EVALUATION OF SEVERAL TYPES OF CURING AND PROTECTIVE MATERIALS FOR CONCRETE

Final Report on Part I — Laboratory and Outdoor Exposure Studies Preliminary to Field Trials

by

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SUMMARY

Concern for improving the durability of concrete has focused renewed attention on all aspects of concrete technology. Numerous proprietary products which are claimed to improve durability have been marketed as protective coatings, curing agents or combinations of the two. The end purpose of this project is to evaluate the performance of several of these materials under field conditions. This report covers Part I of the project, which consisted of preliminary evaluation testing to select the materials to be placed in the field. White pigmented resin, white polyethylene, and chlorinated rubber curing compounds were tested in combination with linseed oil protective coatings and a monomolecular film for their effects in retarding evaporation during the early stages of hydration.

Both air entrained and non-air entrained concretes were subjected to tests for resistance to rapid freezing and thawing in sodium chloride solution, resistance to scaling during exposure to deicing in an outdoor exposure area, compressive strength, and skid resistance.

CONCLUSIONS

Based upon the data and discussion presented in the report it was concluded that:

1. Properly entrained air is overwhelmingly the most effective defense against scaling caused by deicing chemicals.

2. When insufficient entrained air is obtained, linseed oil treatments delay the onset of scaling.

3. Linseed oil treatments are effective when applied to concrete previously cured with resin based curing membrane without the necessity for removal of the membrane. Results from these and prior studies indicate penetration of the membrane by the linseed oil treatment, likely through dissolution of the resin film by the mineral spirits.

4. Chlorinated rubber used as a combination curing and protective sealant is not effective on poorly air entrained concrete. It accelerates deterioration over that of such concrete normally cured with or without linseed oil treatment.

5. The monomolecular evaporation retarding film showed some beneficial effects on resistance to scaling of non-air entrained concrete.

6. Based upon compressive strength of cylinders variously cured, the strength of cylinders cured with sprayed on materials is about 75 percent of that from moist curing or various protective coverings, but this strength is not reflected in resistance to scaling.

7. The chlorinated rubber sealer, because of its tenaceous film, might accentuate the detrimental effect on skid resistance of a moderate surface texture of the concrete.

RECOMMENDATIONS

From Part I of the study it is recommended that:

1. The number of sections devoted to the chlorinated rubbers in field trials should be reduced below that originally proposed.

2. One-half of each quadrant on slabs exposed outdoors which received initial treatments of linseed oil should be retreated prior to the third winter's exposure.

3. The current practice of the Virginia Department of Highways in treating bridge superstructures with linseed oil should be continued. The treatment of concrete previously cured with membrane without removal of the membrane should continue to be permitted. At the same time, continued emphasis should be placed on the importance of obtaining proper amounts of entrained air. This project has not progressed sufficiently to provide information on the need for retreatment, but the literature reviewed indicates the necessity for periodic retreatment.

4. Since there is some indication that the dissolution of the resin material by the mineral spirits permits penetration of the linseed oil, it might be possible to develop a curing material which, when subsequently dissolved by mineral spirits, would penetrate the surface and offer protection against scaling.

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In 1966, the Virginia Department of Highways adopted the use of linseed oil treatments on the concrete in bridge superstructures. This was done in response to nationwide as well as local concern for the durability of concrete bridge decks. Throughout the world extensive research is under way to evaluate the causative factors and to develop preventative measures for premature deterioration. A considerable portion of the bridge research in Virginia has been directed toward improving deck performance and has been recently summarized (Newlon and McKeel — 1968). During the development and conduct of this research, the most commonly reported deficiency in deck durability resulted from deicer scaling and/or deterioration from freezing and thawing. The recently published PCA-BPR Cooperative Bridge Deck Survey (1969) confirmed that scaling was the most common problem in Virginia as shown in Table I.

TABLE I

FREQUENCY OF DEFECTS OF BRIDGES AS REFLECTED BY PCA-BPR RANDOM SURVEY*
(Values in Percent)

Defect	All States	Virginia
Scaling	34	56
Cracking	76	49
Spalling	12	1

*Taken from PCA-BPR — 1969

It will be seen from Table I that the incidence of cracking and spalling was substantially less in Virginia than in the other states studied while the occurrence of scaling was substantially greater. At least a part of the high incidence of this scaling is due to the relatively late initiation of the use of entrained air and the specification of comparatively low values (3% - 5%) for many years.

While it is well established that entrained air is by far the most effective factor in preventing deicer scaling and that linseed oil treatments are beneficial in cases wherein the entrained air content is low for any of several reasons, the search for protective treatments continues.

Since the use of linseed oil requires a separate field spraying operation subsequent to completion of construction, considerable economy could be achieved if the materials used for curing would subsequently provide protection equivalent to that of the linseed oil treatment. New materials that purportedly impart improved resistance to scaling are continuously presented for evaluation and the purpose of this program was to evaluate several classes of such materials in the field. The working plan for the project was approved in 1968 (Newlon — 1968). Preliminary screenings were planned to select specific materials for field exposures.

The preliminary screening, which is the subject of this report, was accomplished by (1) accelerated laboratory freezing and thawing in 2% NaCl solution of variously treated beam specimens, and (2) exposure out-of-doors of slabs exposed to periodic deicing in in NaCl solution. In addition to the evaluation of the protective qualities of the materials, their influence on skid resistance and curing efficiency was assessed in a limited way.

MATERIALS

Curing and/or Protective Materials

The curing and/or protective coatings used in various combinations were (1) white polyethylene sheeting (WPS), (2) pigmented liquid membrane curing compound (LMS), (3) chlorinated rubber sealers (CRS) from four sources, two of which were used at each of two levels of solids content, (4) monomolecular film (MEF) developed to reduce early evaporation (Cordon and Thorpe — 1965), and (5)linseed oil "anti-spalling" solution (LOT). The combinations of materials used and the numerical designations employed in presenting the data are given in Table II. In cases where linseed oil solutions (LOT) were applied to concretes cured with liquid membrane curing compound (LMS), they were applied directly without any effort to remove the LMS. This was based upon previous research which showed that the curing membrane was penetrated by the linseed oil solution and that the freezing and thawing resistance was increased. Because this research has not been published and because it is so closely related to this project, a summary of the laboratory and field experiments is included as Appendix A.

TABLE II

COMBINATIONS OF CURING AND PROTECTIVE COATINGS USED

Number	Condition [1]
0	No Cure
1	LMS
2	WPS
3	(LMS) + LOT
4	(WPS) + LOT
5	MEF + (LMS) + LOT
6	(MEF) + (WPS) + (LOT)
7	(MEF) + (LMS)
8	CRS_1 - H (High Solids)
9	CRS_2 - L (Low Solids)
10	CRS_2 - LP low solids - pigmented
11	CRS_3 - L (Low Solids)
12	CRS_3 - H (High Solids)
13	CRS_4 - L (Low Solids)

Note (1)

LMS Liquid Membrane Seal
WPS White Polyethylene Sheeting
LOT Linseed Oil "Anti-Spalling" Solution
MEF Monomolecular Film

CRS_1 Chlorinated Rubber - Source #1
CRS_2 Chlorinated Rubber - Source #2
CRS_3 Chlorinated Rubber - Source #3
CRS_4 Chlorinated Rubber - Source #4

Materials which would function as curing media were tested in accordance with the Virginia modification of AASHO T 155. This method is given in Appendix B. The moisture losses are shown in Table III along with the values specified by the Virginia Department of Highways and other specifying agencies such as ASTM and AASHO. It should be noted that all materials easily complied with the ASTM and AASHO requirements; but two chlorinated rubbers (Codes 9 and 13) did not conform at either age to the more restrictive VDH requirements, and one did not conform to these requirements at 24 hours.

TABLE III

RESULTS OF TESTS OF CURING MATERIALS

Material	Code	Moisture Loss, gms/in^2 [a] AASHO T 155 (Va. Modification) Average of 3 Specimens		Solids Content, percent
		24 hours	72 hours	
VDH Specs. — Maximum	-	.075	.150	—
LMS	1	.036[b]	.085[b]	—
WPS	2	.004	.009	—
CRS_1 - H	8	.078[c]	.115[b]	31.2
CRS_2 - L	9	.103	.170	25.0
CRS_2 - LP	10	.078[c]	.125[b]	27.6
CRS_3 - L	11	.090	.136[b]	21.4
CRS_3 - H	12	.063[b]	.096[b]	31.0
CRS_4 - L	13	.137	.235	22.2
AASHO Specs. — Maximum	—	—	.355	—

a. Expressed in terms of VDH requirements of gm/in^2. Conversion to more conventional gm/cm^2 requires division of the above values by 6.45.

b. Conforms.

c. Essentially conforms.

The linseed oil solution was supplied as solvent reduced, boiled linseed oil. The analysis of the boiled linseed oil is given in Table IV.

TABLE IV

ANALYSIS OF BOILED LINSEED OIL

Acid Value	4.8
Color (Gardner)	12-
Specific Gravity 77° F.	0.9296
Viscosity (Gardner)	A
Set to Touch	4-1/2 hours
Iodine Value	184
Ash	0.2%

No tests were run on the monomolecular film. It was supplied by the manufacturer, who markets it as a proprietary product.

Concretes

The concretes used in all tests were fabricated to represent that intended for use in the field with the exception that the water reducing-set retarding admixture was used only in the test slabs employed in the evaluation of scaling. All of the job materials have provided excellent service. The nominal proportions were as shown in Table V. The important characteristics of the individual batches are given subsequently with the test results.

TABLE V

NOMINAL CONCRETE CHARACTERISTICS

Property	Value
Cement Factor, sacks/cy	7
Air Content, percent	6-1/2 ± 1
Slump, inches	2-1/2 ± 1/2
Intended Strength, f'_c, psi	4000

Cement — Type II

Fine Aggregate — Natural Siliceous Sand: Specific Gravity 2.60; F.M. 2.83.

Coarse Aggregate — Crushed Granite Gneiss: Specific Gravity 2.83; artificially graded as follows:

- 1 + 3/4	20%
- 3/4 + 1/2	37%
- 1/2 + 3/8	33%
- 3/8 + #4	10%

PROCEDURES

Accelerated Freezing and Thawing Tests

Five replicate beams 3" x 4" x 16" were used to represent each of the 14 combinations previously shown in Table II. The 70 beams and 50 strength cylinders described later were taken randomly from 12 batches made on a schedule dictated by space available in the freezing equipment. The important characteristics of each batch are shown in Table VI.

TABLE VI

CONCRETE CHARACTERISTICS — ACCELERATED LABORATORY SPECIMENS

Batch	Cement Content, sks/cy	Slump, inches	Air Content, percent	W/C Ratio
1*	6.55	2.4	6.7	.37*
2	6.62	2.4	5.6	.42
3*	6.56	2.1	6.2	.56*
4	6.55	2.3	5.4	.46
5	6.93	2.6	6.0	.45
6	6.89	2.8	5.9	.46
7	6.93	2.3	5.9	.47
8	6.93	2.8	5.7	.47
9	6.86	2.8	6.0	.46
10	6.86	3.0	6.3	.47
11	6.86	2.9	6.5	.47
12	6.89	2.9	6.0	.47

*Note: The mixes were controlled to give a slump of 2-1/2 ± 1/2" and an air content of 6.5 ± 1%. Subsequent analyses disclosed the discrepancies indicated. Data for specimens from these batches were not used in the evaluation.

The beams were cast in lightly oiled steel molds. The top surface was struck off in such a way as to eliminate the need for further surface manipulation. Curing materials were applied to the finished surface when the "sheen" disappeared. For conditions 5, 6, and 7, the monomolecular film was applied in a single spray application immediately following the final floating. This delayed the disappearance of the sheen by about one hour beyond that for specimens on which it was not used. Liquid curing materials were applied with a soft bristle brush at a rate of 200 sf/gal.

The beams were removed from the molds after 24 hours and the appropriate curing material applied to the sides, bottoms and ends. The specimens were stored in the laboratory at 73° ± 3° F and 55% ± 5% relative humidity for 14 days. On the 14th day the linseed oil treatments were begun with two applications separated by one day at conventional rates (0.025 gals/sy and 0.015 gals/sy) to specimens representing conditions 3, 4, 5, and 6. As noted previously, no effort was made to remove the membrane curing compound. At the same time the polyethylene coverings were removed from beams representing condition 2. Storage in laboratory air continued to an age of 21 days, at which time all specimens were placed in the freezer and cycled in accordance with

ASTM C 290 except that the surrounding media was a 2% NaCl solution rather than water. The beams were periodically observed for changes in sonic modulus, weight, and surface appearance. Evaluation of the changes in surface appearance was based on the rating system shown in Table VII.

TABLE VII

RATING SYSTEM USED FOR EVALUATION

Condition	Surface Appearance
0	No scaling
1	Very slight scaling (1/8" maximum depth — no coarse aggregate visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

Examples of conditions are shown in Figure 1. Since the degree of deterioration of a given specimen varied, a weighted rating was used such that a surface showing 30% condition 5, 35% condition 3, 20% condition 1, and 15% scale free surface would be rated (.30 x 5 + .35 x 3 + .20 .1 + 15.0) = 2.75. The tops, which were struck off, were rated separately from the sides and bottoms, which were cast against the steel forms.

Curing Efficiency

In addition to the accelerated freezing and thawing specimens, cylinders were cast from randomly selected batches for compressive strength testing at 7 and 28 days. These were treated according to the same schedule as the beams and stored in laboratory air at $73^{o} \pm 3^{o}$ F and 55 ± 5% relative humidity. The intent was to evaluate the influence of the curing condition on strength as an indicator of curing efficiency. Strength specimens were not cast for conditions 5, 6, and 7, in which the monomolecular film was the essential variable.

