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Bulletin 150

Effect of De-Icing Chlorides on Vehicles and Pavements

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2101 Constitution Avenue Washington 25, D. C.

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Contents

Studies of "Salt" Scaling of Concrete

GEORGE J. VERBECK, Manager, and
PAUL KLIEGER, Senior Research Engineer,
Applied Research Section, Research and Development Division
Portland Cement Association

The service record of air-entrained concrete pavements exposed to de-icing salts is excellent. However, the mechanism by which de-icers cause or accelerate surface scaling of non-air-entrained concrete is unknown. Furthermore, there is a not complete understanding of why entrained air is beneficial in this regard.

Although field experience indicates that air entrainment is a practical remedy for surface scaling, some laboratory tests indicate that under certain extremely severe conditions entrained air does not give complete protection.

The objective of this study is to provide more information on the effect of type and concentration of de-icer, curing condition of concrete, air entrainment, and other variables on the surface scaling of concrete. This information should lead to a better understanding of the effect of these variations and should be of assistance in the establishment of further remedial measures.

● THIS study comprised surface scaling tests of non-air-entrained and air-entrained concretes made with two different combinations of fine and coarse aggregate. The first is a manufactured trap rock sand and trap rock coarse aggregate from Dresser, Wisconsin; the second is a predominantly dolomitic natural sand from Elgin, Illinois, and a highly siliceous crushed natural gravel from Eau Claire, Wisconsin.

The concretes had cement contents of approximately 6 sacks per cu yd and slumps of 2½ to 3½ in. The maximum size of coarse aggregate was 1 in. The air-entrained concretes had air contents of about 7 percent, the top of the range of 4 to 7 percent which would normally be desirable for concretes with this maximum size of aggregate. It was anticipated that certain of the test procedures used might represent extremely severe exposure conditions and that a high inherent durability would be required in order to reveal more clearly differences in performance under these conditions. Some concretes at lower air contents were prepared for comparison.

Companion concrete specimens, after different preliminary curing procedures, were subjected to surface scaling tests using various concentrations of either calcium chloride, sodium chloride, ethyl alcohol, or urea as de-icers. Three different scale test procedures were used.

Materials

The cement used in these tests was a blend prepared from four different brands of Type I cements purchased in the Chicago area. Tables 1, 2, and 3 show the chemical composition, calculated potential compound composition, and the results of various physical tests of this Type I blend.

Two aggregate combinations were used. The first combination was a sand and crushed stone manufactured from a siliceous rock (trap rock) from Dresser, Wisconsin. The second combination consisted of a predominantly dolomitic natural sand from Elgin, Illinois, and a highly siliceous crushed gravel from Eau Claire, Wisconsin. Grading, specific gravity, absorption, and thermal coefficient of linear expansion for all aggregates are shown in Table 4. These aggregates have a good service record. The combination of completely manufactured aggregate was included in order to evaluate the influence of both natural and manufactured aggregates on the results of the scaling tests.

All aggregates were air dried and screened into various size fractions, six sizes for the fine aggregate and three for the coarse aggregate. When preparing a batch, the sizes were recombined to yield the gradings shown in Table 4. In order to provide a high degree of control over the total mixing water in a batch, the aggregates were weighed in the air-dried condition (moisture content known) and, 18 to 20 hours prior

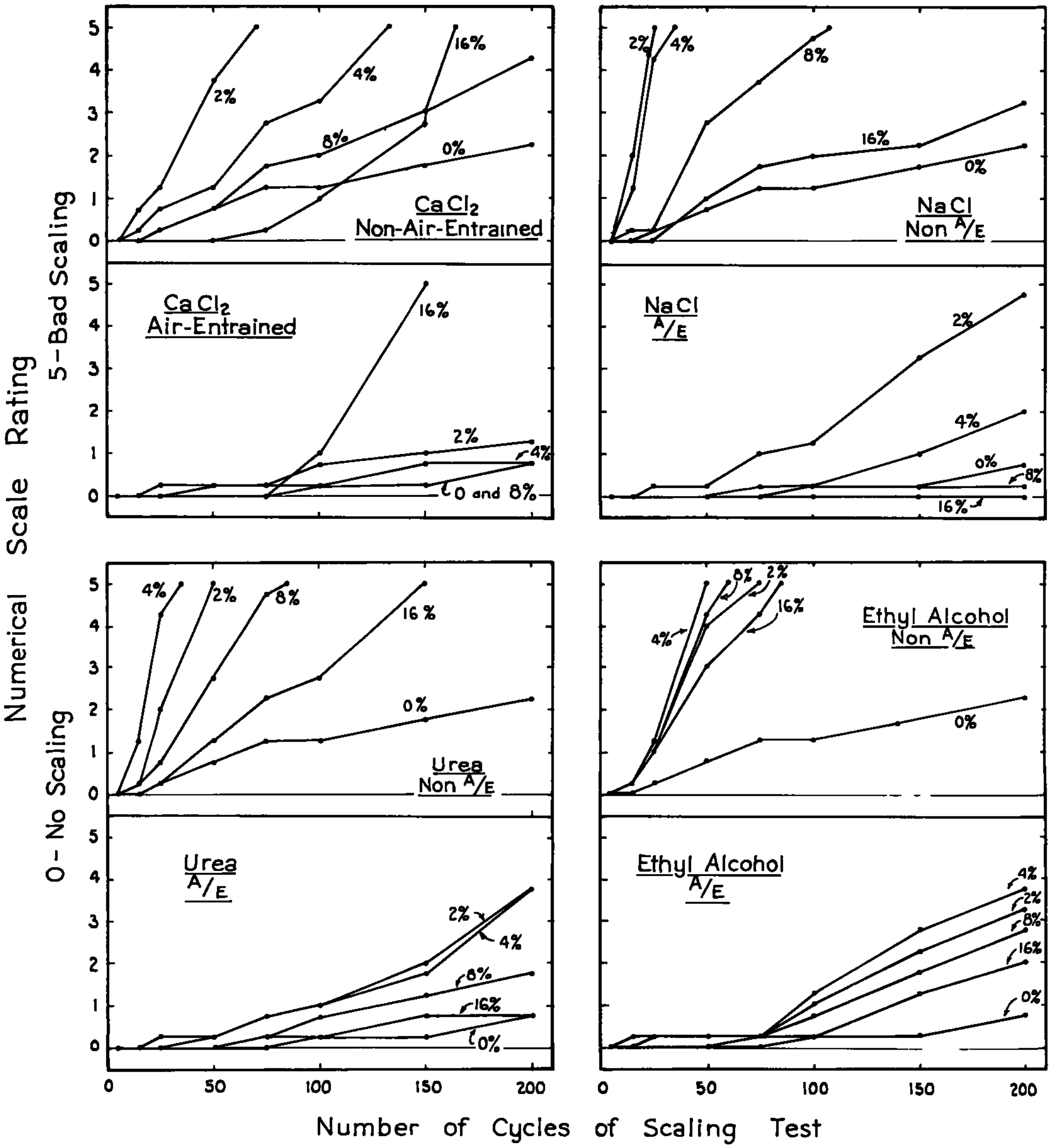

Figure 1. Effect of amount of de-icer on surface scaling on non-air-entrained and air-entrained concretes. Scale Test Procedure No. 2: Thaw solution refrozen on slab surface. Aggregates: Elgin, Illinois sand and Eau Claire, Wis. crushed gravel (1-in. top size) Specimens: 3 by 6 by 15-in. slabs cured continuously moist for 31 days prior to test. Cement Content: 6 sacks per cu yd. Slump: 2 1/2 to 3 1/2 in. Air Contents: Non A/E - 2.2 percent, A/E - 7.4 percent.

to use, inundated with a known amount of water. Excess water was drawn off and weighed immediately prior to mixing the concrete.

Neutralized Vinsol resin in solution was added at the mixer when preparing the air-entrained concrete.

The de-icers used in these scaling tests were commercial flake calcium chloride, sodium chloride, urea, and ethyl alcohol.

Fabrication of Specimens

Each batch contained 1.30 cu ft of concrete. Batches were mixed for 2½ minutes in an open-tub mixer of 1¾-cu ft capacity. A slump test and an air content determination by the pressure method were made on each batch of concrete.

Generally, two specimens were made for a particular test condition. In a few cases, three specimens were made. In all cases, these companion specimens were made on different days.

The specimens used in the scaling test were slabs 3 in. in depth and 6 by 15 in. in area. These slabs were cast in watertight steel molds, the molds were filled in two

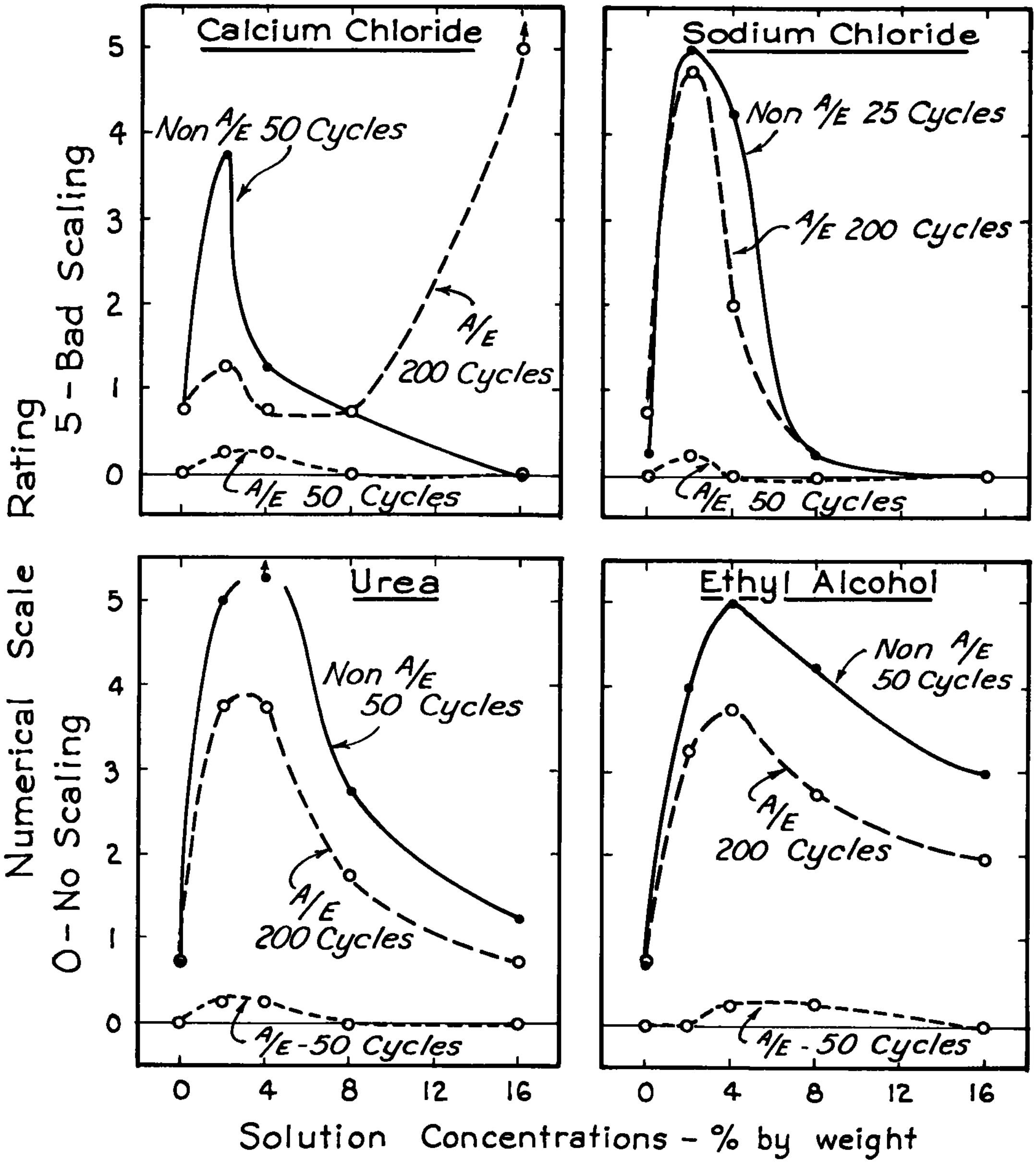

Figure 2. Effect of amount of de-icer on surface scaling (test procedure No. 2 - thaw solution refrozen).

