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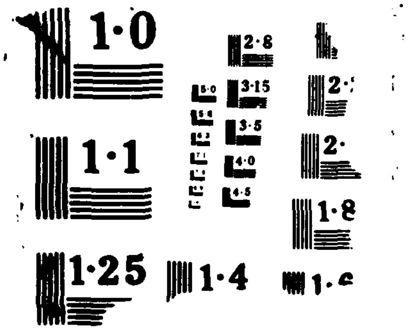
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**REPAIR, EVALUATION, MAINTENANCE, AND
REHABILITATION RESEARCH PROGRAM**

TECHNICAL REPORT REMR-CS-17

SURFACE TREATMENTS TO MINIMIZE CONCRETE DETERIORATION

Report 1

SURVEY OF FIELD AND LABORATORY APPLICATION AND AVAILABLE PRODUCTS

by
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Structures Laboratory

DEPARTMENT OF THE ARMY
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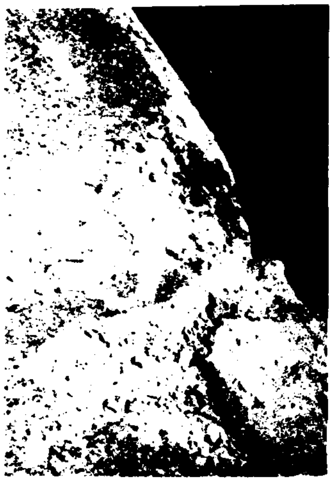

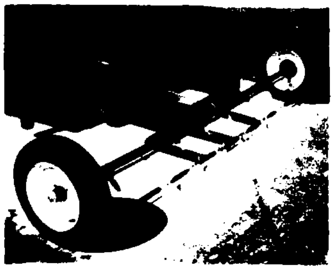

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April 1988
Report 1 of a Series

Approved For Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000
Under Civil Works Work Unit 32302

2 8

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	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Surface spalling - ice protection - Brandon Road

MIDDLE — Lock and Dam, Joliet, Illinois

BOTTOM — Application of surface sealer, McClellan Air Force Base, Sacramento, California

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A literature search was conducted for information about materials used to protect concrete. Little information was found concerning field testing and evaluation of these materials. However, there were several reports describing laboratory testing and results of different chemical compounds and brand-name products. Case histories of materials applied on Corps of Engineers projects are documented within.

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A report of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

18. SUBJECT TERMS (Continued).

Sealers
Surface treatments
Stone consolidants
Vapor transmittance

PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Work Unit 32302, "Surface Treatments to Minimize Concrete Deterioration," for which Mr. Tony B. Husbands, Concrete Technology Division (CTD), Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), is Principal Investigator. This work unit is part of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. Mr. James E. Crews (DAEN-CWO-M) and Dr. Tony C. Liu (DAEN-ECE-D) make up the Overview Committee for REMR and provided overall direction. The HQUSACE Technical Monitor for this effort was Dr. Liu.

The study was conducted at WES during the period October 1984 to October 1985 under the general supervision of Messrs. Bryant Mather, Chief, SL; John M. Scanlon, Chief, CTD; and R. L. Stowe, Chief, Materials and Concrete Analysis Group, CTD. Problem Area Leader for the Concrete and Steel Structures Problem Area is Mr. James E. McDonald, CTD. Program Manager for REMR is Mr. William F. McCleese, CTD. This report was prepared by Mr. Dennis L. Bean, CTD.

The author wishes to express his deep appreciation to the following individuals in the District and Division offices who gave of their valuable time and knowledge:

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Leo Cain, Mobile District
George Hunt, Vicksburg District

Anyone wishing to correct, amend, or add to any of these, or other, case histories may address documented comments to: Mr. Tony B. Husbands or Mr. Dennis L. Bean, US Army Engineer Waterways Experiment Station (ATTN: WESSC-M), PO Box 631, Vicksburg, MS 39180-0631.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
angstroms	1.0×10^{-10}	metres
centipoises	0.001	pascal-seconds
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons (US liquid)	3.785412	litres
gallons per square foot	4.5273149	litres per square metre
inches	25.4	millimetres
mils	0.0254	millimetres
ounces (US fluid)	0.02957353	cubic decimetres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square yards	0.8361274	square metres

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SURFACE TREATMENTS TO MINIMIZE CONCRETE DETERIORATION
SURVEY OF FIELD AND LABORATORY APPLICATION AND AVAILABLE PRODUCTS

PART I: INTRODUCTION

Background

1. The surfaces of many of the Corps' concrete structures are subject to deterioration due to freezing and thawing, weathering, chemical attack, erosion, and other destructive mechanisms. Surface treatment of the concrete with a material to retard action of the forces is one way to reduce the rate of or eliminate deterioration.

2. In the past, various surface treatments have been applied to concrete; some were successful, while others failed. In most cases the failures were due to either selection of the wrong surface treatment material or improper application. There is a need to evaluate various surface treatments to determine which would offer the best protection and what would be the proper ways to apply them.

Objective

3. The objective of this study was to obtain information on the types of current surface treatment materials available, chemical compositions, and properties, and the performance of these materials in service conditions.

Approach

4. The current market was surveyed to determine sources for surface treatments which might be of potential value to reduce or eliminate the further deterioration of concrete.

5. A literature search was made to find test results on commercially available surface treatment materials. It was thought that these findings

could indicate candidate materials that could be applied to concrete to prevent excessive deterioration.

6. A field survey of concrete surface treatments which had been applied to concrete on Corps of Engineers projects was conducted to evaluate the performance of the different materials used. The survey was conducted by reviewing periodic inspection reports from the Corps of Engineers District and Division offices that are on file with the Office, Chief of Engineers, US Army. The remainder of information on surface treatments was provided by personnel in the District/Division offices.

PART II: LITERATURE SEARCH AND LABORATORY TESTING RESULTS

7. A literature search was conducted to gather information about surface treatments for concrete, primarily those treatments which could be used to prevent or reduce damage incurred by various deteriorating mechanisms. Several references were found that discussed the necessities of waterproofing. Other references concerned the subjects of "waterproofing"* and stone consolidants.** Several articles were found which related to preventing water from entering concrete; materials included paints, coatings, sealers, and membranes. Several articles discussed the prevention of chlorides from penetrating concrete. Other articles concerned laboratory testing on the prevention of absorption of water into newly prepared concrete specimens.

8. Most of the information obtained was from reports on bridge-deck treatments and stone consolidants (US Army Engineer District, Rock Island 1984). With bridge-deck treatments, the main concern was with chloride penetration. With stone consolidants, there was a twofold interest. One was to prevent the intrusion of water and the other was to strengthen the stone. Although the treatments of bridge decks and stone are not identical to the treatment of concrete used in hydraulic structures, the principles are basically the same and useful data were obtained from these reports. With bridge-deck treatment, the top surface can be completely sealed to stop moisture and vapor transmittance because the underside of the bridge deck is not treated and allows vapors to escape from the concrete.

9. One of the problems discovered about the use of sealants and coatings on concrete is that the natural alkalinity of concrete attacks certain organic materials, resulting in a failure of those materials to protect the concrete (US Army Engineer District, Rock Island 1984).

10. Another problem is that some coatings and sealants can plug the pores that exist in concrete. Water or water vapor that enter the concrete at a different location (for example, concrete in contact with water) can migrate through the concrete resulting in water trapped beneath the surface treatment

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* "Waterproofing" is a term in widespread use but one that should never be used since it implies an absolute and hence impossible condition.

** Definitions of key words and brief descriptions and general characteristics of some of the chemical classifications of surface treatment materials are found in Appendix A.

material. If no treatment was applied, this water could evaporate into the surrounding atmosphere. If this water cannot escape, it can become frozen in the concrete when exposed to freezing conditions. If entrapped water in the concrete and at the surface treatment to concrete interface freezes, it can cause the surface treatment to become debonded. Sometimes these types of surface treatments can cause more damage to the concrete than if nothing was applied.

11. Additional damage to the concrete can occur if these types of surface treatment materials are applied to a water-saturated concrete and then subjected to freezing and thawing. The ability of a sealer to allow water vapor to escape from the substrate is referred to as breathability. The ideal surface treatment material is one that prevents water from entering and is breathable.

12. Sealants or other surface treatments may be inorganic or organic. The two general types (Clifton 1980) of organic material are: (a) molecules that are polymerized, dissolved in a solvent, and then applied to stone or concrete; and (b) molecules that are applied to stone or concrete and then polymerized within the voids and pores of stone or concrete.

13. Several references were found which discussed basic information on the use of some materials to waterproof or consolidate stone. Much information was found on the materials for waterproofing stone. Several sources gave results of types or classes of chemical compounds (not marketed brand name). This information should prove useful in determining which type or class of material has the potential to perform well as a coating or sealer. However, there may be some exceptions because sometimes the brand name products are a modification of a basic chemical type (e.g., some silane manufacturers claim their products have been modified to correct the deficiencies of silanes) (Pfeifer and Perenchio 1984). The American Concrete Institute (ACI) states that there is "no guarantee that materials made by different manufacturers will perform the same, even when classified as the same generic type" (ACI 1979).

14. Although stones are not identical in structure to portland cement concrete, the mechanics of damage caused by freezing and thawing should be similar for concrete and stone. Knowledge of the surface treatment materials and concentration used to protect stone should prove beneficial in the selection of material to be applied to concrete. The ability of some surface

treatment materials to prevent the intrusion of water in stone is shown in Table 1.

15. With limestone consolidants, it has been found that some materials containing solvents which evaporate rapidly tend to draw the consolidant back to the surface (Clifton 1980). This results in the formation of an impervious hard surface crust with a linear coefficient of thermal expansion different from that of the unconsolidated stone. The elastic modulus of the consolidated stone tends to restrain the movement of the unconsolidated portion of the stone, thereby causing severe stresses at the interface during temperature changes (ACI 1980). According to Clifton (1984), "A large difference in the thermal expansion of consolidated stone and untreated stone may produce sufficient internal tensile stresses to cause development of cracks at the interface between the consolidated and untreated stone."* Table 2 shows the mean coefficient of thermal expansion for some treated stone.

16. Several references discussed the ability of some concrete sealers to prevent the entry of chloride ions into the concrete. They contain data on the chloride content in test specimens with various sealers compared with a control specimen coated with linseed oil. It may be possible to use these data on chloride content to get an indication of the water that was absorbed by the specimens during this testing. Although the testing for chloride penetration and for water absorption are not the same, it is assumed that the chloride ions migrate by fluid mechanics (Schutz 1978). Therefore, the amount of chloride present in a specimen could be an indication of the amount of water the sealer has allowed to pass into the specimen.

17. Sealers that allowed the entry of more chloride than did the control specimen are assumed to have allowed more water to enter the specimen than did the control. Likewise, sealers that allowed less chloride to enter are assumed to have allowed less water to enter the specimen.

18. The product name, manufacturer, chemical classification, and percentage of chloride that has entered the concrete compared to the control are shown in Tables 3 and 4. The testing was performed by the Ohio Department of

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* It is the opinion of the author that large differences in thermal expansion of the surface-treated layer of concrete and the substrate concrete could cause more deterioration than if nothing was applied. This is explained in paragraph 20.

Transportation (Dynamit Nobel 1981) and the Pennsylvania Department of Transportation (Dolphin Industries 1984, Sinak Corporation 1983).