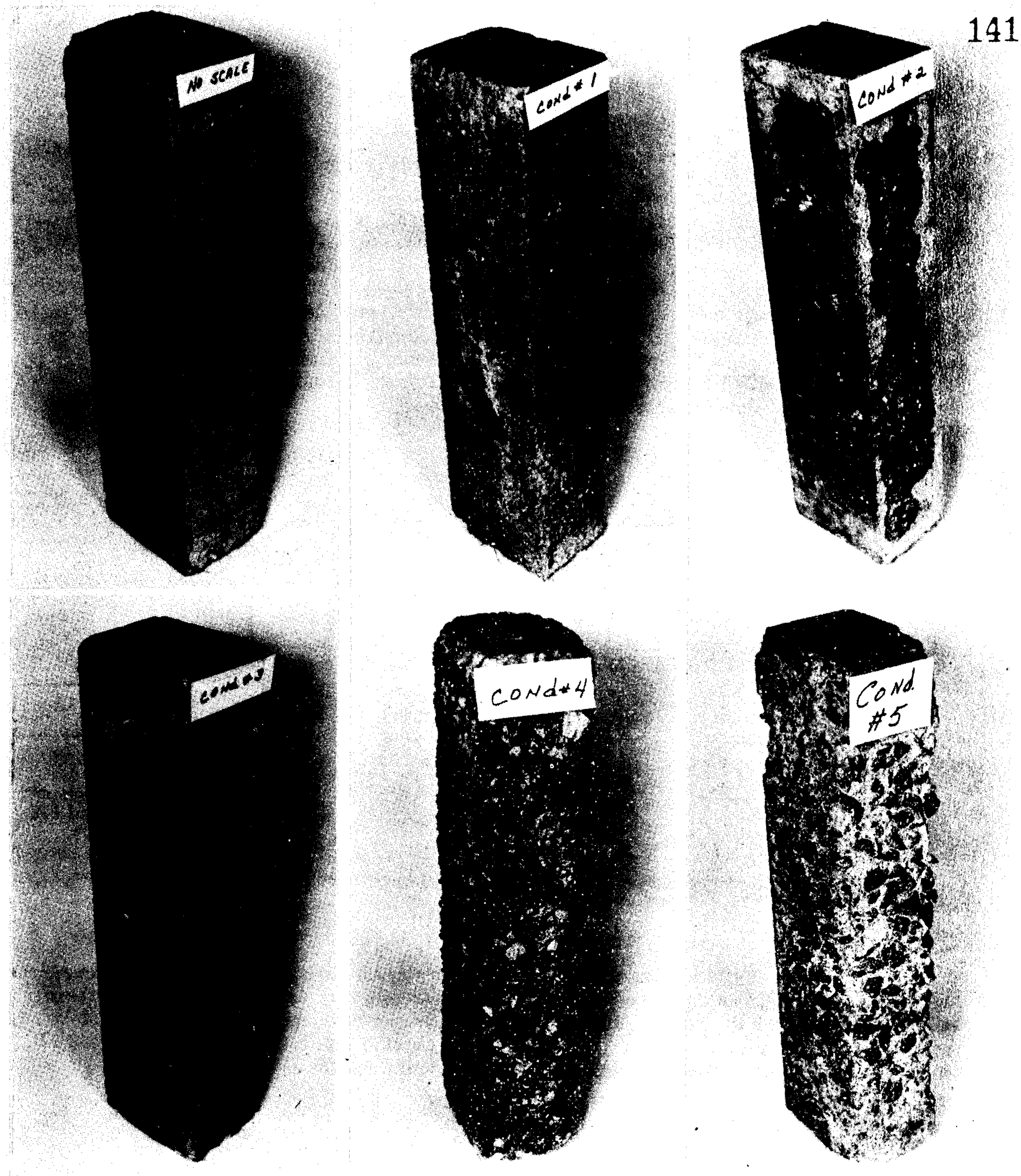

Figure 1. Examples of conditions described in Table VII.

Outdoor Scaling Slabs

Twelve slabs each 2' x 2' x 4" were cast in the laboratory for exposure to deicing tests in an outdoor area. The surface of each slab was divided into four quadrants, each of which received a different treatment. One-quarter of each block thus represented a given curing — treatment condition. Six of the slabs were made of air entrained concrete and six were made of non-air entrained concrete. Air entrained concrete was used because it represented the normal condition. The non-air entrained concrete was used to accelerate the anticipated deterioration. The distribution of the various curing and/or treatment conditions is shown schematically in Figure 2. In order to estimate variability from slab to slab the white pigmented membrane seal (LMS) followed by linseed oil (LOT) was included on each slab and several randomly selected materials were replicated.

5	3
6	4

Slab 1 N and 1 A

3	12
9	10

Slab 2 N and 2 A

5_R	1
7	3

Slab 3 N and 3 A

13	10_R
0	3

Slab 4 N and 4 A

0_R	3
2	8_R

Slab 5 N and 5 A

11	12_R
3	8

Slab 6 N and 6 A

Figure 2. Distribution of curing — treatment conditions on the outdoor scaling blocks.

During fabrication of the slabs in the laboratory, oscillating electric fans were used at the lowest speed to create a gentle movement of air (less than 5 mph) over their surfaces. This was intended to simulate actual construction conditions. This air movement was continued for 24 hours. Concrete for each slab was taken from a separate batch. The important characteristics of each batch are shown in Table VIII.

TABLE VIII

CONCRETE CHARACTERISTICS OF OUTDOOR SCALING SPECIMENS

Batch	Slab	Cement Content, sacks/c.y.	Slump, inches	Air Content, percent	W/C Ratio (by weight)
1	1N	6.74	2.3	1.5	.43
2	2N	6.74	3.0	1.6	.43
3	3N	6.67	2.3	1.7	.44
4	4N	6.67	2.4	1.6	.43
5	5N	6.67	3.0	1.7	.43
6	6N	6.62	3.0	1.5	.45
7	1A	6.67	2.2	6.0	.39
8	2A	6.59	2.7	6.3	.41
9	5A	6.59	2.2	5.9	.42
10	4A	6.67	2.7	6.5	.40
11	3A	6.67	2.4	5.9	.40
12	6A	6.67	2.4	6.1	.40

The concrete was placed in wooden forms and screeded with a metal faced screed. This was followed by minimal wood floating. After the surface was finished, polyvinyl chloride waterstops were inserted to form a dike to hold water during deicing exposure. Liquid curing materials were applied by brushing at a rate of 200 sf./gal. and in all other respects the curing and/or treatment sequence was like that described for the laboratory specimens. The air entrained and non-air entrained specimens were made on separate days. The curing materials were applied when the sheen disappeared. The application times are given in Table IX. It will be seen that the variations in times of application were comparatively small. The slabs, elevated to simulate bridge deck exposures, were placed in the outdoor exposure area adjacent to USWB Station 1-W at an age of one month. The initial freeze occurred when the concrete was 60 days old and had been in the ou door exposure area for 30 days. Eight specimens are shown in Figure 3.

TABLE IX

TIME OF APPLICATION OF CURING MATERIAL BASED UPON TIME OF ADDITION OF WATER
(Average Values Given for Multiple Occurrences)

Condition	Number of Occurrences	Non-Air Entrained Blocks (hours:minutes)	Air Entrained Blocks (hours:minutes)	Difference (minutes)
0	2	-	-	-
1 (LMS)	1	3:05	3:40	+35
2 (WPS)	1	3:10	2:55	-15
3 (LMS + LOT)	6	3:03	3:00	-03
4 (WPS + LOT)	1	3:15	3:00	-15
5 (MEF)	2	0:50	0:50	0
5 (LMS + LOT)	2	3:17	3:27	+10
6 (MEF)	1	1:05	1:00	+05
6 (WPS + LOT)	1	3:15	3:40	+25
7 (MEF)	1	0:35	0:40	+05
7 (LMS)	1	3:30	3:40	+10
8 (CRS_1)	2	3:05	2:50	-15
9 (CRS_2)	1	3:20	3:00	-20
10 (CRS_2)	2	3:17	2:57	-20
11 (CRS_3)	1	3:00	2:45	-15
12 (CRS_3)	2	3:07	2:57	-10
13 (CRS_4)	1	3:15	2:45	-30

Figure 3. Slabs in outdoor exposure area.

The deicing procedure used was as follows:

1. Cover slab with approximately 300 ml/sf of water.

2. Following freeze, distribute NaCl in an amount to give 2% by weight of water in (1).

3. Allow the salt-water solution to freeze and thaw one time.

4. Rinse surface and repeat.

Note: NaCl was used rather than $CaCl_2$ or a mixture so as to increase the number of freezes, some of which would be prevented in the $CaCl_2$-water system.

Freezing and/or thawing was judged by daily visual observation rather than according to temperature and in some cases the ice remained on the surface for several days.

Evaluation procedures and the rating scale were the same as those described for the laboratory specimens.

RESULTS

Freezing and Thawing

Accelerated laboratory freezing and thawing tests were continued for 300 cycles. During exposure through two winters, the specimens in the outdoor exposure have been exposed to 48 cycles as defined earlier. Thirty-seven freezes lasted longer than 24 hours, 35 longer than 48 hours, and the longest period of continuous ice coverage was 8 days. Detailed information on the freezing and thawing cycles is given in Table X.

TABLE X

CHARACTERISTICS OF FREEZING AND THAWING EXPOSURE

Period	Cycles*	Cycles Longer Than 24 hours	Longest Continuous Freeze, Days
Nov. 68	3	3	4
Dec. 68	5	3	6
Jan. 69	5	4	7
Feb. 69	6	6	5
March 69	4	2	2
Total 1st Winter	23	18	-
Nov. 69	4	3	7
Dec. 69	5	4	8
Jan. 70	6	4	6
Feb. 70	6	6	4
March 70	4	2	3
Total 2nd Winter	25	19	-
TOTAL TWO WINTERS	48	37	-

*For cycle definitions, see page 13. Actual freezing and thawing would be approximately double this figure (half with salt, half without).

For each condition exposed to the accelerated freezing and thawing, the weight losses of the individual specimens which were nearest to the averages of all specimens within a given condition are shown as Figures 4 and 5 to indicate the general nature of the progressive deterioration. From these curves it will be seen that the effect of the polyethylene curing and the linseed oil treatments was to delay the onset of significant weight loss. As would be expected the beam with no curing showed the most rapid weight loss. It is also apparent that all of the beams cured with chlorinated rubber lost considerable weight at approximately the same rate. The curves for chlorinated rubber are close to those for beams cured with the membrane but without linseed oil treatment. Similar curves are given in Figures 6 and 7 for the degree of scaling as observed on the top (finished) surface. There is general agreement between weight loss data and those for the scaling ratings. Throughout the testing the conditions of the sides (cast against steel forms) were rated separately from those of the top surfaces (formed with minimal manipulation). It was observed that scaling usually began on the sides before it occurred on the tops, but by the age of 100 cycles there was no consistent difference. Results for the scaling ratings of the sides of beams were in agreement with those for the tops and are therefore not presented. The durability factors computed from sonic tests (ASTM C 215) were all high, which indicated the absence of internal cracking and deterioration. These factors are not presented either. The average weight changes and scale ratings for all beams at 100 and 300 cycles are shown in Figures 8 and 9.

The average values and coefficients of variation for the accelerated laboratory tests are shown in Table XI. As is common with durability testing of this type the coefficients of variation are large. For comparable conditions, these coefficients are, however, all of the same order, and considering that they represent specimens from different batches of concrete, they are consistent with others reported (HRB — 1959). The largest variations occur for the least affected specimens. The lowest variations are for the severely scaled specimens which consistently showed poor performance.

The scaling ratings for the outdoor slabs after one and two winters of exposure are shown in Figure 10.

While the data from the laboratory and outdoor exposure were obtained, analyzed and are presented quantitatively, a qualitative consideration is sufficient to reflect the differences attributable to the curing and/or protective materials. For this purpose, criteria which separate the conditions into two distinct groupings were shown on Figures 8-10. Performance was indicated as acceptable depending upon whether a material performed better or worse than the arbitrarily established values. Study of the results in Figures 4 to 10 will show that specimens representing conditions 2, 3, 4, 5 and 6 performed significantly better than did those representing the remaining conditions. Specimens for conditions 3, 4, 5, and 6 received linseed oil treatments. These treatments were particularly effective during the early exposure as evidenced by the results after 100 cycles of laboratory testing or one winter in the outdoor scaling tests. The increase in scaling with continuing exposure suggests that the protection is temporary and points up the desirability of at least one fairly early retreatment. In all testing the several chlorinated rubber compounds performed poorly when compared with various curing methods followed by a treatment with linseed oil.

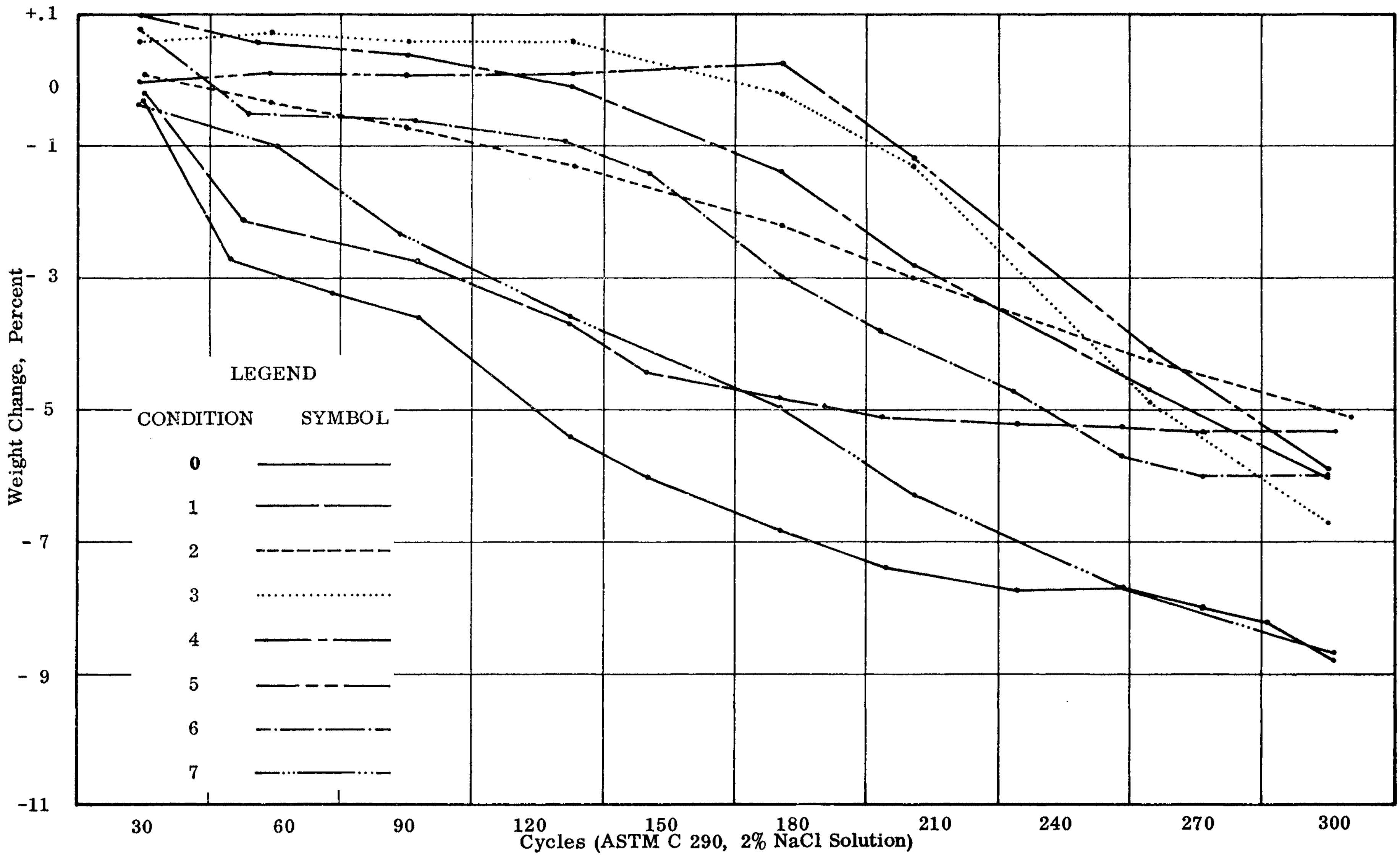

Figure 4. Weight change of the beam specimens nearest the average for all specimens. Conditions 0 through 7 (all materials other than CRS).

