FINAL REPORT

EVALUATION OF EPOXY COMPOUNDS AS A MATERIAL FOR PATCHING AND PROTECTING CONCRETE

by

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

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SUMMARY AND RECOMMENDATIONS

This final report summarizes the results of a study of the use of epoxy compounds in the shallow surface repair and sealing of concrete bridge decks. The research effort, which concentrated on the use of epoxy resin systems as bonded overlays, included evaluations of test strips of seven materials on two structures in northern Virginia, supplemented by observations of approximately fifty full-scale applications.

The wearing of a thin bonded epoxy overlay exposed to traffic, as manifested in the loss of both skid resistance and protection afforded the underlying concrete, is the definitive factor in the service life of the application. The resistance to wearing of the exposed overlays observed in this study was generally disappointing and the use of an asphaltic wearing course to protect the epoxy seal coat is considered essential to the continued effectiveness of an overlay application.

The skid resistance afforded by an exposed epoxy overlay must be considered a limiting factor in its service life. The study indicates that, regardless of the type of deslicking aggregate employed, unprotected epoxy overlays suffer a continuing decline in skid resistance under exposure to traffic. Such applications, particularly those containing coal tar modified epoxy resin systems which tend to lose aggregate and polish, should be evaluated periodically for loss of skid resistance.

Further findings of the study are reflected in the following recommendations pertaining to the application of epoxy seals to bridge decks.

1. The deck surface should be checked for soundness prior to the application of the seal coat and all concrete of poor quality removed. The material characteristics of an epoxy overlay prevent it from protecting concrete which is not structurally sound.

2. The deck surface should be cleaned by sandblasting until the coarse aggregate in the concrete is visible. The debris from the sandblasting should be broomed away and the deck blown clean through use of an air compressor. If at all possible, water should not be applied to the deck.

3. If the deck is wetted prior to the application of the seal coat, the concrete should be allowed to dry for at least 48 hours (2 drying cycles).

4. The two components of the epoxy compound must be accurately proportioned and thoroughly mixed, preferably by mechanical means. A thixatropic agent should be added to the system if the slope of the deck surface is such that flow of the epoxy will present a problem.

5. The epoxy resin system should be applied at a rate of 3 to 3.5 gallons per square yard, unless the manufacturer specifies a thinner application for reasons of material characteristics. The application must be made within the temperature range specified by the manufacturer.

6. Rounded aggregate particles passing the number 20 sieve should be applied to the epoxy layer as soon as possible after its placement. The trajectory of the particles should be near vertical at the time of impact with the epoxy.

7. An asphaltic wearing course should be applied to the cured epoxy membrane to protect it from wear and loss of skid resistance under exposure to traffic. The findings of this study indicate that a dense plant mix surface course will suffice to protect the seal coat on most normal highway bridges, and modification of the mix with the addition of asbestos or rubberized materials is not necessary.

EXPERIMENTAL PROCEDURE

Test Strip Applications

Two structures in northern Virginia, the bridge carrying the northbound lane of Route I-95 over Occoquan Creek and the bridge comprising Ramp C of the interchange of Route I-95 and Route 1, were selected to receive test applications of seven epoxy compounds placed in strips across the width of the roadways, as shown in Figures 1 and 2. These special test strip applications allowed the consideration, with convenience and minimum cost, of the several variables described below.

Epoxy Resin Compounds

The seven epoxy resin systems chosen for inclusion in the tests after conferences with several manufacturers are listed below:

1. P. E. Surface Sealer — a light colored, two component, mineral filled, polysulfide modified system supplied by the Products Research Company, Burbank, California.

2. Surface Kote — a light colored, two component, amine cured system supplied by the Sika Chemical Corporation, Lyndhurst, New Jersey.

3. Resiweld 7120 — a light colored, two component, amine cured system supplied by the H. B. Fuller Company, St. Paul, Minnesota.

4. Concresive 1064-3 — a light colored, two component, petroleum extended, amine cured system supplied by Adhesives Engineering, San Carlos, California.

5. MRAX 1062 (now marketed as Guardkote 250) — a light colored, two component, petroleum extended, amine cured system supplied by the Shell Chemical Corporation.

6. Guardkote 140 — a black, two component, coal tar modified system supplied by the Sika Chemical Corporation, Lyndhurst, New Jersey.

7. Resiweld 7140 — a black, two component, coal tar modified system supplied by the H. B. Fuller Company, St. Paul, Minnesota.

Surface Preparation

As shown in Figures 1 and 2, one of the two test sections on each structure was cleaned by acid etching, the other by sandblasting.

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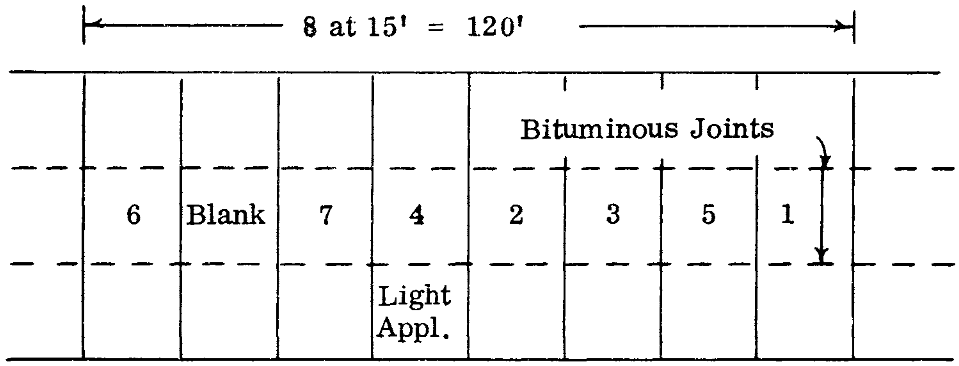
INTRODUCTION

Epoxy resin systems, in a variety of formulations, have been widely used in the maintenance of highway bridges. The results obtained through the use of these compounds have varied from complete success to total disaster, the effectiveness of any given application being dependent on a number of factors involving the use of proper application techniques and a knowledge of the limitations of the epoxy resin system employed. Definition of some of the factors involved in the successful use of epoxy compounds to seal and repair concrete bridge decks was the objective of a study initiated in 1964 by the Virginia Highway Research Council.[1] This final report summarizes the findings of that study.

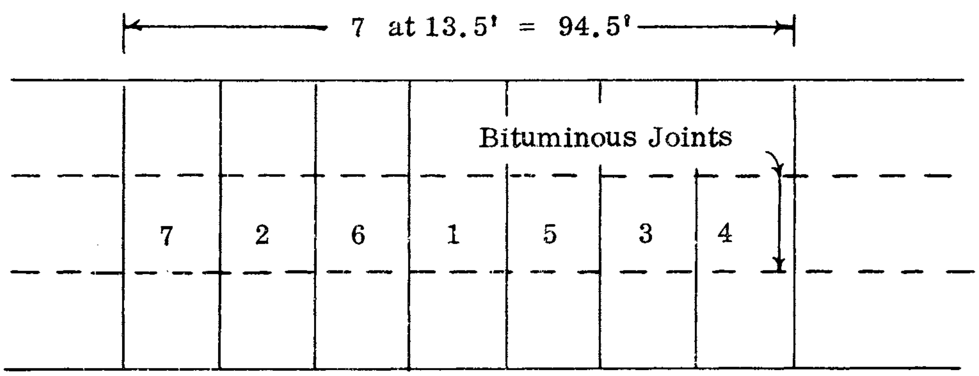
The Virginia research effort has been concentrated almost entirely in the use of a variety of epoxy resin systems as thin bonded overlays, layers of epoxy from 20 to 60 mils thick in which deslicking aggregate is embedded, applied as seal coats on bridge decks. The patching of concrete was studied only in the context of shallow surface repairs effected through the application of an epoxy mortar overlay, which, unfortunately, proved to be less than successful. It is believed that the general use of epoxies in the repair of concrete is well covered in the literature.[2]

SCOPE

The Virginia study included the installation and observation of test applications of seven commercially available epoxy resin compounds serving as thin bonded overlays, utilizing two means of surface preparation and two deslicking aggregates, on newly constructed structures exposed to heavy traffic; a limited program of laboratory testing; and observations of several full-scale applications of epoxy resin overlays of various types. These facets of the study are described in some detail in the following section.



Span 9 — Occoquan Creek
Acid Etched, Aluminum Oxide Grit



Span 10 — Occoquan Creek
Sandblasted, Silica Sand Aggregate

Key

1. Concresive 1064-3
2. Guardkote 140
3. MRAX 1062
4. P. E. Surface Sealer
5. Resiweld 7120
6. Resiweld 7140
7. Surface Kote

Figure 1. General layout of test strips — Occoquan Creek bridge.

