FREEZE-THAW AND SKID RESISTANCE PERFORMANCE OF SURFACE COATINGS ON CONCRETE

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ABSTRACT

Research performed to evaluate the protection against freeze-thaw scaling offered by various surface coatings of materials is reported. The phase covering penetrants, tars, and asphalts which has been completed is covered in this report; other work on the project continues.

Laboratory freeze-thaw tests were made on 10" square plain concrete blocks 2" thick with a 5% salt water solution ponded on the top surface. The surfaces in contact with the brine were treated with various materials to prevent the brine from entering the concrete and destroying it in freeze-thaw action. Scaling of the surface under freeze-thaw cycling was periodically inspected and rated according to the extent of scaling.

Parameters in the study were temperature and relative humidity during curing, number of coats of surface treatment material, skid resistance, cracks in the concrete, air-entrainment, extent of scaling when coated, and the coating materials.

The coatings found to perform best were a mixture of equal parts of boiled linseed oil and kerosene, a mixture of equal parts of tung oil and kerosene, and hot boiled linseed oil. One patented product sold under the name Thompson's Water Seal performed well in some tests but it was not as consistently a good performer as the linseed and tung oils. Tar and asphalt coatings were penetrated by the salt water; and the concrete surface, hidden by the coatings, was deteriorated in freeze-thaw action.

The linseed oil mixture, which has proved beneficial in various parts of the United States in combatting freeze-thaw scaling, is easy to apply and is possibly the least expensive of any of the materials tested. Its skid resistance is relatively high. Air-entrained concrete performed best of all in either coated or uncoated condition. No treatment was found which prevented scaling at cracks in cracked concrete although the air-entrained concrete performed well.

SUMMARY

Reinforced concrete bridge decks are sometimes damaged by mechanical and chemical action of water when it penetrates the concrete. The damage occurs when the water freezes and when it carries corrosive compounds to the reinforcing steel. The damage is in the form of surface scaling due to freeze-thaw action, and spalling due, at least in some measure, to corrosion of the top mat of reinforcing steel. Repeated cycles of freeze-thaw temperatures gradually erode the surface leaving rough surfaces, and corrosion of the steel causes large areas of concrete to burst out leaving the steel exposed for further and more serious deterioration.

Asphaltic surface sealing and surfacing has not always provided the necessary protection of the concrete against these actions. Salt water ponded on top of concrete sealed with an MC-0 primer and Ampet AC-5 cover penetrated the coating and scaling progressed unseen under the asphalt in freeze-thaw tests in the laboratory.

Coatings of a mixture of boiled linseed oil and kerosene on a 50%-50% basis by volume delayed laboratory freeze-thaw scaling of non air-entrained concrete until it had undergone some 30 to 35 freeze-thaw cycles. Tung oil mixed in the same proportion with kerosene had essentially the same effect. Two coats of either of these mixtures, one applied after the other, had thoroughly dried, covering about 40 square feet of surface per gallon gave the best results.

Old concrete that had already begun to scale can be made somewhat more durable with the linseed oil-kerosene treatment, too. The treatment is

not as effective, however, on the lightly deteriorated concrete as it is on new concrete.

The linseed oil treatment had a more noticeable benefit when applied to concrete that had dried out thoroughly.

Of all treatments tested, properly entrained air was the most beneficial. Concrete specimens with 5% entrained air had not scaled to any serious condition at 300 freeze-thaw cycles when tests ended, even when specimens had no surface treatment. Surface treatment added only slightly to the durability of the air entrained concrete.

No surface treatment used in the test, successfully sealed cracks to prevent scaling in the crack area.

Skid resistance was reduced by all surface treatments of the penetrating type, but the linseed oil-kerosene treated surface was the least affected of all.

RECOMMENDATIONS FOR IMPLEMENTING THE FINDINGS FROM THIS RESEARCH

Based on the research reported here and on work done by others, which is referenced in this report, it is recommended that the following steps be taken to reduce deterioration of concrete bridge decks caused by freeze-thaw action:

1. Use only air-entrained concrete for construction of bridge decks.

2. New bridges: Before the bridge is opened to traffic after the deck has dried out from curing apply a cut back boiled linseed oil or tung oil (50% by volume of boiled linseed oil or tung oil with 50% of kerosene or mineral spirits) at the rate of about 40 sq. yd. per gallon followed after a minimum of 4 days with another coat at the rate of about 55 sq. yd. per gallon. The mixture should be uniformly sprayed over the surface.

Subsequent treatments should be made annually for at least two more years at the rate of some 40 to 50 sq. yd. per gallon.

3. Old bridges: Make annual applications for at least 4 years of cut-back boiled linseed oil or tung oil (50% by volume of boiled linseed oil or tung oil with 50% of kerosene or mineral spirits) at the rate of 40 to 50 sq. yd. per gallon depending on the absorptive character of the deck. The deck should be swept clean before application.

TABLE OF CONTENTS

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the Bureau of Public Roads.

FIGURES

TABLES

I. INTRODUCTION

Research directed toward finding a surface treatment that would prevent deterioration of new concrete due to freeze-thaw action, and attenuate deterioration in older concrete, is reported here. Tests designed to evaluate surface treatment materials of interest are described and test results are given. This report covers work completed to date on research which is still in progress.

An earlier report (1) described tests and results that were used to reduce the number of surface coatings to relatively few. The study reported here involves those coatings along with others of interest to the Texas Highway Department, THD.

All specimens received the same moist cure but drying conditions differed depending on the variables under study in a particular series. Surface coatings were applied after the drying period at about one month age.

Numerous variables were studied in laboratory tests. Concrete specimens coated with waterproofing materials were ponded over with a 5% solution of sodium chloride and tap water. They were then subjected to alternating freeze-thaw action until deterioration reached a certain stage. In other tests, skid resistance was studied.

Table I lists the tests made in the study and gives the purpose of each test. Table II lists the surface materials and gives their code numbers.

Specimens were rated by the number of freeze-thaw cycles undergone at certain characteristic surface conditions.

TABLE I. A SUMMARY OF TESTS, OBJECTIVES, AND RESULTS

Test	Objective	Results
Absorption (a)	To determine sealing effect of coatings on concrete	Epoxy & Hot LO had the least absorption; Watco and LO mixture next best. (b)
Freeze-thaw (a)	To find the top ranking coatings for further study	Found to be among best; Hot LO, Tung mix, LO mix, TWS, Epoxy. (b)
Abrasion (a)	To determine effect of wear on sealant	Tung mix, Coal tar, LO mix and Hot LO performed best. (b)
Ultraviolet Light (a)	To find if sun breaks down sealant	No ill effects noted. (b)
1 Freeze-thaw	To find if temperature during 21-day drying affects F-T cycles	With the exception of specimens coated with Hot LO drying at 100°F reduces F-T durability.
2 Freeze-thaw	To find the F-T durability effect of pavement temperature at the time of, and continuing after, coatings.	Scaling was delayed but after it started it continued. Final results show no effect.
3 Freeze-thaw	To find effect of treatment after scaling had begun	F-T durability somewhat greater than with no treatment but less than if treated before scaling.
4 Freeze-thaw	To find effect of temperature and humidity during 21-day drying (only LO mix & no treatment tested)	High humidity during drying enhanced deterioration. Low humidity during drying increased durability.
5 Freeze-thaw	To find if EpoXeal should be applied during rising or lowering temperature	No difference in F-T cycles noted.

TABLE I. (Cont'd.)

Test	Objective	Results
6 Freeze-thaw	To determine if cracked concrete can be sealed with penetrants. Air-entrained and non air-entrained concretes were used	Scaling developed at cracks which indicates that coatings did not seal the concrete at the crack. Entrained air protected those specimens made of air-entrained concrete.
7 Freeze-thaw	Effect of air-entrainment. See also test 6 above.	F-T durability greatly increased.
8 Freeze-thaw	To determine the effect of coatings on skid resistance using British Portable Tester	Best: No treatment. Next: LO Next: Tung Next: TWS

(a) These tests were reported in an earlier report (1).
(b) Boiled Linseed Oil and kerosene mixed in equal volumes. Details are given in Reference 1.

Definitions:

LO - Linseed oil

EpoXeal - commercial product

Watco - commercial product

TWS - Thompson's Water Seal, a commercial product

F-T - Freeze-thaw

TABLE II. DESCRIPTION OF COATINGS

Coating Number	Description
0	No Coating.
1	One coat of 50-50 linseed oil and kerosene.
2-a	Two coats of 50-50 linseed oil and kerosene.
2-b	Two coats of 50-50 linseed oil and kerosene on specimens after scaling had begun.
3	Three coats of 50-50 linseed oil and kerosene.
4	One coat hot, 180°F, linseed oil.
5	Jennite (J-20 primer, J-16 sand slurry).
6	Asphalt (MC-0 primer, Ampet AC-5 with a one grain thickness of sand rolled into the AC-5).
7	Two coats Thompson's Water Seal.
8-a	Two coats of 50-50 tung oil and kerosene.
8-b	Two coats of 50-50 tung oil and kerosene on specimens after scaling had begun.
9	One coat of EpoXeal with a touch-up coat.

Note: See Appendix for further information.

It was found that some surface treatment materials are superior to others, that drying conditions influence the rate of scaling in freeze-thaw tests, and that skid resistance of concrete is affected by treatment of the surface.

II. MATERIALS

The test specimens were made of Type III portland cement concrete using natural sand and gravel taken from pits near Hearne, Texas. The maximum size of aggregate was 3/4 inch and the mixes are given in Table III.

III. SPECIMENS

1. General Treatment: Test specimens were 2-inch thick concrete slabs 10 inches square. All were made of plain concrete, except those of Test Series 6 which contained a single thickness of 1-inch mesh chicken wire. The wire, placed at mid-depth, was used to keep the slab from falling apart when it was cracked prior to testing.

The slabs were vibrated 18 seconds in wood forms on a vibrating table and were given a rough surface finish with a wood screed during vibration. After initial set the slabs were covered with polyethelene sheet and cured for approximately 12 hours. They were then cured in a 73°F, 100% RH chamber until seven days old.

After moist curing, the specimens were dried 21 days under conditions shown in Table IV. Surface coatings were applied immediately after the drying period under conditions explained below and in the Appendix.

TABLE III. CONCRETE MIX

(Weights in Pounds per Cubic Yard of Concrete)

CA (lb)	FA (lb)	Cement Type III	Water (lb)	Air Content (per cent)	Slump (in)
1950	1295	516	300	None	3
1761	1323	518	269	5.5	3

TABLE IV. SCHEDULE OF POST-CURE DRYING AND COATING MATERIALS (DRYING FOLLOWING IMMEDIATELY AFTER MOIST CURING IS DESIGNATED POST-CURE DRYING)

Test Series	Number of Blocks per Coating	Air Content (%)	21-day Post-Cure Drying Condition Temp. (°F)	R.H. (%)	Coating Used (Code Number, pg. 4)
1	3	0	100	50	1,2-a,3,4
1	3	0	73	50	0,1,2-a,3,4,5,6,7, 8-a,9
2	3	0	73	50	0,2-b,7
3	3	0	73	50	0,2-a,2-b,8-a,8-b
4	3	0	73	25	0,1
4	3	0	73	50	0,1
4	3	0	100	50	0,1
4	3	0	100	75	0,1
4	3	0	140	25	0,1
5	3	0	73	50	9 (3 sets)
6	3	0	73	50	0,2-a,5,7,8-a,9
6	3	5	73	50	0,2-a,5,7,8-a,9
7	3	5	73	50	1,2-a,3,5,6,7
8	3	0	73	50	1,2-a,3,4,7-a,8-a

Detailed information on all coating materials and applications is given in the Appendix.