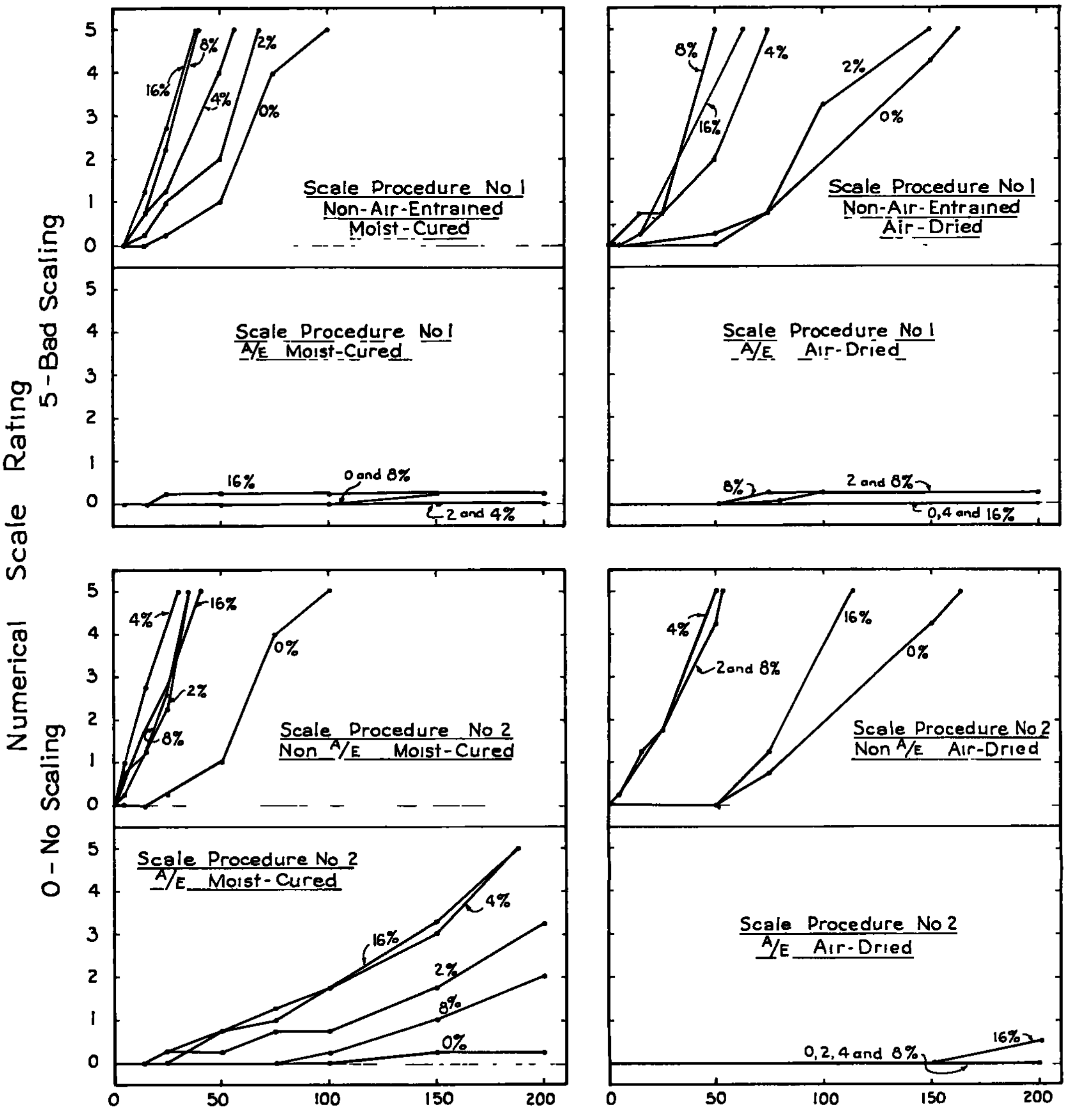

Figure 3. Effect of scale test procedure, concentration of de-icer and curing on the surface scaling of non-air-entrained and air-entrained concretes. Curing: See Table 10 for details. De-Icer: Commercial flake $CaCl_2$. Aggregate Dresser, Wisconsin trap rock (crushed) fine and coarse aggregate (1-in. top size). Cement Content: 6 sacks per cu yd. Slump: 2 to 3 in. Air Contents: Non-A/E - 2.1 percent, A/E - 7.1 percent.

layers of equal depth, and each layer was rodded 50 times with a ⅝-in. diameter hemispherical tip tamper. Immediately after casting, the surface was given a final finish with a wood float, and the specimens were then covered with two thicknesses of damp burlap (not in contact with surface) and a tarpaulin. At the age of 20 to 24 hours, the molds were stripped. The slabs were equipped with an air-entrained mortar dike (approximately ¾ by ¾ in. in section) around the edges of the finished surface, and then the slabs were placed in the moistroom.

Curing Conditions

Companion specimens were subjected to two different sets of curing conditions:

1. Continuously moist cured at 73 deg F for 28 days, followed by an additional 3 days in the moistroom with the surface of the slab covered with water ¼ in. in depth. These will be referred to hereafter as moist cured.

2. Continuously moist cured at 73 deg F for 14 days, then 14 days in the air of the laboratory at 73 deg F and 50 percent relative humidity, followed by an additional 3

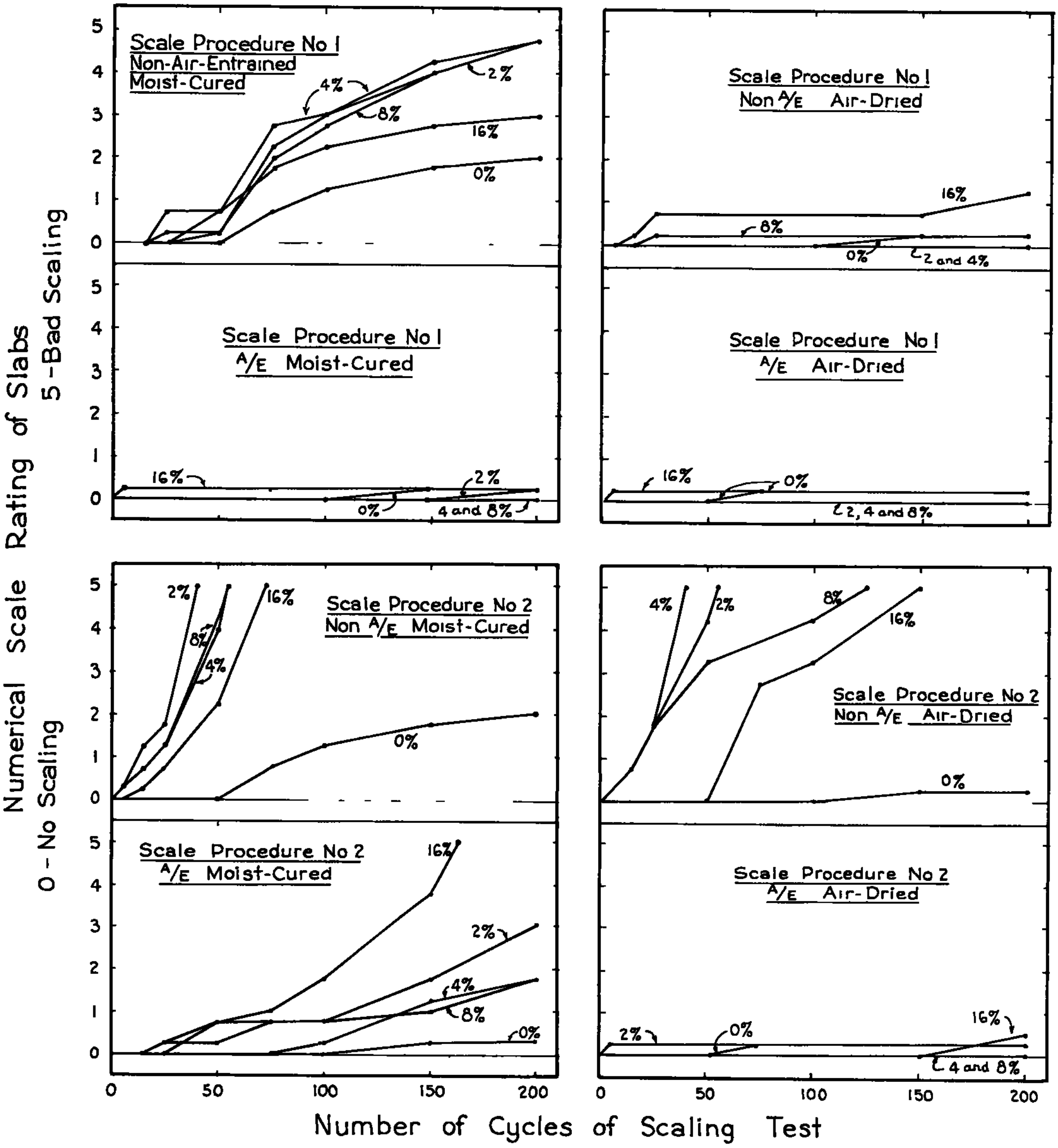

Figure 4. Effect of scale test procedure, concentration of de-icer and curing on the surface scaling of non-air-entrained and air-entrained concretes. Curing: See Table 9 for details. De-Icer: Commercial flake $CaCl_2$. Aggregate: Elgin, Illinois sand and Eau Claire, Wis. crushed gravel (1-in. top size). Cement Content: 6 sacks per cu yd. Slump: 2 to 3 in. Air Contents: Non-A/E - 2.2 percent, A/E - 7.1 percent.

days in air with the surface of the slab covered with water ¼ in. in depth. These will be referred to hereafter as air dried.

Test Methods

Three different procedures were followed in determining the surface scaling resulting from the application of different deicers:

Procedure 1. After freezing 250 ml of water on the surface of a concrete slab

TABLE 1

CHEMICAL COMPOSITION OF TYPE I BLEND

PCA Lot No. 18681. Blend of equal parts by weight of four Type I cements purchased locally.

Major Components	%
SiO_2	20.66
Al_2O_3	5.89
Fe_2O_3	2.84
Total CaO	62.90
MgO	2.96
SO_3	2.16
Ignition Loss	1.58
Minor Components	**%**
Mn_2O_3	0.28
Free CaO	1.09
Insoluble Residue	0.18
Alkalies:	
Na_2O	0.20
K_2O	0.54
Total as Na_2O	0.56

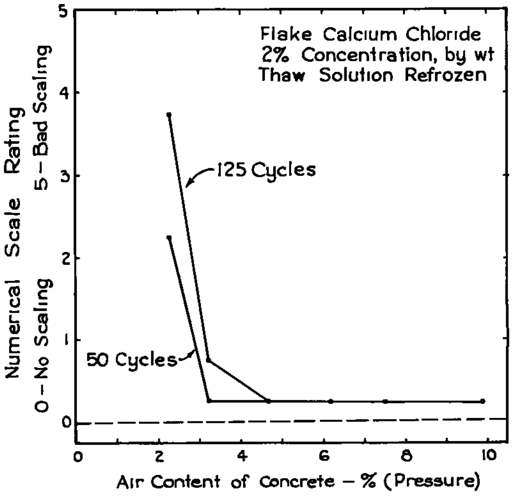

Figure 6. Effect of entrained air on resistance to surface scaling (scale test prodedure No. 2). Aggregates Elgin, Ill. sand and Eau Claire, Wis. gravel. Cement Content: 6 sacks per cu yd. Slump: 3 in. Curing: 14 days moist, 14 days in air plus 3 days in air with water on top surface.

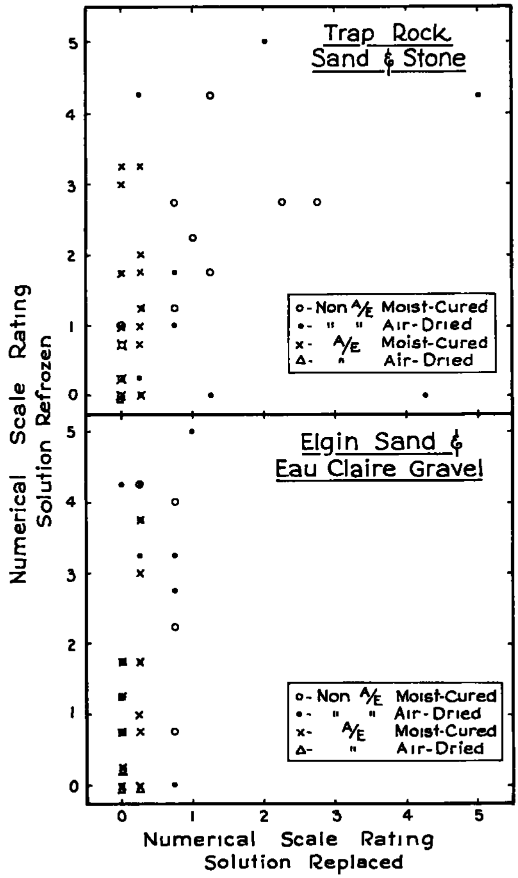

Figure 5. Comparison of scale test procedures.

TABLE 2

POTENTIAL COMPOUND COMPOSITION OF CEMENT

Compound	% by Wt
C_3S	44.8
C_2S	25.4
C_3A	10.8
C_4AF	8.7
$CaSO_4$	3.67
Free CaO	1.09

in a room maintained at -20 deg F, the slab was removed to a room maintained at 70 deg F and de-icer was applied immediately to the ice. After thawing, the resulting solution was removed, the surface was rinsed and 250 ml of water was placed on the surface for the next freeze portion of the cycle. The total time in freezer was approximately 18 hours. The total time in the thawing room was approximately 6 hours.

Procedure 2. The same conditions existed as in No. 1 except that the particular solution of de-icer and water was kept on the specimen during both the freeze and thaw portions of the cycle.