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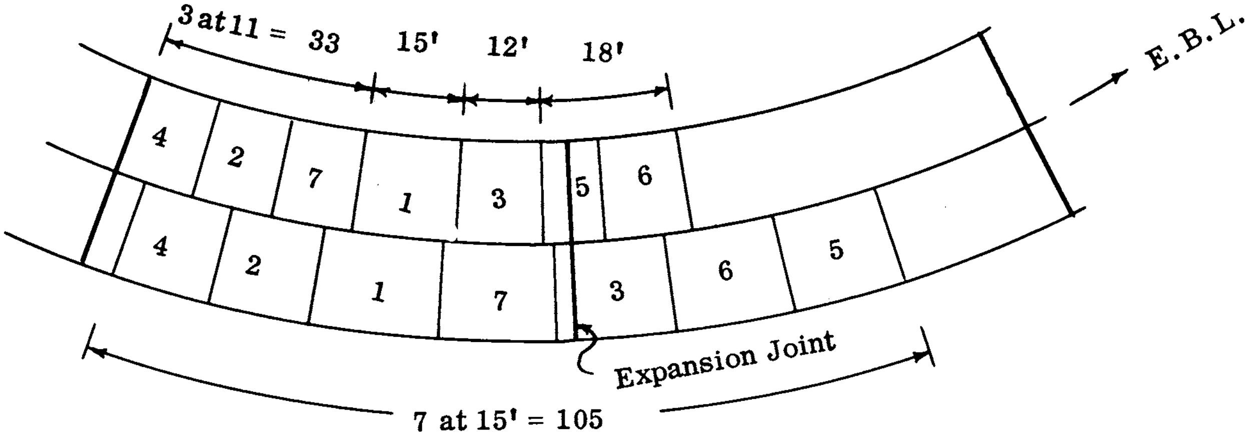
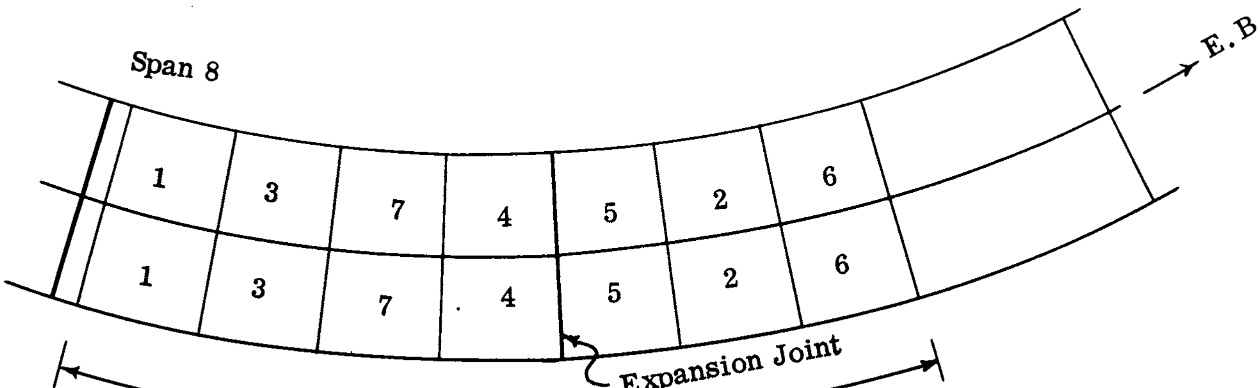


Sandblasted, Aluminum Oxide Grit



Acid Etched, Silica Sand Aggregate

Key

1. Concresive 1064-3
2. Guardkote 140
3. MRAX 1062
4. P.E. Surface Sealer
5. Resiweld 7120
6. Resiweld 7140
7. Surface Kote

Figure 2. General layout of test strips on Ramp C.

Type of Deslicking Aggregate

Two types of aggregate, a silica sand and an aluminum oxide grit, were used on each structure. All of the epoxy materials used identical sand and grit aggregates, and each aggregate was used with both types of surface preparation as shown in Figures 1 and 2. The overlay test strips using silica sand as deslicking aggregate will hereafter be referred to as sand strips, while those using aluminum oxide grit will be referred to as grit strips. The results of a sieve analysis of the aggregates are shown in Table 1.

TABLE 1

SIEVE ANALYSIS OF AGGREGATES

Sieve Size	Silica Sand		Aluminum Oxide Grit	
	% Passing	% Retained	% Passing	% Retained
- 10 + 20	100.00	2.91	100.00	74.58
- 20 + 40	97.09	92.03	25.42	25.23
- 40 + 60	5.06		0.19	
- 60 + 80		3.96		0.08
- 80 + 100	1.10	0.09	0.11	
-100 + 200	1.01	0.09	0.11	
-200	0.92	0.92	0.11	0.11

Structural Design Features

The test spans on the Ramp C bridge are simply supported steel beams, while those on the Occoquan Creek bridge are part of a series of four continuous girder spans, which exhibit considerably more flexibility than the simple spans. The Ramp C bridge, which contains a horizontal curve of approximately 13° curvature with nearly maximum superelevation, carries low speed traffic; the Occoquan Creek bridge carries traffic on a straight tangent at high speeds.

The test strips were evaluated by means of visual inspections and field measurements of skid resistance and bond strength. A limited program of laboratory tests, described in the following section, was conducted to complement the field data obtained from the test strip applications.

Laboratory Tests

Laboratory determinations of the coefficient of thermal expansion and bond strength were conducted for each of the seven materials included in the test strip evaluations.

The thermal expansion tests were conducted in accordance with the Standard Method of Test for Coefficient of Linear Thermal Expansion of Plastics, ASTM Designation D696-44.(3) Specimens included plain epoxy and mixtures of the seven compounds and the sand and grit aggregates described previously. The specimens were tested initially, and at ages of one and two years to determine any changes in the coefficient of thermal expansion due to aging. In order to evaluate the effects of exposure, one set of samples was stored for two years in an outdoor area.

The direct tension bond strength tests were conducted in the Virginia Department of Highways Materials and Testing Laboratories in Richmond in accordance with a standard method then included in the Virginia Specifications.(4)

Observations of Full-Scale Applications

In order to confirm the applicability of the findings of the test strip evaluations and the recommendations based upon them to actual practice, several full-scale deck overlays were inspected to varying degrees. Although the number of structures included in this phase of the study was limited, the observations were sufficient to provide information on the performance of full-scale overlays and to extend the scope of the study to encompass a variety of applications on structures of various ages under exposure to a range of traffic volumes.

DISCUSSION OF RESULTS

Thermal Expansion Tests

The laboratory determination of the coefficient of linear thermal expansion of the seven epoxy resin compounds was conducted in accordance with ASTM D696-44, which utilizes a quartz tube dilatometer. The dilatometer consists of two quartz glass tubes, one of which fits inside the other. The outer tube, which is approximately 18 inches in length with a $\frac{1}{2}$ inch inside diameter, contains the molded cylindrical specimen, which is approximately 2 inches long by 7/16 inch in diameter. The second tube, which is approximately 16 inches long by 7/16 inch outside diameter, rests on top of the specimen. The thermal expansion is measured by a dial gage calibrated to .0001 inch per division, bearing on the top of the inner tube.

Four series of thermal expansion tests were made: one initially, soon after molding of the specimens; two others at intervals of twelve and twenty-four months, using specimens stored in the laboratory; and a fourth on specimens stored twenty-four months in an outdoor exposure area. Three specimens of each of the epoxy resin compounds were tested in each series of tests, a plain epoxy resin specimen and one containing each of the two deslicking aggregates described previously. Because of the tendency for the specimens to creep under elevated temperatures, the coefficients of thermal expansion were determined over a range of temperature from room temperature, approximately 22°C, to a depressed temperature between -5 and -21°C. The results of repetitive tests performed in this temperature range appeared to be fairly consistent.

The results of the thermal expansion tests, shown in Table 2, are inconclusive with respect to the effect of age or weathering on the coefficient of linear thermal expansion. The test method is intended to provide only approximate values, and it appears that the rather wide range of the data is due, at least in part, to variations inherent in the testing procedure. The values in Table 2 are presented primarily to show the general values of the coefficients of thermal expansion and to demonstrate the effect of the addition of aggregate to the system. For comparative purposes, the coefficient of thermal expansion of concrete is commonly taken to be 6 x 10^{-6} in./in./F^{O} or 10.8 x 10^{-6} in./in./C^{O}. The values in Table 2 indicate that the plain oil modified and coal tar modified epoxy resin systems have a considerably higher coefficient of thermal expansion than the other systems, but the difference is decreased markedly by the presence of the aggregate. The coefficients of thermal expansion of the filled specimens of all of the seven materials were shown to be significantly higher than that of concrete. It is believed that this occasionally large difference in the rate of thermal expansion caused stresses which resulted in the fracture of the underlying concrete in several of the test strips on the Occoquan Creek bridge. The concrete in the area appeared to be of poor quality, and the distress indicates the importance of structural soundness of the deck surface to the success of an overlay application.

TABLE 2

GENERAL VALUES OF COEFFICIENTS OF THERMAL EXPANSION

Epoxy Compounds	Aggregate	Initial Specimens in./in./C^{o}x 10^{-6}	x12 month xx Specimens (Laboratory) in./in./C^{o}x 10^{-6}	24 month Specimens (Laboratory) in./in./C^{o}x 10^{-6}	24 month Specimens (Weather) in./in./C^{o}x 10^{-6}
P. E. Surface Sealer	Plain Epoxy	100.4	110.9	94.8	96.1
	Sand	77.5	51.4	42.2	46.4
	Grit	36.0	48.4	37.6	38.3
Surface Kote	Plain Epoxy	70.0	86.6	64.0	70.0
	Sand	22.3	30.3	21.1	26.6
	Grit	13.3	24.9	13.7	25.9
Resiweld 7120	Plain Epoxy	97.7	102.7	108.7	96.5
	Sand	33.0	31.9	26.6	28.1
	Grit	21.0	28.3	17.0	21.2
Resiweld 7140	Plain Epoxy	137.8	158.3	127.9	126.4
	Sand	46.0	49.6	38.1	43.8
	Grit	30.8	43.7	31.9	35.4
Guardkote 140	Plain Epoxy	125.3	147.4	128.2	131.3
	Sand	52.4	58.0	49.8	40.1
	Grit	49.5	54.4	34.2	30.9
Concresive	Plain Epoxy	143.2	165.1	159.2	150.3
	Sand	54.6	60.4	50.9	50.5
	Grit	71.0	43.0	29.2	28.2
Shell MRAX	Plain Epoxy	172.3	193.6	163.0	158.5
	Sand	32.1	39.1	36.6	38.2
	Grit	36.8	No Test	27.4	18.2

Bond Strength Determinations

Bond strengths of the seven epoxy resin systems were determined in the laboratory by means of a standard direct tension test. A three inch by six inch concrete cylinder was cut in half and bonded together with the epoxy resins being tested. The surfaces to be bonded were prepared by either acid etching or filing and wire brushing to simulate field conditions. Five cylinders, two of which were blanks, were subjected to direct tension for each combination of epoxy resin and surface preparation technique. The results of the tests are shown in Table 3.

