MOISTURE PROTECTION FOR CONCRETE

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A study made by the Texas Transportation Institute
for the Texas Highway Department under Bureau
of Public Roads Project Number HPR-1 (3)

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MOISTURE PROTECTION FOR CONCRETE

SYNOPSIS

Tests to identify effective waterproofing materials for hardened concrete are described. Test results and limited cost data are given.

Wetting-drying tests were made to measure the percentage weight of water infiltrating through treated surfaces of concrete partially submerged in tap water. Freeze-thaw tests were made of sealed concrete surfaces ponded with brine.

Eighteen surface treatments were tested; they included linseed oil, silicones, epoxies, and others. Percentage weight of water absorbed and number of freeze-thaw cycles are tabulated. Moisture absorption curves and photographs of freeze-thaw specimens are included.

Epoxies and linseed oil were the most effective of the treatments in these tests. On basis of effectiveness, ease of application, and low cost, linseed oil appeared to be the best suited under the test condition.

INTRODUCTION

The continuing and seemingly accelerated deterioration of reinforced concrete bridge decks by surface scaling, spalling, and cracking is demanding closer attention of highway engineers throughout the country. The use of air-entrained concrete of late has greatly relieved the problem, but many structures of nonair-entrained concrete continue to suffer.

This paper reports a study made for the Texas Highway Department in cooperation with the Bureau of Public Roads under Project HPR-1(3) entitled "Protective Coatings for Hardened Concrete." The study is directed toward finding a treatment or treatments for nonair-entrained concrete that would lessen the deterioration problem. The theory used in the study is that the trouble begins when contaminated water enters concrete through pores and minute cracks. The situation is aggravated by further entrance of such water from time to time. The compounds carried by the water into the concrete cause slow deterioration in some way—mechanical or chemical or both—beginning generally at the top surface of the roadway slab.

In keeping with that theory, various materials were laboratory tested for effectiveness in refusing admittance of water to the hardened concrete.

In general, the deterioration problem encountered in concrete bridge decks involves shallow to deep surface scaling, surface spalling in which relatively large unpatterned chunks of concrete break out, slab cracking in both the transverse and longitudinal directions, breaking out of patterned blocks of concrete bounded by checkerboard cracks sometimes to the depth of the top layer of steel, and nonpatterned cracks. Figure 1 shows some typical surface deterioration of reinforced concrete bridges.

Most highway departments have encountered the deterioration problem in some of its aspects, and various theories have been advanced as possible causes of that deterioration. Some of those possible causes are:[1,2,3,4]

Application of de-icing chemicals to concrete surfaces

Excessive mixing water in concrete

Absence or deficiency of entrained air in concrete

Low-quality control of concrete mix

Overworking the surface for finish

Nonuse or improper use of retarder causing overworking of surface for finish

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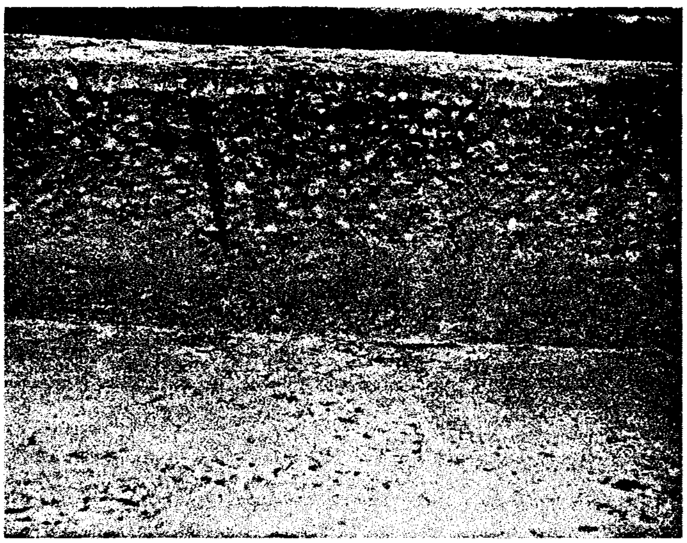
1 Effects of De-icing Chemicals on Structures, A Symposium. Highway Research Board Bulletin 323, 1962.

2 Epoxy Resins for Concrete Construction and Repair-Interim Report, General Report No. 28, April 17, 1961, Division of Engineering Laboratories, U. S. Dept. of Interior, Bureau of Reclamation, Denver, Colorado.

3 Improving the Water Repellency of Hardened Concrete, Highway Research Board Bulletin 197, 1958.

4 Linseed Oil Emulsion Prevents Salt Damage to Concrete Paving, Iowa Municipalities, November, 1962, p. 19.

(a) Deck wearing surface.



(b) Guard wall in splash zone.

(c) Pier below opening in deck.

Figure 1. Some typical surface deterioration in reinforced concrete bridges.

Improper construction (design) details and poor drainage

Insufficient curing before application of de-icing salts

All of these, and possibly others as well, could contribute to the problem of deterioration. No general agreement exists on a definite cause or causes. It appears that high quality design, construction, and material control could contribute to alleviate the problem. These measures must, however, be taken before and during the placement of the concrete.

The concrete that is already in place and which has been in service in some cases for a number of years, presents an entirely different problem for solution. A bridge slab that is breaking up under traffic calls for maintenance of a nature which will at best stop the deterioration, or, at least, slow the rate of deterioration.

A clear understanding of the cause of the trouble is essential for the most efficient and least costly corrective measures. That understanding is not clear at this time.

One of the stated theories involves the action of de-icing chemicals on concrete bridge decks. It is recognized that deterioration has increased at a faster rate with the increased use of de-icing salts on bridges. It is a reasonable assumption, then, that the de-icing salts entering the concrete in solution with water contributes to the problem. Furthermore, if the salt-laden water were denied entry into the concrete, it appears that deterioration would be stopped or that its rate would be slowed down.

It is on this theory that the study reported in this paper was initiated. An effort was made to find a material or materials which would seal the minute pores and cracks when applied to the concrete surface. Selected thin overlay materials and surface penetrants were tested to determine their effectiveness in denying entry of water into the concrete. Wetting-drying tests and freeze-thaw tests were made to test that effectiveness.

Published research material and brochures of commercial product distributers indicate that surface coats—overlays or membranes—which seal out water from concrete and masonry are available. If an overlay is to be used on concrete bridge decks, it must be very tough and wear resistant because traffic abrasion is severe. A penetrant having its effective action inside the concrete would, it seems, offer a better solution because it would not be worn away by the traffic. Concrete is a rather dense material and effective penetration might be very difficult to attain.

Realizing that either or both the membrane treatment and the penetration could possibly offer the solution sought, both were tested in the program.

TEST PROGRAM

Objectives

The problem presented for study was to find an effective sealant for hardened, natural aggregate, nonair-entrained, portland cement concrete.

The objectives of the study were:

(1) To identify materials that effectively seal moisture from hardened concrete.

(2) To determine the degree of effectiveness of materials in (1) above.

(3) To determine effective procedures for applying the materials of (1) above.

(4) To determine comparative costs of effective protection in place.

(5) To determine to what extent the concrete may be deteriorated before materials of (1) above become ineffective.

(6) To determine if the materials of (1) increase the resistance of concrete to deterioration.

A material that would not materially change the color of the concrete and one relatively easy to apply was desired.

Materials

Concrete

The laboratory concrete mix described in Appendix A was designed to meet the requirements of the Texas State Highway Department for Class A concrete.[5] In addition to laboratory mixed concrete, specimens of paving

[5] Standard Specifications for Road and Bridge Construction, Item 421 Concrete Structures. (Natural Aggregates) Class A, (Nonair-entrained), Texas Highway Department, Austin, Texas, 1962.

concrete that had been in service some twenty-seven years were used. These specimens, provided by Texas Highway Department District 17, were taken from a paving slab that was cast April-May 1935 on State Route 21, Burleson County, Texas, within the city limits of Caldwell, Texas. Data on that concrete are given in Appendix B.

The laboratory concrete was mixed in approximately 1 1/2 cubic foot batchs in a vertical drum Lancaster mixer. It was cast in oil coated steel and wood forms, held in forms twenty-four hours, then removed from forms to 73° F, fog spray moist room and allowed to cure until it was fourteen days old. After curing, specimens were removed to atmosphere in the laboratory and allowed to dry from two to three days. The specimens were then treated with the various waterproofing compounds.

Waterproofing compounds. These compounds are described in Appendix C. The treatment designation and trade name of the treating compound are given in Table I.

TABLE I. WATERPROOFING COMPOUNDS

Designation and Name	Used in the following tests						
	Wet-Dry		Freeze-Thaw				Exposed
	A	B	A	B	C	D	Slab
1. No treatment - control	x	x	x	x	x	x	x
2. Linseed oil and kerosene (50-50)	x	x	x	x	x	x	x
3. Linseed oil and applied at abt. 210° F	x	x		x	x	x	x
4. Linseed anti-spall compound	x	x	x	x	x		x
5. DC 770 mineral base silicone	x	x	x	x			x
6. DC 772 water base silicone	x	x	x	x			x
7. Hydrozo (2 coats)	x	x	x	x	x		x
8. Protex-a-crete sealer	x	x	x	x	x		x
9. Chempol 32-1010		x		x	x	x	
10. Trikote TK #18		x		x	x		
11. Chempol 31-10006		x		x	x		
12. Thiokol D-183-601-1	x	x	x	x	x		x
13. Versamid epoxy penetration sealer (General Mills)	x	x	x	x			x
14. Presstite-140 Guardkote		x		x	x		
15. Permaspray CPB-102	x	x		x	x		x
16. Protex-a-cote porselon epoxy saturant	x	x	x	x	x		x
17. Protex-a-cote TAC-T-185-NYS	x		x				x
18. Sika Colma protective coating	x	x	x	x	x		x
19. Thikol-Tipox A	x						x

All waterproofing materials were applied with a small paint brush. Directions for mixing, when given by the manufacturer, were followed. Curing time for the coatings varied from twenty-four hours to seven days.

Description of Tests

Tests were designed to meet the stated objectives within limits of available time and equipment. They consisted of wet-dry tests, freeze-thaw tests, abrasion tests, and exposure tests. Except for an outside panel, the exposure test was incorporated into the freeze-thaw series and the abrasion test was incorporated into the wet-dry series.

Wet-dry tests were made to determine the amount of moisture that would pass into the concrete through a treated surface and to determine if the effectiveness of a coating would be influenced by alternately wetting and drying the specimen. It was reasoned that if a coating were effective in sealing out water in the laboratory, it would probably be effective in the same way in field applications.

Freeze-thaw tests were made to determine if water would soak through a surface treatment, be frozen inside the concrete, and subsequently break up the concrete. A brine solution was used to accelerate the deterioration process and to simulate de-icing salts used in field application.

Abrasive sandblasting of treated surfaces was used to simulate abrasion of traffic on bridge deck surfaces.

Exposure testing was an attempt to determine if exposure to sun would break down the surface treatment.

Wet-dry Tests. The wet-dry tests consisted of alternately wetting treated specimens 24 hours by partial submersion in tap water and then drying them in a 140° F oven for 24 hours. Each specimen was blotted dry and weighed after wetting and was again weighed after oven drying. The amount of moisture absorbed during wetting and lost during drying was computed on a percentage basis by taking the weight of specimen as the average of all wet plus dry weights at the end of the test, according to the following formulas:

$$\text{Percent moisture gain} = 100\left(\frac{\text{Wt. after 24 hrs. in Water} - \text{Wt. after 24 hrs. in Oven}}{\text{Average of all (wet + dry) weights}}\right)$$

$$\text{Percent moisture loss} = 100\left(\frac{\text{Wt. after 24 hrs. in oven} - \text{Wt. after 24 hrs. in Water}}{\text{Average of all (wet + dry) weights}}\right)$$

Because the concrete continued to change weight daily at the time of coating, no fixed value of weight could be set for purposes of computing percent moisture change. During the test, the average of the wet and dry weights changed daily. It was considered that the overall average of wet and dry weights would be a reasonable value on which percentages could be based; that average was used in all wet-dry tests.

Concrete specimens 3" x 3" x 4" cast in lightly oiled steel molds (Figure 2) were used in the wet-dry tests. The top surface was finished to a rough texture with a wood screed. After fouteen days curing and drying, the top surface and the four sides adjacent to the top surface were treated with waterproofing material. The surface cast on the bottom of the mold was not treated, and that surface was left exposed to the air when specimens were set in water. Waterproofing compounds were brushed on in all cases with a clean paint brush 1 1/2" wide.

After the waterproofing had cured at least two days, the specimens were oven dried 24 hours. They were then set into water with untreated face turned up (See Figure 3). Water level in the steel pans was maintained to two-thirds of the height of the specimen by adding water as needed. The steel pans had been previously treated to prevent rusting and subsequent fouling of soaking water.

At the end of the 24-hour soaking period the specimens were blotted dry with paper towels, weighed, and stored in 140° F oven for the drying phase. At the end of 24 hours in the oven the specimens were removed, weighed, and placed in water for the wetting phase.

A cycle consists of 24-hour wetting phase and 24-hour drying phase.

An early wet-dry test of two months duration was made to determine if the wet and dry weights of specimens would stabilize, duration of cycle needed, and depth of submergence required. Four treatments on 32 specimens were used in the test. Eight specimens were uncoated, and eight each were coated with linseed oil and kerosene mixture, linseed anti-spall compound, and Hydrozo.

The test revealed that at least one-half the depth of the specimen should be immersed; 74 percent of total moisture gain occurred within the first 12 hours of wetting, over 90 percent of the total moisture loss occurred during the first 12 hours of drying, and that approximately one week was required of the two-week old concrete to stabilize reasonably well in wet weight and in dry weight.

On the basis of that test, 24-hour wetting and 24-hour drying phases for a wet-dry cycle and immersion of two-thirds of the depth of the specimens were adopted as standard procedures in wet-dry tests.

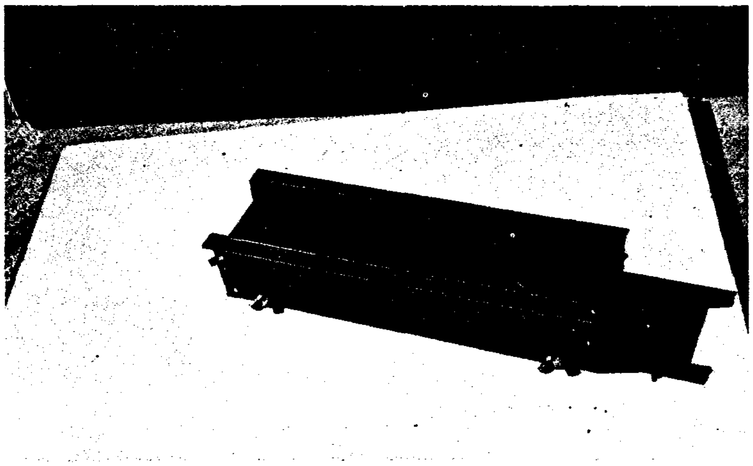


Figure 2. Steel form used for casting 3"x3"x4" plain concrete specimens. Partitions are not shown.

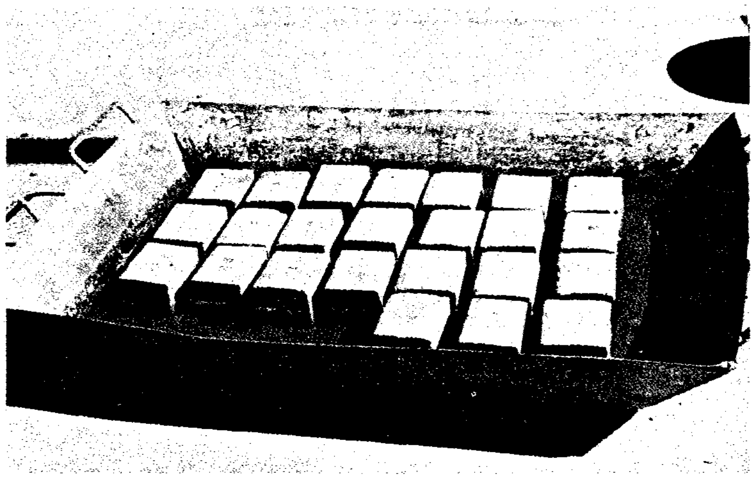


Figure 3. Wet-Dry specimens in soaking pan.

