EVALUATION OF SEVERAL TYPES OF CURING AND PROTECTIVE MATERIALS FOR CONCRETE

Interim Report

Part III - Performance

by

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Assistant State Highway Research Engineer

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

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SUMMARY

Various curing and/or protective coatings were evaluated under three conditions: (1) accelerated laboratory freezing and thawing of specimens in 2 percent sodium chloride solution, (2) exposure in an outdoor area of slabs which were subjected to controlled application of deicers, and (3) exposure of some of the materials on three bridges. The performance of the outdoor slabs and bridge decks has been observed during the interim since the last report.

Based upon observations after additional exposure of the outdoor slabs and the field test sections, the conclusions from the two previous parts of this report were confirmed. Continued observation merits emphasis on the following:

(1) Properly entrained air is overwhelmingly the most effective defense against scaling caused by deicing chemicals. This fact is evident from the continued good performance of the outdoor exposure slabs that contain entrained air and by the absence of scaling on the bridge decks, which also were built with concrete that was uniformly and adequately air entrained.

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

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BACKGROUND

Concern for the premature deterioration of concrete in bridge decks, which became increasingly apparent during the 1960s prompted the promotion of a variety of products intended to provide improved curing, subsequent protection, or both. These products were formulated from a variety of materials — some new or exotic and some more conventional or with long histories of use. Among the new materials were those containing epoxy resins, chlorinated rubber, or other polymers. Old materials were represented by renewed interest in organic oils, such as linseed oil.

In 1966, as part of its defense against deck deterioration, particularly deicer scaling, the Virginia Department of Highways adopted as a general practice the use of linseed oil treatments for all superstructure concrete and pavement surfaces. Most of such concrete is cured with a membrane curing compound and with the advent of the general use of linseed oil several questions arose as to the need to remove the curing compound prior to application of various protective treatments. A number of these questions were studied in limited scope laboratory and field evaluations in Virginia. Results from a variety of research studies by other agencies were also published. In some cases, the results from these studies were in conflict with each other while in other cases they were confirmatory. These studies were summarized in Part I of this report (Newlon 1970a).

Faced with the need for information on a large number of proprietary formulations, the Highway Department requested the Research Council to evaluate the major generic classes of materials in field trials. Prior to the field trials preliminary screening and laboratory tests were to be made to select the most promising materials as outlined in the Working Plan (Newlon 1968). The results of the laboratory and outdoor exposure studies conducted preliminary to field trials were given in Part I of this report (Newlon 1970a). Part II

(Newlon 1970b) contained information on the installation and initial performance of the field test sections.

The conclusions from Parts I and II are included in the Appendix. The project included evaluation under three conditions: (1) accelerated laboratory freezing and thawing of specimens in 2 percent sodium chloride solutions, (2) exposure in an outdoor area of slabs which were subjected to controlled applications of deicers, and (3) exposure of some of the materials on three bridges constructed as a part of an interstate project . Observations have continued for the last two conditions. The results from these observations are contained in this report.

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 1. In cases where linseed oil solutions were applied to concretes cured with liquid membrane curing compound, they were applied directly without any effort to remove the compound. This was based upon previous research, discussed in Part I, which showed that the curing membrane was penetrated by the linseed oil solution and that the freezing and thawing resistance was thereby increased.

Materials which would function as curing media were tested in accordance with the Virginia modification of AASHO T 155. The moisture losses are shown in Table 2 along with the values specified at the time 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.

The linseed oil solution was supplied as solvent reduced, boiled linseed oil. The analysis of the boiled linseed oil is given in Table 3. No tests were run on the monomolecular film. It was supplied by the manufacturer, who markets it as a proprietary product.

TABLE 1

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

TABLE 2

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.

TABLE 3

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%

OUTDOOR SCALING SLABS

Concretes

The concretes used in all specimens exposed out-of-doors were fabricated to represent that intended for use in the field and contained a water reducing-set retarding admixture. All of the concrete materials have provided excellent service. The nominal proportions were as shown in Table 4. The important characteristics of the individual batches were given in Part I. For the slabs exposed out-of-doors both air entrained and non-air entrained slabs were used as described later.

TABLE 4

NOMINAL CONCRETE CHARACTERISTICS

Property	Value
Cement Factor, sacks/cy	7
Air Content, percent (where used)	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

Twelve slabs each 2' x 2' x 4" were cast in the laboratory for exposure to deicing tests in the 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 1. In order to estimate variability from slab to slab the white pigmented membrane seal followed by linseed oil 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 1. 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 were given in Part I.

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 deicer exposure. Liquid curing materials were applied by brushing at a rate of 200 sf./gal., and sequences were as recommended by the manufacturer for the sequences given in Table 1. The air entrained and non-air entrained specimens were made on separate days. The curing materials were applied when the sheen disappeared. The slabs, elevated to simulate bridge deck exposures, were placed in an outdoor exposure area adjacent to USWB Station Charlottesville 1-W at an age of one month. The initial freeze occurred when the concrete was 60 days old and had been in the outdoor exposure area for 30 days. Eight specimens are shown in Figure 2. The slabs have not been retreated with linseed oil during the five winters during which they have been exposed.

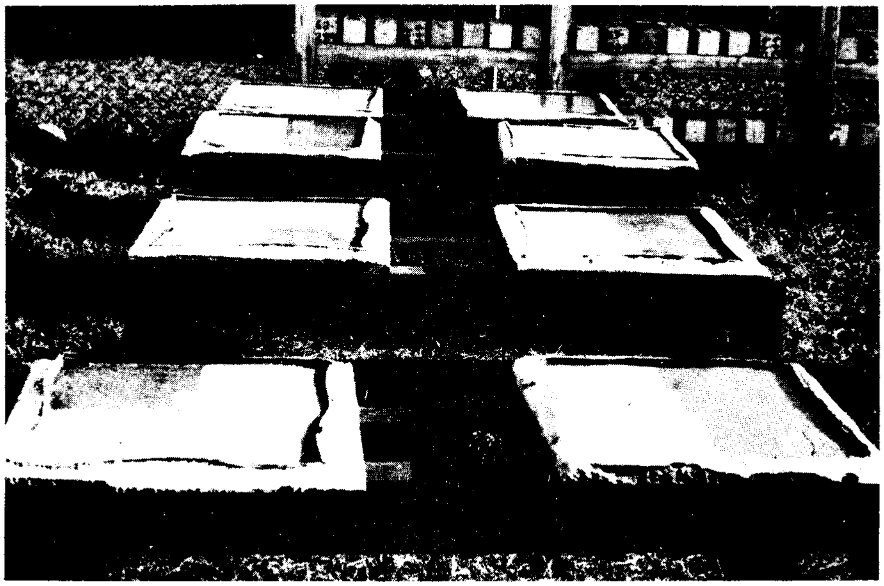

Figure 2. Slabs in outdoor exposure area.

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 percent 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 cycles were judged by daily visual observation rather than according to temperature and in some cases the ice remained on the surface for several days.

The slabs were periodically observed for changes in surface appearance. Evaluation of the changes in surface appearance was based on the rating system shown in Table 5.