TABLE 3

DIRECT TENSION BOND TEST ON 3" x 6" CYLINDER
(ALL RESULTS IN PSI)

	Sika Surface Kote		**Reisweld 7140**		**Sika Guard Kote**		**P. E. Surface Sealer**	
	Acid Etched	Wire Brushed	Acid Etched	Wire Brushed	Acid Etched	Wire Brushed	Acid Etched	Wire Brushed
Blank	307	272 H	258 H	368	226 H	202 H	362	336
Blank	329	308	237 H	375	258	191 H	258 H	255
Bonded	318	396	202	247 E	198 H	226 E	266	371
Bonded	368 H	368	240	237 E	255	265 E	297	269
Bonded		272 A	230		244	212 E	297	385
Ave. Blank	318	290	248	372	242	197	310	296
Ave. Bonded	343	332	224	242	232	234	287	342

	Shell MRAX		Reisweld #120		Concresive 1064 - 3	
	Acid Etched	Wire Brushed	Acid Etched	Wire Brushed	Acid Etched	Wire Brushed
Blank	320	315	354	382	255	234 H
Blank	400	332	301	375	269	152 H
Bonded	354	304 A	339	364	191 E	117 E
Bonded	301	297 E	380		159 E	110 E
Bonded		325	293	357	198 E	113 E
Ave. Blank	360	324	328	379	262	143
Ave. Bonded	328	309	337	361	183	113

E = Epoxy Bond Failure At Bonded Joint

A = Separation In Epoxy Material At Bonded Joint

H = Failure Of Bonding Compound At Steel Head

Unless otherwise noted, break occurred in concrete section, at least ½ inch from any bonded joint

The test results show no significant difference in bond strength caused by the method of surface preparation. The Virginia specification for epoxy resins applicable at the time of the tests required a minimum of 250 psi bond strength.[4] It can be seen that three of the materials, Resiweld 7140, Guardkote 140 and Concresive, fell below the required value, and, in fact, the Concresive material was judged to be an inferior product. However, the performance of these materials in the field test, discussed later in this report, compared favorably with that of the other systems evaluated, and no bond failures were noted. These three materials are not intended for use as adhesives, and it appears that the bond strength requirement might be unduly restrictive with respect to compounds to be used in overlay applications.

It was initially proposed to evaluate the effect of time on the bond strengths of the experimental overlays through the comparison of tension test data taken annually over a three year period using a technique suggested by the American Concrete Institute.[5] In the field procedure, a two inch diameter pipe cap is bonded to the surface of the overlay and the force required to pull up the cap is measured. The circular area to which the cap is bonded is separated from the remainder of the overlay prior to testing. The evaluation of the change of bond strength with time proved impossible because of the many variations such as the strength of the underlying concrete, the temperature at the time of test and the thickness of the epoxy material.

The variations inherent in the test procedure prevented a meaningful comparison of the bond strengths of the seven materials. The epoxy materials generally exhibited no loss of bond, as manifested be delamination of the overlay at the surface of the concrete. Delamination of this nature was noted in only one test strip, the grit strip containing the Shell MRAX oil modified system. Although the bond failure occurred over a relatively large area, the causative factor was impossible to determine.

Performance of the Individual Epoxy Resin Systems

Each of the seven commercially available epoxy compounds chosen for inclusion in the field tests was applied under the direction of a representative of the supplier. The method of application was left to the option of the supplier's representative, with notched squeegees, hand sprayers and a Broyhill distributor being used. The rate of application estimated by the supplier's representative and the chosen method of placing the overlay are shown in Table 4 for each of the test strip applications. Details of the applications, which were made during July 1964, were noted and published in a preliminary report.[6]

Although the test strips allowed a unique comparison of seven epoxy resin systems applied as overlays in each of four relatively small areas, an actual comparison of the suitability of the individual compounds proved to be difficult. It became apparent during the periodic inspections that factors affecting the thickness of the overlay had a significant effect on its wear under traffic. These factors occasionally resulted in significant differences in the durability of the four overlays containing a single material. Thus, the comparison presented in the following sections is one of applications rather than materials.

TABLE 4

APPROXIMATE RATES OF EPOXY AND AGGREGATE APPLICATION

Structure	Material	Rate of Epoxy	Aggregate psy (1)	Method of Application
Occoquan Creek Span 9 (Grit)	Concresive	1/3 gsy	16	Spray
	Guardkote R 140	1/3 gsy	17.5	Squeegee
	MRAX 1062	1/3 gsy (2)	16	Spray
	P. E. Surface Sealer	See note (3)	14.5	Spray
	Resiweld 7120	See note (4)	16	Squeegee
	Resiweld 7140	1/3 gsy	17.5	(Broyhill Paver)
	Surface-kote	1/10 gsy	17.5	Squeegee
Occoquan Creek Span 10 (Sand)	Concresive	1/3 gsy	14.5	Spray
	Guardkote R 140	1/3 gsy	16	Squeegee
	MRAX 1062	1/3 gsy	14.5	Squeegee
	P. E. Surface Sealer	1/7 gsy	14.5	Spray
	Resiweld 7120	3/10 gsy	17	Squeegee
	Resiweld 7140	1/3 gsy	17	Squeegee
	Surface-kote	1/10 gsy	17	Squeegee
Ramp C Span 4-5 (Grit)	Concresive	1/3 gsy	14	Spray
	Guardkote R 140	1/3 gsy	16	Squeegee
	MRAX 1062	1/3 gsy	14	Squeegee
	P. E. Surface Sealer	1/7 gsy	14	Spray
	Resiweld 7120	1/4 gsy	16	Squeegee
	Surface-kote	1/10 gsy	16	Squeegee
	Resiweld 7120	1/3 gsy (5)	16	Squeegee
	Resiweld 7140	4/10 gsy	16	Squeegee LHL
	Resiweld 7140	1/3 gsy	16	RHL (Broyhill Paver)
Ramp C Span 8-9 (sand)	Concresive	1/3 gsy	14	Spray
	Guardkote R 140	1/3 gsy	16	Squeegee
	MRAX 1062	1/3 gsy	16	Squeegee
	P. E. Surface Sealer	1/7 gsy	14	Spray
	Resiweld 7120	1/3 gsy (5)	14	Squeegee
	Resiweld 7120	1/4 gsy	16	Squeegee
	Resiweld 7140	1/3 gsy (6)	16	RHL (Broyhill Paver)
	Resiweld 7140	1/3 gsy	16	Squeegee LHL
	Surface-kote	1/10 gsy	16	Squeegee

(1) Amount used during application including an excess which was recovered.
(2) Due to mechanical difficulties 15% of this area has rate of 1/5 gsy.
(3) Light application of unknown rate.
(4) Right and left lanes 1/4 gsy, center lane 3/10 gsy.
(5) Application made by state personnel.
(6) Due to mechanical difficulties, outer half of lane has rate of 2/10 gsy.

The performance of overlays of each of the seven epoxy resin systems are summarized and general comments on the suitability of the individual materials are presented. However, most of the findings in this study are based on the overall performance of the test strips.

Resiweld 7140

The first inspection, which was made six months after the test strip applications of this coal tar modified epoxy resin system, disclosed reflective cracking in the sand strip on the Occoquan Creek bridge. No cracking was seen in the grit strips or in the test strips on the more rigid simple spans of the ramp bridge during the initial inspection, but some reflective cracking was noted in the sand strip on the ramp during later inspections.

An inspection two years after application disclosed the formation of small blisters, approximately one inch in diameter, in the sand strips of both structures. As will be discussed later, it appears that the blisters formed during placement of the overlay but were not apparent until traffic removed the top surface.

The test strips using Resiweld 7140 with the aluminum oxide deslicking aggregate showed resistance to wearing which was superior to that of the other test strips. Wear was generally uniform throughout the study, and there were only localized areas of exposed concrete at the final inspections. There is some indication that this superior wearing ability was due to a greater overlay thickness rather than material characteristics, because the performance of test strips containing the similar Sika Guardkote 140 material was less satisfactory. Although the grit strips resisted wearing, the coal tar epoxies showed a tendency to lose aggregate and polish under traffic, and loss of skid resistance became a problem.

The sand aggregate test strips showed a greater tendency to wear than did the grit strips. The area of thin application (2/10 gsy, Table 4) on the ramp bridge showed wear after two year's exposure to traffic, and there were several areas of exposed deck surface in the sand strips on both structures at the conclusion of the tests. Wearing resistance was considered fair to good.

No distress of the concrete deck was noted at any of the four test strip locations after the application of the overlays.

Sika Guardkote

Both test overlays on the Occoquan Creek bridge containing this coal tar modified epoxy resin system had reflective cracks six months after application; reflective cracking was noted in both strips on the ramp bridge later in the study.

Blistering was apparent in the sand strips on both structures after two year's exposure to traffic.

Wearing of the test strips containing Sika Guardkote was less satisfactory than that of the strips utilizing the other coal tar modified system, Resiweld 7140. The strips with both deslicking aggregates were showing wear at high points in the deck two years after application. The grit strips on the Occoquan Creek bridge exhibited fair performance with limited areas of wear at the conclusion of the test, but the other three overlays exhibited severe wearing with large areas of the deck surface exposed. The overlays also showed a tendency to polish under traffic similar to that observed in the Resiweld 7140 applications.

Two small areas of delamination of the epoxy overlay with the underlying concrete attached were noted in the grit strips on the Occoquan Creek bridge early in the tests. A similar loss of the overlay and underlying concrete was noted later adjacent to a reflective crack. The failures were ascribed to the presence of poor deck concrete, which had a white powdery appearance, in the area of the grit strips. One chert popout was noted in a worn area of thin overlay application on the ramp bridge two years after placement of the epoxy seals.

Resiweld 7120

Reflective cracking was noted in both strips of the Resiweld 7120 material on the Occoquan Creek bridge during the first inspection six months after installation. The sand strip on the ramp bridge also exhibited reflective cracking later in the study.

Blisters were apparent in the sand strip on the ramp structure after nine months; none appeared in the sand strip on the Occoquan Creek bridge. Deterioration of the deck concrete adjacent to one of the blisters was noted in a subsequent inspection.

The strips with both types of deslicking aggregate on both structures showed isolated points of wear after two year's exposure to traffic, but performance was relatively satisfactory. The four overlays continued to show better than average performance during the remainder of the tests. Final inspections showed the grit strips to have severe wear and exposed concrete at isolated high points or areas of heavy texture, while the sand strips had some exposed concrete due to wear in wheel paths and at high points. However, the performance of both types of strips was generally superior to that of most of the other materials.

Loss of the overlay with underlying concrete attached was noted in the grit strips of the Resiweld 7120 material on the Occoquan Creek bridge. The distress was apparently due to the poor quality of the concrete as was the loss of the overlay and concrete for a distance of one inch around reflective cracks. One popout occurred after the application of the grit strip on the ramp bridge, and, at the last inspection, it was noted that serious spalling of the concrete had occurred on the sand strip. In both cases the strips were severely worn in the distressed area.