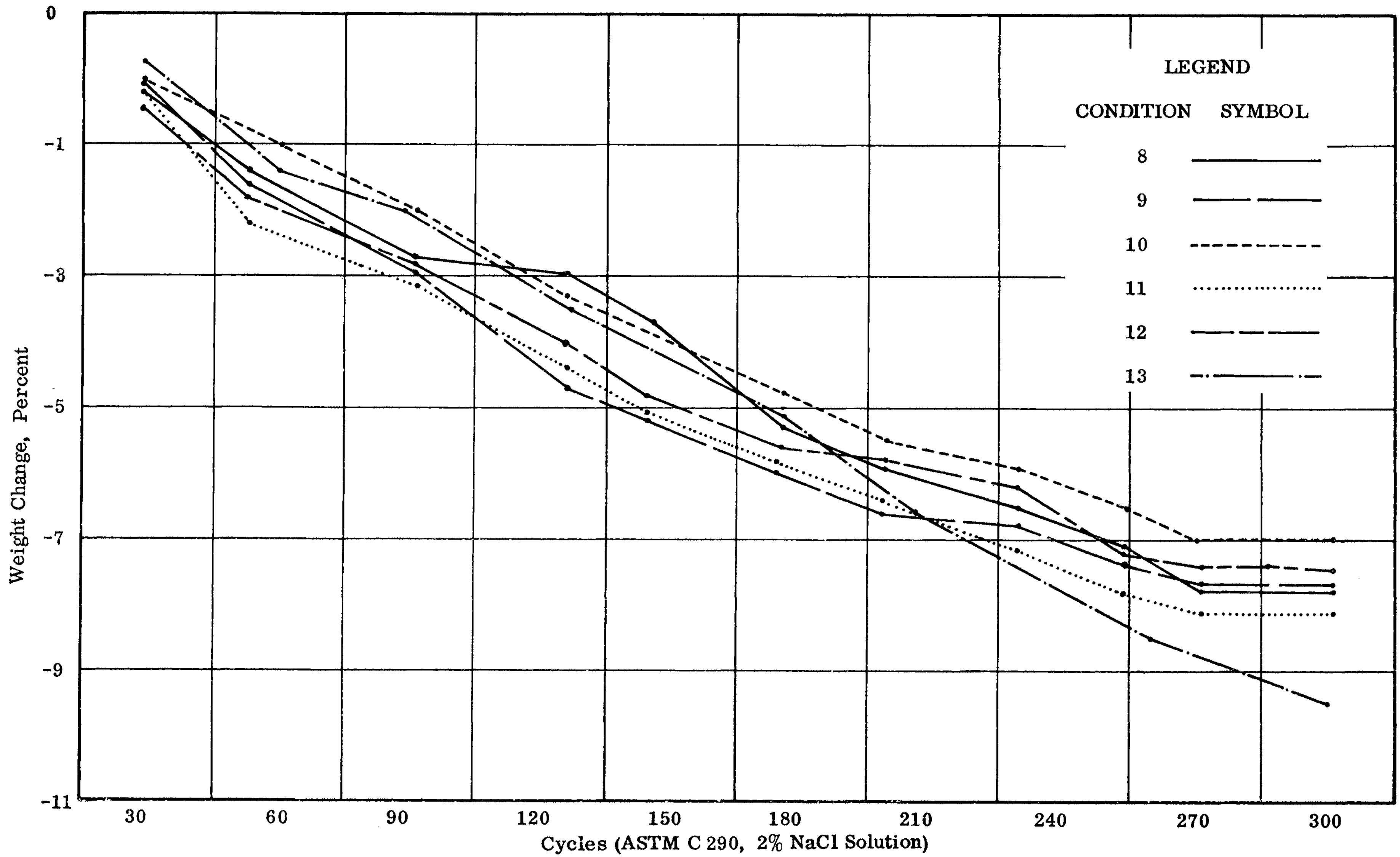

Figure 5. Weight changes of the beam specimens nearest the average for all specimens. Conditions 8 through 13 (CRS materials).

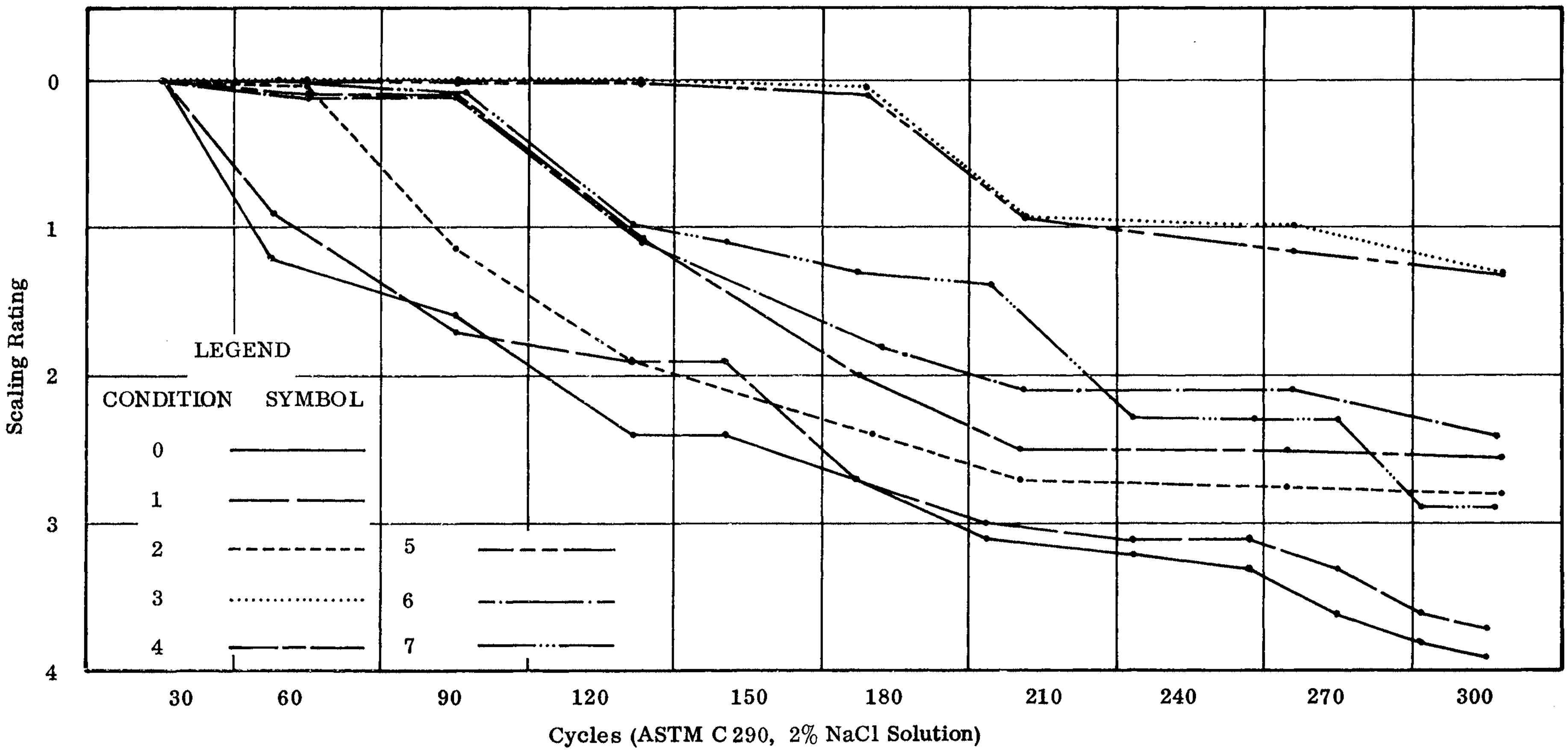

Figure 6. Scaling ratings for tops of beam specimens. Conditions 0 through 7 (all materials other than CRS).

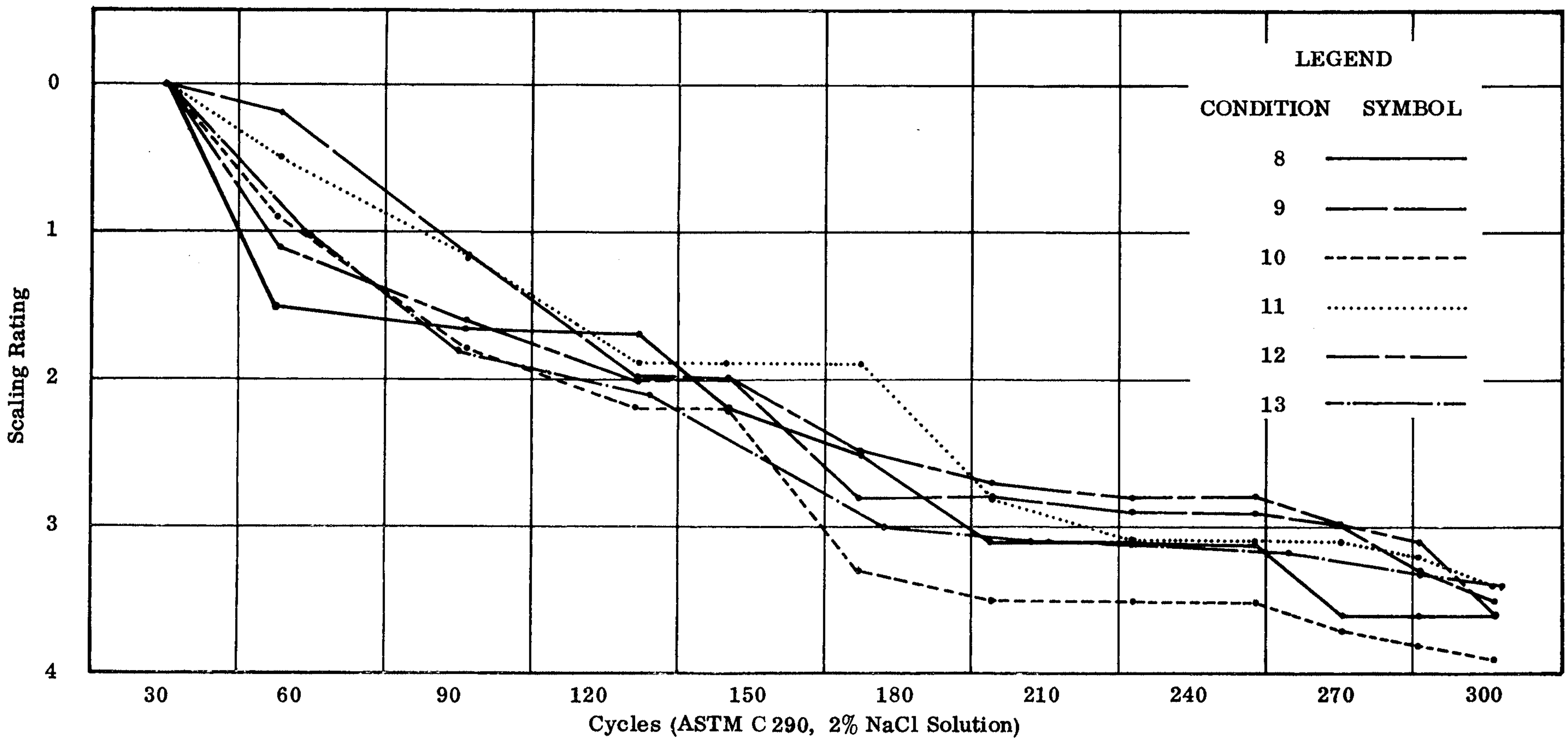

Figure 7. Scaling ratings for tops of beam specimens. Conditions 8 through 13 (CRS materials).

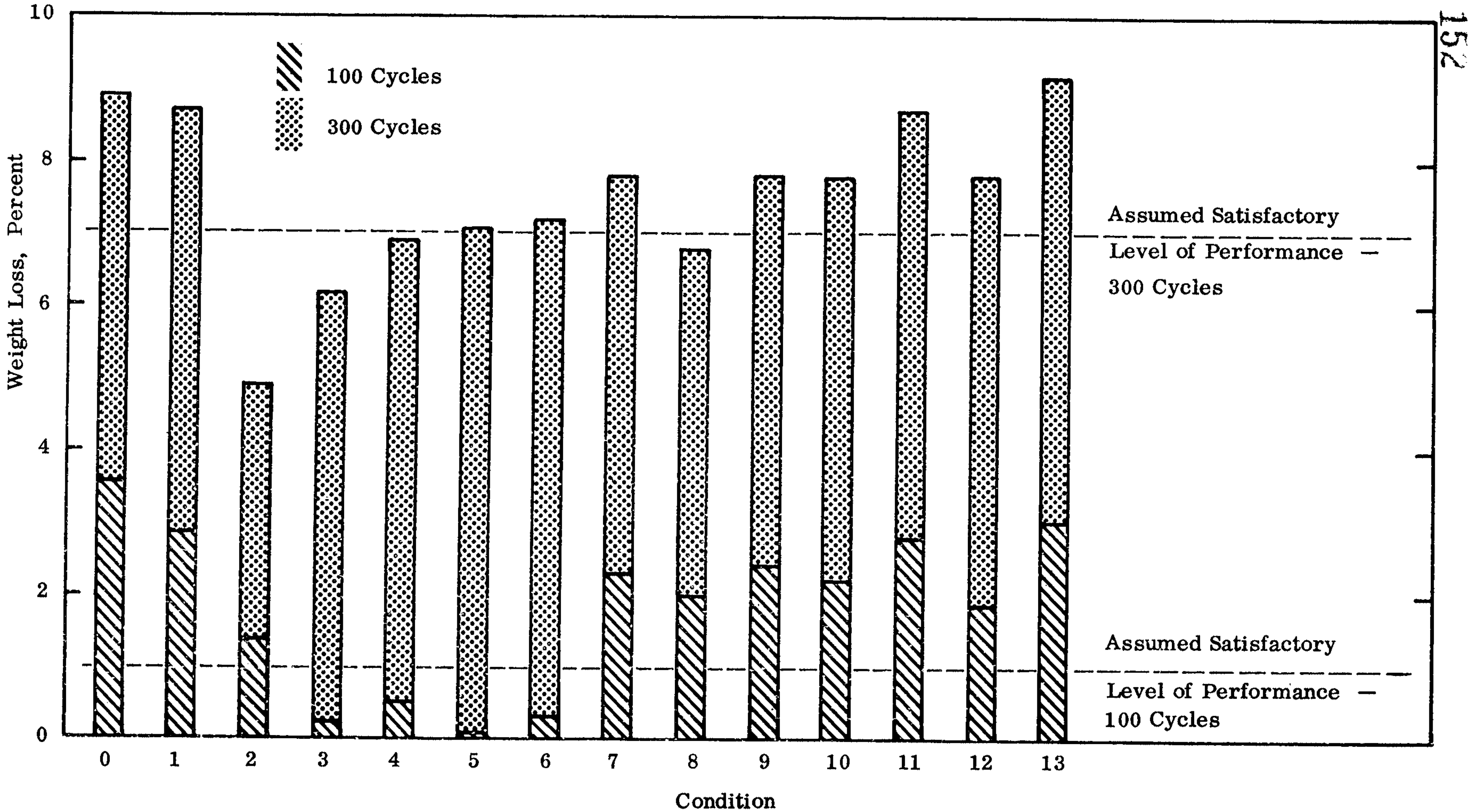

Figure 8. Average weight losses of beam specimens exposed to accelerated freezing and thawing (ASTM C 290, 2% NaCl solution).