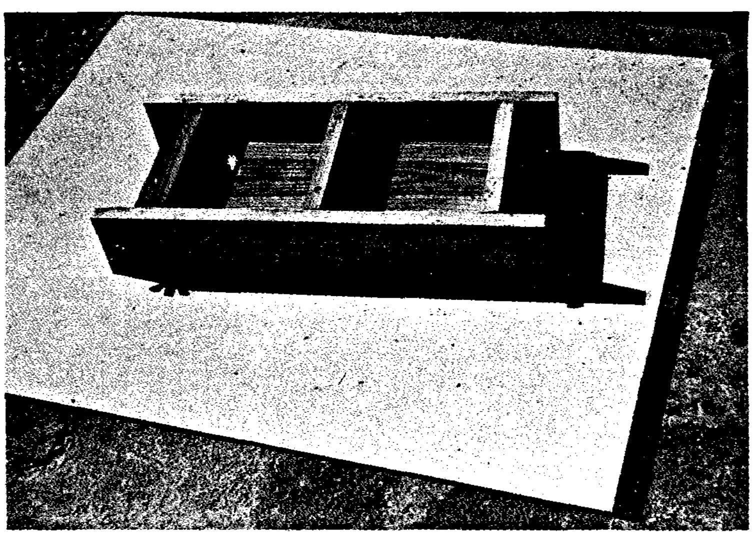


Figure 4. Wood form used for casting 8"x8"x1-1/2" plain concrete specimens.

Two wet-dry tests were made. Series A, consisting of 15 sets of three specimens each, lasted 46 days. Series B, consisting of 17 sets of one specimen each, lasted 73 days. Each series used 3" x 3" x 4" plain concrete blocks cured 14 days before coating. All sides were coated except the side cast on the bottom of the form. Two days cure of coating was allowed, with one or two exceptions, before the wet-dry cycling began. Designations of coating appear in Table I.

Wet-Dry Series A was wet-dry cycled without modification.

Wet-Dry Series B was carried through the same cycling procedure as Series A except that on the 53rd day and 62nd day after the test began the finished concrete surface (on bottom in water) was sandblasted. The blasting was carried out at the end of the drying phase in a box in which a portable sandblast gun and the specimen were mounted. A five-second duration blast of fine sand at 100 psi pressure, feeding 52 grams of sand, was sprayed over the treated surface of specimens one by one. The specimens were placed back in the cycle immediately after blasting.

Freeze-thaw Tests

Four freeze-thaw tests were made. In this report these are designated FT-A, FT-B, FT-C, and FT-D, in the order that the tests were made. In all of these tests, a treated surface or treated surfaces were subjected to freezing and thawing in a 10 percent brine solution made by dissolving ice-cream salt in tap water.

A 10-cubic-foot deep freeze was used for freezing; a 50° F refrigerator was used for thawing. A temperature-time curve of the freeze-thaw cycle is shown in Figure 5. Temperatures were taken by thermocouples cast in 3" x 3" x 4" plain concrete specimens. The test cycling did not follow exactly the schedule shown in that figure, but temperature rise and fall times were probably fairly close to those shown. In the tests, the brine was frozen hard during the freeze cycle, and it completely thawed during the thaw cycle. Temperature control settings on both the freezer and refrigerator were kept constant during the tests. Cycling was performed manually by removing specimens from freezer to refrigerator to freezer. A heavily loaded freezer required 18 hours for a hard freeze, while for a ligher load 12 hours sufficed.

The top surfaces of all laboratory specimens were finished to a rough texture with a wood screed. Specimens were removed from forms at age one day and cured in 73° fog-spray until 14 days old. They were then dried from two to three days and coated with waterproofing compounds. Specimens were three weeks old before testing began.

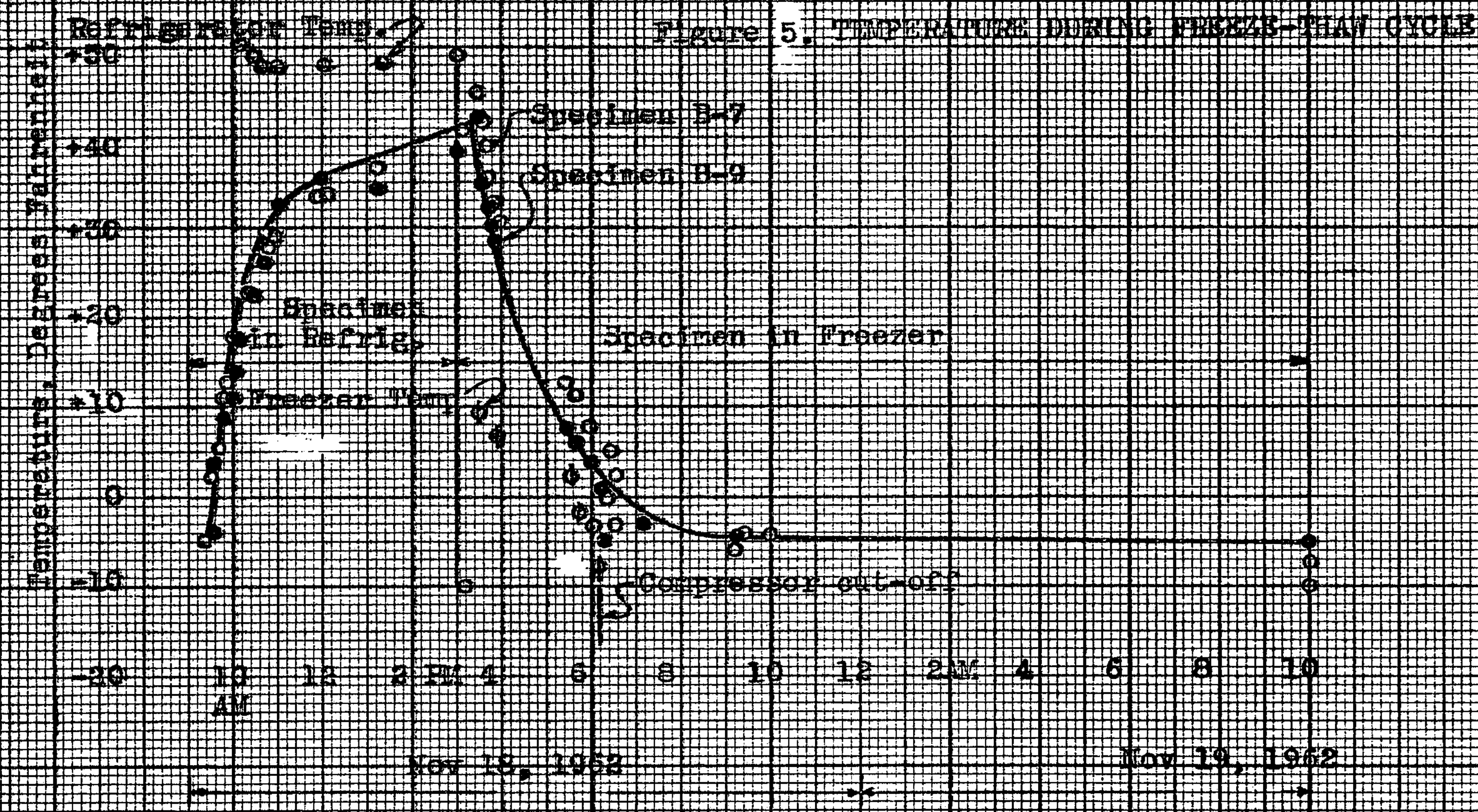


Figure 5. TEMPERATURE DURING FREEZE-THAW CYCLE

Cycling consisted of alternately freezing and thawing without interruption, with the exception that from time to time specimens had to be withdrawn for repair of seal ring (FT-B & C).

No quantitative measure of deterioration was taken; visual inspection was relied upon to determine, in a qualitative way, the deterioration in specimens.

FT-A Series. Specimens 3" x 3" x 4" were cast in lightly oiled metal forms (Figure 2). Three identically treated specimens for each of 12 treatments were used. The top surface and all adjacent surfaces were treated. The bottom-of-form surface was not treated. Top-of-form surface was faced down and immersed one-half inch in brine solution throughout the test. Cycling continued until the specimens were withdrawn for reasons of deterioration or until the test was terminated.

FT-B Series. Specimens were 8" x 8" x 1 1/2" plain concrete blocks cast in lightly oiled form (Figure 4). One specimen for each testing compound was used.

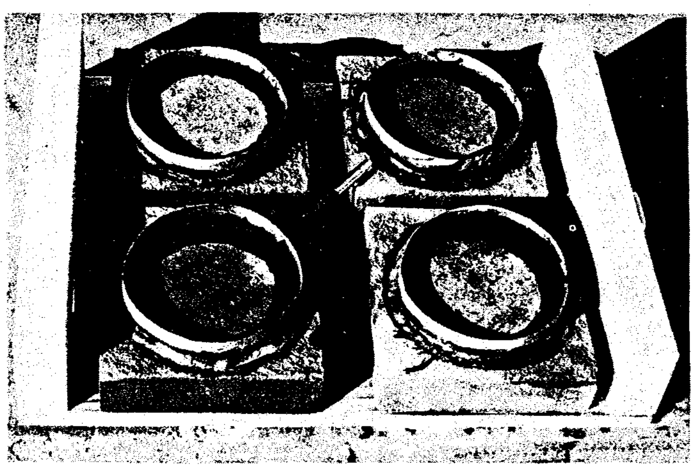
After curing, a 5 1/2-inch diameter area, centrally located on the top surface, was coated with waterproofing compound. A six-inch diameter galvanized steel ring one-inch deep was centered over that treated surface and sealed to it with mastic. A frozen specimen, a thawed specimen, and a loading tray used in handling specimens are shown in Figure 6. The sealing mastic overlapped the coated surface about one-half inch. The surface outside the ring was not treated. The tank formed by the ring was filled to one-half inch depth with 10 percent brine solution (the same as used in FT-A). Freeze-thaw cycling was carried out with this series in the same way as in FT-A. Considerable difficulty was encountered with the bituminous sealing mastic after six to ten cycles. Slight surface scaling worked its way under the seal and permitted serious leakage of brine in some specimens. Maintenance required removal of the specimen, drying it for two days, refixing the ring, curing mastic from one to two days, then putting the specimen back into the cycle. An inquiry of Dow Corning Corporation revealed that they had had similar experience when the ring was sealed to the top surface. Dow Corning Silastic RTV 732 was recommended for sealing; it was used thereafter with good results.

The waterproofing compounds used in FT-B are listed in Table 1.

FT-C Series. The silicons were not included in this series because previous tests had shown them to be unsatisfactory when used as described in these tests. Two very viscous epoxy compounds, too, were not included because it had been shown in previous tests that they were effective sealants.

(a) Frozen specimen

(b) Thawed specimen



(c) Handling rack with four thawed specimens

Figure 6. Freeze-Thaw series B specimens early in the test.

but that they, being viscous, would be difficult to apply in field application. The thin epoxy compound prepared by General Mills, Inc. for penetration of concrete (Versamid epoxy penetration sealer) had not shown up well in earlier tests; it, too, was omitted from this series.

The specimens for FT-C were identical to those in FT-B except that the entire top surface was coated and that Silastic cement was used from the beginning of the test.

One object of this series was to determine if limited exposure to sun would affect the performance of the coatings. Time did not permit a long study. The specimens were divided into two groups. One group was started on freeze-thaw cycling with 10 percent brine solution in the tank whereas the other group was placed outside with empty tanks to be exposed to the elements. During this period the hot summer sun was out each day bearing fully on the specimens.

On the second day of exposure the Permaspray coating began to crack; the next day it began to curl up in small sheets. It was thought that the condition could possibly be caused by fines floated to the top during the finishing operation; therefore, all specimens of the series were withdrawn from test. The rings were removed and the top treated surfaces were sandblasted, recoated over the entire top surface, and the rings were then set back into position.

The specimens were then divided into the same two groups as before, and the test was begun in the same way. Again, on the third day of exposure to the sun, Permaspray peeled just as it did previously on the surface that had not been sandblasted.

The test was continued by alternately exposing specimens one week and freeze-thaw cycling one week.

<u>FT-D Series.</u> Specimens for this series were taken from an old concrete paving slab (State Route 21, Caldwell, Texas) that had been in service since 1935. See Appendix C for a description of the concrete. The six-inch thick slab had been broken up and removed from the roadway. The slab chunks were sawed into pieces and four specimens were selected as suitable for testing (Figure 7). Those four rough pieces were set into cement mortar in pans so that the smooth top surface was level and in a position for waterproofing treatment. Treatments are checked in Table I.

The number of specimens used in this series was small because of the large space needed for cycling. The specimens were large and cumbersome to handle. No more than four could be placed in the freezer at one time, and time did not permit tests of other coatings on this concrete.

Exposed Slab. A four-inch thick plain concrete slab was cast outside on the ground in November 1962 for this test. The slab was ponded after setting up and it cured three days under water. At an age of two months it was divided into 15 panels each approximately two feet square (See Figure 8). Each panel was treated as checked in Table I.

The only evaluation possible as to the effectiveness of the sealants used in this test is by visual inspection. No method was devised whereby a measure of water penetration could be determined.

RESULTS AND DISCUSSION

Wet-Dry Test Results

Curves of moisture absorption versus age of test are shown in Figures 9 and 10. Those curves have been smoothed in among individual day by day points that are not shown in those figures.

Specimen weights were in the approximate range of 1300 to 1500 grams; the change in weight between wet and dry conditions were in the neighborhood of from 3 to 25 grams. The least reading on laboratory balances used to take weights was one gram.

Generally there appeared to be no breakdown of coatings in the alternate wetting and drying of specimens. In Series A curves (Figure 9) there appears to be some diverging after some 30 to 40 days, but this should not be taken as conclusive evidence that those coatings were breaking down with age.

Series A. Three specimens were treated with each coating in this series. All results shown represent the average of three weights for each treatment represented.

Wet-dry coatings 8, 16, 18, and 19 in Figure 9 show a relatively large increase in moisture change at approximately 35 days age. The water used for soaking specimens was changed at that time because water in some of the pans had become slightly discolored from rust in the pans. That change of water is the only reason that can be advanced for the abrupt change in moisture noted. Although the water was not highly contaminated, possibly some of the pores were clogged with rust particles.

Specimen coating 6 underwent a large moisture change at about 20 days age for which no explanation can be offered.

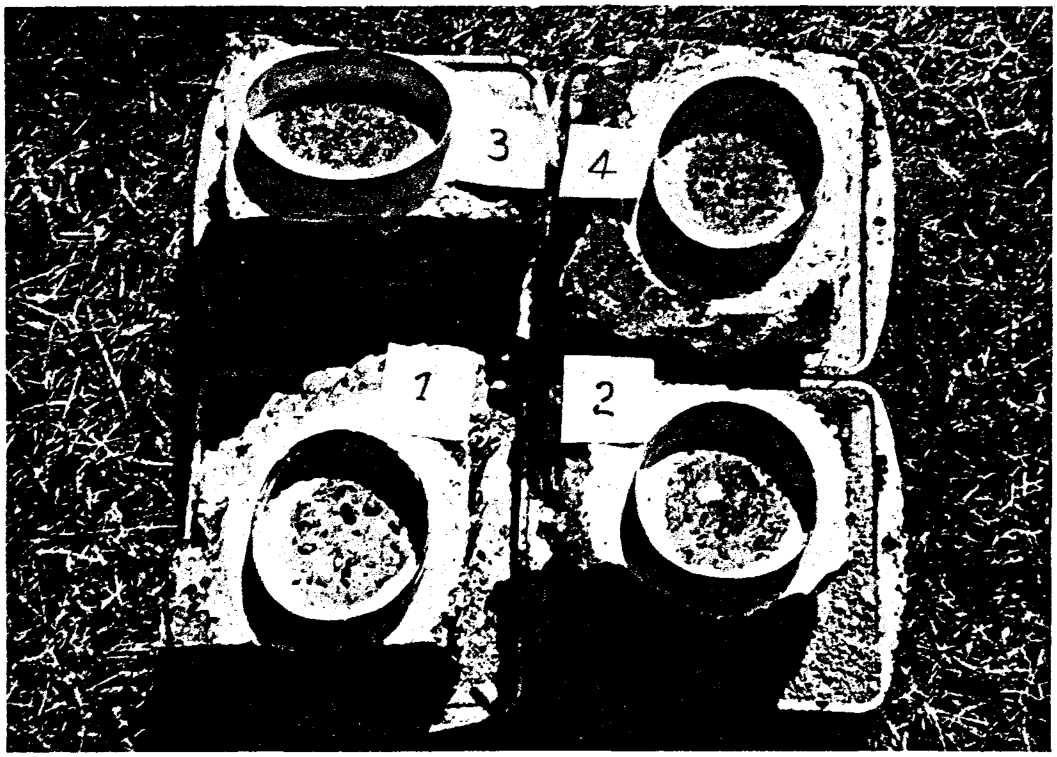


Figure 7. Specimens of old concrete used in FT-D series.