Concresive

Both overlays utilizing this oil modified epoxy resin system on the Occoquan Creek bridge had reflective cracks six months after installation, and cracking developed in the sand strip on the ramp at a later date.

Blistering of the sand aggregate strips was noted on the ramp bridge at six months and on the Occoquan Creek structure nine months after placement of the overlays. The number of blisters increased in subsequent inspections.

The four Concresive test strips quickly displayed a tendency to lose the deslicking aggregates, particularly the large grit particles, under traffic, but the material was wearing uniformly and well two years after installation. Eventually all four strips exhibited severe wear with some exposure of the deck surface in the wheel paths; however, large areas were covered by a thin layer of epoxy resin without aggregate. The relatively weak adhesive strength of the epoxy system, as shown by the bond tests described previously, manifests itself in the loss of deslicking aggregate under exposure to traffic; however, loss of bond between the overlay and the deck was not a problem.

Loss of a portion of the overlay and underlying concrete was noted in the Concresive test strip with grit aggregate; as in the case of other strips in the group the distress was apparently due to poor concrete in the deck. One chert popout occurred after the epoxy application in the grit strip on the ramp bridge, and an area of scaling in the concrete was noted in the same strip during the final inspection.

Shell MRAX

This oil extended epoxy resin system displayed the greatest tendency toward cracking. Reflective cracks were noted in both the sand and grit strips on the Occoquan Creek bridge six months after installation and in the sand strip on the ramp bridge later. Pattern cracking of the surface of the sand strips of both structures, shown in Figure 3, was also noted later, and there was some evidence of loss of bond in the cracked area. One area of loss of bond, unrelated to the pattern cracking, was noted one year after application in the grit strip on the ramp bridge. This area of delamination of the overlay, shown in Figure 4, increased in size under exposure to traffic, and the overlay appeared to have poor bond over a considerable area at the conclusion of the tests.

The concrete deck surface was exposed through wear in localized areas of the grit strips on the Occoquan Creek bridge and the sand strips on the ramp structure one year after application, and the grit strip on the ramp bridge showed severe wear at points of thin application after two year's exposure to traffic. All three overlays were severely worn with exposed concrete over most of the strip areas at the conclusion of the tests. A better performance was shown by the sand strip on the Occoquan Creek bridge, which exhibited relatively satisfactory resistance to wear.

The MRAX grit strip on the Occoquan Creek bridge displayed several small areas of separation of the overlay with the underlying concrete attached due to the poor quality of the concrete. The final inspection of the ramp bridge disclosed one area of concrete spalling in the grit strip and two in the sand strip, indicating that wear had negated the protective qualities of the overlay.

Figure 3. Typical reflective and pattern cracking in a test strip containing Shell MRAX with silica sand deslicking aggregate.

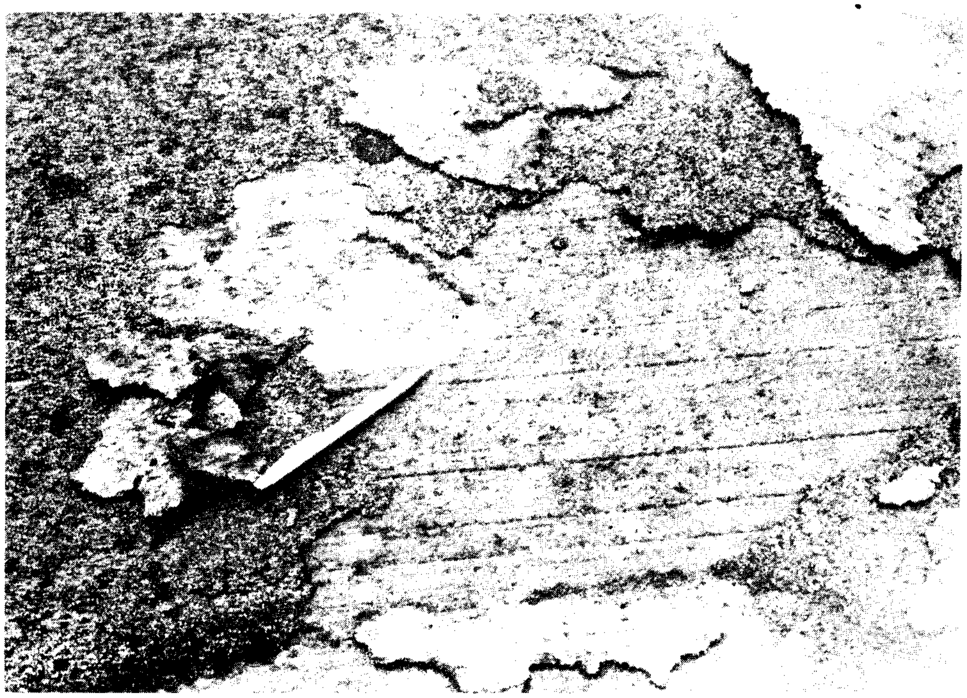


Figure 4. Area of delamination in the Shell MRAX strip with aluminum oxide grit on the Ramp C bridge.

Sika Surface Kote

The Surface Kote overlays on the Occoquan Creek bridge displayed reflective cracking six months after application; the two strips on the ramp exhibited cracking later in the study.

Blisters were noted in the sand strip on the ramp structure six months after application. The number of blisters evident on the ramp strip had increased after one year's exposure to traffic, and blisters were apparent in the sand strip on the Occoquan Creek bridge at that time.

The rather thin Surface Kote overlays (the application rate was 1/10 gsy) showed the effects of wear rather quickly, the strips with aluminum oxide deslicking aggregate showing the worst performance. Two years after application both grit overlays were severely worn with the deck surface exposed over much of the strip areas, while the sand overlays were showing isolated points of wear. All four strips were severely worn with considerable areas of the deck surface exposed at the conclusion of the study, and the overall performance with respect to wear was considered generally poor.

Separation of the overlay and a layer of the underlying concrete was noted in several small areas of poor concrete in the grit strip on the Occoquan Creek bridge, and a similar separation was seen adjacent to the reflective cracks. Spalling of the deck concrete due to loss of the protection afforded by the epoxy seal was noted at worn areas in both test strips on the ramp bridge.

P. E. Surface Sealer

Both of the Occoquan Creek bridge overlays containing this polysulfide modified epoxy resin system showed reflective cracking six months after installation.

The Surface Sealer sand overlays on both bridges had the greatest number of open blisters throughout the study.

The performance under exposure to traffic of the thin Surface Sealer overlays was similar to that of the Sika Surface Kote strips. Overlays of both of these epoxy resin compounds showed severe wear rather quickly, and, in both cases, the sand strips performed better than those with aluminum oxide grit. Although the performance of the light overlay application on span 9 of the Occoquan Creek bridge was discounted, the resistance to traffic wear of the P. E. Surface Sealer was the worst of the materials tested. It appears that the application was too thin to provide sufficient durability.

Separation of the Surface Sealer overlay with the underlying concrete attached occurred over a large area in the grit strip on the Occoquan Creek bridge due to poor concrete. Spalling of the concrete and the occurrence of one chert popout after the epoxy application were noted in the sand strip on the ramp bridge.

General Performance of the Overlays

Effectiveness of Surface Preparation

The test strips exhibited little difficulty that could be attributed to improper cleaning of the deck surface, and it is evident that, properly performed, either acid etching or sandblasting can provide a sufficiently clean surface. However, the blisters, shown in Figures 5 and 6, which appeared within many of the sand strips on both structures are believed to have resulted from the expansion of moisture vapor trapped in the concrete by the epoxy seal at the time of application. When the top surface of a typical blister was removed by traffic, the lower surface was seen to be covered with a thin layer of epoxy containing an open void extending to the concrete deck. Although blisters formed in the overlays regardless of the means of surface preparation, the distress was more evident on the ramp bridge. The means of surface preparation used for the sand strips on this structure was acid etching, which required that the deck be thoroughly flushed twice with clear water to ensure the removal of any reaction products. No water was applied to the deck of the Occoquan Creek bridge during the sandblasting of the sand strip areas, but a sudden storm, which occurred prior to application of the overlays, would have accounted for the presence of moisture in the pores of the concrete. The results of this study indicate that sandblasting, which does not require the application of water to the deck surface, is the superior means of surface preparation. After the deck has been sandblasted, it should be broomed to remove debris and finally blown clean with an air compressor. The deck should be allowed ample time to dry after any wetting occurs. The sand strips on the two structures in this study were placed within twenty-four hours after the flushing of the deck or the occurrence of the storm, and the presence of blisters indicates that this was not sufficient time for drying in spite of the fact that the ambient temperature during the day ranged from 82^{o} - 102^{o}F and the deck surface temperature from 90^{o} - 130^{o}F.

While some of the grit strips exhibited isolated flows which might have been blisters, the distress was generally noted only in the strips with sand deslicking aggregate. This does not indicate a superior characteristic of the grit strips; instead, it seems likely that the grit strips tended to form open voids through the overlay, allowing the escape of the expanding vapor. Research reported by Kubitschek, who investigated the effect of aggregate size and shape on the formation of open voids in epoxy resin overlays, disclosed that in general the number and size of open voids decreased as particle shape changed from angular to round and as particle size decreased.(7) Overlays containing rounded particles passing the number 20 sieve, such as the silica sand used in the test strip applications, were found to be essentially free of open voids or pinholes. Overlays containing large angular particles, such as the aluminum oxide grit used in this study, would tend to develop open voids. The performance of the test strips indicates that the use of a rounded silica sand aggregate of a size similar to that shown in Table 1 is essential to the application of a void-free protective membrane.

Sandblasting is an excellent means of cleaning a deck surface in preparation for the application of an epoxy resin system, but it must be realized that the structural soundness of the concrete is also of vital importance to the performance of an overlay.