TABLE 5

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)

Results

The slabs were placed in the exposure area in the fall of 1968. During the exposure through five winters, the slabs have been exposed to 123 cycles as defined earlier; 51 of which lasted longer than 24 hours. Detailed information on the cycles is given in Table 6.

The scaling ratings for the slabs after one, two, and five winters are shown in Figure 3. In Part I, which included data for the slabs after two winters of exposure and the results from accelerated laboratory freezing and thawing tests after 300 cycles, it was concluded that non-air entrained specimens representing conditions 2, 3, 4, 5, and 6 and all air entrained specimens 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 of exposure in the outdoor scaling tests. In all testing the several chlorinated rubber compounds performed poorly when compared with various curing methods followed by a treatment with linseed oil.

Despite the differences attributable to the curing and/or protective coatings, the overwhelming factor with regard to scaling was the presence of entrained air. The use of a monomolecular film also appeared to improve resistance to scaling. This is still a valid statement of the results as reflected by additional exposure.

In addition to the quantitative evaluation in Figure 3, a qualitative comparison can be made from Figures 4-9, in which are shown photographs of each of the eight non-air entrained slabs after three and five winters and corresponding air entrained slabs after five winters.

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TABLE 6

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
Mar. 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
Mar. 70	4	2	3
Total 2nd Winter	25	19	–
Nov. 70	3	1	2
Dec. 70	5	1	2
Jan. 71	9	3	3
Feb. 71	5	2	5
Mar. 71	7	0	0
Total 3rd Winter	29	7	–
Nov. 71	2	0	0
Dec. 71	3	1	2
Jan. 72	5	1	3
Feb. 72	7	2	4
Mar. 72	4	0	0
Total 4th Winter	21	4	–
Nov. 72	4	0	0
Dec. 72	5	1	3
Jan. 73	6	1	5
Feb. 73	7	1	5
Mar. 73	3	0	0
Total 5th Winter	25	3	–
TOTAL 5 WINTERS	123	51	–

* As defined on page 6

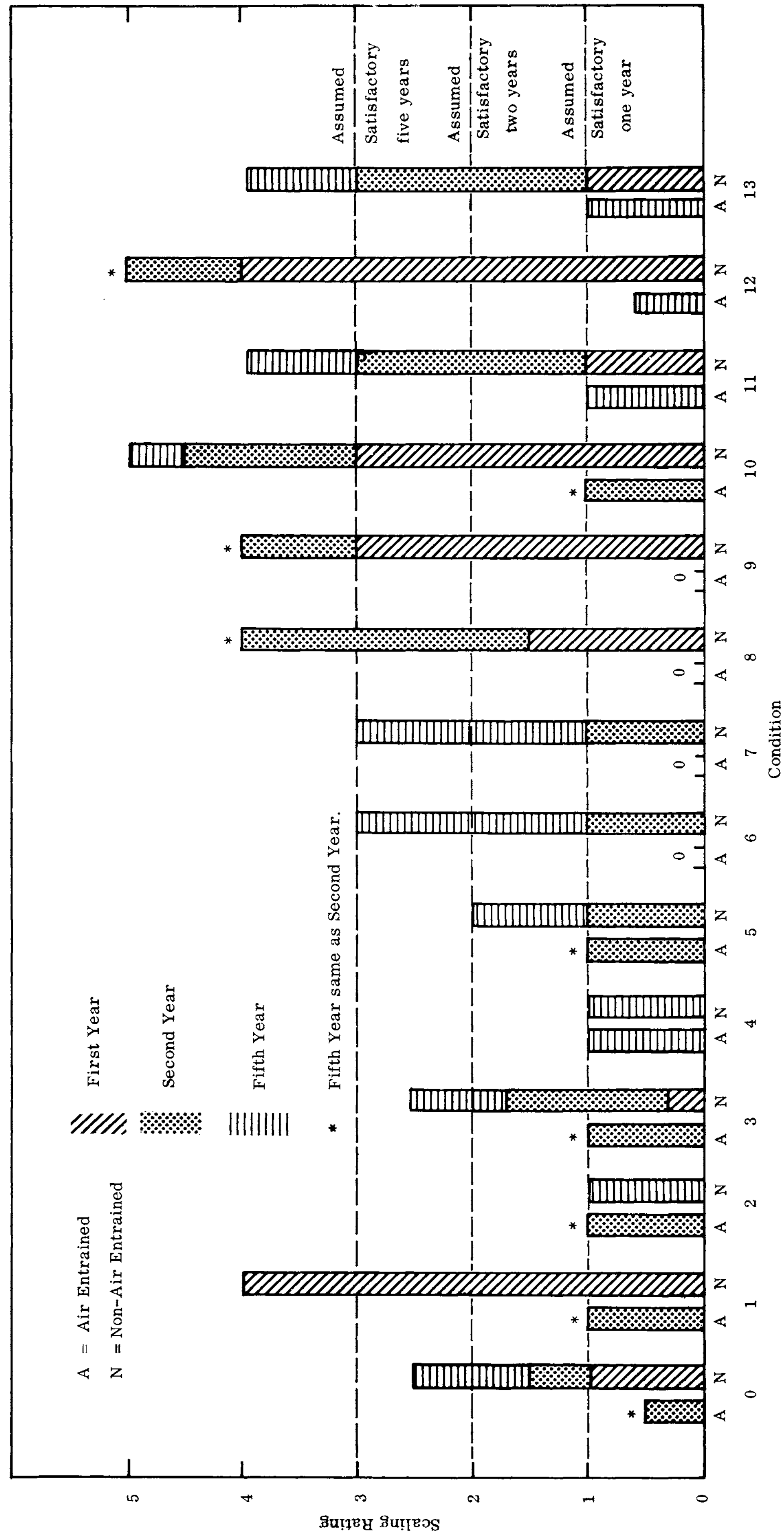


Figure 3. Scaling ratings of slabs in outdoor exposure. Average values are given for multiple occurrences of a test condition.