19. In 1969, Highway Research Record published a report, "Investigation of Concrete Protective Sealants and Curing Compounds" (Stewart and Shaffer 1969). The project evaluated 32 separate products to determine the resistivity of treated concrete to the effects of freezing and thawing. The products were applied at a rate recommended by the manufacturer. Testing involved the ponding of water on the treated surface and subjecting the specimens to cycles of freezing and thawing. Types of materials and the results of the freezing and thawing test are shown in Tables 5 and 6.

20. The surface treatments evaluated were applied to different types of concretes; therefore it is difficult to make a direct comparison of the effectiveness of different materials. The percentages shown in Table 5 were calculated from a visual comparison of the treated surface and the control. The values shown in Table 6 are the result of visual comparison ratings where 0 represents no damage and 5 is the most severe damage. In Table 5, results show that many of the treated specimens sustained more damage than did the control. This indicates that some materials (probably water-vapor-impermeable material or materials that can produce a layer with a different thermal expansion than the substrate) can actually accelerate the rate of deterioration of water-saturated concrete subjected to freezing and thawing. Although these test results are for materials on the market in 1969, they should indicate how the different classes of material perform.

21. Porter (1975) evaluated several different materials to determine their effectiveness in protecting concrete from deterioration due to freezing and thawing. The materials tested were linseed oil; paint systems; fluosilicates; epoxies, both single- and two-component systems; latex paints; synthetic rubber; and neoprene. The materials tested represented only a small portion of the materials claimed to provide protection to concrete. Effects of these surface treatments on concrete are presented in Table 7.

22. Porter also reported the percentage of the number of cycles required for the specimen to achieve a 25-percent loss in mass due to the deterioration of the specimen when compared to the control (Table 8). He concluded that testing conditions affect the test results (e.g., freezing the specimens while they are submerged greatly affects the durability of some materials).

23. In 1981 the Oklahoma Department of Transportation (Dynamit Nobel 1981) tested some sealers on 1- by 2- by 3-in.* mortar specimens. Their results are shown in Table 9. The test results are for specimens soaked for 28 days. This table should be useful in the selection of material to be evaluated.

24. Several recent reports were found that contained data from laboratory testing of coating and sealant for concrete. These laboratory test results should also provide insight for the selection of material to be evaluated.

25. National Cooperative Highway Research Program Report 244 (Pfeifer and Scali 1981) gives the results of the testing of 21 materials marketed as surface treatments for concrete. Although several different types of tests were performed, the primary concern was the water-absorption test. The results of the water-absorption test are shown in Table 10. This report also contains data on gain in mass after 21 days of soaking in a salt solution and the amount of salt absorbed into the concrete at this time. Results indicate that the percent of chloride absorbed is directly proportional to the gain in mass. This supports the assumption that there must be moisture present in the concrete in order for the chlorides to penetrate into and migrate through the concrete.

26. A Federal Highway Administration report (Munshi and Millstein 1984) detailed the laboratory testing of six concrete surface treatment sealers to determine their ability to protect concrete from damage due to freezing and thawing (Table 11). This report included some test methods that might prove useful for the testing of materials.

27. In 1984, several sealants were tested at WES for their ability to prevent the entry of water into mortar.** The results and product information are shown in Table 12. Surface treatments were applied to the mortar specimens at rates greater than recommended by the manufacturers. The materials were applied until it appeared that the surface was completely saturated. This was done to test the ability of the sealant itself to resist water penetration and not the sealant applied at a given application rate. Although

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

** Dennis L. Bean. 1984. "Lab Evaluation of Sealers" (unpublished report), US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

this tested the full capacity of the material to prevent entry of water into the mortar specimen, the heavy dosage could possibly affect the breathability of the treated specimen. This phenomenon will be evaluated in a future testing program.

28. In 1985, the California Department of Transportation (Caltrans) tested several treatments for their ability to prevent the entry of water into portland-cement concrete.* The absorption values obtained are the amounts of increase in mass compared to an untreated specimen. The results and product information are shown in Table 13. Some materials were evaluated using a test for resistance to freezing and thawing, and the failure point was determined visually by a show of distress in the coating or cracks in the concrete block. (The fact that the specimen beneath the coating could be deteriorating while the coating appeared to be in good condition should be considered in reviewing Table 13.)

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* Paul D. Krauss. 1985. "Laboratory Test Results and Evaluation of Sealers" (unpublished report), California Department of Transportation, Sacramento Calif.

PART III: CASE HISTORIES

29. The following case histories are summaries derived from periodic inspection reports, personal interviews, technical reports, and questionnaires.

30. Little information could be obtained concerning surface treatments for the prevention of damage due to freezing and thawing. Most case histories involve materials applied to prevent abrasion and erosion. Some applications of surface treatments for prevention of damage due to freezing and thawing were found but not enough time has elapsed to fully evaluate their potential. These applications are found in the section entitled "Recently Applied Materials."

Results

Baltimore District

31. In 1983, a two-component polyurethane coating, Vibraspray 580, manufactured by Uniroyal, was applied to the outside of the intake structure to stop the water leakage. The coating was applied 110 mils thick in three spray coats. The first two coats were applied at a thickness of 40 mils each and the third coat at a thickness of 30 mils. The coating was applied only to the top one-third exterior of the intake structure. The level of water in the reservoir was dropped so that the coating could be applied on a cleaned non-submerged surface. An inspection conducted in 1983 after the reservoir water level was raised revealed the seepage of water into the interior of the intake structure had lessened in the area of application.

32. Bloomington Dam. In 1974, an epoxy-resin coating was applied to the intake conduit as a concrete protective coating from the acidic water which was to be impounded in the reservoir. The epoxy-resin coating was NuKlad 100, manufactured by Ameron Corrosion Division.

33. The coating was applied during construction of the dam. The concrete on the interior of the conduit was cleaned by sandblasting and primed with an epoxy-resin primer before coating. The epoxy-resin coating was applied by the contractor to a thickness of approximately 40 mils using a sprayer. The epoxy-resin coating contained a powder filler, and a sprayer made for application of highly filled coatings was used. The conduit was dry

during the application except for a few areas. In 1978 when water began flowing through the conduit, a cofferdam failed and debris passed through the conduit. In August 1981, 1,500 ft (approximately 10 percent) of the epoxy coating in the tunnel surface had deteriorated and had to be removed and replaced with the same brand of epoxy resin. Most of the damage was located in the bend of the tunnel and the failure was attributed to the debris from the failed cofferdam. In 1984 an inspection revealed that the condition of the tunnel was about the same as it was after the 1981 repair work.

34. Cowanesque Lake. In October 1984, mobile home roof coating (tar and aluminum) was applied to the concrete roof of the Thompson Water Plant Building to protect the surface from water intrusion. In 1985, the coating had bubbled, and the failure was attributed to moisture in the concrete.

35. Raystown Dam. In December 1981, NuKlad 100 (the same treatment used at Bloomington Dam) was applied to the warmwater chute-spillway to protect the aggregate and mortar from the aggressive water. The concrete surface was sandblasted and coated using the same treatment and methods used at Bloomington. The area coated was about 8 by 20 ft for the floor and 7 by 20 ft for the wall. The air temperature was below freezing when the coating was applied. The concrete was heated, but the actual temperature of the concrete surface was unknown.

36. After about 6 months, the coating was peeling off the floor. The contractor recoated the floor and attributed the failure to cold weather conditions.

37. One year after the initial coating, 80 percent of the coating on the floor had been removed. The coating on the wall appeared to be in good condition. Poor adhesion on the floor was attributed to improper surface preparation.

Chicago District

38. In 1975 an epoxy-resin mortar armor plate was placed on the recently rehabilitated lock walls at Marseilles Lock to protect the concrete from impact damages sustained from barge collisions. Two epoxy resins were used, Sikadur Hi-Mod Gel and Colmadur. The protective strips of epoxy mortar were 1 ft wide and 600 ft long and were 1/2 in. thick for each lock wall. Sikadur Hi-Mod Gel was used for one lock wall and one half of the other lock wall, while Colmadur was used for the remainder of that lock wall.

39. The epoxy-resin mortar strips started to fail shortly after

placement. Delamination of the epoxy-resin mortar had occurred over about 60 to 70 percent of the epoxy-resin mortar resurfaced area. Fifteen percent of the delamination was evidenced by missing epoxy-resin mortar. The failure was attributed to poor surface preparation and inadequate mixing of the epoxy-resin mortar.

Kansas City District

40. Milford Dam. In 1964 during the original construction, epoxy compounds were applied to the passageway in the intake tower. As a cost savings, the epoxy was placed in lieu of steel armor plate in the low-flow impact areas. The concrete was sandblasted and primed with the neat epoxy resin before the epoxy mortar was applied. The mortar consisted of epoxy resin, sand, silica fume, and asbestos fibers. The epoxy resin was manufactured by Steelcote Manufacturing Company of St. Louis, Mo.

41. On the right passageway, a 3/4-in.-thick application of epoxy mortar was applied to the floor and right wall; and a 3/8-in.-thick application was applied to the left wall. On the left passageway, a brush coat of epoxy grout was applied to the left wall and left side of the floor.

42. In 1973, 80 percent of the 3/4-in.-thick epoxy-mortar application on the floor had peeled off, and debonding was evident in several small areas of the remaining coating. In the left passageway, the epoxy loss was limited to about 10 percent of the area coated.

43. The epoxy mortar contained asbestos fibers as a filler. Since asbestos is now known to be a safety hazard, systems containing asbestos should not be considered for use.

44. Pomona Lake. In April 1972 an epoxy mortar consisting of 3 parts sand to 1 part epoxy resin (by volume) was placed on the transition slab of the stilling basin to repair abrasion damage. The repair included (a) a 1/2-in. minimum thickness of epoxy mortar applied to approximately one half of the transition slab, (b) an epoxy mortar applied to the upstream face of the right three upstream baffles, (c) a 2-ft-thick concrete overlay slab placed on the upstream 70 percent of the basin slab, and (d) a sloped concrete face added to the end sill.

45. The surfaces to receive the epoxy mortar were cleaned by sandblasting to expose approximately 50 percent aggregate. The cleaned surface was primed with epoxy-resin binder just prior to placement of the epoxy mortar, which consisted of approximately five parts silica sand to one part epoxy

binder. Specifications required the epoxy coatings to be kept dry and at a temperature of about 60° F for a period of one week.

46. The work was performed by contract. The epoxy-resin binder conformed to Federal Specification MMM-B-350, and the epoxy distributor had a representative on the jobsite. The epoxy used was Sikadur 320 Lo-Mod LV (low modulus, low viscosity). Although this is a moisture-insensitive epoxy, the surface was dry when it was applied.