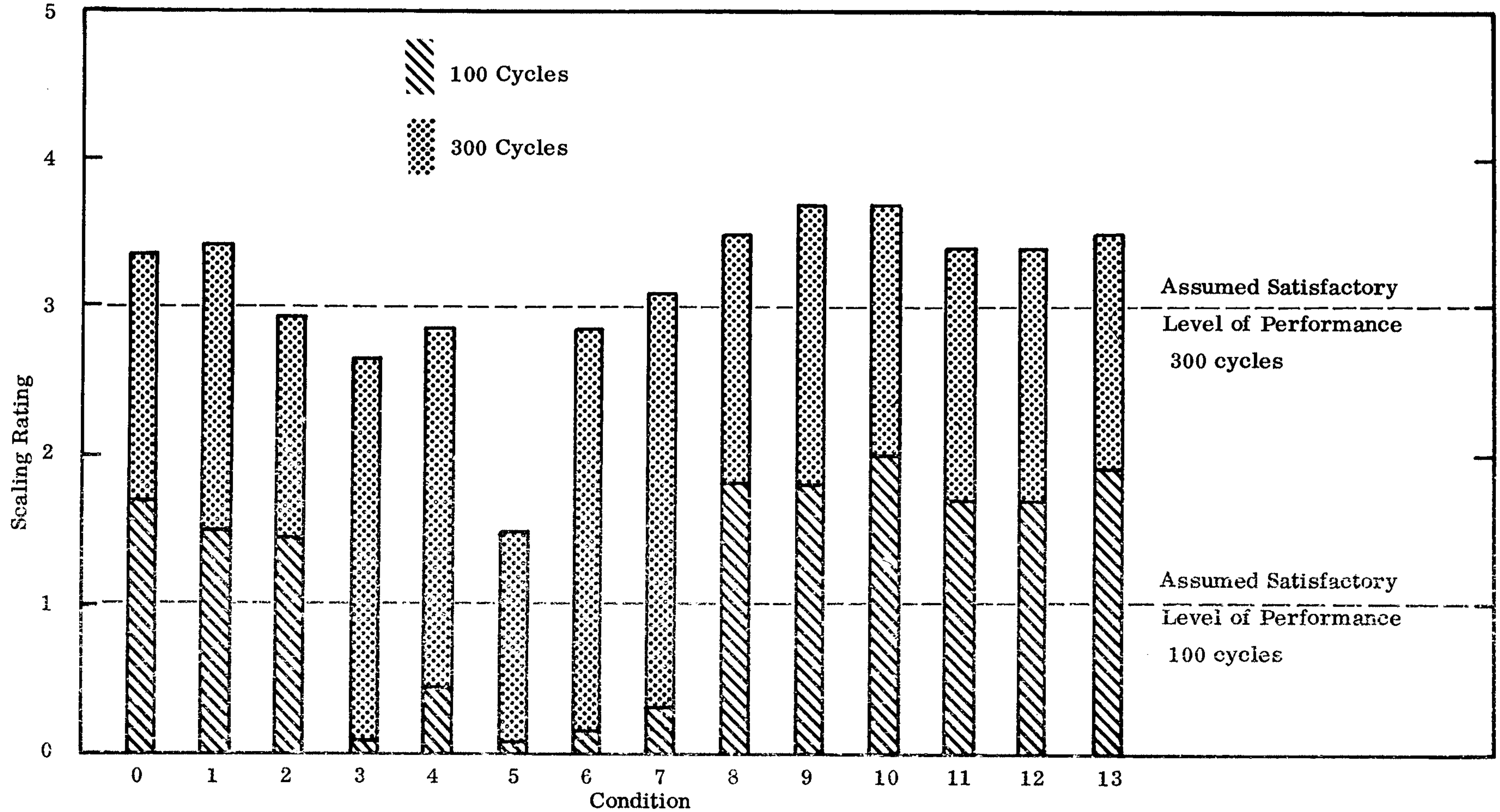

Figure 9. Average scaling ratings of top surfaces of beams in Figure 8.

TABLE XI

AVERAGES ($\overline{X}$) AND COEFFICIENTS OF VARIATION (V) FOR DATA FROM ACCELERATED FREEZING AND THAWING TESTS

Condition		Weight Loss, percent		Scaling Rating of Top Surfaces	
		100 cycles	300 cycles	100 cycles	300 cycles
0	$\overline{X}$	3.6	8.9	1.7	3.4
	V	21.0	12.0	57.0	3.0
1	$\overline{X}$	2.8	8.7	1.5	3.4
	V	29.0	14.0	27.0	6.0
2	$\overline{X}$	1.4	4.9	1.5	2.9
	V	93.0	16.0	20.0	21.0
3	$\overline{X}$	0.2	6.1	0.1	1.6
	V	330.0	37.0	76.0	162.0
4	$\overline{X}$	0.5	6.9	0.4	2.9
	V	195.0	13.0	119.0	22.0
5	$\overline{X}$	0.0	7.0	0.0	1.5
	V	183.0	18.0	20.0	36.0
6	$\overline{X}$	0.3	7.2	1.7	2.8
	V	165.0	14.0	6.9	18.0
7	$\overline{X}$	2.8	7.8	0.3	2.7
	V	28.0	17.0	33.0	14.0
8	$\overline{X}$	2.9	7.4	1.8	3.5
	V	19.0	26.0	13.0	7.0
9	$\overline{X}$	2.7	7.8	1.8	3.7
	V	24.0	18.0	37.0	4.0
10	$\overline{X}$	2.8	8.3	2.0	3.7
	V	16.0	14.0	8.0	7.0
11	$\overline{X}$	3.2	8.7	1.7	3.4
	V	17.0	31.0	21.0	11.0
12	$\overline{X}$	1.9	7.8	1.7	3.4
	V	53.0	19.0	15.0	10.0
13	$\overline{X}$	3.2	9.2	1.9	3.5
	V	16.0	17.0	3.0	7.0

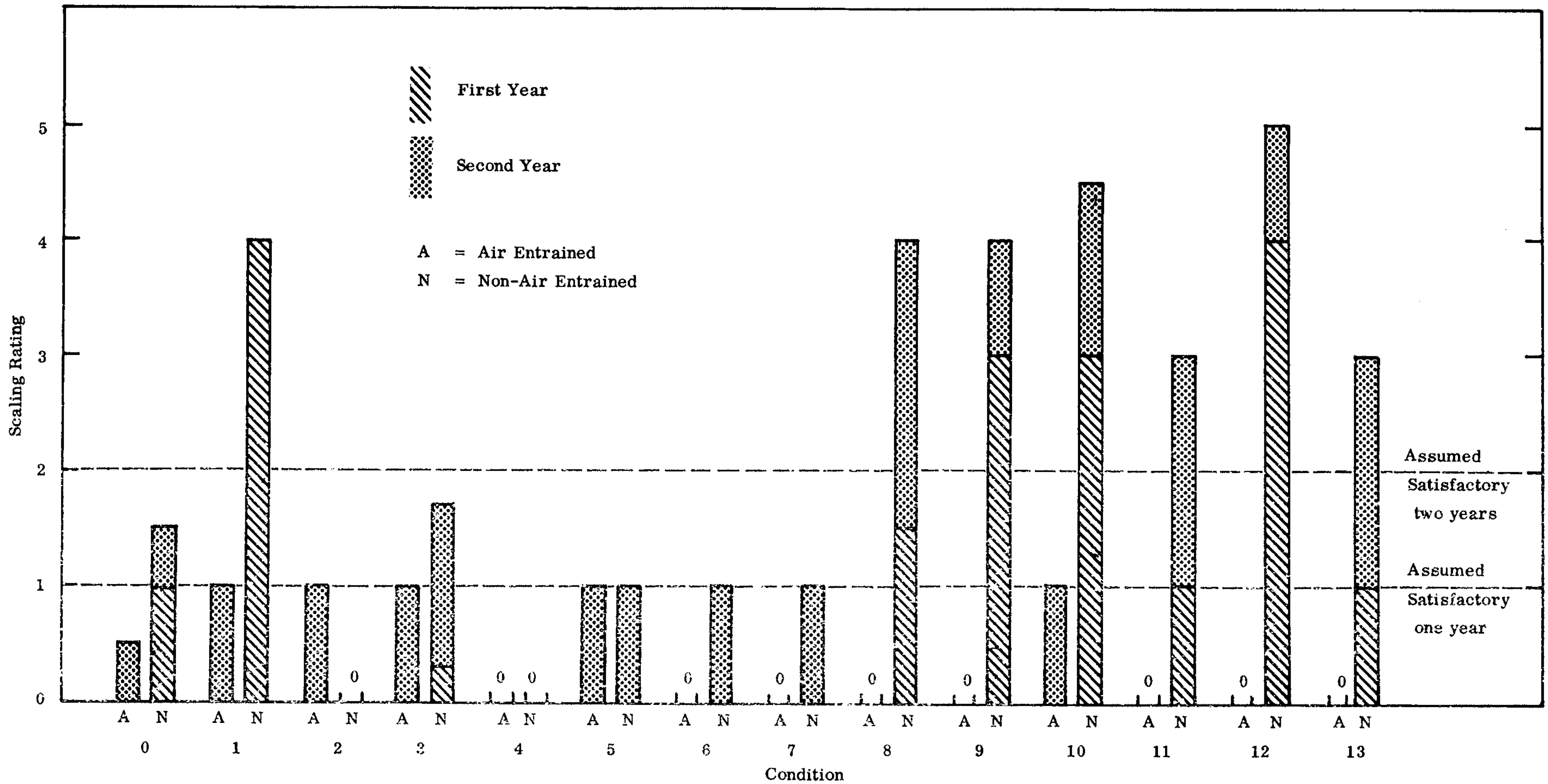

Figure 10. Scaling ratings of slabs in outdoor exposure. Average values are given for multiple occurrences of a test condition.

A qualitative estimate of the comparative performances of the various combinations can be obtained by considering the scaling and weight loss data arranged according to performance from worst to best as is done in Table XII. Not including the air entrained blocks exposed to outdoor scaling, all of which performed well, each material had six opportunities to meet the arbitrary criteria indicated on previous figures and in Table XII. The numbers of times each combination showed performance equal to or better than the satisfactory level are shown in Table XIII.

TABLE XII

RELATIVE RANKING OF CONDITIONS (MATERIALS)
(Performance Improves from Top to Bottom)

Concrete	Air Entrained						Non-Air Entrained	
Test Procedure	Accelerated Freezing & Thawing		Accelerated Scaling Top		Outdoor Scaling		Outdoor Scaling	
Exposure Time	100	300	100	300	1 Winter	2 Winters	1 Winter	2 Wint
Worst	0	13	10	9,10	No		1,12	12
	13	0	13	8.13	Scaling	10,5,3,2,1	9,10	10
	1	8	8,9	1	on	0	8	8,9,10
	11	11	0,11,12	11,12	any	13,12,11,9*	0,11,13	11,13
	9	1	1	0	Specimens	8,7,6,4	3	3
	7	7,9,10, 12	2	7			2,4,5,6,7*	0
	10	6	4	2				5,6,7
	8	5	7	4				2,4*
	12	4	6	6				
	2	8	3	3				
	4	3	5	5				
	6	2						
	3							
Best	5							

*No Scaling

———— Lines indicate criteria arbitrarily assumed as level of satisfactory performance shown in Figures 8, 9, and 10.

TABLE XIII

RELATIVE PERFORMANCE OF MATERIALS WITH RESPECT TO CRITERIA ESTABLISHED AS SATISFACTORY

Condition Designation	Performance Better than Established Criteria	
	Number	Percentage
0	1	17
1	0	0
2	4	67
3	6	100
4	6	100
5	5	83
6	5	83
7	3	50
8	1	17
9	0	0
10	0	0
11	1	17
12	0	0
13	1	17

Only the concrete cured with polyethylene (WPS) or membrane (LMS) and subsequently treated with linseed oil (LOT) met the established limits in all cases. The same combination preceded by application of the monomolecular film also performed well. Of special interest is the uniformly poor performance of the chlorinated rubber materials (Designations 8-13) and that of the membrane (LMS) without subsequent linseed oil treatment. This latter finding confirms earlier studies of the Council which indicated beneficial effects for concrete cured with membrane and subsequently treated with linseed oil without prior removal of the membrane; a finding contrary to widely accepted ideas. These earlier studies are included in a summary of the unpublished work in Appendix A.

Several other observations can be made from the data developed thus far. Comparison of the outdoor specimens containing entrained air with those not containing air shows that air entrainment is the overwhelming factor with regard to satisfactory scale resistance, as is well known. Even the linseed oil treatment is seen only to delay rather than to eliminate scaling. Another interesting fact is the improvement in performance, particularly at early ages, generally associated with the use of the monomolecular film. This was not expected; however, it is consistent with one mechanism of scaling suggested by Cordon (1966), who postulates that a surface compacted either by finishing or by rapid sedimentation can cause scaling as a result of continued bleeding below the surface which results in a plane of separation. It will be remembered that during the fabrication of the outdoor specimens a gentle breeze which would accentuate drying was used. This was not the case with the beams used in the accelerated laboratory tests. It will be noted that the improvement resulting from the use of the monomolecular film was not as evident in these beams although there was a slight improvement.

It was noted during inspections of the scaling blocks that the membrane curing compound (LMS) had degraded as required by the VDH specifications and was not apparent after the initial winter. Where the monomolecular film was used, however, the LMS did not degrade and was still evident even after two winters. The significance of this is not known but it does suggest some modification or alteration of the curing compound or the surface from use of the monomolecular film.

In the outdoor exposure, all of the non-air entrained specimens treated with chlorinated rubber scaled severely during the first winter's exposure while those treated with linseed oil, regardless of the early curing (that is membrane or polyethylene), still have not shown significant scaling after the second winter. Inclusion of a quadrant containing condition 3 (LMS + LOT) on each of the 12 outdoor blocks offers considerable assurance as to the consistency of the test results.

After one winter, only two of the six non-air entrained specimens were free from scaling and the remaining four showed scaling in varying degrees. After two winters, all of the non-air entrained blocks showed scaling, but none of the air entrained blocks were affected by more than slight scaling. While quantitative results are indicative, better appreciation of the differences in performance can be gained from pictures of the various specimens. Figure 11 shows four beams from the accelerated laboratory tests after 12 cycles of freezing and thawing; these beams are representative of the appearance of various beams at the beginning of testing. Figures 12 and 13 show beams representing several materials (conditions) after 187 cycles of freezing and thawing.

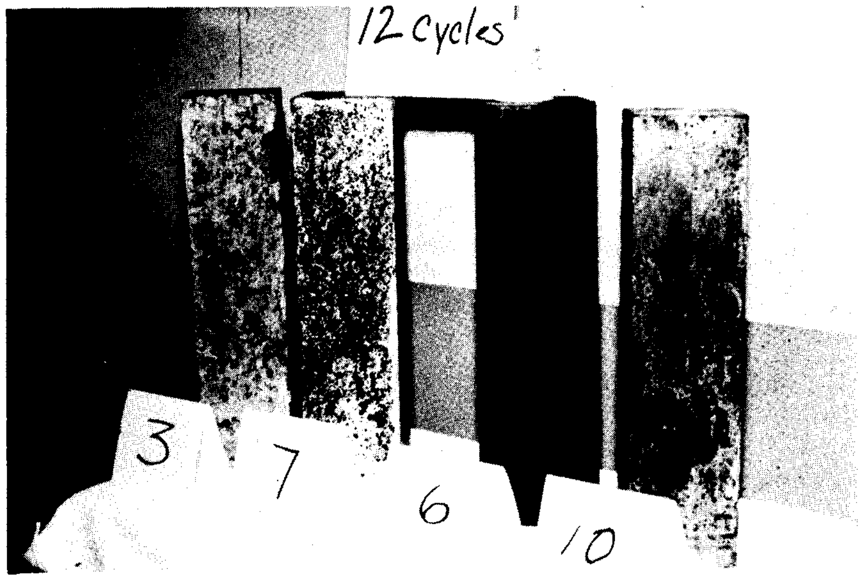

Figure 11. Beams from accelerated freezing and thawing tests. Number of cycles and treatment conditions as indicated.

