HIGHWAY RESEARCH BOARD

Bulletin 128

Durability of Concrete

National Academy of Sciences—

National Research Council

publication 416

HIGHWAY RESEARCH BOARD

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1956

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Bulletin 128

DURABILITY
CONCRETE
CEMENT
TESTS
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Durability of Concrete

PRESENTED AT THE
Thirty-Fourth Annual Meeting
January 11–14, 1955

1956
Washington, D. C.

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Contents

Effect of Entrained Air on Strength and Durability of Concrete with Various Sizes of Aggregates

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Previous tests using a natural sand and a curshed siliceous gravel indicated that, for concretes of constant cement content and consistency (varying water-cement ratio), adequate resistance to freezing and thawing of air-dried concretes was secured when the air content of the mortar fraction was 9 ± 1 percent, regardless of the maximum size of aggregate used.

The tests reported herein are for concretes made with cements from the same source as the initial tests and the same natural sand. However, the coarse aggregate used was a crushed limestone with particle shape and texture different from those of the gravel previously used. Three cement contents were used at a constant slump of 5 to 6 inches: 4.0, 5.5 and 7.0 sacks per cubic yard of concrete. The maximum sizes of aggregate used were $^3/_8$-in., $^3/_4$-in. and $1^1/_2$-in. For each combination of cement content and maximum size of aggregate, five concretes covering a fairly wide range of air contents were prepared.

The results of freezing and thawing tests of these concretes confirmed the results of the earlier tests. Adequate resistance to freezing and thawing was obtained when the air content of the mortar fraction was in the range of 9 ± 1 percent.

The report also includes information on the effect of entrained air on strength, resistance to salt scaling, volume change and absorption of these concretes.

●THIS is a second report concerning a group of tests designed to provide quantitative information regarding the proper amount of entrained air for adequate frost resistance and the effect of the entrained air on the strength of concretes made with various maximum sizes of aggregate.

The first series of tests[1] using a natural sand and a crushed gravel indicated that, for concretes of constant cement content and consistency, adequate resistance to freezing and thawing of air-dried concretes was secured when the air content of the mortar fraction was in the range of 9 ± 1 percent regardless of the maximum size of aggregate used. In these tests, the Type IA cement generally provided this necessary amount of air as required.

The second series of tests, the results of which are reported herein, were made using a different type of coarse aggregate and concrete of higher slump to determine whether, with these changes, the same requirement would be found for air content of mortar.

SCOPE OF TESTS

The concretes used in this second series of tests had cement contents of 4.0, 5.5 and 7.0 sk. per cu. yd. with net water-cement ratios varied so that the consistency was maintained at 5 to 6 inches as measured by the slump test. For each cement content, three maximum sizes of aggregate were used: $^3/_8$-in., $^3/_4$-in. and $1^1/_2$-in. Five concretes were prepared for a particular cement content and maximum size of aggregate covering a fairly wide range of air contents. The range in air contents was ob-

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[1] "Effect of Entrained Air on Strength and Durability of Concrete Made With Various Maximum Sizes of Aggregate," by Paul Klieger, Proceedings Thirty-First Annual Meeting, 1952 Highway Research Board. Reprinted as Bulletin 40, Portland Cement Association, Chicago, Ill.

TABLE 1

CHEMICAL COMPOSITION OF CEMENTS

Chemical analyses of cements made in accordance with ASTM Methods of Test current in February, 1953. Sodium oxide and potassium oxide by flame photometry, ASTM C228-49T.

Cement	Major Components - %						Minor Components - %						
											Alkalies		
Lot No.	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	Total as Na_2O
							TYPE I CEMENTS						
18787	22.03	5.98	2.40	62.35	2.45	2.30	1.06	0.07	1.09	0.18	0.13	1.12	0.87
18788	20.77	6.28	3.12	63.67	1.90	1.79	1.30	0.20	1.11	0.11	0.27	0.55	0.63
18789	20.73	6.10	2.78	63.16	2.43	2.11	1.64	0.47	1.72	0.16	0.11	0.15	0.21
18790[a]	21.18	6.12	2.77	63.06	2.26	2.07	1.33	0.25	1.31	0.15	0.17	0.16	0.57
							TYPE IA CEMENTS						
18791	21.98	5.76	2.38	62.66	2.39	2.39	1.00	0.07	0.79	0.10	0.14	1.07	0.84
18792	20.59	6.55	3.17	63.90	2.04	1.82	0.68	0.23	0.64	0.11	0.27	0.55	0.63
18793	21.31	5.27	2.48	64.01	2.80	1.90	1.51	0.49	1.73	0.16	0.08	0.14	0.17
18794[a]	21.29	5.86	2.68	63.52	2.41	2.04	1.06	0.26	1.05	0.12	0.16	0.59	0.55

[a] These are blends of the three individual brands of each type. The analyses indicated are the arithmetical averages of the analyses of the individual cements.

tained by using Type I cement, Type I and Type IA blend, Type IA and Type IA plus the addition of neutralized Vinsol resin in solution during mixing.

The concretes prepared were subjected to the following tests: (1) flexural and compressive strength tests of 6 by 6 by 30-in. beams at 28 days, (2) freezing and thawing tests of 3 by 3 by 11¼-in. prisms, both air dried and continuously moist cured, (3) resistance to surface scaling resulting from the use of salts for ice removal purposes and (4) drying shrinkage and absorption tests.

In addition, the characteristics of the air voids in the hardened concrete are being determined, together with actual determinations of freezable water and length change during freezing. These data will form the basis for a future report evaluating their influence on the measured durabilities.

MATERIALS

The cements were a Type I blend and a Type IA blend, each prepared from three

TABLE 2

POTENTIAL COMPOUND COMPOSITION OF CEMENTS

Corrected for free CaO

Cement	Calculated Compound Composition - %					
Lot No.	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	Free CaO
			TYPE I CEMENTS			
18787	31.7	39.2	11.8	7.3	3.91	1.09
18788	45.0	25.6	11.4	9.5	3.04	1.11
18789	41.5	28.1	11.5	8.5	3.59	1.72
18790[a]	39.4	31.0	11.6	8.4	3.51	1.31
			TYPE IA CEMENTS			
18791	35.9	36.0	11.2	7.2	4.06	0.79
18792	47.3	23.4	12.0	9.6	3.10	0.64
18793	47.2	25.5	9.8	7.5	3.23	1.73
18794	43.5	28.3	11.0	8.1	3.46	1.05

[a] Blends. Results are averages of individual cements.

TABLE 3

MISCELLANEOUS PHYSICAL TESTS OF CEMENTS

Tests made in accordance with ASTM Methods of Test current in November, 1952. Each value is the average of two or more determinations.

Cement Lot No.	Fineness		Specific Gravity	Normal Consistency, %	Time of Setting				Autoclave Exp., %	Air Content, % 1-4 Mortar
	Sp.Surf. sq. cm. per g. Wagner	Passing 325 Mesh %			Vicat Initial h. m.	Vicat Final h. m.	Gillmore Initial h. m.	Gillmore Final h. m.		
TYPE I CEMENTS										
18787	1710	94.8	3.148	26.5	2:30	5:45	3:30	5:55	0.21	8.9
18788	1710	92.5	3.141	24.5	2:40	5:40	3:30	5:45	0.21	14.5
18789	1800	91.8	3.124	26.0	3:15	6:30	4:10	6:30	0.09	8.9
18790	1740[a]	93.0[a]	3.138[a]	25.0	3:00	6:05	3:55	6:15	0.22	9.5
TYPE IA CEMENTS										
18791	1750	96.3	3.153	26.5	3:55	6:40	4:40	6:40	0.19	16.7
18792	1760	94.1	3.170	25.0	3:00	6:05	4:10	6:10	0.20	18.1
18793	1860	93.7	3.127	27.5	3:50	6:30	4:35	6:40	0.10	20.4
18794	1790[a]	94.7[a]	3.150[a]	26.0	4:00	7:00	4:55	7:10	0.14	18.3

[a] Arithmetical average of three individual cements.

different cements purchased in the Chicago area. The chemical compositions, calculated potential compound compositions and results of various physical tests of the cements are shown in Tables 1, 2 and 3. Tensile and compressive strengths of mortars are shown in Table 4.

Both aggregates used in these tests have excellent service records. Grading, specific gravity and absorption data are shown in Table 5. The fine aggregate used was sand from Elgin, Illinois, a predominatly dolomitic natural sand. The coarse aggregate was a crushed limestone from Thornton, Illinois.

Aggregates were air dried and screened into various size fractions prior to use, six sizes for the fine aggregate and three sizes for the coarse aggregate as shown in Table 5. Aggregates were weighed air dry and soaked for 18-20 hours prior to mixing of concrete batches.

TABLE 4

STRENGTH TESTS OF MORTARS

Briquets: ASTM C190-49. Cubes: ASTM C109-50.
Each value is the average of three specimens, each made on a different day.

Cement Lot No.	Tensile Strength, 1-3 Std. Sand Mortar Briquets - lb. per sq. in.				Compressive Strength, 2-in. Plastic Mortar Cubes, lb. per sq. in.			
	1d.	3d.	7d.	28d.	1d.	3d.	7d.	28d.
TYPE I CEMENTS								
18787	220	380	460	490	730	1790	2710	4610
18788	185	375	435	465	545	1720	2910	4520
18789	175	340	390	535	510	1450	2280	4370
18790	175	360	385	525	540	1690	2650	4800
TYPE IA CEMENTS								
18791	195	360	400	455	730	1830	2720	4540
18792	160	370	410	470	540	1910	3220	4920
18793	135	280	335	440	480	1290	2250	4090
18794	165	345	400	455	580	1700	2780	4570

TABLE 5

DATA ON AGGREGATES

Elgin, Illinois, Sand

Grading - % Retained on Sieve No. Indicated						Fineness Modulus	Bulk Specific Gravity, S.S.D.[a]	24-Hour Absorption, % by Wt.
4	8	16	30	50	100			
0	18	33	57	87	95	2.90	2.645	2.25

Thornton, Illinois, Crushed Limestone

Maximum Size of Aggregate, in.	Grading - % Retained on Sieve Size Indicated				Bulk Specific Gravity, S.S.D.[a]	24-Hour Absorption, % by Wt.
	1½-in.	¾-in.	⅜-in.	No. 4		
1½	0	50	75	100	2.631	1.49
¾	0	0	50	100	2.632	1.73
⅜	0	0	0	100	2.637	1.90

[a] Saturated, surface-dry.

TABLE 6

CONCRETE MIX DATA AND 28-DAY MOIST-CURED STRENGTHS 4 SK. PER CU. YD.

Concrete specimens: 6 by 6 by 30-in. beams. Elgin, Illinois, sand and Thornton, Illinois, stone.
Cement content of all concretes - 4 sk. per cu. yd. Slump: 5 to 6 inches.
Type I cement - Lot 18790. Type IA cement - Lot 18794.
Each strength value is the average of tests of three specimens, two flexural tests and two compressive tests per specimen.