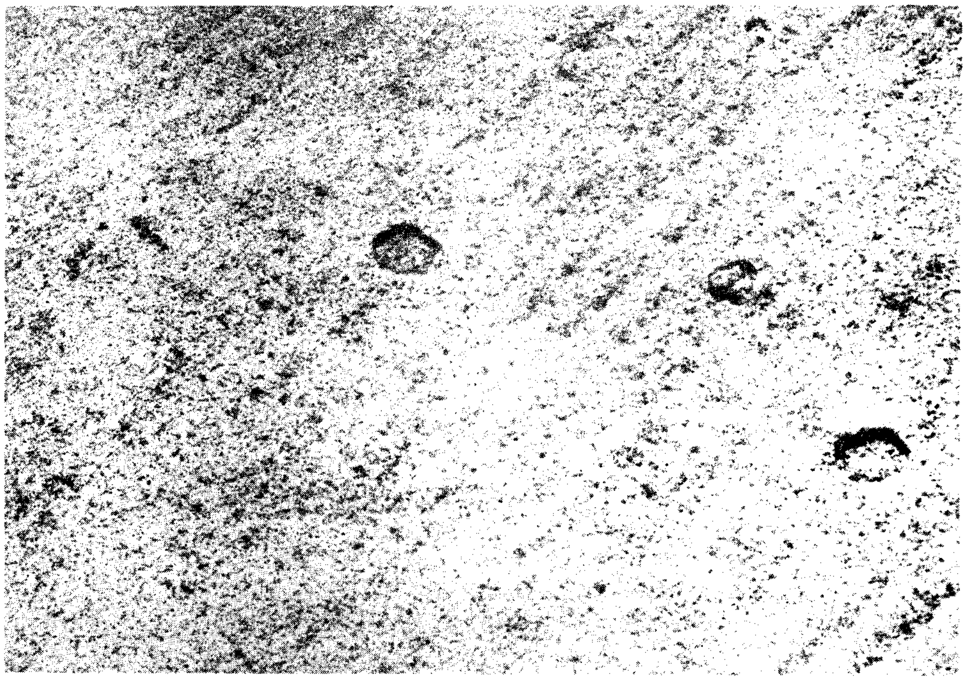


Figure 5. Close view of blisters in epoxy overlay with sand aggregate. Largest blister has a diameter of approximately 1".

Figure 6. Overall view showing distribution of blisters in epoxy test strip with sand aggregate.

As noted in the performance records for the individual epoxy resin compounds, areas of separation of the overlay with a layer of concrete attached occurred in five of the grit strips on the Occoquan Creek bridge and a similar separation was observed adjacent to cracks, as shown in Figure 7, in four of the strips. The deck concrete in the area of the grit strips generally appeared to be of poor quality, and bond tests conducted adjacent to one point of overlay distress produced breaks in the concrete at very low stresses, 48 and 80 psi. It appears likely that the failure in the concrete may have been caused by stresses resulting from thermal expansion and contraction of the overlay. As described previously, the coefficient of thermal expansion of the epoxy resin and grit mixture comprising the overlay is significantly higher than that of concrete.

Figure 7. Typical separation of the overlay with a thin layer of concrete attached, adjacent to a reflective crack in the grit strips on the Occoquan Creek bridge.

Cracking of the Overlays

All of the materials included in the test strip study exhibited reflective cracking, the formation of cracks in the seal coat over those in the deck slab, the distress being most evident in those strips which utilized the silica sand de-slicking aggregate. The work of Kubitschek, discussed previously, would indicate that the test strips containing the silica sand would be more dense than those containing the aluminum oxide grit of the size used in this study. It appears that the increased density of the strips is accompanied by a reduction in flexibility and a greater tendency toward reflective cracking.

The continuous spans on the Occoquan Creek bridge were much more flexible than the simply supported spans comprising the Ramp C bridge. Several cracks were noted in each of the two test areas on the Occoquan Creek bridge prior to the overlay applications, and reflective cracking was noted in every strip except the one containing Resiweld 7140 in conjunction with aluminum oxide grit during the initial field inspection six months after the applications. Cracking appeared at a later date in six of the sand strips and two of the grit strips on the ramp bridge, in which no cracks were noted at the time the overlays were placed.

A loss of the overlay for a distance of up to one inch adjacent to the length of reflective cracks was noted in some instances in the grit strips on the Occoquan Creek bridge. This phenomenon, which did not occur in the other groups of test strips, is ascribed to the presence of poor concrete in that portion of the deck and is not considered to be a normal result of reflective cracking. The pattern cracking in the surface of the Shell MRAX overlays containing silica sand aggregate is not reflective in nature. It is apparently due to some characteristic of the epoxy resin system, which exhibited the greatest difficulty with cracking during the test strip study.

Based on the results of this study, it is difficult to recommend an epoxy resin system which has superior resistance to reflective cracking or to present a method by which reflective cracking can be prevented. Unfortunately, most of the cracking was noted in those strips containing the small rounded aggregate which is apparently essential to the application of a void-free overlay. The consequences of reflective cracking should be considered in the evaluation of epoxy as a membrane seal on the deck of a flexible structure or one which exhibits a large number of cracks.

Wearing of the Overlays

At the beginning of the field tests a twelve hour traffic count, classified by lanes, was made for both structures. The counts showed a total of 4,574 vehicles crossing the Occoquan Creek bridge from 7 a.m. to 7 p.m., with the flow heaviest in the center lane (2,299 vehicles) and the right lane (1,878 vehicles) and very light in the left-hand passing lane (397 vehicles). A similar count on the Ramp C bridge showed approximately 4,500 vehicles crossing the bridge, the flow being equally divided between the two traffic lanes upon entry of the structure. Three traffic counts conducted in 1970 showed between 12,000 and 16,000 vehicles crossing the Occoquan Creek bridge between 7 a.m. and 7 p.m. While the rise in the volume of traffic has not been so dramatic in the case of the ramp structure, traffic counts indicate that in excess of 6,000 vehicles cross the bridge during the same twelve hour period. The periodic inspections of the test strips did not allow a correlation between the wearing of the strips and the rapidly increasing traffic volume.

The performance of the test strips under the heavy traffic volume was in general quite disappointing. Two years after application, in August 1966, most of the test strips exhibited at least small areas of exposed concrete, and seven grit strips and one sand strip were noted as wearing badly. It was noted that, if a completely waterproof seal coat was desired, many of the strips would require maintenance or replacement.

The test strips on the Occoquan Creek bridge were removed by grinding five years after application. The overlays on the ramp structure were inspected one additional time six years after application. During the final inspections, at least isolated areas of severe wear were noted in all of the test strips on both structures, and test strips of four of the materials showed large areas in which the overlay was completely worn away, exposing the deck concrete. The resistance to wear exhibited by the two Resiweld materials was generally superior to that of the others. The Concresive material proved to be less durable than the Resiweld systems but its performance was generally considered fair, while the performances of the remaining materials with respect to wear was generally poor. However, several factors other than material characteristics affected the performances of the exposed overlays.

Resistance to wearing under traffic appeared to be predominantly a function of the rate of application of the epoxy resin compound and, thus, the thickness of the finished overlay. The center lane of the Resiweld 7120 grit strip on the Occoquan Creek bridge, which had a relatively heavy application rate of 0.3 gallon per square yard (Table 4) exhibited excellent wear resistance throughout the tests. The Resiweld 7140 grit strips on the ramp bridge had significantly less evidence of wearing than did the other six grit strips in the area. The difference in the thickness of the overlay is considered to be the key factor in the superior performance of the Resiweld 7140 material, which appeared to be applied at a liberal rate, in contrast to the generally poor resistance to wear shown by the similar Sika Guardkote 140 material. With respect to wear, the poorest performances in the test strip study were those of the overlays made with the Sika Surface Kote and P. E. Surface Sealer systems. These rigid materials are applied at the light rates of 1/10 and 1/7 gallon per square yard, respectively, in order to avoid overstressing the concrete surface during thermal expansion and contraction. The resultant thin overlay does not provide sufficient durability under exposure to traffic.

The other factors affecting wear are those which determine the uniformity of the overlay. The normal flow of the epoxy resin compound causes a thin application of the material at high points on the deck surface, resulting in isolated areas of severe wear after relatively short exposure to traffic. Areas in which the deck surface is heavily textured are also subject to rapid wearing. The flow of the epoxy on a sloped surface, such as the superelevated deck of the ramp bridge, also presents difficulties in the even application of a seal coat. The long-term effect of the type of aggregate on wear resistance was variable. The two coal tar modified systems and the Concresive system exhibited slightly better wearing qualities when the aluminum oxide grit was used, while the more rigid systems had slightly better performance with the silica sand. The effect of the aggregate was significant mainly in the maintenance of skid resistance, which is discussed in a separate section of this report.

The fact that the best of the test strips had isolated areas of severe wear with exposure of the concrete deck surface indicates the need for an asphaltic wearing course to protect the epoxy seal from traffic, as recommended previously in this and other studies.(8,9) Use of a properly designed wearing course, which allows the relatively expensive epoxy application to function solely as a seal coat, greatly extends the service life of an overlay application. As will be discussed in the following sections, protection of the overlay is essential to its skid resistance and effectiveness.

Skid Resistance of the Overlays

Measurements of the skid resistance of the test strip overlays were made periodically throughout the course of the study. This work was concentrated on the applications on the Occoquan Creek bridge for two reasons: first, the structure carried the heaviest volume of traffic, and second, the path of the traffic followed well defined wheel paths in each of the three lanes.

Frictional values, a measure of skid resistance, were obtained primarily through the use of a British Portable Tester, shown in Figure 8, in accordance with a procedure described by the British Road Research Laboratory.(10) This device measures the frictional resistance as a rubber slider on the end of a pendulum crosses the wetted deck surface. A frictional value reading known as the British Pendulum Number, or BPN, is indicated on the scale by a pointer which is carried by the pendulum to the top of its swing. The average of five such readings is taken as the frictional value of the test location. A limitation of the skid resistance evaluations made in this study lay in the fact that the British Portable Tester measures the skid resistance over a distance of only five inches, and time generally permitted only two tests in each lane of the test strips. While a greater number of tests would have been required to accurately assess the frictional value of the overlays, it was believed that the data presented a valid indicator of changes in the skid resistance. Frictional values were obtained initially and at intervals of one, two, four, and five years after application of the overlays.

During the first two years of the study, the frictional value was measured at five random locations in each lane of each strip. An analysis of the data showed a pattern of variation transversely across the strip with low readings occurring in the wheel paths and higher readings at other points. Because of this transverse variation, the procedure was altered during later tests, and the frictional value was determined at two randomly selected points in the wheel paths in each lane. The heavy traffic and resultant difficulties in closing the structure during periods of peak flow necessitated the reduction in the number of test sites. Traffic control problems also prevented testing of the center lane except during the final inspections.