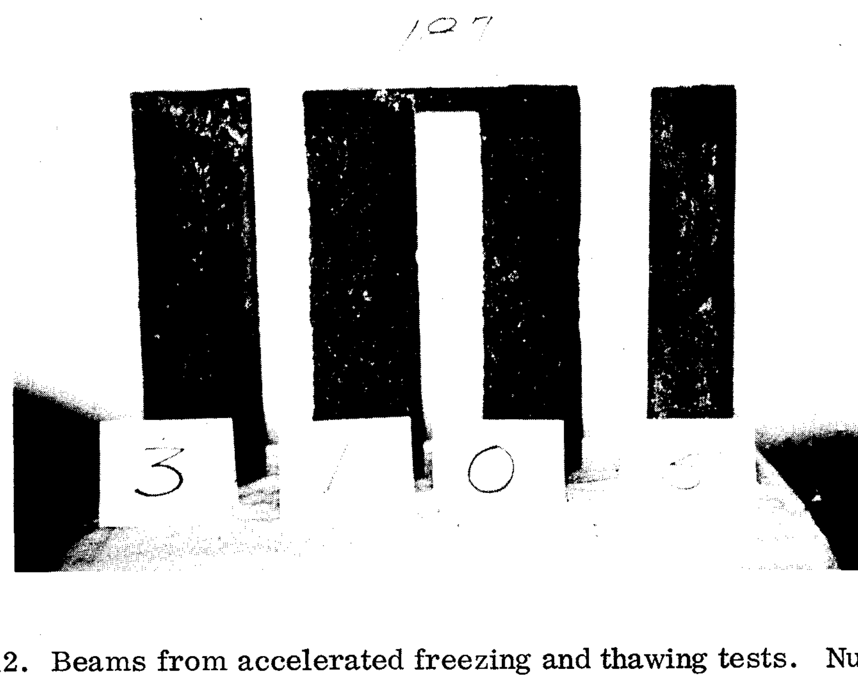

Figure 12. Beams from accelerated freezing and thawing tests. Number of cycles and treatment conditions as indicated.

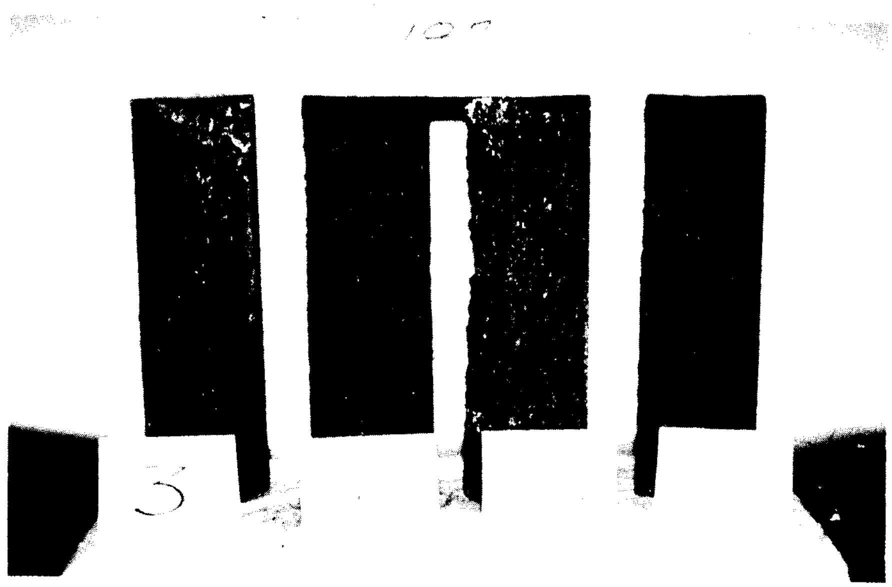

Figure 13. Beams from accelerated freezing and thawing tests. Number of cycles and treatment conditions as indicated.

Figures 14 - 17 show views of selected scaling blocks comparing some of the various conditions. Figures 14 and 15 illustrate the uniformly poor performance of the chlorinated rubber materials. Figure 17 illustrates the beneficial effect of the monomolecular film. A comparison of Figures 15 and 16 vividly shows the beneficial influence of air entrained concrete for the same materials. It is of interest to note that for the air entrained specimens which have been exposed to precisely the same environment as the non-air entrained specimens, most of the protective materials are still intact after two winters. It is also of interest to note that the test method, in which the materials are compared side by side on the same block, has proved quite satisfactory. Very definite delineations in the performance occur at the junction between different materials. The retention of curing compound by the surfaces treated with the monomolecular film is also evident in Figure 17.

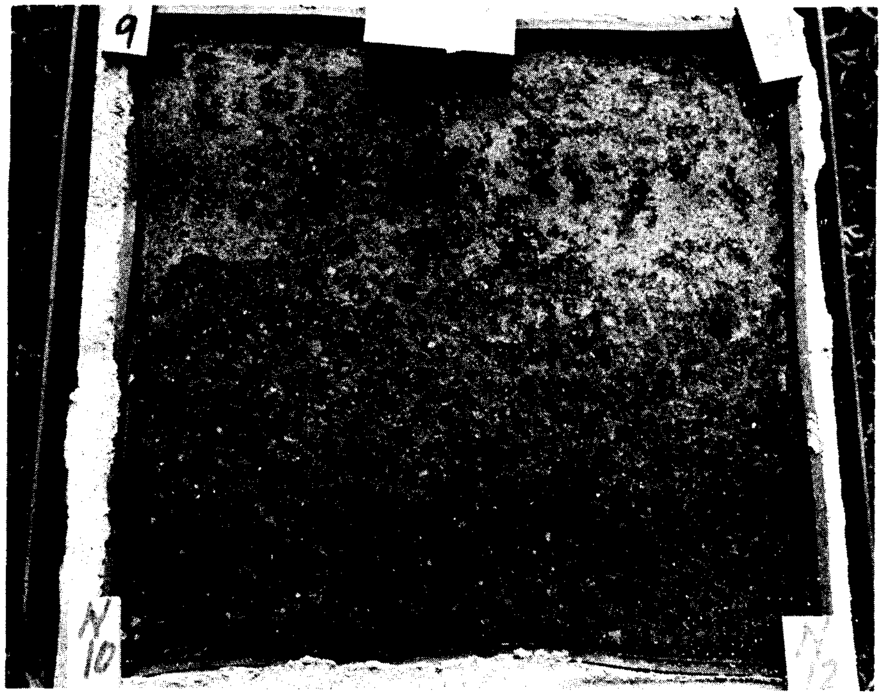

Figure 14. View of Slab 2 N after two winters' exposure (46 cycles) showing scaling of non-air entrained concrete, which is most severe with curing by chlorinated rubbers.

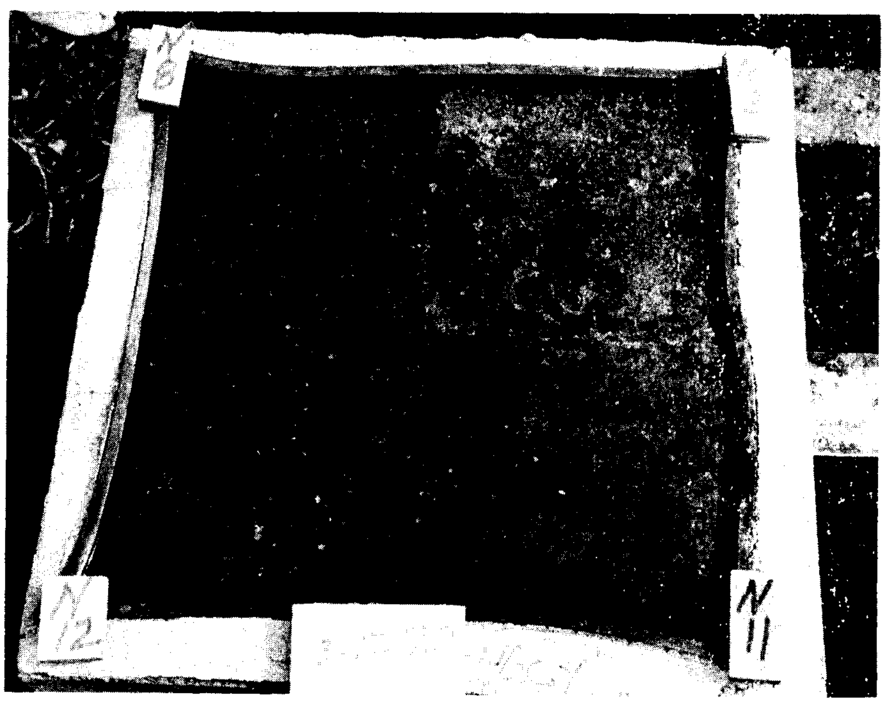

Figure 15. View of Slab 6 N after two winters' exposure (46 cycles) showing scaling of non-air entrained concrete, which is most severe with curing by chlorinated rubbers.

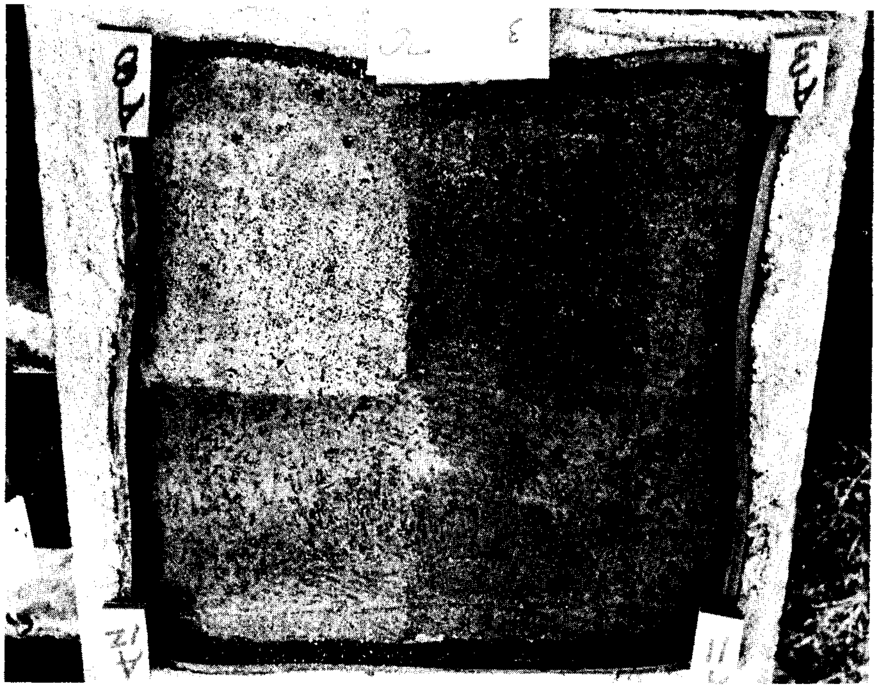

Figure 16. View of Slab 6 A after two winters' exposure (46 cycles). Photo inverted to give same orientation as Figure 15. Note absence of scaling on air entrained slab and presence of curing and/or protective materials.

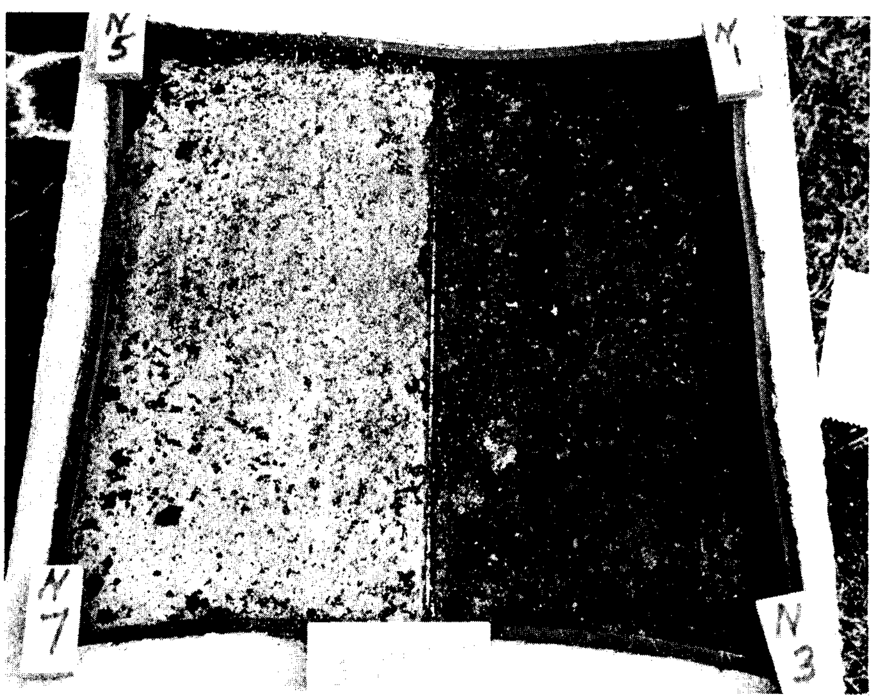

Figure 17. View of Slab 3 N after two winters' exposure (46 cycles). Note influence of monomolecular film (left side).

Curing Efficiency

The curing properties of the various products were evaluated on the basis of compressive strength. Strength tests were run at 7 and 28 days on cylinders randomly selected from the same batches of concrete as those used to fabricate the accelerated laboratory beams. The strength of the cylinders cured by various means was compared with that of moist cured cylinders. The relative strength results are shown in Table XIV.

TABLE XIV

CURING EFFICIENCY AS MEASURED BY COMPRESSIVE STRENGTH

Code	Relative Compressive Strength, percent	
	7 Days	28 Days
Moist	100 (3905 psi)	100 (5173 psi)
0	71	71
1	76	81
2*	94	95
3	80	74
4*	87	100
8	78	84
9	79	79
10	77	76
11	80	77
12	83	77
13	81	70

*Coverings, non-sprayed.

From these results it will be seen that the curing efficiencies of the sprayed on materials are all of the same order, ranging from 70% - 75%, and are low when compared with those of the coverings or moist curing. Further, there is no indication that the linseed oil affords any additional curing between its application at 14 days and the testing at 28 days. Thus, the slightly reduced scale resistance shown earlier in Figure 9 for conditions 2 and 4 as compared with condition 1 is very likely the result of differences in moisture contents. The poor performance of the chlorinated rubbers cannot be explained entirely in terms of a higher initial moisture content, but apparently relates to some influence on mobility of the salt solution during freezing and thawing.

The results in Table XIV are in excellent agreement with those presented by Stewart and Shaffer (1969), who reported an average efficiency of 76 percent for similar materials and 66 percent for uncured specimens.

Skid Resistance

Prior to placement of the 12 slabs in the outdoor exposure area, skid resistance values were determined for each quadrant using the British Portable Tester. An analysis of the data showed that there were no significant differences among similar surfaces from slab to slab nor were there differences related to either the direction of finishing or the presence or absence of air entrainment. There were, however, substantial differences related to the curing material. These are shown in Table XV in terms of the British Portable Tester number prediction of the value likely to be obtained by the stopping distance method at 40 mph based on the correlation presented by Dillard and Mahone (1963). The surfaces are ranked from best to poorest on the basis of the predicted coefficients. Note that these tests were made before the application of the linseed oil treatments so that conditions 5 and 7, 2 and 4, and 3 and 1 were the same. It will be seen that the surfaces cured by covering (WPS) and without subsequent coatings are highest and also that all of the chlorinated rubber materials (conditions 8 - 13) showed poor skid resistance. Detailed examinations of the surfaces suggest that in addition to the influence of the coating material some of the results were likely to be related to the slight differences in texture between the blocks. The higher coefficients measured for conditions 5, 6, and 7 are related to textural differences created when the curing materials were brushed on. These probably would not exist under field conditions.

The other differences appear to be real and related to materials since all textural factors were similar. In general, the sprayed on materials resulted in lower coefficients than the coverings and the chlorinated rubber materials reduced the coefficients more than did the other membrane materials.