47. In a report on this work, McDonald (1980) states:

> In 1977 the epoxy-mortar overlay had not suffered any visible erosion damage; however, cracks were observed in several areas. In one of these areas the epoxy-mortar coating was not bonded to the concrete. When pressure was applied to the cracked epoxy-mortar, moisture seeped up through the cracks. Because of the possibility that large discharges may remove the unattached epoxy, this area of unattached epoxy was removed. An area approximately 5 ft square was removed and saw-cut along its perimeter. It was observed that the unattached epoxy area had failed from approximately 1/16 to 3/4 inch within the concrete slab. The failure plane in the remaining epoxy, which was stripped from the 5- by 5-ft area, was both at the epoxy-concrete interface and within the concrete; the majority of the failure occurred within the concrete. Following removal of the epoxy, the slab surface was cleaned and backfilled with a low-modulus, low-viscosity, moisture-insensitive epoxy mixed with approximately 3-1/4 parts sand to 1 part epoxy. In all other overlay areas, even those with cracks, the epoxy mortar appeared to be soundly attached. The reason for the cracks in the epoxy is not known. However, several reasons were suggested for the similar failure of large portions of an epoxy mortar on the floor of the tower water passageway at Milford Lake. The Missouri River Division Laboratory determined that the epoxy mortar at Milford Lake had a linear thermal expansion coefficient of approximately 17×10^{-6} in./in./° F. This coefficient of linear expansion is approximately three times greater than the coefficient of linear expansion for concrete. Although temperature variations may only range to about 30° F, the difference in the thermal coefficients of the two materials may be responsible for the cracks.
>
> Two other explanations for the cracks in the epoxy are as follows: (a) properties of the epoxy mortar may change when it is submerged in water and (b) the ability of epoxy mortar to contract without cracking during temperature change decreases with age.

48. The epoxy mortar appeared to offer good resistance to the wear caused by the grinding action of stones moved by currents. In 1982 an inspection revealed that the overlay was in excellent condition.

49. Tuttle Creek. In May 1968 three surface treatments were applied to deteriorating concrete on the spillway slab to determine the effectiveness of the materials to prevent further damage from freezing and thawing. The surface treatments were linseed oil in mineral spirits, Thompson's Water Seal, and Aqua-fel (silicone). An inspection in 1970 revealed that none of the materials applied significantly prevented further deterioration of the concrete.

50. In 1974, several coatings were applied to some deteriorating concrete on the trash deck of the intake structure and the left stilling basin to determine the best coating to prevent further deterioration. The concrete to be coated was cracking and spalling and had some popouts as a result of freezing and thawing. Six different treatments were applied. Treatments 1 and 2 were applied to deteriorated concrete on the trash fender platform. Treatments 3, 4, 5, and 6 were applied to the stilling basin walls. The six treatments were:

a. Treatment 1. Two-component polysulfide-epoxy penetrating sealer (P.E. 50, manufactured by Steelcote Manufacturing Co.) with a second and third application of a two-component brushable thiocaulk.

b. Treatment 2. Two applications of penetrating silicone water repellent (manufacturer unknown).

c. Treatment 3. This coating treatment consisted of applying one coat of the two-component epoxy penetrating sealer, Sikastix 370, Sikadur Hi-Mod followed by two coats of the two-component Sikagard 664/9 Hi-Bild. The materials were manufactured by the Sika Chemical Corporation.

d. Treatment 4. This treatment consisted of applying three coats of the two-component epoxy coating Plasite No. 7122. The first coat was thinned with an equal part of Plasite No. 71 thinner. The materials were manufactured by the Wisconsin Protective Coating Corporation.

e. Treatment 5. This treatment consisted of applying two coats of one-component methacrylate, Carboline No. 2109. The material was manufactured by the Carboline Company.

f. Treatment 6. This treatment consisted of applying two coats of the two-component epoxy binder conforming to Federal Specification MMMB350. The epoxy compound No. 202 was supplied by Carter-Waters Corporation.

51. In 1976, two years after the application of the materials,

treatments 2 and 5 appeared to be performing satisfactorily. Treatments 3, 4, and 6 began failing during the first year. Treatment 1 appeared to be performing the best.

52. In 1980, six years after the application of the materials, none of the surface treatments was successful in stopping the deterioration of the concrete. Treatment 1 appeared to be the best system tried.

Little Rock District

53. Arkansas River Dam No. 2. In 1979 Sikagard epoxy resin was applied to the top surface of the landing of a pier (10 by 12 ft) to prevent the entry of water into cracks which were developing in the surface of the concrete. In 1985 an inspection revealed that the coating was in excellent condition.

54. Gillham Dam. In 1976 epoxy coatings were applied to the stilling basin to prevent erosion of the concrete. The epoxies used were 1-215 HM and 1-215 HM Gel manufactured by Permagile-Solmon. In 1979 there was some staining and cracking of the coatings with minor spalling. In 1983 there were numerous cracks in both the 1-215 HM and 1-215 HM Gel epoxy coatings.

Louisville District

55. Brookville Lake. In April 1981 an inspection revealed cavitation damage on both sides of the conduit walls downstream from the low-flow bypass outlets. The damage areas were relatively small with the largest area being approximately 2 by 3 ft. The depth of the erosion ranged from 1/2 in. to 3 in. for the largest area.

56. In May 1981 repairs were made by in-house personnel because the quantity of material needed was less than 2 ft^3. Sikatop 122, an acrylic copolymerized mortar was recommended for repair by the Chief of the Operations Division. One reason it was recommended is that it would allow the conduit to resume passing water within 2 hours after placement.

57. The unsound concrete was removed and the concrete adjoining the spalled area was saw cut and chiseled out to a minimum depth of 1/2 in. to eliminate featheredging of the patching material. Before the repair material was applied, the concrete was cleaned by thoroughly brooming a detergent into the surface and rinsing. The repair work began on the smaller area first. Personnel doing the repair work experienced difficulty with materials placement which resulted in a rough finish to the repair.

58. In 1983 an inspection revealed that the high discharge velocities

had not detrimentally affected the Sikatop patch, although the surrounding concrete did show some damage.

59. Cave Run Lake. In November 1982, Sikatop 122 acrylic latex mortar was applied to the intake conduit to protect the concrete surface from cavitation. The material never achieved set. The failure to set was attributed to the use of old material. Sika supplied new material to replace the material which did not set.

60. In July 1983 the new material (Sikatop 123 acrylic mortar) was applied in the conduit. Sikatop 123 was recommended instead of Sikatop 122 by the distributor because it was thicker and more suitable for vertical uses. The work was performed by project personnel in accordance with manufacturer's instructions. The concrete was damp when the material was applied, and water was kept off the material until it set. The workers did not like the material for the following reasons: (a) it emitted strong fumes, (b) the product became easily diluted with water, (c) it required precise measurements for small batches, and (d) it was difficult to work because of film-forming properties. An inspection revealed that the material applied was still good after one year of service.

Norfolk District

61. Gathwright Dam. In November 1982 two epoxies (Delta Plastic AS69-9018 and AS69T-900) were applied to some areas of spalled concrete in the intake structure. The materials were applied when the temperature was below 50° F. The contractor informed Corps personnel that these materials should not be applied at lower temperatures. The materials failed the same month.

Pittsburgh District

62. Kinzua Dam. In 1973 an epoxy mortar was applied to the base of the spillway and to the sides, top, and back of six damaged baffle blocks. The baffles had substantial abrasion-erosion damage. The epoxy mortar consisted of a 1 to 1 ratio of epoxy and sand. The epoxy was Sikagard 694 and the work was performed by Pittsburgh District personnel.

63. In 1974 two large areas of epoxy repairs at the base of the spillway were missing. The failure was attributed to severe abrasion conditions.

64. Monongahela Lock No. 3. In 1978 a 1/4-in.-thick latex-modified mortar was applied to the top of a lock wall flume. The concrete was nonair-entrained and had minor spalling. Sikatop 122 was applied to an approximate area of 15 by 16 ft. The concrete surface was chipped and water blasting was

used to clean it. Manufacturer's recommendations for surface preparation and application were followed.

65. After one winter, the overlay material had cracked into pieces measuring about 2 by 2 in. The failure plane occurred within the old concrete and the failure was attributed to weak substratum concrete.

Sacramento District

66. Pine Flat Dam. In 1957 two types of epoxy manufactured by Hodges Chemical Company were applied by contract in the lower conduit in Monolith 20 downstream from the steel conduit liner. The two epoxies were Hypon-89A (adhesive) and Hypon-89M (mastic coating). The surface was sandblasted, and oil-fired space heaters were used to dry the surface and raise the air temperature from about 55° to 90° F. After the coatings had cured for two weeks, they were tested with flowing water with a head of 381 ft.

67. The first 20-ft section downstream from the steel conduit liner was coated with Hypon-89M at a thickness of about 15 mils. After 21 days of testing, the mastic coating showed no erosion.

68. The second 20-ft section downstream from the steel conduit liner was coated with Hypon-89A at a thickness of about 15 mils followed by a 3/16-inch plaster coat of cement-sand mortar. After the plaster coat had cured for 24 hours, then a 15-mil coating of Hypon-89A was brushed over it. After 21 days of testing the cement-sand mortar was eroded over large areas but in no case did the erosion extend completely through the mortar and adhesive binder to the original concrete surface.

69. The third 20-ft section downstream from the steel conduit liner was given a 3/16-in. trowel-on layer of cement-sand mortar. After 24 hours Hypon-89M was brushed over the mortar. After 21 days of testing, the epoxy and mortar were completely removed over large areas. The failure was attributed to insufficient bonding of the cement-sand mortar.

Seattle District

70. Libby Dam. In 1977 a contractor impregnated 4-ft sections of the surface along the joints in the stilling basin with an organic polymer to repair severe abrasion-erosion damage. The polymer system was 95-percent methyl methacrylate (MMA), 5 percent trimethylol propane trimethacrylate (TMPTMA, cross linking agent S-9A0), and 0.5 percent azobisisobutylonitrile (AIBN) catalyst. Special heating forms were used to dry the concrete and to polymerize the monomer. Radiant heat was used to dry the concrete at

temperatures between 250° and 345° F for 8 to 10 hours. After the concrete cooled to 75° to 105° F, the monomer was applied in the range of 0.07 to 0.15 gal/ft^2 and soak times ranged between 5 and 8 hours. A 3/8-in. layer of sand along with clean polyethylene sheeting was used to reduce evaporation.

71. Polymerization was accomplished using steam to heat the surface to 150° to 260° F for periods ranging from 30 minutes to 3 hours. Several problems (e.g., water seepage and excess monomer evaporation) were encountered while impregnating the concretes; however, viable solutions to the problems were obtained before the polymerization process was started. The depth of polymerization in the concrete ranged from 3/4 to 1-1/4 in. During an inspection in 1982, the surface treatment was rated as good to excellent. However, it was noted that the stilling basin has not had much usage.

St. Paul District

72. Mississippi River Lock and Dam No. 9. In 1978, an acrylic mortar was applied to the top surface of a lock wall to repair shallow spalling and worn areas and to assure that the surface would have a uniform appearance. The mortar consisted of 1 part portland cement, 2 parts silica sand, and enough liquid latex (diluted 1:1 to obtain about 15 percent latex solids to portland cement) to make the consistency of a brick mortar. The latex used was AKKRO-TT manufactured by Tamms. The concrete was damp but not wet when the mortar was applied. The finished mortar was air cured. In 1985, the latex mortar repairs were rated in excellent condition.

73. Upper St. Anthony Falls Lock. In January 1976, small test sections of a low-modulus epoxy mortar and epoxy concrete were applied to the floor of one filling and emptying lateral. The mortar was used to repair considerable abrasion-erosion damage and to provide an abrasion-resistant surface in the lateral. The epoxy mortar consisted of one part epoxy (Sikastix 340 Sikadur Lo-Mod) to 3 parts silica sand. The mortar was applied at a thickness of 1/2 to 1 in. The conditions during the repair were described as fair to poor with too much standing water to do a satisfactory job.

