also, it was obvious that the styrene/polystyrene admixture had coagulated in the bottom of the drum because the resin was stored at temperatures as low as 20°F. Fortunately, the contractor had 55-gal drums of polyester styrene resin 2 that were being used on multiple-layer polymer overlay installations elsewhere in Virginia. Trial batches were performed at the job site using polyester styrene resin 2, basalt aggregate, and coke breeze prior to starting the overlay placement.

The supply of coke breeze was not adequate to complete the overlay; therefore, the percent of coke breeze was reduced from 50 to 40 for the southern most span by adding silica sand 3. Therefore, the filler for the southern most span was 50 percent basalt, 40 percent coke breeze, and 10 percent silica sand 3.

Installations 5 and 6

The Teflon-coated metal disk roller used to texture the surface had to be cleaned frequently since the polymer mixtures tended to stick to the metal much more frequently than to the plastic rollers used for installations 1 and 2.

Installation 7

The paver could not pave the 2 ft strip next to the parapet. The strip was struck off and finished by hand without vibration. The supply of silica sand and coke breeze was exhausted prior to completing the strip.

The contractor used silica sand 3 from a shipment that was being used on multiple-layer polymer overlay installations elsewhere in Virginia to complete the placement. The strip had a brown silica aggregate color rather than a black coke breeze color.

BOND STRENGTH

Obviously, a polymer overlay must be bonded to the deck surface to seal the concrete or to conduct electric current to the concrete and to provide skid resistance. Bond strength test methods used to measure the bond strength of the overlays included the ACI 503R tensile adhesion test 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 (Rupture) 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. Test results are usually reported as tensile bond strengths. However, if there is an adhesive failure, the bond strength is equal to the rupture strength, and if there is a failure in the overlay or base concrete, the bond strength is greater than the rupture strength. A modified version of the ACI 503R test (described in references 1 and 2) was used to obtain the results shown in Tables 5a and 5b of the Appendix and Figure 20. The VDOT Special Provision for Polymer Overlays requires a minimum bond strength of 250 psi, a value that is usually obtained in less than 24 hr. According to the American Concrete Institute, a tensile bond strength $\geq$100 psi is adequate for satisfactory performance (6).

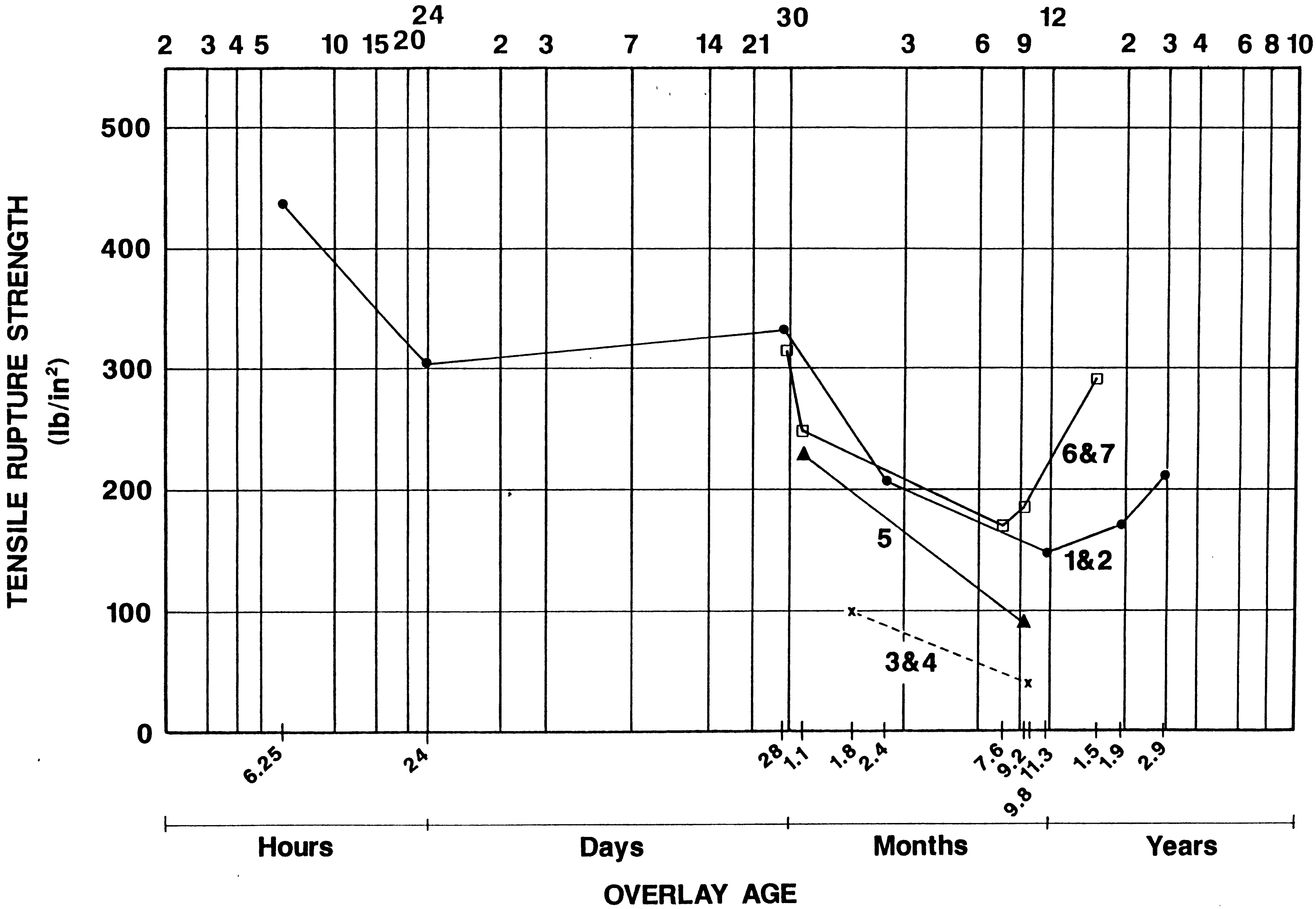

Figure 21. Tensile bond (rupture) strength v. age.

As can be seen from Figure 21, very high rupture strengths were obtained for the mixtures used on installations 1 and 2; high strengths were obtained for the conductive mixtures used on installations 5, 6, and 7; and low strengths were obtained for the mixtures used on installations 3 and 4. The low values obtained for installations 3 and 4 were a result of failures in the base concrete and are not indicative of the strength of the bond (see Table 5b). The base concrete was weak and deteriorated; also, it was fractured by the surface preparation procedure. The strengths were too low for adequate performance, and as would be expected, the overlay failed completely and was removed after 1.5 years in service.