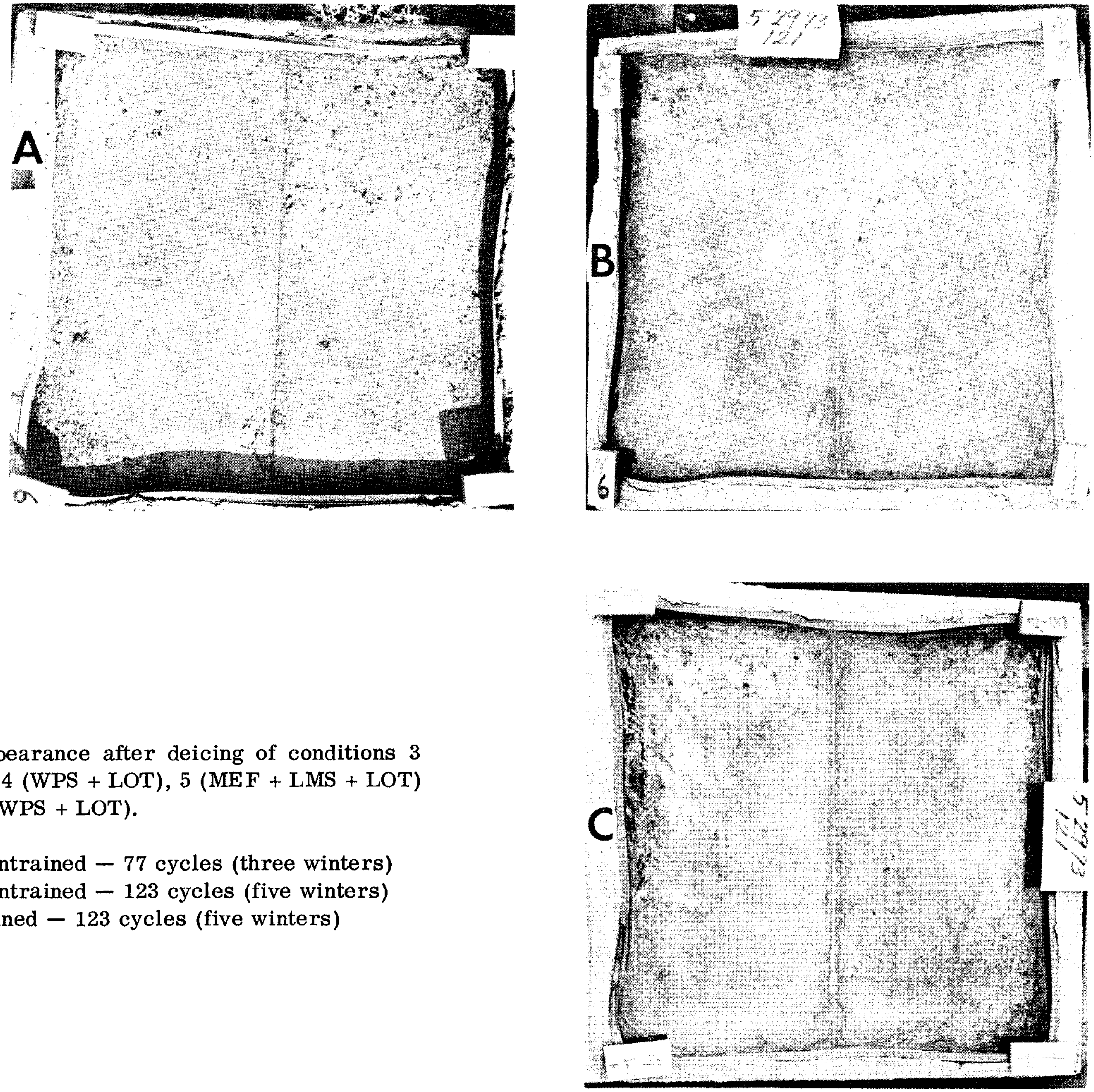


Figure 4. Appearance after deicing of conditions 3 (LMS + LOT), 4 (WPS + LOT), 5 (MEF + LMS + LOT) and 6 (MEF + WPS + LOT).

(A) Non-air entrained — 77 cycles (three winters)
(B) Non-air entrained — 123 cycles (five winters)
(C) Air entrained — 123 cycles (five winters)

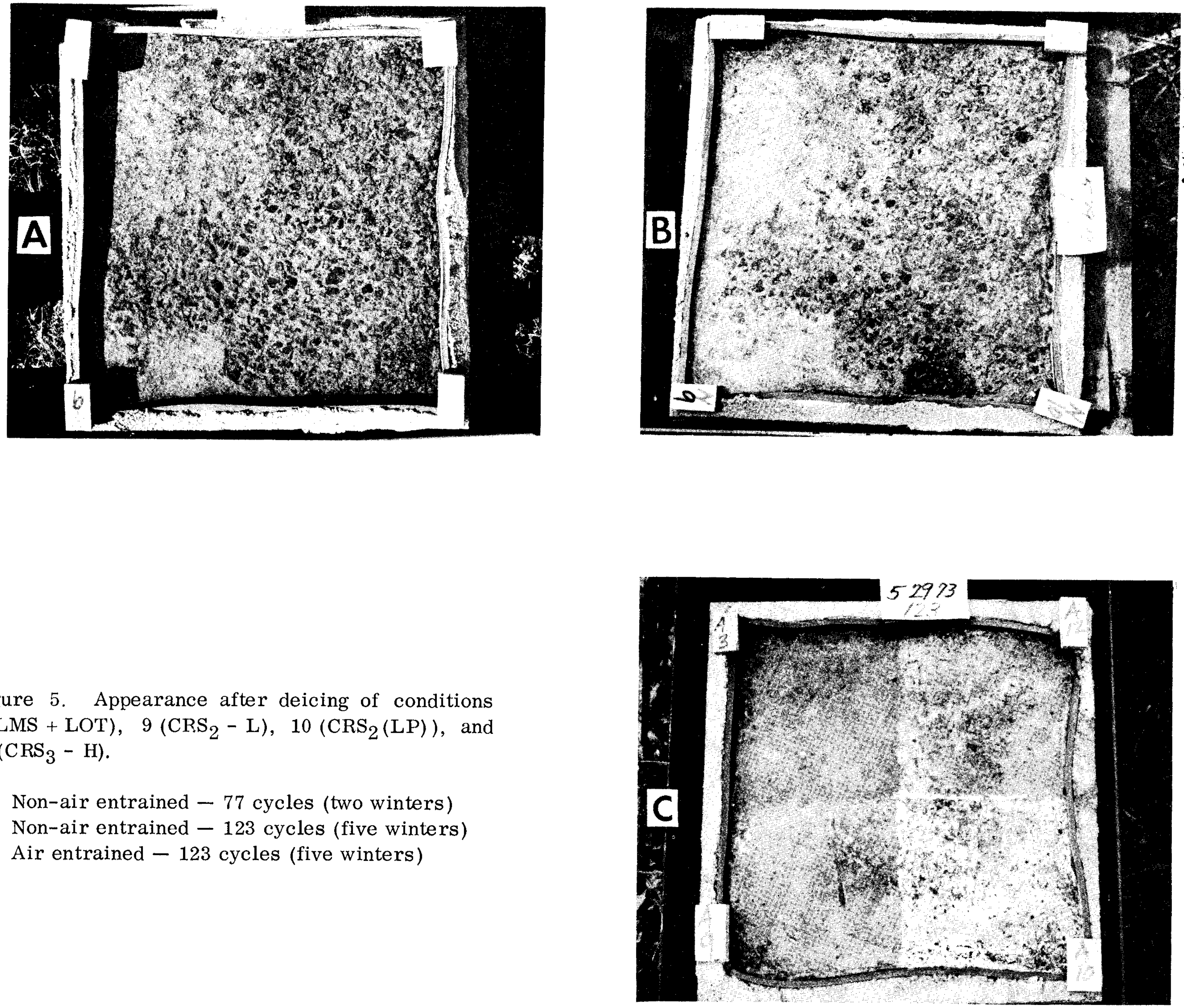
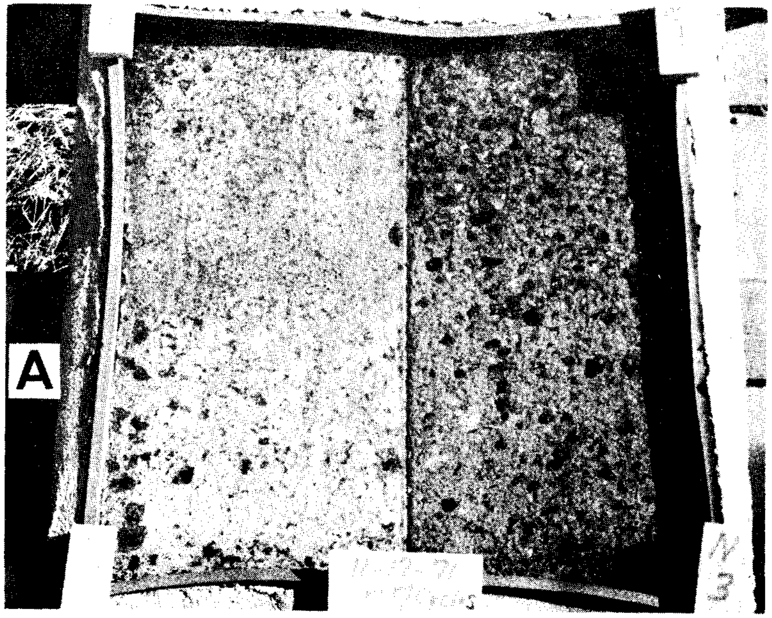
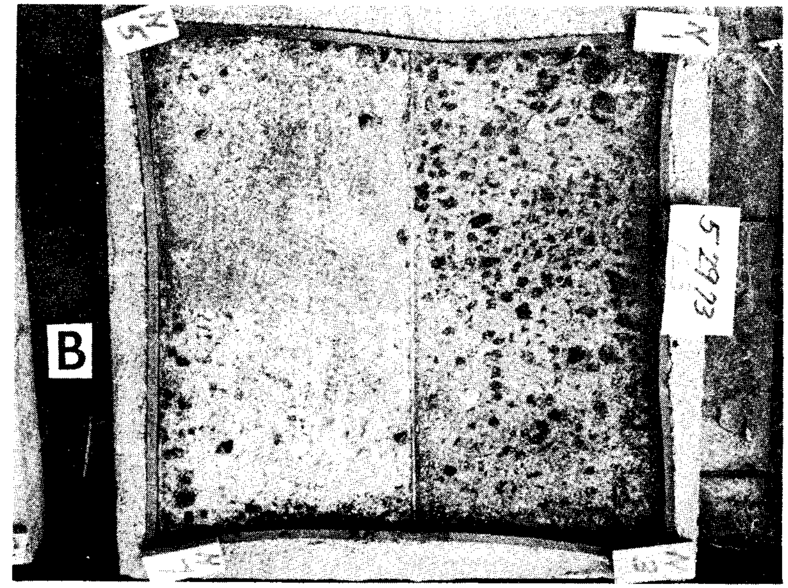