TABLE XV

STOPPING DISTANCE COEFFICIENTS PREDICTED FROM BRITISH PORTABLE TESTER

Ranking	Number	Condition	Surfaces Tested*	Coefficient
1	5 & 7**	MEF + LMS	6	70
2	6	MEF + WPS	2	69
3	0	No Cure	4	59
4	2 & 4**	WPS	4	56
5	1 & 3**	LMS	14	46
6	11	CRS_3 - L	2	45
7	12	CRS_3 - H	4	39
8	13	CRS_4 - L	2	37
9	8	CRS_1 - H	4	35
10	9	CRS_2 - L	2	32
11	10	CRS_2 - LP	4	29

*Includes both air entrained and non-air entrained surfaces and all duplications (designated by "R").

**Duplication results from testing of surfaces prior to treating with linseed oil.

Two additional blocks were cast using concrete like that of the outdoor exposure blocks especially for skid testing and great care was taken to impart a more realistic texture than existed on the other slabs. Block A was divided into sections which were cured with polyethylene sheeting, liquid membrane seal, or chlorinated rubber (condition 9). This curing was applied at the time the sheen disappeared. From Block B half was cured with a white polyethylene sheeting and the other half with liquid membrane seal.

At an age of 14 days half of each of these halves was treated with chlorinated rubber (condition 9). This divided Slab B into four quadrants; namely, polyethylene with no subsequent treatment, liquid membrane seal with no subsequent treatment, and each of these with a subsequent treatment of chlorinated rubber at an age of 14 days. In order to reduce the possible influence of hand texturing, these slabs were struck off and then given a burlap treatment. This resulted in a very gritty texture possessing high skid resistance like that to be found on most pavements. At an age of 21 days each of these sections was tested with the British Portable Tester. The results of these tests are shown in Table XVI. It will be noted from these results that there is a slight reduction in skid resistance with the use of this particular chlorinated rubber when compared with the other modes of curing; however, all conditions showed values sufficiently high to permit their use.

TABLE XVI

PREDICTED SKID NUMBERS

Block A	Materials Applied to Fresh Concrete		
		Against "Grain"	With "Grain"
	LMS	66	--
	WPS	73	71
	CR (#9)	64	52
Block B	Curing Applied to Fresh Concrete, Chlorinated Rubber (#9) applied at age of 14 Days		
		Against "Grain"	With "Grain"
	LMS	67	69
	WPS	65	--
	LMS + CR	72	--
	WPS + CR	63	58

The measured increase in skid resistance associated with delayed application was checked twice and may be the result of dissolution of the membrane by the chlorinated rubber. It would appear from these results that the chlorinated rubbers in themselves do not impart a dangerous skid resistance; however, in the absence of a skid resistant texture such as existed on the scaling blocks they would, when used as curing media, reduce the coefficient that would result from the nature of the cement mortar itself.

Comparison of Results with Those of Other Published Studies

While the results from the several testing procedures used in this study are consistent in terms of what would be expected from theoretical considerations, it is appropriate to compare the findings with those from similar studies, several of which have been recently published. The overwhelming ability of properly entrained air to impart scale resistance was again documented, as it has been in every similar study reported since the initial discoveries of the 1940's. These findings strongly suggest that sporadically reported occurrences of scaling of supposedly air entrained concrete are likely cases in which the intended air content and/or distribution of voids were not in fact achieved, rather than cases wherein adequately entrained air (as indicated by construction records) failed to provide protection.

The beneficial influence of linseed oil for non-or poorly- air entrained concretes is likewise thoroughly documented (Stewart and Shafer — 1969, Brink, et al — 1967, Snyder — 1965, Scholer and Best — 1965, Furr, Ingram and Winegar — 1969). A recent report by Ryell and Chojnacki (1969) recommended against the use of linseed oil since it delayed rather than prevented scaling and led to a "false sense of security". They emphasized the importance of air-entrainment. A detailed comparison of their results with those reported here and elsewhere discloses no real conflict, but rather adoption of a different strategy for ensuring desired performance.

The results from the research reported here also indicate that linseed oil treatments delay rather than eliminate scaling. Although no retreatments have been employed in this research, the data from others (Scholer and Best — 1965, Brink, et al — 1964) suggest the need for retreatments. The results of Ryell and Chojnacki (1969) also suggest this need. It is anticipated that half of each quadrant of the air entrained slabs in this study which received an initial LOT treatment will be retreated to evaluate any long time effects.

The published data regarding the protection against scaling provided by chlorinated rubbers applied as curing agents are conflicting. Brink, et al (1967) reported beneficial effects. Beneficial effects are reported in extensive use in the field by Holland (1967), but no data are given by which these benefits are judged. Ryell and Chojnacki (1969) observed good performance of clear chlorinated rubber curing and sealing materials but poor performance for pigmented materials. Results reported by Stewart and Shafer (1969) coincide closely with those reported here in that all chlorinated rubbers performed poorly.

The indications from this study are that when used as a curing material to provide subsequent protection against deicer scaling chlorinated rubber is not effective. This is not necessarily a condemnation of the material per se, but rather a reflection of the likelihood that no material can perform these dual functions, each of which is different. An effective curing material must be applied early to retain as much moisture as possible. This the chlorinated rubbers do without question. To be effective protective coatings must penetrate the surface of the concrete. Such penetration would seem incompatible with a material applied at the proper time for curing when the near-surface voids are filled with water.

Although not within the scope of this study these materials might have some benefit when applied later as a protective sealer, but they cannot compete economically with linseed oil treatments.

The penetration of curing compounds by linseed oil has not been widely reported. The results reported here confirm the initial findings from the studies outlined in Appendix A. Kubie, Gast, and Cowan (1969) have reported direct evidence of penetration but without supporting data on resistance to scaling. Ryell and Chojnacki (1969) showed some protection for concrete treated with linseed oil after being cured with membrane, but they ascribed this to a modification of the membrane rather than penetration. The results in Figures A-2 and A-3 of Appendix A definitely indicate benefits from penetration.

CONCLUSIONS

Based upon the data and discussion presented the following conclusions are drawn:

1. Properly entrained air is overwhelmingly the most effective defense against scaling caused by deicing chemicals.

2. When insufficient entrained air is obtained, linseed oil treatments delay the onset of scaling.

3. Linseed oil treatments are effective when applied to concrete previously cured with resin based curing membrane without the necessity for removal of the membrane. Results from prior studies and those reported here indicate penetration of the membrane by the linseed oil treatment. This likely occurs by dissolution of the resin film by the mineral spirits.

4. Chlorinated rubber used as a combination curing and protective sealant is not effective on poorly air entrained concrete. It accelerates deterioration over that of such concrete normally cured with or without linseed oil treatment.

5. The monomolecular evaporation retarding film showed some beneficial effects on resistance to scaling of non-air entrained concrete.

6. Based upon compressive strength of cylinders variously cured, the strength of cylinders cured with sprayed on materials is about 75 percent of that from moist curing or various protective coverings, but this strength is not reflected in resistance to scaling.

7. The chlorinated rubber sealer, because of its tenaceous film, might accentuate the detrimental effect on skid resistance of a moderate surface texture of the concrete.

RECOMMENDATIONS

1. The number of sections devoted to the chlorinated rubbers in field trials should be reduced below that originally proposed.

2. One-half of each quadrant on slabs exposed outdoors which received initial treatments of linseed oil should be retreated prior to the third winter's exposure.

3. The current practice of the Virginia Department of Highways in treating bridge superstructures with linseed oil should be continued. The treatment of concrete previously cured with membrane without removal of the membrane should continue to be permitted. At the same time, continued emphasis should be placed on the importance of obtaining proper amounts of entrained air. This project has not progressed sufficiently to provide information on the need for retreatment, but the literature reviewed indicates the necessity for periodic retreatment.

4. Since there is some indication that the dissolution of the resin material by the mineral spirits permits penetration of the linseed oil, it might be possible to develop a curing material which, when subsequently dissolved by mineral spirits, would penetrate the surface and offer protection against scaling.

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APPENDIX A

SOME OBSERVATIONS FROM STUDIES OF PROTECTIVE COATINGS (PARTICULARLY LINSEED OIL) TO INCREASE THE SCALE RESISTANCE OF CONCRETE

by

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and
Howard H. Newlon, Jr., Assistant State Highway Research Engineer

In 1966, the Virginia Department of Highways adopted as standard procedure the application of linseed oil-kerosene mixtures to all exposed concrete surfaces. Local adoption of a new procedure, even if it has been commonly used elsewhere, usually requires that it be tried experimentally to enable modifications for local conditions. The use of linseed oil also resulted in the modification of curing methods, particularly the extent to which liquid curing membranes could be used.

The Research Council has conducted and assisted operating divisions in conducting experimental work directed toward improving the scale resistance of concrete by means of various combinations of protective coatings and curing methods.

The work to date can be divided into three phases:

(1) Rapid laboratory freezing and thawing tests of concrete beam specimens in a salt solution,

(2) Exposure out-of-doors of slabs simulating bridge deck concrete with application of deicing salts,

(3) Treatment of a section of Interstate 64, part of which had been cured with polyethylene and the remainder with a white pigmented membrane.

In the rapid freezing and thawing phase, there were two series of tests. The initial series was designed to gain a rapid comparative evaluation of linseed oil when applied after polyethylene and membrane curing in anticipation of the field experiment. An epoxy curing agent, which proportedly would remain in place to serve as a protective coating, was also evaluated.

Because of the good performance of the white pigmented compound in the initial series, a second series was conducted. It was designed specifically to answer the question Was the linseed oil kerosene mixture penetrating the curing compound, or was it simply sealing the surface?.

In addition to the rapid freezing and thawing tests slabs were tested in a natural outdoor exposure plot intended to provide more realistic data than would be expected from the rapid laboratory tests.

The field applications were intended to extend the findings of the laboratory work, provide familiarity with application problems, and allow skid tests before and after application.

Because research and field experience had established that scale resistance is a function of (1) concrete composition (especially entrained air content and water cement ratio), (2) curing, (3) degree of saturation, (4) age at time of exposure, as well as (5) presence of coatings, attempts have been made throughout the various phases of this work to include these factors as variables or at least to evaluate as many of them as possible. Particular attention has been directed toward the interaction of protective coatings and curing methods.

Information relating to the variables in each phase, some results, and some observations made after a preliminary evaluation are given in the following pages.

TABLE A-1

INITIAL RAPID FREEZING AND THAWING TESTS (ASTM C 290 - 10% NaCl Solution)

1. Purpose — To gain a rapid indication of effectiveness of linseed oil treatments combined with several curing procedures.

2. Concrete Quality Constant — Cement — 6 sks/cy
   Water — 6 gal/sk
   Air — 5 ± .5%
   Slump 2.5"

3. Specimens — 3" x 4" x 16" beams

4. Cure and Treatment — Variable

Age

Condition	3 hours	1 day*	12 days		14 days		21 days
a.	wet burlap →	water + polyethylene	70° R.H. 55% →		Curing Removed	70° R.H. 55% →	Freezer**
b.	wet burlap →	water + polyethylene	70° R.H. 55%	Curing Removed 70° R.H. 55% →	Linseed Oil Treatment	70° R.H. 55% →	Freezer
c.	epoxy cure and protection compound	70° R.H. 55% →					Freezer
d.	white pigmented compound	70° R.H. 55% →			Linseed Oil Treatment	70° R.H. 55% →	Freezer

*When specimens were demolded, the sides were given same treatment as at 3 hours.

Table A-1 continued

Observations:

1. When it was put in the freezer, concrete cured with polyethylene was at a higher degree of saturation than was that cured with membranes as evidenced by increases in weight (See Figure A-1). Based upon the weight at 21 days the increases in weight after 30 cycles of freezing and thawing (maximum weight attained) were:

   Epoxy Cure — 3.9%
   White Pigmented Membrane + Linseed Oil — 3.6%
   Polyethylene + Linseed Oil — 1.6%
   Polyethylene — 1.7%

2. Scaling as measured by weight loss increased as follows:

   a. Based upon weight when beams put in freezer.

      White membrane + Linseed Oil (least)
      Epoxy Cure
      Polyethylene + Linseed Oil
      Polyethylene (greatest)

   b. Based upon maximum weight attained.

      White membrane + Linseed Oil (least)
      Polyethylene + Linseed Oil
      Polyethylene
      Epoxy Cure (greatest)

   The latter measure (2b) appears to be the most realistic measure of scale resistance.

3. Visual evidence of scaling confirms the weight loss data.

4. Linseed oil delayed the onset of scaling in all cases.

5. The moisture content of the concrete as influenced by the type of curing dictated the scale resistance in these rapid tests. The white membrane (which allowed some drying during the curing period) was less affected by the cycle than the polyethylene, which while better cured was more highly saturated.

6. The concrete cured with white membrane and subsequently treated with linseed oil showed the least scaling of any combination tested.

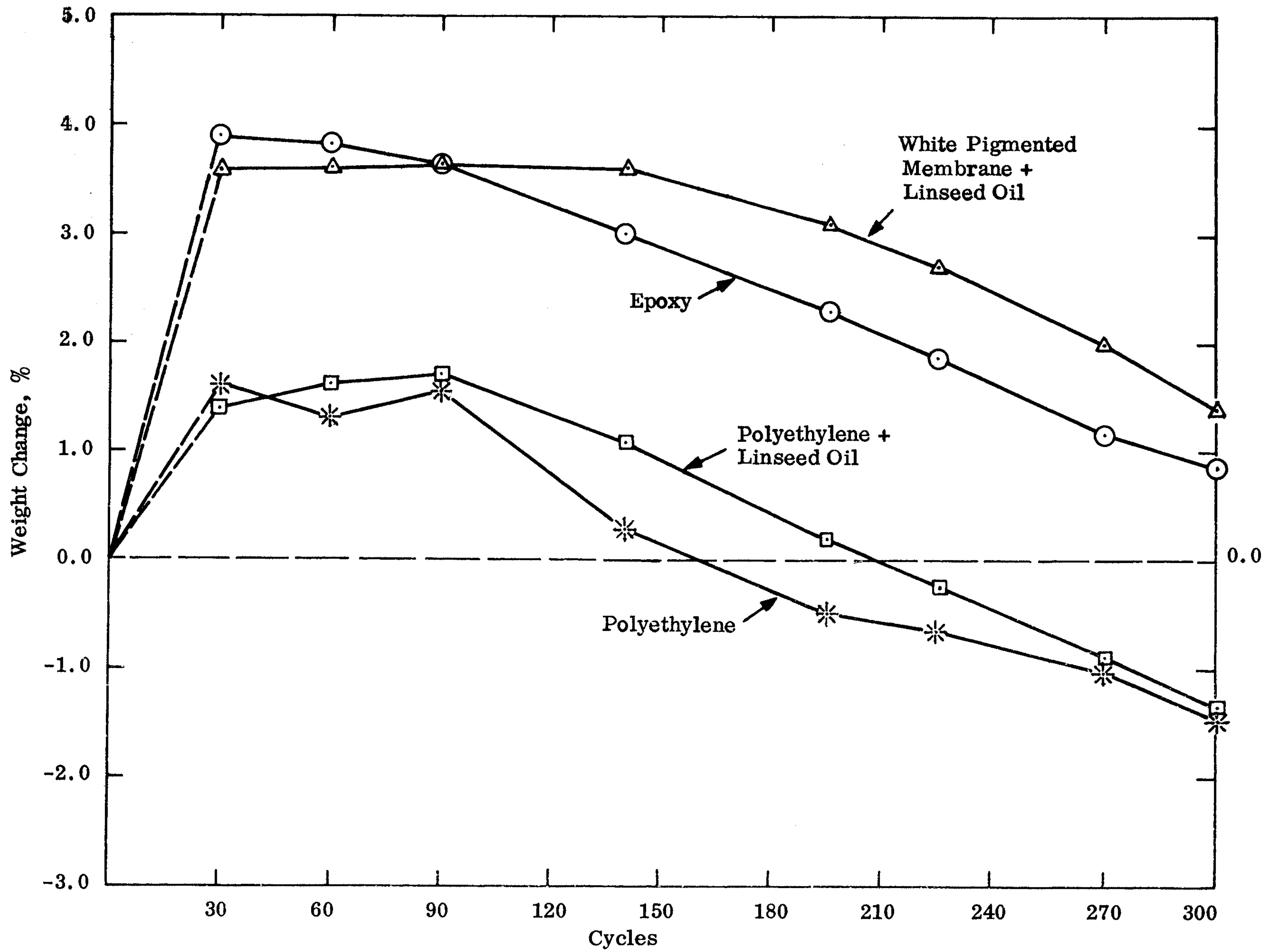

Figure A-1. Average weight change from initial

TABLE A-2

SECOND RAPID FREEZING AND THAWING TESTS (ASTM C 290 - 10% NaCl Solution)

1. Purpose — To establish whether or not the linseed oil penetrated the white pigmented curing compound.

2. Concrete Quality — Same as A-1.

3. Specimens — 3" x 4" x 16" beams.

4. Cure and Treatment — Variable, but all related to the use of linseed oil after curing with white pigmented compound.

Condition	3 hours	1 day*	14 days	21 days	
a.	white pigmented compound	70° / 55% R. H. →	→	→	Freezer
	(24 hr. loss - AASHO - T 155 - 0.0121 gm/cc max.)				
b.	white pigmented compound	70° / 55% R. H. →	→	→	White Compound Removed by Wire Brush — Freezer
c.	white pigmented compound	70° / 55% R. H. →	Linseed Oil Treatment	→	Freezer
d.	white pigmented compound	70° / 55% R. H. →	Linseed Oil Treatment	→	White Compound Removed by Wire Brush ** — Freezer

*When specimens were demolded, the formed sides were given same treatment.