2. Series 1: Some coatings were included in this series for purposes of evaluating their performances in freeze-thaw scaling durability when the coatings were dried under ordinary conditions, 73°F and 50% RH. The primary reason for this series of tests was to determine if drying conditions under different, but constant, temperatures would influence freeze-thaw scaling.

Coatings 1, 2-a, 3, and 4 were applied to some specimens which had dried at 73°F, 50% RH, and to others dried at 100°F, 50% RH. They were then alternately frozen and thawed to determine if an influence of drying temperature was evident.

A specimen with no coating and others with coatings 5, 6, 7-a, 8, and 9 were dried at 73°F, 50% RH before testing in freeze-thaw action. These were included for purposes of gathering more information on the value of coatings 7-a and 8, which had been reported in earlier tests (1), and to gather original information on coatings 5, 6, and 9.

3. Series 2: This test series was made to determine if 140°F exposure of concrete for different periods of time prior to coating would have an effect on freeze-thaw scaling. Some areas of Texas undergo long periods during the summer without rain during which time humidities are generally very low. Pavements reach rather high temperatures during such periods.

Spot checks of temperature of concrete pavement at the test site in June of 1969 revealed surface temperatures ranging from 139°F to 146°F using Pacific Transducer Corporation Surface Thermometer Model 310F. The duration of those temperatures was not measured. The 140°F temperature used in this series falls within the range of values found in the spot check.

Coatings are sometimes applied in hot dry weather and it is reasonable to expect the concrete to be very dry near the surface under such conditions. The test would reflect the influence of prolonged drying of the concrete as well as dissipation of volatiles in the coating material at 140°F temperature.

A set of uncoated specimens was included in the series.

4. Series 3: Coatings 2-b and 8-b of this series were used to determine if scaling already under way on untreated concrete would be influenced by the application of coating materials. Before treatment, the blocks were covered with brine and freeze-thaw cycled. Scaling first occurred at six cycles, and the blocks were continued through seven more cycles, making a total of 13, at which time they were withdrawn from cycling. The specimens were then dried 48 hours at 140°F and then coated. Freeze-thaw tests continued after the coatings dried.

5. Series 4: This series was designed to determine the effect of different combinations of temperatures and relative humidities during the 21-day drying period before surface treatments were applied. Specimens were treated in room air and were returned immediately after coating to dry under the same conditions as during the 21-day post cure drying period.

A set of uncoated specimens accompanied each set of coated specimens throughout the test.

6. Series 5: This series was designed to determine if the freeze-thaw performance of concrete treated with coating material 9 would be influenced by an increase or a decrease of temperature occurring during coating and drying of the coating.

In order to determine the effect of the treatment, three sets of specimens, all cured and dried in the same way, were tested. After the 21-day drying period they were transferred to the 100°F, 50% environmental chamber.

Set A remained in the chamber for 15 minutes then it was removed to room air for 5 minutes during which period it was coated. It was then returned to the 100°F, 50% RH chamber.

Sets B and C remained in the 100°F, 50% RH chamber for 6 hours so that their temperatures would stabilize at 100°F.

Set B was then removed for 5 minutes during which time it was coated. Then, it was immediately returned to the 100°F, 50% RH chamber.

Set C was moved to the 73°F, 50% RH chamber where it remained 15 minutes. It was then removed to room air for a period 5 minutes during which time it was coated. Then, it was immediately returned to the 73°F, 50% RH chamber.

From the above history it is seen that immediately after coating, Set A specimens increased in temperature, Set B remained unchanged, and Set C decreased.

7. Series 6: This series was designed to determine if the more promising coatings found in earlier series were effective in preventing freeze-thaw scaling in cracked concrete.

The specimens were the same as all others except that a sheet of one inch mesh chicken wire was cast in the concrete at mid-depth. After curing and drying, they were supported at two opposite edges and cracked by a mid-span load applied by a Universal testing machine. The single small crack penetrated the full depth from side to opposite side and it appeared to be about the same width in all specimens. The wire served only to hold the pieces of the slab together so that they could be handled during cycling.

Coatings were applied after cracking, and extreme care was taken to saturate the crack area and to let the coating material flow abundantly into the crack.

8. Series 7: This series was run to determine the freeze-thaw scaling performance of specimens made with air-entrained concrete. The specimens were dried at 73°F, 50% RH and surface coated in the same way as similar specimens of Series 1, which permitted a comparison of the performances of air-entrained and non air-trained concretes.

9. Series 8: This series was designed to make a comparative evaluation of skid resistance of uncoated specimens and specimens coated with some of the materials which appeared at the time to be among the most attractive for field application. The British Portable Tester was used in the evaluation of skid resistance of the surfaces of the 10 inch square test specimens.

IV. TESTS

1. Freeze-Thaw Scaling: All specimens of test series 1 through 7 were subjected to the freeze-thaw scaling test. After the coatings dried, an 8 inch diameter, galvanized sheet steel ring 1 inch high was bonded to the top surface of each specimen in preparation for the test. Dow Corning Silastic 732 RTV was beaded inside and outside to the bottom of the ring and top surface of the concrete to form an impervious bond of the ring to the concrete. Specimens were then set aside in the laboratory until they could be brought into the test. Generally, the waiting period was about 12 hours, but it was extended in some cases to several days.

A sodium chloride salt was mixed with tap water to provide a solution of 5% salt by weight. The wells formed by the metal rings were then filled to 1/2 inch depth with the solution. The specimens, mounted on hand carts, Fig. 1, were moved into the zero degree F freezing chamber to begin the freeze-thaw cycling.

Specimens remained in the zero degree chamber for 6 hours, being completely frozen by then, and they were then transferred to an adjacent 40°F chamber where they thawed over a 6 hour period.

At the end of one or two weeks, depending on the progress of scaling, specimens were removed to the laboratory where the old brine was discharged. The specimens were then flushed with tap water and their test areas were brushed free of loose scale. They were closely examined by eye at that time and photographs were made where deemed fitting.

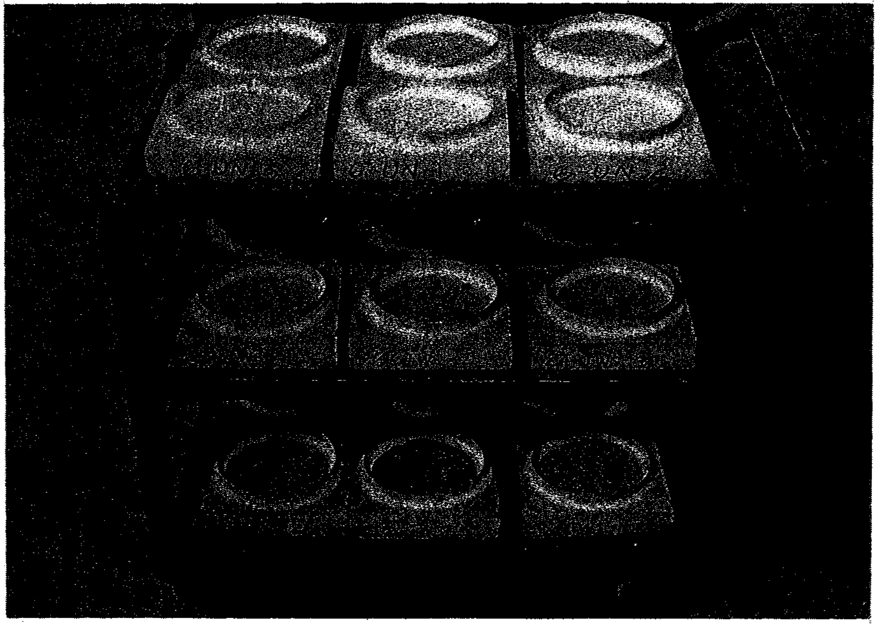


Figure 1. Freeze-thaw Specimens Mounted on a Hand Cart.

Specimens were charged with fresh brine after examination and the cycling was begun again. When scaling had progressed to a very serious state in any specimen, it was removed from the test.

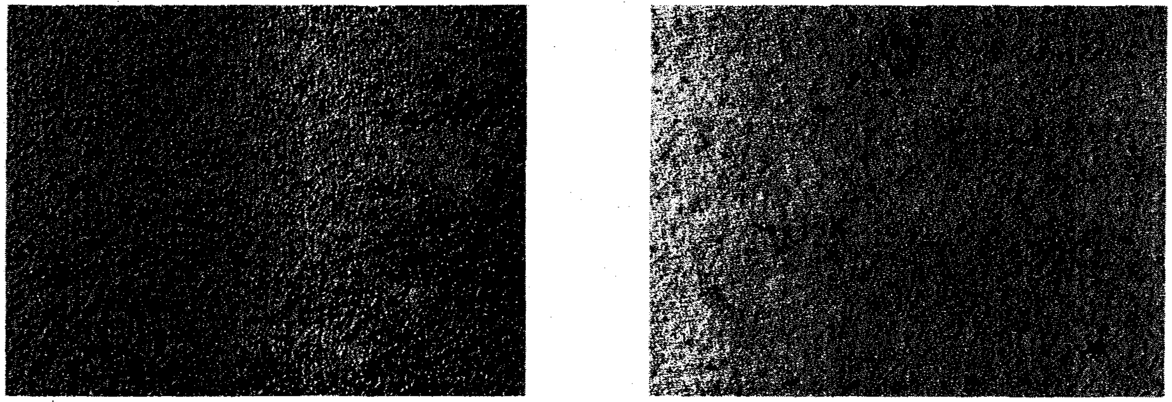
Deviation from the above procedure was made in the cases of specimens coated with asphalt and tar materials. The coatings, which hid the concrete surface, had to be scraped away before the condition of the concrete could be determined. Specimens covered with those materials were prepared in such numbers that some of them could be withdrawn at certain intervals and inspected. Since the coatings were destroyed during inspection, the withdrawn specimens of this type were discarded.

Visual surface scaling was rated by a scale of 1 to 5, following Snyder's (3) plan, in which the number increases with severity of scaling. Figure 2 shows a typical set. The number of freeze-thaw cycles producing moderate scaling and very severe scaling, numbers 3 and 5, respectively, were recorded.

2. <u>Skid Resistance</u>: The British Portable Tester, Figure 3, was used to determine comparative behavior of the coatings in skid resistance. The ASTM E303-66T test procedure, which calls for a wet surface, was followed.