Figure 5. Appearance after deicing of conditions 3 (LMS + LOT), 9 (CRS_2 - L), 10 (CRS_2(LP)), and 12 (CRS_3 - H).

(A) Non-air entrained — 77 cycles (two winters)
(B) Non-air entrained — 123 cycles (five winters)
(C) Air entrained — 123 cycles (five winters)





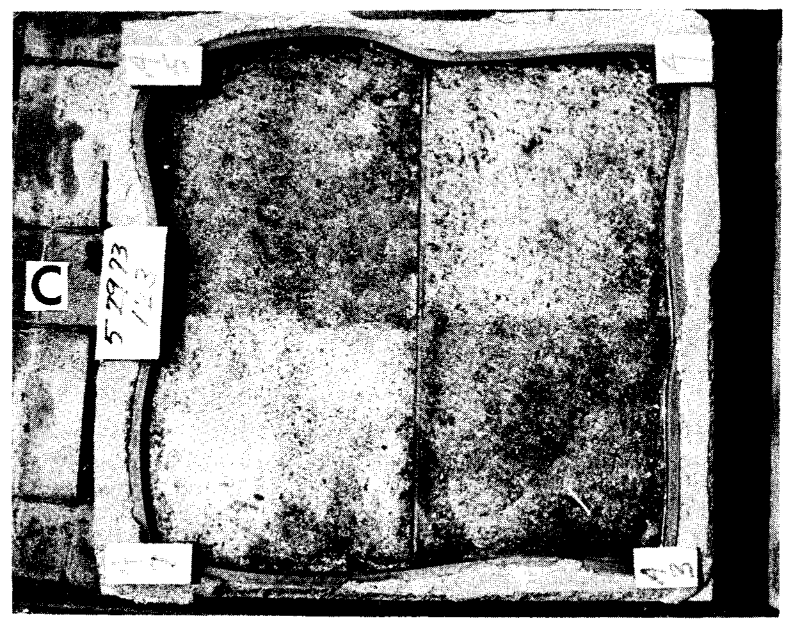
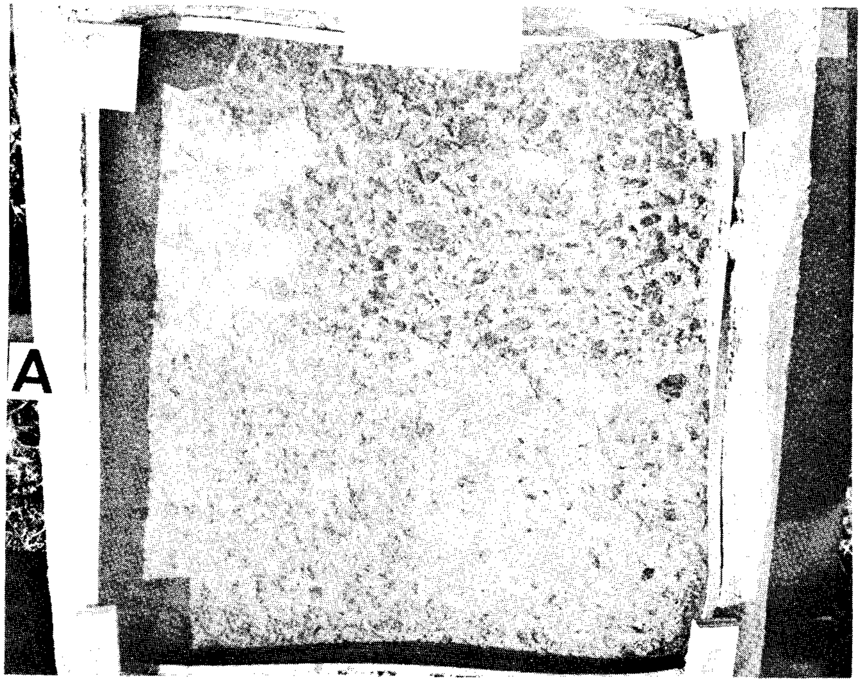


Figure 6. Appearance after deicing of conditions 1 (LMS), 3 (LMS + LOT), 5 (MEF + LMS + LOT), and 7 (MEF + LMS).