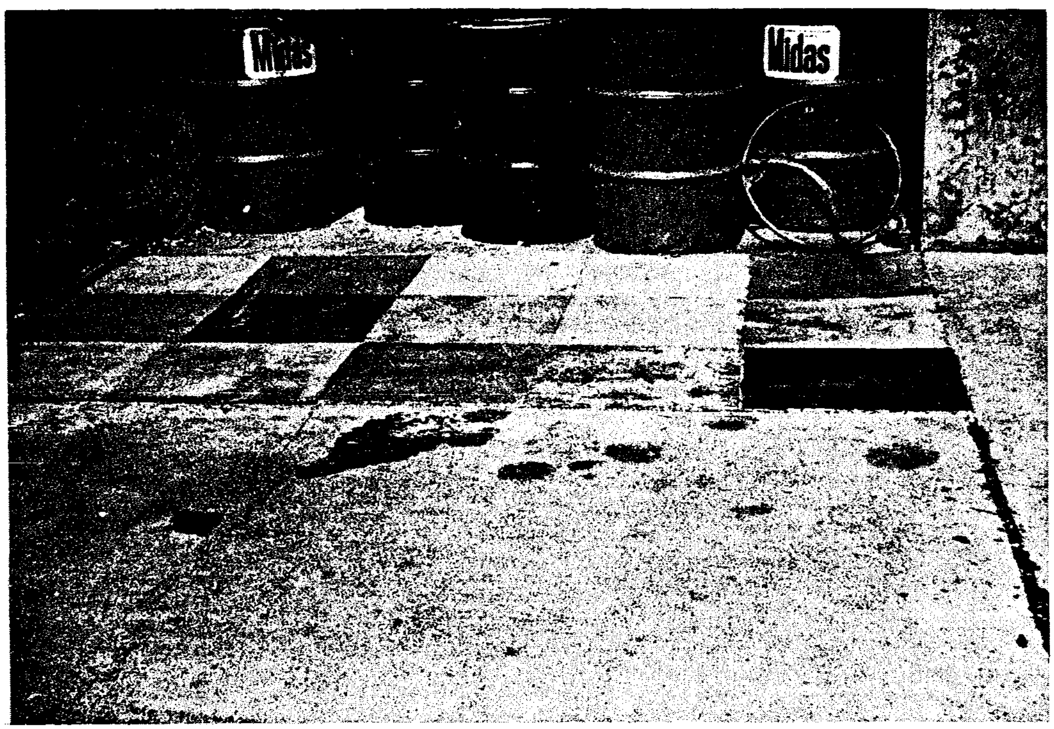


Figure 8. Exposed slab. Panels are treated with waterproofing compounds.

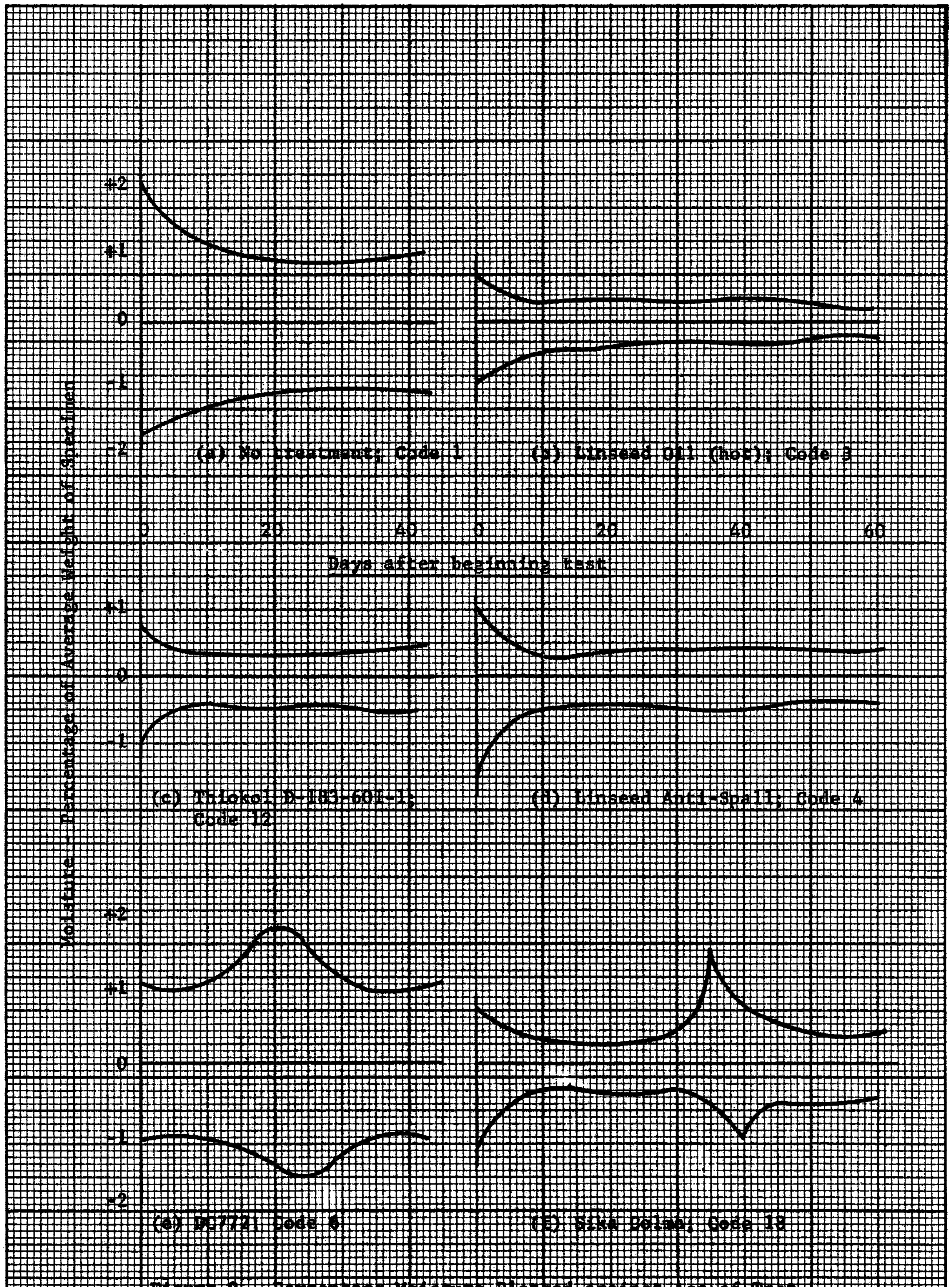


Figure 9. Percentage Moisture Plotted against Age of Test
Wet-Dry Series A

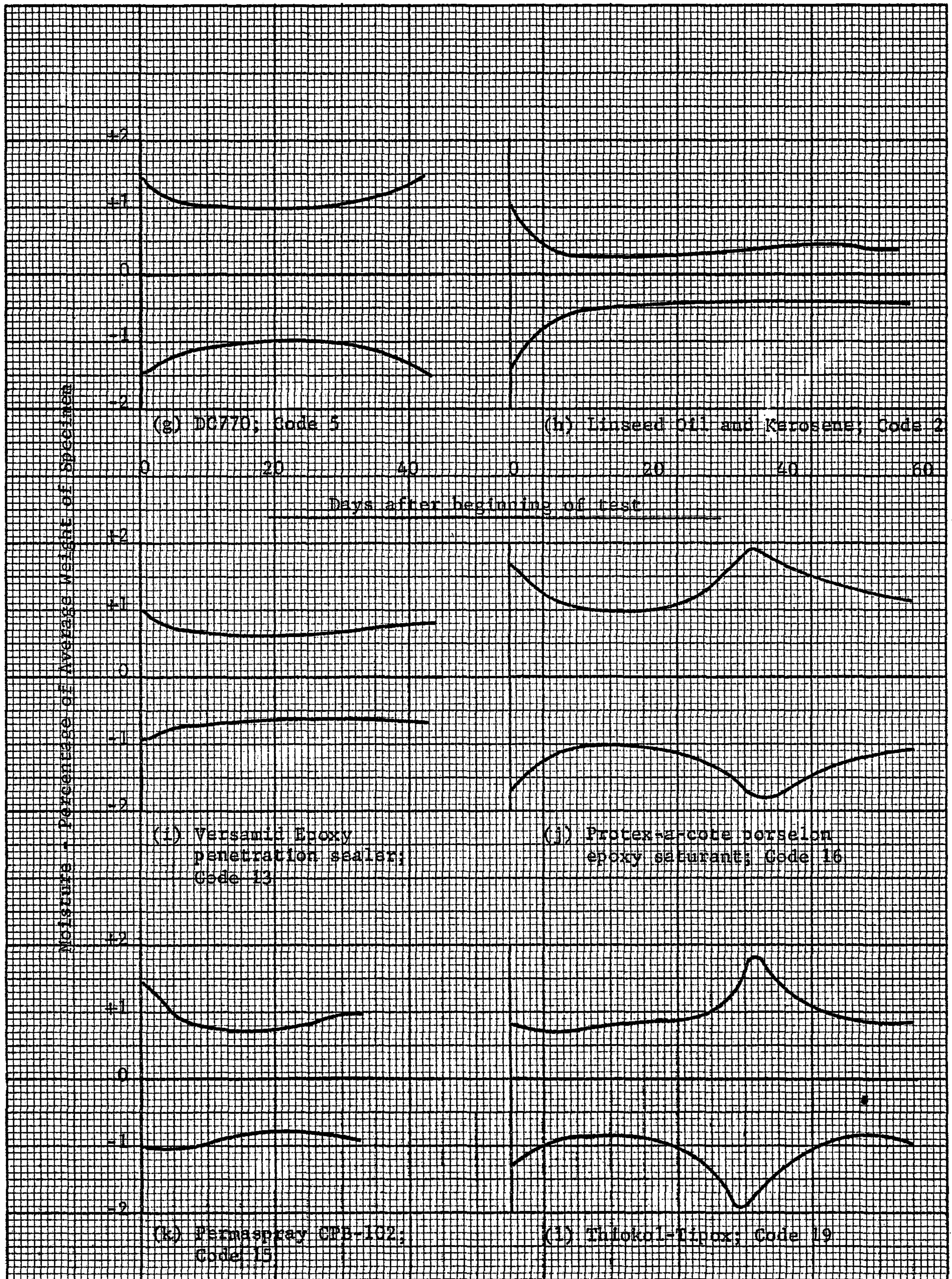


Figure 9 (continued). Percentage Moisture Plotted against Age of Test
Wet-Dry Series A

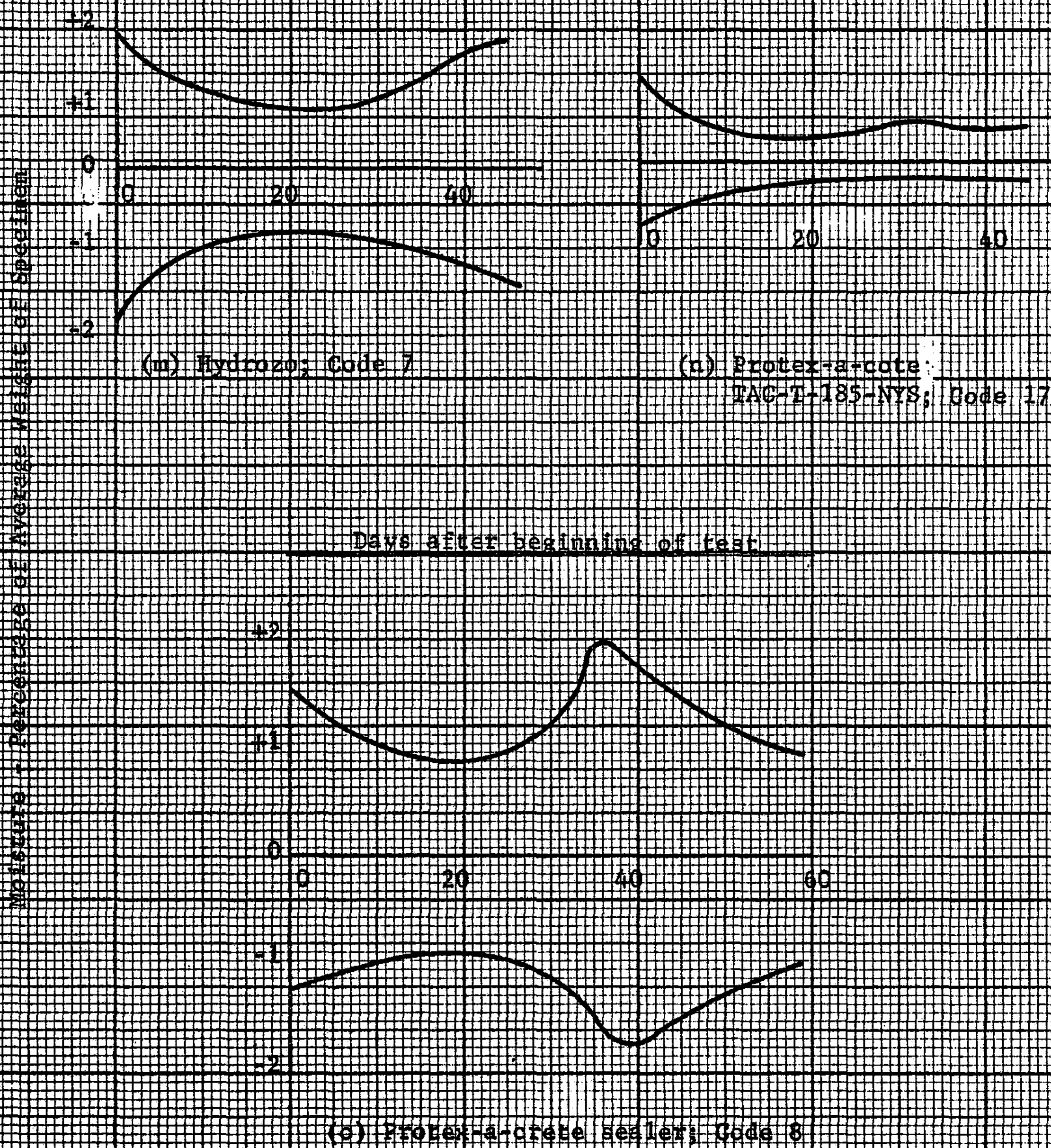


Figure 9 (continued). Percentage Moisture Plotted against Age of Test

Wet-Dry Series A

After an initial adjustment period of about 5 days the moisture changes generally stabilized, and in most cases there was not a great change from then until the test was terminated.

The average of percentage moisture gain and loss for each specimen is shown in Table II. Linseed oil treatments 2, 3, and 4, and epoxy treatments 12 and 17 performed best in this series. All of these have an average of less than 0.5 percent of the average weight of the specimen. This represents generally a change in weight from oven dry to soaked and from soaked to oven dry of approximately 7 grams for a 1400 gram specimen.

The specimen with no treatment had a moisture change of 1.135 percent or about 16 gram average change from the wet to dry and dry to wet condition. This is over twice the change noted in the lower percentage specimens.

It will be noted from Table II that some specimens had moisture changes greater than the untreated specimen. It does not appear that any of the treatments would enhance passage of water into the specimen; therefore, the untreated specimens must have been either more dense than others or residue of form oil could have possibly caused the difference. All specimens were treatedwithout cleaning because they had a clean appearance when dried prior to coating. A light application of form oil was used at casting, and there was probably a residue of that oil on or just under the surface after curing.

Series B. Because of the consistency of moisture change of individual specimens of a set in series A, only one specimen of each treatment was used in series B. Specimens were handled the same as in series A except that the top surface, as cast in the form, was sandblasted on the 53rd and 62nd day after the test began. Moisture curves are shown in Figure 10. Some specimens were placed in the test later than others. For that reason some specimens had not been cycled as many times as others had when they were sandblasted.

The control specimen—no treatment—jumped from 1.13 average percent moisture with no sandblasting (series A) to 1.96 percent with sandblasting—a gain of 0.83 percent. This would indicate that a dense surface film existed on the top surface of the specimen before it was abraded. None of the treated surfaces changed that much after sandblasting.