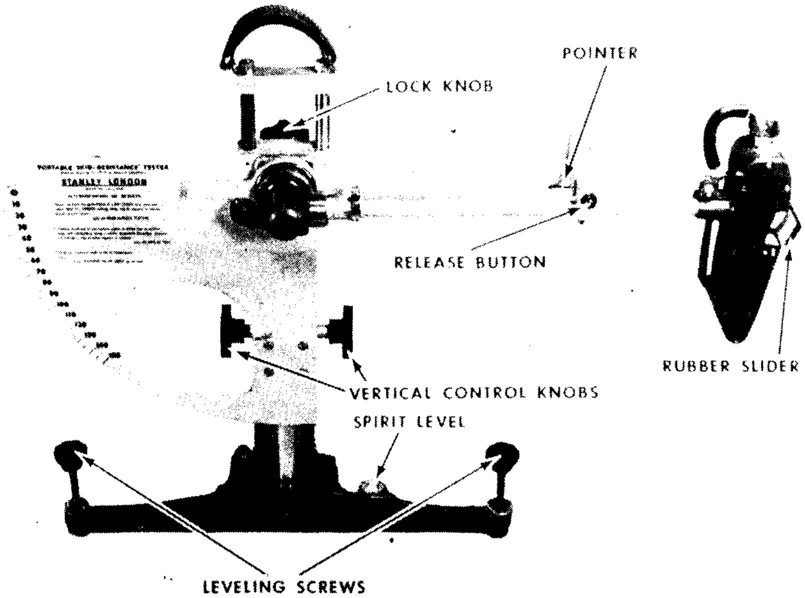


Figure 8. British Portable Skid Resistance Tester.

The initial tests showed the strips on the Occoquan Creek bridge to have frictional values of 78 and 72, respectively, for the grit and sand aggregates. The bare concrete deck had a frictional value of 72. The variation of frictional values between strips having the same deslicking aggregate was found to be insignificant, and the difference between the values for the grit and sand strips was significant at the 99 percent level, with the grit strips having the better skid resistance.

The frictional values for the first two years after application, shown in Tables 5 and 6, are the lowest values for which no significant difference could be determined by means of an analysis of variance. It was believed that the lowest comparable group of values represented the skid resistance of the most worn portion of the strip. The frictional values obtained at the ends of the fourth and fifth years, shown in Tables 7 and 8, were all taken in the vehicle wheel paths.

Although an analysis of the two year data gave some indication that the frictional values might stabilize after an initial loss, the later data show a continuing marked decline in the skid resistance of the overlays, demonstrated emphatically by a comparison of the two year and four year data for the right-hand traffic lane. Frictional values obtained during the final inspection in the relatively unworn area adjacent to the curbs ranged from 67-74 for the grit strips and 63-64 for the sand strips, showing only a slight decline from the initial values of 78 and 72. The comparison of materials is generally obscured by the fact that the British Portable Tester records the frictional value of only a small area of the surface, and rather large differences in the readings were often observed between sites in a single material.

TABLE 5

MEANS OF LOWEST COMPARABLE FRICTIONAL VALUES (BPN)
ONE YEAR DATA - OCCOQUAN CREEK TEST STRIPS

Right Lane

Grit Strips			Sand Strips		
Concresive	—	63	MRAX	—	57
Surface Sealer	—	67	Guardkote	—	59
Bare Concrete	—	68	Resiweld 7140	—	60
Surface Kote	—	69	Surface Sealer	—	62
Guardkote	—	69	Resiweld 7120	—	63
Resiweld 7140	—	70	Concresive	—	64
MRAX	—	70	Surface Kote	—	64
Resiweld 7210	—	70	Bare Concrete	—	68

Left Lane

Grit Strips			Sand Strips		
Bare Concrete	—	64	MRAX	—	62
Concresive	—	70	Bare Concrete	—	64
Resiweld 7140	—	73	Guardkote	—	64
MRAX	—	74	Concresive	—	65
Surface Sealer	—	74	Resiweld 7140	—	66
Surface Kote	—	74	Resiweld 7120	—	67
Guardkote	—	75	Surface Sealer	—	69
Resiweld 7120	—	75	Surface Kote	—	70

TABLE 6

MEANS OF LOWEST COMPARABLE FRICTIONAL VALUES (BPN)
TWO YEAR DATA - OCCOQUAN CREEK TEST STRIPS

Right Lane

Grit Strips			Sand Strips		
Bare Concrete	—	66	Resiweld 7140	—	55
Resiweld 7140	—	66	MRAX	—	59
Surface Sealer	—	68	Surface Sealer	—	60
Surface Kote	—	70	Bare Concrete	—	60
Resiweld 7120	—	71	Concresive	—	62
Concresive	—	71	Guardkote	—	62
Guardkote	—	72	Resiweld 7120	—	65
MRAX	—	74	Surface Kote	—	70

Left Lane

Grit Strips			Sand Strips		
Resiweld 7120	—	67	Resiweld 7120	—	62
Bare Concrete	—	69	Bare Concrete	—	62
Surface Kote	—	71	Resiweld 7140	—	62
Concresive	—	71	Guardkote	—	63
Resiweld 7140	—	72	Surface Sealer	—	64
Surface Sealer	—	72	Concresive	—	64
MRAX	—	73	Surface Kote	—	65
Guardkote	—	73	MRAX	—	66

TABLE 7

MEAN FRICTIONAL VALUE (BPN) IN WHEEL PATHS
FOUR YEAR DATA - OCCOQUAN CREEK TEST STRIPS

Right Lane

Grit Strips			Sand Strips		
Bare Concrete	—	57	Resiweld 7140	—	41
Guardkote	—	58	Guardkote	—	43
Resiweld 7140	—	60	Concresive	—	48
Surface Sealer	—	60	MRAX	—	48
MRAX	—	61	Surface Sealer	—	48
Concresive	—	62	Surface Kote	—	52
Surface Kote	—	63	Resiweld 7120	—	53
Resiweld 7120	—	63	Bare Concrete	—	56

Left Lane

(No Tests Performed)

TABLE 8

MEAN FRICTIONAL VALUE (BPN) IN WHEEL PATHS
FIVE YEAR DATA (FINAL) - OCCOQUAN CREEK TEST STRIPS

Right Lane

Grit Strips			Sand Strips		
Resiweld 7140	—	52	Resiweld 7140	—	44
Surface Sealer	—	52	Guardkote	—	44
Guardkote	—	53	Surface Kote	—	44
Concresive	—	53	Concresive	—	46
Surface Kote	—	57	Resiweld 7120	—	50
Resiweld 7120	—	57	Surface Sealer	—	50
Bare Concrete	—	61	MRAX	—	52
MRAX	—	62	Bare Concrete	—	56

Center Lane

Grit Strips			Sand Strips		
Resiweld 7140	—	42	Resiweld 7140	—	38
Guardkote	—	42	Guardkote	—	40
Surface Sealer	—	43	Resiweld 7120	—	42
Surface Kote	—	44	MRAX	—	43
Concresive	—	46	Surface Kote	—	44
Resiweld 7120	—	46	Surface Sealer	—	46
Bare Concrete	—	58	Concresive	—	50
MRAX	—	60	Bare Concrete	—	56

Left Lane

Grit Strips			Sand Strips		
Guardkote	—	53	Resiweld 7140	—	44
Resiweld 7140	—	56	Guardkote	—	46
MRAX	—	56	Surface Sealer	—	48
Surface Sealer	—	57	Resiweld 7120	—	48
Concresive	—	58	Concresive	—	49
Surface Kote	—	61	Surface Kote	—	50
Resiweld 7120	—	61	MRAX	—	52
Bare Concrete	—	62	Bare Concrete	—	58

It should be noted that after five years the bare concrete deck generally exhibits better skid resistance than the overlays. The relative superiority in the frictional value of the bare concrete was later confirmed by tests using the Virginia Highway Research Council skid trailer.

An analysis of variance performed on the data presented in Table 8 showed the difference in aggregates to be most significant, the difference in lanes to be half as significant as that of the aggregate type, and the difference between materials to be of minimal significance. The British Portable Tester results indicated that the MRAX material differed significantly from the Resiweld 7140 and Guardkote systems in frictional value, but the subsequent tests using the skid trailer failed to confirm the difference in skid resistance.

The frictional values obtained through the use of the skid trailer were converted to the predicted car values shown in Tables 9 and 10. These data show the MRAX test strips to have relatively low skid resistance, in contrast to the data presented previously. The incongruity was probably due to the nature of the surface texture of the strips.

The predicted car values indicate that the sand strips had only marginal skid resistance with respect to the minimum value of 40 acceptable in Virginia. The values taken in February 1969 formed the basis for the decision to remove the strips from the deck surface; the August values were taken just prior to the removal of the overlays.

The predicted car values confirm the fact that use of the small rounded silica sand is unacceptable in an exposed overlay and that an additional wearing course must be included in the application. While the skid resistance of the grit aggregate strips was acceptable in all cases, the results show that loss of skid resistance is a limiting factor in the service life of an overlay application.

The data in Table 10 indicate that the two coal tar modified systems containing the large angular grit particles have relatively low skid resistance. During the inspections it was noted that these strips tended to lose aggregate and polish under exposure to traffic, presenting a smooth shiny surface, as shown in Figure 9. Existing overlay applications of coal tar modified epoxy resin systems should be evaluated periodically for loss of skid resistance.