(A) Non-air entrained — 77 cycles (two winters)
(B) Non-air entrained — 123 cycles (five winters)
(C) Air entrained — 123 cycles (five winters)



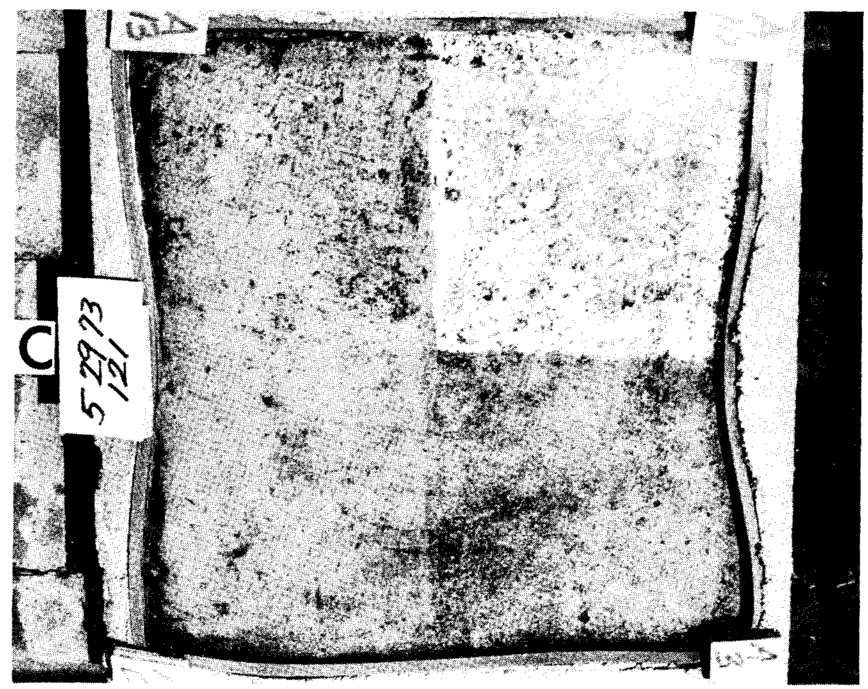


Figure 7. Appearance after deicing of conditions 0 (no cure), 3 (LMS + LOT), 10 (CRS_2 - L), and 13 (CRS_4 - L).

(A) Non-air entrained — 77 cycles (three winters)
(B) Non-air entrained — 123 cycles (five winters)
(C) Air entrained — 123 cycles (five winters)

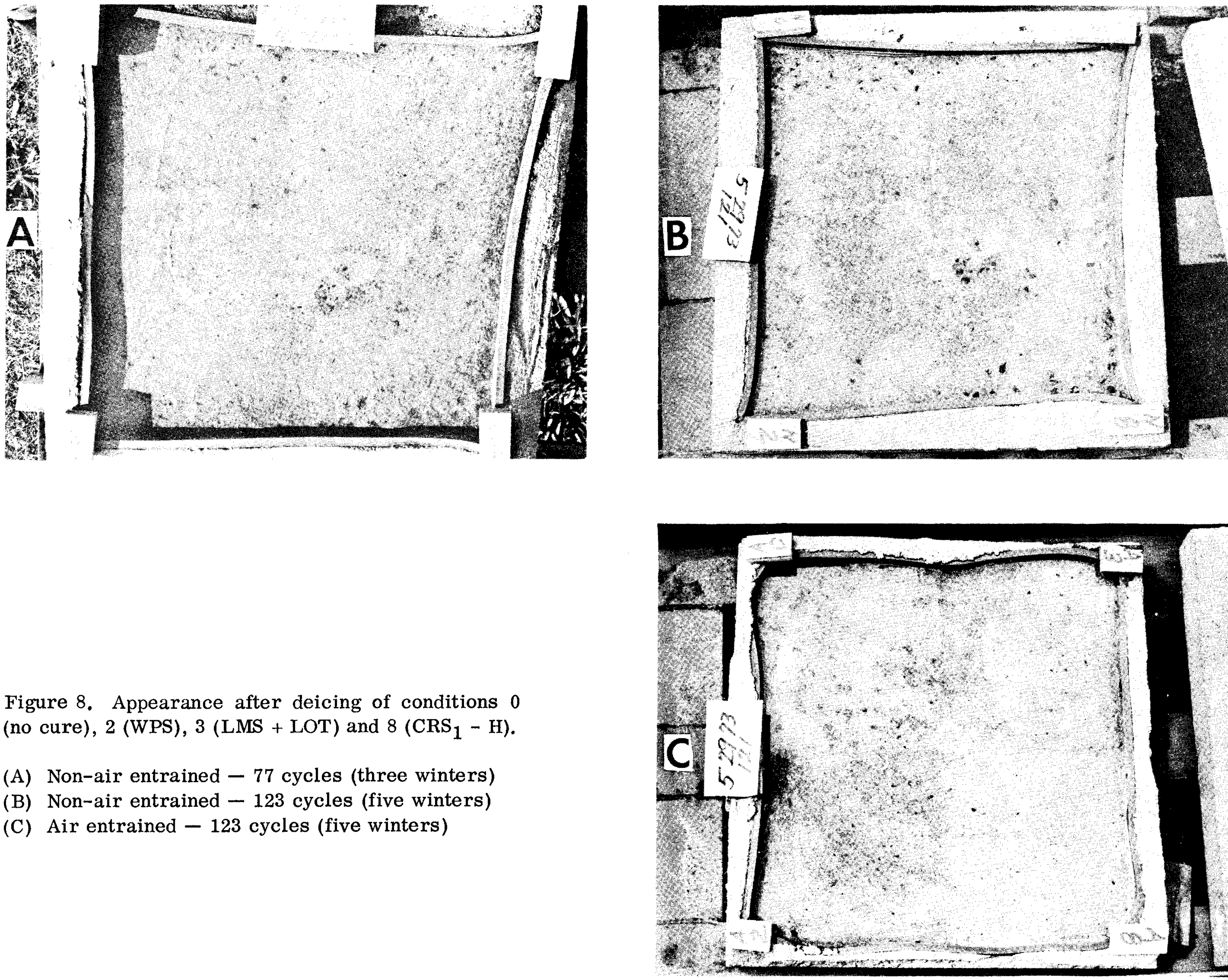


Figure 8. Appearance after deicing of conditions 0 (no cure), 2 (WPS), 3 (LMS + LOT) and 8 (CRS_1 - H).