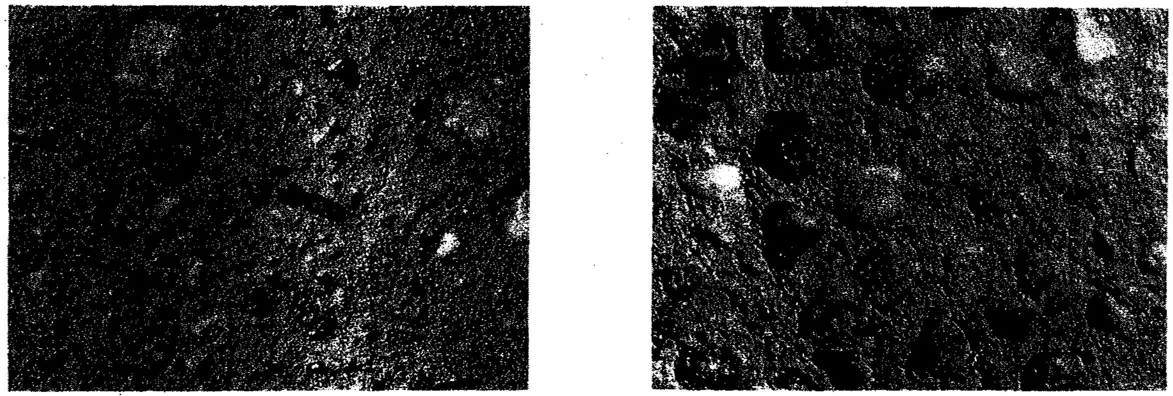
The wet surfaces of uncoated specimens were dried after testing. Those surfaces were then coated and again allowed to dry. In each case specimens were stored in a 73°F, 50% RH chamber 24 hours for drying.

The blocks were positioned so that the skid shoe contacted the same area in each of its four passes both before and after coating.



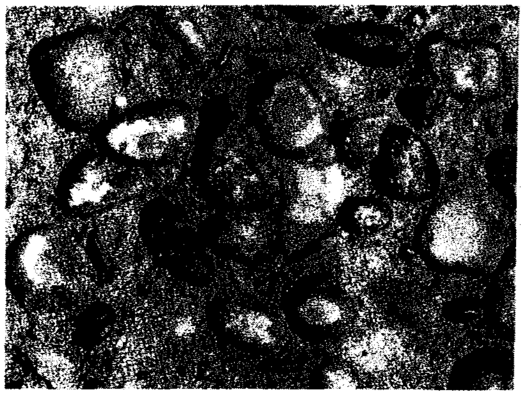
(a) Rating 1. No scaling.

(b) Rating 2. Slight scaling.



(c) Rating 3. Moderate scaling.

(d) Rating 4. Severe scaling.



(e) Rating 5. Very severe scaling

Figure 2. Ratings of Surface Deterioration Illustrated by a Set of Freeze-thaw Specimens

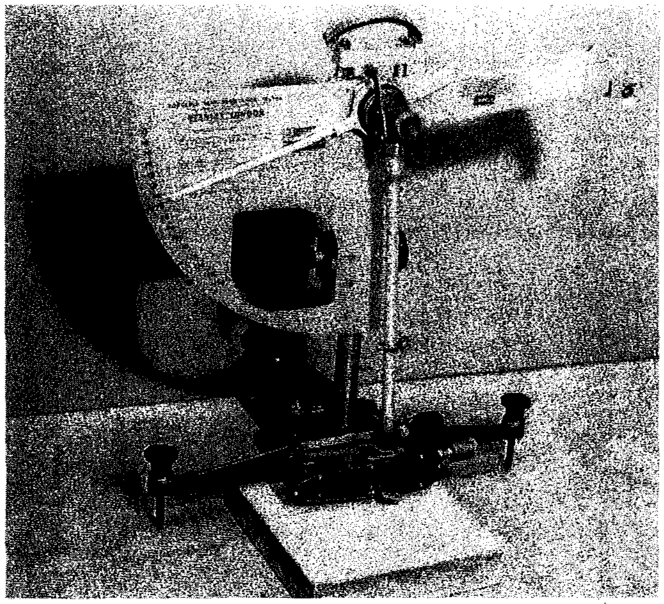


Figure 3. British Portable Tester.

Three penetrants, those that had performed best in freeze-thaw tests, were tested in the series.

V. TEST RESULTS

1. Results of tests are given in this section in the form of tables, charts, and discussion. Surface scaling ratings are judgment ratings because no absolute measure of scaling is known which would serve adequately for the purpose. Measurements depending on change of weight of the specimen are not practical for use in tests such as these. Dynamic modulus tests provide good information on internal structure changes but not for surface scaling. The results, then, should be viewed from the light of judgment ratings. Possibly a range of number of cycles between plus and minus 3 to 5 cycles from values shown here would be reasonable in evaluating the test results. There are some cases, of course, where action was very rapid and the range suggested here would not be applicable.

2. Series 1: Scaling performance of specimens in this series is given in Table V. The number of freeze-thaw cycles required to produce moderate and severe scaling are listed in appropriate headings. Drying conditions before specimens were coated were 73°F, 50% RH and 100°F, 50% RH.

Coatings 5 and 6, tar and asphalt materials, appeared to be in good condition until surface bubbles were noticed at 36 cycles. They were then inspected by removing the coating and it was found that deterioration had already progressed rather far in small localized spots. It was estimated that moderate scaling had developed at about 28 cycles and

TABLE V. SERIES 1 TEST RESULTS

Coating Code (pg. 4)	Number of F-T Cycles to Produce the Indicated Scaling			
	Dried at 73°F, 50% RH		Dried at 100°F, 50% RH	
	Moderate Scaling	Severe Scaling	Moderate Scaling	Severe Scaling
0	5	28	(No test)	
1	48	84	17	26
2-a	37	71	23	26
3	55	84	30	38
4	18	24	25	34
5	28 (a)			
6	28 (a)			
7	15	43		
8-a	118	170		
9	48	134		

(a) Coatings removed for inspection and specimens discarded.

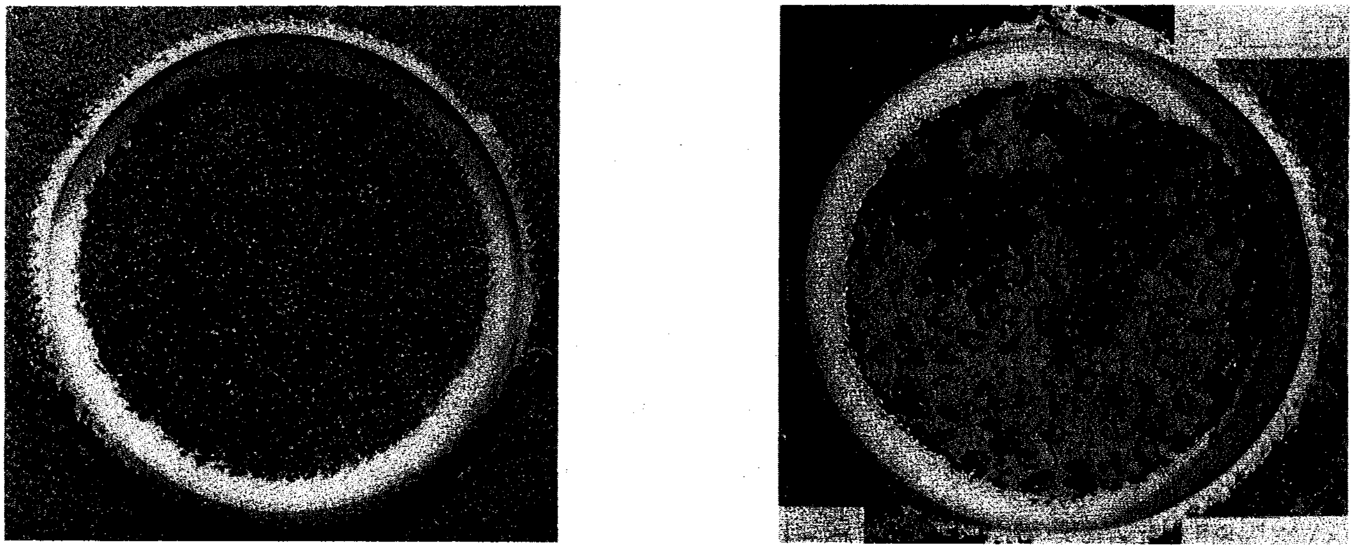
that value was recorded in the table. Since the coating was destroyed when it was removed to inspect the concrete, specimens were discarded leaving none to continue in the test. Photographs taken before and after cycling appear in Figure 4.

The condition of coating 5 was further complicated by being easily stripped from the concrete after two to three weeks under ponded brine. When the specimens were dried the coating developed cracks as shown in Figure 5, but bonding was good again when it dried. After being again ponded, the cracks disappeared and slippage again developed. The material used in this coating was not recommended by the supplier for use on concrete, and this test shows that slippage might be a problem if it is used that way. This coating does not provide a perfect seal over concrete.

All of the other coatings of this series were the penetrating type. In the 73°F, 50% RH drying series, all specimens that were treated with penetrants performed better than the control specimen with no coating. Coatings 4 and 7 did not perform as well as others, and coating 8-a far excelled all others.

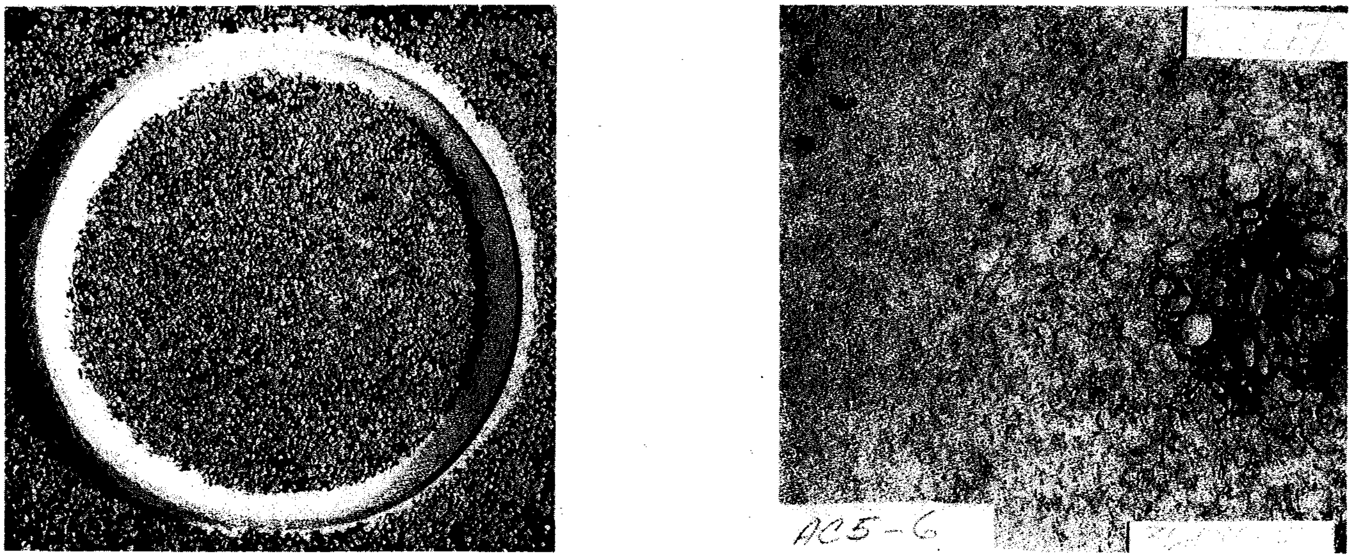
Top performers, in descending order of performance, were coating 8-a, Tung oil and kerosene mix; coating 9, EpoXeal; coatings 1 and 3, one and three coats of linseed oil and kerosene mix, respectively; and coating 2-a, two coats of linseed oil and kerosene. There does not appear to be any advantage of multiple coats of cut-back linseed oil in these tests. Selected photographs are shown in Figure 6.