Abrasion of treated surfaces increased the amount of water absorbed, but the percentage increase in the two cut-back linseed oil treatments—2 and 4—was negligible, as was the increase in treatment 8. Treatment 8, however, had a high percentage of absorption in both series. Only the linseed oil treatments showed up consistently low in these tests.

TABLE II. AVERAGE PERCENTAGE MOISTURE—WET-DRY TESTS

Code Name	Series A Percentage gain	loss	avg	Series B Percentage gain	loss	avg	Differences of Avgs (%)
1. No treatment	1.14	1.13	1.13	1.98	1.94	1.96	0.83
2. Linseed oil & kerosene	0.43	0.52	0.47	0.48	0.55	0.51	0.04
3. Linseed oil (hot)	0.29	0.39	0.34	0.41	0.47	0.44	0.10
4. Linseed anti-spall	0.43	0.53	0.48	0.48	0.55	0.51	0.03
5. DC 770	1.15	1.14	1.14	1.35	1.33	1.34	0.20
6. DC 772	1.28	1.29	1.28	1.99	1.94	1.96	0.68
7. Hydrozo	0.96	0.95	0.95	1.62	1.60	1.61	0.56
8. Protex-a-crete seal	1.43	1.42	1.42	1.55	1.47	1.51	0.09
9. Chempol 32-1010	(not incl)			0.97	0.93	0.95	
10. Trikote	(not incl)			1.57	1.54	1.55	
11. Chempol 31-10006	(not incl)			0.99	0.95	0.97	
12. Thiokol D-183-601-1	0.44	0.47	0.45	0.95	0.93	0.94	0.49
13. Versamid Epoxy Penetr. sealer	0.71	0.74	0.72	1.15	1.13	1.14	0.42
14. Presstite 140-Guardkote	(not incl)			0.48	0.47	0.47	
15. Permaspray	0.89	0.87	0.88	1.36	1.37	1.36	0.48
16. Protex-a-cote Proselon epoxy	1.30	1.31	1.30	1.53	1.51	1.52	0.22
17. Protex-a-cote T-185-NYS	0.32	0.38	0.35	(not incl)			
18. Sika Colma coating	0.54	0.58	0.56	1.03	1.05	1.04	0.48
19. Thiokol Tipox	0.98	0.99	0.98	(not incl)			