**If Linseed Oil Treatment did not penetrate compound, it would also be removed.

Table A-2 continued

Observations:

1. Scaling occurs on molded surfaces and then spreads to the finished surface.

2. The scaling as measured both by weight loss (Figure A-2) and an arbitrarily established visual rating system (Figure A-3) is delayed by linseed oil. Thus the increased scale resistance of the specimens cured with white pigmented membrane (Figure A-1) resulted from the linseed oil, not the membrane.

3. The linseed oil does penetrate the white pigmented membrane as evidenced by the equal performance regardless of whether the membrane was left on after coating or removed.

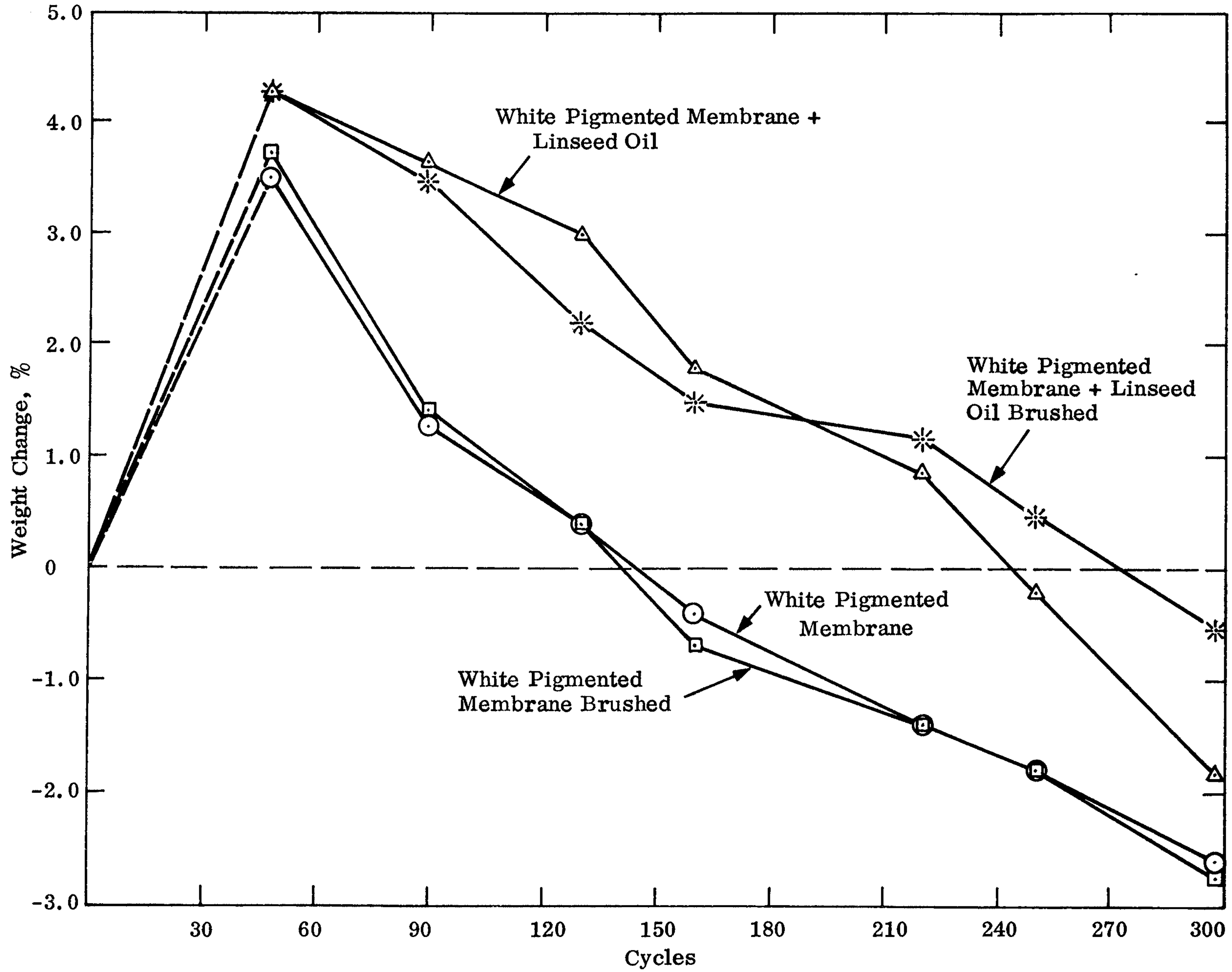

Figure A-2. Average weight change from second rapid freezing and thawing tests.

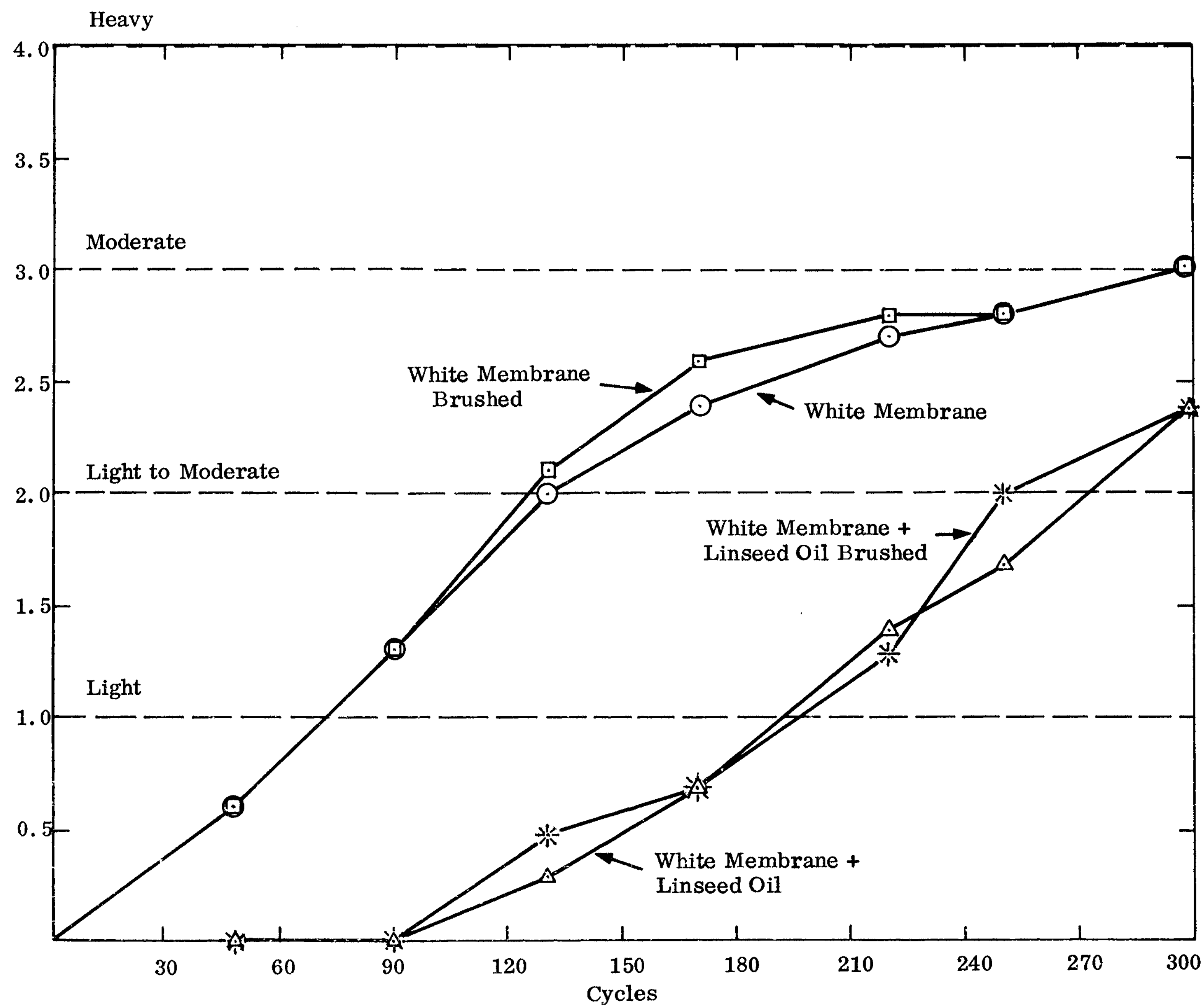

Figure A-3. Average degree of scale of specimens shown in Figure A-2.

TABLE A-3

EIGHT SLABS DEICED IN NATURAL (OUTDOOR) EXPOSURE PLOT

1. Purpose -- Verification of rapid tests and evaluation of scaling specimens.

2. Concrete Quality: Minor Variable, but generally poor.
   Cement — 6.9 sks/cy
   Water — 5.6 gal/sk and 7.2 gal/sk
   Air Content — None (1 slab — 3%)

3. Slabs 2' x 2' x 4". Different treatments applied to different quadrants of approximately 1 sq. ft.

4. Placement — Conditions — Laboratory (70^{o}F and 55% R.H.). Forms placed and remained in circulatory air current of from 2 to 5 mph for 48 hours.

5. Curing, treatment and exposure (see summary in Table A-4).

Observations:

1. Use of specimens which permit comparisons of methods on a single slab so as to eliminate fabrication and finishing differences was very successful.

2. Composition, curing methods, and linseed oil all influenced scale resistance. In some cases the treatment controlled and resulted in better concrete than would be expected based on the curing. In other cases the reverse was true.

3. There was a significant difference in the protection provided by the linseed oil for mature concretes and less mature concretes all of relatively poor quality. In the case of mature concrete, the linseed oil treatment was universally and spectacularly beneficial. In the case of the less mature concretes, the linseed oil treatment was universally detrimental. This apparently reflects the fact that the coating used did not "breathe" or at least did not have sufficient time to "breathe" in the less mature concrete.

4. Adequate curing was more important than presence of linseed oil in the immature concretes. Likewise curing was more important than in the mature concrete.

5. The small amount of air which was used in one slab of mature concrete was markedly beneficial.

6. The epoxy cure did not significantly increase the scale resistance.

7. Linseed oil was applied over white pigmented curing compound only in the immature concrete. The performance was not good as indicated in Observation #3. The performance was no worse than on polyethylene cured slabs of immature concrete.

8. The use of a monomolecular film prior to polyethylene curing and/or linseed oil treatment dramatically increased the scale resistance of both the mature and immature slabs.

9. Most of the scaling distress occurred during several periods of prolonged freezing rather than during cycles of freezing and thawing.

10. Very small differences in treatments or microclimate on the slab surfaces (areas shaded by the 1" dike, for example) resulted in large differences in performance.

TABLE A-4

SUMMARY OF TEST RESULTS FROM OUTDOOR EXPOSURE SLABS

Slab	Quandrant	Immediately After Floating	Dissappearance of Sheen 2-3- hrs.	14 Days	21 Days (All Slabs placed in Outdoor Exposure)	Age at First Freeze	Concrete Properties	Scale Rati[ng] 1 = None 2 = Min[or] 3 = Defi[nite]
	A	Nothing	Polyethylene	Cure removed L.O. Treatment	-	4 months	Cement - 6.9 sk/yd Slump- 1.6" H_2O - 6.0 gal/sk Air - 3.0%	1
	B	"	Clear Membrane (non spec)	L.O. Treatment	-	"	" "	1
1	C	"	Polyethylene	Cure Removed	-	"	" "	3
	D	"	Clear Membrane (non spec)	-	-	"	" "	3
	A	"	Polyethylene	Cure removed L.O. Treatment	-	4 months	Cement - 6.9 sk/yd Slump - 3.3" H_2O - 7.5 gal/sk Air - none (1.1%)	1
	B	"	Clear Membrane (non spec)	L.O. Treatment	-	"	" "	3
2	C	"	Polyethylene	Cure Removed	-	"	" "	3
	D	"	Clear Membrane (non spec)	-	-	"	" "	2
	A	"	Epoxy Cure	-	-	4 months	Cement - 6.9 sk/yd Slump - 3.1" H_2O - 7.2 gal/sk Air - none (1.0%)	3
	B	"	Polyethylene	-	Cure Removed	"	" "	3
3	C	"	"	-	" "	"	" "	3
	D	"	Epoxy Cure	-	-	"	" "	3
	A	Monomolecular Film	Polyethylene	Cure Removed	-	4 months	Cement - 6.9 sk/yd Slump - 2.5" H_2O - 5.6 gal/sk Air - none (1.1%)	2
	B	Nothing	"	"	-	"	" "	3
4	C	"	"	L.O. Treatment	-	"	" "	1
	D	Monomolecular Film	"	" "	-	"	" "	1
	A	Nothing	Polyethylene	Cure Removed	-	1 week	Cement - 6.9 sk/yd Slump - 2.9" H_2O - 5.6 gal/sk Air - none (1.0%)	1
	B	"	"	Cure Removed L.O. Treatment	-	"	" "	2
5	C	"	White Pigmented Membrane	L.O. Treatment	-	"	" "	3
	D	"	"	-	-	"	" "	3
	A	Nothing	White Pigmented Membrane	L.O. Treatment	-	1 week	Cement - 6.9 sk/yd Slump - 2.8" H_2O - 5.8 gal/sk Air - none (1.0%)	3
	B	"	"	-	-	"	" "	3
6	C	"	Polyethylene	Cure Removed	-	"	" "	1
	D	"	"	Cure Removed L.O. Treatment	-	"	" "	3
	A	Nothing	Polyethylene	-	Cure Removed	1 week	Cement - 6.9 sk/yd Slump - 2.9" H_2O - 5.6 gal/sk Air - none (1.0%)	2
	B	"	"	-	" "	"	" "	2
7	C	"	Epoxy Cure	-	-	"	" "	2
	D	"	"	-	-	"	" "	2
	A	"	Polyethylene	Cure Removed	-	1 week	Cement - 6.9 sk/yd Slump - 2.9" H_2O - 5.6 gal/sk Air - none (1.0%)	2
	B	"	"	Cure Removed L.O. Treatment	-	"	" "	2
8	C	Monomolecular Film	"	Cure Removed L.O. Treatment	-	"	" "	1
	D	" (partial coverage)	"	Cure Removed	-	"	" "	1

TABLE A-5

FIELD INSTALLATION

1. Purpose —

    (a) extend laboratory study to field and
    (b) delineate problems of application
    (c) measure skid resistance

2. Location — See Figure A-4.

3. Variables — See Table A-6.

    (a) treated vs. control (no treatment)
    (b) presence of white pigmented cure vs. polyethylene
    (c) age of concrete
    (d) reapplications (future)

4. Data Obtained

    (a) Application Rates (See Table A-7)
    (b) Skid Resistance (See Table A-8)
    (c) Air Contents (See Table A-9)
    (d) Weather Conditions

Observations:

1. The linseed oil distributor developed by the Council performed adequately for the small job on I-64 and would be adequate for large scale work provided a larger tank and more powerful pump were employed.