Ref. No.	Percentage of Each Type of Cement Used		Net W/C, gal. per sk.	Slump, in.	% Sand, Abs. Vol.	Mortar Content % by Abs. Vol.	Air Content, % (pressure)	28d. Str.-lb. per sq. in.	
	I	IA						Mod. of Rupture 3rd Pt. Loading 18-in. Span	Comp. Str. 6-in. Modified Cubes
MAXIMUM SIZE OF AGGREGATE - 1½-IN.									
301	100	0	8.35	6.2	46.0	60.0	2.37	490	3180
302	50	50	7.67	5.9	44.0	59.3	5.01	530	3310
303	0	100	7.22	5.0	42.0	58.3	6.94	525	3370
304	0	100[a]	6.84	5.1	40.0	57.4	8.45	500	3210
305	0	100[a]	6.41	5.5	38.0	57.1	11.15	445	2610
MAXIMUM SIZE OF AGGREGATE - ¾-IN.									
306	100	0	9.23	6.0	54.0	67.0	3.37	410	2300
307	50	50	8.37	5.2	51.0	65.7	6.40	475	2690
308	0	100	7.86	5.8	49.0	64.8	8.53	460	2640
309	0	100[a]	7.45	5.9	47.5	64.3	10.20	450	2740
310	0	100[a]	6.73	5.2	45.0	63.3	12.99	435	2380
MAXIMUM SIZE OF AGGREGATE - ⅜-IN.									
311	100	0	10.26	6.0	72.0	81.3	5.83	340	1640
312	50	50	9.30	5.6	69.5	80.0	8.60	360	1880
313	0	100	8.67	5.7	67.5	78.8	10.83	400	2070
314	0	100[a]	7.90	5.3	65.4	77.7	13.13	370	2110
315	0	100[a]	7.27	5.9	62.9	76.7	16.00	345	1850

[a] Neutralized Vinsol resin in solution added to entrain additional air.

FABRICATION OF SPECIMENS

All materials were at 73° F. at the time of mixing. Concrete batches were mixed for 3 minutes in an open-tub Lancirick mixer. Each batch contained 1.30 cu. ft. of concrete. For each particular concrete, three like batches were prepared, each on a different day, containing sufficient concrete to make one 6 by 6 by 30-in. beam, one 3 by 6 by 15-in. slab and four 3 by 3 by 11¼-in. prisms. A slump test and an air content determination by the pressure method were made on each batch of concrete.

Specimen molds (steel) were filled in two equal layers each rodded with a ⅝-in. diameter bullet-nose tamper, 63 roddings per layer for the beams, 25 per layer for the prisms and 50 per layer for the slabs. Immediately after casting, the surface of the prism was finished with a steel trowel, and the surfaces of the beam and slab were finished with a wood float.

TABLE 7

CONCRETE MIX DATA AND 28-DAY MOIST-CURED STRENGTHS 5¼ SK. PER CU. YD.

Concrete specimens 6 by 6 by 30-in. beams. Elgin, Illinois, sand and Thornton, Illinois, stone.
Cement content of all concretes - 5¼ sk. per cu. yd. Slump: 5 to 6 inches.
Type I cement - Lot 18790. Type IA cement - Lot 18794.
Each strength value is the average of tests of three specimens, two flexural tests and two compressive tests per specimen.

Ref. No.	Percentage of Each Type of Cement Used		Net W/C, gal. per sk.	Slump, in.	% Sand, Abs. Vol.	Mortar Content % by Abs. Vol.	Air Content % (pressure)	28d. Str. - lb. per sq. in.	
	I	IA						Mod. of Rupture 3rd Pt. Loading 18-in. Span	Comp. Str. 6-in. Modified Cubes
				MAXIMUM SIZE OF AGGREGATE - 1½-IN.					
316	100	0	6.04	5.0	43.0	59.1	2.25	710	5860
317	50	50	5.75	5.0	40.5	58.2	4.29	695	5760
318	0	100	5.60	5.4	39.0	58.0	6.15	685	5440
319	0	100[a]	5.47	5.3	37.5	57.8	7.90	650	4920
320	0	100[a]	5.26	5.5	35.6	57.4	10.03	600	4090
				MAXIMUM SIZE OF AGGREGATE - ¾-IN.					
321	100	0	6.55	6.0	51.0	66.0	3.15	670	4580
322	50	50	6.10	5.3	49.0	65.3	5.60	665	4780
323	0	100	5.88	5.7	47.0	64.6	7.44	645	4540
324	0	100[a]	5.68	5.6	44.9	64.2	9.77	620	4190
325	0	100[a]	5.46	5.5	43.0	63.8	11.95	585	3850
				MAXIMUM SIZE OF AGGREGATE - ⅜-IN.					
326	100	0	7.03	5.2	68.9	79.5	5.28	570	3650
327	50	50	6.57	5.8	66.0	78.0	7.55	595	3910
328	0	100	6.34	5.7	64.4	77.3	9.30	585	3820
329	0	100[a]	5.97	5.8	62.4	76.6	11.75	570	3620
330	0	100[a]	5.73	5.7	60.4	75.9	13.70	530	3330

[a] Neutralized Vinsol resin in solution added to entrain additional air.

The specimens were covered with two layers of damp burlap (not in contact with the surface) and a tarpaulin over the burlap. The following day the molds were stripped. The slab specimens were then provided with a 1:2 mortar dike, approximately ¾ by ¾-in. in section, around the perimeter of the finished top surface.

CURING CONDITIONS

The beams for strength tests were cured continuously moist until time for test. Some of the prisms used in the freezing and thawing tests were cured 1 day in molds, 13 days in the moist room, 14 days in the air of the laboratory (50 percent R. H.) and 3 days in water prior to the start of tests. The remainder of the prisms were cured 1 day in molds, 27 days in the moist room and 3 days in water prior to test. Curing temperature was 73.4 ± 3° F.

The slabs for scaling test were cured 1 day in molds, 13 days in the moist room, 14 days in the air of the laboratory (50 percent R. H.) and 3 more days in air with a ⅜- in layer of water on the top surface.

TEST METHODS

Strength tests of beams and cylinders were made in accordance with current ASTM methods of test. Beams were tested in flexure using third-point loading over an 18-in. span, permitting two flexural breaks per beam. The beam ends were used as 6-in. modified cubes for compressive strength tests.

Two complete cycles of freezing and thawing were obtained every 24 hours, the prisms being immersed in tap water at all times. The rate of cooling was approximately 20° F. per hour. Periodic determinations of changes in weight, length and sonic modulus were used as criteria of durability.

TABLE 8

CONCRETE MIX DATA AND 28-DAY MOIST-CURED STRENGTHS 7 SK. PER CU. YD.

Concrete specimens: 6 by 6 by 30-in. beams. Elgin, Illinois, sand and Thornton, Illinois, stone.
Cement content of all concretes - 7 sk. per cu. yd. Slump: 5 to 6 inches.
Type I cement - Lot 18790. Type IA cement - Lot 18794.
Each strength value is the average of tests of three specimens, two flexural tests and two compressive tests per specimen.

Ref. No.	Percentage of Each Type of Cement Used		Net W/C, gal. per sk.	Slump, in.	% Sand, Abs. Vol.	Mortar Content % by Abs. Vol.	Air Content, % (pressure)	28d. Str. - lb. per sq. in.	
	I	IA						Mod. of Rupture 3rd Pt. Loading 18-in. Span	Comp. Str. 6-in. Modified Cubes
				MAXIMUM SIZE OF AGGREGATE - 1½-IN.					
331	100	0	4.90	5.1	40.1	59.0	2.16	800	7260
332	50	50	4.87	5.1	38.5	58.8	3.68	760	6880
333	0	100	4.86	5.2	37.0	58.6	4.99	780	6590
334	0	100[a]	4.79	5.2	35.5	58.6	6.65	730	5940
335	0	100[a]	4.77	5.5	34.0	58.6	8.38	690	5320
				MAXIMUM SIZE OF AGGREGATE - ¾-IN.					
336	100	0	5.15	4.9	47.9	65.2	2.77	790	6480
337	50	50	5.08	5.4	46.0	64.8	4.73	790	6200
338	0	100	5.01	5.5	44.5	64.6	6.35	765	5850
339	0	100[a]	4.94	5.5	43.0	64.5	8.10	715	5290
340	0	100[a]	4.87	5.6	41.0	64.2	9.87	680	5080
				MAXIMUM SIZE OF AGGREGATE - ⅜-IN.					
341	100	0	5.55	5.9	66.9	78.9	4.57	745	5580
342	50	50	5.40	6.0	64.9	78.2	6.70	740	5470
343	0	100	5.23	5.5	63.9	77.9	7.96	715	5380
344	0	100[a]	5.08	5.7	61.9	77.1	9.78	685	5040
345	0	100[a]	4.93	5.3	60.9	76.9	11.40	650	4640

[a] Neutralized Vinsol resin in solution added to entrain additional air.

The surface scaling test consisted of freezing a ¼-in. layer of water on the top surface of the slab and then thawing the ice with flake calcium chloride, applied in an amount equivalent to 2.4 lb. per sq. yd. of surface area. The slabs were subjected to one cycle of this freezing and thawing per day. The amount of scaling was determined by visual examination and rated numerically as follows:

0 - no scale
1 - slight
2 - slight to moderate
3 - moderate
4 - moderate to bad
5 - bad

The middle section of each 6 by 6 by 30-in. beam is being used for determining the air void characteristics of these concretes, such as bubble distribution and spacing. These determinations are being made by the linear traverse method.[2]

Companion prisms to those being subjected to the freezing and thawing test are being used for determinations of freezable water and length changes during freezing using a specially designed calorimeter strain apparatus, to be described in a future report.

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[2] "Linear Traverse Technique for Measurement of Air in Hardened Concrete," by L.S. Brown and C.U. Pierson, ACI Proc. Vol. 47, October, 1950.

TABLE 9

EFFECT OF ENTRAINED AIR ON CONCRETE STRENGTHS

Flexure: 6 by 6 by 30-in. beams. Third-point loading, 18-in. span. Two breaks per beam.
Compression: 6-in. modified cubes. Two cubes per beam.
Age at test: 2 8 days. Curing: continously moist.
Data obtained by averaging results of tests on three like specimens.

Maximum Size of Aggregate	Average Percentage Change in Strength for Each One Percent of Entrained Air for Total Amounts of Entrained Air Shown											
	Flexure						Compression					
	1%	2%	3%	4%	5%	6%	1%	2%	3%	4%	5%	6%
4 SK. PER CU. YD. 5 TO 6-IN. SLUMP												
1½-in.	+3.7	+3.1	+2.2	+1.5	+1.1	+0.5	+1.9	+1.9	+1.7	+1.4	+0.8	+0.2
¾-in.	+7.3	+6.1	+4.9	+3.7	+2.8	+2.0	+6.1	+6.3	+5.7	+5.0	+4.3	+3.6
⅜-in.	+3.0	+3.0	+3.1	+3.1	+2.8	+2.2	+4.9	+4.9	+5.7	+5.5	+5.0	+4.7
5½ SK. PER CU. YD. 5 to 6-IN. SLUMP												
1½-in.	-1.1	-0.9	-0.9	-1.0	-1.4	-1.6	-0.9	-0.7	-1.4	-2.0	-2.4	-3.0
¾-in.	-0.4	-0.4	-0.5	-0.7	-0.9	-1.1	+2.6	+2.1	+1.2	+0.1	-0.3	-0.8
⅜-in.	+2.1	+2.0	+1.5	+1.0	+0.4	0	+3.3	+2.1	+2.0	+1.3	+0.8	+0.2
7 SK. PER CU. YD. 5 to 6-IN. SLUMP												
1½-in.	-1.3	-1.4	-1.7	-1.9	-2.0	-2.2	-3.3	-3.3	-3.6	-3.8	-4.0	-4.2
¾-in.	0	-0.3	-0.8	-1.3	-1.5	-1.8	-2.5	-2.3	-2.7	-2.8	-3.0	-3.0
⅜-in.	-0.5	-0.4	-0.9	-1.2	-1.4	-1.7	-0.7	-0.7	-0.9	-1.3	-1.7	-2.0

TABLE 10

LENGTH AND WEIGHT CHANGES OF CONCRETES PRIOR TO FREEZING AND THAWING

Cement content: 4sk. per cu. yd. Slump: 5 to 6 inches.
Specimen size: 3 by 3 by 11¼-in. prisms.