74. The epoxy concrete mixture proportions (to yield approximately 1/2 to 3 ft^2 of surface treatment repair) were 1 gal of epoxy (Sikastix 340), 25 lb of grit, and 20 lb of silica sand. The epoxy concrete was applied to two areas measuring approximately 6 by 12 by 24 ft. At the time of placement, it was the opinion of the representative of the firm who produced the epoxy and who was present during the repair, that the chances of getting good

results were slim due to free water and sand in the holes prior to placement.

75. In 1978 (approximately two years after the repairs) the epoxy mortar repairs (in spite of the pessimism during placement) appeared to have performed fairly well. With the exception of some minor erosion along the edges of the repair and a few small localized areas within the repair where the overlay appeared to be very thin, the epoxy mortar was in good condition.

76. The section of epoxy concrete repair subjected to abrasion was essentially intact with only slight erosion of the two corners. The erosion resistance of the epoxy concrete is particularly significant when compared to previous repair materials and the conventional concrete in this structure. The second area of epoxy concrete, which was not subjected to the abrasive effects of rocks, appeared to be in its original condition. Periodically divers have inspected the coating and reported that it still appears to be in good condition.

Portland District

77. Dalles Dam, Dalles, Oregon. In June 1978, an epoxy coating (Adhesive Engineering Concresive 1170) was applied to prevent further erosion in the wall and floor of a trash sluiceway. The coating was rolled on with paint rollers. In 1984, an inspection revealed the coating to be in excellent condition.

Tulsa District

78. Oologah Dam. In 1976, a protective epoxy coating system was applied to baffle blocks and the end sill to protect the concrete surfaces from abrasion-erosion action. The treatment consisted of a primer coat of Aqua Base, followed by a surface coating of Aqua Top, both manufactured by the Sika Corporation. The surface coat was applied 4 days after applying the base coat. The top coat was kept dry for 4 days to allow the epoxy to cure properly. The epoxy coating was applied over a new concrete overlay which had been lightly sandblasted and moist cured for a minimum of 7 days. The work was performed by a private contractor with assistance from Tony Husbands of WES and a representative of Products Research Corporation. The air temperature was always above 50° F when the materials were applied.

79. Stilling-basin baffles 15, 16, and 17, were coated with two different, polyurethane coatings to evaluate these coatings for protecting concrete from erosion. The polyurethanes selected were PRC 1654 (Products Research Corporation) and Elastuff 504 (United Paint). The concrete was

lightly sandblasted before the coatings were applied.

80. Baffle 15 was primed with the Unitile sealer. The following day Elastuff 504 was applied by airless spray. Baffle 16 was primed with PRC 41 primer and the following day PRC 1654 was applied by airless spray. Baffle 17 was primed with Unitile 301 primer and the following day Elastuff 504 was applied by airless spray.

81. In 1979, all coatings on the baffles had sustained some damage. The polyurethane coating exhibited many small blisters and a few areas of bond failure between the coating and the primer. In 1985 the coating on baffle 15 (Unitile sealer and Elastuff 504) was in good condition with about 95 percent of the coating still remaining. The coating on baffle 16 (PRC 41 primer and PRC 1654) had some delamination with about 70 percent of the coating still remaining. The coating on baffle 17 (Unitile 301 primer and Elastuff 540) had nearly all delaminated from the baffle with only 5 percent remaining. All the epoxy coating was gone, but it was believed to have stayed on for about 8 years. The failures were attributed to debonding caused by the influence of flowing water.

Vicksburg District

82. Between 1976 and 1978 epoxy mortar was applied to the stilling basin floors and baffle blocks for the prevention of abrasion at Arkabutla, Enid, Grenada, and Sardis Dams. All four projects were done using the same treatment and the same contractor. The epoxy was H.P. binder manufactured by Hunt Process, Madison, Miss. The work was also performed by Hunt Process. The surface was lightly sandblasted and dried before being primed with a light coat of the epoxy-resin binder. A 1/4-in.-thick epoxy mortar wearing course was then applied. The mortar consisted of one part epoxy to three parts silica sand by volume.

83. In 1979 inspections revealed the epoxy mortar was in good condition, with minor abrasion-erosion occurring in a few places (1/2-in. maximum depth). The eroded areas were repaired with the same type of epoxy-resin mortar. In 1984 inspections revealed the epoxy-resin mortar to be in moderate condition with some of the surfaces having abrasion-erosion damage. The stilling-basin floor at Grenada Dam appeared to have sustained more abrasion-erosion damage than the others.

Walla Walla District

84. Dworshak Dam. In 1975, a concrete polymer impregnation project was

undertaken at Dworshak Dam, Idaho. It was the first major field application of polymer impregnated concrete (PIC), the first competitive bid project using PIC, the first application of PIC to vertical surfaces, the first field application of PIC to fibrous concrete, and the first impregnation of dry-pack patching for any Corps of Engineers project.

85. The work was performed in an outlet conduit and in the stilling basin of the dam to repair major cavitation-erosion damage and to serve as a protective barrier against abrasive and erosive elements. The polymer treatments applied were a mixture of MMA, TMPTMA, and VAZO 64 catalyst in the proportions 95:51:0.5 in the outlet and 97.5:2.5:0.5 in the outlet and stilling basin.

86. Special forms were constructed to dry the concrete and to polymerize the monomer. Infrared heaters were used to dry the concrete at a temperature of approximately 300° F for 7 hours. After a cooling period of about 8 hours the concrete was maintained at a temperature of about 120° F until the monomer was applied.

87. Outlet polymerization. Vertical surfaces in the outlet (10 ft high) that had sustained minor erosion were impregnated. The concrete was dried by infrared heaters, placed 9 in. from the wall and spaced on 12-in. centers. Thermocouples were bonded to the wall to measure the temperature and to maintain uniform temperatures over the entire surface. During the impregnation step, care was taken to ensure that the interior of the concrete was not too hot. Some sections of the walls were dry packed (60 yd^2 at 3/8 in. to 1 in. deep). Soaking (vertical face) was accomplished with 10- by 10-ft stainless steel panels pressed against the wall to serve as a reservoir for the monomer during the soak cycle or impregnation step. After the soaking cycle the MMA was polymerized by filling the panel with hot water.

88. Stilling basin polymerization. Concrete that was impregnated in the stilling basin was on a horizontal surface and contained steel fibers. The surface was dried with infrared heat lamps before soaking with MMA. Areas 700 ft^2 were treated at a time. A 3/8-in. layer of sand was used to minimize evaporation of the monomer during impregnation. Steam was used to polymerize the MMA. The depth of penetration ranged from 1/2 in. to 1-1/4 in. and the rate of application was approximately 0.1 gal/ft^2. After 50 days the PIC had performed better than epoxy mortar repairs which were made at the same time. After 1 year of exposure to limited discharges, the polymer-impregnated

concrete was in good condition with some minor erosion.

89. In 1984 (nine years after the treatment), an inspection of the stilling basin was made. PIC surfaces had evidence of minor erosion but limited usage of the outlet was reported since the treatment. The PIC dry-pack concrete was in excellent condition.

90. Little Goose Dam. In October 1973 an epoxy coating was applied to the surface on the trunnion in the spillway to prevent spalling of the concrete. The coating was Acme's Hydroepoxy 300 and was applied by Corps personnel. In 1985 the result of a visual inspection indicated that the coating was performing very well.

91. Lower Monumental Lock and Dam. Complete details are given in Schrader (1981). Eight years after the lock was put into service, aggregate in the concrete was fully exposed because of surface deterioration due to freezing and thawing of the concrete. Shotcrete containing a latex admixture and fibers was used to coat the lock walls. The shotcrete mixture consisted of portland cement type I or II and the fibers were single-strand, multiple-filament, alkali-resistant fiberglass. The latex (Saran Dow*) contained approximately 50 percent solids and an antifoaming additive. The fine aggregate was presacked sand. The water-reducing agent met the applicable requirements of American Society for Testing and Materials (ASTM) C 494 (ASTM 1985).

92. This mixture was pneumatically applied to the surfaces of the lock walls in 1980 by a contractor. The water-cement ratio was low (0.26) since the latex acts as a fluidifier, thus allowing a low water-cement ratio to be used. The fiberglass fibers (about 1/2 to 1 in. long) were chopped and blown against the surface simultaneously with the shotcrete.

93. The thickness of the shotcrete applied was about 1/8 in. per pass. Between passes the surface was rolled with a roller that resembled a serrated paint roller. Rolling pressed the glass fibers into close contact with the mortar. The total thickness of shotcrete applied was about 3/8 in. The surface to be shotcreted was prepared with high-pressure water-jet equipment which normally operates at about 10,000 psi. However, as the nozzle tips wore out, the pressure dropped, resulting in a concrete surface which was not

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* Saran is a chlorinated compound and might release chloride ions. It should not be used where chloride ions will have a detrimental effect on the structure.

satisfactorily prepared. The surface of the concrete was blown dry before the shotcrete was applied. The material proportions were:

Item	Weight, lb/yd^3
Water	245
Cement	1,720
Fibers	117
Latex (Saran, Dow Chemical)	520
Fine aggregate (saturated surface-dry)	860

Item	Amount/yd^3
Water-reducing admixture	75 oz.
Entrained air	3.7 percent by volume

94. Six months after application (one winter) the shotcrete material had performed well. In 1983, an inspection revealed that the shotcrete had about 3 percent surface area failure. A 1984 inspection revealed that the shotcrete had about 7 percent surface area failure.

Recently Applied Materials

95. In the following material applications, not enough time has elapsed to determine whether the surface treatment will provide adequate protection. However, these applications may prove useful for future reference.

Mobile District

96. Bankhead Lock and Dam. In 1982, an epoxy (Sika product) was applied to about 100 ft^2 of a vertical splitter wall to repair eroded concrete and to act as a protective barrier against further erosion. The work was performed by lock personnel. The concrete surface was prepared by high-pressure water jet. The concrete was still damp when the epoxy was applied. The dam has not been dewatered to determine the effectiveness of the coating.

Rock Island District

97. Brandon Road. In August 1984 a 3-in.-thick latex mortar was applied to the top of a guide wall (4 by 700 ft). The concrete in the guide

wall was nonair-entrained and minor spalling had occurred. The latex was DOW DPS-Mod a. The mortar was mixed in a 4-yd^3 truck mixer and ferried out to the jobsite. The concrete surface to be treated had been surface-chipped and water-blasted. The concrete surface was very hot and was moistened with a little water which quickly steamed off prior to applying the overlay. When the mortar was applied, the surface was not primed with a latex slurry. The high temperature caused the latex mortar to set quickly resulting in a poor finish. However, this proved advantageous because it left a rough surface desirable for foot traffic. Results of this application as of August 1985 were excellent.

98. Moline Bridge. In 1985 the surface of the concrete on Moline Bridge was treated with alkyltrialkoxy silane to protect it from damage from freezing and thawing. The materials applied were Sil-Act and Chem-trete.

Little Rock District

99. In 1983 and 1984, the Little Rock District applied epoxy concrete at DeQueen, Bull Shoals, and Clearwater on the stilling basins to prevent erosion. The epoxy was manufactured by Permagile-Solmon (product name not available).

100. Arkansas River Lock and Dam No. 9. In 1984, Thompson's Water Seal was applied to the top of the lock wall by personnel from the Russelville area office. Two lock wall surfaces were treated (24,000-ft^2 area). The purpose of the sealer was to prevent water from entering the concrete, thereby reducing the damage caused by freezing and thawing action.