(A) Non-air entrained — 77 cycles (three winters)
(B) Non-air entrained — 123 cycles (five winters)
(C) Air entrained — 123 cycles (five winters)

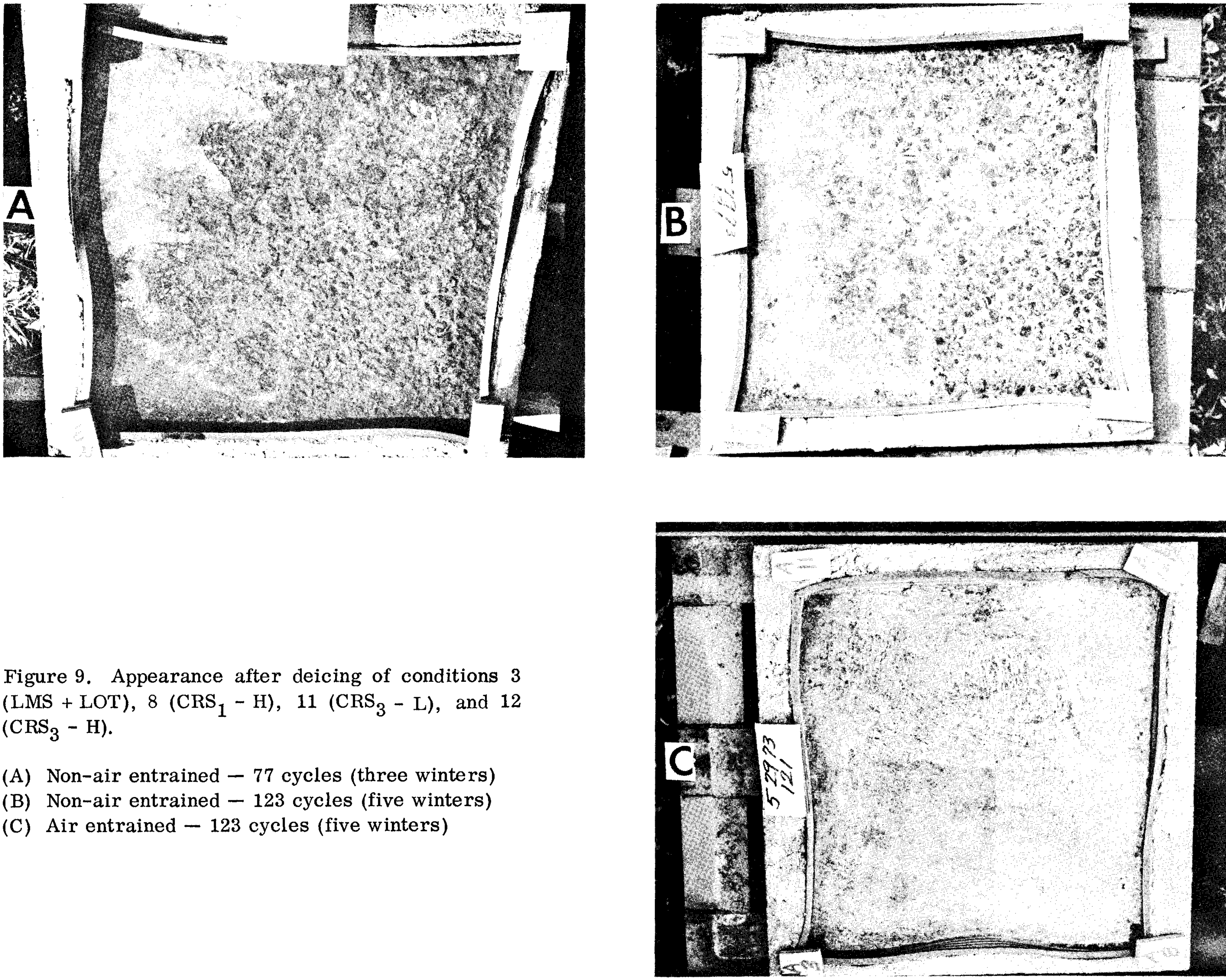


Figure 9. Appearance after deicing of conditions 3 (LMS + LOT), 8 (CRS_1 - H), 11 (CRS_3 - L), and 12 (CRS_3 - H).

(A) Non-air entrained — 77 cycles (three winters)
(B) Non-air entrained — 123 cycles (five winters)
(C) Air entrained — 123 cycles (five winters)

Complete photographs were not taken after two winters for direct comparison with Figure 3 although several slabs after two winters' exposure were shown in Part I. There was essentially no change in appearance from the second to the third winter's exposure.

Reference to Figures 3-9 will show that the major portion of the scaling appeared on the non-air entrained slabs during the first or second winter. The progression of scaling has slowed. The obvious influence of the surface treatments placed upon different quadrants is particularly evident in Figures 5, 6, 7 and 9. But by far the most dramatic comparison is between the performance of the air entrained and non air-entrained slabs (B and C in each figure). On the air entrained slabs many of the protective treatments are still intact. This reconfirms the well documented fact that the best defense against deicer scaling is properly proportioned air entrained concrete.

The project anticipated that observations of the field sections would continue for five winters. Since the outdoor slabs have achieved this length of exposure, testing of them has terminated. Analyses of the concrete for chloride content will be made and the results included in the final report.

FIELD TRIALS

Installation

This portion of the project was designed to provide a field evaluation under carefully documented conditions for several of the combinations of the materials studied in the laboratory and on the scaling slabs. Nine combinations of materials were included on 29 test panels on three structures on Interstate Route 64 in Albemarle County.

Two structures (B651 and B652), each with three spans, are on the mainline; and one (B648) carries a secondary route over I-64. Applications on the mainline structures were intended to be duplicated on the secondary structure in order to gain an indication of the effect of differences in traffic volumes and frequencies of deicer application as well as differences in the orientation of the structures.

On the basis of the preliminary screening tests the materials and combinations given in Table 7 were selected for application. When the LOT was used, it was applied without any surface preparation other than sweeping. The effectiveness of LOT applied without prior removal of the (LMS) had been demonstrated in Part I of this study.

TABLE 7

CURING AND PROTECTIVE COATING COMBINATIONS
USED IN THE FIELD TESTS

Condition	Material
1	Liquid Membrane Seal (LMS)
2	White Polyethylene Sheeting (WPS)
3	LMS plus Linseed Oil Treatment (LOT)
4	(WPS) + (LOT)
5	Monomolecular Evaporation Film (MEF) + (LMS) + (LOT)
6	MEF + WPS + LOT
7	MEF + LMS
7-A*	MEF + WPS
8	Chlorinated Rubber (CRS)