2. The measured application was very close to the intended application of .040 gal/sy. Also, the longitudinal consistency of application was good. The transverse distribution was quite variable, but this probably has been corrected somewhat by reducing the nozzle spacing from 15" on center to 7-1/2" on center.

3. Skid tests were performed prior to treatment, during the first half hour after treatment, and after lapses of 24 and 48 hours. From these tests it is concluded that the pavement is still slippery after thirty minutes of curing, but not after 24 hours of curing. More testing is necessary to determine just how long the pavement remains slippery.

4. The air void characteristics are such that scaling is unlikely in either the treated or the untreated sections.

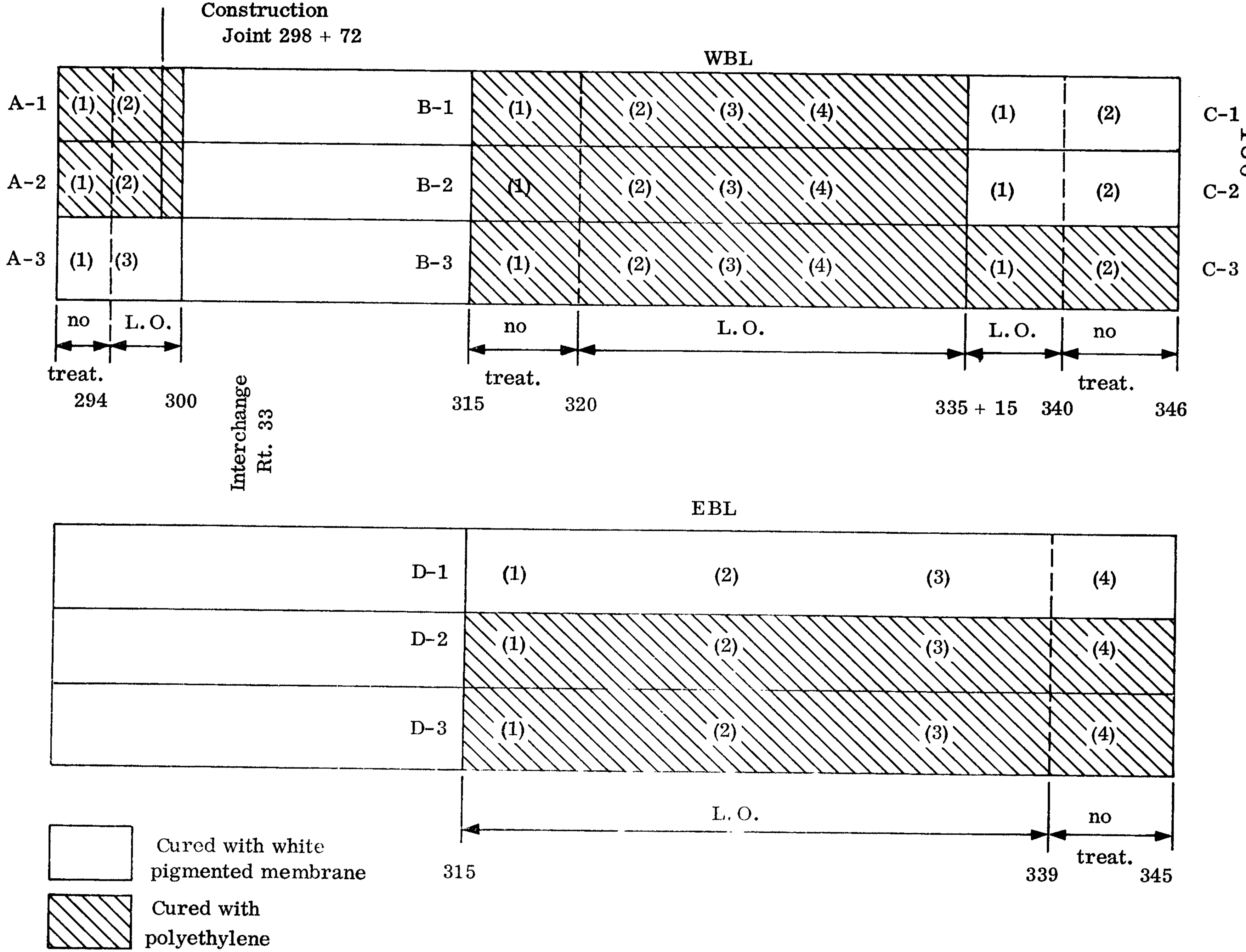

Figure A-4. Sketch of I-64 sections
(not to scale)

TABLE A-6

SUMMARY OF INFORMATION RELATING TO TEST SECTIONS ON I-64

Section	Subsection	Approximate Length	Age Range (days) (May 15)	Cure	Linseed Oil Treatment
A1	1	500	180	Cover	control
	2	500	180	Cover	initial
A2	1	500	180	Cover	control
	2	500	180	Cover	initial
A3	1	500	363	membrane	control
	2	500	363	membrane	initial
B1	4	500	218	cover	initial
	3	500	218	cover	initial + 1 retreatment
	2	500	218	cover	initial + 2 retreatments
	1	600	218	cover	control
B2	4	500	218	cover	initial
	3	500	218	cover	initial + 1 retreatment
	2	500	218	cover	initial + 2 retreatments
	1	600	218	cover	control
B3	4	500	218	cover	initial
	3	500	218	cover	initial + 1 retreatment
	2	500	218	cover	initial + 2 retreatments
	1	600	218	cover	control
C1	1	500	219	membrane	initial
	2	500	219	membrane	control
C2	1	500	219	membrane	initial
	2	500	219	membrane	control
C3	1	500	201	cover	initial
	2	500	201	cover	control
D1	1	800	191	membrane	initial
	2	800	191	membrane	initial + 1 retreatment
	3	800	184	membrane	initial + 2 retreatments
	4	800	184	membrane	control
D2	1	800	191	cover	initial
	2	800	191	cover	initial + 1 retreatment
	3	800	184	cover	initial + 2 retreatments
	4	800	184	cover	control
D3	1	800	191	cover	initial
	2	800	191	cover	initial + 1 retreatment
	3	800	184	cover	initial + 2 retreatments
	4	800	184	cover	control

TABLE A-7

INITIAL LINSEED OIL APPLICATION: AMOUNT BY SECTION

	Avg. Application for Section as Determined by Tank Measure (gal/sy)			Application as Measured by Cotton Pads			
Section	1st	2nd	Total	1/3 way thru	2/3 way thru	Application	Comments
A-1-2	.019	.025	.044	.017	.009	1st	s.d., σ = .005
A-2-2	.030	.010	.040	.021	.022	2nd	"
A-3-2	.022	.018	.040	.013	.018	1st	"
B-1-2 B-1-3 B-1-4	.021	.021	.042				
B-2-2 B-2-3 B-2-4	.020	.016	.036				
B-3-2	.018	.018	.036				
B-3-3	.020	.020	.040	.018	.017	1st	3rd Application σ = .005 Total = .045
B-3-4	.020	.019	.039				" " = .044
C-1-1	.021	.021	.042				
C-2-1	.020	.016	.036				
C-3-1	.017	.020	.037				" " = .042
D-1-1 D-1-2 D-1-3	.018	.016	.034				
D-2-1 D-2-2 D-2-3	.019	.022	.041	.012	.020	1st	s.d., σ = .005
D-3-1 D-3-2 D-3-3	.015	.014	.029	.019	.014	1st	s.d., σ = .005

TABLE A-8

SKID RESISTANCE
(Measured by Stopping Distance Method at 40 mph)

Section	Station	Oil Application (gal/sy)	Time Interval (between treatment and testing)	Coefficient	Mean Coefficient
B-2	321 + 50	0	0	.59	
		0	0	.59	
		0	0	.59	
					.59
D-2	322 + 50	.041	5 Min. to	.38	
			10 Min.	.38	
				.38	
					.38
B-1	321 + 50	.042	8 Min. to	.24	
			15 Min.	.27	
				.30	
				.28	
				.25	
D-1	338 + 25	.034	12 Min. to	.33	
			20 Min.	.37	
				.36	
				.37	
B-2	321 + 50	.036	20 Min. to	.32	
			30 Min.	.30	
				.29	
				.29	
D-3	322 + 50	.029	24 Hours	.47	
				.49	
					.48
B-3	321 + 50	.042	48 Hours		
				.51	
				.51	
					.51

TABLE A-9

AIR VOID DATA
(ASTM C 457)

Core	Station	Linseed Oil	Total Voids, percent	Entrained Voids percent	Specific Surface (Total) in.$^{-1}$
A-1-2	297 + 91	Yes	6.72	4.11	1317
A-2-1	291 + 96	No	5.79	4.51	1356
A-3-2	294 + 35	Yes	5.97	3.74	1268
B-1-1	318 + 57	No	5.85	4.04	1138
B-2-2	322 + 49	Yes	6.58	5.00	1531
B-2-4	331 + 41	Yes	5.49	3.30	1158
B-3-1	317 + 73	No	5.81	4.01	1430
B-3-3	327 + 74	Yes	6.00	5.10	1694
C-1-1	337 + 17	Yes	6.67	3.52	1273
C-2-2	341 + 00	No	6.64	4.19	1335
C-3-1	336 + 46	Yes	6.36	4.43	1300
C-3-2	341 + 50	No	5.38	2.58	810
D-1-1	320 + 09	Yes	6.37	3.45	1213
D-1-2	328 + 76	Yes	6.32	3.31	1093
D-1-3	333 + 91	Yes	6.83	3.49	1108
D-1-4	343 + 92	No	6.34	4.30	1256
D-2-2	323 + 52	Yes	7.45	3.84	1226
D-2-3	331 + 75	Yes	6.75	4.46	1460
D-3-1	318 + 34	Yes	6.36	4.73	1658
D-3-4	341 + 33	No	6.36	3.71	1226

Summary:

	Voids Total	Voids Entrained	Total Specific Surface
Linseed Oil	Average 6.45 Std. Dev. 0.48	Average 4.04 Std. Dev. 0.65	Average 1331 Std. Dev. 197
Control	Average 6.02 Std. Dev. 0.43	Average 3.91 Std. Dev. 0.64	Average 1221 Std. Dev. 205

APPENDIX B

— TENTATIVE —
NOT APPROVED FOR
OFFICIAL USE

Virginia Test Method

For

Water Retention Efficiency of Liquid Membrane Sealers

Designation VTM-2-70

1. Scope: To measure moisture retention performance of liquid membrane-forming compounds for curing concrete.

2. Apparatus:
   (a) Molds - Molds shall be pie tins having the shape of the frustrum of a right cone approximately 5 3/8 inches in diameter at the top, approximately 4 inches diameter at the bottom and 15/16 inches ± 1/16 inches in depth, or other suitable containers of the same approximate dimensions.

   (b) Curing Cabinet - A cabinet for curing the specimen at a temperature of 100 ± 2° F. and a relative humidity of 50 ± 10 percent.

   (c) Reynolds Electric two speed mixer with paddle and ten quart bowl.

   (d) Oil can for dispensing hot melted wax.

   (e) Torsion balance accurate to ± 0.1 grams.

3. Procedure: Proportioning and Mixing Mortar

Premix 1300 grams of dry VDH concrete sand with 500 grams of type II cement at low speed for one minute. The cement must conform to Section 216 of the specifications. Add approximately 220 grams of water and mix for two minutes. The flow of mortar used in the specimen shall be optional with the laboratory but, shall not be greater than that specified in AASHO T-155.

Molding and Storing Specimen

The pie tins shall be filled in one layer vibrated and struck off even with the top rim. A v-shaped groove approximately 1/8 inch deep and not more than 1/16 inch wide shall be formed between the edge of the mortar specimen and the mold. A set of three test specimen shall be made to constitute one test of a given curing material. Immediately after molding the specimen shall be placed in the curing cabinet. The specimen shall be level, not subject to vibration and be so arranged as to provide a minimum of two inches space on all sides.

Application of Curing Materials

(a) The specimens shall be removed from the cabinet immediately upon disappearance of the surface water and the surface shall then be lightly brushed with a stiff bristle brush. If surface water appears upon brushing, the specimen shall be returned to the cabinet and removed therefrom immediately upon disappearance of the surface water brought to the surface by the brushing operation, and again brushed. The groove shall be filled with a suitable compound that will not be effected by the curing material under test. The sealing compound shall effectively seal against moisture loss between the boundary of the specimen and the mold, and shall not extend more than 1/4 inch from the mold onto the surface of the specimen. (Note)

Note - The proper surface condition will be attained when the brushing operation will not bring free water to the surface or produce smearing. The proper time for the brushing operation can be determined by rubbing an area with the finger tip.

(b) The mortar surface shall have neither surface water on it nor be dry below the surface. The specimen shall be weighted and the curing material applied immediately. The curing material shall be applied at the rate of 200 sq. ft. per gallon. The curing material shall be applied in controlled laboratory atmosphere to only one specimen at a time. The specimen shall be returned to the curing cabinet immediately after application.

(c) Liquid membrane-forming curing compounds for spraying shall be uniformly sprayed on the surface with a spray gun or hand atomizer held vertically over the specimen surface at the height required to give uniform application and minimum over-spray. The proper coverage shall be determined by weighing, to the nearest 0.1 gram, the spray gun before and after application of the curing compound.

(d) Liquid membrane-forming curing compounds for brush application shall be uniformly brushed on the surface with a soft bristle brush 1 inch in width. The proper coverage shall be determined by weighing to 0.1 gram the container for the curing compound and the brush in the container before and after application.

Calculation of Loss in Weight

The amount of water loss shall be determined at 24 hours and 72 hours after application of the curing material by weighing the specimen.

The loss in weight of volatile matter from a liquid membrane-forming curing compound shall be determined by coating a metal pan or plate, having an area equal to the top of the test specimen with the same quantity of curing material as used on the specimen. The pan or plate shall be placed in the curing cabinet with the test specimen and weighed each time the specimen is weighed. If the pans or plates reach constant weight, no further weighings are necessary. The loss in weight of the liquid material shall be used as a correction calculating the curing material added.

The curing compound, when applied to a clean and dry tin panel at the rate specified in the determination of water loss, shall dry to touch in one hour and dry through in not more than 4 hours. When used in the field it shall show drying properties satisfactory to the Engineer.

At the end of the 24 hour and 72 hour period the loss of water from the mortar based on the weight of the specimen and mold prior to the application of the curing material, shall be calculated with corrections allowed for the curing material added and volatile matter loss. All weights shall be in grams and the water loss reported in grams per sq. cm.