New England Division

101. In 1984, Chevron Industrial membrane was applied to the Bourne Highway Bridge sidewalls. In 1984, Hydrozo Clear Double 7 was applied to the control tower masonry superstructure of the Knightville Dam. In 1985 Sikatop 144 was applied to the access stairway on the Westville Lake Dam.

Philadelphia District

102. In 1972 water seepage was observed inside the intake structure. The leaks were at joints, hairline cracks, and form-tie locations below the pool level. Extreme calcite deposits were formed on the inside walls. In 1977, Vandex, a cementitious silicate coating, was applied to a section of the interior wall of the intake tower to prevent the leakage. The coating did not stop the leakage possibly because the manufacturer and installer indicated

that two or more coats of the product would be required. However, only one coat was applied, and the District elected to attempt no further applications.

PART IV: VENDORS

103. The current product market was surveyed for products which can be applied as surface treatments for concrete. Forty companies were contacted about evaluating their products. The selection of manufacturers and distributors to be contacted was obtained from laboratory testing reports, personal contact, references from other manufacturers, and advertisements in journals. The treatment materials were classified into 24 chemical classes with some companies submitting more than one class of material. The product names and their chemical classifications are listed in Table 14. The number of products continues to grow due to new materials being introduced by vendors. Information about these products is being obtained by WES.

104. Manufacturers of products with good performance reputations and manufacturers who claim to have great products were selected to ascertain the ability of their products to prevent the intrusion of water into the concrete.

105. The products listed in Table 14 include those primarily intended for preventing entry of water into concrete and for preventing the intrusion of waterborne salts. If it is decided to do a laboratory study on the use of surface treatments for the prevention of abrasion and erosion damage, more vendors will be contacted.

106. Some manufacturers of protective treatments acknowledge the limitations of their product and include this information in their product literature. Below is an excerpt taken from Sika's product literature (Sika Corporation 1984):

> Limitations: Both systems are vapor barriers and as such should not be applied to surfaces where transmitted vapor can condense under the coating and freeze, particularly to the surface of nonair-entrained concrete subject to cycles of freeze and thaw. Also, saturated concrete and mortar should not be completely encapsulated using either system.

107. This type of information could eliminate unnecessary laboratory testing and prevent the selection of an unsuitable material for surface treatment. The manufacturer's literature should be checked for limitations before the selection of a product.

PART V: CONCLUSIONS AND RECOMMENDATIONS

108. The data obtained from the literature search concerning the testing performed by other laboratories will be useful in the selection of treatments for the laboratory study being conducted. The water-absorption test data will provide a means of selecting the materials that merit further testing. If a material cannot prevent water from entering nonair-entrained concrete, then the freezing and thawing action will continue to cause deterioration of the concrete when it is saturated. Therefore the water-absorption test should be an excellent indicator of a surface treatment material's effectiveness for treating concrete that is inherently nonfrost-resistant because it is nonair-entrained. The criteria for the amount of absorption allowed will be established at a later date, after additional testing in the laboratory.

109. From the information obtained from the case histories, the treatments providing positive results indicate a good material for that particular application. However, negative results may not necessarily indicate a poor material. Possible reasons to be considered for the negative results are surface preparation, application rates, and climatic and surface conditions.

110. The test for resistance to freezing and thawing should be mandatory to fully evaluate a sealant or coating. It is possible for a material to prevent water from entering the pores of the concrete and be breathable, and still not be a good surface treatment (Cady, Weyers, and Wilson 1984). Wilson et al. (1983) reported that a specimen treated with a brand of silane actually performed worse than an untreated specimen, yet the silane vendor claimed it to be a breathable waterproof material.

111. The test for resistance to freezing and thawing should only be performed on treatments passing the water absorption test unless a vendor has a strong claim or a material was found to be satisfactory in a previously documented test.

112. The concrete in existing structures is not identical to freshly prepared laboratory specimens. The existing concrete may be carbonated, which has reduced the alkalinity of the concrete on the surface. Therefore some products which perform well in a laboratory environment on freshly prepared specimens may not necessarily be as effective on old concrete which has been carbonated.

Coverage Rate

113. An important aspect of coatings that should be considered is the application rate. The porosities of different concretes are not the same. The coverage rate for a concrete of medium density might not be adequate for a less dense concrete. The same amount applied to denser concrete might be too much, resulting in a concrete that might be sealed against vapor transmittance. The vendor usually recommends a coverage rate for their product. More testing is needed to determine the optimum application rate and the effect of improper coverage for some products. A test should be devised to ensure proper coverage for different products on different concretes.

Penetration

114. One concern mentioned by the OCE Technical Monitor in the data reviewed was the depth of penetration of a surface treatment. Some coatings might have a deleterious effect on the concrete surface if the treated surface forms a distinct layer having a different linear coefficient of thermal expansion from the substrate (Clifton 1980). If this happens, expansion and contraction due to temperature changes could destroy the outer surface of the concrete faster than if the concrete were untreated. Depth of penetration tests may not be needed if a material performs well in the water-absorption test and the test for resistance to freezing and thawing. The depth that the material penetrates should not matter unless the surface of the concrete will be subjected to abrasive forces. Highway Research Record No. 423 (Ingram and Furr 1973) reports, "No correlation between depth of penetration and protection provided against freezing and thawing action was evident in the laboratory."

115. In the laboratory testing phase of the surface treatments to minimize concrete deterioration, some topics to be considered are: (a) compatibility with concrete (new and old), (b) compatibility with joint sealant materials, (c) crack-bridging ability, (d) time required for the surface treatment to be effective, (e) effect of outgassing, (f) abrasion resistance, (g) weatherability of the materials, and (h) the overall structure and overall condition of the concrete considered for a surface treatment, and (i) surface preparation.

Recommendations

116. Much of the information obtained is not conclusive concerning the ability of the materials to protect concrete that is exposed to the elements. However, a good indication of the effectiveness of a material can be obtained from the reported results of laboratory water-absorption tests and tests for resistance to freezing and thawing. When the laboratory testing phase of this project is completed, enough data should be available to establish minimal laboratory testing requirements and performance criteria for the various types of surface-treatment materials for concrete. Until then the water-absorption test should be required to evaluate the potential of the materials, with the maximum acceptable absorption value being 2.5 percent increase in mass in 48 hours for 4-in. cubes or similar specimens.

117. It is the opinion of the author that materials meeting the 2.5 percent absorption criteria, as shown in the work of Bean,* Pfeifer and Scali (1981), and Krauss,** could be considered as potential materials. However, the breathability of a treatment must be considered. Epoxy resins (not dissolved in solvent) can do an excellent job of preventing moisture from entering concrete, but epoxy resins also prevent moisture vapor from escaping, as described in paragraph 10. This must be considered before selecting a treatment to be applied to concrete.

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* Bean, op. cit., page 11.

** Krauss, op. cit., page 12.

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Table 1

Stone Preservative Materials (Sleater 1977)

Classification	Nonvolatile Content, %	Percent Absorption as Compared to Control
Control (untreated stone)		100.0
Methyl silicone	23.0	7.0
Fluorocarbon	--	8.8
Fluorocarbon	2.0	10.5
Methyl silicone	55.0	12.2
Methyl silicone	53.0	12.2
Silicone	10.0	14.0
Acrylic polymer	10.0	15.8
Acrylic polymer	10.0	21.0
Silicone	6.6	24.5
Silicone	16.7	24.5
Acrylic polymer	10.0	28.0
Sodium methyl siliconate	33.0	29.8
Inorganic	26.0	31.5
Sodium methyl siliconate	31.0	35.0
Acrylic polymer	23.0	45.6
Methyl silicone	80.0	52.6
Methyl silicone	33.0	56.1
Acrylic polymer	27.0	57.8
Silicone	4.9	59.6
Sodium silicate, 40° baume	56.0	66.6
$Ba(OH)_2$ + additives	30.0	73.6
Methacrylate polymer	39.0	77.1
Acrylic copolymer	20.0	82.4
Linseed oil	103.0	82.4
Polyisobutyl methacrylate	31.0	84.2
Methacrylate	27.0	87.7
Methyl silicone	37.0	89.4

(Continued)

Table 1 (Concluded)

Classification	Nonvolatile Content, %	Percent Absorption as Compared to Control
Polyisobutyl methacrylate	33.0	89.4
Silicone	12.5	91.2
Methyl silicone	53.0	91.2
Acrylic resin	30.0	91.2
Fluorocarbon	2.0	91.2
Tetraethyl ortho-silicate	0.0	91.2
Methacrylate polymer	30.0	92.9
Inorganic	47.0	92.9
Inorganic	45.0	94.7
Methyl methacrylate	18.5	96.4
Methyl silicone	6.6	96.4
Fluorocarbon	11.0	96.4
Fluorocarbon	18.0	96.4
Acrylic-epoxy	39.0	100.0
Methyl methacrylate	20.7	101.7
Plastic emulsion	3.0	101.7
Plastic emulsion	28.0	101.7
Calcium hydroxide	--	101.7
Organism	10.0	103.5
Methyl silicone	6.7	105.2
Acrylic polymer	21.0	105.2
Acrylic resin	47.0	107.0
Methyl silicone	7.0	108.7

Table 2

Thermal Expansion of Treated Stones (Clifton 1984)

Consolidation Materials	Mean Coefficient of Thermal Expansion* per °C × 10^6	
	Sandstone	Limestone
No treatment	9.7	4.3
8 epoxy	8.5	5.0
10 epoxy	8.2	4.3
19 acrylic ester	8.7	3.7
22 silane	9.0	6.1
24 methyl methacrylate	9.3	3.2

Note: The numbers in the left column are the product identification used in Clifton's report.

* Temperature range of 0° to 65° C.