All coatings applied to specimens dried at 100°F, 50% RH performed less well than they did at the lower temperature, with the exception of coating 4 which did better. The performance of coating 1 can be compared



(a) Coating 5 before cycling.

(b) Coating 5 after 38 cycles.



(c) Coating 6 before cycling.

(d) Coating 6 after 36 cycles. The coating had been removed for inspection of concrete.

Figure 4. Series 1 -- Coatings 5 and 6 Before and After Freeze-thaw Cycling.

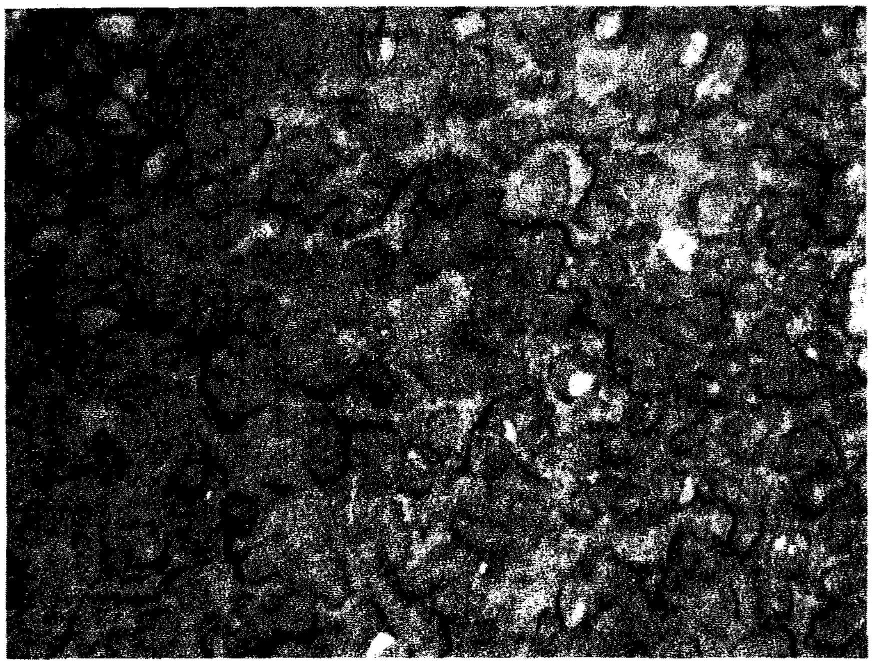
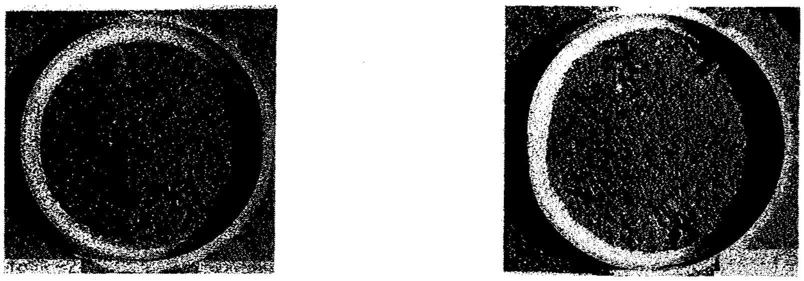


Figure 5. Cracks in Coating 5 After Drying (Enlarged Photograph).

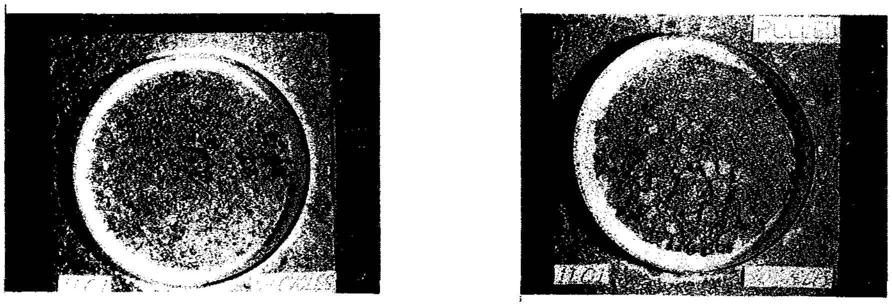


(a) Coating 8-a after 74 cycles

(b) Coating 8-a after 141 cycles

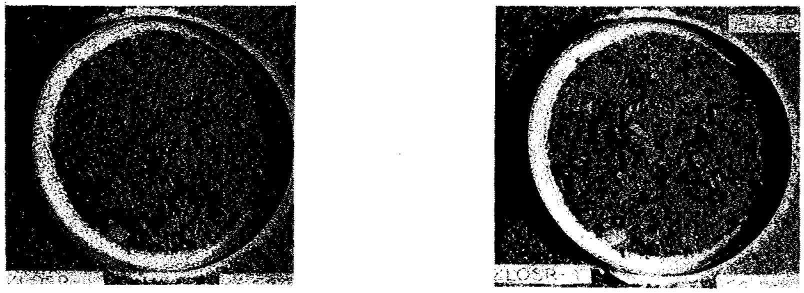
(c) Coating 9 after 48 cycles

(d) Coating 9 after 130 cycles



(e) Coating 1 after 54 cycles

(f) Coating 1 after 80 cycles



(g) Coating 2-a after 48 cycles

(h) Coating 2-a after 60 cycles

Figure 6. Series 1--Non air-entrained concrete showing scaling for coatings 1, 2a, 8a, and 9.

with one supposedly identical in Series 4, Table VIII. That coating performed comparably well on the 73°F, 50% RH dried specimens, but performances on the 100°F, 50% RH dried specimens are in very poor agreement. There was no known deviation from standard operating procedures and concrete mixes in the two cases, yet Series 1 values fall far below those in Series 4. Since Series 1 values are consistently low there is very strong evidence in test results that it used a poorer grade of concrete.

Because of the inconsistency in 100°F, 50% RH specimens between Series 1 and 4, no conclusion can be reached as to the influence of the two different drying conditions of Series 1 tests for freeze-thaw scaling durability.

3. Series 2: In studying test results of this series shown in Table VI, it should be noted that uncoated specimens were stored 24 hours in the 140°F chamber with coated specimens when coatings were drying. The uncoated specimen, then, was actually exposed one hour; and coated specimens, 7 and 25 hours total, respectively, for two sets, one hour of which was after coatings were applied.

Moderate scaling durability decreased markedly between 1-hour and 6-hour exposure, but there was no significant change in that degree of scaling between 6-hour and 24-hour exposure. Serious scaling cycles were the same regardless of exposure in the series.

The linseed oil treatment showed progressive reduction of moderate scaling durability with increases in exposure but serious scaling began to grow worse only after 6 hours of exposure. There was only a little difference in cycles at moderate and serious scaling conditions. Scaling was delayed considerably by the coating, but once it reached a moderate stage it developed rapidly.

Thompson's Water Seal displayed small influence of exposure duration at either moderate or serious scaling. At 24-hour exposure serious scaling durability was essentially the same for the linseed oil and TWS.

Durability was enhanced by both coatings for all exposures studied. It was reduced very much from the basic condition of 73°F, 50% RH drying followed in test Series 1.

It is reasonable to expect continuous periods of 4 to 6 hours of 140°F temperature on pavement surfaces in most parts of Texas during summer months. Such periods are followed by gradually lowering temperatures in the evening and night. The next day, it increases and the cycle is repeated. This is different than the cycle of the test where 21-day drying of 73°F, 50% RH was followed by a period of 140°F, 25% RH, then coating, then 24 hours of 140°F, 25% RH. A day or so spent in preparing retaining rings and brine permitted the specimens to come to room temperature before freeze-thaw cycling began.

The heat by itself did not reduce durability as can be seen by the more extensive tests of Series 4 explained below. No information that can be applied directly to field operations was given by the tests. It might be joined by information developed in the future to provide useful information.

4. Series 3: The results of this test series shown in Table VII indicate moderate scaling developed quicker in specimens treated with

TABLE VI. TEST SERIES 2 -- EFFECT OF 140°F CONCRETE ON PERFORMANCE OF LINSEED OIL-KEROSENE AND TWS COATINGS

Coating Code (pg. 4)	Coating	Number of Hours That Specimen Was Held at 140°F Prior to Coating (a)	Freeze-Thaw Cycles Producing:	
			Moderate Scaling	Severe Scaling
0	None	0	12	18
0	None	6	7	18
0	None	24	6	18
2-b	2-LO+Kerosene	0	32	36
2-b	2-LO+Kerosene	6	27	36
2-b	2-LO+Kerosene	24	22	27
7	TWS	0	13	28
7	TWS	6	15	25
7	TWS	24	12	25

Non air-entrained concrete; 7-day moist cure; 21 days at 73°F, 50% RH drying.

(a) All specimens were dried 24 hours in 140°F, 25% RH chamber after the coating operation. They were then placed into F-T cycling.

TABLE VII. SERIES 3 -- EFFECT OF SURFACE COATINGS APPLIED AFTER SCALING WAS IN PROGRESS

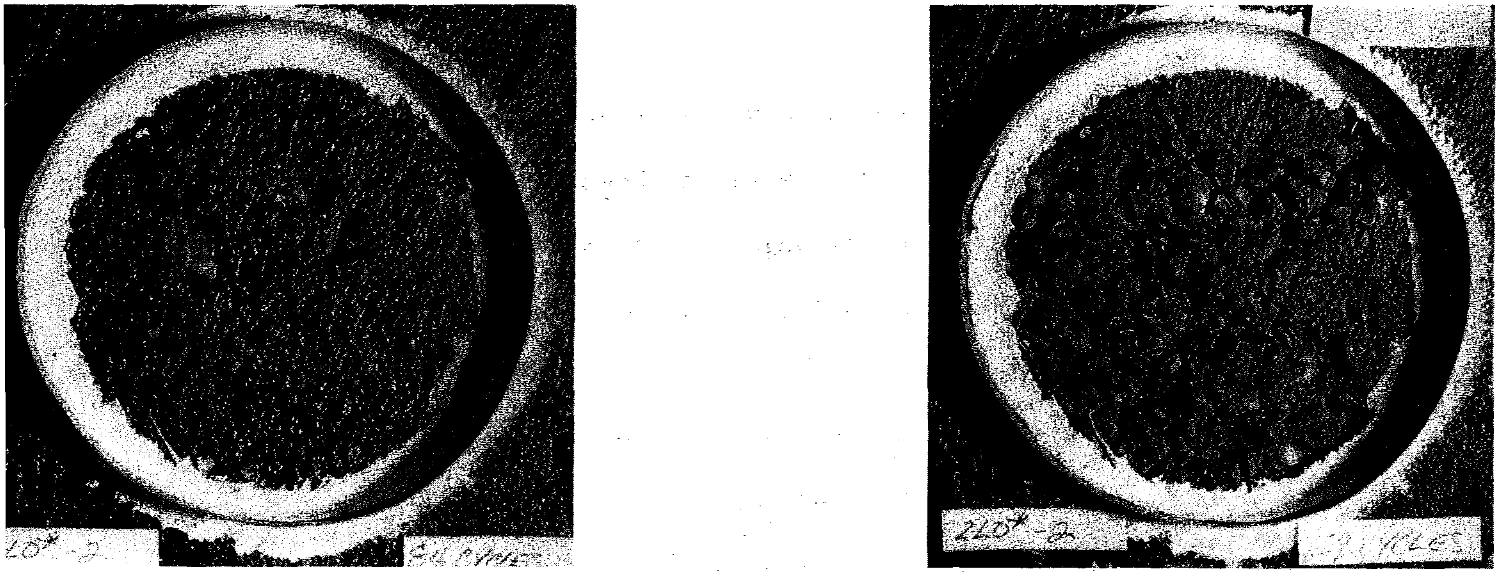
Data From Series	Coating (pg. 4)	Number of Freeze-Thaw Cycles: Before Coating	At Moderate Scaling	At Severe Scaling
1	0	0	5	28
1	2-a	0	37	71
3	2-b	13	29	114
1	8-a	0	118	170
3	8-b	13	58	118