TABLE 3

MISCELLANEOUS PHYSICAL TESTS OF CEMENT

Tests made in accordance with ASTM Standards current in December, 1951 (specific gravity determined in water rather than kerosene)

Specific surface, sq cm per gram	
Wagner	1710
Blaine	3310
Passing No. 325-mesh, %	91.1
Specific gravity, in water	3.182
Normal consistency, %	24.5
Time of setting: Vicat	
Initial	3 hr 15 min
Final	6 hr 20 min
Gillmore	
Initial	4 hr 20 min
Final	6 hr 30 min
Autoclave expansion, %	0.135
Air content, 1-4 standard mortar, %	8.2

TABLE 4

DATA ON AGGREGATES

Fine Aggregate										
Source and Type	% Retained on Sieve No. Indicated						Fineness Modulus	Bulk Sp Gr, S. S. D.[a]	24-Hr Absorption, % by Wt	Mean Linear Thermal Coeff of Expansion,[b] x10^6/°F
	4	8	16	30	50	100				
Dresser, Wis (crushed)	0	5	30	55	80	92	2.62	2.918	1.14	4.74
Elgin, Ill. (natural)	0	18	33	57	87	95	2.90	2.645	2.25	5.73

Coarse Aggregate							
Source and Type	% Retained on Sieve Indicated				Bulk Sp Gr, S. S. D.[a]	24-Hr Absorption, % by Wt	Mean Linear Thermal Coeff of Expansion,[b] x10^6/°F
	1-in.	¾-in.	⅜-in.	No. 4			
Dresser, Wis (crushed)	0	25	70	100	2.980	0.20	4.74
Eau Claire, Wis (natural)	0	25	70	100	2.693	1.33	5.94

[a] Saturated, surface-dry.
[b] Dilatometer method.

TABLE 5

CONCRETE MIX DATA

Cement	Cement Content, sacks per cu yd	Net W/C, gal per sack	% Sand, Abs Volume	Slump in	Air Content, % (pressure)
Dresser, Wis Fine and Coarse Aggregate (Crushed)					
Type I	6.0	7.2	46	2 2	2.1
Type I + Vinsol Resin	5.8	6.9	42	3.0	7.1
Elgin, Ill. Fine Aggregate and Eau Claire, Wis Coarse Aggregate (Natural)					
Type I	6.0	5.2	41	3.2	2.2
Type I + Vinsol Resin	6.0	4.8	36	3.3	7.2

The sodium chloride, calcium chloride, and urea solutions were replaced with fresh solutions once each week. The ethyl alcohol solutions were replaced twice each week.

Procedure 3. In this procedure, the specimen was frozen with the surface damp (no excess water). On removal to the thawing room, the surface was covered with 250 ml of solution containing the particular amount and type of de-icer required. After completion of thawing, the solution was removed, and the surface was rinsed and drained completely for the next freeze portion of the cycle.

TABLE 6

RESULTS OF SCALING TESTS WITH DIFFERENT DE-ICERS

Scale Test: Thaw solution refrozen (Procedure 2)
Specimens: 3- by 6- by 15-in. slabs cured continuously moist for 31 days prior to start of test
Cement Content: 6 sacks per cu yd, 2½ to 3½-in. slump
Aggregates: Elgin, Illinois sand and Eau Claire, Wisconsin gravel (1-in. top size)
Air Contents: Non-A/E - 2.2%, A/E - 7.4%

Concentration of Soln after Thawing, % by Wt	Numerical Scale Rating at Indicated Number of Cycles															
	Non-Air-Entrained Concrete								Air-Entrained Concrete							
	5	15	25	50	75	100	150	200	5	15	25	50	75	100	150	200
No De-Icer																
0	0	0	0+	1-	1+	1+	2-	2+	0	0	0	0	0	0+	0+	1-
Flake Calcium Chloride																
2	0	1-	1+	4-	(70)[a]				0	0	0+	0+	0+	1-	1	1+
4	0	0+	1-	1+	3-	3+	(133)		0	0	0	0+	0+	0+	1-	1-
8	0	0	0+	1-	2-	2	3	4+	0	0	0	0	0	0+	0+	1-
16	0	0	0	0	0+	1	3-	(164)	0	0	0	0	0	1	(150)	
Sodium Chloride																
2	0	2	(25)						0	0	0+	0+	1	1+	3+	5-
4	0	1+	4+	(35)					0	0	0	0	0+	0+	1	2
8	0	0+	0+	3-	4-	5-	(108)		0	0	0	0	0+	0+	0+	0+
16	0	0	0	1	2-	2	2+	3+	0	0	0	0	0	0	0	0
Urea																
2	0	0+	2	(50)					0	0	0+	0+	1-	1	2	4-
4	0	1-	3	(35)					0	0	0	0+	1-	1	2-	4-
8	0	0+	1-	3-	5-	(85)			0	0	0	0	0+	1-	1+	2-
16	0	0	0+	1+	2+	3-	(150)		0	0	0	0	0+	0+	1-	1-
Ethyl Alcohol																
2	0	0+	1+	4	(75)				0	0	0	0	0+	1	2+	3-
4	0	0+	1+	(50)					0	0+	0+	0+	0+	1+	3-	4-
8	0	0+	1	4+	(60)				0	0	0+	0+	0+	1-	2-	3-
16	0	0+	1	3	4+	(85)			0	0	0	0	0+	0+	1+	2

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

The following listing shows which de-icers and which concretes were used in these three procedures:

Procedure 1 - Calcium Chloride
    Both aggregate combinations
    Non-air-entrained and air-entrained
    Both curing conditions
Procedure 2 - Calcium Chloride
    Both aggregate combinations
    Non-air-entrained and air-entrained
    Both curing conditions
    Sodium Chloride, Urea, and Ethyl Alcohol
    Elgin sand and Eau Claire gravel
    Non-air-entrained and air-entrained
    Moist-cured concretes only
Procedure 3 - Calcium Chloride
    Dresser trap rock sand and coarse aggregate
    Non-air-entrained
    Both curing conditions

At intervals during the scaling test, the surfaces were examined carefully, rated as to extent and depth of scale and assigned a numerical rating as follows: 0 - no scaling, 1 - very slight scaling, 2 - slight to moderate scaling, 3 - moderate scaling, 4 - moderate to severe scaling, and 5 - severe scaling.

TABLE 7

RESULTS OF SCALING TESTS - TRAP ROCK FINE AND COARSE AGGREGATE

Specimens: 3- by 6- by 15-in. slabs De-Icer: Flake calcium chloride
Curing: (a) 31 days moist (b) 14 days moist, 14 days in air plus 3 days in air with water on surface
Cement Content: 6 sacks per cu yd, 2 to 3 in. slump
Aggregates: Dresser, Wis. trap rock fine and coarse aggregate (1-in. top size)
Air Content: Non-A/E - 2.1%, A/E - 7.1%

Concentration of Soln after Thawing % by Wt	Numerical Scale Rating at Indicated Number of Cycles															
	Thaw Solution Replaced (Procedure 1)								Thaw Solution Refrozen (Procedure 2)							
	5	15	25	50	75	100	150	200	5	15	25	50	75	100	150	200
								Non-Air-Entrained - Moist Cured								
0	0	0	0+	1	4	(100)[a]			-	-	-	-	-	-	-	-
2	0	0+	1	2	(68)				1-	1+	2+	(35)				
3	0	1-	1	3	(68)				-	-	-	-	-	-	-	-
4	0	1-	1+	4	(57)				1	3-	4+	(30)				
6	0	1-	2	(43)					-	-	-	-	-	-	-	-
8	0	1-	2+	(40)					0+	1+	3-	(35)				
10	0	1+	2+	(39)					-	-	-	-	-	-	-	-
16	0	1+	3-	(39)					0	2-	3-	(40)				
								Non-Air-Entrained - Air Dried								
0	0	0	0	0	1-	2	4+	(163)	-	-	-	-	-	-	-	-
2	0	0	0	0+	1-	3+	(150)		0+	1	2-	4+	(53)			
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	0	0+	1-	2	(75)				0+	1+	2-	(50)				
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0+	1-	1-	(50)					0+	1	2-	4+	(53)			
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	0	0+	1+	4-	(63)				0	0	0	0	1+	4-	(113)	
								Air-Entrained - Moist Cured								
0	0	0	0	0	0	0	0+	0+	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0	0	0	0+	0+	1-	1-	2-	3+
3	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
4	0	0	0	0	0	0	0	0	0	0	0+	1-	1	2-	3	(188)
6	0	0	0	0	0	0	0	0+	-	-	-	-	-	-	-	-
8	0	0	0	0	0	0	0+	0+	0	0	0	0	0	0+	1	2
10	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
16	0	0	0+	0+	0+	0+	0+	0+	0	0	0	1-	1+	2-	3+	(188)
								Air-Entrained - Air Dried								
0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0+	0+	0+	0	0	0	0	0	0	0	0
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0	0	0	0	0+	0+	0+	0+	0	0	0	0	0	0	0	0
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0[b]

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.
[b] At 325 cycles entire surface scaled off abruptly as a layer about 1/16 in. thick..

TABLE 8

RESULTS OF SCALING TESTS - ELGIN SAND AND EAU CLAIRE GRAVEL

Specimens: 3- by 6- by 15-in. slabs De-Icer: Flake calcium chloride
Curing: (a) 31 days moist (b) 14 days moist, 14 days in air plus 3 days in air with water on surface
Cement Content: 6 sacks per cu yd, 2- to 3-in. slump
Aggregates: Elgin, Ill. sand and Eau Claire, Wis.crushed gravel (1-in. top size)
Air Content: Non-A/E - 2.2%, A/E - 7.1%

Concentration of Soln after Thawing % by Wt	Numerical Scale Rating at Indicated Number of Cycles															
	Thaw Solution Replaced (Procedure 1)								Thaw Solution Refrozen (Procedure 2)							
	5	15	25	50	75	100	150	200	5	15	25	50	75	100	150	200
Non-Air-Entrained - Moist Cured																
0	0	0	0	0	1-	1+	2-	2	-	-	-	-	-	-	-	-
2	0	0	0	0+	2+	3	4	5-	0+	1+	2-	(40)				
3	0	0	0	0+	2-	3-	4	5-	-	-	-	-	-	-	-	-
4	0	0	0	1-	3-	3	4+	5-	0+	1-	1+	4	(55)			
6	0	0	0+	0+	3-	4-	(138)[a]		-	-	-	-	-	-	-	-
8	0	0	0+	0+	2	3-	4	5-	0+	1-	1+	4+	(55)			
10	0	0	1-	1-	2+	3-	4	5-	-	-	-	-	-	-	-	-
16	0	0	1-	1-	2-	2+	3-	3	0	0+	1-	2+	(72)			
Non-Air-Entrained - Air Dried																
0	0	0	0	0	0	0	0+	0+	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0	0+	1-	2-	4+	(55)			
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	0	0	0	0	0	0	0	0	0+	1-	2-	(40)				
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0	0	0+	0+	0+	0+	0+	0+	0+	1-	2-	3+	4-	4+	(125)	
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	0	0+	1-	1-	1-	1-	1	1+	0	0	0	0	3-	3+	(150)	
Air-Entrained - Moist Cured																
0	0	0	0	0	0	0	0+	0+	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0+	0	0	0+	0+	1-	1-	2-	3
3	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0+	1+	2-
6	0	0	0	0	0	0	0	0+	-	-	-	-	-	-	-	-
8	0	0	0	0	0	0	0	0	0	0	0+	1-	1-	1-	1	2-
10	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
16	0+	0+	0+	0+	0+	0+	0+	0+	0	0	0	1-	1	2-	4-	(163)
Air-Entrained - Air Dried																
0	0	0	0	0	0+	0+	0+	0+	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0	0+	0+	0+	0+	0+	0+	0+	0+
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	0+	0+	0+	0+	0+	0+	0+	0+	0	0	0	0	0	0	0	0[b]

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

[b] Surface shell scaled off, about 1/16-in. thick. Discontinued at 237 cycles.

TABLE 9

RESULTS OF SCALING TESTS - TRAP ROCK FINE AND COARSE AGGREGATES

Test Cycle: Slabs frozen with surface damp (no excess of water). Thaw solution placed directly on surface at start of thawing period (Procedure 3)
Specimens 3- by 6- by 15-in slabs De-Icer Flake calcium chloride
Curing (a) 31 days moist (b) 14 days moist, 14 days in air plus 3 days in air with water on surface
Cement Content. 6 sacks per cu yd, 2- to 3-in. slump, non-air-entrained.
Aggregates. Dresser, Wisconsin, trap rock fine and coarse aggregates (1-in. top size).
Air Content: 2.1%

Concentration of Thaw Solution % by Wt	Numerical Scale Rating at Indicated Number of Cycles 25	50	75	100	150	25	50	75	100	150
0	0	0	0	0	0	0	0	0	0	0
2	0+	0+	0+	0+	0+	0	0	0	0	0
4	0+	0+	0+	0+	0+	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0

DISCUSSION OF RESULTS

Effect of Concentration of Different De-Icers on Scale Resistance

The work of Arnfelt[1] has indicated that concretes frozen and thawed while immersed in solutions of different materials showed maximum deterioration at relatively low solution concentrations and that further increase in concentration resulted in a decrease in deterioration. Field observations in this country appeared to indicate that scaling of concrete pavements increased with increase in the amount of calcium chloride or rock salt used as de-icers.

Before making a general attack on the problem of surface scaling, it was desirable to substantiate Arnfelt's work using four materials as de-icers: calcium chloride, sodium chloride, urea, and ethyl alcohol. The concretes used in this portion of the study were made with the Elgin sand and Eau Claire gravel. Further information on these concretes is shown in Table 5.