Table 3

Federal Highway Administration Chloride Permeability Test Results (Dynamit-Nobel 1981)

Product	Company	Classification	Percent of Chloride Compared to Control Depth, in. 1/16" - 1/2"	1/2" - 1"
Control (no treatment)			100	100
Chem-Trete BSM40	Dynamit-Nobel	Silane	29	22
Deco Rez Latex Mod. Concrete	General Polymer	Acrylic	59	36
Dylex 1186 Latex Mod. Concrete	Polysar	SBR	65	33
Mega Sill	A & T Development Corp.		74	45
Dow Mod Latex Mod. Concrete	Dow	SBR	77	39
Thermoflex Latex Mod. Concrete	Thermo-Chem		78	112
Vandex Slurry	Vandex	Sodium silicate	78	64
Stop Spall	Commercial Chemical Corp.	Epoxy in solvent	86	88
Thompsons External	Thompson	Strearate	97	94
Vandex Trovelled	Vandex	Sodium silicate	103	88
Chem Stop	Chem Stop Mfg. Co.		104	112
Hydrozo		Strearate	108	118
Meta Seal	American Metaseal	Epoxy in solvent	111	79
Thompsons Internal	Thompson	Strearate	132	127
Prima Pel	Chemprobe Corp.		172	176

Table 4

Chloride Penetration Test Results (Dolphin Industries 1984)

Product	Company	Classification	Percent of Chloride Compared to Linseed Oil Treated Mortar Depth, in. 1/16" - 1/2"	1/2" - 1"
Linseed oil (control)			100	100
Bridge 10	Dolphin Industries	Sodium silicate	45	20
Hydro-Therm		Silicate	81	80
IBEX-10B		Polymer resin	103	45
Chem-Trete	Dynamit-Nobel	Silane	105	128
CUI-Sealer		Polymer	118	140
Thoro-Clear	Thoro	Silicone	152	151
Chloride Penetration Test Results (Sinak Corp. 1983)				
Linseed oil (control)			100	100
Sinak S-102	Sinak	Sodium silicate	45	20
Orgeno silane		Silane	105	128
Polymer resin			104	45
Epoxy			110	180
Silicone			152	151
Mineral gum			198	518

Table 5

Surface Treatments for Freezing and Thawing Resistance (Stewart and Shaffer 1969)

Product No.	Classification	Coverage ft^2/gal 1st	Coverage ft^2/gal 2nd	Percent Deterioration Compared to Control after 75 Cycles
5	Control (nonair entrained pavement mix)	N/A		100
10	Control (nonair entrained pavement mix)	N/A		100
5-11	Chlorinated phenyl-biphenyl resin compound	500	650	75
5-12	Chlorinated resin silicone rubber compound	400	550	125
5-13	Petroleum solvents, resins, and metallics	300		100
5-14	Combination of silicone modified polyesters 36 percent solids in alcohol solvents	300		100
5-15	Aliphatic naphtha base	250	400	100
5-16	Mixture of chlorinated rubbers and solvents	300		125
5-17	Blend of low-viscosity coal tars	400		50
5-18	Solution of coal tar resins in hydrocarbon solvents	300		50
5-19	Polymerized cyclopentadiene and alkylcyclo pentadiene of petroleum	400		75
10-18	Solution of coal tar resins in hydrocarbon solvents	300		200
10-19	Polymerized cyclopentadiene and alkylcyclo pentadiene of petroleum origin	400		200
10-20	Same as 19 with 10 percent lead and 0.5 percent cobalt incorporated as metal soaps based on resin solids	400		200
10-21	Polyester penetrating sealer	350		300

(Continued)

Table 5 (Concluded)

Product No.	Classification	Coverage ft²/gal 1st	Coverage ft²/gal 2nd	Percent Deterioration Compared to Control after 75 Cycles
10-22	Petroleum hydrocarbon, 42 percent soluble in mineral spirits	500		200
10-23	Linseed oil in 50 percent mineral spirits	400	600	0*
10-24	Linseed oil in 50 percent mineral spirits	400	600	100
10-25	Petroleum distillates	500		200
10-26	Highly plasticized, chlorinated polymer resins	400		200

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* This specimen was zero (or no scale) on a rating scheme between 0 and 5.

Table 6

Surface Treatments for Freezing and Thawing Resistance (No Control Concrete for Comparing)

(Stewart and Shaffer 1969)

Product No.*	Classification	Coverage ft^2/gal		Rating after 75 Cycles**
		1st	2nd	
2-1	Epoxy resin of low viscosity	200		0
4-1	Epoxy resin of low viscosity	200		2
2-2	Epoxy resin of low viscosity	150		0
4-2	Epoxy resin of low viscosity	150		2
2-3	Epoxy resin of low viscosity	250		0
4-3	Epoxy resin of low viscosity	250		1
2-4	Polysulfide epoxy resin of low viscosity	200		0
4-4	Polysulfide epoxy resin of low viscosity	200		3
2-5	Polysulfide epoxy resin of low viscosity	250		0
4-5	Polysulfide epoxy resin of low viscosity	250		1
3-6	Polyester resin	200		4
4-6	Polyester resin	200		3
3-7	Epoxy resin of low viscosity	200		1

(Continued)

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* The first number is the concrete mix and the second number (after the dash) identifies the surface treatment material.

** The numerical values for the rating system are defined as follows: 0 equals no scale, 1 equals slight scale, 2 equals slight to moderate scale, 3 equals moderate scale, 4 equals moderate to heavy scale, and 5 equals heavy scale.

(Sheet 1 of 3)

Table 6 (Continued)

Product No.	Classification	Coverage ft^2/gal			Rating after 75 Cycles
		1st		2nd	
3-8	Vinyl hydrocarbon copolymer		450		5
4-8	Vinyl hydrocarbon copolymer		450		5
3-9	Petroleum hydrocarbon resin 45 percent soluble in mineral spirits		450		4
4-9	Petroleum hydrocarbon resin 45 percent soluble in mineral spirits		450		4
3-10	Blend of refined coal tar pitch and resinous hydrocarbon plasticizers		400		3
4-10	Blend of refined coal tar pitch and resinous hydrocarbon plasticizers		400		1
9-11	Chlorinated phenyl-biphenyl resin compound	500		650	4
9-12	Chlorinated resin silicone rubber compound	400		550	4
9-13	Petroleum solvent, resins and metallics		300		3
9-14	Combination of silicone modified polyesters 36 percent solids in alcohol solvents		300		4
9-15	Aliphatic naphtha base	250		400	3
9-16	Mixture of chlorinated rubbers and solvents		300		5
9-17	Blend of low viscosity coal tars		400		1
11-20	Polymerized cyclopentadiene and alkyl cyclopentadiene of petroleum origin with 10 percent lead and 0.5 percent cobalt incorporated as metal soaps based on resin solids		400		3
11-21	Polyester penetrating sealer		350		4

(Continued)

(Sheet 2 of 3)

Table 6 (Concluded)

Product No.	Classification	Coverage ft^2/gal 1st	Coverage ft^2/gal 2nd	Rating after 75 Cycles
11-22	Petroleum hydrocarbon, 42 percent soluble in mineral spirits	500		4
11-23	Linseed oil in 50 percent mineral spirits	400	600	0
11-24	Linseed oil in 50 percent mineral spirits	400	600	0
11-25	Petroleum distillates	500		4
11-26	Highly plasticized, chlorinated polymer resins	400		4
11-27	Blend of chlorinated rubbers and epoxies	500		3
12-27	Blend of chlorinated rubbers and epoxies	500		5
11-28	Chlorinated rubber with solvent carrier	400		4
12-28	Chlorinated rubber with solvent carrier	400		5
11-29	Mixture of aliphatic hydrocarbon resin and aliphatic solvents	300		1
12-29	Mixture of aliphatic hydrocarbon resin and aliphatic solvents	300		2
12-30	Wax poly blend emulsion: approximately	400		4
12-30	43 percent solids: water base	400		3
12-31	Synthetic rubber: plasterizing resin and aromatic solvent	300		5
12-31	Synthetic rubber: plasterizing resin and aromatic solvent	300		5
12-32	Vinyl terpolymer derivative	400		5
12-32	Vinyl terpolymer derivative	400		5

(Sheet 3 of 3)

Table 7

Effects of Some Surface Treatments (Porter 1975)

	Effect on Concrete Subjected to Freezing and Thawing in Water	
Coating	Single Coating	Repeated Coatings
Linseed oil, turpentine and paint	Harmful	Slight benefit
Zinc fluorosilicate	Harmful	Indeterminate
Magnesium fluosilicate	Slight benefit	Beneficial
Wall seal epoxy	Beneficial	Beneficial
Wall seal epoxy	Beneficial	Beneficial
Pigmented epoxy	Beneficial	Beneficial
Exterior latex paint	Beneficial	Beneficial
Exterior emulsion latex	Harmful	Indeterminate
Synthetic rubber	Questionable	Beneficial
Chlorinated rubber	Harmful	Questionable
Neoprene (liquid)	Beneficial	Beneficial
Waterproofing sealer	Harmful	Beneficial
Penetrating sealer (epoxy)	Questionable	--
Penetrating sealer (epoxy)	Beneficial	--
Penetrating sealer	Questionable	--

Table 8

Freezing and Thawing Tests (Porter 1975)

Surface Treatment Material	Percentage of the Number of Cycles of the Control to Obtain 25 percent Weight Loss
Control (no treatment)	100
Linseed oil	78
Zinc fluosilicate	81
Magnesium fluosilicate	109
Wall seal epoxy	179 and 238
Pigment epoxy	172
Exterior latex paint	115
Exterior emulsion latex	82
Synthetic rubber	254
Chlorinated rubber	73
Neoprene (liquid)	134
Waterproofing sealer	98
Penetrating sealer epoxy	106 and 150
Penetrating sealer	95

Table 9

Water Absorption of 1 × 2 × 3 Treated Mortar (Dynamit-Nobel 1981)

Product	Company	Classification	28 Day Absorption Test (Percent Absorption Compared to Control)
Control		Untreated	100
Chemtrate	Dynamit-Nobel of America	Silane	40
Conspec	Construction materials		89
Watts			90
Boiled linseed oil	--		94

Table 10

Water Absorption Test (Pfeifer and Scali 1981)

		Percent Absorption Compared to Control*		
Product	Classification	24 hr	48 hr	72 hr
Control	No treatment	100.0	100.0	100.0
16	Epoxy (polyamine) methyl methacrylate	10.0	5.2	6.0
8	Methyl siloxane + ethyl acrylate	20.0	5.2	12.0
15	Epoxy (polyamine)	20.0	5.2	12.0
6	Alkyl-alkoxy silane	20.0	5.2	16.0
4	Urethane (isocyanate polyester)	40.0	5.2	12.0
10	Polyisobutyl methacrylate	40.0	26.3	32.0
18	Epoxy (polyamide)	40.0	26.3	32.0
17	Epoxy (polysulfide)	100.0	63.1	56.0
2	Linseed oil with mineral spirts	100.0	68.4	60.0
14	Aliphatic urethane	100.0	73.6	76.0
21	Epoxy (polyamide)	100.0	73.6	64.0
20	Epoxy (polysulfide)	100.0	78.9	68.0
19	Epoxy (polyamide)	100.0	100.0	84.0
11	Vinyl toluene butadiene copolymer	100.0	100.0	84.0
12	Isobutylene and aluminum stearate	100.0	100.0	84.0
13	Methyl methacrylate-ethylacrylate copolymer	100.0	100.0	84.0
9	Sodium silicate	100.0	100.0	88.0
5	Chlorinated rubber	100.0	100.0	88.0
1	Siloxane mixture	100.0	100.0	100.0
3	Sodium methyl siliconate	100.0	100.0	100.0
7	Styrene-butadiene polymer	100.0	100.0	100.0

* $\frac{\text{wt. treated specimens}}{\text{wt. untreated specimens}} \times 100$ for each time period. The data were presented in this manner because some reports cited gave results as weight gain in the specimens. This author believed that a comparison to the untreated "control" specimen would facilitate the comparison of the different materials in all reports cited.

Table 11

Water Absorption of Treated Mortar (Munshi and Millstein 1984)

Product	Company	Classification	Percent Absorption Compared to Control* 24 hr	48 hr	72 hr
Control		Untreated	100.0	100.0	100.0
Pen Seal 50	American Metaseal	Epoxy in solvent	31.7	29.7	24.4
Radcon Formula #7	Radcon	Sodium silicate	33.3	33.8	27.8
Nickle Epoxy 1-30	Rocky Mountain Chemical Co.	Epoxy in solvent	35.0	37.8	36.7
HLM 1000	Sonne Born-Building Product	Epoxy	36.7	36.5	35.6
Hydrozo 56	Hydrozo Coatings	Strearate	43.3	37.8	31.1
Tremco 150	Tremco	Asphalt	41.7	37.8	46.7

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* $\frac{\text{wt. treated specimens}}{\text{wt. untreated specimens}} \times 100$ for each time period. The data were presented in this manner because some reports cited gave results as weight gain in the specimens. This author believed that a comparison to the untreated "control" specimen would facilitate the comparison of the different materials in all reports cited.