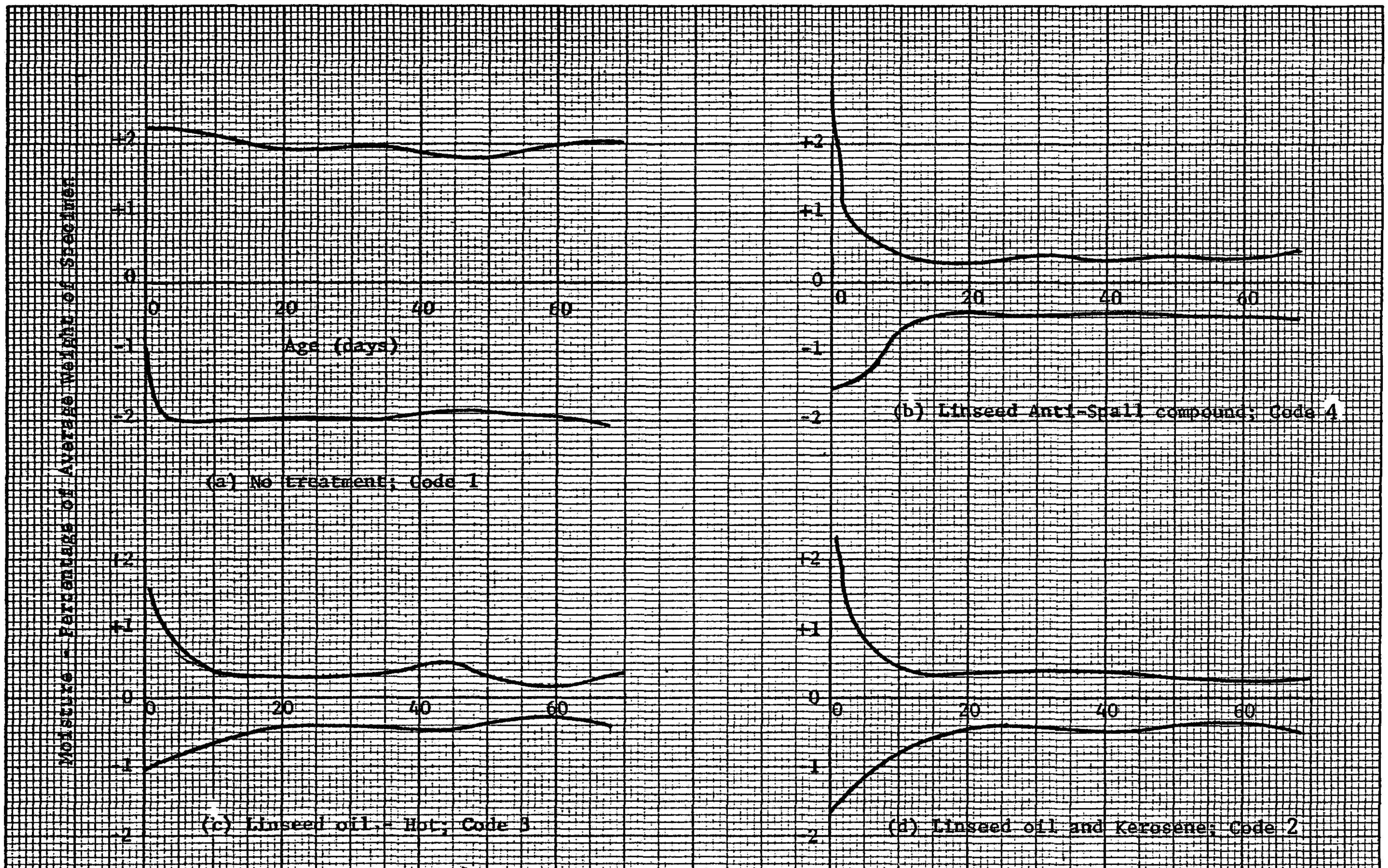


Figure 10. Percentage Moisture Blotted against Age of Test,

Wet-Dry Series B

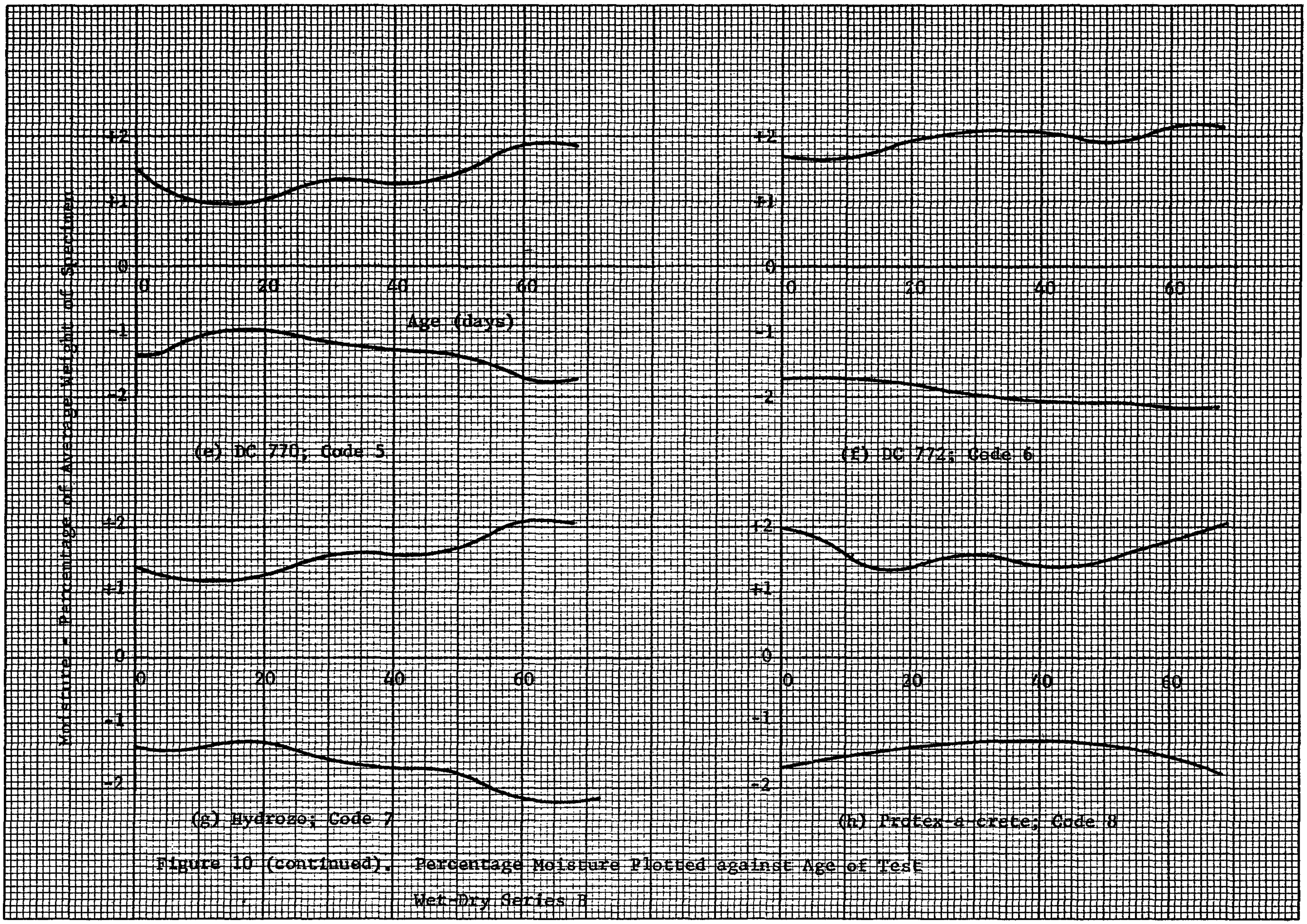


Figure 10 (continued). Percentage Moisture Plotted against Age of Test

Wet-Dry Series B

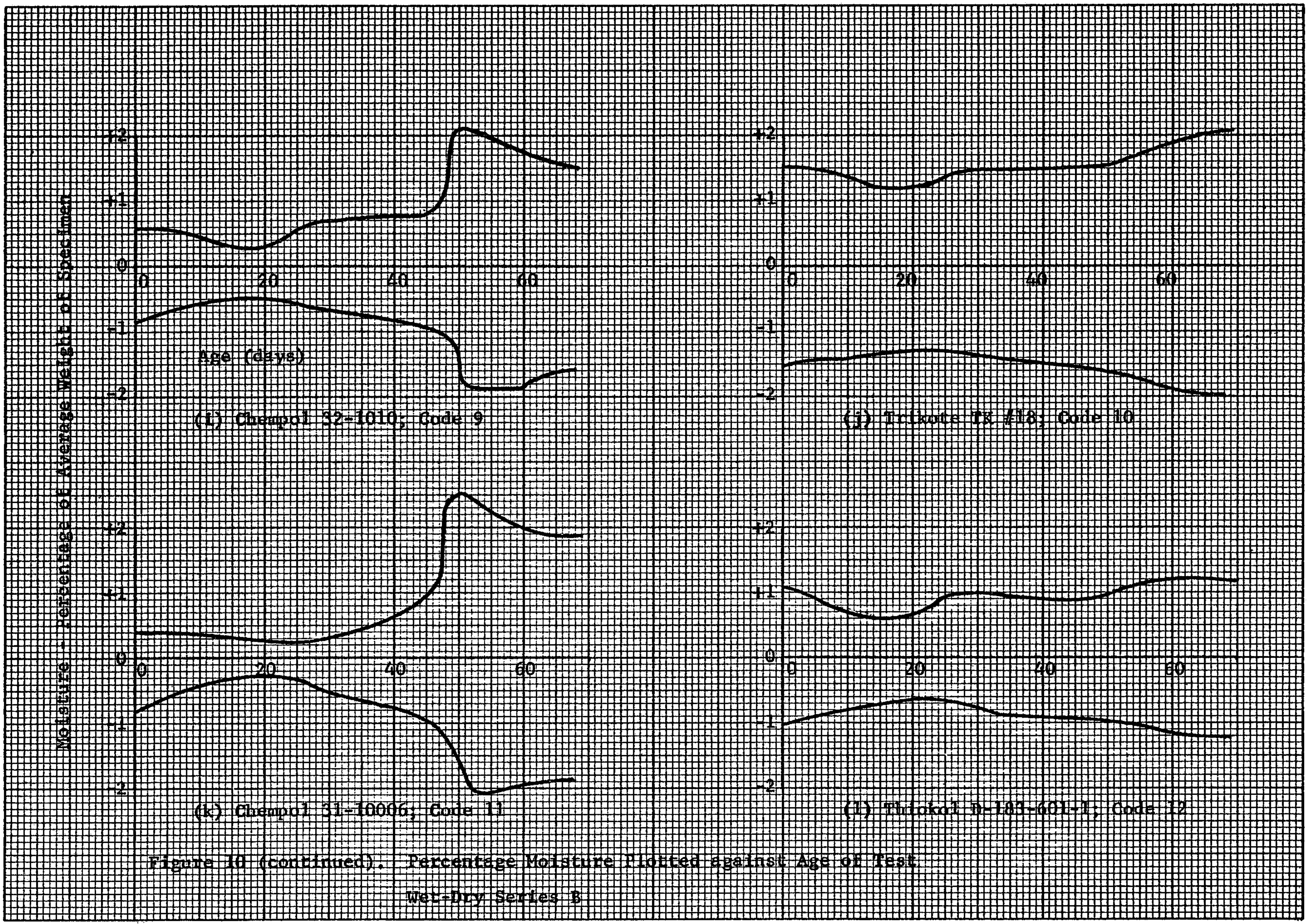


Figure 10 (continued). Percentage Moisture Plotted against Age of Test

Wet-Dry Series B

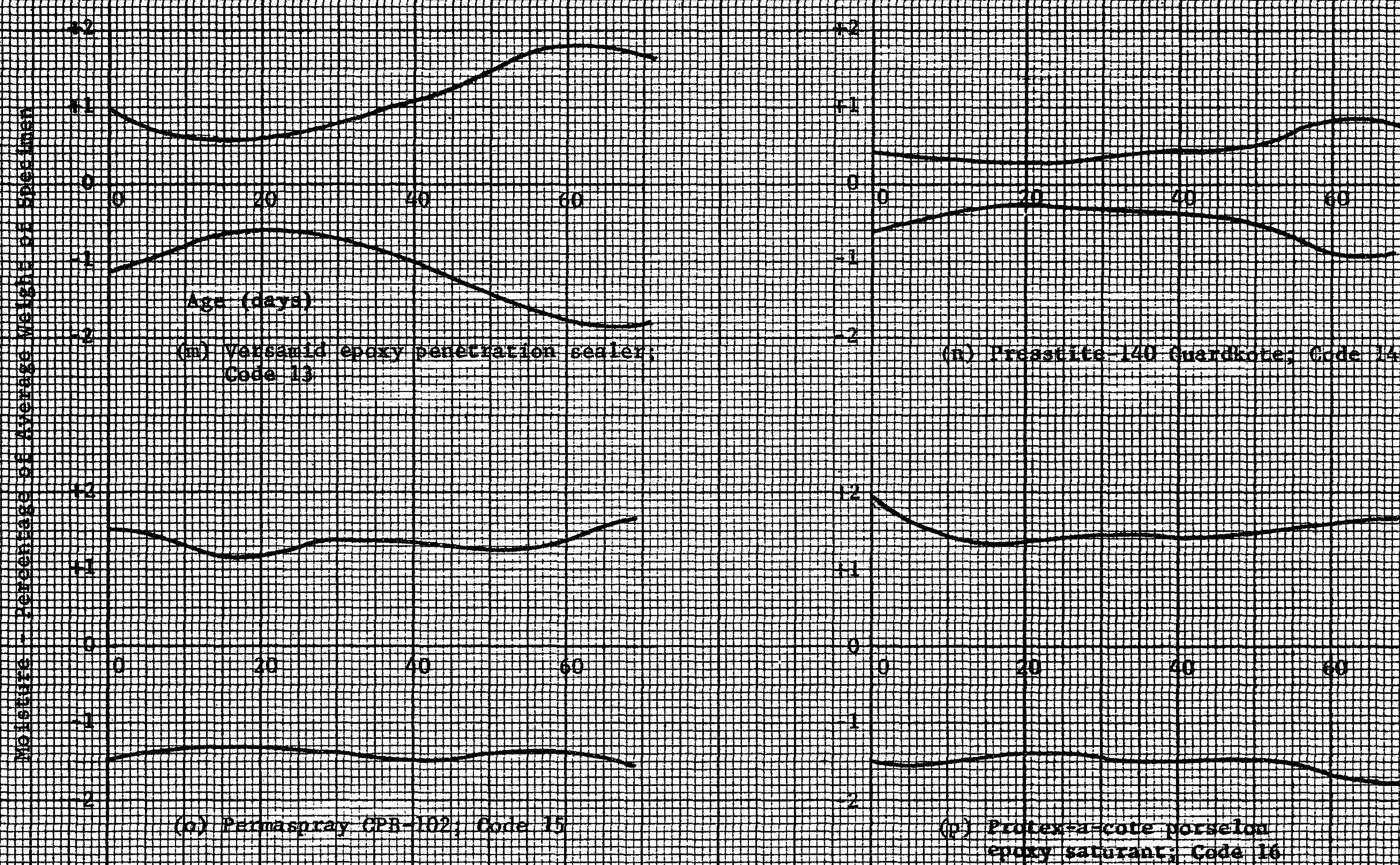
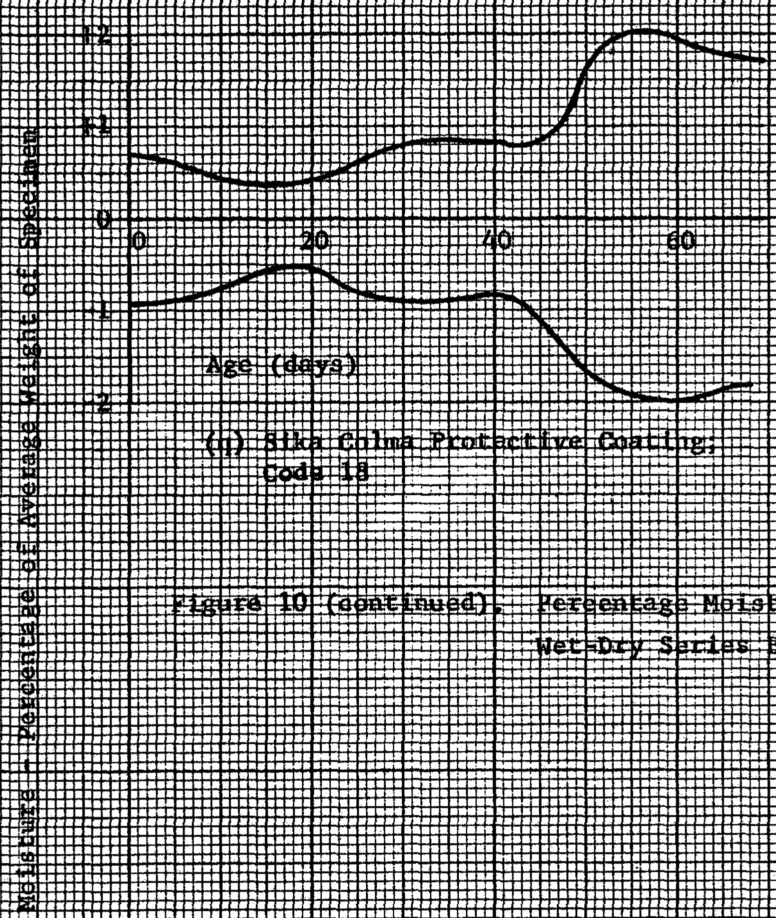


Figure 10 (continued). Percentage Moisture Plotted against Age of Test
Wet-Dry Series B



(q) Sika Colma Protective Coating;
Code 18

Figure 10 (continued). Percentage Moisture Plotted against Age of Test

Wet-Dry Series B

Freeze-thaw Test Results

FT-A Series

All specimens of this series had deteriorated to some degree at 18 freeze-thaw cycles, and most of these were well on their way to destruction by that time. Photographs of typical specimens are shown in Figure 11. Break down began at corners and edges—see, for example, Figure 11 (d). The concrete first began to flake off, then it began to crumble along the edges. Failure progressed from the crumbled edges along immersed surfaces until, in some cases, the entire bottom surface was undermined and broke away.

Some of the epoxies stood up well, as did the two linseed oil treatments. The first sign of deterioration was noted at five cycles. After eight cycles coatings 1, 6, 7, 8, 13, and 16 all showed corner and edge chipping. At 11 cycles the first signs of deterioration showed up in coatings 2, 4, and 5. Some specimens were so badly deteriorated at 21 cycles that they were withdrawn; all cycling was stopped at 25 cycles.

FT-B Series

Photographs of all specimens taken after cycling was discontinued are shown in Figure 12; Table III gives information on deterioration. Treatments 4, 9, 10, 12, 13, 14, and 18 showed little or no sign of deterioration of the coating itself, but in some of these cases deterioration occurred under and outside the ring. It cannot be said definitely that 18 had its initial failure under the ring, but it appears that was the case. When brine found its way under the sealing mastic, it penetrated uncoated concrete and deterioration set in. It appears now that the entire top surface of all specimens should have been treated before the ring was attached.

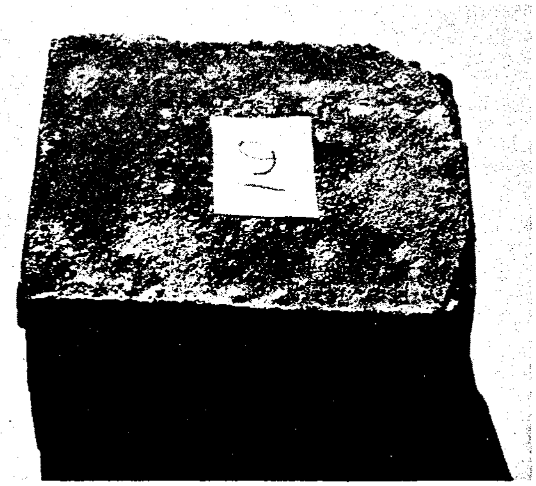
Coatings 9, 14, and 18 could probably have been cycled longer had the failure under the ring not occurred. Of the one-component coatings 2 through 10, the linseed oils and Trikote TK#18 performed best. Designations higher than 10 are two component treatments, and most of those held up well in the test.

FT-C Series

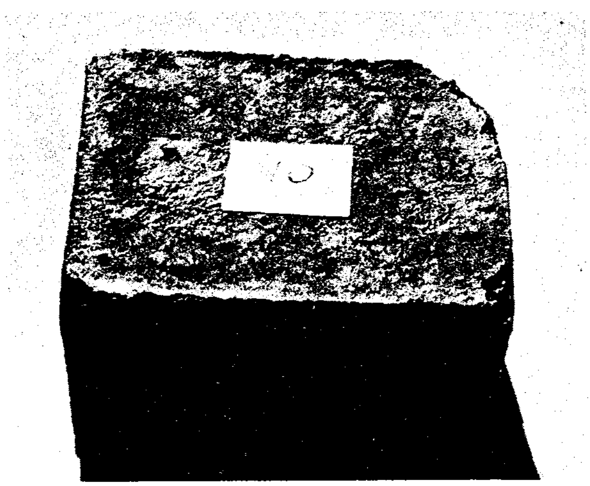
Two specimens were used for most of the treatments tested. Table IV gives information on specimens, and Figure 13 shows the end-of-test condition of the three specimens that began to break down before the test was terminated.

All specimens were exposed outside for 28 days and were carried through 28 freeze-thaw cycles. Figure 14 shows four specimens after four days of exposure to the sun. The specimen marked 12-C in that figure shows Permaspray coating peeling away from the concrete.

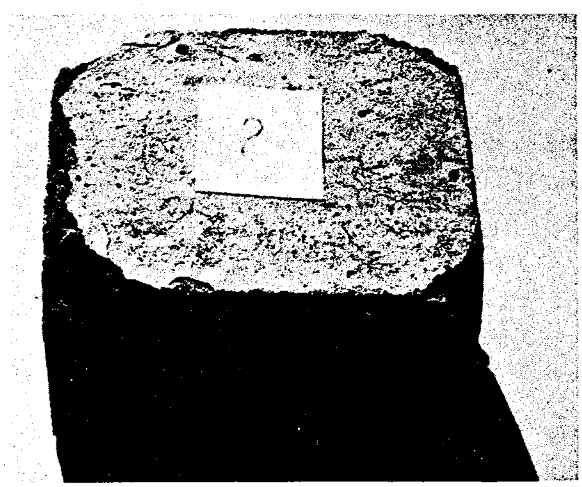
(a) Code 1 - No treatment (21 cycles)



(b) Code 2 - Linseed oil and kerosene (23 cycles)



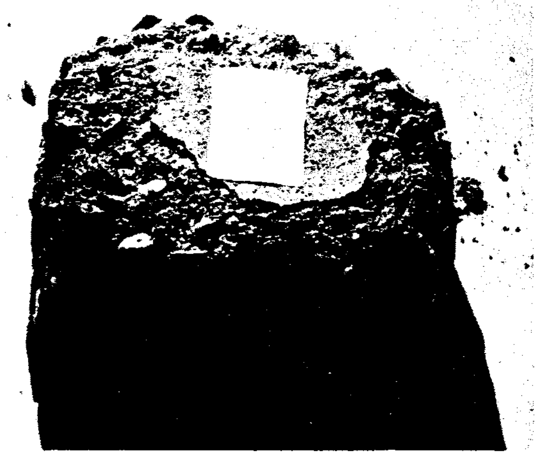
(c) Code 4 - Linseed anti-spall compound. (23 cycles)



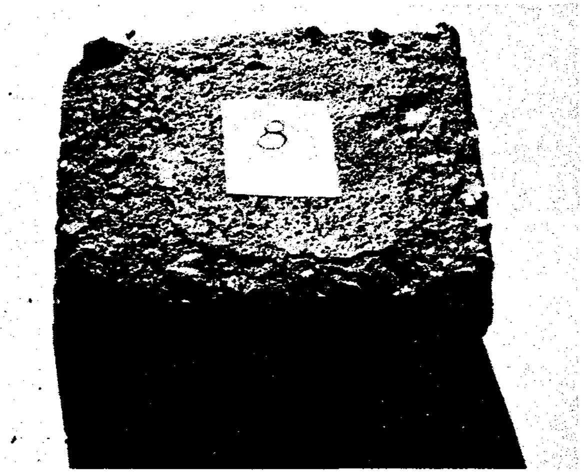
(d) Code 5 - DC 770 (23 cycles)

Figure 11. Freeze-Thaw Series A specimens

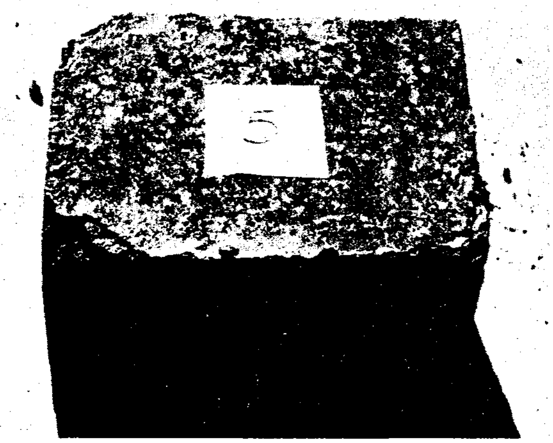
(e) Code 6 - DC 772
(21 cycles)



(f) Code 7 - Hydrozo
(21 cycles)

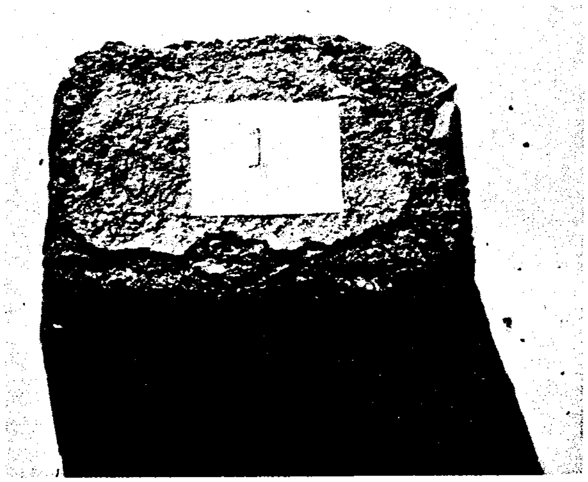


(g) Code 8 - Protex-a-crete
(21 cycles)

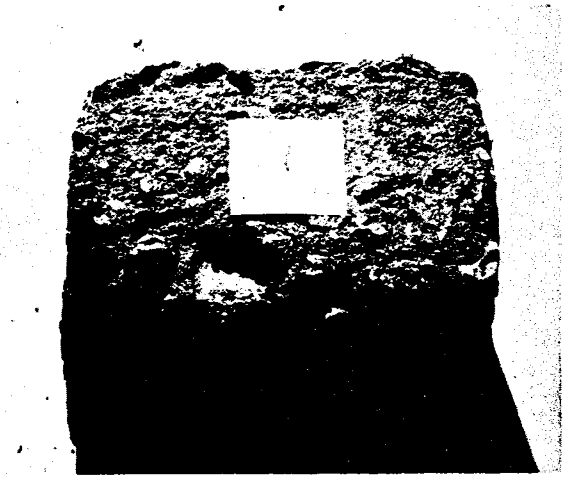


(h) Code 12 - Thiokol D183-601-1
(25 cycles)

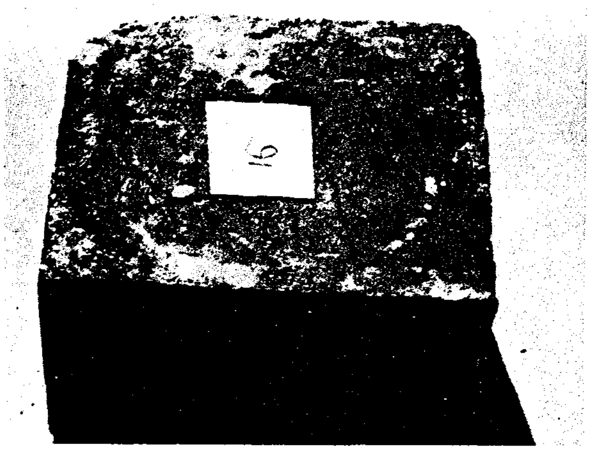
Figure 11 (continued). Freeze-Thaw Series A specimens.