These concretes were moist cured prior to test. Scale test Procedure 2 was used to simulate in some respects Arnfelt's tests in which the concretes were frozen and thawed while immersed in the solution. In Procedure 2, the solution of water and de-icer remained on the surface of the specimen during both the freeze and thaw portions of the cycle.

Table 6 and Figure 1 show the effect of concentration of solution on the scale resistance of these concretes. The non-air-entrained concretes show severe scaling much sooner than the air-entrained concretes, with the rate of scaling much greater at solution concentrations of 2 and 4 percent than at 0, 8, and 16 percent. These data confirm the observations of Arnfelt. Figure 2 shows more clearly the greater amounts of surface scaling occurring with the intermediate and relatively low concentrations of de-icers.

These data are important with regard to the mechanism by which scaling occurs. The opinion advanced most frequently is that the mechanism is primarily a chemical attack. If this were true, surface scaling would be expected to increase with an increase in concentration of de-icer. These tests show that this is not so. In addition, the de-icers used in these tests are dissimilar chemically. It appears, therefore, that the mechanism producing surface scaling is primarily physical.

Effect of Test Procedure on Scale Resistance

Tables 7 and 8 show the results of scaling tests of non-air-entrained and air-entrained concretes made with the Dresser trap rock aggregate and the Elgin sand and Eau Claire gravel, using both Procedure 1 and 2 and calcium chloride as the de-icer. In Procedure 1 the thaw solution is replaced with fresh water for the freeze portion of the cycle; in Pro-

TABLE 10

RESULTS OF SCALING TESTS - ELGIN SAND AND EAU CLAIRE GRAVEL

Scale Test Thaw solution refrozen (Procedure 2)
De-Icer. Flake calcium chloride, 2% solution concentration (by weight).
Specimens. 3- by 6- by 15-in slabs cured 14 days moist, 14 days in air plus 3 days in air with water on surface.
Cement Content 6 sacks per cu yd, 3-in slump
Aggregates: Elgin, Illinois sand and Eau Claire. Wisconsin gravel (1-in. top size).
Air Content. Agent added at mixer to produce range in air contents shown

Air Content of Concrete %	Numerical Scale Rating at Indicated Number of Cycles 5	15	25	50	75	100	125
2.3	1-	1	2-	2+	3+	3+	4-
3.2	0+	0+	0+	0+	1-	1-	1-
4.7	0+	0+	0+	0+	0+	0+	0+
6.2	0	0	0+	0+	0+	0+	0+
7.5	0	0	0	0	0+	0+	0+
9.9	0	0	0+	0+	0+	0+	0+

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[1] "Damage on Concrete Pavements by Wintertime Salt Treatment," Arnfelt, Harry, Meddelande 66, Statens Vaginstitut, Stockholm, 1943.

cedure 2 the thaw solution is refrozen. Companion concretes were cured continuously moist or moist plus a period of air drying prior to test.

Figures 3 and 4 show the numerical scale ratings as a function of the calcium chloride solution concentration for these concretes and test procedures during 200 cycles of test. Where scaling has developed, note that, in general, the more severe scaling occurs at some intermediate and relatively low solution concentration. The scaling which occurs when the thaw solution is refrozen is generally more severe than when the solution is replaced. The usual laboratory procedure of replacing the thaw solution with fresh water (Procedure 1) apparently does not represent the most severe exposure attainable. For the purpose of determining the scale resistance for the most severe exposure conditions, the laboratory test should involve refreezing the thaw solution (Procedure 2). There appears to be no general relationship between the scaling produced by Procedures 1 and 2. Figure 5 shows only that Procedure 2 is generally much more severe than Procedure 1.

Some non-air-entrained concretes, both moist cured and air dried, made with the Dresser trap rock aggregate were tested for scale resistance using Procedure 3. The results are shown in Table 9. In test Procedure 3 the concrete specimen is frozen with the surface damp (no excess water) and the surface is then thawed with the appropriate calcium chloride solution. The scale ratings obtained during 150 cycles of test are shown in Table 9. No scaling has developed on any of these concretes exposed to calcium chloride solutions concentrations ranging from 0 to 16 percent, except for some very slight scale on the moist cured concretes exposed to the 2 and 4 percent solution concentrations. These very same concretes would have scaled rapidly under the test conditions of Procedure 1 and 2. It would appear that the scale resistance of the surface was enhanced by the rapid drying of the top surface of the slab, such as would occur when a warm wet specimen is placed in cold atmosphere having a low moisture content.

Effect of Prior Curing on Scale Resistance

Pavements rarely obtain curing comparable to continuous moist curing in the laboratory. Generally, after a minimum prescribed curing period, the concrete is exposed to drying conditions with subsequent rewetting at intervals by rainfall. On rewetting, however, the amount of water reabsorbed rarely equals that lost during the drying period, unless the period of wetting is exceptionally long. This results in a lowered degree of saturation.

The effect on scale resistance of continuous moist curing and a curing period comprised of both moist curing and air drying is shown in Figures 3 and 4. In almost all instances, continuous moist curing resulted in concrete surfaces less resistant to surface scaling than the concretes which underwent some air drying prior to test. For the non-air-entrained concretes, although the period of air drying reduced the amount of scaling, the resistance of the surfaces was not satisfactory, with the exception of the air-dried concrete made with the Eau Claire aggregate which was tested for scale resistance by Procedure 1, replacing the thaw solution with fresh water.

The air-dried air-entrained concretes made with both combinations of aggregates showed only very slight scaling during 200 cycles of Procedure 1 or 2. Despite the severity of Procedure 2, the period of air drying of the air-entrained concretes produced concretes resistant to 200 cycles of this test procedure. Concrete pavements may sometimes be subjected simultaneously to conditions of exposure similar to that of Procedure 2 and to low de-icer concentrations. Despite this particularly severe combination of exposure conditions, air-entrained concrete pavements have an excellent performance record, which may in part be the result of periodic air drying of the pavement surface. Laboratory tests should therefore include tests on air-dried concretes.

Effect of Amount of Air on Scale Resistance

From over-all durability considerations, the desired air content for concretes made with aggregate of 1-in. maximum size is in the range of 4 to 7 percent based on previous laboratory tests and field experience. The air-entrained concretes used in this study had air contents near the upper limit of this range, since preliminary tests had indicated that a combination of continuous moist curing followed by exposure to low de-icer concentrations in scale test Procedure 2 (thaw solution refrozen) was an extremely severe test. Additional concretes were prepared in order to evaluate the scale resistance at various air contents within this range. Figure 6 shows some of these data which indicate that the concretes with 4.7 percent air content showed surface scale ranging from none to very slight as evidenced by a scale rating of 0+ at 125 cycles. For concretes cured and tested in the same manner (see Table 8) and made with the same aggregate and an air content of 7.1 percent, the scale rating at 125 cycles was identical. This indicates that an air content at the middle of the recommended range of 4 to 7 percent for this type of concrete performed as well as the concrete with 7.1 percent air content. Further details of these tests are shown in Table 10.

SUMMARY AND CONCLUSIONS

These laboratory tests provide new information on the effect of de-icers on the surface scaling of non-air-entrained and air-entrained concretes, each made with two different coarse aggregates, cured differently, and tested under a variety of scale test procedures. While these tests did not provide data from which a complete concept of the mechanism involved can be drawn, they have provided a basis for further study, some of which is already under way.

Based on these laboratory tests, the following statements appear valid:

1. Chemically dissimilar materials, inorganic or organic, salts or non-salts, which function as de-icers also cause "salt" scaling, which more appropriately should be called "de-icer scaling."
2. Relatively low concentrations (of the order of 2 to 4 percent by weight) of de-icer produce more surface scaling than higher concentrations or the absence of de-icer.
3. On the basis of the foregoing, it appears that the mechanism of surface scaling is primarily physical rather than chemical.
4. Surface scale test procedures greatly influence the rate of scaling. The most severe test procedure yet discovered is one in which the concrete is alternately frozen and thawed with the de-icer solution remaining on the top surface of the concrete rather than being replaced with fresh water prior to each freezing.
5. No scaling was produced when the concrete surface had no free water on it during the freeze portion of the cycle.
6. A period of air drying of the concretes prior to the start of scaling tests increased the resistance to surface scaling. Air-entrained concretes treated in this manner were immune to the most severe scale test procedure for more than 200 cycles of test.
7. With the fixed cement content and slump as specified by these tests, the concrete made with the Elgin sand and Eau Claire gravel showed more resistance to surface scaling than the concretes made with the Dresser trap rock fine and coarse aggregate.

Effect of De-Icing Salts on the Corrosion of Automobiles

RALPH J. WIRSHING, Head, Chemistry Department
Research Staff, General Motors Corporation

●THE use of salt on roads and streets has become a controversial subject primarily in relation to the increase in the amount of corrosion to automobiles, conduits and other equipment made of ferrous metals. However, by far, the greater number of complaints concern the rusting of automobiles.

The job of the highway engineer is to keep the roads open to traffic, and there is no argument against the fact that icy roads play havoc with the orderly movement of cars and commercial vehicles.

This nation has become dependent upon the motor vehicle for the movement of people, materials, food stuff and other perishables, and any interference with the rapid transfer from origin to destination can bring about large monetary losses.

For example, Glenn C. Richards, General Superintendent of the Department of Public Works of the City of Detroit has given the following estimates as to the savings resulting from the use of salt on the streets of Detroit: (a) Loss of work caused by people getting to work late because of icy conditions. Based on the average person being one-half hour late, the total loss to Detroit employers is $1,589,000 per icy day or approximately $55,000,000 per year (approx 35 storms per year). (b) Loss to cartage and traveling companies, due to their being able to move at half their regular speed, $2,000,000 or $7,000,000 per year. (c) Loss in business — sale of merchandise — customers unable to get to stores, which do about half their regular volume, $766,000 per day or $426,000,000 per year. (d) Department of Street Railways — loss in income, $67,000 per day or $2,300,000 per year.

Other items might be included which would bring the total to over $100,000,000 annually. As against this the cost of removing snow each year amounts to about $875,000, of which $300,000 is spent for salt.

The foregoing figures do not include the cost of accidents which can and do bring injury and even death to drivers, passengers and pedestrians.

It can be seen that it is essential and even imperative that something be done to remove snow and ice, or at least treat it in some way so that traffic can move at as nearly a normal rate as possible.

A number of methods have been proposed and tried; scraping, plowing, the spreading of sand and cinders and the actual melting by the use of chemicals. All of these methods have disadvantages, as highway engineers well know. After numerous tests, made in many localities, the most widely accepted method is the spreading of rock salt.

Much has been written about the corrosive effect of salt on automobiles, but in no case are figures presented. One article could be quoted which stated that salt is not harmful to the finish on cars. While this is true, the statement is misleading. Salt is not harmful to the lacquers and enamels used on present day automobiles, but when the finish is broken in any way and the salt solution is allowed to reach the underlying metal then the trouble begins. Once the corrosion has started it continues to spread under the paint film, lifting it, exposing the rusted metal and causing the unsightly appearance to which the customer objects.

As far back as 1943 we began a series of surveys, in various cities in the United States, to study the performance in service of the finish used on our cars. This was in an effort to determine any weaknesses and to enable us to take corrective measures to improve their performance.

While we were continually making tests in the laboratory to study our finishing materials, these accelerated tests are never as conclusive as the actual behavior in the hands of the customer.

In these surveys we visited parking lots and examined not only cars built by General Motors, but competitors makes as well. While it was our original intention to be concerned only with the actual film failures, we soon became aware of the fact that corrosion

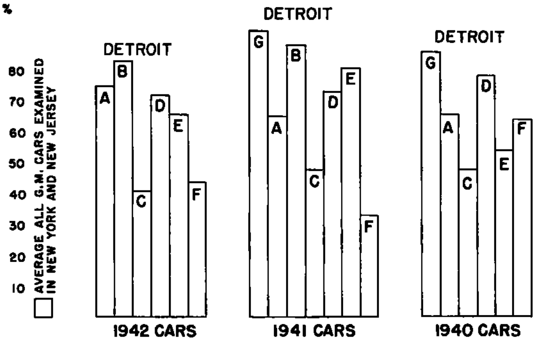

Figure 1. Percent of cars examined showing corrosion failure at fender welt joint - 1943.

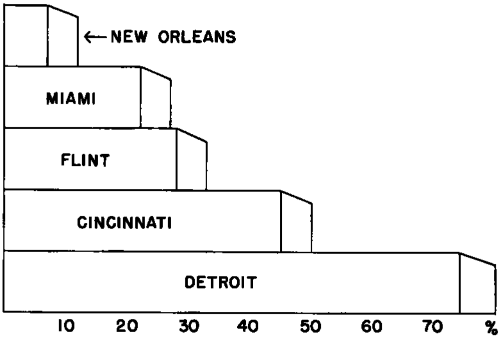

Figure 2. Percent of cars examined showing corrosion at fender welt joint - 1946.

was a problem that could not be overlooked. We, therefore, began to make notations of the number of cars that evidenced this type of failure at certain points on the cars that seemed to be vulnerable.

It soon became evident that the percent of cars showing corrosion failure was much higher in cities using salt than in the warmer climates where ice removal was not required.