Table 12

Water Absorption-Treated Mortar*

Product	Company	Classification	Percent Absorption Compared to Control**		
			24 hr	48 hr	72 hr
Control	--	Untreated	100.0	100.0	100.0
Torex 800	Koppers	Rubber enamel	2.1	2.8	4.0
B12, B36	Raylite	Isobutyl methacrylate	4.2	6.0	8.0
5000 Ter-polymer	VIP	Polymerized acrylic	4.2	10.0	14.0
4100-4200	Gibson & Holmin	Neoprene	6.3	8.0	10.0
E.A. Sealer	Preco	MMA + ethylareylate	8.4	10.0	12.0
Elvocite	DuPont	Acrylic	8.4	16.0	24.0
Permagile 1-215 HMLC	Permagile-Solmon	Epoxy	10.4	12.0	14.0
Vabar 792	United Paint	Polyurethane	14.6	16.0	20.0
CIM	Chevron	Urethane	16.7	24.0	30.0
Thompson's Water Seal	Thompson	Stearate mixture	20.8	28.0	28.0
Pen Seal 50	American Metaseal	Epoxy in solvent	37.5	48.0	56.0
MC-76 slurry	Rohm & Haas	Acrylic latex	66.7	72.0	80.0

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* Bean, op. cit., page 11.

** $\frac{\text{wt. treated specimens}}{\text{wt. untreated specimens}} \times 100$ for each time period. The data were presented in this manner because some reports cited gave results as weight gain in the specimens. This author believed that a comparison to the untreated "control" specimen would facilitate the comparison of the different materials in all reports cited.

Table 13

Water Absorption Test Results*

Product	Company	Classification	Percent Absorption Compared to Control, 24 hr	Number of Freezing and Thawing Cycles to Failure
Control	--	Untreated	100.0	
E.A. Sealer	Preco	Siloxane + methacrylic	2.4	
Chlorinate Rubber Curing Compound	--	Chlorinated rubber	6.5	73
Preservacrete II	Preserva Products	Silicone base	8.3	
Chem-Trete	Dynamit-Nobel	Silane	7.1	
VIP 5500	VIP	Polymerized acrylic	9.8	275
HL Siloc	Hodson Lab	Siloxane	10.0	120
VIP Opaque	VIP	Methyl methacrylate	8.5	73
Multicoat II	Slatin Rogers	Latex acrylate	15.6	
Pen Seal	American Metaseal	Epoxy in solvent	12.9	42
Hydrozo	Hydrozo	Stearate	12.7	140
Consolideck-SX	Proso Co.	Siloxane	15.1	
Crete Shield	Princeton Chemicals Inc.	Epoxy	18.8	
VIP 5100	VIP	Polymerized acrylic	17.3	73
AQUATI POXI	American Chemical Corp.	Epoxy	1.7	

(Continued)

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* Krauss, op. cit., page 12.

(Sheet 1 of 3)

Table 13 (Continued)

Product	Company	Classification	Percent Absorption Compared to Control, 24 hr	Number of Freezing and Thawing Cycles to Failure
Miracote	Miraco Inc.	Acrylic latex	8.3	
Thoro Clear "77"	Thoro	Silicone	18.2	
Chem Stop	Chem Stop Mfg. Co.	Resin based	23.9	
Moxi 1400	International	Silicone	30.4	
VIP 5500	VIP	Polymerized acrylic	9.79	
Thoro Seal	Thoro	Portland cement based	37.4	
Dunn 3500	Frank Dunn Co.	Polyacrylate	35.1	200
Macon	Macon	Resin base	34.8	
"Wet" 2400 Sidewalk Seal	W.E.T.	Silicone	58.2	42
Dynabond	American Chemical Corp.	Cementitious	55.5	
GS Sealer	GS Products	Acrylic emulsion	58.0	
Sinak 101	Sinak	Sodium silicate	89.4	42
Radcon Formula #7	Radcon	Sodium silicate	55.4	42
Thoro Coat	Thoro	Latex paint	83.8	160
Thoro Glaze	Thoro	Acrylic	88.5	42
VIP 5100	VIP	Polymerized acrylic	17.3	73
Sinak 103	Sinak	Silicate	100.0	42
Sinak 102	Sinak	Silicate	89.4	42

(Continued)

(Sheet 2 of 3)

Table 13 (Concluded)

Product	Company	Classification	Percent Absorption Compared to Control, 24 hr	Number of Freezing and Thawing Cycles to Failure
Con Seal "Wet"	W.E.T.	Sodium silicate	94.6	42
Moxi 1500	International	Sodium silicate	104.6	73
Vandex-Mortar	Vandex	Cementitious powder	98.2	
Vandex Super	Vandex	Cementitious powder	101.8	
Gladiator I	Gladiator	Sodium silicate	82.5	
Xypex	Xypex	Sodium silicate	93.8	
Gladiator II	Gladiator	Sodium silicate	88.5	

(Sheet 3 of 3)

Table 14

Product Names and Chemical Classifications

	Acrylic	Acrylic Hi-Molecular	Acrylic Polyester	Butyrate Polymer	Chlorinated Rubber	Epoxy/Solvent	Linseed Oil	MMA/Mixture	Polyvinyl Chloride	Polyisobutyl Methacrylate	Oil/Resin	Organic Silane	Polyester	Silane	Silicate	Siloxane	Silica (Mod)	Stearate Mixture	Styrene Acrylate	High Molecular Weight Methacrylate	Urethane	Urethane (Mod)	Vinyl-Acrylate
A & F Enterprise				X																			
Alocite						X																	
Belzona														X									
Bridge 10 (Dolphine Ind)															X								
Burkes																			X				
Belzona (clear clad)																X							
Commercial Chemical						X																	
Crystal Seal															X								
Ven-chem												X											
Dural						X																	
Dynamit Nobel												X											
Fair Field (Aquablock)							X																
Gilson-Homans			X																				
Horn									X														
W. R. Meadows		X																					
Nox-crete														X									
Pennseal						X																	
Permagile						X																	
Preco								X						X									
Price Research		X																					
Proso Co.																					X		
Preston Pacific	X				X																		
Protex					X		X																
Poly Crab						X																	
Poly Coat																	X						
PSI												X											
Polymorphic Resin													X										
Raylite										X													
Radcon 7															X								
Sinak															X								
Specco*																			X				X
Steel Cote (Polysulfide)						X																	
E. A. Thompson (Water Seal)																		X					
Transpo																				X			
Tremco, Inc.																					X		
TCA (texture coating)										X													
Union Carbide															X								
Union Coating							X															X	
Polyvinyl Chemical	X																						
Hydrozo											X												
Select	X																						

APPENDIX A: DEFINITIONS AND GENERAL CHARACTERISTICS OF SOME MATERIALS

This appendix gives brief definitions of some terms, general characteristics of surface-treatment materials, and statements about the classification of some surface treatments. Statements are generalized, and some treatment materials may perform better than indicated for their particular class. Some manufacturers claim to have overcome the deficiencies associated with a particular class of materials. Laboratory testing is needed to evaluate the usefulness of any candidate material.

Much information was obtained from ACI (1979), Roth (1985), Kubanick (1981), Clifton (1980), and ASTM (1984).

Definitions

Breathability - ability of a treatment or material to allow water vapor to migrate through and dissipate through at the surface. Although water-vapor transmittance can be expressed with some unit of measurement, most vendors use breathability as either a yes or no property of their product.

Consolidants - materials that penetrate into the substrate for the purpose of strengthening and preventing moisture entry.

Waterproofing - treatment of a surface or structure to prevent passage of water under hydrostatic pressure (ASTM 1984).

Dampproofing - treatment of a surface or structure to resist the passage of water in the absence of hydrostatic pressure (ASTM 1984).

UV - ultraviolet radiation.

General Characteristics

Acrylics

Polymer of acrylic acid, methacrylic acid, esters of these acids, or acrylonitrite. The resins range from soft, sticky semifluid materials to hard solids.

General characteristics:

good resistance to outdoor weathering

good resistance to chemicals at service temperatures

good resistance to water and aqueous salt solutions good resistance to moderate concentrations of acids and bases

poor resistance to certain organic solvents

Comments:

Acrylates have been shown to improve substantially the mechanical properties and durability of porous materials such as concrete.

Acrylic copolymers

Copolymers are produced by joining two or more different monomers in a polymer chain.

General characteristics:

Same as acrylics.

Comments:

Commercially available acrylic copolymers used for stone consolidation are usually produced from ethyl methacrylate or methyl acrylate. The acrylic copolymers are usually dissolved in organic solvents. Unless dilute solutions are applied, solvent evaporation will tend to draw some acrylic copolymers back to the surface of stone. Methyl methacrylate and to a lesser extent butyl methacrylate have been used to consolidate concrete and stone. These monomers can be applied solvent-free to porous solids and can be polymerized in situ. MMA's are volatile and flammable and could present a health hazard. MMA can displace some water in concrete but it is best to remove most of the evaporable water (90 percent in the pores) prior to impregnation. In Wilson et al. (1983), MMA was the best material tested for protecting concrete from freezing and thawing damage; 500 cycles were obtained before failure.

Asphalts

There are two types, natural asphalt and oil-refinery products. Usually asphalt sealers are the oil-refinery type. Sometimes the asphalt is dissolved in a solvent for ease of application (cold-applied).

General characteristics:

good resistance to acids and oxidizing solutions

poor resistance to certain organic solvents

lower resistance to water than coal tar derived products

Butyrate polymers

A salt or ester of butyric acid (either of 2 isomer fatty acids), usually a derivation from animal milk fats.

General characteristics:

good penetration into concrete

good bridging of hairline fractures

good moisture vapor transmittance (breathable)

Comments:

The surface to be sealed must be dry and free of rain or other moisture for 48-72 hours.

Chlorinated rubbers

Chlorinated rubbers are usually produced by chlorinating isoprene rubber. Usually chlorinated rubber coatings dry by solvent evaporation. The resulting product no longer possesses the resiliency and elasticity of the rubber from which it was produced.

General characteristics:

excellent resistance to water, salts, acids and alkalies

good weatherability (when pigmented or UV absorbers are added)

easy application when recoating

poor resistance to certain solvents

limited resistance to heat (deterioration begins at 150° F)

good adhesion to concrete

Comments:

A chlorinated rubber curing compound performed well in the testing performed by the California Department of Transportation in 1985.

Epoxy resins

An epoxy consists of an epoxy resin and a polymerization agent. Mixing the epoxy resin with the curing agent converts it into a hard, thermosetting cross-linked polymer. The most commonly used epoxy resins are derived from diphenylolpropane (bisphenol A) and epichlorohydrin. Resins produced from these reactants are liquids that are too viscous to deeply penetrate stone or concrete. Therefore, they are usually diluted with organic solvents.

General characteristics:

excellent adhesion to stone and concrete

excellent resistance to water, solvents, and chemicals

highly dependent upon mixing of components

poor resistance to chalking caused by UV

excellent resistance to abrasion

good resistance to mildew and bacteria growth

highly dependent upon temperature for curing

poor resistance to embrittlement caused by long-term aging poor recoatability once cured

excellent toughness and durability

Comments:

The good performance of an epoxy is documented in Wilson et al. (1983). A specimen underwent 304 cycles of freezing and thawing before failure.