Ref. No.	Net W/C, gal. per sk.	Air Content, % Pressure	Length Changes During Periods Indicated -%			Weight Changes During Periods Indicated -%		
			14d. Moist (+)	14d. Air (-)	3d. in Water (+)	14d. Moist (+)	14d. Air (-)	3d. in Water (+)
MAXIMUM SIZE OF AGGREGATE - 1½-IN.								
301	8.35	2.37	.014	.028	.019	0.6	3.9	3.3
302	7.67	5.01	.012	.030	.021	0.8	3.9	3.3
303	7.22	6.94	.011	.029	.020	0.9	3.6	2.9
304	6.84	8.45	.011	.030	.021	1.0	3.5	2.8
305	6.41	11.15	.012	.032	.021	1.2	3.5	2.7
MAXIMUM SIZE OF AGGREGATE - ¾-IN.								
306	9.23	3.37	.011	.031	.022	0.7	4.9	4.4
307	8.37	6.40	.012	.032	.022	0.9	4.5	4.0
308	7.86	8.53	.012	.034	.023	1.1	4.3	3.6
309	7.45	10.20	.012	.034	.023	1.2	4.2	3.5
310	6.73	12.99	.012	.036	.024	1.5	4.0	3.1
MAXIMUM SIZE OF AGGREGATE - ⅜-IN.								
311	10.26	5.83	.015	.040	.028	0.9	6.3	5.7
312	9.30	8.60	.011	.040	.027	1.2	5.9	5.2
313	8.67	10.83	.013	.042	.028	1.3	5.5	4.9
314	7.90	13.13	.013	.044	.029	1.5	5.2	4.5
315	7.27	16.00	.012	.046	.029	1.8	5.2	4.2

These data regarding air void characteristics, freezable water and length changes will be presented in a future report.

DISCUSSION OF RESULTS

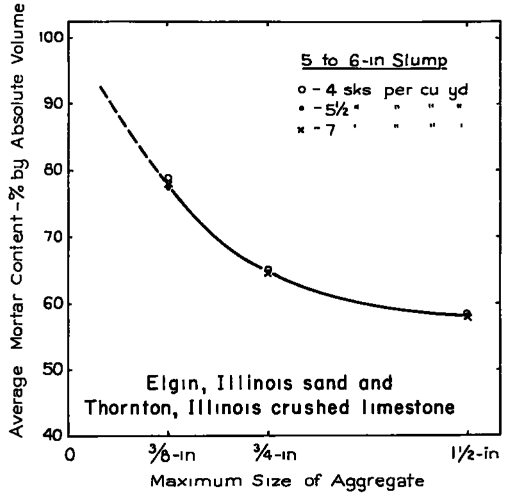


Figure 1. Relationship Between Maximum Size of Aggregate and Mortar Content for Concretes of Constant Cement Content and Consistency.

Characteristics of Concretes

Tables 6, 7 and 8 show data on the concrete mixes used in these tests. Figure 1 shows the changes in mortar content resulting from changes in maximum size of aggregate in mixes of constant cement content and consistency.

Figure 2 shows the changes in air content with changes in maximum size of aggregate and the average mortar content for each size of aggregate.

The water requirements of the concretes as a function of entrained air, for each maximum size of aggregate, are shown in Figure 3.

Effect of Entrained Air on Concrete Strength

Flexural and compressive strength data are shown in Tables 6, 7 and 8 and in Figure 4, 5 and 6.

Table 9 summarizes the results of the strength tests and shows the average percentage change in strength for each one percent of intentionally entrained air up to 6 percent

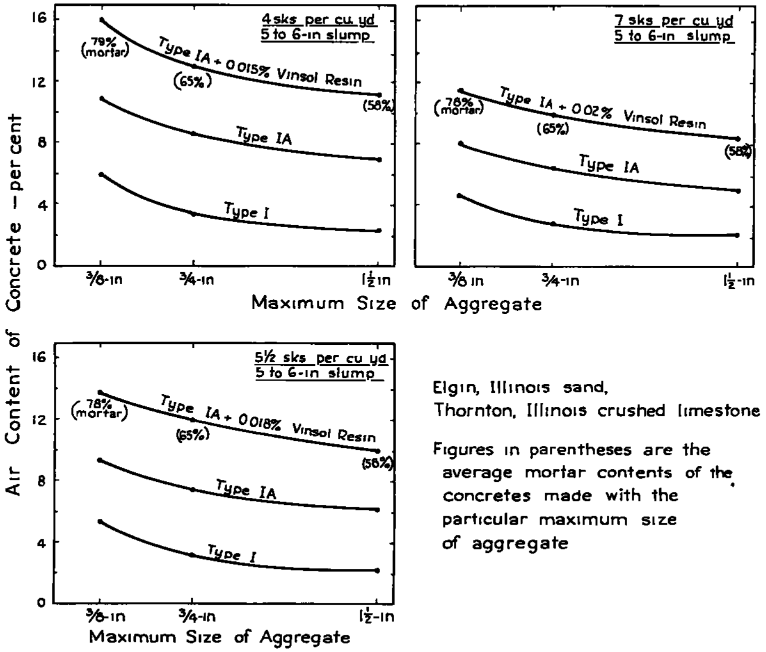
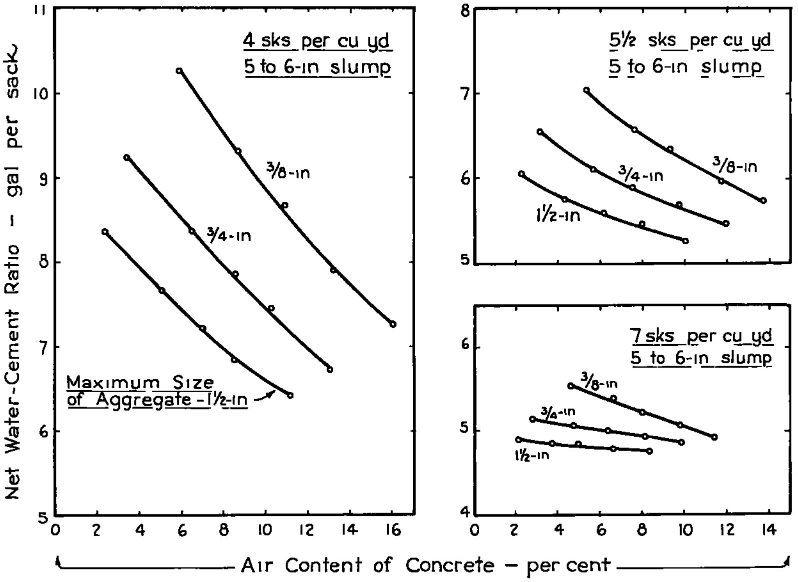


Figure 2. Relationships Between Maximum Size of Aggregate and Air Content for Concretes of Constant Cement Content and Consistency.

(intentionally entrained air is defined as that portion of air entrained in addition to the amount entrained with the Type I cement alone). These percentage changes in strength are calculated from the average air content-strength relationships shown in Figures



Elgin, Illinois sand and
Thornton, Illinois crushed limestone

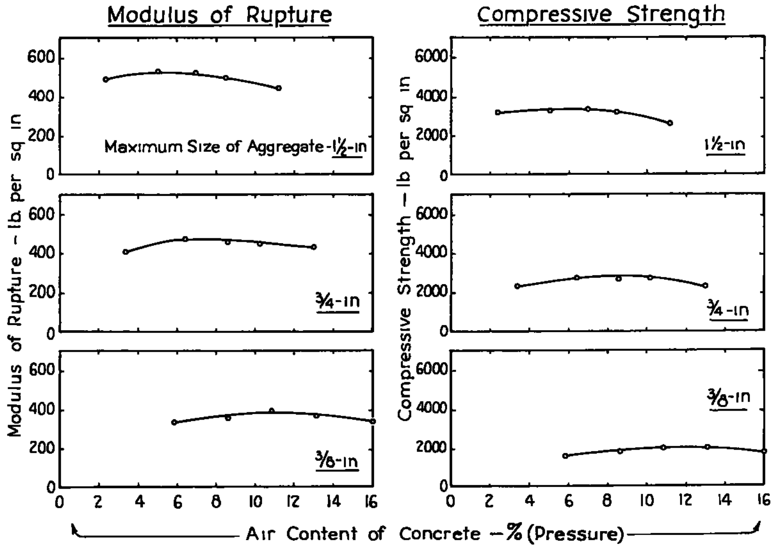
Figure 3. Effect of Air Content on the Water Requirement of Concretes of Constant Cement Content and Consistency Made With Various Maximum Sizes of Aggregate.

TABLE 11

LENGTH AND WEIGHT CHANGES OF CONCRETES PRIOR TO FREEZING AND THAWING

Cement content: 5½ sk. per cu. yd. Slump: 5 to 6 inches.
Specimen size: 3 by 3 by 11¼-in. prisms.

Ref. No.	Net W/C. gal. per sk.	Air Content, % Pressure	Length Changes During Periods Indicated-%			Weight Changes During Periods Indicated-%		
			14d. Moist (+)	14d. Air (-)	3d. in Water (+)	14d. Moist (+)	14d. Air (-)	3d. in. Water (+)
		MAXIMUM SIZE OF AGGREGATE -1½-IN.						
316	6.04	2.25	.006	.028	.020	0.6	2.9	2.2
317	5.75	4.29	.006	.028	.021	0.7	2.7	2.1
318	5.60	6.15	.006	.028	.022	0.8	2.7	2.0
319	5.47	7.90	.006	.031	.023	0.9	2.8	2.1
320	5.26	10.03	.008	.031	.023	1.2	2.8	2.1
		MAXIMUM SIZE OF AGGREGATE - ¾-IN.						
321	6.55	3.15	.013	.034	.024	0.7	3.5	2.6
322	6.10	5.60	.011	.036	.025	0.9	3.3	2.4
323	5.88	7.44	.010	.038	.026	0.9	3.1	2.2
324	5.68	9.77	.010	.039	.026	1.2	3.1	2.3
325	5.46	11.95	.010	.038	.026	1.3	3.2	2.2
		MAXIMUM SIZE OF AGGREGATE - ⅜-IN.						
326	7.03	5.28	.009	.041	.027	0.8	4.1	3.2
327	6.57	7.55	.011	.043	.028	0.9	3.9	2.9
328	6.34	9.30	.013	.044	.029	1.1	3.8	2.8
329	5.97	11.75	.012	.045	.029	1.3	3.7	2.5
330	5.73	13.70	.012	.048	.031	1.5	3.8	2.5



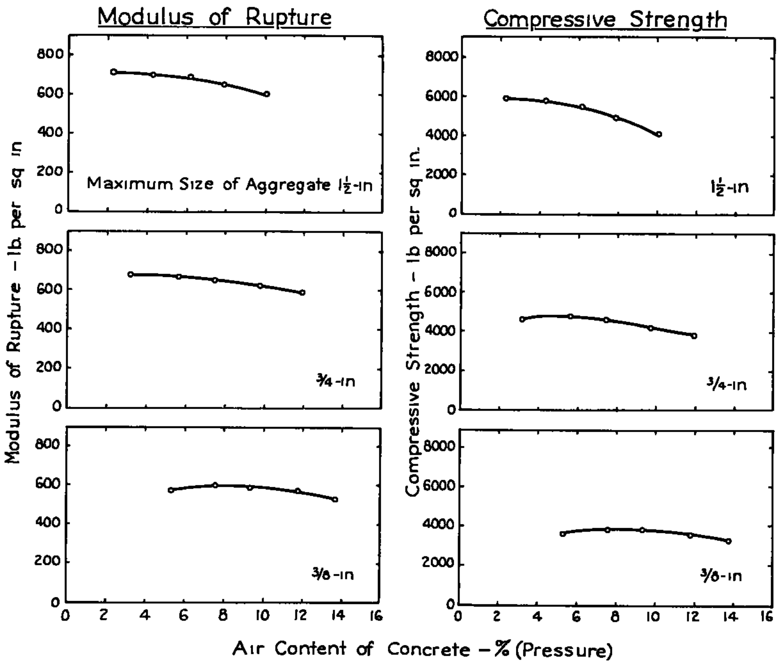
Cement Content 4sks per cu yd Slump 5 to 6 inches
Aggregate Elgin, Ill sand and Thornton, Ill crushed limestone
Cements Type I, Type IA, and Type IA + neutralized Vinsol resin
Curing Continuously moist Compression 6-in modified cubes
Flexure 6 x 6 x 30-in beams, third point loading on an 18-in span

Figure 4. Effect of Entrained Air on the 28-day Strength of Concretes of Constant Cement Content and Consistency Made With Various Maximum Sizes of Aggregate.