The rupture values obtained for installations 1 and 2 have declined with time but are adequate for satisfactory performance after 2.9 years in service. In general, higher values have been maintained on installation 2 because the overlay was placed on new concrete (see Figure 1). The lower values on installation 1 are indicative of the quality of the old concrete on which the overlay was placed and to fractures caused by the scarification of the base concrete.

The tensile rupture values obtained for the conductive vinyl ester mixture used on installation 5 declined rapidly, and the mixture was replaced after 9.2 months in service (installation 7). The conductive polyester mixtures placed on installations 6 and 7 are performing adequately, although it would appear that some decline in strength has occurred on installation 7.

Assuming the bond strength continues to decline with age as shown in Figure 21, installations 1 and 2 and 6 and 7 should have a tensile adhesion bond strength of 100 psi in 15 to 20 yr. Assuming the service life of the overlays is controlled by bond strength and the trends shown in Figure 21 continue, the overlays should perform satisfactorily for 15 to 20 yr.

Guillotine Shear Bond Strength

Tables 6a and 6b of the Appendix and Figures 22 and 23 show the guillotine shear bond strength data collected for specimens prepared at the job site (Table 6a) and cores removed from the bridge decks (Table 6b). A test value was determined by placing a 2 3/4-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 sheared the overlay from the base concrete. A value for the shear strength of the base concrete was determined by directing the shear force through the base concrete approximately 2 1/2 in below the interface. The loading was applied at the rate of 10,000 lb/min. According to Felt, shear bond strengths $\geq$200 psi are adequate for good performance (7).

The data in Tables 6a and 6b and Figures 22 and 23 complement the tensile rupture strength data; therefore, similar conclusions can be drawn from it. It's interesting that a shear bond strength value of 210 psi was recorded for installation 4 after 9.8 months in service, and a value of 260 was recorded for installation 3 after 1.8 months, and the overlays failed completely after 1.5 years (see Table 6b). It would appear that values of 200 psi are indicative that a failure will occur in a short time, and values in excess of 400 psi are needed for adequate performance of premixed polymer overlays.

As can be seen from the data in Table 6a of the Appendix, high bond strengths were obtained for mixtures on installations 3 and 4 when the mixtures were placed on specimens of base concrete typical of that used in new bridge decks. The surface of the specimen was prepared by using a diamond-toothed water saw to cut a 2 3/5-in slice from a 4 in x 8 in cylinder. The base was air dried in the laboratory for one week or more prior to placing the polymer overlay.

Selected specimens were subjected to a thermal cycling test prior to measuring the shear bond strength. One thermal cycle consists of cooling a specimen to 0^{o}F, heating it to 100^{o}F, and cooling it to room temperature. A specimen is put through three cycles per day. Although the test has caused a decay in bond strength with time for some polymer overlay systems because of thermal stress (see references 1 and 2), it is obvious from the data in Table 6b that the mixtures used on installations 1, 2, 3, and 4 did not show a significant loss in bond strength because of thermal cycles.

Delaminations and Spalls

Delaminations occur when the bond strength of the overlays drops to zero. Once the overlay is delaminated, it will likely spall in a short time although the time between the delamination and the spall is related to the size of the delamination, the strength of the overlay, moisture under the overlay, movements of the structure, and traffic. Table 7a of the Appendix and Figure 24 show the percentage of the deck surfaces that are delaminated as a function of age. Table 7b shows the percentage of the surfaces that are spalled. Because of the large percentage of delamination that occurred with the overlays used in installations 3, 4, and 5, the overlays were replaced after 1.5 yr, 1.5 yr, and 9.2 months (respectively). If the trends shown in Figure 24 continue, overlays 1 and 2 and 6 and 7 should have less than 20 percent delamination at 20 yr of age.