Hydrocarbon resin (oils-resin)

Hydrocarbon means consisting of or structured with hydrogen and carbon (the basic building block for organic compounds). Resins are solid or semisolid, viscous materials that are compounds of carbon, hydrogen, and oxygen. They are derived naturally from secretions of certain plants and trees. Some common examples are rosin, amber, pine tar, and pitch. Although hydrocarbon resin is a class of sealer, the number of formulations using hydrocarbon resin can be large.

General characteristics:

excellent resistance to water

good resistance to UV and weathering

poor resistance to certain organic solvents

Linseed oil

A yellowish drying oil obtained from flax seeds. It is one of the oldest materials used to dampproof concrete.

General characteristics:

poor resistance to weathering; therefore requires reapplication about every three years

Comments:

More recent test results indicate that it alone does very little to stop the entry of water into concrete. It is often used as a control to compare other sealers.

Metallic stearates

Stearate - a salt or ester of stearic acid

Stearic acid - a fatty acid, $C_{18}H_{36}O_2$, made from tallow or other hard fats

General characteristics:

poor resistance to UV and weathering

Comments:

The Texas Department of Transportation reported that the performance of one such product was poorer than linseed oil (Furr, Ingram, and Winegar 1969).

Mineral gums

Mineral gums are swelling clay derivatives (usually suspended in a solvent) that expand in the presence of moisture to prevent moisture intrusion. Usually an organic polymer is added to promote adhesion to the concrete substrate.

General characteristics:

excellent protection to concrete not subjected to traffic wear

Comments:

Although the clay does not degrade, the polymer does, requiring reapplication, especially in areas subjected to exposure to sunlight.

Polyesters

A large group of synthetic resins, almost all produced by reaction of dibasic acids with dihydric alcohols.

General characteristics:

excellent resistance to chemicals
excellent resistance to moisture transmittance (impermeable)
excellent temperature tolerance (up to 400° F.)
good resistance to impact
highly dependent upon application requirements
highly dependent upon clean, dry, and alkali-neutralized concrete
moderately dependent upon curing temperature (preferably above 50° F.)

Comments:

May form an impervious layer which prevents the passage of entrapped moisture (not breathable). According to the ACI (1979):

> Although there are many generic types of polyester resins, there are two that are normally used for barrier materials in the more severe chemical environments. One is based on the reaction between maleic anhydride and bisphenol A, and the other is produced by reacting acrylic acid with an epoxy and is commonly called a "vinyl ester." These resins are mixed with approximately 50 percent styrene monomer to lower viscosity (approximately 150 centipoises) to improve workability. The styrene also reacts chemically with the polyester resin after the appropriate catalytic hardening or curing agents are added.

The liquid resin is converted to a solid using a peroxide catalyst such as benzoyl peroxide and an accelerator such as dimethyl aniline. The concentration of the catalyst may be varied to change the rate of hardening. There are two conditions that can prevent polyester resins from hardening completely:

a. Water will inhibit hardening of polyesters; and therefore, when polyesters are used, a primer that is not sensitive to water should be applied to the concrete first.

b. Air inhibits the curing of some polyesters. This problem is solved by applying a final top coat that contains about 1-2 percent paraffin. The paraffin rises to the surface and prevents direct contact of the polyester surface with air. Without paraffin in the top coat, the surface will remain tacky.

Polyurethane resins

Synthetic polymers (isocyanate resins) that may be either thermoplastic or thermosetting. They are used for flexible or rigid foam, flexible and stiff fibers, coatings, linings, and as elastomers. A polyurethane coating can be either a one-component or two-component system. The one-component urethane is sometimes referred as urethane prepolymer.

General characteristics:

excellent toughness and hardness
excellent mar-resistant surface
excellent flexibility
excellent resistance to chemicals and alkalinity
excellent adhesion to dry concrete
excellent resistance to solvents
excellent weathering properties
poor resistance to yellowing with aging
poor recoatability once cured
highly dependent upon dry surfaces

Comments:

Multiple coat application requires specific timing between coats. The breathability of urethanes are in question. One company, Thane Coat of Houston, Tex., claims to be able to apply a 40-ml coat that is permeable to water vapors.

Silanes

Although alkyl alkoxy silane is the correct identification, the term silane is frequently used. A silane is any of various silicon hydrides that have the general formula $Si(n)H_2(n+1)$ and are analogous to hydrocarbons of the methane series.

General characteristics:

good penetrating ability

highly dependent on application rate (material is volatile)

Comments:

The silane itself is not the active substance which prevents water intrusion. The repellant is formed when the silane reacts with moisture in the presence of a catalyst (usually the alkalinity of the concrete). The most important condition necessary for the reaction is the presence of moisture. If the materials are dry and there is little atmospheric humidity, no reaction will take place.

It is the opinion of the author that since most commercially produced silane requires an alkaline environment for the product to achieve a water-repellant compound, it may not be too successful in older concrete. Carbonation of concrete reduces alkalinity, thus rendering the silane applied to a carbonated concrete useless. The penetration of silane in porous stone is claimed to be about 20-25 mm. The depth of carbonation will determine whether the silane compound will seal the concrete. In older structures the depth of carbonation might be greater than the penetration of silane. Testing should be performed on concrete specimens which have carbonated or old concrete to verify that the silane can penetrate to noncarbonated concrete.

Silanes are volatile and sometimes can evaporate from the substrate before the water repellant is formed. Since much of the silane can be lost to evaporation, the packaged material must be high enough in solids (up to 40 percent) to allow for losses during the sealing operation. In worst cases, high temperatures and high wind, so much silane can be lost that hardly any water repellant is formed. Also if silane-impregnated surfaces are exposed to rain soon after application, the silane will be leached out.

Certain silane compounds produce less water repellancy than others (e.g., methyl silane may be regarded as unsuitable). One company (Chem-trete) claims to have a silane compound to be used on surfaces which are essentially neutral (no alkalinity required for reaction to occur).

Some companies claim that silanes are compatible with alkaline building material, while others claim silanes are not compatible. Also some claim that silane compounds exhibit good vapor permeability. Wilson et al. (1983) states that "the silane greatly decreased the durability of the specimen."

Silicates

A salt or ester derived from silicic acid; can be any of numerous complex metal salts that contain silicon and oxygen in the anionic portion of the molecule.

General characteristics:

poor adhesion and bonding to concrete

poor resistance to weathering

Comments:

The silicate product tested in the NCHRP 244 (Pfeifer and Scali 1981) project did not perform well. One manufacturer describes his product as a blend of silicates, wetting agents, water, and cross-linking agent that reacts with calcium. He claims that his product is better than other silicates because his material will stay in suspension longer and has an additive to reduce surface tension.

Siliconates

Siliconates are silicone compounds that react with CO_2 in the atmosphere to form the silicone resin which acts as the water repellant when it becomes chemically bonded to the substrate.

Comments:

Generally siliconates were replaced with silicone resin in the mid-fifties (Roth 1985) and are not normally applied to exterior walls to make them water repellant. Propyl siliconates are claimed to have good water repellancy characteristics if air is kept away from the freshly impregnated surface. Also they claim to offer a higher resistance to alkalinity of concrete. However, siliconate can be leached out of the concrete if the freshly impregnated surface is prematurely exposed to rain (if it rains on the surface before the chemical reaction is complete). A white deposit is formed if an excess amount is applied.

Silicone resins

Silicones are synthetic materials made up of the elements silicon and oxygen combined with organic groups.

Depending on the nature of its organic group and on the conditions of its compounding, the silicone may be an oily, resinous, or rubbery material. The term silicone, therefore, does not refer to a specific chemical composition but to a large group of materials.

General characteristics:

excellent resistance to alkalinity of concrete

good long-term resistance to water

poor resistance to UV

good penetrating ability

Comments:

Silicone resins that are marketed for waterproofing concrete are produced during the manufacturing process (as opposed to forming the molecule within the substrate) and dissolved in an organic solvent, usually in 5 percent solutions. Because of the smallness of the molecules, they have the ability to penetrate into the pores and capillaries of the building material easier than other organic resins. The type of solvent used has a marked effect on the resin's penetrating power. When the solvent evaporates, the resin will react with and adhere to the substrate.

Sometimes silicones are mixed with other compounds to improve their performance. There are conflicting opinions about silicones. Some claims indicate that silicone resins provide good water repellancy, offer long-term protection, and have outstanding resistance to alkalinity of concrete. Still others claim that silicone resins provide poor water repellancy and will degrade upon exposure to UV. The surface should be dry before applying silicone. Driving rain will not leach the silicone 4-5 hours after application.

Silicones

Any of various polymeric organic silicon compounds. Most are organic-silicon compounds and are commonly referred to as silicones. There are many silicone products on the market with confusing and misleading names. Some silicones that are used as water repellants are polymerized alkoxysilanes dissolved in organic solvents.

Comments:

There are claims that silicone offers little frost resistance to stone and will deteriorate when exposed to UV rays and weathering. Silicone water repellants have been used in recent years to treat masonry for protection from water and wind-driven rain. There are claims that silicone treatment of masonry has promoted deterioration rather than prevented it.

Siloxanes

Although oligomerous alkyl alkoxy siloxanes is their proper identification, they are commonly called siloxanes. They may consist of various compounds containing alternate silicon and oxygen atoms in either a linear or cyclic arrangement usually with one or two organic groups attached to each silicon atom. "Oligomerous" means having short chains (e.g., small molecules). Because of their small size they have good penetrating power. Siloxanes also require moisture and a catalyst to complete their reaction. Since they do not evaporate, the percent solid is about 6-8 percent. Some are diluted with solvent to reduce their viscosities to allow for better penetration.

General characteristics:

good penetration
good water repellancy
excellent stability against alkalinity of concrete
good moisture vapor transmittance (breathable)

Comments:

Siloxanes have the same advantages as silanes, but according to claims have none of the disadvantages. Siloxane compounds contain a built-in catalyst which reduces the system's dependency on the alkalinity. Even if the substrate is neutral, the reaction takes place quickly provided that moisture is present (e.g., atmospheric humidity).

Vinyl polymer

Several vinyl polymers--poly(vinyl chloride), chlorinated-poly (vinylchloride), and poly(vinylacetate)--have been used for conservation and consolidation of stone. The polymers are dissolved in organic solvents and then applied to stone. Photochemical processes could release chlorine from the chloride polymer, which could damage stone. If used on steel-reinforced concrete, the newly formed chloride ions could affect the steel reinforcement, thus compounding the problems. If the vinyl polymers are not carefully applied and if not sufficiently diluted, an impervious layer may be formed which could entrap moisture.

General characteristics:

Listed under "Polyesters."

Waxes (paraffin waxes)

High molecular substances composed of carbon and hydrogen which are insoluble in water but soluble in most organic solvents.

General characteristics:

good consolidation of stone (increases tensile strengths)

excellent durability

Comments:

Waxes have been applied to stone for more than 2,000 years. Waxes have been found to be effective consolidants. For example, a paraffin wax was found to increase the tensile strength of a porous stone from 150 to 590 psi, while triethoxymethylsilane only increased it to 270 psi. In addition, paraffin waxes are among the most durable stone consolidant materials and can immobilize soluble salts.

If deep penetration is not achieved, a nonporous surface layer may be formed, causing the eventual spalling of the treated surface (Clifton 1980). Major problems encountered in using waxes to consolidate stone include their tendency to soften at high ambient temperatures and to entrap dust and grime.