the boiled linseed oil-kerosene mixture after scaling began than when applied before scaling. Severe scaling, however, was prolonged more in those treated after scaling began. Tung oil-kerosene treatment proved more effective when applied prior to scaling. See results in Fig. 7.

The post-scaling treatment results are compared with pre-scaling treatment results from other series, and it has been pointed out in Series 1 discussion that variations probably occur between series although standard procedures were used.

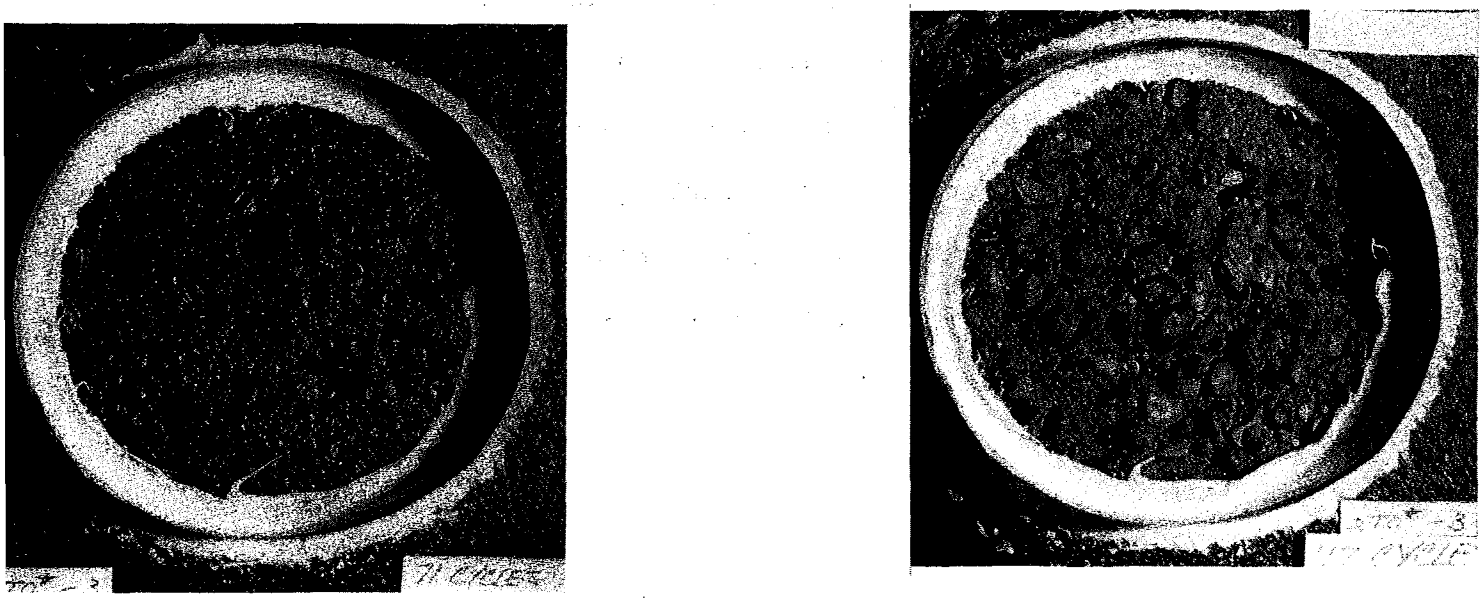
Scholer and Best (10) showed that post-scaling treatments of linseed oil definitely interrupted the progress of scaling. Their work showed that recoating an initially coated specimen greatly extended the life of the specimen. Brink, Grieb, and Woolf (5) suggest that linseed oil treatments should be repeated after one or two years of exposure.

The evidence here and from work of others indicates that coating after scaling has begun will retard scaling to some degree. The current practice of THD of coating new concrete and of applying subsequent coatings annually for at least two years appears to be sound.



(a) Coating 2-b after 84 cycles

(b) Coating 2-b after 109 cycles



(c) Coating 8-b after 71 cycles

(d) Coating 8-b after 117 cycles

Figure 7. Series 3 specimens coated after 13 freeze-thaw cycles. Cycling was resumed after coating.

5. Series 4: The results of tests in which five sets of specimens, uncoated and coated with linseed oil plus kerosene, were dried under different conditions are given in Tables VIII and IX. The best performer of uncoated specimens dried at 73°, 25% RH and the poorest at 73°, 50% RH. The 50% RH specimens were the lowest performers in uncoated specimens regardless of temperature, whereas the best performers dried at 25% RH. It should be noted here that the 73°, 50% RH condition was used as the standard drying condition in all series.

Among coated specimens, 140°, 25% RH proved to produce the most resistant specimens, and 100°, 75% RH the least resistant. The two sets under 50% curing performed a little better than the 73°, 25% RH specimens.

Although the 140°, 25% RH condition produced specimens most resistant to surface scaling, deterioration set in around untreated edges. This indicates that moisture migrated through the surface treatment to edges where it caused deterioration. The implication is that surface scaling resistance is benefited greatly by high temperatures and low humidity drying, but the coating does not completely seal the surface.

It is probably that the 73°, 50% RH condition is more representative of overall field conditions in the summer than any of the others of this series. Performance was good under that condition, and if field application could be made under conditions somewhat similar to it, the performance would possibly be best.

6. Series 5: This special series was scheduled to test the hypothesis that a treatment applied to a concrete specimen after it began to lose heat, shortly after reaching its peak level of stored

TABLE VIII. TEMPERATURE AND RELATIVE HUMIDITY EFFECT ON FREEZE-THAW SCALING -- BOILED LINSEED OIL AND KEROSENE COATING

Coating Code (pg. 4)	21 Day Drying Condition		Cycles to Produce Moderate Scaling	Cycles to Produce Severe Scaling
	Temperature (°F)	Relative Humidity (%)		
0	73	25	5	61
1	73	25	59	64
0	73	50	5	28
1	73	50	58	73
0	100	50	5	35
1	100	50	57	74
0	100	75	5	44
1	100	75	32	48
0	140	25	5	51
1	140	25	67	85

TABLE IX. FREEZE-THAW CYCLES VERSUS PRE-COAT DRYING CONDITION FOR SERIES 4

Number of Cycles	No Scaling	Slight Scaling	Moderate Scaling	Severe Scaling
90-99		(E)*		
80-89				
70-79	(E)		(A)	A
60-69		(A)	(C),(B)*	(C)
50-59	(A),(C)	(C),(B)	E	(D)
40-49			(D)	D
30-39	(B)		A,D	C
20-29		(D)	C	
10-19	(D)		B	
0-9		A,B,C,D,E		

*Severe edge deterioration, would not hold water

Code:	Temp.	RH	No Coating	1 Coat Lo+K
	73°	25%	A	(A)
	73°	50%	B	(B)
	100°	50%	C	(C)
	100°	75%	D	(D)
	140°	25%	E	(E)

heat energy, would pull the surface treatment material into the pores by negative interior pressure caused by contraction of the cooling interior gas. It was reasoned that more material would penetrate under such a condition, thereby closing off more entry ports for water and increase the freeze-thaw scaling durability.

Three sets of three specimens per set were prepared for coating by heating them to constant temperatures: one set at 73°F, two sets at 100°F.

The 73°F set was then placed into a 100° chamber, left 15 minutes, removed and quickly coated, then returned to the 100° chamber. Under this treatment the temperature of the set increased while the coating was curing.

The second set was removed momentarily from the 100° chamber, was coated, and immediately returned to the 100° chamber. Its temperature remained essentially unchanged during the entire pre-coating, coating, and post-coating period before its testing.

The third set was removed from the 100° chamber, placed in a 73°F chamber where it was left 15 minutes, then removed and quickly coated, then returned to the 73°F chamber where it cooled while drying.

After the three sets had dried, they were placed into freeze-thaw cycling and treated in the same way as other specimens.

Table X gives the results of the test. Moderate scaling was reached first, at 12 cycles, by the specimens which cooled during drying of the coating. The constant temperature specimen reached moderate scaling next, at 23 cycles, followed at 40 cycles by the specimen which increased in temperature during drying. There is no significant difference

TABLE X. EFFECT OF TEMPERATURE CONDITION AT TIME OF TREATMENT WITH COATING 9 -- SERIES 5

Surface Treatment	Temperature of Specimen at Time of Treatment	Cycles at Moderate Scaling	Cycles at Severe Scaling
9-A	Rising from 73°F to 100°F	40	66
9-B	Constant at 100°F	23	61
9-C	Decreasing from 100°F to 73°F	12	61

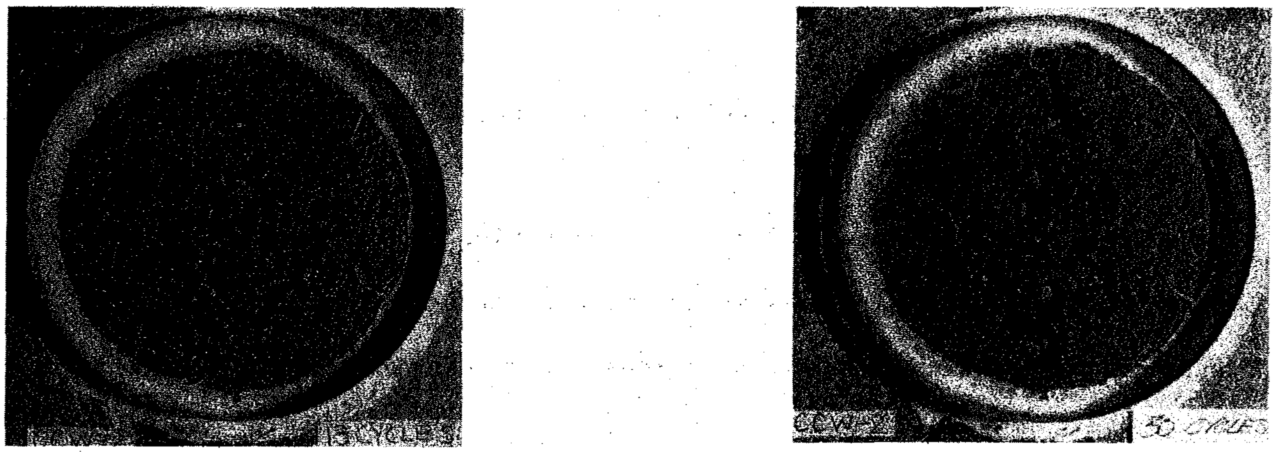
in the cycles required to produce severe scaling. The results of the test indicate that the condition of temperature at time of coating has an effect on the number of cycles necessary for moderate scaling, but not for severe scaling. And, in this series, application at rising temperatures, rather than at lowering temperatures, produced the best results.