In our first survey we examined cars in Detroit (where salt was used) and in several small communities in New York and New Jersey that did not use salt. The results are shown in Figure 1. Here we show the percent of cars examined that evidences corrosion at the fender welt joint. This is the juncture where the rear fender was attached to the body. Cars one, two and three years old were examined and the results in Detroit are compared with results in New York and New Jersey. The letters on the various blocks were used to designate different makes of cars.

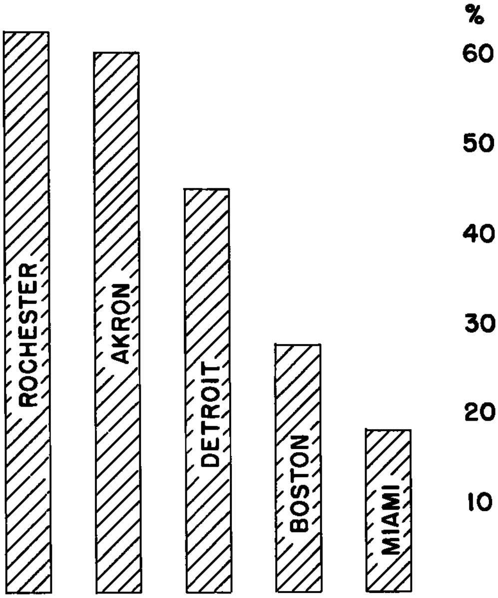

Figure 3. Effect of inhibitors used with salt spread on streets in Akron and Rochester, N.Y. No inhibitor used in Detroit, very little salt used in Boston, none in Miami. Failures at fender welt area - 1951.

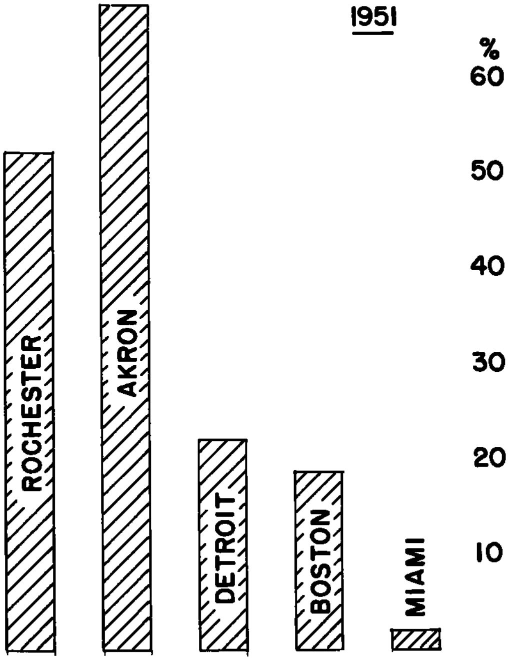

Figure 4. Effect of inhibitors used with salt spread on streets in Akron and Rochester, N.Y. No inhibitor used in Detroit, very little salt used in Boston, none in Miami. Failures at gravel deflector joint 1951.

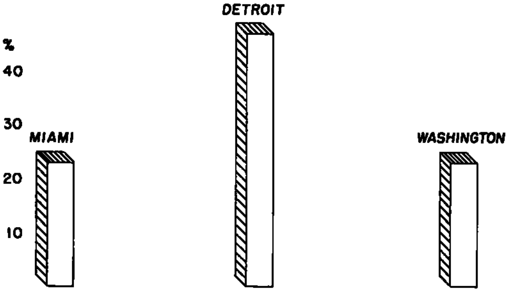

Figure 5. Corrosion failure at rear gravel deflector, all cars - 1953.

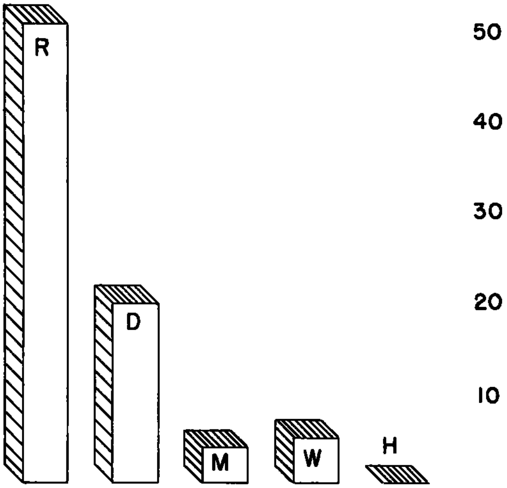

Figure 6. Effect of de-icing salt used on streets. Corrosion on front gravel deflector on one year old cars - Rochester, Miami, Washington, Houston and Detroit - 1955.

In Figure 2 are shown results of a survey made in 1946. Here again the fender welt joint was the area considered, and it can be seen that in Detroit, the only city where considerable salt was used, the incidence of corrosion was considerably higher.

From the evidence presented thus far it can readily be seen that corrosion is much more prevalent in cities where salt is used.

By the time the 1951 survey was undertaken there was much agitation and many were advocating the addition of so-called inhibitors to the salt spread on the streets. It is true that under certain carefully controlled conditions in the laboratory it can be shown that these inhibitors have some effect in reducing corrosion. For example, if you carefully clean and weigh two steel test panels, and then subject one to a salt solution and the other to a salt solution

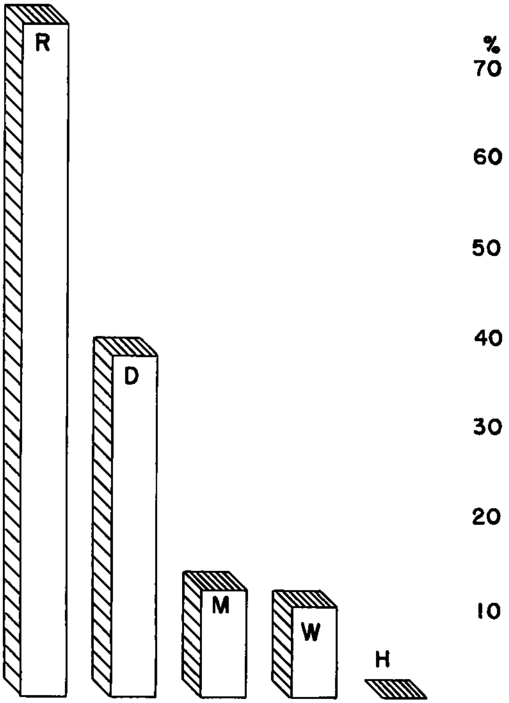

Figure 7. Effect of de-icing salt used on streets. Corrosion on front gravel deflector on two year old cars - Rochester, Miami, Washington, Houston and Detroit - 1955.

H-HOUSTON (No Salt)------------154 cars
W-WASHINGTON (No Salt)----------669 "
M-MIAMI (No Salt)----------------745 "
D-DETROIT (Salt)----------------937 "
R-ROCHESTER (Salt+ Inhibitor)---- 704 "

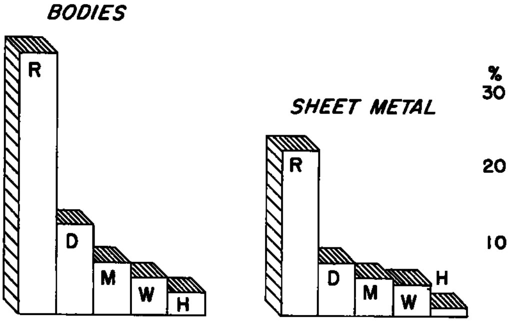

Figure 8. Effect of de-icing salt used on streets. Corrosion at gravel deflector joint on one year old cars - 1955.

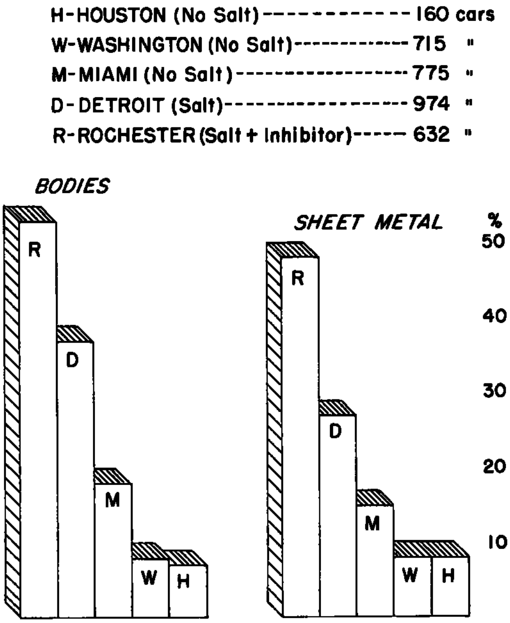

Figure 9. Effect of de-icing salt used on streets. Corrosion at gravel deflector joint on two year old cars - 1955.

containing an inhibitor and carefully control the ratio of inhibitor to salt, the one exposed to the straight salt solution will lose a little more weight than the other.

However, we believe this to be of little interest to the car owner. He is concerned only with the appearance of rust at any point on his car. At this time we included in our survey Akron and Rochester where inhibitors were being used at that time. The observations made in these two cities were then compared with those obtained in Detroit, where salt without inhibitor was used. We also included Boston, which used less salt than Detroit and Miami where, obviously, no salt was used. The percent of cars showing corrosion at the fender welt area in these four cities are shown in Figure 3.

At the same time we collected data on failures at the gravel deflector joint. The gravel deflector is the horizontal piece between the body and the rear bumper. These results are shown in Figure 4.

Results of the 1953 survey which included Miami, Washington and Detroit are shown in Figure 5 and again in Detroit, where salt is used, the percent of cars showing corrosion at the gravel deflector is much higher.

In the 1955 survey observations were made in Detroit, Miami, Washington, Houston and Rochester with the latter being the only city where an inhibitor was used with the salt. The percent of one year old cars examined that showed corrosion on the front gravel deflector is shown in Figure 6. To show how this type of corrosion increases as the car ages the results on two year old cars is shown in Figure 7.

The amount of corrosion observed in the 1955 survey at the rear gravel deflector joint, both on the body and the deflector itself, is shown for one year old cars in Figure 8 and for two year old cars in Figure 9.

It is true that the severity of conditions varies from year to year and from city to city. This makes comparison open to some criticism. However, it is believed that since repeated surveys continue to show the same results there is little to be said from the car owners viewpoint in favor of the use of inhibitors.

Automobile manufacturers are aware of the problem. They realize that salt is an accelerator of corrosion, but they also know that its use on the streets helps to prevent injury and death to their potential customers. They are also keenly interested in the development of inhibitors used with salt that would reduce the amount of corrosion. By changes in design such as the elimination of the fender welt joint and the gravel deflector and by improvements in protective coatings, they hope to minimize the susceptibility to corrosion.

Curing Requirements for Scale Resistance Of Concrete

PAUL KLIEGER, Senior Research Engineer, Applied Research Section
Research and Development Division, Portland Cement Association

The record of field performance of air-entrained concrete pavement with regard to surface scaling resulting from the use of de-icers is excellent. Approximately 15 years of field experience, together with extensive laboratory tests, have shown that the use of entrained air has solved an important pavement problem which was becoming more serious with the increasing use of chemicals for ice control.

The problem of the earliest age at which de-icers, such as calcium chloride, may safely be used on new air-entrained concrete pavements is of concern to highway engineers. This concern stems from previous practical experience with non-air-entrained concrete pavements. Shortly after the introduction of the use of de-icers, field surveys indicated that older non-air-entrained pavements resisted surface scaling better than relatively new non-air-entrained pavements. This led to the establishment of minimum ages at which de-icers might safely be used; however, the various highway departments were far from agreement on these age requirements. A recent survey of highway department practices, conducted by Committee B-7 of the Highway Research Board, indicates that these minimum ages ranged from a few months up to 5 and 10 years. Despite the excellent performance record of air-entrained concrete pavements, many states are applying the same age requirements to both types of concrete pavement.

Only a limited amount of information is available bearing directly on this problem (1). This study was undertaken, therefore, to provide additional information which might interest those concerned with the use of de-icers on new air-entrained concrete pavements.

● THE study consisted of laboratory surface scaling and strength tests of both non-air-entrained and air-entrained concretes. Types I, II, and III portland cements were used in preparing these concretes having essentially identical cement contents and slumps. Concretes with Type I and II cements were made both with and without calcium chloride added as an accelerator. Air entrainment was accomplished by adding an agent at the mixer.

The concretes were fabricated at one temperature level (40 deg F) to simulate cold weather construction. Specimens were cured at three different temperature levels (73 deg F, 40 deg F, and 25 deg F) for different periods of time before making strength determinations and testing for scale resistance. Curing periods prior to testing ranged from one day to 60 days, the selected intervals depending upon type of cement, presence or absence of an accelerator, and temperature of curing.

Materials

The cements used in these tests, all meeting applicable ASTM requirements, were obtained from commercial sources. The Type I cement was a blend prepared from equal parts of four different brands, the Type II was an individual brand, and the Type III cement was a blend of equal parts of two different brands. Tables 1, 2, 3, and 4 show the chemical compositions, calculated potential compound compositions, and the results of various physical tests of the cements and mortars made.

The fine aggregate was a predominantly dolomitic natural sand from Elgin, Illinois. The coarse aggregate, a highly siliceous crushed gravel from Eau Claire, Wisconsin, was selected as representative of sound, durable coarse aggregates commonly used in concrete pavement construction. Grading, specific gravity, absorption, and thermal coefficient of linear expansion are shown in Table 5.