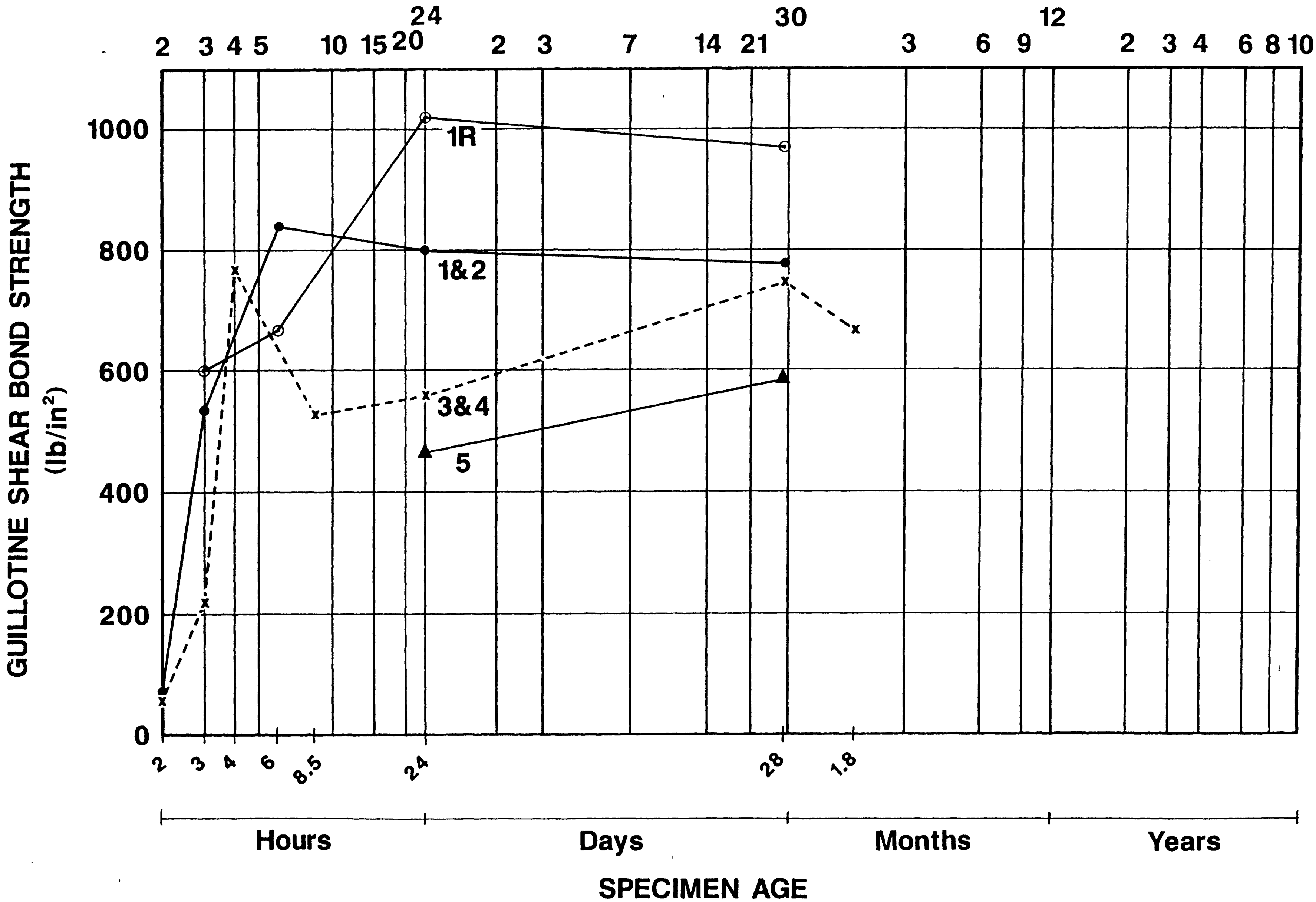

Figure 22. Guillotine shear bond strength of specimens v. age.

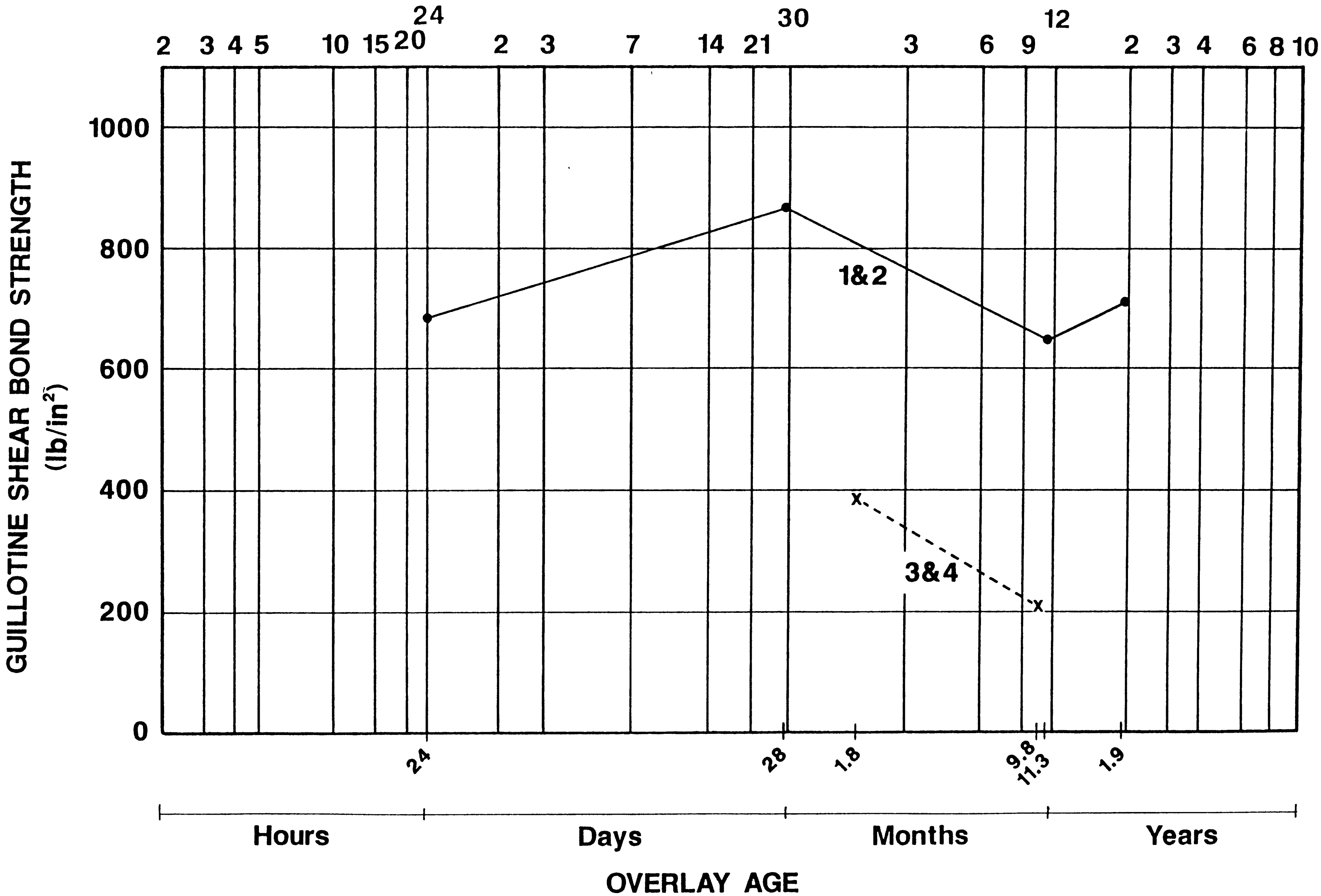

Figure 23. Guillotine shear bond strength of cores v. age.