TABLE 12
LENGTH AND WEIGHT CHANGES OF CONCRETES PRIOR TO FREEZING AND THAWING

Cement content: 7sk. per cu. yd. Slump: 5 to 6 inches.
Specimen size: 3 by 3 by 11¼-in. prisms.

Ref. No.	Net W/C, gal. per sk.	Air Content, % Pressure	Length Changes During Periods Indicated-%			Weight Changes During Periods Indicated-%		
			14d. Moist (+)	14d. Air (-)	3d. in. Water (+)	14d. Moist (+)	14d. Air (-)	3d. in. Water (+)
		MAXIMUM SIZE OF AGGREGATE-1½-IN.						
331	4.90	2.16	.008	.028	.020	0.8	2.2	1.6
332	4.87	3.68	.008	.030	.024	0.9	2.3	1.6
333	4.86	4.99	.008	.030	.022	0.9	2.3	1.6
334	4.79	6.65	.009	.031	.021	1.0	2.4	1.7
335	4.77	8.38	.009	.033	.022	1.1	2.5	1.8
		MAXIMUM SIZE OF AGGREGATE-¾-IN.						
336	5.15	2.77	.008	.035	.023	0.8	2.4	1.7
337	5.08	4.73	.010	.036	.024	0.8	2.4	1.8
338	5.01	6.35	.006	.036	.025	0.9	2.4	1.7
339	4.94	8.10	.006	.039	.026	1.0	2.4	1.8
340	4.87	9.87	.008	.040	.027	1.2	2.6	1.8
		MAXIMUM SIZE OF AGGREGATE-⅜-IN.						
341	5.55	4.57	.010	.041	.027	0.9	3.0	2.1
342	5.40	6.70	.010	.044	.029	1.0	3.0	2.1
343	5.23	7.96	.011	.045	.029	1.0	2.8	1.9
344	5.08	9.78	.010	.046	.030	1.0	2.7	1.9
345	4.93	11.40	.011	.048	.031	1.2	2.8	1.9



Cement Content 5½ sks per cu yd Slump 5 to 6 inches
Aggregate Elgin, Ill sand and Thornton, Ill crushed limestone
Cements Type I, Type IA, and Type IA + neutralized Vinsol resin
Curing Continuously moist Compression 6-in modified cubes
Flexure 6 x 6 x 30-in beams, third point loading on an 18-in span

Figure 5. Effect of Entrained Air on the 28-day Strength of Concretes of Constant Cement Content and Consistency Made With Various Maximum Sizes of Aggregate.

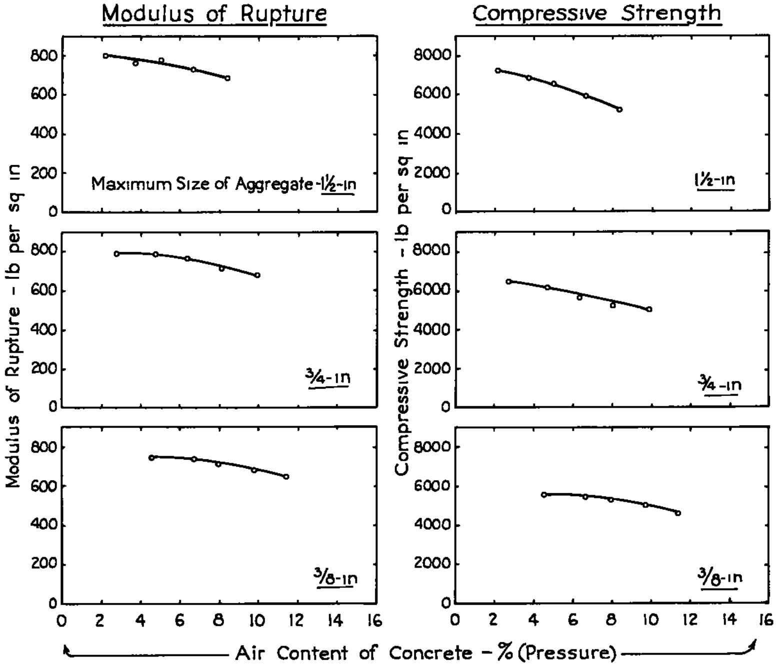
TABLE 13

RESULTS OF SURFACE SCALING AND FREEZING AND THAWING TESTS - 4 SK. PER CU YD

See text for description of test specimens and procedure Three specimens per reference number
Cement content of concretes - 4 sk. per cu yd. Slump· 5 to 6 inches
Elgin, Illinois, sand and Thornton, Illinois crushed limestone
Curing· 14 days moist, 14 days in air and 3 days in water prior to start of tests.

Ref No	Air Content, % Pressure	Rating of Slab Surface After 125 Cycles of F & T	Expansion, Change in Dynamic E and Wt. Loss During 300 Cycles of F & T			No. of Cycles of F & T. for 0.10% Expansion
			% Expansion	% Change in E	% Wt. Loss	
			MAXIMUM SIZE OF AGGREGATE - 1½-IN.			
301	2.37	(85)[a]	(95)[a]	(95)	(95)	60
302	5.01	0+	0.023	-7	5.7	076 at 800 Cycles
303	6.94	0+	0.019	+2	1.4	048% " " "
304	8.45	0+	0.020	+3	0.7	052% " " "
305	11.15	0+	0.024	+3	0.8	.069% " " "
			MAXIMUM SIZE OF AGGREGATE-¾-IN.			
306	3.37	(70)	(70)	(70)	(70)	47
307	6.40	0+	0.030	-20	9.2	565
308	8.53	0+	0.019	+1	2.1	049% at 800 cycles
309	10.20	0+	0.021	+2	1.1	054% " " "
310	12.99	0+	0.023	+2	0.7	.064% " " "
			MAXIMUM SIZE OF AGGREGATE-⅜-IN.			
311	5.83	(65)	(70)	(70)	(70)	39
312	8.60	1+	0.027	-27	12.6	825
313	10.83	1-	0.020	-5	4.4	054% at 800 cycles
314	13.13	1-	0.020	-1	2.1	052% " " "
315	16.00	1-	0.021	-2	1.8	.053% " " "

[a] Numbers in parentheses indicate cycles at which test was discontinued due to excessive scaling or expansion.



Cement Content 7 sks per cu yd Slump 5 to 6 inches
Aggregate Elgin, Ill sand and Thornton, Ill crushed limestone
Cements Type I, Type IA, and Type IA + neutralized Vinsol resin
Curing Continuously moist Compression 6-in modified cubes
Flexure 6 x 6 x 30-in beams, third point loading on an 18-in span

Figure 6. Effect of Entrained Air on the 28-day Strength of Concretes of Constant Cement Content and Consistency Made With Various Maximum Sizes of Aggregate.

TABLE 14

RESULTS OF SURFACE SCALING AND FREEZING AND THAWING TESTS - 5½ SK PER CU YD.

See text for description of test specimens and procedure Three specimens per reference number
Cement content of concretes - 5½ sk. per cu. yd Slump 5 to 6 inches.
Elgin, Illinois, sand and Thornton, Illinois, crushed limestone
Curing: 14 days moist, 14 days in air and 3 days in water prior to start of tests.

Ref No	Air Content, % Pressure	Rating of Slab Surface After 125 cycles of F. & T.	Expansion, Change in Dynamic E and Wt. Loss During 300 cycles of F & T			No of cycles of F. & T for 0.10% Expansion
			% Expansion	% Change in E	% Wt. Loss	
			MAXIMUM SIZE OF AGGREGATE - 1½-IN.			
316	2 25	(110)[a]	(175)[a]	(175)	(175)	125
317	4 29	0+	0.029	+3	0 3	069% at 800 cycles
318	6 15	0+	0 027	+4	+0.2	057% " " "
319	7 90	0+	0.026	+5	+0 6	054% " " "
320	10 03	0+	0 029	+3	+0 7	068% " "
			MAXIMUM SIZE OF AGGREGATE - ¾-IN			
321	3 15	4	(225)	(225)	(225)	175
322	5 60	0+	0.027	0	0.9	.064% at 800 cycles
323	7 44	0+	0 023	+5	+0 1	049% " " "
324	9 77	0+	0 024	+3	+0.3	052% " " "
325	11 95	0+	0 024	+3	+0 3	056% " " "
			MAXIMUM SIZE OF AGGREGATE - ⅜-IN			
326	5 28	4-	0.230	-75	16 8	225
327	7.55	0+	0 025	+2	0 4	062% at 800 cycles
328	9 30	0+	0 021	+4	0	048% " " "
329	11 75	0+	0 021	+5	+0 2	044% " " "
330	13 70	0+	0 020	+4	+0 3	043% " " "

[a] Numbers in parentheses indicate cycles at which test was discontinued due to excessive scaling or expansion

TABLE 15

RESULTS OF SURFACE SCALING AND FREEZING AND THAWING TESTS
7 SK. PER CU. YD.

See text for description of test specimens and procedure. Three specimens per reference number.
Cement content of concretes - 7 sk. per cu. yd. Slump: 5 to 6 inches.
Elgin, Illinois, sand and Thornton, Illinois, crushed limestone.
Curing: 14 days moist, 14 days in air and 3 days in water prior to start of of tests.

Ref. No.	Air Content, % Pressure	Rating of Slab Surface After 125 Cycles of F. & T.	Expansion, Change in Dynamic E and Wt. Loss During 300 Cycles of T. & T.			No. of Cycles of F. & T. for 0.10% Expansion
			% Expansion	% Change in E	% Wt. Loss	
		MAXIMUM SIZE OF AGGREGATE - 1½-IN.				
331	2.16	4	(100)[a]	(100)	(100)	62
332	3.68	0+	0.043	-2	0.1	560
333	4.99	0	0.034	+4	+0.3	.070% at 800 cycles
334	6.65	0	0.031	+2	+0.4	.063% " " "
335	8.38	0	0.031	+4	+0.7	.061% " " "
		MAXIMUM SIZE OF AGGREGATE - ¾-IN.				
336	2.77	2+	(125)	(125)	(125)	100
337	4.73	0+	0.036	+1	0.4	.083% at 800 cycles
338	6.35	0+	0.028	+3	+0.1	.057% " " "
339	8.10	0+	0.028	+4	+0.5	.053% " " "
340	9.87	0	0.027	+4	+0.6	.051% " " "
		MAXIMUM SIZE OF AGGREGATE - ⅜-IN.				
341	4.57	2	(240)	(240)	(240)	170
342	6.70	0+	0.034	+2	0.3	.076% at 800 cycles
343	7.96	0+	0.026	+4	+0.4	.053% " " "
344	9.78	0+	0.025	+3	+0.5	.048% " " "
345	11.40	0+	0.023	+4	+0.7	.044% " " "

[a] Numbers in parentheses indicate cycles at which test was discontinued due to excessive scaling or expansion.