7. Series 6: One question always before us in looking at anti-spalling agents is: "How effective is a surface treatment in preventing scaling in cracked concrete?" Experience in our laboratories (1,11) has shown that old concrete pavement and bridge deck slabs subjected to freeze-thaw action under ponded brine fail by internal crumbling and not by scaling. Coated and uncoated specimens alike failed in that way. Such behavior indicates that the concretes tested contained fine cracks or pores through which the brine migrated to the interior. The freeze-thaw action then destroyed the concrete from the inside rather than from the surface. Specimens of new concrete of this series were prepared to test effectiveness of sealants around cracks.

The specimens, air-entrained and non air-entrained, were cracked as explained in section III-7 and tested in freeze-thaw action in the same way as all others. It was found that entrained air was effective in significantly increasing durability against scaling adjacent to the cracks. Typical scaling began at the sharp edges of the crack just as it begins at sharp corners and edges of any moist concrete. The scaling then worked deeper into the material and laterally, along the surface, away from the crack.

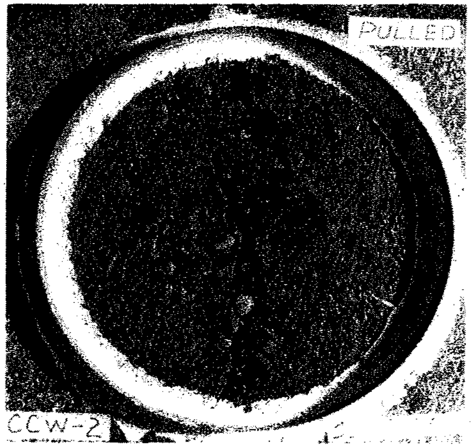
There was very little surface scaling of the air-entrained specimens. When the results of this series are compared with those of Series 7, it is seen that the entrained air, not the coatings, is responsible for the increased durability.

Photographs in Figure 8 show the condition for non air-entrained concrete, and Table XI gives information on number of cycles. The surface of the specimens remained in reasonably good condition throughout.



(a) Condition after 13 cycles

(b) Condition after 30 cycles



(c) Condition after 56 cycles

Figure 8. Deterioration in non air-entrained concrete which was cracked before coating.

TABLE XI. CRACKED CONCRETE IN FREEZE-THAW ACTION -- SERIES 6

Coating Code (pg. 4)	Air-Entrained	Cycles to Produce Moderate Scaling	Cycles to Produce Severe Scaling
0	No	10	60
2-a	No	32	57
5	No	39(a)	---
7	No	43	62
8-a	No	41	57
9	No	18	47
0	Yes	19	145(b)
2-a	Yes	104	190(b)
5	Yes	---	33(b)
7	Yes	66	154(b)
8-a	Yes	56	180(b)
9	Yes	68	195(b)

(a) Slippage developed at this stage; the coating was easily stripped from the concrete with fingers.

(b) Specimens were withdrawn from test when they no longer retained the surface water. Surfaces were generally in good condition but scaling had eroded the thin cracks to V-shape grooves of widths about 1/4 inch to 1 inch and to depth about the same as the widths.

This test shows that the penetrants used here are not effective in sealing the crack itself nor in sealing the concrete surfaces formed by the cracks. The only known treatment for complete sealing is an impervious membrane or topping. Since thin membranes are so easily punctured by abrasion, thicker coverings are needed for secure, positive sealing measures.

8. Series 7: Evidence is abundant that entrained air, properly used, extends the freeze-thaw scaling durability of concrete (4,5,6,7,8,9). It probably has no known equal, as an economical, practical agent for combatting freeze-thaw deterioration of concrete in highway installations.

Linseed oil-kerosene solutions made up three of the penetrating coatings of this series, and a patented material made the fourth. Two other coatings, a tar and an asphalt, completed the list of coatings of the series. No tests were made on uncoated specimens.

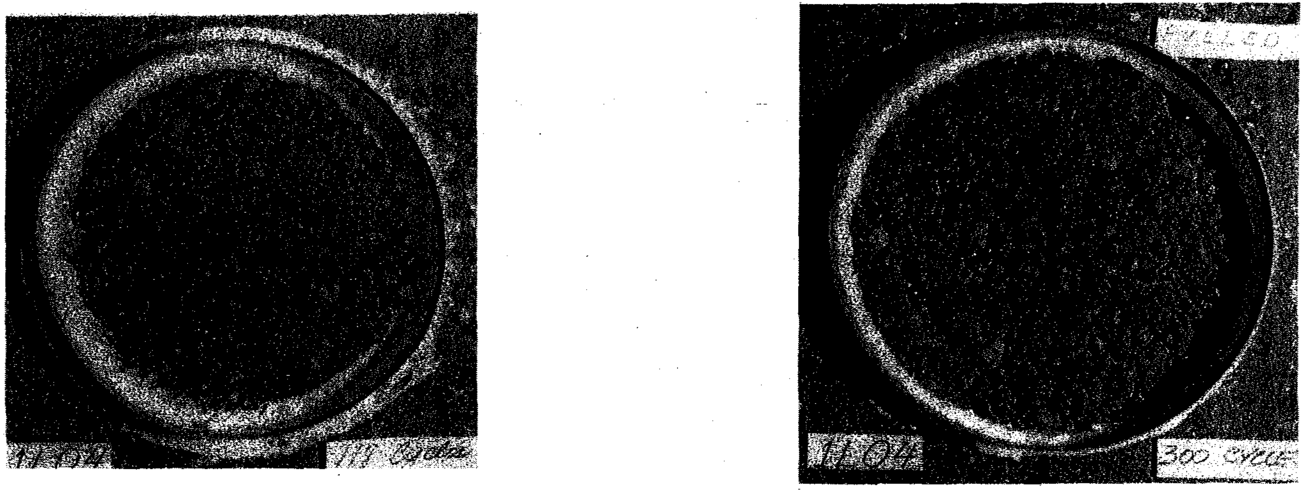
Results shown in Table XII show that there was a rather wide range of cycles at moderate scaling. The penetrants all appeared to be in about the same condition of severe scaling when they were withdrawn at 300 cycles. These results, when compared with those from non air-entrained specimens in other series, indicate that the effects of coatings were overshadowed by the effect of air-entrainment. Figure 9 shows coatings 1 and 6 after withdrawal at 300 and 115 cycles respectively.

Complete disintegration was not reached in coatings 1, 2, 3, or 7 when specimens had to be withdrawn to release equipment for other tests. The blanketing materials, coatings 5 and 6, were withdrawn at the cycles indicated in Table XII, and inspection at those events showed no serious deterioration.

TABLE XII. AIR-ENTRAINED CONCRETE PERFORMANCE IN FREEZE-THAW ACTION -- SERIES 7

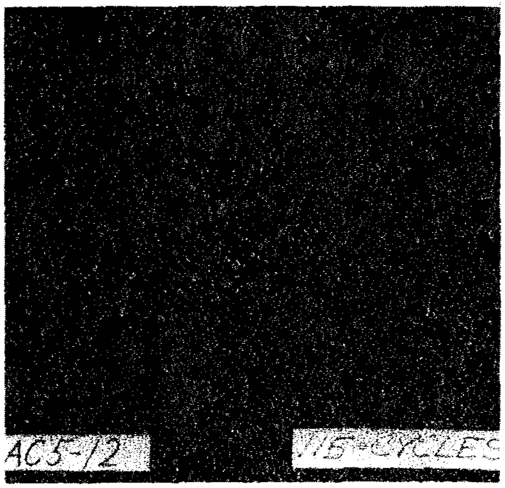
Coating Code (pg. 4)	Cycles to Produce Moderate Scaling	Cycles at Withdrawal from Test
1	28	300
2-a	105	300
3	88	300
5	--	108(a)
6	--	50, 64, 115(a)
7	10	300

(a) These specimens were withdrawn at the cycles shown so that the coating could be removed to reveal the concrete surface. When the coatings were removed, the inspection showed that no deterioration was evident.



(a) Coating 1 after 118 cycles

(b) Coating 1 after 300 cycles



(c) Coating 6 after 115 cycles after removal of coating for inspection of the concrete

Figure 9. Scaling of air-entrained concrete, Series 7.

This series confirms the findings of others that air-entrainment is very effective in combatting freeze-thaw deterioration. It gives no direct information on effectiveness of coatings because no uncoated control specimens were included. It is noted, however, in the discussion of Series 1 that coatings 1, 2-a, and 3 extended deterioration of non air-entrained specimens some 30 to 40 cycles beyond that of uncoated specimens. If the coatings have the same general effectiveness on air-entrained concrete as on non air-entrained, it might be reasonable to expect a non-coated air-entrained specimen to reach a severe scaling state in some 260 or 270 cycles.

9. Series 8: Results of the skid resistance tests made with the British Portable Tester, BPT, are tabulated in Table XIII and are shown graphically in Figure 10. Only the materials which had given good freeze-thaw durability and which were of the penetrating type were tested. Surfaces were tested after coatings were dry, 24 hours after application of coating.

In Figure 10 and Table XIII the highest number represents the greatest resistance to skidding of the shoe on the tester, and the smallest number represents the least resistance. Four passes were made on the same spot on each specimen before and after coating and the four readings were averaged to give the number shown for the specimen. The average of all specimens before coating is 61.6, and 48.0 after coating. The average difference before and after coating numbers is 13.6.