1250

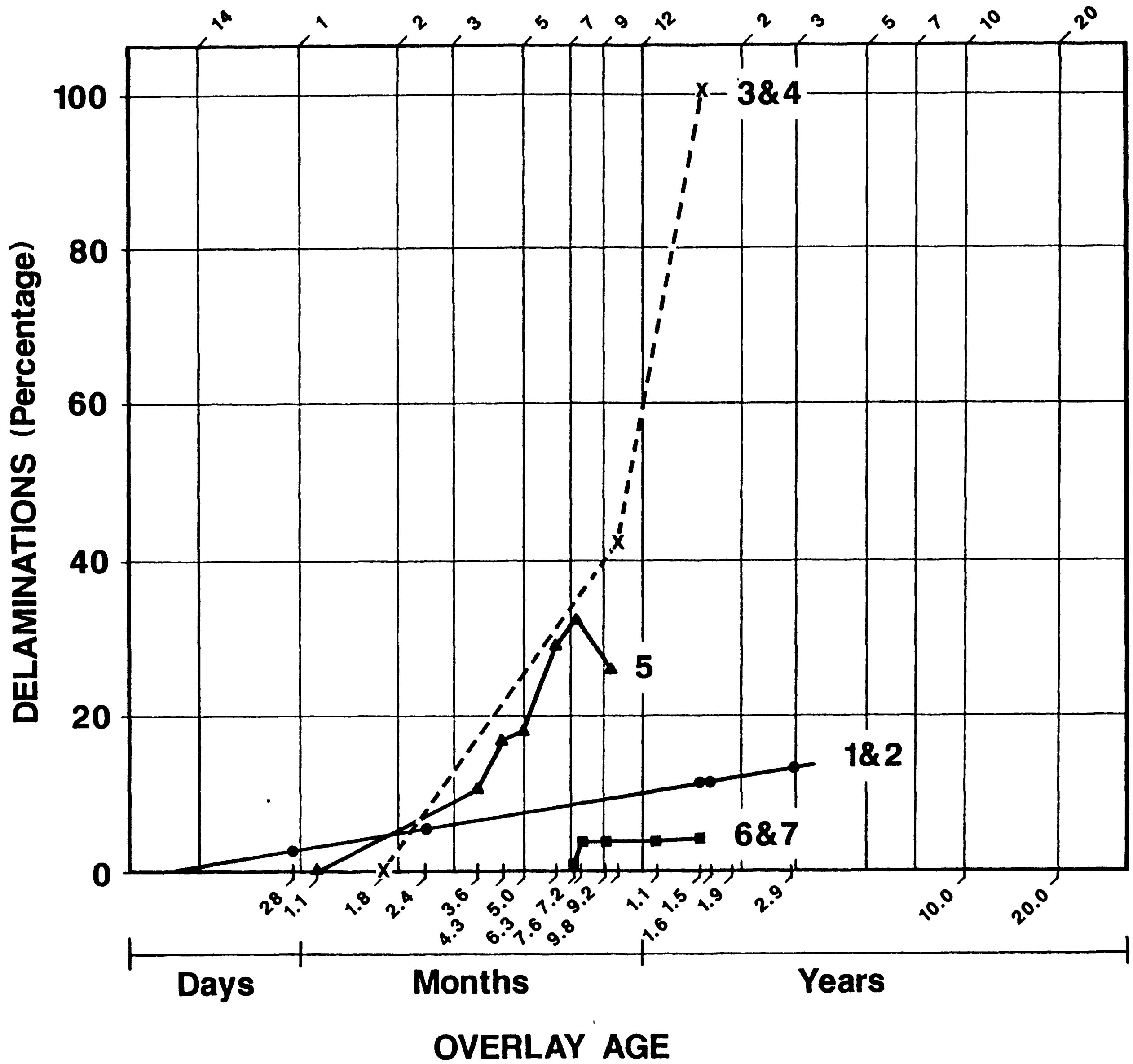

Figure 24. Percent of deck surface delaminated v. age.

PROTECTION PROVIDED BY OVERLAYS

Polymer concrete 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 PMPCO is provided by the rapid permeability test (AASHTO T-277). The test 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 8 and Figure 25 show the permeabilty test results for cores taken from the bridges with PMPCO. The results for the top 2 in are based on the average of three or more cores, and the results for the base concretes are based on the average of slices taken from two or more cores 2 in to 4 in from the top.

The data show that slices taken from the top 2 in of the cores (includes overlay) exhibit much lower permeability than slices taken from the next 2 in of the cores (base concrete). Figure 25 and Table 8 show that the permeability of the overlays is increasing with age. The data in Table 8 show that the thermal cycling test had no significant effect on their permeability. The high permeability of the old base concrete in installations 3 and 4 was likely a factor in the early deterioration of the overlay. Assuming the trend shown in Figure 25 continues, overlays 1 and 2 should have a permeability of less than 600 coulombs at 20 years, which is similar to the protection provided by a latex-modified concrete overlay at 20 years.

The rapid permeability test was not run on specimens from installations 5, 6, and 7 because these overlays are conductive by design. An indication of the performance of the conductive overlays is provided by the electrical data that is collected periodically on the performance of the cathodic protection system. The data can be found in reference 3. According to reference 3 the corrosion rate in the reinforcing steel has been reduced, and the overlay is performing adequately after 18 months in service.

Freeze-Thaw Performance of Polymer Concrete

Table 9 of the Appendix shows the results of rapid freezing and thawing tests conducted on two groups of specimens using the Research Council's ASTM C666 Procedure A method. The test deviates from ASTM C666 in that the test water contains 2 percent NaCl.