TABLE 1

CHEMICAL COMPOSITION OF CEMENTS

Chemical analyses of cements made in accordance with ASTM method of test current in May, 1954. Sodium oxide and potassium oxide by flame photometry, ASTM C228-49T.

Cement		Major Components - %							Minor Components - %					
												Alkalies		
Lot No.	ASTM Type	SiO_2	Al_2O_3	Fe_2O_3	Total CaO	MgO	SO_3	Ign Loss	Mn_2O_3	Free CaO	Insol Res	Na_2O	K_2O	Tot. as Na_2O
18868	I	21.44	5.94	2.67	63.10	2.62	2.05	1.07	0.26	0.83	0.18	0.22	0.66	0.65
18914	II	21.26	5.08	3.72	61.61	3.77	1.70	1.61	0.07	0.86	0 18	0.26	0.75	0.75
18893	III	19.77	5.88	2 61	64.77	1.76	2.83	1.59	0.19	1.55	0.13	0.16	0.46	0.46

TABLE 2

POTENTIAL COMPOUND COMPOSITION OF CEMENTS

Corrected for free CaO

Cement		Calculated Compount Composition - %					
Lot No.	ASTM Type	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	Free CaO
18868	I	40.9	30.6	11.2	8 1	3.49	0 83
18914	II	41.4	29.7	7.2	11.3	2 89	0.86
18893	III	55.8	14.6	11 1	7.9	4 81	1 55

Aggregates were air-dried and screened into various size fractions — six sizes for the fine aggregate and three for the coarse aggregate. When batching, the sizes were recombined to yield the gradings shown in Table 5. Aggregates were weighed in the air-dried condition (moisture content known) and, 18 to 20 hours prior to use, inundated with a known amount of water. Prior to mixing, excess water was drawn off and weighed to permit calculating the net water-cement ratios.

Neutralized Vinsol resin in solution was added at the mixer when preparing the air-entrained concretes. Commercial flake calcium chloride was used both as the de-icer and the accelerator.

TABLE 3

MISCELLANEOUS PHYSICAL TESTS OF CEMENTS

Tests made in accordance with ASTM methods of test current in May, 1954. Each value is the average of two or more determinations.

Cement		Fineness					Time of Setting				
		Spec Surface sq cm per g						Gilmore			
Lot No.	ASTM Type	Wagner	Blaine	Passing 325 Mesh %	Specific Gravity	Normal Consistency %	Vicat h. m.	Initial h. m.	Final h. m.	Autoclave Exp %	Air Content % 1-4 Mortar
18868	I	1630	3230	89.0	3.160	24.5	3:35	4:00	5:35	0.11	9.2
18914	II	1710	3275	90.0	3.180	23.0	4:20	5:25	7:10	0.13	9.3
18893	III	2520	5120	98.4	3.114	29.0	1:30	2:00	4:20	0.11	5.0

TABLE 4

STRENGTH TESTS OF MORTARS

Briquets: ASTM C190-49. Cubes: ASTM C109-52.
Each value is the average of three specimens, each made on a different day.

Cement		Tensile Strength, 1-3 Std Sand Mortar Briquets - psi				Compressive Strength, 2-in. Plastic Mortar Cubes - psi			
Lot No.	ASTM Type	1d	3d	7d	28d	1d	3d	7d	28d
18868	I	185	325	415	485	810	1850	3080	4460
18914	II	150	240	355	450	600	1420	2230	4000
18893	III	355	425	520	545	2110	3720	5200	6400

TABLE 5

DATA ON AGGREGATES

Elgin, Illinois, Sand

Grading - % Retained On Sieve No. Indicated						Fineness Modulus	Bulk Specific Gravity S. S. D.[a]	24-Hr Absorption % by Wt	Mean Linear Thermal Coeff of Expansion[b]
4	8	16	30	50	100				
0	18	33	57	87	95	2.90	2.645	2.25	5.73x10^{-6}

Eau Claire, Wisconsin, Gravel

Grading - % Retained On Sieve Size Indicated				Bulk Specific Gravity S. S. D.[a]	24-Hr Absorption % by Wt	Mean Linear Thermal Coeff of Expansion[b]
1-in.	¾-in.	⅜-in.	No. 4			
0	25	70	100	2.693	1.33	5.94x10^{-6}

[a] Saturated - surface dry.
[b] Dilatometer method.

Concrete Mix Data

The concretes were designed to have a cement content of 6 sacks per cu yd and a slump of 2½ to 3½ in. at 40 deg F. The maximum size of aggregate was 1 in. For the air-entrained concretes, the air content was maintained in the range of 5 ± ½ percent the optimum amount for these concretes (2). Where calcium chloride was used as an accelerator, it was used in the amount of 2 percent by weight of the cement and dissolved in a portion of the mixing water immediately before mixing. Table 6 shows the pertinent data for the concrete mixes used in this investigation.

Fabrication of Specimens

All materials were at a temperature of 40 deg F for 24 hours prior to mixing concretes. Mixing and fabricating operations were conducted in a laboratory maintained at 40 deg F, simulating temperature conditions likely to prevail during late fall paving.

Eight batches were prepared for each type of concrete. Batches were mixed for 2½ minutes in an open-tub mixer of 1¾-cu-ft capacity. A slump test and an air content determination by the pressure method were made on 4 of the 8 like batches. Each batch contained sufficient concrete for 4 scale test specimens and four 6- by 12-in. cylinders, making a total of 32 slabs and 32 cylinders per type of concrete.

The scale test specimens were slabs 3 in. in depth and 6 by 15 in. in area. These slabs were cast in watertight steel molds, the molds were filled in two layers of equal depth, and each layer was rodded 50 times with a ⅝-in. diameter bullet-nose tamper. Immediately after casting, the surface was given a final finish with a wood float. Approximately three hours after casting, the slabs were equipped with a 1: 2 air-entrained mortar dike around the edges of the finished surface.

TABLE 6

CONCRETE MIX DATA

Ref No.	Cement Lot No	ASTM Type	Net W/C gal per sack	Slump in	Cement Content sacks per cu yd	Air Content % (Pressure)
No $CaCl_2$ - Non-Air-Entrained						
1	18868	I	4.83	3.3	6.00	1.60
14	18914	II	4.63	2.8	6.02	1.70
3	18893	III	5.62	3.2	5.96	1.60
2% $CaCl_2$ - Non-Air-Entrained						
4	18868	I	4.79	2.6	5.96	1.90
15	18914	II	4.56	2.5	5.93	1.85
No $CaCl_2$ - Air-Entrained[a]						
7	18868	I	4.45	2.9	5.98	4.70
16	18914	II	4.37	2.8	5.96	5.30
9	18893	III	5.34	3.7	5.98	5.10
2% $CaCl_2$ - Air-Entrained[a]						
10	18868	I	4.32	2.5	5.96	4.80
17	18914	II	4.25	2.6	5.95	4.90

[a] Neutralized Vinsol resin in solution added at mixer.

TABLE 7

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE I CEMENT

Type I Cement - Lot 18868. No $CaCl_2$.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 4. 8 gal per sack. A/E concrete - 4. 5 gal. per sack.
Air content (pressure): Non-A/E - 1. 60%. A/E - 4. 70%

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles									
			5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	960	2	3	4+	(16)[a]						
3	73	2700	1-	2+	(15)							
28	73	6270	0	0	0+	3	(50)					
2	40	330	2	3	(15)							
4	40	1120	3+	4+	(13)							
6	40	1940	1+	3+	4+	(16)						
8	40	2960	1	3+	(15)							
12	40	4020	1	3	4+	(17)						
19	40	4880	1+	3	4+	(19)						
30	40	5540	1	4-	5-	(16)						
60	40	6410	0+	3+	4+	(23)						
9	25	440	0+	2	(15)							
18	25	560	0+	1	2	(16)						
28	25	560	0+	(10)								
40	25	520	1-	1+	3	(17)						
60	25	680	0+	1+	(15)							
			Air-Entrained									
1	73	1050	1+	2	2	2+	3+	4-	(95)			
3	73	2720	0	0	0	0+	1-	1	1+	2-	2-	2-
28	73	5500	0	0	0	0+	0+	0+	0+	0+	0+	0+
2	40	420	3-	3+	4-	4+	(35)					
4	40	1060	2-	2	3+	4-	(40)					
6	40	1780	0+	0+	1-	1-	3-	3	3+	5-	5-	5-
8	40	2730	0	0+	0+	1-	1+	2	2+	4+	5-	5-
12	40	3460	0	0+	0+	1-	1+	2-	2-	2+	3+	4-
19	40	4360	0	0	0	0+	0+	0+	0+	1-	1+	2
30	40	4900	0	0	0	0+	0+	0+	0+	1-	1	1+
60	40	5680	0+	0+	0+	0+	0+	0+	0+	0+	1-	1-
9	25	540	0+	1-	2+	3+	(31)					
18	25	720	0+	1-	1	(22)						
28	25	900	0	0	0+	0+	1-	1	1+	(106)		
40	25	1030	0	1-	1-	1-	1-	1-	1	3	3	(220)
60	25	1010	0+	1-	1-	1-	1	1+	1+	2	(167)	

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 8

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE I CEMENT

Type I Cement - Lot 18868 plus 2% $CaCl_2$, by weight of cement.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 4. 8 gal. per sack. A/E concrete - 4. 3 gal. per sack.
Air content (pressure): Non-A/E - 1. 90%. A/E - 4. 80%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles									
			5	10	15	25	50	75	100	150	200	250
Non-Air-Entrained												
1	73	2260	3	4+	(11)[a]							
3	73	3940	0	0+	2	5-	(27)					
28	73	6460	0	0	0+	1	3-	(60)				
1	40	350	(5)									
2	40	1290	5-	(6)								
3	40	2340	2+	(9)								
4	40	2940	2+	4+	(13)							
7	40	4120	2-	3+	4+	(17)						
12	40	4970	1-	2	4	(21)						
30	40	5820	1-	2-	3-	(22)						
60	40	6560	0	0	0	0+	2	(55)				
2	25	640	4+	(6)								
5	25	1670	3-	4+	(12)							
10	25	2840	2-	3	5-	(16)						
30	25	3960	1-	1-	2-	2+	(36)					
60	25	3960	1+	2-	3-	3+	(36)					
Air-Entrained												
1	73	2020	0+	1	1+	2-	3+	4-	4	4+	4+	5-
3	73	3450	0	0	0	0+	1-	1-	1+	2	2+	2+
28	73	5330	0	0	0	0+	0+	0+	0+	0+	0+	0+
1	40	340	(3)									
2	40	1340	3+	4+	4+	(19)						
3	40	2000	2-	3	3+	4-	(34)					
4	40	2540	0+	1-	1+	2-	2+	3-	3	3+	4-	4
7	40	3670	0	0	0	0	0+	0+	0+	0+	0+	1-
12	40	4530	0	0	0	0	0+	0+	0+	1-	(190)	
30	40	5170	0	0	0	0	0	0	0+	0+	0+	0+
60	40	5580	0	0	0	0	0	0	0	0+	0+	0+
2	25	340	2+	3+	4+	(19)						
5	25	980	2	3+	4+	(25)						
10	25	1480	1-	3+	4-	4+	(28)					
30	25	2270	0+	1	1	1	1	1	1	1	1	1
60	25	2520	0	0	0	0	0+	0+	0+	0+	0+	0+

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 9

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE II CEMENT

Type II Cement - Lot 18914. No $CaCl_2$.
Cement content of all concretes - 6 sacks per cu yd.
Nautralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete -4.6 gal. per sack. A/E concrete - 4.4 gal. per sack.
Air content (pressure): Non-A/E - 1.70%. A/E - 5.30%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles									
			5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	780	0+	3	(14)[a]							
7	73	3860	0+	1	2-	(22)						
28	73	6300	0+	1-	1+	2	3-	3+	(83)			
3	40	880	1-	3	(15)							
7	40	2560	0+	2-	2+	(20)						
12	40	3660	0+	0+	2+	(22)						
20	40	4780	0+	0+	2+	(25)						
30	40	5220	0+	0+	1-	2	(39)					
40	40	5990	0+	0+	1-	2	(38)					
50	40	6060	0+	0+	1-	1-	3					
60	40	6060	0+	0+	1-	2+	(50)					
8	25	560	0+	1+	(15)							
20	25	900	0+	1-	1+	(25)						
35	25	1180	0+	1-	1	2-	(29)					
45	25	1480	0+	1-	1	2-	(32)					
60	25	1490	0+	1-	1	1+	(50)					
			Air-Entrained									
1	73	650	0+	1	1+	2+	3	3	3+	3+	3+	3+
7	73	3250	0	0	0	0+	0+	0+	0+	0+	0+	0+
28	73	5520	0	0+	0+	0+	0+	0+	1-	1-	1-	1-
3	40	880	1-	3	4	4+	(42)					
7	40	2280	0	0+	0+	0+	1-	1-	1	1	1+	1+
12	40	3420	0	0	0+	0+	0+	0+	0+	1-	1-	1-
20	40	4280	0	0	0+	0+	0+	0+	0+	1-	1-	1-
30	40	4360	0	0	0+	0+	0+	0+	0+	1-	1-	1-
40	40	5010	0+	0+	0+	0+	0+	1-	1-	1	1	1
50	40	5360	0+	0+	0+	0+	0+	1-	1-	1-	1-	1
60	40	5120	0+	0+	0+	0+	1-	1	1	1	1	1
8	25	500	0	0+	0+	1-	1	1+	2-	2-	2	(190)
20	25	750	0+	0+	0+	1-	1-	1	1	1+	1+	1+
35	25	880	0	0+	1-	1-	1-	1-	1-	1-	1-	1-
45	25	1070	0	0+	0+	1-	1-	1-	1-	1-	1-	1-
60	25	1240	0+	0+	1-	1-	1-	1-	1-	1-	1-	1-