Of all individual sets of specimens, coating 3 produced the highest resistance, and coating 7 the lowest. The greatest reduction in resistance

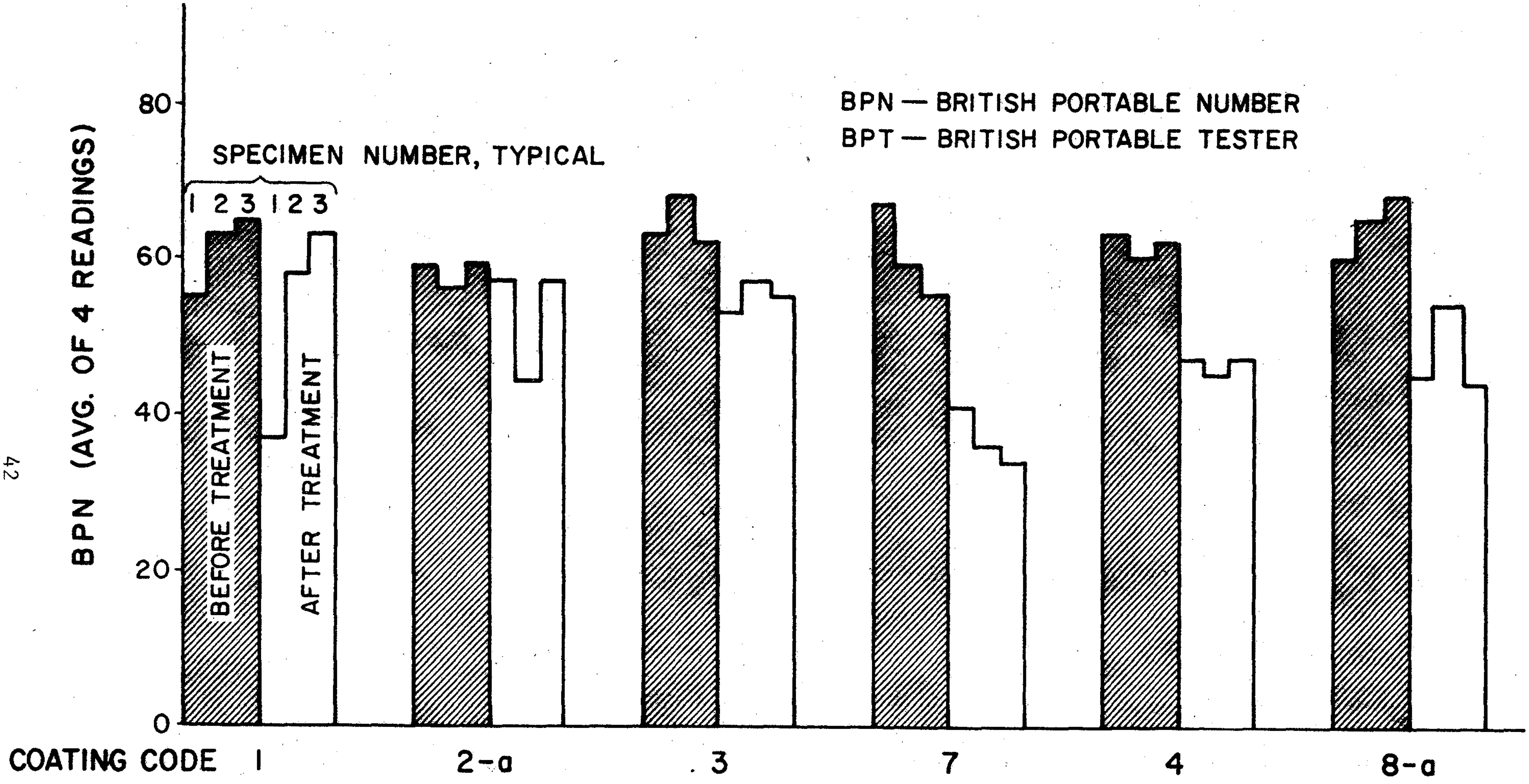


FIGURE 10. SKID RESISTANCE OF LABORATORY SPECIMENS BY BPT METHOD.

TABLE XIII. SKID RESISTANCE PERFORMANCE -- SERIES 8

Code (pg.4)	Treatment	Specimen 1		Specimen 2		Specimen 3		Avg. of 3		
		BPN Before	BPN After	BPN Before	BPN After	BPN Before	BPN After	Before	After	Diff.
1	1 coat (50-50) Linseed Oil	55	37	63	58	65	63	61	53	8
2-a	2 coats (50-50) Linseed Oil	59	52	56	44	59	52	58	49	9
3	3 coats (50-50) Linseed Oil	63	53	68	57	62	55	64	55	9
4	1 coat hot Linseed Oil	63	47	60	45	62	47	62	46	16
7	Thompson's Water Seal	67	41	59	36	55	34	60	37	23
8-a	2 coats (50-50) Tung Oil	60	45	65	54	68	44	64	48	16

Avg. of all before:	61.6
Avg. of all after:	48.0
Difference	13.6

from the uncoated to the coated condition is coating 7 and the least reduction is coating 1.

The numbers represented are characteristic of the testing apparatus and should not be assumed to represent the number characteristic of full-size skid trailers. There are certain inherent weaknesses in the BPT among which are the small area tested, the condition of the shoe, the velocity of the pendulum when the shoe strikes, and the roughness of the tested surface. These factors and the correlation of results taken from the BPT with skid trailer results have been discussed by others (13 to 20).

The BPT is a good instrument for giving comparative measures of surface slipperiness; it correlates reasonably well with skid trailers for velocities up to about 30 mph, but not higher, and that is good for laboratory work and for spot testing in the field.

Sufficient numbers of samples and a sufficient number of passes were made on each of the samples tested here to produce reliable characteristic numbers for the BPT on these coatings. One shortcoming of the test was that the effect of aging and of abrasion could not be taken into account.

Kubie, Gast, and Cowan (12) made tests on linseed oil treated concrete pavements and bridge decks over periods of time from immediately after application to years later. They obtained reasonably good agreement between the PCA (Portland Cement Association) Trailer and the BPT in aged areas on interstate bridges. They found that wet skid resistance values were restored in linseed oil treated surfaces from 3 to

24 hours after treatment. No advantage from skid resistance was found in those tests by applying sand to fresh treated areas. The sand acted only to absorb the excess oil on the surface.

The good performance of linseed oil solutions here added to its good freeze-thaw durability performance to make it a difficult material to match.

VI. QUANTITIES AND COSTS

Pre-test coatings were made on blocks to determine application rates for multiple coated specimens. It was found that specimens fully saturated with the first coat of linseed oil solution would absorb very little in succeeding coats after drying from the previous coat. It was decided that for those multiple coated blocks the first coat would be reduced and successive coats, too, would be reduced so that the specimen would take a reasonable quantity at each coat. The linseed oil and tung oil treated specimens took less material on successive coats, but coating 7 absorbed far more on the second coat than it did on the first.

Drying time between coatings ranged from 2-1/2 hours to 24 hours. Field work in coating bridge decks normally allow considerably more time than this between the first and second coats, and following coats are generally applied annually. Field practice, then, would probably apply about the same quantity at each application.

The coating materials must isolate the concrete from water if they are to be effective against freeze-thaw scaling. They must go even beyond mere isolation to the point of preventing entry of water or they must be able to cushion the mechanical forces of expansion and contraction if water does enter and freeze. Absorption tests made on coated concrete (1,11) show that at least some water is absorbed by specimens treated with penetrating type of materials.

Test results reported here indicate that there is no advantage to applying a third coat of linseed oil treatment and there is little or no advantage to the application of a second coating in the laboratory trials. It appears, then, that one heavy coat of linseed oil solution is sufficient to serve effectively as a deterrent to freeze-thaw deterioration, but it does not offer full protection, nor do any other of the penetrants reported here. The advantage of a second coat of linseed oil solution would probably be in covering some spots not adequately covered in a first coating.

Surfaces should be clean before any coating is applied, but some materials are more tolerant of minor uncleanliness than others are. All penetrants used in these tests may be applied to concrete cleaned of dust and debris by broom or brush. Thick oil and grease spots will not let the materials penetrate, but the penetration of oil and grease themselves probably serves to protect those spotted areas. More effective penetration is realized in clean concrete, which, in the case of bridge slabs, is generally new concrete.

Quantities used in these tests are reported, along with some cost information, in Table XIV. There will be differences in materials required by different concretes when they are treated to the saturation level. Costs will vary with geographic location, working conditions, condition of the deck, and the value of the dollar. The figures shown in Table XII reflect all of the variables mentioned. They were developed for the most part by THD on jobs handled by its own maintenance forces.

A wider range of maintenance costs reporting penetrants, membranes, overlays and patching materials is given in NCHRP report 1 prepared in 1963 (21).

VII. DISCUSSION

Surface coatings that are practical, effective, and economical for

TABLE XIV. QUANTITIES AND COSTS

Coating Code (pg. 4)	Coating Material	Coverage (sq yd/gal)	Cost in Dollars per sq yd		
			Application	Material	Total
1	Linseed oil + kerosene (1 coat)	28	0.0156(a)	0.0121	0.0277
2-a	Linseed oil + kerosene (2 coats)	1st coat 37 2nd coat 56	0.0156 0.0156	0.0090 0.0061	
			.0312	.0151	0.0463
3	Linseed oil + kerosene (3 coats)	1st coat 46 2nd coat 56 3rd coat 73	0.0156 0.0156 0.0156	0.0070 0.0061 0.0046	
			.0468	.0181	0.0649
4	Linseed oil, hot	28	(no record)	.0121	------
5	Jennite + Primer	1/8 in. thick	------	------	------
6	Asphalt (AC-5 with primer MC-0)	1/16 in. thick	See below		(b)
7	Thompson's Water Seal (2 coats)	1st coat 29 2nd coat 18	0.0156(c) 0.0156(c)	unknown	
8-a	Tung oil + kerosene (2 coats)	1st coat 37 2nd coat 56	0.0156(c) 0.0156(c)	unknown	
9	EpoXeal (2 coats)	1st coat 13 2nd coat 75			0.50(d)

(a) THD District 18 records for applying Linseed Oil Anti-Spall Compound (a mixture of Boiled Linseed Oil and Mineral Spirits) with THD maintenance forces.

0.022 gals/sq yd
$0.0154/sq yd for material
$0.0156/sq yd for labor and equipment

Since the Anti-Spall Compound and the mixture of linseed oil and kerosene appear to be about the same consistency, it is assumed that application costs for the two materials will be essentially the same.

TABLE XIII. (Continued)

(b) No costs available but it is estimated that maintenance forces can apply the primer, coating, and stone finish for a total cost of about \$0.20 to \$0.25 per sq yd.

(c) This number represents the cost to THD maintenance forces for labor and equipment in applying Linseed Anti-Spall Compound. It is assumed here that the cost of applying coatings 7 and 8 will be essentially the same as for that compound.

(d) This figure was reported to one of the authors by letter, dated June 19, 1968, from Mr. R. Lyle Brace, Protective Products Corporation.

use on concrete highways have been narrowed down to relatively few in number by several studies. Those coatings include penetrants and thin membranes up to about 1/8 inch or less in thickness. A few of the coatings which were shown in other studies to be among the best were tested in the program reported here.

There are many different conditions of material, traffic and weather that must be contended with in planning a program for coating of bridge decks. There are probably many methods and materials which might be combined to produce a satisfactory maintenance practice. The difficulty comes in finding the combination that works best in a given situation. In the laboratory it is impossible to control variables and at the same time to faithfully reproduce field conditions under which coating materials must serve. These tests attempted to produce a concrete which simulated prototype deck concrete in mix and finish, and some of the drying temperatures went as high as those encountered in the field, but did not fluctuate as much. Extensions of laboratory test results should be made with the knowledge that field and laboratory conditions differ.

The most beneficial agent for concrete exposed to freeze-thaw cycling is properly disposed entrained air. That has been shown in many studies, including this one, and highway departments throughout the country use it in exposed concrete.