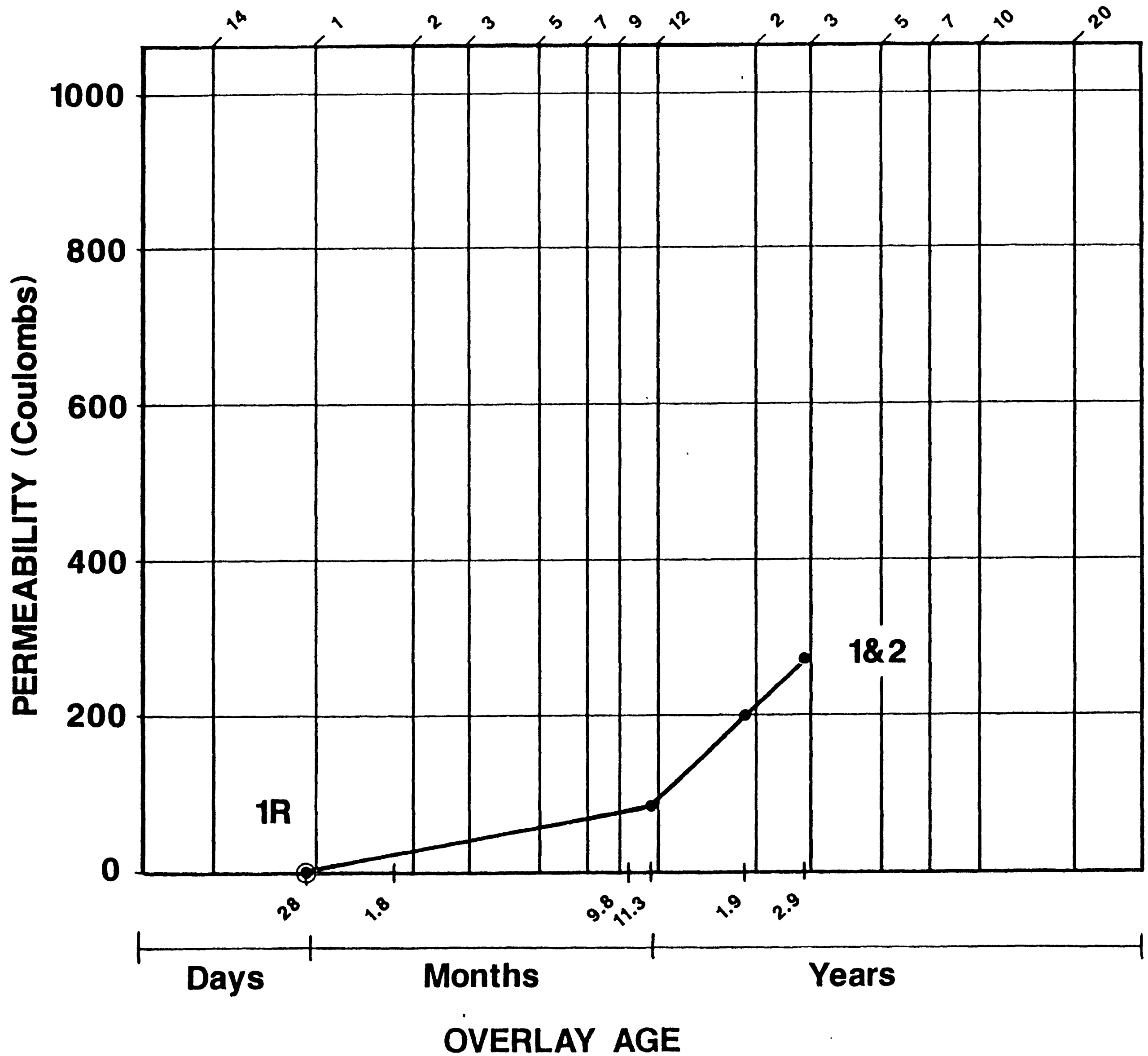

Figure 25. Permeability to chloride ion v. age (AASHTO T277).

The data in Table 9 show that the mixtures used on installations 1R, 1, and 2 performed extremely well; the conductive mixtures passed the test, but the mixtures used on installations 3 and 4 may or may not have passed the test. Because of the problem with the audio oscillator, the durability factor for the specimens from installations 3 and 4 is in question. All the specimens showed negligible weight loss and no change in the surface condition after 300 cycles, which is indicative of excellent performance. The 5.5 percent absorption reported for the specimens representing installations 3 and 4 is high and could result in freeze-thaw deterioration.

SKID RESISTANCE AND WEAR

Skid Number

Polymer concrete overlays have been placed on bridge decks to increase the skid resistance of decks constructed with polishing aggregate. Tables 10a and 10b of the Appendix show the results of skid tests (ASTM E501-76 and E524-76) conducted at 40 mph. Corrective action is usually recommended for surfaces with a treaded tire ≤ 37 or bald tire number ≤ 20. The factors that affect the skid number and wear of the overlay are the hardness and the shape of the aggregate, the gradation of the aggregate, the aggregate content (of the polymer), the adhesive strength of the polymer, the traffic volume, and tire characteristics. The overlays tested had very good skid resistance immediately following their application, and have maintained it throughout the evaluation period.

Wear

An overlay that wears excessively may loose its protective or conductive properties and its skid resistance. Table 11 of the Appendix shows the thickness of the overlays based on measurements of tensile test specimens and cores taken from the decks during the evaluation period. The data indicate that the wear is negligible.

DISCUSSION OF RESULTS

The overlays constructed with the polyester amide para resin were successful because of the extensive laboratory testing done prior to the installation of the overlays and the excellent assistance and supervision provided by the representatives of DOW Chemical U.S.A. The cracking that occurred was a result of the shrinkage-compensating admixture being lost: during the shipment of the aggregate the admixture leaked from the bags and during the batching of the mixture the admixture blew away. These problems can be eliminated on future installations.

The overlays constructed with polyester styrene resin 1 were unsuccessful because surface preparation was done with a scarifier and either the continuous batching mobile concrete mixer and slip form paver failed to provide a dense overlay mixture or the mixture proportions would not provide a dense mixture.

The conductive vinyl ester overlay was unsuccessful because the mixture did not cure properly and because some of the old concrete left in place had a low tensile strength.

The conductive polyester styrene resin 2 overlays were successful because the resin was being used successfully on other overlay projects in Virginia and an on-site decision was made to substitute the resin for that proposed for the installation.

Although only four of the seven overlay installations were successful, it is reasonable to expect that with proper planning and with the installation and favorable evaluation of test sections that provide an indication that the surface preparation procedures, the mixture proportions, and the placement equipment and procedures are satisfactory, premixed polymer concrete overlays with a life of 15 yr or more, can be constructed. Conductive overlays have the potential to serve as a secondary anode for 15 yr or more, and nonconductive overlays have the potential to provide excellent protection against the infiltration of chloride ion and water for 15 yr or more.

CONCLUSIONS

1. Nonconductive premixed overlays constructed with polyester amide para resin and silica sand have the potential for providing excellent protection against the infiltration of chloride ion and water for 15 yr or more. The overlays can be installed during off-peak traffic periods.

2. Conductive premixed overlays constructed with polyester styrene resin, coke breeze, and silica sand or basalt aggregate could provide the secondary anode of a cathodic protection system for 15 yr or more.

3. Type B patching with polyester amide para resin concrete caused reflective cracks through the overlay around the perimeter of the patch.

RECOMMENDATIONS

1. Monitor the performance of overlays 1, 2, 6, and 7 for 10 yr to determine the expected service life.

2. Polyester amide para resin concrete should not be used for Type B patching.

ACKNOWLEDGEMENTS

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APPENDIX

Table 1

General Information on Premixed Polymer Concrete Overlay Installations

Installation No.	Date	Bridge Location	Mixture	Mixing Method	Placement Method	Contractor	Surface Area, yd^2
1	7/14/86	Rte. 340 NBL/ Hawksbill Creek Rockingham Co., Struct. No. 1008	Polyester amide para resin, silica sand 1, non-shrink admixture, and urethane primer supplied by DOW Chemical,U.S.A.	Portable concrete mixer	Vibratory screed	Lanford Brothers, Inc.	94
2	7/15/86	Rte. 340 SBL/ Hawskbill Creek, Rockingham Co., Struct. No. 1008	Polyester amide para resin, silica sand 1, non-shrink admixture, and urethane primer supplied by DOW Chemical, U.S.A.	Portable concrete mixer	Vibratory screed	Lanford Brothers, Inc.	94
3	10/08/87	Rte. 629 EBL/ Tidal Channel King & Queen Co. Struct. No. 6021	Polyester styrene resin 1, silica sand 2, and polyester primer supplied by Quality Controlled Industries	Mobile concrete mixer	Vibratory paver	Quality Controlled Industries	96
4	10/09/87	Rte. 629 WBL/ Tidal Channel King & Queen Co. Struct. No. 6021	Polyester styrene resin 1, silica sand 2, and polyester primer supplied by Quality Controlled Industries	Mobile concrete mixer	Vibratory paver	Quality Controlled Industries	96
5	10/15/87	Rte. 99 EBL/ Peak Creek, Pulask Co. Struct. No. 1039	Vinyl ester resin, silica sand 2, and coke breeze supplied by Ashland Chemical Company and Brookhaven National Laboratory	Portable mortar mixer	Vibratory screed	Lanford Brothers, Inc.	245
6	10/16/87	Rte. 99 WBL/ Peak Creek, Pulaski Co., Struct. No. 1039	Polyester styrene resin 2, basalt aggregate, and coke breeze supplied by Reichhold Chemical, Inc. and Brookhaven National Laboratory	Portable mortar mixer	Vibratory screed	Lanford Brothers, Inc.	245
7	9/15/88	Rte. 99 EBL/ Peak Creek, Pulaski Co., Struct. No. 1039	Polyester styrene resin 2, silica sand 3, and coke breeze supplied by Reichhold Chemical, Inc., and Brookhaven Laboratory	Portable mortar mixer	Vibratory paver	Lanford Brothers, Inc.	245