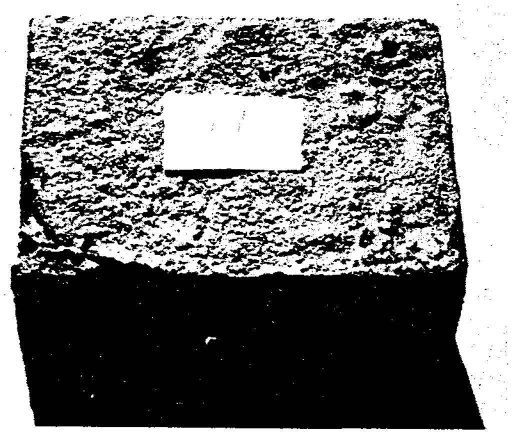
(i) Code 13 - Versamid Epoxy. (21 cycles)



(j) Code 16 - Protex-a-cote porselon epoxy. (21 cycles)

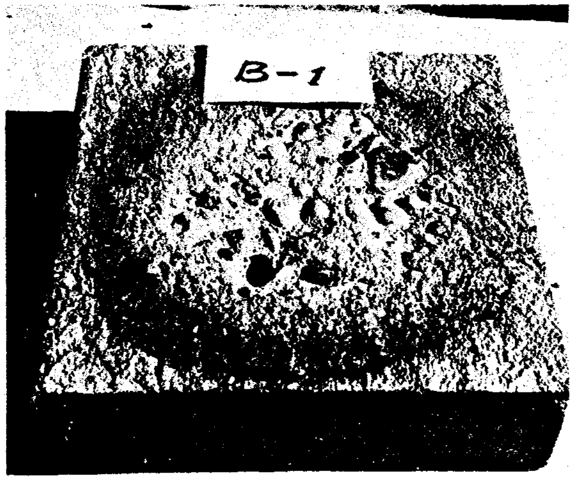


(k) Code 17 - Protex-a-cote TAC-T-185 NYS (25 cycles)

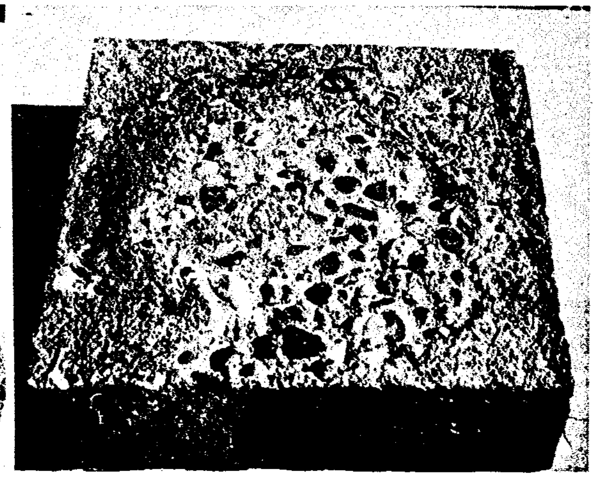


(1) Code 18 - Sika colma protective coating. (23 cycles)

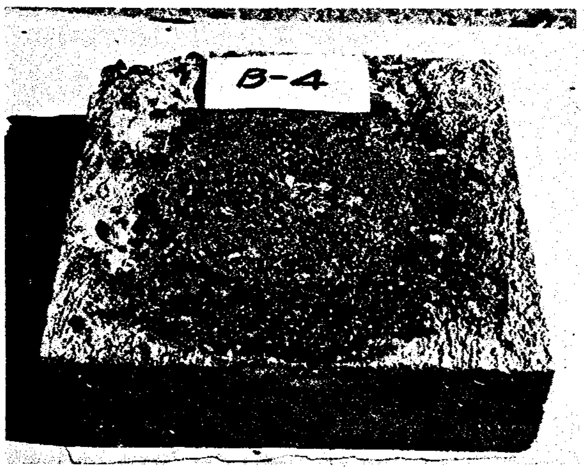
Figure 11 (continued). Freeze-Thaw Series A specimens



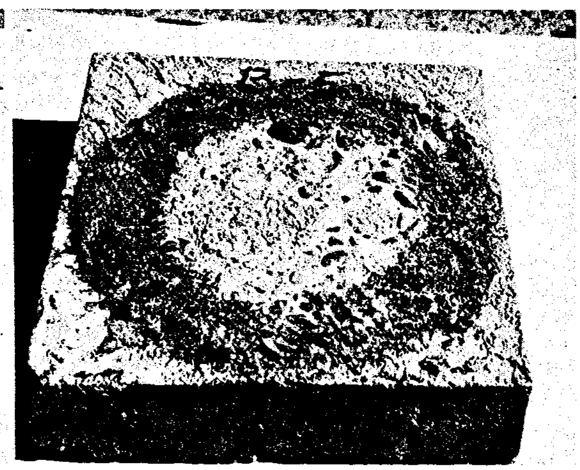
(a) Code 1 - No treatment



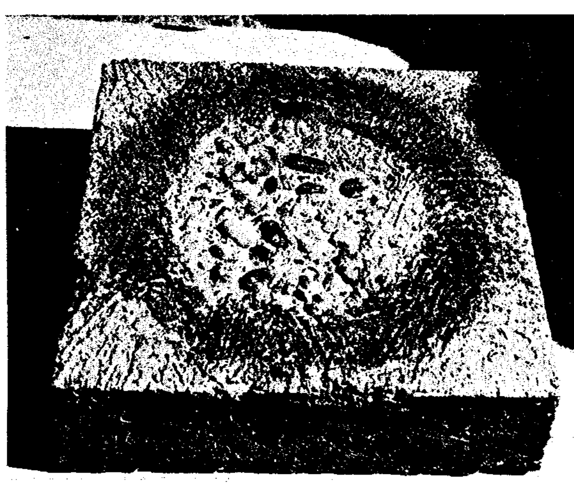
(b) Code 2 - Linseed oil and kerosene



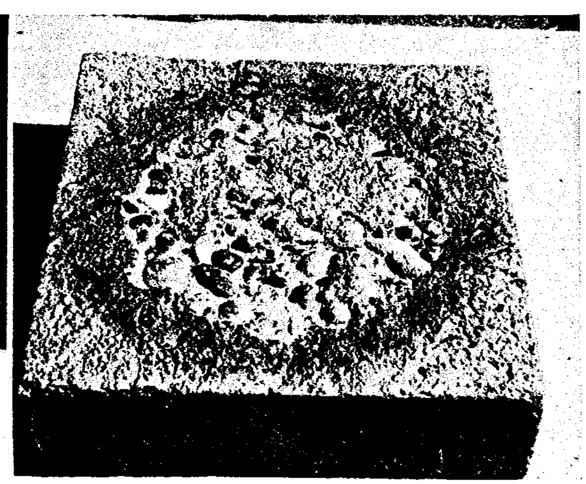
(c) Code 3 - Linseed oil (hot)



(d) Code 4 - Linseed anti-spall compound



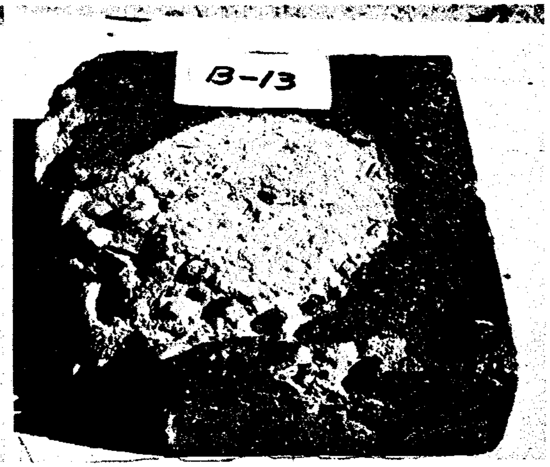
(e) Code 5 - DC 770



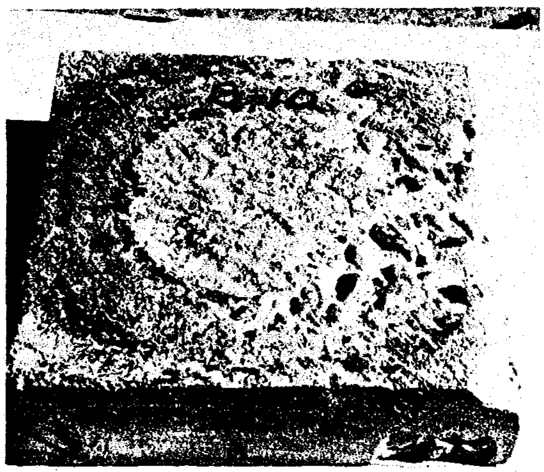
(f) Code 6 - DC 772

Figure 12. Freeze-Thaw Series B specimens

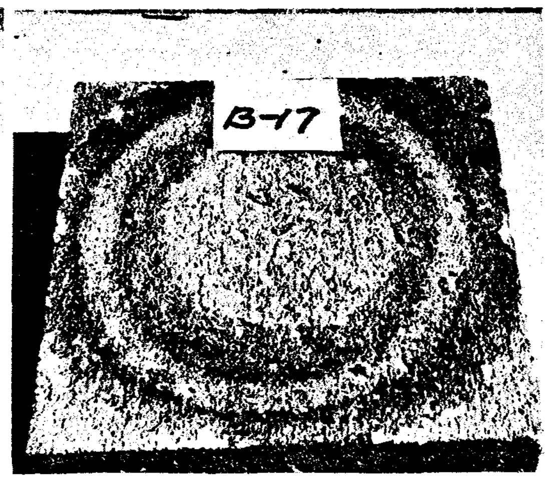
(g) Code 7 - Hydrozo



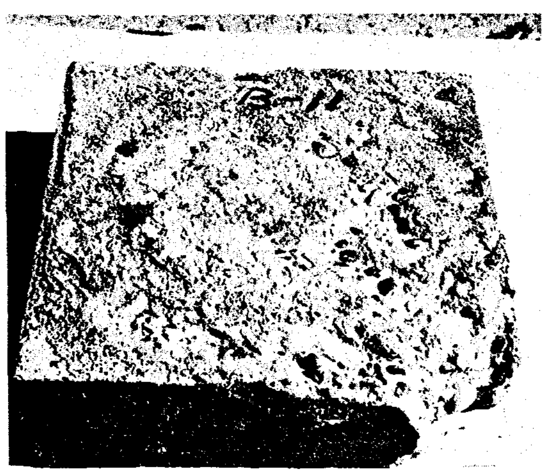
(h) Code 8 - Protex-a-crete



(i) Code 9 - Chempol 32-1010



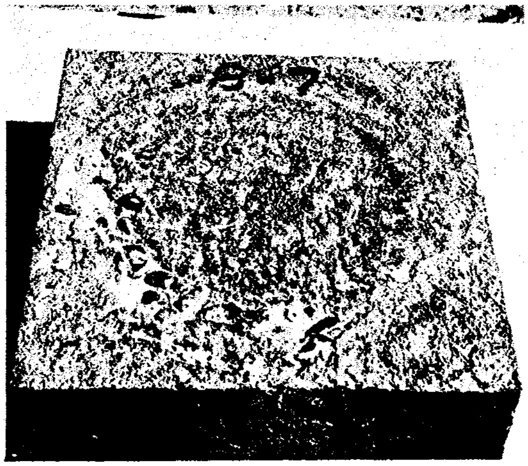
(j) Code 10 - Trikote TK-18



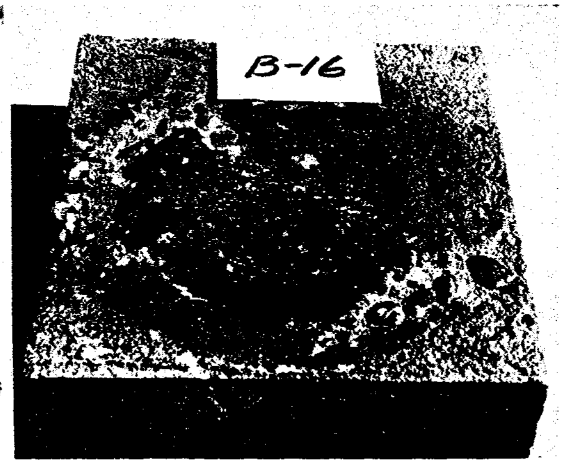
(k) Code 11 - Chempol 31-10006

(l) Code 12 - Thiokol D-183-601-1

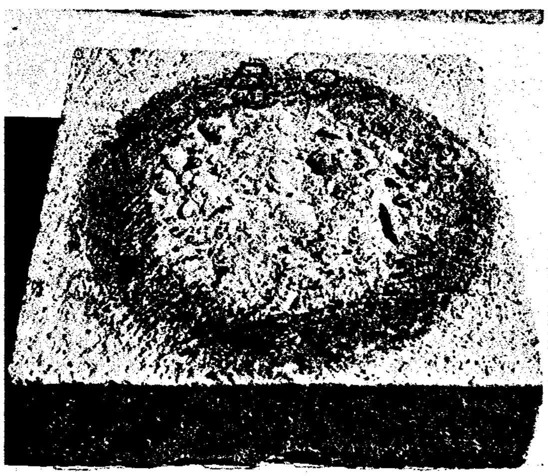
Figure 12 (continued). Freeze-Thaw Series B specimens



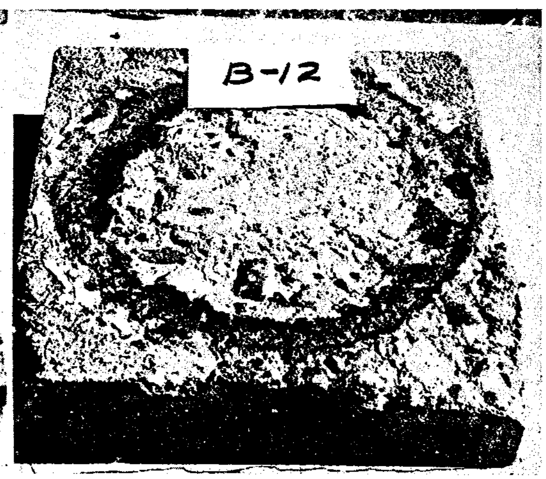
(m) Code 13 - Versamid epoxy penetrating sealer



(n) Code 14 - Presstite 140 Guardkote



(o) Code 15 - Permaspray CPB 102



(p) Code 16 - Protex-a-cote porselon epoxy saturant

(q) Code 18 - Sika Colma protective coating

Figure 12 (continued). Freeze-Thaw Series B specimens

TABLE III. PERFORMANCE OF SPECIMENS, FT-B

Specimen	1st Sign of Deterioration	Discontinued	Remarks
1. No treatment	9th cycle	24 cycles	Pitted surface
2. Linseed oil & kerosene	35th cycle	84 cycles	Pitted surface
3. Linseed oil (hot)	51st cycle	98 cycles	Good condition
4. Linseed anti-spall	36th cycle	56 cycles	Shallow surface pits
5. DC 770	20th cycle	26 cycles	Surface pitting
6. DC 772	17th cycle	33 cycles	Deep surface pits
7. Hydrozo	12th cycle	59 cycles	Surface pits
8. Protex-a-crete	6th cycle	41 cycles	Surface scaling and failure under ring
9. Chempol 32-1010	11th cycle	54 cycles	Failure under ring
10. Trikote TK #18	8th cycle	97 cycles	Good condition
11. Chempol 31-10006	47th cycle	77 cycles	Surface scaling
12. Thiokol D-183-601-1	No failure of coating	79 cycles	Failure outside ring
13. Versamid epoxy	No failure of coating	93 cycles	Failure under ring
14. Presstite Guardkote	9th cycle	90 cycles	Failure under ring
15. Premaspray CPB 102	21st cycle	23 cycles	Severe surface scaling
16. Protex-a-cote porselon epoxy	6th cycle	41 cycles	Surface scaling
18. Sika Colma coating	15th cycle	59 cycles	Failure under ring

Note: Freeze-thaw cycling began March 14, 1963. Test discontinued June 27, 1963. Freezing phase-12 hours, thawing phase-12 hours.

Deterioration first set in at seven freeze-thaw cycles when treatments 3 and 13 began to flake off. At nine cycles treatment 15, too, began to flake. Those were the only specimens that showed any signs of deterioration during the entire test, and they did not progress to the point where they were considered to be in serious condition. In the previous tests, however, it was found that once flaking began, pitting followed and continued until the specimen was in danger of breaking up.

Time did not permit this series to continue long enough to determine if extended exposure to the sun would have any effect on treated specimens.

It was shown that Permaspray did not stand up under exposure to the sun even though it had not been frozen prior to exposure. Except for a slight fading of color in some of other specimens, no harmful effects from sun were noted.

Hydrozo, treatment 7, began to flake at the same time as the untreated specimen, following the pattern of early failures as shown in earlier tests. Protex-a-crete, treatment 8, began flaking at nine cycles which, too, follows earlier test performances of early failure.

FT-D Series

These were specimens taken from an old paving slab; Figure 15 shows those specimens after removal from test and Table V gives information on performance. There was no surface scaling on these, but each one of them was cracked to the extent that it would not retain water at the end of the test. None of the cracks was visable at beginning of test, but the concrete surface was old and stained by traffic wear so as to make minute crack detection very difficult.

The first cracks were noted at 37 cycles; all four specimens had cracked at 40 cycles, and they were withdrawn at 41 cycles because they would not retain brine on the treated surfaces. The outside untreated edges were in serious cracked condition indicated that brine had filtered into the concrete and broken it up by freezing and thawing action. This would indicate that the cracks had been in existence some time—say at least five cycles—before they were noticed on the ponded surfaces.

Exposed Slab

No quantitative data could be taken on this test. Coatings were applied in January, 1962, when the concrete was two months old. It was examined periodically since that date. The only evidence of any type of surface coating failure was scaling off of Thiokol Tipox six weeks after application. The slab was exposed to the elements during the entire period.