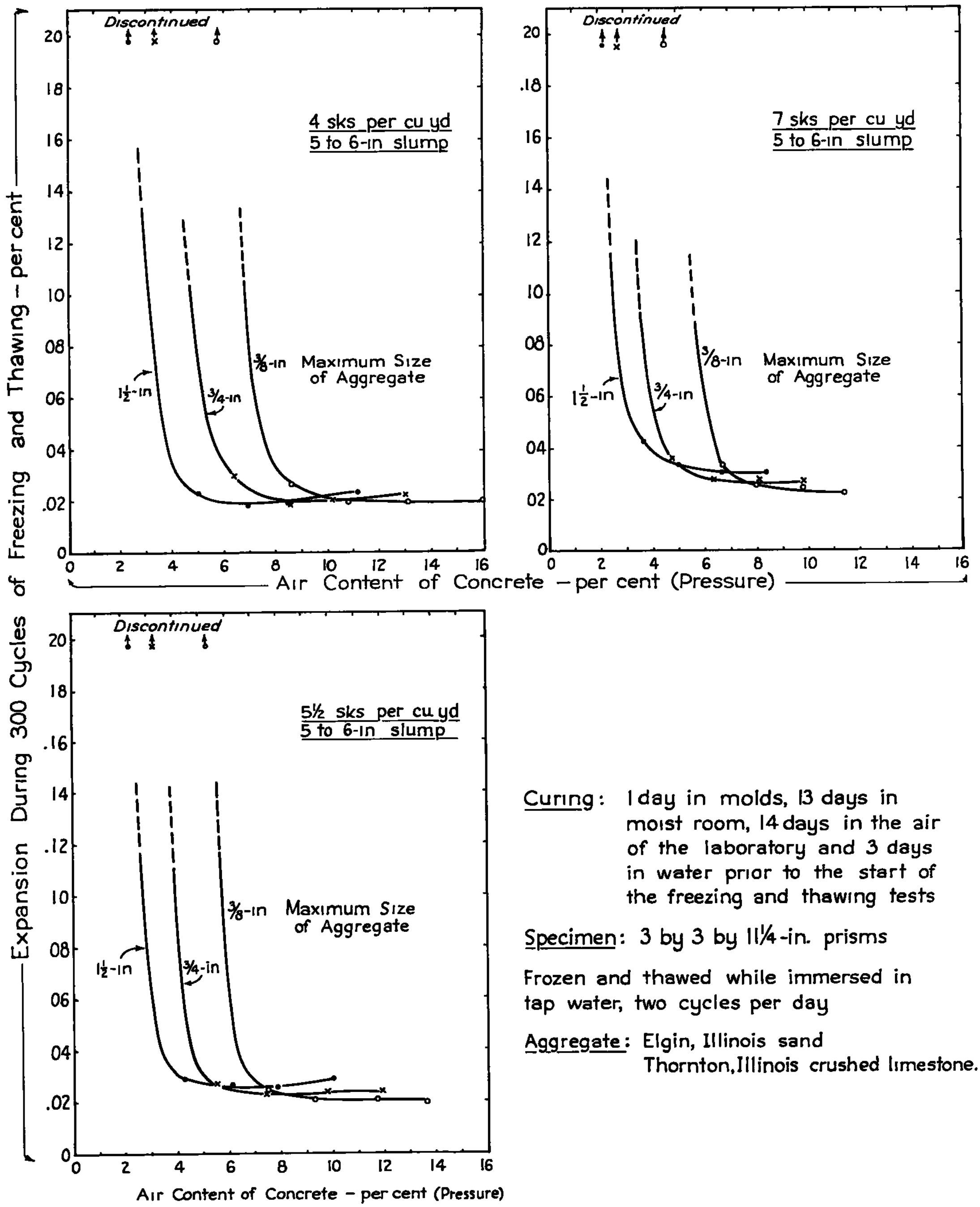
4, 5 and 6, using the strength of the non-air entrained concrete in each group as the reference strength.

The data shown in Table 9 indicate that all of the 4-sk. concretes showed increases in strength with entrainment of up to 6 percent additional air. In these mixes, the reductions in water requirement with entrainment of air were large enough to offset the effect of the entrained air on the strength. The 5½-sk. concretes made with the ⅜-in. aggregate showed strength increases. In the remainder of the 5½-sk. and all of the 7-sk. mixes, the entrainment of air resulted in small decreases in strengths. The greater reductions in water requirement effected by the entrained air as the size of aggregate was decreased resulted in less of a decrease in strength for these mixes.

The maximum air contents used in these tests were well above those which would ordinarily be used in practice on well controlled jobs. These higher air contents were used to aid in establishing trends revealed by the data.

Effect of Entrained Air on Length and Weight Changes During Curing

Tables 10, 11 and 12 show the length and weight changes of the freezing and thawing prisms determined during the curing period consisting of 14 days moist, 14 days in the air of the laboratory and 3 days in water prior to the start of freezing and thawing tests.



Curing: 1 day in molds, 13 days in moist room, 14 days in the air of the laboratory and 3 days in water prior to the start of the freezing and thawing tests

Specimen: 3 by 3 by 11¼-in. prisms

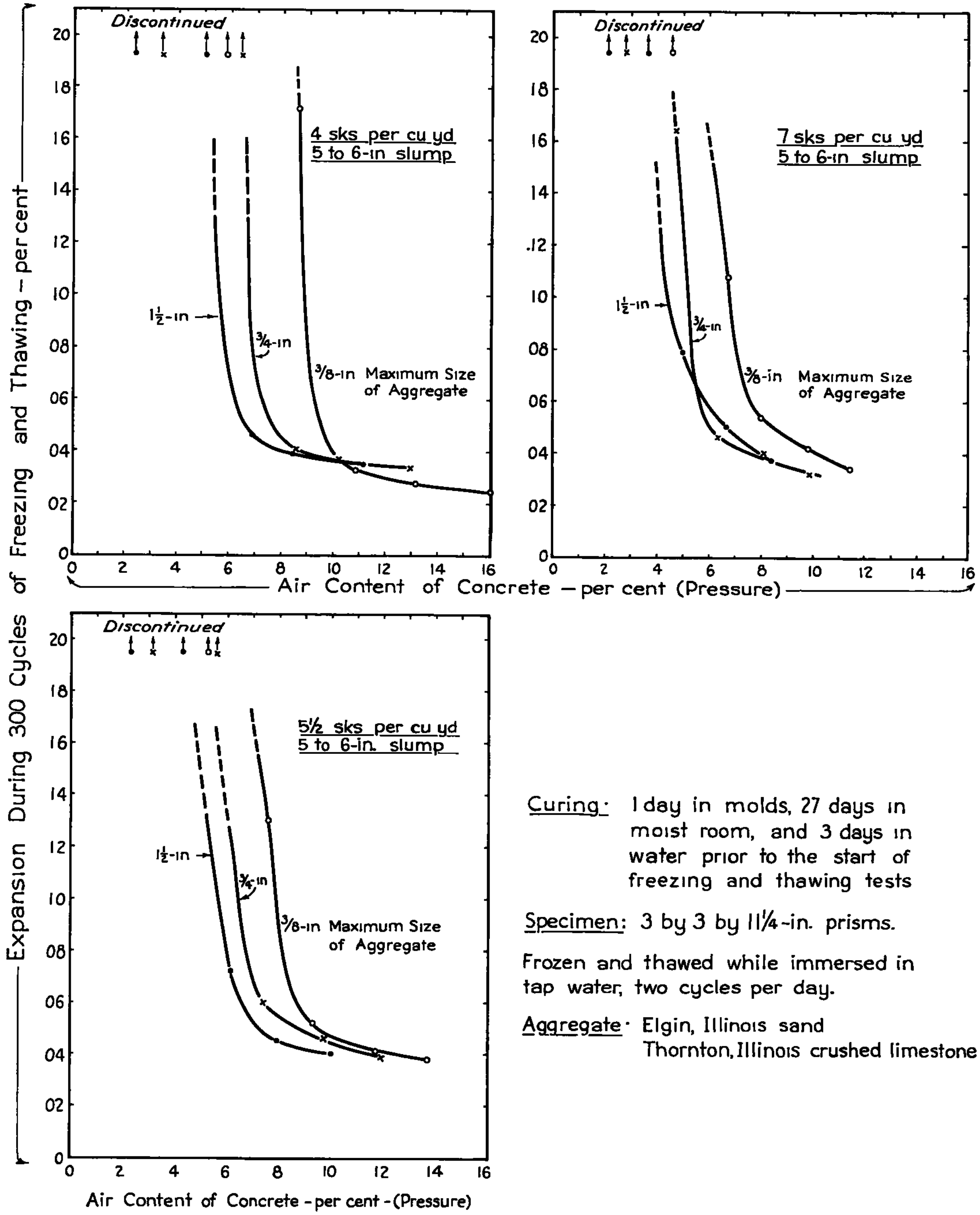
Frozen and thawed while immersed in tap water, two cycles per day

Aggregate: Elgin, Illinois sand
Thornton, Illinois crushed limestone.

Figure 7. Expansion of Concretes During 300 Cycles of Freezing and Thawing.

As in the first series of tests, there appears to be no significant effect of entrained air on the length changes during the initial 14 days of moist storage, a slight increase in contraction with increase in air content during the following 14 days in the air and only a slight trend toward increased expansion with increase in air content during the 3 days storage in water.

All of the concretes showed increasing weight gains with increase in air content during the initial 14 days of moist storage. During the 14 days in the air of the laboratory, none of the concretes showed any signigicant differences in loss of water with



Curing: 1 day in molds, 27 days in moist room, and 3 days in water prior to the start of freezing and thawing tests

Specimen: 3 by 3 by 11¼-in. prisms.

Frozen and thawed while immersed in tap water, two cycles per day.

Aggregate: Elgin, Illinois sand
Thornton, Illinois crushed limestone

Figure 8. Expansion of Concretes During 300 Cycles of Freezing and Thawing.

air content. In general the absorptions decreased slightly for all concretes with increase in air content.

Effect of Entrained Air on Resistance to Freezing and Thawing of Concretes

Tables 13, 14 and 15 show the expansions, changes in dynamic modulus and changes in weight for the air-dried concretes during 300 cycles of freezing and thawing. Concretes in the first series of tests were also compared as to durabilities during 300 cycles. In addition, where available, the number of cycles for 0.10 percent expansion are also shown. Where the specimens have not yet reached 0.10 percent expansion, the latest available expansion data are presented.