Coatings can increase the freeze-thaw scaling durability of both air-entrained and non air-entrained concretes. The beneficial effects are noticed more, though, in non air-entrained concrete because the air-entrained material is so much more durable. Air-entrainment enabled the specimens of these tests to go through about 4 to 5 times as many freeze-thaw cycles before failure as did the non air-entrained concrete.

Tar and asphalt coatings developed leaks in some cases which permitted freeze-thaw deterioration to progress unnoticed until the coatings were stripped. The development of leaks appears to be one of the major shortcomings of coatings made of such materials. Holes that permit water to penetrate the coatings cannot be seen, and scaling may not be seen either until it has progressed very far or until the cover is stripped back.

Jennite, made for asphaltic concrete (22), and not for portland cement concretes, was easily stripped from the portland cement concrete blocks after a few days under salt water. After drying it regained its bond, but lost it again under sustained soaking in salt water. Because of the likelihood of portions of a bridge deck being continuously wet over periods of days, this material would not serve satisfactorily as a concrete coating unless it is modified in some way. Slippage of continuously wet asphalt overlays on portland cement concrete can possibly present problems, too (23).

Most of the specimens that had been dried at 100°F for days before coating scaled fast under freeze-thaw tests, and reached the severe scaling stage at far fewer cycles than those dried at room temperature and humidity. The only exception was the hot linseed oil treatment for which durability was equal or better than those dried at room temperature. This indicates that concrete should be coated before long hot dry seasons or after the weather has moderated following such seasons.

Boiled linseed oil applied while it was hot provided good protection to the laboratory specimens. It darkened the concrete somewhat and reduced the skid resistance of the concrete.

VIII. CONCLUSIONS

With respect to freeze-thaw scaling durability the following conclusions are drawn from the tests reported:

1. Freeze-thaw scaling is more effectively combatted with entrained air than with the penetrating and non-penetrating coatings tested in the program.

2. Two coats of 50-50 mixture of boiled linseed oil and kerosene applied to new concrete at the rates of 40 sq. yards per gallon for the first coat and 55 sq. yards per gallon for the second was among the most effective coatings tested. It is easily applied and it is comparatively inexpensive. Commercially available mixtures of boiled linseed oil and mineral spirits have been reported as effective and are used widely.

3. Tung oil cut back with kerosene to a 50-50 mixture applied at the same rate as linseed oil and kerosene is an effective coating performing about the same in the laboratory as linseed oil and kerosene.

4. Hot boiled linseed oil is effective in reducing scaling but it is more difficult to handle than it is when mixed with kerosene, and it is less skid resistant.

5. Thompson's Water Seal provided a good measure of scaling resistance. Its cost in place is not known. Its skid resistance is rather low.

6. No penetrating coating tested here was effective in materially reducing scaling at cracks.

7. The effective coatings will extend the life of concrete which

has minor scaling before treatment.

8. Coatings are more effective when applied to concrete which has been aged, after normal cure, at low humidity (25% RH) and 140°F temperature. High humidity aging tends to produce less resistant concrete if freeze-thaw action takes place shortly after coating.

9. Skid resistance is reduced by the coatings tested. The linseed oil-kerosene mixture reduced skid resistance less than any others tested.

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APPENDIX

A-I. COATING PROCEDURE

The listings in this Appendix follow this outline:

1. Coating Number 1
   a. Material (name, type mix, etc)
   b. Surface preparation
   c. Number of coats
   d. Application procedure
   e. Rate of application
   f. Drying of coating(s)
   g. Remarks

1. Coating Number 1
    a. Material: Boiled linseed oil mixed with kerosene, 50% each by volume.
    b. Surface preparation: Brush clean.
    c. Number of coats: one.
    d. Application procedure: The mixture was sprayed on with a DeVilbiss spray gun at 40 psi air pressure.
    e. Rate of application: 28 sq yd per gal.
    f. Drying: Coating dried 24 hours under the same temperature and relative humidity conditions at which specimens were stored just prior to coating.
    g. Remarks: Drying was complete, except for isolated spots, 2 hours after application. Those isolated spots were located over coarse aggregate particles which were just beneath the surface.
2. Coating Number 2-a
    a. Material: Boiled linseed oil mixed with kerosene, 50% of each by volume.
    b. Surface preparation: brush clean.
    c. Number of coats: two.
    d. Application procedure: The mixture was sprayed on with a DeVilbiss spray gun at 40 psi air pressure.
    e. Rate of application: First coat - 37 sq yd per gal.
    Second coat - 56 sq yd per gal.
    f. Drying of coatings: Coatings dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.

   g. Remarks: The first coat was dry, except for isolated spots, 2 1/2 hours after application at which time the second coat was applied. The second coat was dry, except for isolated spots, 5 hours after application. Those isolated spots were over coarse aggregate particles which were just beneath the surface.

3. Coating Number 2-b
   a. Material: Boiled linseed oil mixed with kerosene, 50% of each by volume.
   b. Surface preparation: brush clean.
   c. Number of coats: two.
   d. Application Procedure: The mixture was sprayed on with a DeVilbiss spray gun at 40 psi air pressure.
   e. Rate of Application: First coat - 37 sq yd per gal.
      Second coat - 56 sq yd per gal.
   f. Drying of coatings: The coatings dried 24 hours at the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.
   g. Remarks: Following 13 freeze-thaw cycles, the specimens were dried 48 hours at 140°F, 25% RH. The first coat was then applied requiring 2 hours to dry. The second coat was then applied and allowed to dry for 24 hours.

4. Coating Number 3
   a. Material: Boiled linseed oil mixed with kerosene, 50% of each by volume.
   b. Surface preparation: brush clean.
   c. Number of coats: three.

d. Application procedure: The mixture was sprayed on with a DeVilbiss spray gun at 40 psi air pressure.

e. Rate of Application: First coat - 46 sq yd per gal.
Second coat - 56 sq yd per gal.
Third coat - 73 sq yd per gal.

f. Drying of coatings: Coatings dried approximately 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.

g. Remarks: The first coat was dry, except for isolated spots, 2 1/2 hours after application at which time the second coat was applied. The second coat was dry, except for isolated spots, 2 to 3 hours after application at which time the third coat was applied. The third coat was dry, except for isolated spots, 5 to 7 hours after application. Those isolated spots were over coarse aggregate particles which were just beneath the surface.

5. Coating Number 4

a. Material: Hot (180°F) boiled linseed oil.

b. Surface preparation: Brush clean.

c. Number of coats: one.

d. Application procedure: The mixture was sprayed on with a DeVilbiss spray bun at 40 psi air pressure.

e. Rate of Application: 28 sq yd per gal.

f. Drying of coating: Coating dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.

   g. Remarks: Drying was complete 2 to 3 hours after application.

6. Coating Number 5

   a. Material: (J-20) Jennite primer and (J-16) Jennite sand slurry.

   b. Surface preparation: Brush clean.

   c. Number of coats: one.

   d. Application procedure: The primer coat was brushed onto a "chocolate" color. The sand slurry was troweled onto the primer coat.

   e. Rate of Application: The primer coat was applied in a quantity to produce a "chocolate" coat. The sand slurry, 3 parts of Jennite (J-16) to 2 parts sand by volume, was troweled onto the primer coat approximately 1/8" thick.

   f. Drying of coatings: Each coat dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.

   g. Remarks: Drying was complete for the primer coat 1 hour after application. Drying was complete for the sand slurry 8 hours after application. The sand used in the slurry mix was #12 to #20 U.S. standard sieve of which 95% was retained on #12 and 5% was retained on #20.

7. Coating Number 6

   a. Material: MC-0 primer and Ampet, A C-5.

   b. Surface preparation: Brush clean.

   c. Number of coats: one.

   d. Application procedure: The primer was brushed on to an even coat. The A C-5 was heated until viscous and spread to an even coat of approximately 1/16" thickness. Heated sand was then rolled and worked into the AC-5 layer.

e. Rate of Application: Primer coat - 0.06 gal per sq yd.

A C-5 coat - 0.15 gal per sq yd.

f. Drying of coating: Each coating dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored prior to coating.

g. Remarks: Five minutes after the primer was applied, one pass was made over the block with a small, heavy, brass roller 3" wide. A total of ten passes were made with a time lapse of 20 minutes between passes of the roller.

The heated sand consisted of #12 to #20 U.S. standard sieve size of which 95% was retained on the #12 and 5% on #20.

8. Coating Number 7

a. Material: organic and inorganic compounds which are polymerized and carried in an aromatic solvent (Thompson's Water Seal).

b. Surface preparation: Brush clean.

c. Number of coats: two.

d. Application procedure: The sealant was sprayed on with a DeVilbiss spray gun at 40 psi air pressure.

e. Rate of Application: First coat - 29 sq yd per gal.

Second coat - 18 sq yd per gal.

f. Drying of coatings: Each coating dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.

g. Remarks: The first coat appeared dry after 4 hours but was tacky to the touch. A total of 24 hours was allowed for drying of the first coat. The second coat was then applied with 24 hours being allowed for it to dry.

The air-entrained specimens were left at room conditions (75°F) for 30 days before being placed in freeze-thaw cycle. The non air-entrained specimens were dried 24 hours at 75°F then placed in freeze-thaw cycle.

9. Coating Number 8-a
   a. Material: Raw tung oil mixed with kerosene, 50% of each by volume.
   b. Surface preparation: brush clean.
   c. Number of coats: two.
   d. Application procedure: The mixture was sprayed on with a DeVilbiss spray gun at 40 psi air pressure.
   e. Rate of Application: First coat - 47 sq yd per gal.
      Second coat - 56 sq yd per gal.
   f. Drying of coatings: The coatings dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.
   g. Remarks: Drying was complete 2 hours after application for the first coat at which time the second coat was applied. The second coat dried approximately 3 hours after application.
10. Coating Number 8-b
    a. Material: Raw tung oil mixed with kerosene, 50% of each by volume.
    b. Surface preparation: brush clean.
    c. Number of coats: two.

d. Application procedure: The mixture was sprayed on with a DeVilbiss spray gun at 40 psi air pressure

e. Rate of Application: First coat - 37 sq yd per gal.
Second coat - 56 sq yd per gal.

f. Drying of Coatings: The coatings dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.

g. Remarks: Following 13 freeze-thaw cycles, the specimens were dried 48 hours at 140°F, 25% RH. The first coat was then applied requiring 2 hours to dry. The second coat was then applied and allowed to dry for 24 hours.

11. Coating Number 9

a. Material: A two component epoxy thinned with a volatile solvent (EpoXeal).

b. Surface preparation: Brush clean.

c. Number of coats: two.

d. Application procedure: The mixture was sprayed on with a DeVilbiss spray gun at 40 psi air pressure.

e. Rate of Application: First coat - 13 sq yd per gal.
Second (touch-up) coat - 75 to 80 sq yd per gal.

f. Drying of coatings: The coatings dried 24 hours under the same temperature and relative humidity conditions at which the specimens were stored just prior to coating.

g. Remarks: Drying was complete 1/2 hour after application for the first coat. The second coat was then applied requiring approximately 3 hours to dry.