TABLE IV. PERFORMANCE OF SPECIMENS, FT-C

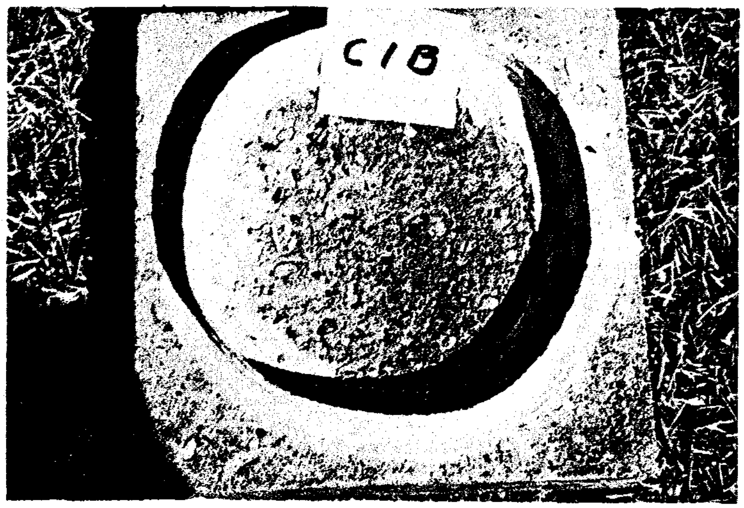
Specimens were alternately exposed under the sky (24-hour day) for 7 days then freeze-thaw cycled for 7 days for a period of 8 weeks. Each specimen was exposed 28 days and underwent 28 freeze-thaw cycles.

Specimen		Number of Specimens	Remarks
1.	No treatment	2	First scaling 7th cycle
2.	Linseed oil and kerosene	2	No perceptible deterioration
3.	Linseed oil - hot	2	No perceptible deterioration
4.	Linseed anti-spall	2	No perceptible deterioration
7.	Hydrozo	2	First scaling 7th cycle
8.	Protex-a-crete	2	First scaling 9th cycle
9.	Chempol 32-1010	2	No perceptible deterioration
10.	Trikote TK #18	1	No perceptible deterioration
11.	Chempol 31-10006	2	No perceptible deterioration
12.	Thiokol D-183-601-1	1	No perceptible deterioration
14.	Presstite 140 Guardkote	1	No perceptible deterioration
15.	Permaspray	1	Coating peeled off in sun
16.	Protex-a-cote Porselon epoxy	2	No perceptible deterioration
18.	Sika Colma Coating	2	No perceptible deterioration

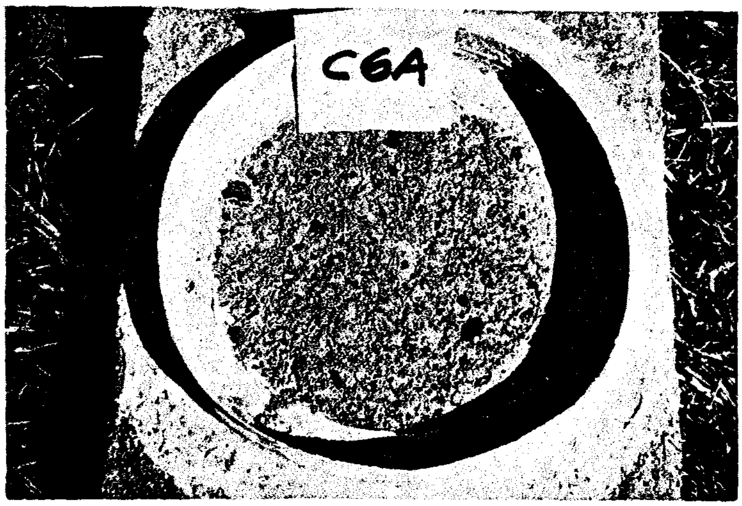
TABLE V. PERFORMANCE OF SPECIMENS, FT-D

Specimen	Number of cycles	Remarks
1. No treatment	40	Crack 1/64 to 1/32 inch wide at 37 cycles. No surface scaling.
2. Linseed oil and kerosene	41	Crack 1/64 inch wide at 40 cycles. No surface scaling.
3. Linseed oil—hot	41	Crack 1/64 inch wide at 40 cycles. No surface scaling.
9. Chempol 32-1010	40	Crack 1/128 inch wide at 37 cycles.

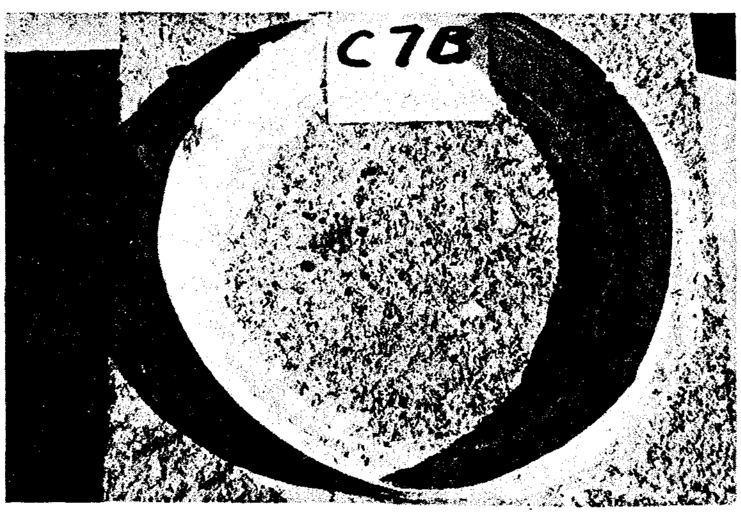
Note: Specimens were cut from old concrete slab 27 years old.



(a) No treatment



(b) Hydrozo treatment



(c) Protex-a-crete treatment

Figure 13. Specimens from FT-C series showing condition at end of test after 28 days of exposure under the sky and 28 freeze-thaw cycles.

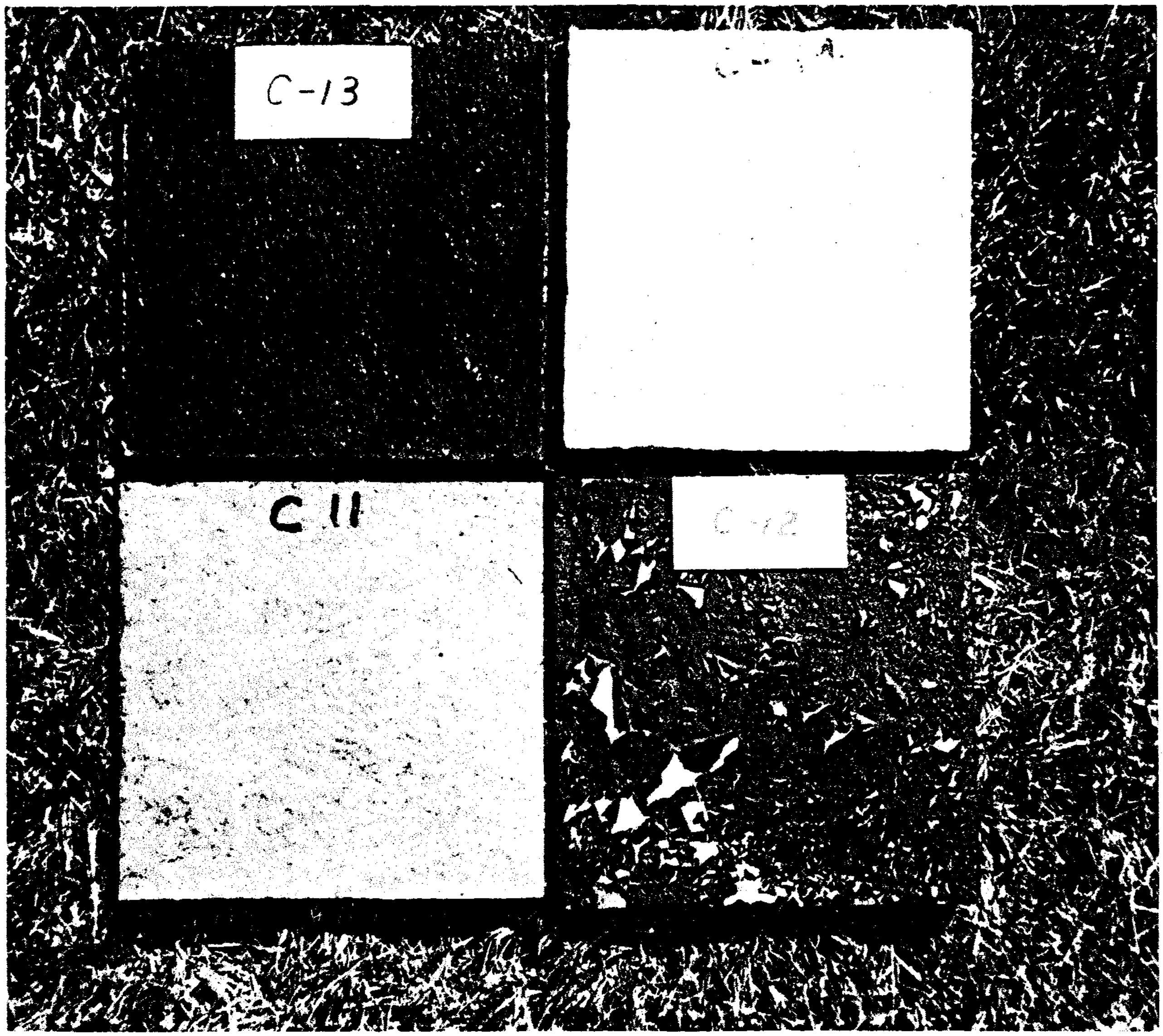


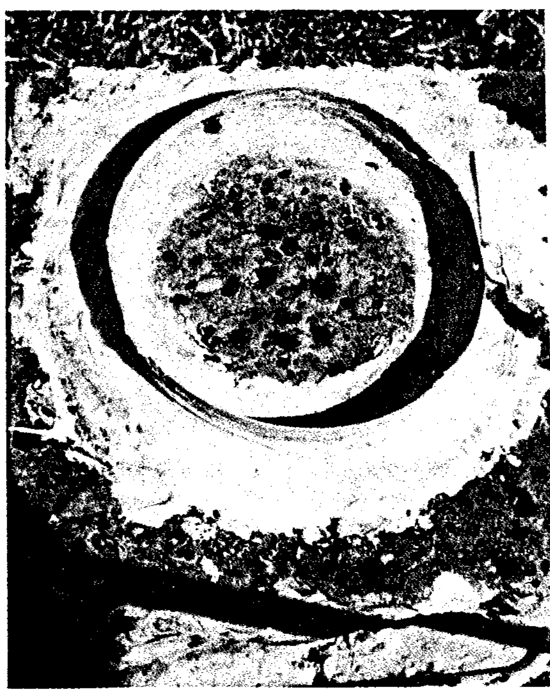
Figure 14. Freeze-Thaw Series C specimens after four days of exposure to sun. Coating labeled 12-C (Permaspray) has cracked and is peeling away from the concrete.

TABLE VI. TEST RESULTS

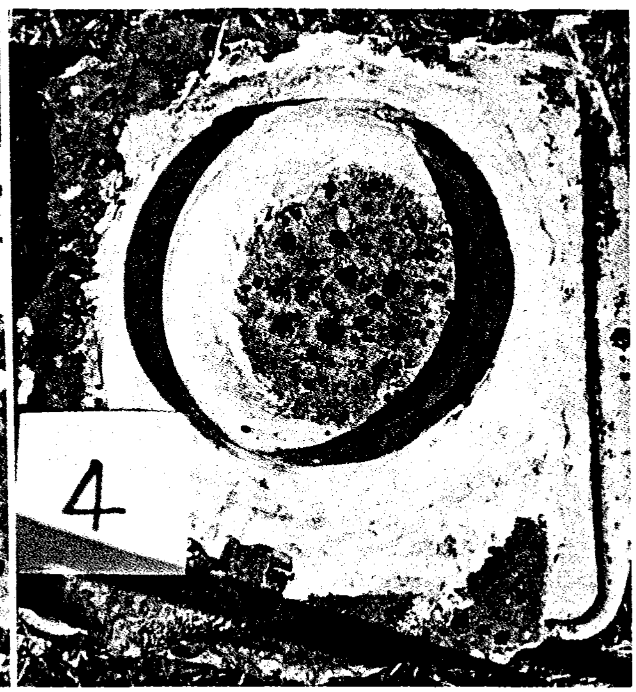
Wet-Dry Tests % Moisture Change				Freeze-Thaw Tests *(Cycles at withdrawal/cycles at first deterioration)							
Series A		Series B		Series A		Series B		Series C		Series D	
Code	%	Code	%	Code	*	Code	*	Code	*	Code	*
3	.34	3	.44	17	25/21	3	98/51	2	28/-	2	41/40
17	.35	14	.47	12	25/18	10	97/8	3	28/-	3	41/40
12	.45	2	.51	2	23/15	13	93/-	4	28/-	9	40/37
2	.47	4	.51	4	23/10	14	90/9	10	28/-	1	40/31
4	.48	12	.94	5	23/15	2	84/35	11	28/-		
18	.56	9	.95	18	23/8	12	79/-	12	28/-		
13	.72	11	.97	13	21/9	11	77/47	14	28/-		
15	.88	18	1.04	1	21/8	18	59/15	16	28/-		
7	.95	13	1.14	6	21/8	7	59/12	18	28/-		
19	.98	5	1.34	16	21/7	4	56/36	15	28/0		
1	1.13	15	1.36	7	21/5	9	54/11	1	28/7		
5	1.14	8	1.51	8	21/5	8	41/6	7	28/7		
6	1.28	16	1.52			16	41/6	8	28/9		
16	1.30	10	1.55			6	33/17				
8	1.42	7	1.61			5	26/20				
		6	1.96			1	24/9				
		1	1.96			15	23/21				

(a) View of the four specimens

(b) Code 2 - Linseed oil and kerosene



(c) Code 9 - Chempol 32-1010



(d) Code 3 - Linseed oil (hot)

Figure 15. Freeze-Thaw specimens Series D at end of cycling

Overall Test Results

Table VI gives a resume of test results of two wet-dry tests and four freeze-thaw tests. Wet-dry specimens are ordered in the tabulation from lowest to highest percentage moisture change. The numbers in freeze-thaw columns represent cycles at which first deterioration was noted (top number) and cycle at which the specimen was withdrawn (bottom number).

Considering both wet-dry tests, the lowest percentage moisture change was 0.34 while the highest was 1.96—almost six times the lowest. In Series A the ratio of untreated to lowest was 1.13/0.34 = 3.32; in Series B, 1.96/0.44 = 4.45.

Series B shows an abrupt increase from 0.51 percent to 0.94 percent between treatments 4 and 12, with four specimens having percentages less than 0.94. Three of those specimens, 2, 3, and 4, had linseed oil treatments; the other one, 14 was not on hand for testing in Series A nor in Freeze-Thaw Series A.

In freeze-thaw tests the one-component coatings that performed best are 2, 3, 4, and 9. Of the two-component coatings (11 through 19), all except 15 and 16 performed well. In evaluating performance in freeze-thaw tests, more emphasis should be given the number of cycles at withdrawal than number of cycles at first deterioration. In some cases first deterioration was slight surface scaling which did not progress far. On the other hand, specimens were run to a state of considerable deterioration before they were withdrawn when the test was not terminated earlier.

The top performing coatings in all six series contain treatment 2 in all except FT-B where it ranks fifth; treatment 3 in all except FT-A (it was not included in that series); and treatment 4 in three of the six series. Treatments 12 and 17 rank in the top four in two series—Wet-Dry A and FT-A. Treatment 14, too, appears in the top four in Wet-Dry B and FT-B. The following then, appeared in the top four listing the numbers of times indicated:

Code	Times appearing in top four
2	5 (appeared in 5th place in one)
3	5 (used in only 5 series)
4	3 (used in only 5 series)
10	2 (used in only 3 series)
12	2 (used in only 5 series)
17	2 (used in only 2 series)
14	2 (used in only 3 series)
13	1 (used in 5 series)
9	1 (occurred in FT-D only)

These nine coatings make up one-half of the total number of coatings used in all tests. Coating 9 ranked in the top four in only one test, FT-D, and in that test only four coatings were used. If coatings 13 and 9 are omitted, being very low in the top fourth rating, four one-component treatments—2, 3, 4, and 10, and three two-component treatments—12, 14, and 17—remain. The highest rating one-component coatings are linseed oil treatments. Treatment 10, Trikote TK#18, is an epoxy chlorinated rubber compound. Treatments 12 (Thiokol D-183-601-1) and 17 (Protex-a-cote TAC-T-185-NYS) are epoxy resins.

Treatment 14 (Presstite-140 Guardkote) is a black, coal-tar epoxy and has been used by the Texas Highway Department as an overlay on a bridge that was cracking and spalling.[6] Guardkote is a two-component treatment and it leaves the treated surface black. Since it is desirable that the appearance of the deck not be materially changed by the application of coating, this treatment would be placed low on the priority list if others are suitable.

Treatments 17 and 12, too, are two-component epoxy treatments and require extensive cleaning of the deck before application. Treatment 17 is very viscous and would be difficult to handle in application. Treatment 12 is thin enough to be sprayed on, but it ranked in the top four treatments in these tests in only two cases out of five applications.