TABLE 9

FRICTIONAL VALUE (PREDICTED CAR VALUE) IN WHEEL PATHS FEBRUARY, 1969 — OCCOQUAN CREEK TEST STRIPS

Right Lane

Grit Strips			Sand Strips		
Guardkote	—	47	MRAX	—	39
MRAX	—	48	Guardkote	—	40
Concresive	—	48	Surface Sealer	—	40
Surface Sealer	—	48	Resiweld 7140	—	40
Resiweld 7120	—	48	Concresive	—	41
Resiweld 7140	—	50	Surface Kote	—	42
Surface Kote	—	50	Resiweld 7120	—	44
Bare Concrete	—	52	Bare Concrete	—	52

Center Lane

Grit Strips			Sand Strips		
Surface Sealer	—	43	Surface Sealer	—	39
Guardkote	—	46	Guardkote	—	39
Concresive	—	47	MRAX	—	39
Surface Kote	—	47	Resiweld 7140	—	40
MRAX	—	48	Concresive	—	42
Resiweld 7140	—	49	Resiweld 7120	—	42
Resiweld 7120	—	49	Surface Kote	—	43
Bare Concrete	—	51	Bare Concrete	—	51

Left Lane

Grit Strips			Sand Strips		
Guardkote	—	50	Surface Sealer	—	42
MRAX	—	50	MRAX	—	43
Concresive	—	51	Guardkote	—	44
Surface Sealer	—	52	Resiweld 7140	—	45
Resiweld 7140	—	54	Concresive	—	45
Resiweld 7120	—	56	Resiweld 7120	—	46
Bare Concrete	—	56	Surface Kote	—	51
Surface Kote	—	57	Bare Concrete	—	56

TABLE 10

FRICTIONAL VALUE (PREDICTED CAR VALUE) IN WHEEL PATHS
AUGUST, 1969 — OCCOQUAN CREEK TEST STRIPS

Right Lane

Grit Strips			Sand Strips		
MRAX	—	42	MRAX	—	38
Guardkote	—	43	Surface Sealer	—	38
Resiweld 7140	—	44	Guardkote	—	39
Surface Kote	—	45	Concresive	—	39
Resiweld 7120	—	45	Resiweld 7140	—	40
Surface Sealer	—	46	Surface Kote	—	40
Concresive	—	47	Resiweld 7120	—	43

Center Lane

Grit Strips			Sand Strips		
Concresive	—	44	MRAX	—	36
Guardkote	—	45	Resiweld 7140	—	38
Resiweld 7140	—	45	Surface Sealer	—	39
Surface Sealer	—	45	Guardkote	—	39
Surface Kote	—	46	Resiweld 7120	—	41
MRAX	—	46	Concresive	—	41
Resiweld 7120	—	47	Surface Kote	—	43

Left Lane

Grit Strips			Sand Strips		
Surface Sealer	—	44	MRAX	—	41
Guardkote	—	45	Surface Sealer	—	41
MRAX	—	45	Guardkote	—	42
Resiweld 7140	—	47	Resiweld 7140	—	43
Resiweld 7120	—	47	Resiweld 7120	—	44
Surface Kote	—	48	Surface Kote	—	46
Concresive	—	48	Concresive	—	48

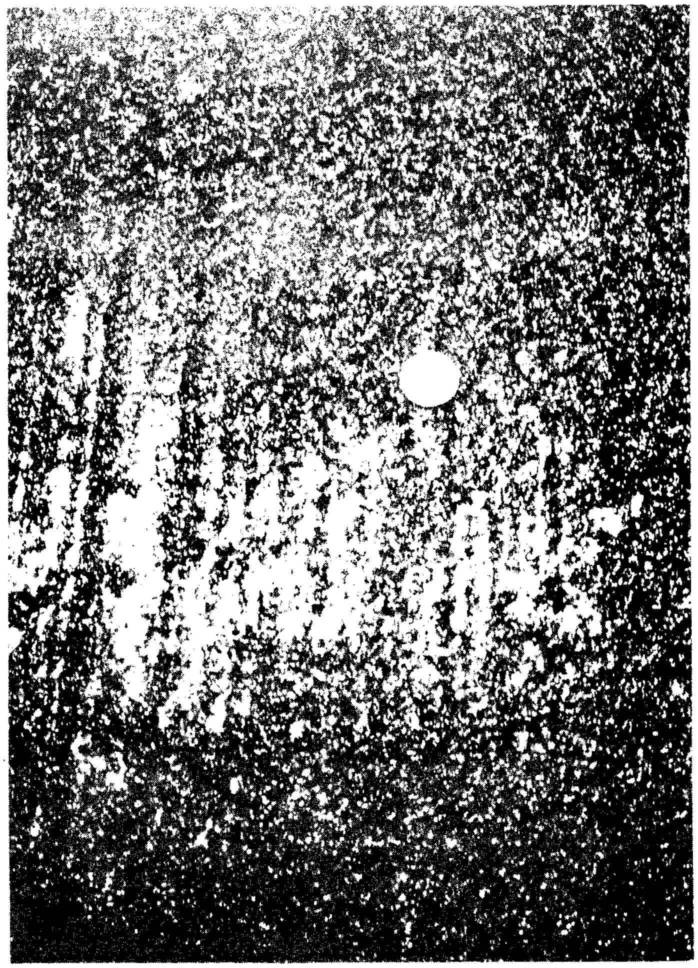


Figure 9. Polishing of the surface in a worn area of a coal tar modified epoxy resin test strip with aluminum oxide deslicking aggregate.

Effectiveness of the Overlays

It was desired that thin bonded overlay applications of the type included in the field tests serve either or both of two functions: provision of a skid resistant surface on a bridge deck, and sealing of the deck surface to provide a protective moisture barrier. The results of the test strip applications indicate that a thin bonded overlay exposed to heavy traffic cannot be relied upon to meet these requirements for any extended period of time.

The frictional value data presented in the preceding section showed the test strips utilizing large angular grit particles to be subject to a continuing decline in skid resistance, approaching marginal values after five years' exposure to traffic. Several of the strips utilizing the fine rounded silica sand, which provides a superior moisture barrier, showed unacceptable skid resistance at five years.

The effectiveness of the moisture barrier can be negated by either improper surface preparation or wear. Failure to remove concrete of poor quality from the deck resulted in the loss of considerable areas of the protective overlay on the Occoquan Creek bridge, and it is obvious that the application of an epoxy resin overlay can neither protect such concrete nor compensate for its questionable quality. Failure to allow time for proper drying of the deck concrete resulted in the formation of blisters in the overlay that destroyed the integrity of the overlay and allowed, in one case, deterioration of the underlying concrete.

Loss of the effectiveness of worn portions of the test strips as moisture barriers was evidenced by the occurrence after the epoxy applications of four popouts due to the presence of expansive chert aggregate particles in the concrete of the ramp bridge. The presence of moisture is essential to the expansion of the aggregate.[11] A more serious form of distress was the spalling of the concrete in worn areas of seven test strips of both aggregate types on the ramp bridge. The spalling, which was also evident in unprotected areas of the deck, was due to insufficient cover over the reinforcing steel, now acknowledged to be the principal factor in the occurrence of the distress.[12] The exposed thin bonded overlay was not capable of protecting the deck from serious deterioration after five years of wearing under traffic. The addition of a separate wearing course is obviously essential to proper performance of the overlays as seal coats.

Observation of Full-Scale Applications

Several bridge deck overlays were observed throughout the study in an effort to supplement the detailed test strip evaluations with general information on the performance of full-scale applications of epoxy seal coats, including some with asphaltic concrete wearing courses, on decks of varying ages. Most of the field observations were of coal tar modified epoxy resin systems, as this is the compound commonly specified in Virginia; however, three installations of a relatively thick epoxy mortar overlay utilizing Guardkote 250 were also evaluated. The general field survey, which will be described only briefly, essentially confirmed the findings of the test strip studies.

Acca Yards Bridge, Richmond, Virginia

Approximately one year after the Washington area test strips were placed, a full-scale application of a thin bonded overlay of an oil modified epoxy resin system, Guardkote 140, was made on the newly completed Acca Yards Bridge in Richmond. The application was observed and reported in some detail in an earlier report in this study.[9]

Surface preparation was accomplished by sandblasting after the deck had been checked for soundness. The deck surface had several light oil spots which remained after surface preparation, but future inspections disclosed no delamination of the overlay in the affected areas. The epoxy resin system was spread on the deck with notched rubber squeegees and a silica sand deslicking aggregate was applied by hand.

An inspection of the bridge approximately one year after the completion of the application revealed the presence of isolated areas on the deck from which the overlay had apparently been scraped, perhaps by snow removal equipment. An inspection approximately one and one half years after the application revealed several areas of severe wear in the lanes exposed to the heaviest traffic. The deck concrete was visible in these areas, although a very thin film of epoxy without grit remained. The relatively rapid appearance of severely worn areas was probably due to the effect of high spots in the deck surface or the lack of uniformity of the hand application of the epoxy compound.

Subsequent inspections have shown severe wearing of the exposed overlay in a pattern similar to that observed in the test strip applications. The isolated areas showing severe wear increased in size under exposure to traffic, and five years after application the overlay is severely worn with substantial areas of exposed concrete. The application is showing signs of the loss of aggregate and polishing typical of the performance of the coal tar modified systems in the test strip study, and it is possible that its skid resistance may be low.

General Survey of Epoxy Applications

Overlays composed of a coal tar modified epoxy resin system with silica sand of various sizes on approximately fifty structures were inspected and their performance briefly recorded during the course of the study. In contrast to the test strip and Acca Yards applications, these overlays had been placed on older structures, many of which had exhibited deck deterioration, as part of the Department of Highways maintenance program.

Almost without exception the exposed thin bonded overlays exhibited wear accompanied by at least small isolated areas of exposed deck surface at high points often located near the crown of the roadway or at the joints. While wear was not severe on many rural highways with low traffic volumes, the overlays were virtually completely worn off some of the heavily traveled structures, and severe wear was generally apparent in the wheel paths of overlays on major highways. Several of the worn areas exhibited the characteristic polishing noted in the test strip applications, and the exposed overlays with small grained sand aggregate usually had evidence of a decline in skid resistance.

Delamination of the overlay due to improper bond was noted in several instances. Often the distress was confined to very small areas with good bond evident at the edges. Delamination of the earliest overlays, which were often applied on older bridges with heavy traffic flow, was occasionally quite severe; proper surface preparation in such cases is extremely difficult.

The proper placement of an overlay remains something of an art. Applications made by experienced contractors generally exhibited little distress connected with surface preparation or application techniques. Other applications showed marked differences in performance between individual batches of the epoxy compound, and some of the overlays appeared to contain material which had not completely reacted, possibly because of insufficient mixing of the components.

The survey disclosed instances of distress in the concrete deck in conjunction with overlays containing both fine and coarse aggregate. The cause of the distress was difficult to determine, but it was usually associated with a severely worn overlay or apparently poor concrete.

Eighteen of the overlays in the survey had asphaltic wearing courses. The main problem noted in these cases was the occasional loss of the asphaltic material over steel deck joints, but the distress was localized and did not appear to be serious. With the exception of one instance in which areas of a poorly compacted wearing course had been removed by traffic, the installations appeared to be satisfactory with no evident distress. However, one disadvantage of the wearing course is the fact that it can obscure any distress associated with the epoxy seal coat.