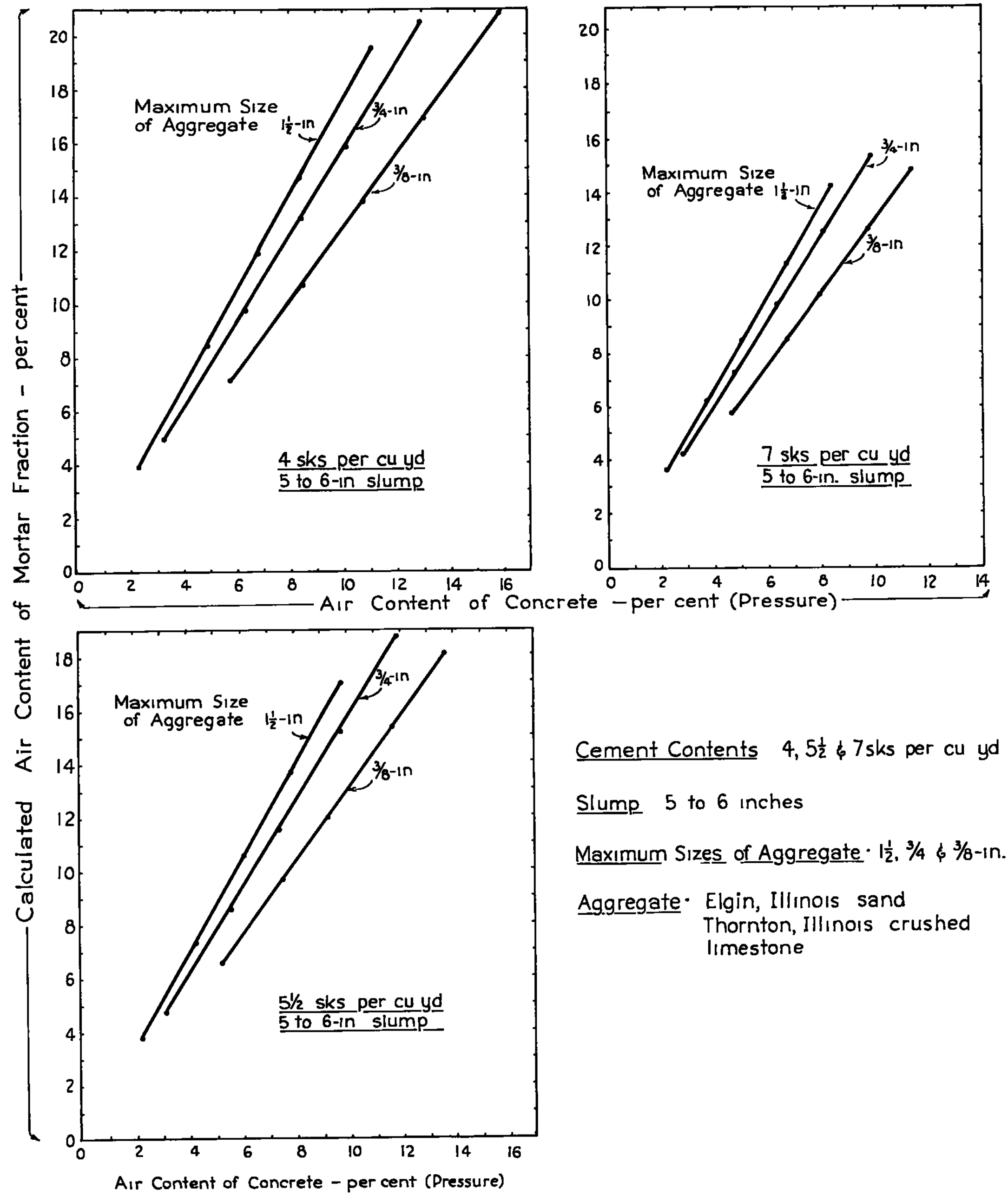


Figure 9. Relationships Between Air Content of Concrete and Calculated Air Content of Mortar Fraction.

Figure 7 shows the expansion during the 300 cycles of freezing and thawing as a function of the air content of the air-dried concretes. Figure 8 shows the same relationships for the continuously moist-cured concretes. For both curing conditions, the resistance to freezing and thawing increased greatly as the air content was increased to some particular level. Further increases in air showed no commensurate further increase in durability, particularly for the air-dried concretes. This level of air content was defined in the first report on this study as that minimum air content beyond which further increases in air result in only a marginal decrease in expansion and is therefore considered to be a balance point between increase in durability and reduction in strength. This air content has been termed the optimum concrete air content.

Table 16 shows the optimum concrete air contents for the air dried concretes as determined visually from Fig. 7. More emphasis is placed on the results of tests of the air-dried concretes than those of the continuously moist-cured concretes, since practically all concrete in service undergoes some drying during its early life. This drying is generally beneficial with regard to resistance of the concrete to freezing and thawing action.

TABLE 16

CHARACTERISTICS OF CONCRETES AT OPTIMUM AIR CONTENTS

Elgin, Illinois, sand and Thornton, Illinois, crushed limestone.
Optimum concrete air contents determined visually from Figure 7.
Air contents of mortar fractions calculated and shown in Figure 9.[a]
Air contents of paste fractions calculated.[a]

Maximum Size of Aggregate, in.	Air Content of concrete Made With Type IA Cement, %	Data for Optimum Concretes		
		Optimum Concrete Air, %	Air in Mortar Fraction %	Air in Paste Fraction, %
		4 SK. PER CU. YD.		
1½	6.9 (5.8)[b]	5.0 (4.5)	8.5 (8.3)	18.2 (18.2)
¾	8.5 (7.4)	6.5 (5.5)	10.0 (8.9)	21.5 (19.8)
⅜	10.8 (9.6)	8.0 (8.5)	10.0 (11.1)	23.4 (26.2)
		5½ SK. PER CU. YD.		
1½	6.2 (4.0)	5.0 (4.5)	8.6 (8.5)	16.6 (16.4)
¾	7.4 (5.6)	6.0 (5.0)	9.2 (8.3)	18.6 (16.9)
⅜	9.3 (8.3)	7.5 (6.5)	9.6 (8.7)	21.2 (19.7)
		7 SK. PER CU. YD.		
1½	5.0 (2.9)	5.0 (4.5)	8.5 (8.4)	14.5 (14.3)
¾	6.4 (4.3)	6.0 (5.5)	9.2 (9.2)	16.4 (16.8)
⅜	8.0 (6.9)	7.5 (7.0)	9.6 (9.6)	19.4 (19.4)

[a] Percent air in mortar fraction $= \frac{A}{C+W+S+A} \times 100$

Percent air in paste fraction $= \frac{A}{C+W+A} \times 100$

Where C = absolute volume of cement.
W = volume of net mixing water.
S = absolute volume of sand (minus No. 4 mesh), saturated, surface-dry.
A = Volume of air voids.

[b] Figures in parentheses are the data obtained in the first series of tests using a crushed gravel as the coarse aggregate.

The optimum concrete air contents shown in Table 16 are, for a particular maximum size of aggregate, practically the same for each of the three cement contents. At the same cement content, the optimum concrete air content increases with a decrease in the maximum size of aggregate.

These optimum concrete air contents may be used to determine the air contents of the mortar fraction by means of the relationships in Figure 9. Table 16 shows these mortar fraction air contents and it can be seen that they fall in the range of 9 ± 1 percent of air, the same range determined in the first series of tests using a different coarse aggregate and concrete at a lower slump. The calculated paste air contents are also shown in this table, but while the mortar fraction air contents for the optimum concretes are relatively stable, the air requirements of the paste increase with a decrease in maximum size of aggregate. The method used to calculate the air contents of the mortar and paste fractions is shown in Table 16.

It appears from these data and the data obtained in the first report (shown in parentheses in Table 16) that concrete which will undergo some drying prior to exposure to frost action can be made resistant to freezing and thawing by providing a relatively constant amount of air in the mortar fraction, despite changes in cement content, maximum size of aggregate, consistency and probably types of aggregate. These tests were made with two types of coarse aggregate and two concrete consistencies.

The optimum concrete air contents for these limestone concretes were from $\frac{1}{2}$ to 1 percentage points higher than those for the gravel concretes in the first series of tests. This resulted from the higher mortar contents of the limestone concretes.

The continuously moist-cured concretes, although showing considerable increase in durability with entrainment of air, apparently require more air for the same degree of durability than do the air-dried concretes (See Figure 8). This difference in air requirements was less pronounced as the cement content was increased from 4 to 7 sk. per cu. yd.

The Role of Type IA Cement in Providing Optimum Air Contents

In the first series of tests the Type IA cement in most cases produced as much or slightly more than the amount of air indicated to be necessary. In these tests, the air contents produced by the Type IA, shown in Table 16, were in every case equal to or somewhat greater than the indicated optimum concrete air contents, despite changes in maximum size of aggregate and cement content.

At the concrete air contents produced by the Type IA cement, the resistance to freezing and thawing for all of the moist-cured concretes in these tests during 300 cycles of test is considered satisfactory based on the expansion-air content relationships shown in Figure 8.

Effect of Entrained Air on Resistance to Surface Scaling

Tables 13, 14 and 15 also show the results of tests for resistance to surface scaling resulting from the use of calcium chloride for ice removal.

All of the concretes with intentionally entrained air showed excellent resistance to surface scaling, with the possible exception of the 4-sk. concrete made with the $\frac{3}{8}$-in. maximum size of aggregate, although even in this case the improvement in scale resistance was great.

GENERAL OBSERVATIONS

This second series of tests has produced what might be considered excellent confirmation of the conclusion reached in the first series of tests reported on earlier, namely that despite changes in cement content, maximum size of aggregate, consistency and type of coarse aggregate a relatively constant amount of air in the mortar fraction in the range of 9 ± 1 percent will provide the optimum air content in concrete. These observations with regard to optimum concrete air content and air content of the mortar fraction should apply to concretes showing the normally occurring distribution of air void sizes, a situation which will in general prevail. There may be instances where an abnormal distribution of air void sizes will limit the practical usefulness of this criterion. However, it is believed that these occurrences will be few in actual practice.

This information provides a practical approach to the problem of specifying the amount of air required for adequate resistance to frost action by specifying merely the air content of the mortar fraction. Based on the desired mix proportions, this mortar air content may then be converted to concrete air content. Control of actual mixing operations would then center about this concrete air content.

At this time, there appears to be no special theoretical significance to ascribe to the utility of the 9 ± 1 percent mortar fraction air content in producing frost-resistant concrete.

Continued efforts are being made to determine the basic factors controlling the resistance of concrete to freezing and thawing. Previous tests indicated the importance of the air void characteristics, such as bubble spacing, and the influence of the amount of water actually freezing within the concrete. Data of this type are now being obtained for these concretes and the evaluation of these data will constitute a future report. The next phase of this study will place emphasis on the effect of concrete temperature during mixing on the air void characteristics together with the effect of different curing temperatures on the freezable water characteristics of the concretes. These data will then be correlated with actual laboratory freezing and thawing data. Further studies will include the effect of vibration, mixing time, sand grading and other variables.

SUMMARY

Based on both these recent tests and the first series of tests reported previously, the following observations and conclusions appear pertinent. Many of these have been made as a result of prior tests[3] and tests by other investigators, but appear worthy of repetition. These conclusions were derived from concretes made and cured at normal temperature (73° F.) and having a normally occurring distribution of air void sizes such as produced by the commonly accepted air-entraining agents.

1. For constant cement content and consistency, the reduction in strength with entrainment of air decreases as the maximum size of aggregate decreases, due to the greater reductions in water requirements possible with the smaller size aggregates.
2. For a particular consistency, the reduction in strength with entrainment of air decreases with a decrease in cement content, due to the greater reduction in water requirements possible in the leaner mixes. These larger reductions in water requirements often result in increases in strength as air is entrained in the lean mixes.
3. There appears to be no significant effect of air content on volume change or weight change during moist storage or air storage, or on absorption during 3 days immersion in water.
4. In all cases, the entrainment of air increased the resistance of concrete to freezing and thawing and to surface scaling resulting from the use of salts for ice removal.
5. The optimum concrete air requirement for frost resistance increased as the maximum size of aggregate decreased.
6. For the air-dried concretes at a particular maximum size of aggregate there appears to be little effect of cement content on the optimum concrete air content.
7. For the air-dried concretes, the tests indicate that the optimum concrete air content can be obtained by providing a relatively constant air content in the mortar fraction, despite changes in cement content, consistency, maximum size of aggregate or type of aggregate. This mortar air content appears to be in the range of 9 ± 1 percent.
8. Concretes cured continously moist required more entrained air for adequate resistance to freezing and thawing than the air-dried concretes. The Type IA cement provided a sufficiently high level of air content for these concretes.
9. For any given cement, the use of a constant amount of air-entraining agent per unit of cement appears to provide a self-regulating means for obtaining optimum concrete air contents despite variations in the proportions of concrete mix constituents and changes in the type of aggregate.