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 10

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE II CEMENT

Type II Cement - Lot 18914 plus 2% $CaCl_2$, by weight of cement.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 4. 6 gal. per sack. A/E concrete - 4. 3 gal. per sack.
Air content (pressure): Non-A/E - 1. 85%. A/E - 4. 90%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x12-in. Cyl	Scale Ratings at Indicated Number of Cycles									
			5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	1640	2+	(10)[a]								
7	73	4590	0	0	0+	1-	(36)					
28	73	6180	0	0+	0+	1-	2-	(69)				
1	40	260	3+	(7)								
2	40	930	3+	(9)								
5	40	2820	3+	(10)								
7	40	3680	1-	2+	3	(21)						
12	40	4620	0	0	0+	1-	(47)					
20	40	5630	0	0	0+	1-	(42)					
30	40	5980	0	0	0	0+	(45)					
60	40	6950	0	0	0	0+	(32)					
3	25	530	4-	(8)								
8	25	1890	3	4+	(12)							
16	25	3000	1-	2-	4-	4+	(32)					
32	25	4200	0	0+	1-	2+	3+	(70)				
60	25	4880	0	0+	0+	1-	3-	(60)				
			Air-Entrained									
1	73	1540	2+	4-	(13)							
7	73	4480	0	0	0	0+	0+	0+	0+	0+	1-	1
28	73	5720	0	0	0	0	0+	0+	0+	0+	0+	0+
1	40	250	4	(10)								
2	40	1000	4	(10)								
5	40	2820	0+	1+	2-	2+	3-	3+	3+	4-	4+	4+
7	40	3300	0	0+	1-	1-	1-	1-	1-	1-	1-	1-
12	40	4180	0	0	0	0	0	0+	0+	0+	0+	0+
20	40	4800	0	0	0	0	0	0	0	0	0	0+
30	40	5140	0	0	0	0	0	0	0	0	0	0
60	40	6020	0	0	0	0	0	0	0	0	0	0
3	25	530	3	(10)								
8	25	1500	2-	3+	4	4+	(34)					
16	25	2580	0	0+	1	1+	2+	2+	2+	2+	2+	3-
32	25	3340	0	0+	0+	0+	0+	0+	0+	0+	0+	0+
60	25	4200	0+	0+	0+	0+	0+	0+	0+	0+	0+	0+

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

TABLE 11

RESULTS OF SURFACE SCALING AND STRENGTH TESTS - TYPE III CEMENT

Type III Cement - Lot 18893. No $CaCl_2$.
Cement content of all concretes - 6 sacks per cu yd.
Neutralized Vinsol resin added at mixer for air-entrained concrete.
All specimens cured continuously moist for times indicated.
Net W/C: Non-A/E concrete - 5.6 gal. per sack. A/E concrete - 5.3 gal. per sack.
Air content (pressure): Non-A/E - 1.60%. A/E - 5.10%.

Days of Curing	Curing Temp F	Compressive Strength psi 6- x 12-in. Cyl	Scale Ratings at Indicated Number of Cycles 5	10	15	25	50	75	100	150	200	250
			Non-Air-Entrained									
1	73	1600	2	2+	(13)[a]							
3	73	3560	0+	2+	4+	(18)						
28	73	5550	0	0+	2-	3-	(50)					
1	40	160	2	(10)								
3	40	1480	1	(10)								
5	40	2920	0	4	(15)							
7	40	4280	1-	3+	(14)							
9	40	4970	0+	1+	4	(19)						
12	40	5410	0	1+	3+	(23)						
30	40	6370	0	0+	1	3-	(40)					
60	40	6960	0	0	0+	2	(50)					
6	25	600	1-	2+	(15)							
13	25	1020	0	1+	3+	(19)						
21	25	770	0	0+	1+	(25)						
32	25	720	0	0	0+	(25)						
60	25	720	0	0	0+	1-	(31)					
			Air-Entrained									
1	73	1400	1-	2-	3-	4+	5-	(75)				
3	73	3020	0	0	0	0+	0+	1-	1+	3	3+	4-
28	73	4730	0	0	0	0	0+	0+	0+	0+	1-	1-
1	40	100	1+	3+	4+	(20)						
3	40	1350	1	2+	3+	4	(40)					
5	40	2660	0	0	0	0+	0+	1-	1+	2-	3	4-
7	40	3760	0	0	0	0+	0+	0+	1-	1+	2+	3+
9	40	4160	0	0	0	0	0	0	0+	0+	1-	1-
12	40	4920	0	0	0	0	0	0	0+	0+	1-	1-
30	40	6200	0	0	0	0	0	0	0+	0+	0+	0+
60	40	6310	0	0	0	0	0	0	0	0+	1-	1-
6	25	740	0+	2+	3+	4	(30)					
13	25	1830	0	0	0+	0+	1-	2	3	5-	5	(175)
21	25	2820	0	0	0	0	0+	1-	1+	2	2+	3
32	25	3440	0	0	0	0	0	0+	0+	0+	0+	0+
60	25	3260	0	0	0	0	0	0+	0+	0+	0+	0+

[a] ( ) - Number of cycles at which test was discontinued at a rating of 5.

The 6- by 12-in. cylinders were cast in watertight steel molds, the molds were filled in three layers of equal depth, and each layer was rodded 25 times with a ⅝-in. diameter tamping rod.

Curing Conditions

Immediately after casting, six companion slabs and cylinders for each type of concrete were removed to a room maintained at 73 deg F; ten companion slabs and cylinders, to a room maintained at 25 deg F; and the remaining 16 companion slabs and cylinders remained in the casting room at 40 deg F. At the same time, specimens were covered with two thicknesses of damp burlap (not in contact with surface) and a tarpaulin. The molds were stripped the following day and moist curing continued in the 73 deg F and 40 deg F rooms. In the 25 deg F room, specimens were covered with two thicknesses of damp burlap which froze and prevented the specimens from drying out.

For each storage temperature, two companion slabs and cylinders were removed for scale and strength tests at different ages: three ages for the 73 deg F specimens, eight ages for the 40 deg F specimens, and five ages for the 25 deg F specimens. These curing periods varied with cement type, temperature of curing, and the presence or absence of an accelerator. Tables 7-11, presenting the strength and scale resistance data, indicate the specific lengths of curing before strength tests were made or the scale resistance cycles started.

Test Methods

Concrete cylinders were tested for compressive strength in accordance with current ASTM standards. A proprietary sulfur-containing capping compound was used to cap the top end of the cylinder. The cylinders stored at 25 deg F were thawed in the 73 deg F moist room for one hour prior to testing. The temperature at the center of the cylinder was about 45 deg F at the end of the thaw period.

The slabs were tested for resistance to surface scaling by alternately freezing a layer of water on the top surface and thawing the ice while a de-icer was distributed over the surface of the ice. The thaw period was limited to the amount of time required to raise the temperature of the concrete (½ in. below the top surface) to 35 deg F. This procedure kept further hydration to a minimum during the course of the test.

The amount of water frozen on the slab was 250 ml. The freezing was accomplished in a room maintained at -20 deg F. Thawing took place in a room at approximately 73 deg F. Upon removal from the cold room, commercial flake calcium chloride was used as the de-icer in the amount of 2.4 lb per sq yd of surface area, the maximum amount applied in practice. At the end of the thaw period, the solution was flushed off the surface and was replaced by 250 ml of fresh water for the freeze portion of the cycle. The slabs were in the freezer room for approximately 20 hours and in the thaw room approximately 4 hours.

At intervals during the scaling test, the surfaces were examined, rated as to extent and depth of scale and assigned a numerical rating as follows:

0 - no scaling
1 - very slight scaling
2 - slight to moderate scaling
3 - moderate scaling
4 - moderate to bad scaling
5 - severe scaling

In addition to the visual ratings, photographs of the surfaces were taken periodically to provide a record of the amount and rate of development of scaling.

DISCUSSION OF RESULTS

This series of laboratory tests was conducted in order to secure information which would be of value in determining the minimum amount of curing required before permitting the use of de-icers on air-entrained concrete pavements. Non-air-entrained concretes were included for an over-all comparison with the air-entrained concretes.

In reviewing the results of these tests, two factors are believed to be of considerable significance. These are the continuous moist curing of the concretes prior to test and

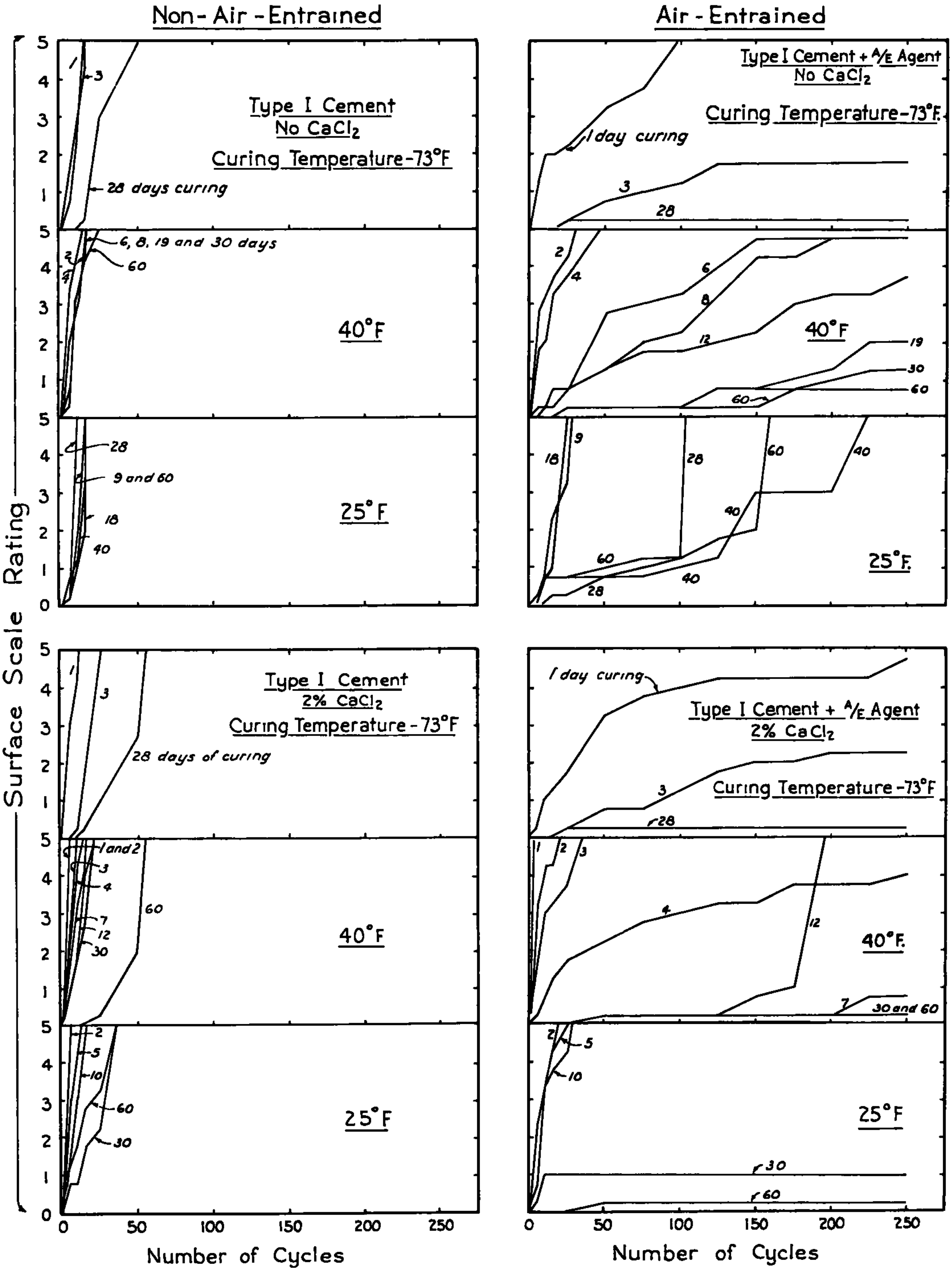

Figure 1. Effect of duration and temperature of curing on the scale resistance on concretes made with Type I cement - Lot 18868.