Table 2

Mixture Proportions[a)]

Installation No.	1R	1 and 2	3 and 4	5	6	7
Resin, lb/yd^3 [b)]	257	410	497	496	491	444
Resin, % by wt. mix	6.4	11.2	14.0	16.7	17.5	17.5
Promoter, % by wt. resin[c)]	0.3	0.3	0.3	0.4	0.4	0.4
Initiator, % by wt. resin[d)]	1.5	1.2	1.5	0.9	1.4-1.6	1.0-1.5
Fine Aggregate, lb/yd^3 [e)]	2,042	3,267	1,524	2,474	2,317	2,093
Coarse Aggregate, lb/yd^3 [f)]	1,688	0	1,524	0	0	0
Admixtures, lb/yd^3 [g)]	71	114	0	32	35	10
Density, lb/yd^3 [h)]	3,987	3,677	3,545	2,970	2,808	2,537

a) Approximate, based on notes taken at job site on weights of ingredients added to the mixer and specific gravity of materials (1R, 1, 2, 7) and density of 4" x 8" cylinders (3, 4, 5, 6).

b) Resins for indicated installations (wt. includes wt of initiator, promoter and other liquid additives):
   1) 1R,1,2: Polyester amide para resin supplied by DOW Chemical, U.S.A.
   2) 3,4: Polyester styrene resin 1 supplied by Quality Controlled Industries.
   3) 5: Vinyl ester styrene resin (Hetron Q6305) supplied by Ashland Chemical Company.
   4) 6,7: Polyester styrene resin 2 (32-044) supplied by Reichhold Chemical.

c) Promoters for indicated installations:
   1) 1R,1,2,3,4,6,7: Resins prepromoted with cobalt naphthenate (6% in mineral spirits).
   2) 5: Dimethyl analine added to mixer.

d) Initiator for indicated installations:
   1) 1R,1,2,3,4,7: Methyl ethyl ketone peroxide (MEKP) with 9 percent active oxygen added to mixer.
   2) 5: BZP-C50X - aggregate precoated with 0.4 percent by weight of aggregate and 0.5 percent by weight of resin added to mixer.
   3) 6: BZP-C50X - aggregate precoated with 0.4 percent by weight of aggregate and 1.0 to 1.2 percent MEKP by weight of resin added to mixer.

e) Fine aggregate, % passing indicated sieve size for indicated installations.

Installations	Aggregate	No.4	No.8	No.12	No.16	No.20	No.30	No.100
1R,1,2	Silica No. 1 (includes admixture)	99	69	—	32	—	—	23
3,4,5	Silica No. 2	100	95-100	—	Max 15	Max 5	Max 2	Max 1
7	Silica No. 3(50%)	100	95-100	—	Max 15	Max 5	Max 2	Max 1
	(50%)	—	100	95-100	30-70	Max 10	Max 3	Max 1
6	Basalt	100	34	3	Max 1	—	—	—

(Table 2 continued)

f) Coarse Aggregate, % passing indicated sieve size for indicated installations:

Installation	Aggregate	1 1/2	1	3/4	1/2	3/8	No. 4	No. 8	No. 16
1R	River Gravel	100	—	50	—	—	—	—	—
3,4	River Gravel	—	—	—	—	100	10-30	0-10	0-5

g) Admixtures for indicated installations (wt. included in weight of resin or aggregate as indicated):

1) 1R,1,2: finely ground polystyrene blended with aggregate.
2) 5: resin contained 1 percent A-174 silane coupling agent by weight and aggregate was precoated with 1.1 percent S440 wetting agent.
3) 6: resin contained 1 percent A-174 silane coupling agent and 1 percent S440 wetting agent by weight and aggregate was precoated with 1.1 percent S440 by weight.
4) 7: resin contained 1 percent A-174 and 1 percent S440 by weight.

h) Density based on weight of resin and aggregates for 1R, 1, 2, and 7 and weight of 4" x 8" cylinders for 3, 4, 5, and 6.

Table 3

Installation Data

Installation	1	2	3	4	5	6	7
Scarify Deck	Approx. 6/1/86	Approx. 6/1/86	10/8/87 8:00 a.m.	10/8/87 8:00 a.m.	Not Scarified	Not Scarified	Not Scarified
Remove old concrete	Approx. 7/10/86	Approx. 6/1/86	Approx. 8/1/87	Approx. 8/1/87	Approx. 9/1/87	Approx. 9/1/87	Approx. 9/1/87
Patch Deck	7/14/88 9:50 a.m. -10:50 a.m.	Approx. 6/10/86	Approx. 8/1/87	Approx. 8/1/87	Approx. 9/1/87	Approx. 9/1/87	Approx. 9/1/87
Shotblast Deck	7/11/86* 8:00 a.m.	7/15/86 8:00 a.m. -9:00 a.m.		10/9/87* 8:30 a.m. -10:30 a.m.	10/15/87 8:00 a.m. -11:00 a.m.	10/16/87 8:00 a.m. -11:00 a.m.	9/14/88 1:00 p.m. -3:00 p.m.
Apply Primer	7/14/86 9:00 a.m. Patches 10:45 a.m. Deck	7/15/86 10:00 a.m. -10:30 a.m.	10/8/87 11:50 a.m. -11:56 a.m.	10/9/87 10:55 a.m. -11:03 a.m.	No primer	No primer	No primer except along curb west span
Place Overlay	7/14/86 12:20 p.m. -2:35 p.m.	7/15/86 10:45 a.m. -12:02 p.m.	10/8/87 1:45 p.m. -2:07 p.m.	10/9/87 1:24 p.m. -2:02 p.m.	10/15/87 2:00 p.m. -3:50 p.m.	10/16/87 2:30 p.m. -4:00 p.m.	9/15/88 12:12 p.m. -1:46 p.m.
Air Temp., $^{\circ}$F.	83°F @ 10:45 a.m., 93°F @ 4:40 p.m.	77°F @ 11:00 a.m.	68°F @ 12:00 noon, 61°F @ 2:30 p.m., 46°F @ 10:30 p.m.	67°F @ 1:24 p.m.	60°F @ 2:00 p.m., 68°F @ 3:00 p.m.	74°F @ 3:00 p.m.	85°F @ 2:00 p.m.
Deck Surface, Temp., $^{\circ}$F.	—	90°F @ 11:00 a.m.	—	—	—	—	78°F @ 11:50 a.m.
Gel Time, min.	18-27	28-30	14 12**	10 27**	12-15	20-25	20
Open to Traffic	7/14/88 5:45 p.m.	7/15/88 4:00 p.m.	10/8/87 5:30 p.m.	10/9/87 4:30 p.m.	10/16/87 7:00 a.m.	10/17/87 9:00 a.m.	9/16/88 2:00 p.m.