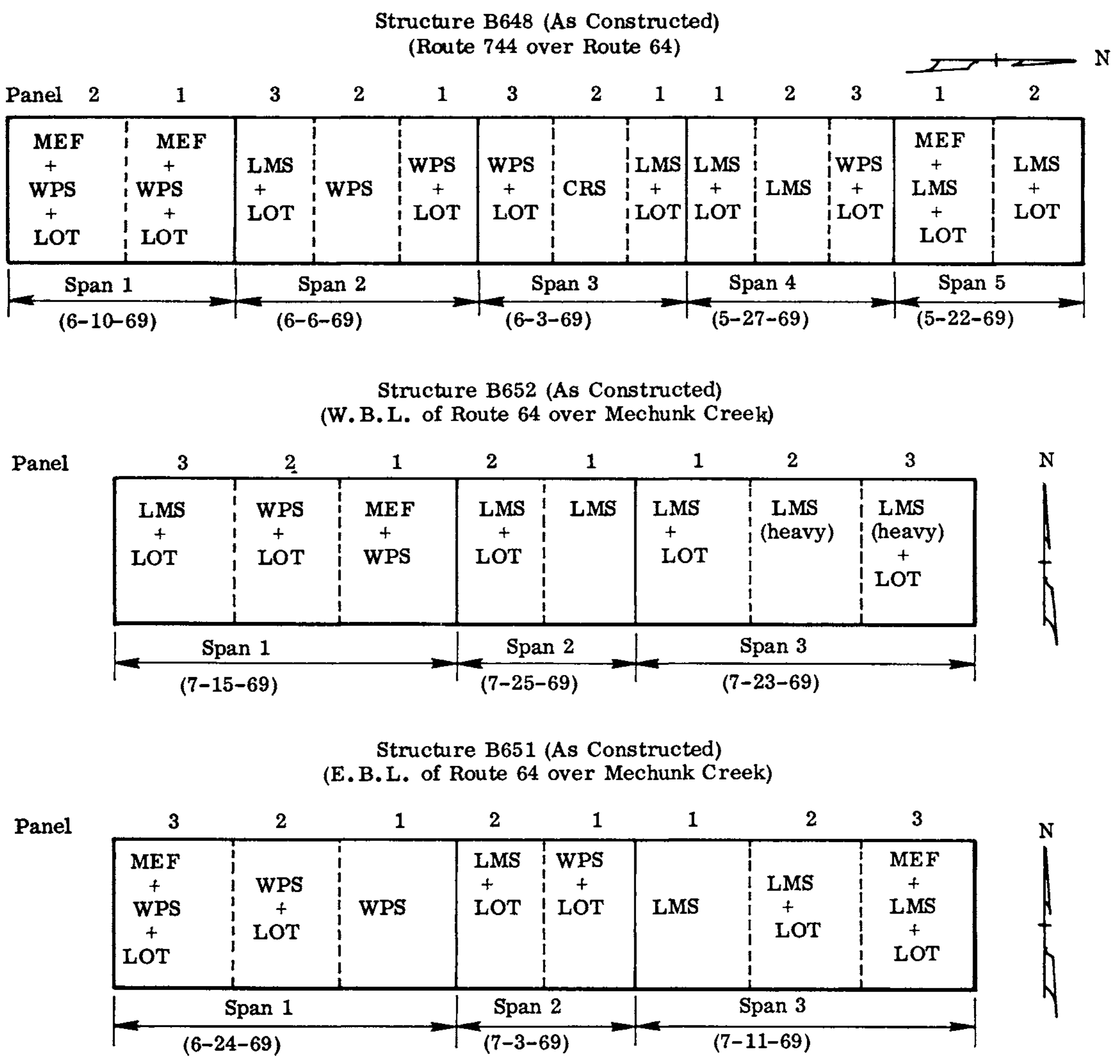
*Not evaluated in preliminary tests.

Originally, it was proposed to include several other materials but some were eliminated from consideration based upon results developed in the preliminary screening phase and several panels were interchanged to provide minimal inconvenience for the contractor. The final layout of test panels is shown in Figure 10. Within a given span, the numerical sequence of the panels coincides with the order of placing.

The decks were placed during the summer of 1969. B648 was opened to traffic in 1969 and B651 and B652 were opened in 1970. Thus, the field sections have been exposed to weathering one winter less than the outdoor slabs and the two structures which receive deicers have had two less winters of exposure than the scaling slabs.

Detailed observations of materials, construction procedures, and atmospheric conditions were described in Part II. As reflected in the conclusions from that report, contained in the Appendix, the most significant findings were:

(1) The uniformly satisfactory air contents indicated a high probability of good performance of the deck surfaces,



(WPS) — White Polyethylene Sheeting
(LMS) — Liquid Membrane Seal
(LOT) — Linseed Oil Treatment
(MEF) — Monomolecular Evaporation Film
(CRS) — Chlorinated Rubber Sealant

Figure 10. Test panels for evaluation of concrete curing and protective materials. (0064-002, B648, B651, B652, I 64-2 (55) 93.)

(2) The coverage rates of the sprayed curing materials were lower than those specified, even though complete coverage appeared to be achieved presumably because of the high solids content specified for the materials, and

(3) The performance of the chlorinated rubber was unsatisfactory, apparently because of a combination of factors including characteristics of the material used, those of the concrete on which it was placed, and the atmospheric conditions that existed during the construction.

Performance

The results from condition surveys made in 1969 and 1970 were presented in Part II. These results were stated as follows:

> Condition surveys were made on all structures in September 1969, and again in September 1970. In the initial surveys, at which time the decks had been exposed to essentially no traffic, the only significant performance characteristic was the very fine surface cracking in the center panel of Span 3 on B648. . . . After moderate traffic, the cracking was beginning to be obscured by traffic, dust, etc. and was visible only upon close inspection.
>
> At the time of the 1970 survey, B648 had been open to traffic for about one year. B651 and B652 were scheduled to be opened to traffic in three weeks and had been subjected to construction traffic for about one year. On B648 there was some very light scaling in the gutter areas of Panels 2 and 3 of Span 2. These areas appeared to be the result of removal of laitance in the areas hand finished after removal of screed rails. In Span 3 of B648, light scaling is evident over most of Panel 2, which was cured with CRS. This scaling appears to be the result of removal of the CRS and the upper surface of the concrete. Scaling is spotty, but covers about fifty percent of the surface. The southernmost one-third of the panel is less affected than the remaining portion. No defects were observed on the portions of Span 3 cured with WPS and LMS.
>
> The only defects noted on B651 and B652 were transverse cracks over each pier in the negative moment areas. There are five to seven cracks at each pier and their widths vary from very fine to moderate. These cracks apparently formed under construction traffic during paving of the adjacent roadway segments.

Surveys have been made in 1971, 1972, and 1973. The statement from the earlier report quoted above is still a valid description of the performance. There have been very slight increases in the very minor defects noted, but there has been no essential change in condition. This would be expected based upon the excellent control of the concrete during construction, particularly the levels of entrained air.

Results from measurements of skid resistance are given in Tables 8 and 9.

The skid resistance of the various sections was determined prior to and after exposure to one year's traffic. These results were presented in Part II. Skid resistance measurements were made in June 1973 using the same equipment and techniques conforming to those described in ASTM E274. The skid trailer has recently undergone modifications which will change the predictive equations previously used to estimate the stopping distances from the trailer measurements. Until these appropriate correlations can be established, skid numbers for the most recent data cannot be given. The raw numbers obtained from the trailer are given in Tables 8 and 9, along with the trailer numbers and skid numbers from the earlier tests. The skid numbers are predicted for a car stopping from 40 mph.

Although a direct comparison cannot be made until the predictive equations are available, there appears to be no difference in skid resistance that can be related to the mode of curing or protection. The progressive polishing by traffic is evident from the differences between the results from the traffic and passing lanes of B 651 and B 652.

Subsequent to the installation of field test sections considerable interest developed in a method developed by Stratfull and his associates (1958) for measuring the potential for corrosion of reinforcement. This method, which measures the electrical potential of the steel, was extensively demonstrated by the FHWA (1971) and is being used in another Council study (Smith and Newlon 1972). Potential measurements were made on the decks of two of the three structures using this method. Measurements were made on a five-foot grid over the entire surface of B 648 and over the traffic lane of of B 651. These provided 567 points for B 648 and 156 for B 651. The results are summarized in Table 10.