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[3] "Effect of Entrained Air Strength and Durability of Concrete Made With Various Maximum Sizes of Aggregate" by Paul Klieger, Bulletin 40, Portland Cement Association, Chicago, Illinois.

Resistance of Concrete Surfaces to Scaling Action of Ice-Removal Agents

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This report is a résumé to date of investigations conducted to test materials and procedures for protecting concrete pavements against scaling and disintegration caused by calcium chloride and other thawing agents used for ice removal. A laboratory investigation by the Bureau of Public Roads was started in 1948 on methods of protecting the wearing surface of concrete against the action of calcium chloride. Later a similar study was made of the effect of outdoor weather conditions on small slabs on the ground. It was found that resistance to scaling is affected by air content, type of air-entraining admixture, surface treatments or coats, admixtures of oils, inhibitors, flyash as a replacement for portland cement, rate of application of $CaCl_2$, curing methods, thawing agents other than $CaCl_2$ or common salt and by the vacuum method of placing concrete.

● DURING the winter months when ice has formed on pavements and bridge decks, sodium chloride or calcium chloride or mixtures of the two are spread on the surfaces to thaw the ice and make the riding surface safe for traffic. This practice has been common in many parts of the country for 25 years or more. The continued use of these salts, usually spread in flake, pellet, or crystal form, has frequently resulted in excessive scaling of the wearing surface of portland cement concrete. In some cases the action has been so severe as to cause complete disintegration.

In states where ice covers the pavements many times each winter, the problem of ice removal by chemicals and the attendant scaling and disintegration of the concrete is a serious problem. Since sodium and calcium chlorides are very effective for melting ice, there is great interest in developing methods of making concrete resistant to their action. In New York, particularly, and in several of the other northeastern states, climatic conditions, hilly terrain, and heavy traffic have intensified this problem of developing a concrete resistant to the scaling caused by chloride salts.

The Bureau of Public Roads began a laboratory investigation in 1948 of methods of protecting the wearing surface of concrete against the action of calcium chloride. Later because of the extreme severity of the laboratory test which caused doubt as to its similarity to field conditions a similar study was made under outdoor weather conditions on small concrete slabs on the ground. This is a progress report of a continuing research program and has been prepared to summarize the information obtained on the laboratory tests and the outdoor exposure tests through the winters of 1951-1952, 1952-1953, and 1953-1954.

SCOPE

The laboratory investigation was divided into five parts:

Part 1. Study of the effect of increasing the air content of the fresh concrete beyond the 6 percent maximum limit now generally permitted in specifications for concrete for pavement construction.

Part 2. Study of delaying the scaling action by surface coatings of crankcase oil undiluted and diluted with various percentages of gasoline, and a study of the effect of time of application of the oils.

Part 3. Effect of using paraffin and asphaltic base lubricating oils (both new and used) as admixtures in concrete. Study of the effect of these materials on strength, shrinkage and resistance to freezing and thawing in water.

Part 4. Investigation of the following miscellaneous factors: Effect of using various amounts of calcium chloride applied to a given area for ice removal, the effect of a possible rust inhibitor mixed with calcium chloride, and effect of urea used for ice removal in place of calcium chloride.

Part 5. Study of the improvement in the quality of the wearing surface produced by vacuum treating of the concrete.

The outdoor investigation to date covers tests over three winters. The variable studied during the first winter was type of air-entraining admixture. Twenty-seven commercial air-entraining admixtures were used in amounts that produced about the same air content in each of the concrete slabs.

During the second and third winters the outdoor program was divided into four parts:

Part 1. A repeat of the tests made the first winter with most of the 27 air-entraining admixtures but using two cements (Brand A-high alkali content and brand B-low alkali content). Five more air-entraining admixtures were included which had been received too late for the first series. These concrete slabs were cast in molds both on a metal base and on a sand base.

Part 2. Effect on the resistance to scaling of replacing part of the portland cement with flyash was studied. A fine and coarse flyash from each of two sources were used because previous experience indicated that the finer the flyash from a given source the lower the carbon content. Two concretes, plain and air-entraining, were used for each flyash replacement, with each of the two different cements. (Brands A and B).

Part 3. Effect of methods of curing the concrete on resistance to chloride attack was studied. In conncetion with the curing study surface applications of oil were also made following the curing period.

Part 4. The effect of vacuum treating the surfaces of both plain and air-entrained concrete was studied.

CONCLUSIONS

The principal conclusions of the laboratory tests (artificial freezing) were as follows:

1. A scaling test which involved freezing of water on the surface of concrete test slabs and thawing with an application of flake calcium chloride showed that the resistance of the concrete was a function of the amount of entrained air. An air content in excess of 6 percent was more effective in making concrete resistant to the scaling action of calcium chloride than increasing the cement content.

2. Concrete which was cured and seasoned and then coated with mineral oil showed greater resistance to calcium chloride attack than similarly cured concrete which received no protective treatment. Multiple coats of oil were slightly more beneficial than a single coat of oil. Application of the oil to freshly placed concrete decreased the resistance to scaling.

3. Neither paraffin nor asphaltic base oil used as admixtures were of much value in either delaying or controlling the progress of scaling. Used crankcase lubricating oil was effective in retarding the start of scaling, because of the air entrained in the fresh concrete by this material.

The use of 1/3 or 2/3 of a gallon of paraffin or asphalt base oil per sack of cement as an admixture had no effect on the air entrained in the concrete. A slight reduction in shrinkage and in strength and a slight improvement in durability as measured by resistance to freezing and thawing in water resulted from the use of these oils.

The use of 1/3 or 2/3 of a gallon of used crankcase lubricating oil per sack of cement entrained air in the concrete. Concretes containing these admixtures showed a reduction in strength and an improvement in durability proportional to the amount of air entrained. The shrinkage of the concrete containing crankcase oil was about the same as the concrete without admixture.

4. Urea, reported to be a thawing agent non-corrosive to metals, when used to thaw ice on concrete was slower in thawing action than calcium chloride. Also it caused scaling but not so quickly as calcium chloride.

Varying the amount of the thawing agent (calcium chloride or urea) had little effect either on the start or rate of progress of the scaling. The use of a metal corrosion inhibitor had only a slight retarding action on scaling of concrete when used with calcium chloride for ice removal.

5. Concretes containing 6 or 7 sacks of cement per cubic yard, both plain and air-entrained were benefited in their resistance to scaling by the use of the vacuum treatment of the plastic concrete.

The principal conclusions of the outdoor exposure tests were as follows:

1. All the air-entraining admixtures tested in concrete were effective in delaying the start of serious scaling. As indicated by the preliminary tests of the first winter the synthetic detergents and the salts of proteinaceous materials were less effective than the admixtures in the other groups. In the subsequent tests made the next two winters the shythetic detergents were relatively more effective than they were in the preliminary tests. For the concrete containing aggregates with a 1- inch maximum size, the tests indicate that more satisfactory resistance is obtained when the air content is greater than 5 percent.

2. For the variables studied, the scaling of concrete was less pronounced when the concrete had been cast in a mold with a sand base than when cast in a mold with a metal base. The water retention of the concrete cast on the sand base is less than that cast on a metal base. The resulting decrease in the water-cement ratio accounts for the difference in resistance to scaling.

3. The two portland cements used did not produce concretes of equal resistance. The concretes made with cement B (low alkali content) were more resistant than the concretes made with cement A (relatively high alkali content). The different treatments of the concretes did not appear to change this relative difference between the cements in resistance to scaling.

4. Replacing portland cement in the mix with flyash, regardless of the fineness or carbon content, was detrimental to the resistance of the concretes to attack by calcium chloride used for ice removal. Maintaining a fixed air entrainment within the usual specification limits did not balance the lowered resistance caused by the use of flyash.

TABLE 1

CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF PORTLAND CEMENTS AND FLYASHES

	Portland Cement		Flyash			
	A	B	A	B	X	Y
Chemical composition in percent						
Silicon dioxide	22.0	22.3	47.1	49.2	41.2	38.5
Aluminum oxide	5.6	5 4	18.2	19.9	22.1	23 5
Ferric oxide	2.5	2.4	19.2	16.2	20.6	18.8
Calcium oxide	62.8	66.1	7 0	5 5	6 0.	3.2
Magnesium oxide	3 0	1.0	1.1	1.4	1 2	1.0
Sulfur trioxide	2 0	1.7	2 8	2.7	0 9	0.6
Loss on ignition	0.8	1 2[a]	1 2[a]	1 2[a]	5 4[a]	11.6
Sodium oxide	0.40	0.04	1.80	2 00	1 00	0 60
Potassium oxide	1.05	0 15	2.15	2 35	1.42	1 88
Total equiv. alkalies as NA$_2$0	1.09	0.14	3.21	3.55	1.93	1.84
Insoluble residue	0.16	0.12	-	-	-	-
Chloroform-soluble organic substances	0.009	0.003	-	-	-	-
Free calcium oxide	0.85	0.56	-	-	-	-
Water-soluble alkaki						
NA$_2$0	0.11	0.01	-	-	-	-
K$_2$0	0.63	0.02	-	-	-	-
Computed compound composition in percent						
Tricalcium silicate	42	55	-	-	-	-
Dicalcium silicate	31	22	-	-	-	-
Tricalcium aluminate	11	10	-	-	-	-
Tetracalcium aluminoferrite	8	7	-	-	-	-
Calcium sulfate	3 4	2.9	-	-	-	-
Carbon	-	-	0.2	0.6	5 0	11 2
Carbon dioxide	-	-	0 01	0 04	0.04	0.03
Physical properties						
Apparent specific gravity	3.20	3 17	2 49	2 52	2 51	2.43
Specific surface (Wagner) cm ^{2}/g.	1800	1625	-	-	-	-
Specific surface (Blaine) cm.^{2}/g	-	-	3075	4305	2565	3220
Autoclave expansion-----percent	0.32	0.04	-	-	-	-
Normal consistency -----percent	25.5	25.0	-	-	-	-
Time of setting (Gillmore test)						
Initial--------------------hours	3.2	4 2	-	-	-	-
Final --------------------hours	5.2	6 4	-	-	-	-
Compressive strength (1·2 75 mortar)						
At 7 days------------------psi	2340	2960	-	-	-	-
At 28 days-----------------psi.	3670	5070	-	-	-	-
Mortar air content----------- percent	9.1	6 8	-	-	-	-

[a] Determination made at 600°C.