* Sandblasted deck.

** Gel time for primer.

Table 4a

Compressive Strength[a] of 4" x 8" Cylinders, lb/in^2

Age	Installation No. 1R	1	2	3	4	5	6
1 hr.	—	—	40	—	—	—	—
2 hrs.	—	—	340	—	—	—	—
3 hrs.	1,140	—	1,930	—	—	—	—
4 hrs.	—	—	—	—	4,710	—	—
6 hrs.	4,780	—	4,300	—	—	—	330
8 hrs.	—	—	—	—	5,630	—	—
24 hrs.	7,350	6,530	5,210	—	5,730	6,600	3,380
28 days	8,130	7,760	6,180	5,280	5,560	6,090	4,080

[a] Results based on average of tests on 2 specimens.

Table 4b

Compressive Strength[a] of 2 in Cubes, lb/in^2

Age	Installation No. 1	2	3	4	5	6	7
1 hr.	—	60	—	—	—	—	—
2 hrs.	—	360	190	—	280	190	—
3 hrs.	1,980	1,920	380	—	—	260	—
4 hrs.	—	—	—	3,700	—	—	—
6 hrs.	5,580	4,780	—	—	2,250	360	—
8 hrs.	—	—	4,020	2,080	—	—	—
19 hrs.	—	—	—	—	2,990	—	—
24 hrs.	5,390	4,330	2,980	2,550	3,670	2,350	—
28 hrs.	—	—	—	—	—	—	2,380
48 hrs.	5,180	—	—	—	—	—	—
51 hrs.	—	—	—	—	—	—	3,360
28 days.	7,340	4,940	3,560	2,600	4,680	6,220	5,180

[a] Results based on average of tests on 3 specimens.

Table 5a

Tensile Rupture Strengths[a)], lb/in^2

Age	Installation No. 1	2	3	4	5	6	7
6.25 hrs.	—	437	—	—	—	—	—
24 hrs.	—	—	—	—	—	—	—
28 days	—	333	—	—	—	—	—
29 days	—	—	—	—	—	—	314
1.1 mo.	—	—	—	—	230	250	—
1.8 mo.	—	92	105	—	—	—	—
2.4 mo.	168	250	—	—	—	—	—
7.6 mo.	—	—	—	—	—	—	172
9.2 mo.	—	—	—	—	92	186	—
9.8 mo.	—	—	32	50	—	—	—
11.3 mo.	116	180	—	—	—	—	—
1.5 yr.	—	—	—	—	—	291	—
1.9 yr.	124	219	—	—	—	—	—
2.9 yr.	166	263	—	—	—	—	—

a) Results based on average of 3 or more tests.

Table 5b

Failure Mode[a] ACI 503R Test, %

	Installation No.																				
	1			2			3			4			5			6			7		
Age	OL[b]	BI[c]	B[d]	OL	BI	B	OL	BI	B	OL	BI	B	OL	BI	B	OL	BI	B	OL	BI	B
6.25 hrs.	—	—	—	0	3	97	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24 hrs.	0	0	100	—	—	—	0	17	83	—	—	—	—	—	—	—	—	—	—	—	—
28 days	—	—	—	8	60	32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29 days	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	27	69
1.1 mo.	—	—	—	—	—	—	—	—	—	—	—	—	0	20	30	0	0	0	—	—	—
1.8 mo.	—	—	—	—	—	—	10	10	80	30	12	58	—	—	—	—	—	—	—	—	—
2.4 mo.	0	11	89	10	3	87	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7.6 mo.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	56	36
9.2 mo.	—	—	—	—	—	—	—	—	—	—	—	—	18	71	11	42	21	37	—	—	—
9.8 mo.	—	—	—	—	—	—	2	43	55	8	37	55	—	—	—	—	—	—	—	—	—
11.3 mo.	4	37	61	28	44	28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.5 yr.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	15	60	—	—	—
1.9 yr.	0	29	71	25	46	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2.9 yr.	13	34	53	16	40	44	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

a) Results based on average of 3 or more tests. When a partial failure occurs in the adhesive used for the test, the results shown are less than 100%.

b) Failure in the overlay.

c) Failure at the interface between the overlay and the base concrete.

d) Failure in the base concrete.

Table 6a

Shear Bond Strength[a] of 4" Diameter Specimens, lb/in^2

Age	Installation No. 1 R	1	2	3	4	5	6	7
1 hr.	—	—	90	—	—	—	—	—
2 hrs.	—	—	70	60	—	—	—	—
3 hrs.	600	430	640	220	—	—	—	—
4 hrs.	—	—	—	—	770	—	—	—
6 hrs.	670	960	720	—	—	—	—	—
8.5 hrs.	—	—	—	530	—	—	—	—
24 hrs.	1,020	860	740	560	—	470	—	—
28 days	970	740	816	—	750	590	—	—
1.8 mo.	—	—	—	—	670	—	—	—

a) Results based on tests of 2 or more specimens.

Table 6b

Shear Bond Strength[a] of 2.75" Diameter Cores, lb/in^2

Age	Installation No. 1	2	3	4
24 hrs.	690 930*	—	—	—
28 days	—	870 1,060*	—	—
28 days[b]	600 850*	—	—	—
1.8 mo.	—	—	240 990*	530 640*
1.8 mo.[c]	—	—	260 550*	440 850*
9.8 mo.	—	—	—	210 880*
11.3 mo.	650 1,310*	650 1,130*	—	—
1.9 yr.	650 1,580*	770 1,190*	—	—

a) Results based on tests of 2 or more specimens.

b) After 200 thermal cycles.

c) After 100 thermal cycles.