From the data in Table 10 there is no consistent relationship with the type of curing or protective treatment. The measurements on B 651 were more variable than those on B 648. This finding probably reflects the fact that B 651 had received applications of deicers while B 648 had not. Based upon currently accepted criteria, there is no significant potential for corrosion at this time as indicated by this method.

TABLE 8

SKID RESISTANCE FOR B 648

Condition	No. of Sections	Skid Number Private Traffic		Trailer Number After 1 Yr.		Skid Number After 1 Yr.		Trailer No. After 4 Yr.		Skid No. After 4 Yr.
		NBL	SBL	NBL	SBL	NBL	SBL	NBL	SBL	
WPS	1	48	50	58	58	47	47	69	61	*
LMS	1	57	54	55	53	45	44	69	67	
CRS	1	38	38	54	51	44	42	49	63	
MEF + LMS	1	54	54	—	—	—	—	—	—	
MEF + WPS	2	50	50	—	—	—	—	—	—	
WPS + LOT	3	—	—	54	55	44	45	69	63	
LMS + LOT	4	—	—	55	52	45	43	70	65	
MEF + LMS + LOT	1	—	—	56	49	46	41	66	63	
MEF + WPS + LOT	2	—	—	59	56	48	46	74	61	

* Predicted Skid Number not available

TABLE 9

SKID RESISTANCE FOR B 651 AND B 652

Condition	No. of Section	Trailer No. After 1 Yr.		Skid Number After 1 Yr.		Trailer Number After 3 Yr.		Skid Number After 3 Yr.
		TL	PL	TL	PL	TL	PL	
WPS	1	50	57	42	46	61	69	*
LMS	3	51	55	42	45	59	68	
WPS + LOT	3	50	55	42	45	56	67	
LMS + LOT	6	52	55	43	45	60	69	
MEF + WPS + LOT	1	50	55	42	45	58	69	
MEF + LMS + LOT	1	48	56	40	46	61	67	
MEF + WPS	1	52	57	43	46	61	69	

* Predicted Skid Number not available

TABLE 10

POTENTIAL READINGS
(In Volts)

Condition	B 648			B 651			Both Bridges	
	Average		Std. Dev.	Average		Std. Dev.	Average	Std. Dev.
1 (LMS)	4-2	.065	.041	3-1	.076	.077	.068	.054
2 (WPS)	2-2	.065	.030	1-1	.055	.074	.029	.073
3 (LMS + LOT)	2-3	.063	.047	2-2	.009	.054	—	—
	3-1	.112	.036	3-2	.061	.069	.080	.057
	4-1	.103	.047	—	—	—		
	5-2	.060	.057	—	—	—	—	—
4 (WPS + LOT)	2-1	.063	.034	1-2	.048	.056	—	—
	3-3	.097	.040	2-1	.013	.046	.068	.049
	4-3	.067	.050	—	—	—	—	—
5 (MEF + LMS + LOT)	5-1	.098	.033	3-3	.077	.071	.090	.052
6 (MEF + WPS + LOT)	1-2 } 1-1 }	.091	.045	1-3	.087	.054	.090	.047
7 (MEF + LMS)	—	—	—	—	—	—	—	—
8 (CRS)	3-2	.071	.037	—	—	—	.071	.037
Each Bridge	—	.081	.045		.042	.078	.072	.056

CONCLUSIONS

Based upon observations after additional exposure of the outdoor slabs and the field test sections, the conclusions from the two previous parts on this report were confirmed. Continued observation merits emphasis of the following:

(1) Properly entrained air is overwhelmingly the most effective defense against scaling caused by deicing chemicals. This fact is evident from the continued good performance of the outdoor exposure slabs that contain entrained air and by the absence of scaling on the bridge decks, which also were built with concrete that was uniformly and adequately air entrained.

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

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APPENDIX

CONCLUSIONS AND RECOMMENDATIONS

From Part I (Newlon 1970a)

Conclusions

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 tenacious 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.

OBSERVATIONS AND CONCLUSIONS AND RECOMMENDATIONS

From Part II (Newlon 1970b)

Observations and Conclusions

1. The operations of the contractor were efficient as reflected in the lack of rejections of concrete, the low coefficients of variation, and the timing of his various operations. The uniformity achieved will greatly reduce the influence of the concrete on the behavior of the performance of the curing and protective treatments.

2. The uniformly satisfactory air contents indicate a good probability of good performance of the deck surfaces.

3. The results of laboratory freezing and thawing tests of concrete specimens made during construction and cured, treated and stored in the field, agreed well with and confirmed the results of similar tests reported in Part I of this report. Specimens treated with linseed oil showed reduced scaling and weight loss as compared to those without the treatment and those cured with chlorinated rubber.

4. Coverage rates of sprayed curing materials were lower than those specified. It is probable that materials meeting the more restrictive requirements of the Virginia Department of Highways need not be applied at the rates of 150 - 200 ft.^{2}gal. commonly specified for materials meeting AASHO requirements.

5. Polyethylene coverings were applied later than the sprayed curing materials. The average difference was about 45 minutes.

6. Linseed oil coverage rates were very close to the target value of 0.040 gal/yd.^{2} At this coverage rate, the presence of the linseed oil is barely discernible after a month or two.

7. The performance of the chlorinated rubber was unsatisfactory. It developed a very tenacious film which blistered and reduced skid resistance by about 25 percent. It is believed that the bleeding characteristics of the concrete, which contained a water reducing-set retarding admixture, and the severe atmospheric conditions significantly contributed to this behavior; however, these are always present in bridge decks built under Virginia Department of Highways Specifications during the summer when curing requirements are most critical. The conditions did not develop in supplementary tests on a rest area using paving concrete.

8. Desirable benefits of the monomolecular film in extending time available for finishing and for use in emergency situations was qualitatively confirmed. The reduced moisture loss prior to application of curing was also verified although the observed test panels were comparatively few.

9. Difficulties with finishing were associated with days when the computed evaporation rates exceeded 0.10 lb./ft.^{2}/hr.

10. High mixture temperatures combined with high air temperatures were reflected in a measurable reduction of compressive strengths and acceleration of setting.

Recommendations

1. The currently specified curing procedures for concrete bridge decks followed by linseed oil treatments continue to be the most satisfactory of the several alternatives practically available for improved durability.

2. Application of the linseed oil treatments following curing with a white pigmented resin based compound of the type specified by the Virginia Department of Highways was once again shown to be satisfactory.

3. Procedures for utilization of the monomolecular film should be initiated so that it can be available in situations where it is needed. These include (1) days with high evaporation potential, (2) delayed application of curing, and (3) equipment breakdowns. Specification of its use for all decks is not desirable.

4. Unless penetration can be demonstrated, no further consideration should be given to materials designed to cure and protect in a single application since the two functions are mutually exclusive (i.e., one requires keeping water in while the other requires keeping it out) and they should be thought of as two separate operations.