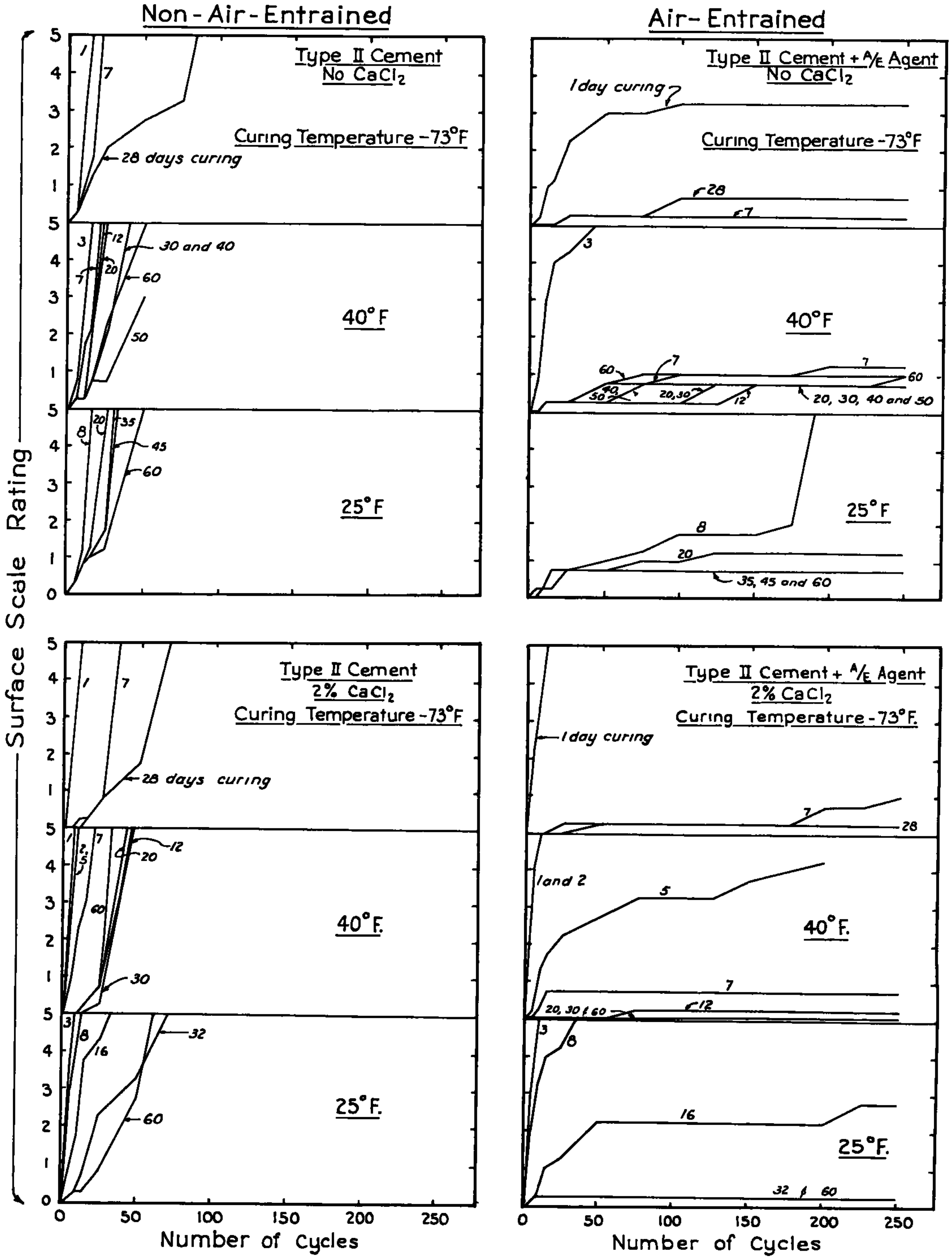

Figure 2. Effect of duration and temperature of curing on the scale resistance of concretes made with Type II cement - Lot 18914.

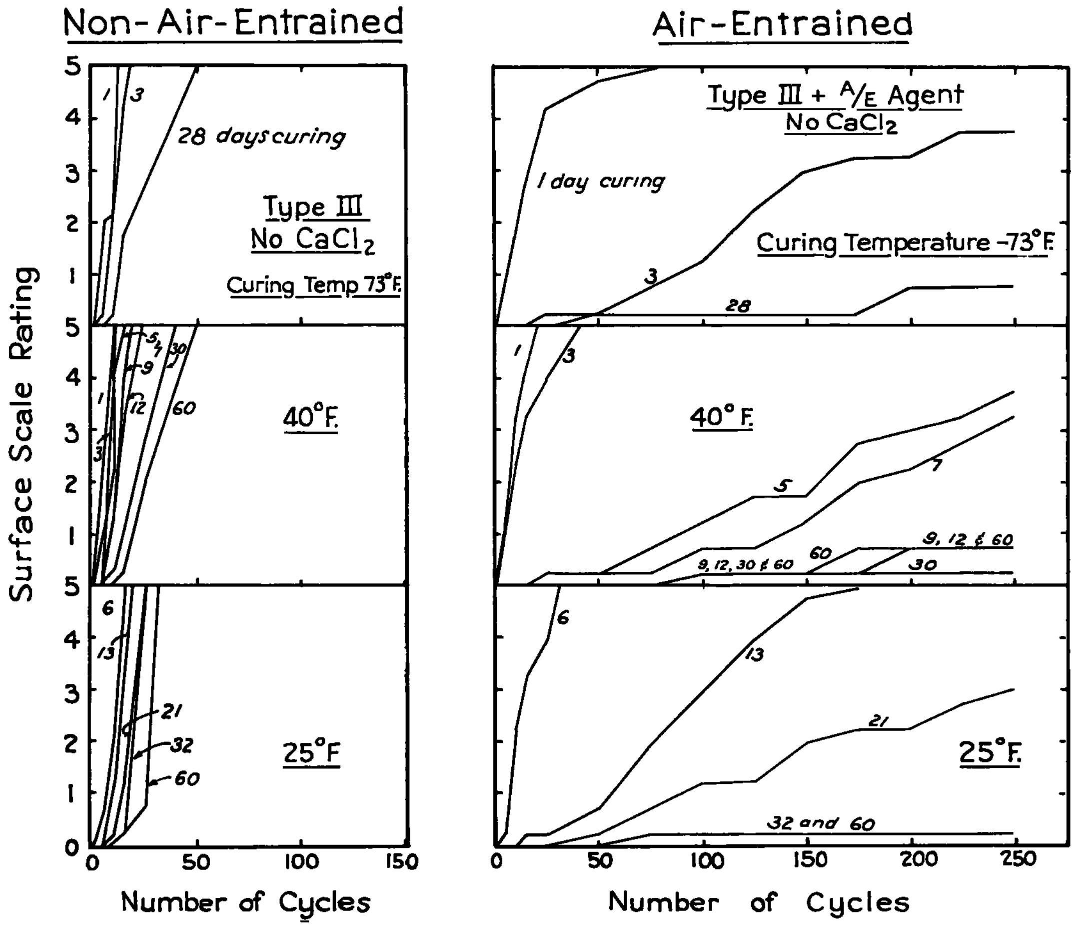

Figure 3. Effect of duration and temperature of curing on the scale resistance of concretes made with Type III cement - Lot 18893.

the termination of the thaw portion of each cycle when the concrete surface temperature reached approximately 35 deg F. The continuous moist curing prevented drying of the concretes prior to testing. All concrete pavements undergo some drying, even during their early life. This drying in almost all cases increases the resistance to surface scaling. Terminating the thaw portion of the cycle at 35 deg F tends to keep further hydration at a minimum during the test and represents a severe exposure from the standpoint of continued hydration or curing.

Another important factor is that these tests were made with one combination of a fine and coarse aggregate, both having good service records. The use of a poor aggregate in a study of this type would not be warranted since curing would not overcome the deficiencies of a poor aggregate.

Scale Resistance of Non-Air-Entrained Concretes

Detailed data on the scale resistance of the different non-air-entrained concretes are presented in Tables 7-11 and Figures 1-3. The number of cycles required to produce severe scaling (a scale rating of 5) ranged from 5 to 83. These data indicate clearly that none of the non-air-entrained concretes showed a satisfactory degree of resistance to surface scaling — regardless of temperature, amount of prior curing, type of cement, or the use of an accelerator.

Scale Resistance of Air-Entrained Concretes

Tables 7-11 and Figures 1-3 show the same detailed information for the air-entrained concretes. The data indicate that some minimum amount of prior curing is required for air-entrained concrete to insure a high degree of resistance to surface scaling. Also, it is apparent that these minimum amounts of curing are not alike in all cases, but depend on the type of cement, the temperature of curing, and the presence of an accelerator. It appears that increasing the rate of hydration by one means or another results in a shorter required minimum period of curing; in other words, the minimum curing period might be considered as a particular degree of hydration, by whatever manner it is attained.

The selection of the required minimum curing periods for these different air-entrained concretes involves the question as to what performance in a laboratory scaling test is equivalent to excellent performance under various field conditions of exposure. For these tests, the minimum required curing period was defined as the minimum length of time necessary to reduce the scale rating to 1 (very slight scaling) at 100 cycles of test. Extended laboratory experience has shown that 100 cycles of this test procedure with no more than very slight scaling normally indicate excellent resistance to surface scaling under field conditions. Since the number of cycles to produce severe scaling ranged from 5 to 83 for the non-air-entrained concretes, it appears that the criterion selected for a minimum curing period is a conservative one.

The following table lists the minimum required curing periods for adequate scale resistance (the use of Figures 1-3 facilitates these selections):

Cement Type[a]	Percent $CaCl_2$ (accelerator)	Minimum Curing Period - days		
		at 73 deg F	at 40 deg F	at 25 deg F
I	0	7	15	60+
	2	7	7	30
II	0	7	12	35
	2	7	7	28
III	0	7	7	24

[a] A/E agent added at mixer to entrain 5 ± ½% air.

It is apparent that the minimum curing periods for the 25 deg F storage condition are long, and in some cases uncertain, emphasizing the importance of temperature of curing, as well as duration. For Types I and II, the use of an accelerator was beneficial at the lower curing temperatures, but was not beneficial at 73 deg F.

Considering the 73 deg F and 40 deg F temperatures, it is evident that the minimum curing periods for these air-entrained laboratory concretes are approximately the same as normally required by highway departments to insure adequate development of strength before opening to traffic. These laboratory tests indicate that air-entrained concretes cured at temperatures of 40 deg F or higher require no more curing to develop adequate scale resistance than to develop an adequate level of strength. These minimum curing periods might be increased somewhat in recommendations for field practice. In special cases, a factor of 3 seems justified to allow for additional influences on field concrete.

The strengths developed by these concretes at the minimum curing periods are shown in the table on the following page. At 73 deg F and 40 deg F the strengths range from 3250 to 4500 psi, the average being 3740 psi. It appears that the minimum curing period prior to permitting the use of de-icers was indicated by the development of a compressive strength level of about 4000 psi.

SUMMARY AND CONCLUSIONS

These laboratory tests have provided a basis for the determination of minimum required curing periods for concretes prior to permitting the use of calcium chloride as a de-icer. The moisture condition of the specimen and the manner of testing were such that the conclusions reached should be on the conservative side. This presumes the use of acceptable aggregates and the optimum air content for the concrete mix.

Cement Type[a]	Percent $CaCl_2$ (accelerator)	Compressive Strength - psi Minimum Curing Period		
		at 73 deg F	at 40 deg F	at 25 deg F
I	0	3800	3900	(1010)[b]
	2	4100	3700	2300
II	0	3250	3400	880
	2	4500	3300	3200
III	0	3700	3750	3050

[a] A/E agent added at mixer to entrain 5 ± ½% air.
[b] Figure in parentheses is strength developed at maximum period of curing. These concretes showed poor resistance to scaling.

The following statements appear valid:

1. Non-air-entrained concrete has little resistance to surface scaling resulting from the use of de-icers. Increased amounts of curing up to 60 days raised the level of resistance, but the highest level attained by these non-air-entrained concretes is unsatisfactory.
2. Air-entrained concrete has a high resistance to surface scaling resulting from the use of calcium chloride as a de-icer. However, adequate curing is required before calcium chloride may safely be used. This should apply also to the use of other de-icing materials.
3. At temperatures above freezing (specifically at 40 deg F and 73 deg F) the amount of curing required for the air-entrained laboratory concretes is little more than is necessary to develop a level of strength sufficient to carry traffic loads. These curing periods were 7 days at 73 deg F and 7 to 15 days at 40 deg F. These periods should be increased by a factor of 3 for actual field practice.
4. The periods of curing for these air-entrained concretes were approximately the same for Type I and II cements, both with and without an accelerator, for temperatures of 40 deg F and 73 deg F. For Type III cement without an accelerator, the curing period at 73 deg F was the same as for the Type I and II cements, but at 40 deg F the required curing period was less.
5. For these air-entrained concretes, the use of calcium chloride as an accelerator resulted in shorter minimum curing periods at temperatures of 40 deg F and 25 deg F.
6. A curing temperature below freezing (25 deg F) resulted in excessively long curing periods. In some cases where adequate scale resistance was obtained, the concrete is unacceptable because of low strength.
7. The development of a certain level of strength has merit as an index to the amount of curing required for air-entrained concrete prior to permitting the use of de-icers.

REFERENCES

1. Hansen, W. C., "Effect of Age of Concrete on Its Resistance to Scaling Caused by Using Calcium Chloride for Ice Removal," ACI Proc Vol 50, p. 341, January, 1954.
2. Klieger, Paul, "The Effect of Entrained Air on Strength and Durability of Concretes Made with Various Maximum Sizes of Aggregate," Highway Research Board Proceedings, 31st Annual Meeting, 1952, p. 177.

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