Treatment 10 has a light straw color and it is thin enough to be sprayed on. It performed well under freeze-thaw cycling, but did not show up well in wet-dry testing. If the coating permitted entry of brine, the specimens would be expected to break up in freeze-thaw cycling. Such breaking up was not the case, however, and no reason can be given for the apparent inconsistency.[7] The manufacturer recommends two coats, however, and only one coat was used in the tests. This coating dries to a hard finish within one hour.

The three top ranking coatings are all linseed oils and can be easily sprayed. Boiled linseed oil was mixed with kerosene on a one-to-one basis by volume to make up treatment 2. Kerosene served as a thinner, and it is likely that a less viscous thinner could be used even more effectively. Treatment 4, a commerical mixture of boiled linseed oil and mineral spirits (50% to 50%),

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6 "Memo to a Pock-Marked Bridge: Epoxy Upon you," M. U. Ferrari, Texas Highways, April, 1963, pp. 14-18.

7 The manufacturers stated in a telephone conversation that brush cleaning of the old concrete surface is adequate for application and that the Minnesota Highway Department applies it to bridge decks by spraying at the rate of one gallon per 200 square feet of surface. This is approximately the application used in these tests.

is thinner and lighter in color than linseed oil and kerosene and is easily sprayed.[8]

Hot linseed oil with no additions was suggested by Mr. M. U. Ferrari, D-18, Texas Highway Department, as a possible waterproofing compound. It was tried as such with results as tabulated. The boiled linseed oil was heated to 210°F just before application to room temperature concrete. The oil becomes less viscous when heated, and it was easily applied by brush. In field application there would possibly be some difficulty holding the oil to a high temperature before application. If the concrete surface were preheated just before applying the oil, better penetration might be obtained.

The linseed oils appear to be very favorable from the results of these tests, but no information was developed to indicate how long the treatment would be effective either in the laboratory or in service. Such information is needed for this as well as for other treatments.

Since FT-D is the only series involving other than new concrete, no information was collected on the extent of deterioration at which coatings become ineffective. At least one report,[9] however, tells of plans of treating bridges over 10 years old, as well as newer structures, with a mixture of linseed oil and petroleum spirits. That reference also gives condensed specifications for application of the mixture.

QUANTITIES AND COSTS

Quantities of materials used on laboratory specimens were recorded and have been reduced to requirements per square foot of concrete surface—see Table VII. Requirements for a concrete of different porosity than that used in these tests would, of course, generally require a different amount of sealant.

Costs were obtained for some of the coatings; those are recorded in Table VII.

SURFACE PREPARATION

In general, a clean concrete surface is required for application of waterproofing coatings. For the epoxies, "dilute muriatic acid etch followed by

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8 "Toll Road Pavements Protected With Linseed Oil Applications," L. G. Byrd, Public Works, May, 1963.

9 "Linseed Oil Treatment on Bridge Structures," Henry E. Diers, Public Works, February, 1963.

TABLE VII. QUANTITIES AND COSTS

Code and Name	Sq. Ft. Covered per gallon	Coats Applied	Material Costs($/sq.ft)	Application Cost ($/sq.ft)
1. No treatment				
2. Linseed oil and kerosene	229	1	.0043	
3. Linseed oil (hot)	269	1	.0068	
4. Linseed anti-spall	250	1	.0033	.0091*
5. DC 770	246	1		
6. DC 772	253	1		
7. Hydrozo	240		.008	.001
8. Protex-a-crete	236	1		
9. Chempol 32-1010	106	1		
10. Trikote TK#18	200	1	.0126	
11. Chempol 31-10006	110	1		
12. Thikol D-183-601-1	230	1	.0478	
13. Versamid epoxy penetrant	230	1	.0127	
14. Presstite-140 Guardkote	195	1		
15. Premaspray	206	1		
16. Protex-a-cote Porselon epoxy	295	1		
17. Protex-a-cote TAC-T-185-NYS	150	1		
18. Sika Colma	195	1		
19. Thilokol Tipox	250	1		

*Texas Highway Department District 17 (Dallas, Texas) provided these figures with the explanation that application costs were high in this case because the bridges were open to traffic during application and the figures include cost of handling traffic. That district also provided cost data on Hydrozo application and explained that application cost of the L.O. treatment was more than that for Hydrozo because L.O. cost includes traffic handling whereas Hydrozo does not. During the summer of 1963 that district placed over 900 gallons of Linseed anti-spall compound on 28 bridges at an overall cost of approximately $0.0078 per sq. ft. of bridge surface.

Illinois Toll Road reported cost of about 6¢/square yard for material and application. (See Selected Reference 7.)

thorough rinsing and drying"[2] has been reported to be very effective. Grease solvents, detergents, and sandblasting are used in some instances.

The penetrants—linseed oil, Hydroze, Trikote TK-18, and the silicones—must pass into the pores of the concrete to be effective. The best results, then, would be obtained with concrete having a clean surface. Usually a surface that is brushed clean is satisfactory for application of penetrants of these kinds.

This series of tests did not undertake to determine the best surface preparation. Most product manufacturers have collected valuable information on their products and can supply recommendations on the various individual coatings.

CONCLUSIONS

Eighteen waterproofing compounds were tested on plain, natural aggregate, nonair-entrained concrete in two wet-dry tests and four freeze-thaw tests. Not all compounds were included in each test. In addition, control specimens of untreated concrete of the same batch as treated specimens were included in the tests. At the beginning of testing the concrete was three weeks old with one exception in which the concrete was twenty-seven years old.

It was found that three boiled linseed oil treatments and a one-component epoxy chlorinated rubber formulation were the top four ranking treatments based on minimum percentage of water absorption and maximum number of freeze-thaw cycles. Those treatments are:

Boiled linseed oil and kerosene (equal volume mixture), Code 2.

Boiled linseed oil applied at about 210° F, Code 3.

Linseed anti-spall compound, Code 4.

Trikote TK #18 (one component epoxy chlorinated rubber), Code 10.

The following three two-component epoxies ranked next in order of effectiveness:

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[2] Op. cit.

Thiokol D-183-601-1, Code 12.

Protex-a-Cote TAC-T-185-NYS, Code 17.

Presstite-140 Guardkote, Code 14.

The Presstite treatment leaves the concrete black. The Protex-a-Cote product is very viscous. The Thiokol product is thin enough to be sprayed.

With the exception of Presstite-140 Guardkote, none of the seven coatings listed cause any appreciable color change in the concrete.

Protex-a-Cote TAC-T-185-NYS would be difficult to apply by spray; all others listed above are thin enough for spraying with common spraying equipment.

The costs of the linseed oil treatments are considerably lower than any other of the seven listed.

All of the top four noted treatments may be brushed on or sprayed. Spraying is favored for large surfaces.

Prior to application of treatments the concrete surface should be clean and dry. Cleaning requires that all material that might prevent penetration of the coating material be removed. Such treatment might be simple brushing or cleaning by air hose in the case of clean decks, or washing with acid, detergents, and water in the case of decks that are soiled with grease and the like.

It was not determined if coatings such as were used in this study would be effective on decks that are already in a state of deterioration.

Application of commercially prepared products should follow the recommendations of the manufacturer of the product.

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1. Effect of De-Icing Chemicals on Structures, A Symposium. Highway Research Board Bulletin 323, 1962.

2. Epoxy Resins for Concrete Construction and Repair—Interim Report, General Report No. 28, April 17, 1961. Division of Engineering Laboratories, U. S. Dept. of Interior, Bureau of Reclamation, Denver, Colorado.

3. Improving the Water Repellency of Hardened Concrete, Highway Research Board Bulletin 197, 1958.

4. Linseed Oil Emulsion Prevents Salt Damage to Concrete Paving, Iowa Municipalities, November, 1962, p. 19.

5. Standard Specifications for Road and Bridge Construction, Item 421, Concrete Structures. (Natural Aggregates) Class A, (Nonair-entrained), Texas Highway Department, Austin, Texas, 1962.

6. "Memo to a Pock-Marked Bridge: Epoxy Upon You," M. U. Ferrari, Texas Highways, April, 1963, pp. 14-18.

7. "Toll Road Pavements Protected with Linseed Oil Applications," L. G. Byrd, Public Works, May, 1963.

8. "Linseed Oil Treatment on Bridge Structures," Henry E. Diers, Public Works, February, 1963.

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"The Use of Waterproofing Paints for Minimizing Structural Concrete Deterioration," K. B. Woods, J. B. Blackburn, and D. W. Lewis, AREA, Vol. 52, 1951.

Progress Report on Investigation of Surface Coatings for Improving the Durability of Concrete, Concrete and Structural Branch Laboratory Report No C-1025, Division of Engineering Laboratories, United States Department of the Interior, Bureau of Reclamation, Denver, Colorado, October 18, 1962.

Guide for Use of Epoxy Compounds with Concrete, reported by ACI Committee 403, ACI Proc. v. 59, September, 1962, pp. 1121-1142.

APPENDICES

APPENDIX A - LABORATORY CONCRETE MIX

Aggregates:

Fine Aggregate: graded natural sand from pit at Hearne, Texas

Fineness modulus = 2.317
Specific gravity = 2.63

Unit weight (saturated surface dry)

Loose 100.0 pcf
Vibrated 108.6 pcf

Coarse aggregate: natural gravel from pit at Hearne, Texas, graded to give a mixture of equal weights of the following:

Passing 3/4" retained on 1/2"
Passing 1/2" retained on 3/8"
Passing 3/8" retained on 1/4"

Fineness modulus - not determined
Specific gravity = 2.633

Unit weight (saturated surface dry)

Loose 98.5 pcf
Vibrated 107.8 pcf

Cement: Type 1

Concrete Mix:

Water: 6 1/2 gal/sack
Cement: 5.9 sacks/cy
Fine Aggregate: 1505 #/cy
Coarse Aggregate: 1650 #/cy
Slump: 3"

APPENDIX B - DATA CONCRETE PAVEMENT

Location: West city limits to East city limits, State Route 21, Caldwell, Texas.

Date of pour: April 15, 1935, to May 11, 1935.

Materials used: Coarse aggregate - from Glass pit, Hearne, Texas.
Fine aggregate - from Glass pit, Hearne, Texas.
Fine aggregate # 2 - from Hillard pit fine (local) sand.
Cement - Atlas and Lone Star
Water - Davidson Creek

Average grading:

Size	Coarse Agg. % ret'd	Fine Agg. % ret'd	Fine Agg. #2 % ret'd
3"	0		
2 1/2	1		
3/8		0	
1/4	97	1	
10			0
20			0
30			3
50		85	40
100		98	80

Design Data: Av. batch wgts: Cement 564#; Fine agg 1431#; Coarse agg 2554#; Size of batch 32.4 cu. ft.; C. R. 5.0; W. F. 83; slump 2 1/2"; W/C 6.3 - 6.5.

Average Strengths: 7 day 691 psi; 28 day 744 psi.

	Sp gravity	% voids	free moisture
Coarse agg	2.62	42	0.7
Fine agg (glass)	2.64	39	3.5
Fine agg #2	2.61		

Note: These concrete specimens and the data given above were provided by Texas Highway Department District 17, Bryan, Texas.

APPENDIX C - SEALANTS USED IN THE TEST PROGRAM

DC-770 Water Repellant: A mineral base silicone resin concentrate (30% solids) contributed by Dow Corning Corporation, Midland, Michigan. The concentrate was diluted to 5% concentration by the addition of xylene. Price information sheet dated September 1, 1962, distributed by Dow Corning lists the cost at $0.75/lb. in 440 lb (55 gallon drum) lots f. o. b. shipping point. Other information may be found in Dow Corning Bulletin 07-026, June, 1962.

DC-772: A water-soluble sodium methyl siliconote solution, 30% solids, contributed by Dow Corning Corporation, Midland, Michigan. The concentrate was diluted to 5% solids by the addition of distilled water. Supplier's price sheet dated May 3, 1962, lists the cost at $0.43/lb. in 550 lb (55 gallon drum) lots, f.o.b. shipping point. Additional information may be found in Dow Corning Bulletin 07-018, April, 1962.

Boiled linseed oil: Purchased from Texas A&M University stores. Ordinary boiled linseed oil commonly used as paint vehicle.

Linseed Anti-Spall Compound: A mixture of 50% (volume) boiled linseed oil with 50% mineral spirits; purchased from Archer Daniels Midland Company, Minneapolis, Minnesota at a cost of $2.50/gallon in two-gallon lot. The supplier did not provide information on what mineral spirit was used. A letter, August, 1963, from that Company quoted a price of $0.97 per gallon in carload lots f.o.b. Houston, Texas.

Linseed oil and kerosene: A mixture of ordinary boiled linseed oil and kerosene (50% x 50% by volume). Both the linseed oil and kerosene were obtained from A&M University stores.

Hydrozo: A synthetic mineral gum combined with a volatile vehicle. It is essentially colorless when brushed on and has a thin consistency. The product was donated by Hydrozo Products Company, Lincoln, Neb.

Protex-a-crete sealer: A clear, thin, one-component chlorinated rubber solution donated by Protex-a-cote, Inc., 27 Haynes Avenue, Newark 14, New Jersey.

Chempol 32-1010: A one-component clear "moisture-cure urethane" donated by H. B. Eliefson Company, Fort Worth, Texas, and a product of Freeman Chemical Corporation, Port Washington, Wisconsin. The product is described as : 40% solids, viscosity B-C, Color 4 max., W/G 8.2.

Trikote TK #18: A one-component, 18% solids, epoxy chlorinated rubber based concrete treatment donated by T K Products Company, Minneapolis, Minnesota. This is a straw colored, thin liquid.

Chempol 31-10006: A clear, two-component resin system requiring 4 parts of Chempol 31-10006 per 100 parts of 32-0006 resin. It was donated by H. B. Eliefson Company, Fort Worth, Texas, and is a product of Freeman Chemical Corporation, Port Washington, Wisconsin. The product is described as: 50% solids, Viscosity A, W/G 8.1, Batch 43-14, pot life at least 8 hours, catalyst accelerates cure.

Thiokol D-183-601-1 Experimental Penetration Sealer: A polysulphide polymer/epoxy resin consisting of two parts to be mixed in equal volumes. Part A liquid is moderately thin having an amber color; Part B liquid is moderately thin and clear. The product was donated by Thiokol Chemical Corporation, 708 N. Clinton Avenue, Trenton 7, New Jersey, and is described in their Bulletin CA-1. Cost in small lots is about $11.00/ gallon.

Versamid-Epoxy: A penetration sealer donated by General Mills, Inc., Kankakee, Illinois. This is a clear, two-component system consisting of epoxy and versamid which were mixed together in equal volumes. Formulation (information furnished by General Mills) was as follows:

Component A		Component B	
75% Gen Epoxy 525 in xylene	33.3%	Versamid 401	41.7%
Aromatic solvent	29.2%	N-Butanol	10.8%
DiAcetone alcohol	37.5%	Aromatic solvent	47.5%

Presstite-140, Guardkote: A two-component system consisting of "A" component (a viscous clear liquid) and "B" component, a black viscous liquid. The resulting mixture was a black liquid which was hard when it set up. The product was donated by Presstite Division, Martin Marietta Corp., 39th and Chouteau, St. Louis 10, Missouri.

Permaspray CPB-102: Described by the supplier as "A blend of resin, inert fillers, and solvents." This is a two-component, black liquid requiring two coats each of about 4 mills thickness. The product was donated by Permaspray Manufacturing Corporation, P. O. Box 875, League City, Texas.

Protex-a-cote Porselon Epoxy Saturant: Donated by Protex-a-cote, Inc., 27 Haynes Avenue, Newark 14, New Jersey. A thin, clear two-component liquid system consisting of equal parts of porselon epoxy #1 with porselon epoxy #2.

Protex-a-cote TAC-T-185-NYS: Donated by Protex-a-cote, Inc., 27 Haynes Avenue, Newark 14, New Jersey. This is a two-component epoxy-polysulfide resin system at 100% solids; it may be thinned 20% with xyol for lower viscosity and 80% solids. The 100% solids system is very thick and viscous; no reduction was attempted in the application.

Sika-Coma Protective Coating: Donated by Sika Chemical Corporation, Southwestern Division Office, Meadows Building, Central Expressway at Milton, Dallas, Texas. This is a two-component epoxy resin system, 48% minimum solids, 650 centipoises at 70° F, light amber color. Two coats are required. Manufacturer does not recommend use with sand or grit to produce nonskid surfaces.