In summary, the general field survey reinforced the findings of the test strip evaluations in pointing out the need for thorough cleaning of the deck surface, removal of poor concrete, and careful mixing of the components of the epoxy resin system. The inspections also indicated the need for and effectiveness of asphaltic wearing courses to protect the epoxy seal coats.

Epoxy Mortar Overlays

A final set of applications included in this study were three epoxy mortar overlays, 3/8 inch in thickness, with a screeded top surface. These applications promised three major advantages: the incorporation of surface patching and deck sealing in a single maintenance operation, superior durability and renewal of skid resistance due to the thickness of the overlay, and improved riding quality resulting from the screeded top surface. Unfortunately, the performance of two of the overlays has been unsatisfactory.

The application of one of the three mortar overlays was observed. The structure, which was located on Interstate Route 81, was badly deteriorated with both cracking and spalling of the deck in several areas. The surface was prepared by sandblasting after the removal of all poor concrete. Exposed reinforcing steel was cleaned with wire brushes just prior to placement of the overlay.

The epoxy resin system used in the application was Guardkote 250, the Shell MRAX compound included in the test strip studies, and the aggregate was an angular silica sand. The mortar was mixed in a plaster mixer and placed continuously in front of the screed, shown in Figure 10. The screed, which covered approximately seven feet of deck width on each pass, was pulled along steel rails at a uniform rate, and the only hand finishing generally required was at the edges of the strip. The overall appearance of the overlay was attractive, and the surface seemed to be free of open voids.

An inspection approximately two and one half years after application of the overlay showed it to be wearing well, and its skid resistance was believed to be quite satisfactory. However, two large areas, one approximately 3 feet square and the other 2 feet by 4 feet, of delamination were noted. Relatively little of the overlay had been

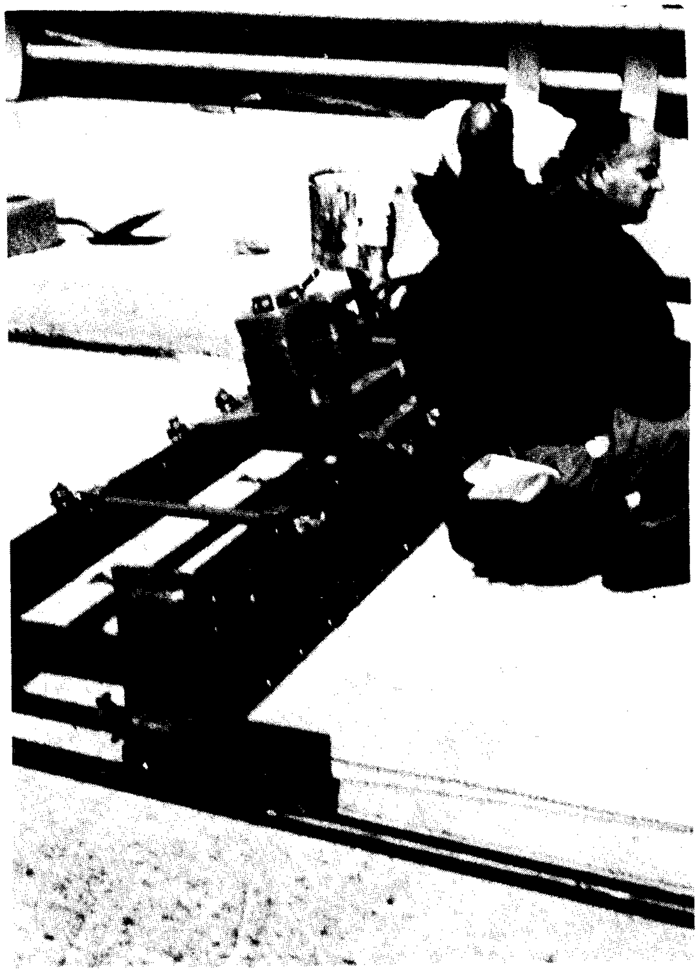


Figure 10. Screed used to finish the top surface of the Guardkote 250 mortar overlay.

lost, as shown in Figure 11, but the large areas were unbonded. A second application, also applied to a severely deteriorated deck, exhibited extreme distress including loss of the overlay and the development of severe cracking quite rapidly. The third overlay, a more recent application, has been inspected only once, slightly less than one year after its placement. No distress of any sort was noted at that time.

The delamination of the overlay is due to loss of bond rather than the presence of inferior concrete, and it appears that the problem is one of application. In spite of the fact that the mortar mixture was pulled aside periodically to ensure proper wetting of the deck surface by the epoxy binder, the bottom of pieces of the overlay removed during inspections have a porous appearance with many voids apparent, indicating poor wetting of the surface. There is no indication that the failure was due to the nature of the oil modified epoxy resin system, which is not 100 percent reactive.

Because of the poor performance of two of the three mortar overlays, use of the procedure cannot be recommended.

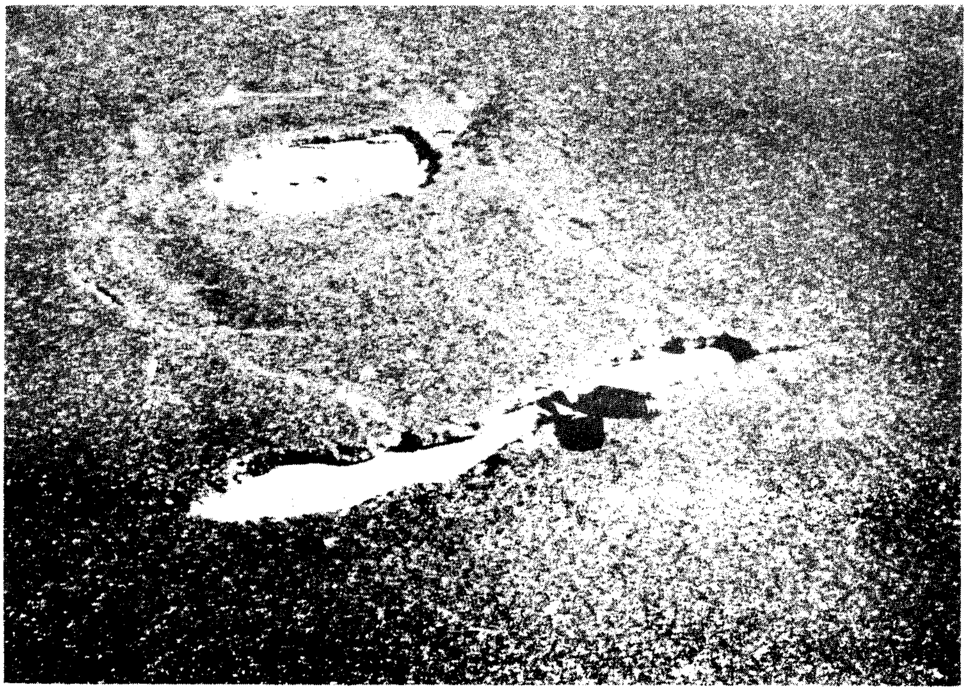


Figure 11. Delamination of the Guardkote 250 overlay due to loss of bond.

CONCLUSIONS

The conclusions drawn from this study are based on observations of the test strip installations of seven epoxy resin compounds, supplemented by inspections of approximately fifty full-scale applications of thin bonded overlays, all of which utilized a coal tar modified system. It is believed that the findings listed below are pertinent to the application of thin bonded overlays of most common epoxy resin systems. Alternate methods of deck protection, of which there are many available, were not investigated.

1. The coefficient of thermal expansion of an epoxy resin compound may range from approximately seven to more than ten times that of concrete. While the difference is decreased markedly by the addition of aggregate to the epoxy system, the resulting coefficient remains significantly higher than that of concrete, and stresses resulting from thermally induced expansion and contraction of an epoxy patch or overlay can cause fracture in the underlying concrete if it is not structurally sound. Placement of an epoxy overlay is not appropriate to remedy the presence of concrete of poor quality in a bridge deck.

2. Proper bond of an epoxy overlay is vital to its proper performance, but it must be realized that an epoxy paving cement need not function as a structural adhesive. Delamination of the overlays was a serious problem in only one instance in the test strip study, and it appears that bond strength requirements for adhesives might be unduly restrictive with respect to compounds intended for use as seal coats.

3. Properly performed, either acid etching or sandblasting can provide a suitably clean surface for the application of epoxy compounds. The use of sandblasting is recommended because it can be accomplished without the application of water to the deck surface.

4. If the deck surface is wetted, it must be given ample time, probably more than twenty-four hours, in which to dry.

5. The test strip study reinforces the work of others in indicating that particle size and shape influence the formation of open voids, or pinholes, in an overlay.[7] Use of an aggregate composed of rounded particles passing the number 20 sieve is recommended, but an overlay made with this aggregate must be covered by a wearing course because of low skid resistance.

6. Reflective cracking, the formation of cracks in the seal coat over those in the deck concrete, is apparently a problem common to many epoxy compounds, and the consequences of such cracking should be considered in the choice of an epoxy membrane versus a seal of some other type.

7. Wearing of an exposed epoxy overlay under traffic, as manifested in the loss of both skid resistance of the surface and protection afforded the underlying concrete, is the definitive factor in the service life of the application. Use of an asphaltic wearing course to protect the epoxy seal coat is considered essential to the continued effectiveness of an overlay application.

8. Regardless of the type of deslicking aggregate employed, unprotected epoxy overlays suffer a continuing decline in skid resistance under exposure to traffic. The skid resistance of such overlays, particularly those containing coal tar modified epoxy resin systems which tend to lose aggregate and polish, should be evaluated periodically.

9. The results of this study do not indicate a superior epoxy compound for use in sealing bridge decks. Use of the two rigid systems, Surface Kote and P. E. Surface Sealer, which have a recommended rate of application too thin to provide durability, is not recommended in exposed overlay applications. The coal tar modified systems, which are among the most widely used compounds, performed as well as any in the study.

10. Based on the results of this study, there is no reason to believe that a bridge deck cannot be effectively sealed by means of an epoxy membrane. There are, however, many pitfalls in the application procedure, and careful attention to the details of the technique is mandatory.

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