* Shear strength of base concrete.

Table 7a

Delaminations Based on Chain Drag[a], %

Installation No. / Area/yd^2 / Age	1 / 94	2 / 94	3 / 96	4 / 96	5 / 245	6 / 245	7 / 245
28 days	4	3	—	—	—	—	—
1.1 mo.	—	—	—	—	0	0	—
2.4 mo.	4	7	—	—	—	—	<1
3.6 mo.	—	—	—	—	11	0	—
4.3 mo.	—	—	—	—	17	<1	—
5.0 mo.	—	—	—	—	18	<1	—
6.3 mo.	—	—	—	—	29	<1	—
7.2 mo.	—	—	—	—	33	1	—
7.6 mo.	—	—	—	—	—	—	6
9.2 mo.	—	—	—	—	26	2	—
9.8 mo.	—	—	60	24	—	—	—
1.1 yr.	—	—	—	—	—	2	—
1.5 yr.	—	—	100[b]	100[b]	—	3	—
1.6 yr.	9	14	—	—	—	—	—
1.9 yr.	9	14	—	—	—	—	—
2.9 yr.	10	16	—	—	—	—	—

a) Excludes spalled areas (see Table 7b for percent of overlay spalled).

b) Chain drag not used but 100% estimated to be delaminated as the overlay was removed with front end loader.

Table 7b

Spalls Based on Visual Inspection, %

Installation No. / Area, yd/[2] / Age	1 / 94	2 / 94	3 / 96	4 / 96	5 / 245	6 / 245	7 / 245
28 days	0	0	—	—	—	—	—
1.1 mo.	—	—	—	—	28[a)]	0	—
2.4 mo.	0	0	—	—	—	—	0
3.6 mo.	—	—	—	—	28	0	—
4.3 mo.	—	—	—	—	28	0	—
5.0 mo.	—	—	—	—	28	0	—
6.3 mo.	—	—	—	—	28	0	—
7.2 mo.	—	—	—	—	29	—	—
7.6 mo.	—	—	—	—	—	—	0
9.2 mo.	—	—	—	—	45	0	—
9.8 mo.	—	—	0	0	—	—	—
1.1 yr.	—	—	—	—	—	0	—
1.5 yr.	—	—	—	—	—	0	—
1.6 yr.	0	0	—	—	—	—	—
1.9 yr.	0	0	—	—	—	—	—
2.9 yr.	0	0	—	—	—	—	—

a) Assumes the 28% of the overlay replaced with polyester styrene mixture is spalled vinyl ester overlay.

Table 8

Permeability[a], Coulombs

Age	Specimen	1R	1	2	3	4
		Installation No.				
28 days	Cylinders	10	0	—	—	—
28 days	Cores	—	0	0	—	—
				2,723*		
28 days[b]	Cores	—	24	0	—	—
1.8 mo.	Cores	—	—	—	5,258	520
1.8 mo.[c]	Cores	—	—	—	1,960	775
9.8 mo.	Cores	—	—	—	1,800	1,299
					10,850*	19,777*
						204**
11.3 mo.	Cores	—	129	37	—	—
1.9 yr.	Cores	—	232	175	—	—
			3,322*			
2.9 yr.	Cores	—	343	194	—	—
			3,186*	583**		

a) Results based on tests of 3 or more specimens.

b) After 200 thermal cycles.

c) After 100 thermal cycles.

* Permeability of old base concrete.

** Permeability of new rapid setting base concrete.

Table 9

Freezing and Thawing Performance[a], ASTM C666-A

Installation	Weight Loss, %	Surface Rating	Durability Factor, %	Absorption, %[b]
1R	0.00	0	95	—
1 & 2	0.15	0	94	—
3 & 4	0.69	0	49[c]	5.50
5	0.00	0	68[c]	0.15
6	0.00	0	76[c]	0.09
Minimum Requirements	$\leq$7.0	$\leq$3.0	$\geq$60	—

a) Results based on tests of 3 specimens 4" x 3" x 16".

b) Percent loss in weight determined by oven drying specimens after 300 cycles of freezing and thawing in 2% NaCl (wet weight @ 300 cycles — oven dry weight)/(oven dry weight).

c) Values may not be accurate due to malfunction in the audio oscillator.

Table 10a

Treaded Tire Skid Numbers at 40 mph (ASTM E501)

	Overlay	Installation No.						
Test Date	Age	1	2	3	4	5	6	7
10/87	1.3 yr.	—	45	—	—	—	—	—
11/18/87	1.3 mo.	—	—	—	49	—	—	—
8/17/88	10 mo.	—	—	—	—	—	43	—
10/26/88	1.0 yr.	—	—	40	44	—	—	—
10/23/89	1.1 yr.	—	—	—	—	—	—	44
10/23/89	2.0 yr.	—	—	—	—	—	44	—
10/23/89	3.3 yr.	—	48	—	—	—	—	—
10/24/89	6 mo.	—	—	50*	47*	—	—	—

* Bituminous concrete.

Table 10b

Bald Tire Skid Numbers at 40 mph (ASTM E524)

Test Date	Overlay Age	Installation No. 1	2	3	4	5	6	7
10/87	1.3 yr.	—	38	—	—	—	—	—
11/18/87	1.3 mo.	—	—	—	43	—	—	—
8/17/88	10 mo.	—	—	—	—	—	39	—
10/26/88	1.0 yr.	—	—	34	41	—	—	—
10/23/89	1.1 yr.	—	—	—	—	—	—	39
10/23/89	2.0 yr.	—	—	—	—	—	40	—
10/23/89	3.3 yr.	—	45	—	—	—	—	—
10/24/89	6 mo.	—	—	43*	43*	—	—	—

Table 11

Overlay Thickness, in.

Age	Installation No. 1	2	3	4	5	6	7
24 hr.	—	0.9	—	—	—	—	—
28 days	—	1.0	—	—	—	—	—
29 days	—	—	—	—	—	—	0.6
1.8 mo.	—	—	0.6	0.8	—	—	—
7.6 mo.	—	—	—	—	—	—	0.7
9.8 mo.	—	—	0.6	0.8	—	—	—
11.3 mo.	0.8	0.9	—	—	—	—	—
1.5 yr.	—	—	—	—	—	0.6	—
1.9 yr.	0.8	0.9	—	—	—	—	—
2.9 yr.	1.0	0.9	—	—	—	—	—