TABLE 2

MIX DATA LABORATORY SLABS (6 BY 12 BY 2 INCHES THICK)

Mix by Dry Weight	Admixture		Cement	Water	Slump	Air	Weight of Plastic Concrete
	Amount	Type					
Pounds	per sack of cement		Sk. /cu. yd.	Gal. /sk.	Inches	Percent	pcf.
Part 1 - Effect of air content							
94-210-320	-	None	6.0	5.7	2.3	1.5	149.0
94-200-320	.004%[a]	Vinsol resin	6.0	5.4	2.4	2.7	148.0
94-180-320	.011%	Vinsol resin	6.1	5.1	2.6	6.0	143.7
94-160-320	.025%	Vinsol resin	5.9	4.7	3.2	13.0	131.6
94-170-270	-	None	7.0	4.8	2.6	1.5	149.3
94-155-270	.005%	Vinsol resin	7.2	4.5	2.4	2.7	148.9
94-140-270	.011%	Vinsol resin	7.2	4.2	2.2	4.9	143.8
94-130-270	.022%	Vinsol resin	7.1	4.1	2.2	7.2	139.6
Part 2 - Effect of oil surface treatment							
94-210-320	-	None	5.9	6.1	3.5	1.9	147.3
Part 3 - Effect of oil admixtures							
94-210-320	-	None	5.9	6.1	3.0	2.0	146.6
94-170-320	⅔ Gal.	Used crankcase oil	6.0	5.4	4.8	5.7	140.0
94-200-320	⅔ Gal.	Paraffin oil	5.9	5.7	4.0	2.0	146.3
94-200-320	⅔ Gal.	Asphalt oil	5.9	5.7	3.5	2.4	145.3
Part 4 - Effect of thawing agent							
94-210-320	-	None	5.9	6.1	3.5	1.9	147.3
Part 5 - Effect of vacuum surface treatment							
94-210-320	-	None	6.0	5.7	-	1.7	148.6
94-160-320	.020%	Vinsol resin	6.2	4.7	-	7.4	141.1
94-170-270	-	None	7.0	4.8	-	1.7	148.6
94-130-270	.022%	Vinsol resin	7.1	4.1	-	7.8	139.3

Materials used: Cement - brand A; siliceous sand - F.M. = 2.70; siliceous gravel-¾-inch maximum size.

[a] Expressed as percent by weight of cement.

5. In general, the type of curing had little apparent effect on the resistance of the concretes to calcium chloride attack. The membrane curing, when the film remained unbroken, had some protective action. Under traffic conditions such as a film would probably be of little or no value.

6. The concrete cast in molds with metal bases and subjected to a vacuum treatment was little different in resistance to scaling from similarly cast undreated concrete. However, when the concretes were cast in molds with sand bases the concrete on which the vacuum treatment was used was more resistant to scaling than the untreated concrete. This same relationship held for concrete with air contents ranging from 1 to 10 percent.

LABORTARY EXPOSURE SERIES

The portland cement used was an ASTM Type I cement. It is designated as brand A cement and is the same cement as brand A used in the outdoor investigation. Table 1 gives the chemical composition and physical properties of the cement.

TABLE 3

RATING OF RESISTANCE TO SURFACE SCALING OF CONCRETE SLABS CONTAINING VARIOUS PERCENTAGES OF AIR

Part 1 Laboratory Tests

Cement	Air[a]	Rating after cycles of freezing and thawing indicated[b]				
		30	36	42	50	60
Sk. / cu. yd.	Percent					
6.0	1.5	8	10			
6.0	2.7	6	8	10		
6.1	6.0	2	3	5	6	8
5.9	13.0	0	0	0	2	2
7.0	1.5	3	7	10		
7.2	2.7	2	5	8	10	
7.2	4.9	0	2	5	10	
7.1	7.2	0	1	2	4	6

Each value is average of 3 tests.
Slabs cured in moist air for 21 days followed by 14 days storage in laboratory air.

[a] Air content determined by ASTM tentative method C 231-49 T.

[b] Freezing and thawing tests were discontinued when surface scaling rating was 10, or at 60 cycles.

The aggregates used for all concrete mixes for the scaling tests consisted of a siliceous sand having a fineness modulus of 2.70 and a well graded siliceous gravel of ¾-inch maximum size. For the test specimens used for determining strength, resistance to freezing and thawing in water and volume change, crushed limestone was used as coarse aggregate. Concretes made from similar aggregates have good service records for durability.

The concrete mix data are given in Table 2.

The specimens used in the laboratory scaling test consisted of concrete slabs having a wearing surface of 6 by 12 inches and a thickness of 2 inches.

TABLE 4

EFFECT OF OIL SURFACE COATINGS ON THE RESISTANCE OF CONCRETE TO SCALING

Part 2 - Laboratory Specimens

Number of Applications	Surface treatment	$CaCl_2$ thawing	Rating after cycles of freezing and thawing indicated	
			15	40
-	None	No	2	4
-	None	Yes	4	8
1	50% SAE 10 oil, 50% gasoline	Yes	2	4
1	75% SAE 10 oil, 25% gasoline	Yes	2	3
1	100% SAE 10 oil	Yes	2	2
-	None	No	2	4
-	None	Yes	4	8
3	50% SAE 10 oil, 50% gasoline	Yes	2	2
3	75% SAE 10 oil, 25% gasoline	Yes	2	3
2	100% SAE 10 oil	Yes	2	3

Each value is average of 3 tests.
Slabs cured in moist air for 21 days followed by 14 days storage in laboratory air.

[a] Surface treatment applied at the rate of 1 gallon per 20 square yards at age of 28 days.

TABLE 5

EFFECT OF TIME OF APPLICATION OF OIL COATING ON THE RESISTANCE OF CONCRETE TO SCALING

Part 2 Laboratory Tests

Surface treatment	Rating after cycles of freezing and thawing indicated			
	15	25	50	60
None	3	4	5	6
Oil applied after 3 hours[a]	4	4	6	10
Oil applied after 14 days[a]	2	2	3	3

Each value is average of nine tests.

[a] Slabs cured in moist air for 7 days followed by 28 days storage in laboratory air followed by 4 days soaking.

The slabs were cast and the concrete rodded and spaded in the usual manner. In one group of slabs a vacuum treatment was applied to the plastic concrete after casting.

Approximately three hours after molding, the top surface of each specimen was given a broomed finish to simulate the surface finish frequently given pavement slabs. Subsequent to brooming a mortar dam approximately ½-inch in height was cast around the perimeter of the specimen. In general, the concrete was cured in moist air, the bottoms and sides of the specimens were water-proofed with a heavy coating of paraffin, and then stored in the air of the laboratory before start of the freezing and thawing cycle. The exact period of curing is shown in the notes of Tables 3 to 6.

The top surfaces of the slabs were first flooded with ¼ inch of water, after which the specimens were placed in the freezer and the surrounding air temperature reduced to -10° F. The slabs were kept in the freezer approximately 15 hours, then removed from the freezer, and flake calcium chloride applied directly to the ice-covered surface. In general, the amount of calcium chloride applied was 2.4 pounds per square yard of ice encrusted surface. This is the maximum amount usually applied in practice and is the amount used by other investigators. In one group of tests different amounts of calcium chloride were applied per square yard. After the ice had thawed, the calcium chloride solution was washed from the surface of the slabs, fresh water applied and the cycle repeated. One cycle was completed each 24 hours from Monday through Friday. The slabs remained in the freezer from Friday night until Monday morning.

In general, three slabs were made for each condition and two or more rounds

TABLE 6

RATING OF RESISTANCE TO SURFACE SCALING OF CONCRETE SLABS CONTAINING OILS AS ADMIXTURE

Part 3 Laboratory Specimens

Admixture	Air[a]	Rating after cycles of freezing and thawing indicated				
		20	30	50	65	75
	Percent					
None	2.0	1	2	3	9	10
Used crankcase oil	5.7	1	1	1	2	4
Paraffin Oil	2.0	3	4	4	10	10
Asphalt Oil	2.4	3	5	5	10	10

Each value is average of 5 tests.

Slabs cured in moist air for 14 days followed by 40 days storage in laboratory air.

[a] Air content determined by ASTM tentative method C 231-49T.

of slabs made on different days for each condition of test. Only one round of slabs was photographed and since the rounds in general checked each other very closely the results of only one round are reported.

The various slabs were rated periodically for surface scale. The ratings were based on visual observation of the extent and depth of scale. The following tabulation describes the numerical significance of the rating:

Rating of 0 - No scale; 1, scattered spots of very light scale; 2, scattered spots of light scale; 3, light scale over about ½ the surface; 4, light scale over most of surface; 5, light scale over most of surface, few moderately deep spots; 6, scattered spots moderately deep scale; 7, moderately deep scale over ½ the surface; 8, moderately deep scale over entire surface; 9, Scattered spots deep scale otherwise moderate scale; 10, deep scale over entire surface.

Typical examples of the various ratings are shown in Figure 1, and Figure 2 illustrates progressive scaling of three identical slabs as the number of cycles of freezing and removal of ice with calcium chloride was increased.

OUTDOOR EXPOSURE SERIES

The portland cements used were ASTM Type 1 cements. Two cements were used, brand A and brand B. Brand A had a relatively high alkali content and brand B a very low alkali content. Table 1 gives the chemical and physical properties of the cements.

Figure 1 Rating scale. Resistance of concrete to scaling after laboratory freezing and thawing with $CaCl_2$.

The aggregates used for all mixes consisted of a siliceous sand having a fineness modulus of 2.70 and a crushed limestone coarse aggregate of 1-inch maximum size. Concretes containing these aggregates have a good service record for durability. The concrete mix data for these materials are given in Table 14.

The rapidity with which scaling started on the small slabs frozen in the laboratory freezer, suggested the possibility that the conditions were far more severe

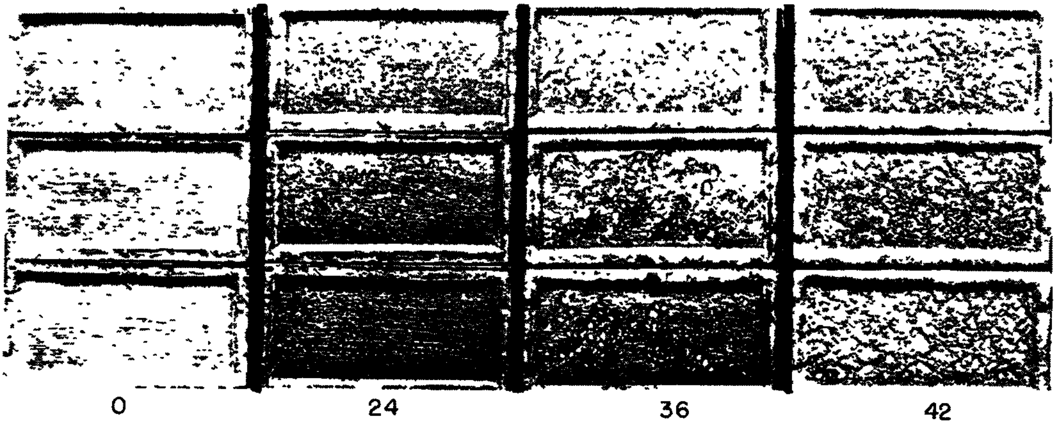

Figure 2. Progressive scaling of non-air-entrained concrete after indicated cycles of laboratory freezing and thawing with $CaCl_2$.

than those occurring under field applications of calcium chloride. In order to study this feature further, slabs 16 by 24 by 4 inches deep with raised edges or dams around the perimeters were made for outdoor exposure.

The surfaces of the slabs were given a broomed finish and most of them were then cured in the moist room from 28 to 90 days and then placed in the exposure area. The specimens were in the exposure area from 30 to 100 days before the first application of calcium chloride was made. A description of the treatment is in the notes to Tables 15 to 21. Broom finishing was selected because observations indicate that a broom finish tends to hold the calcium chloride solution on the pavement surface and retards its removal by drainage. In the fall and winter, the top surfaces of the test specimens were kept covered with water.

The first slabs were made in the laboratory in water-tight molds with a metal base. This condition simulates concrete placed on an impervious subgrade or on paper or asphalt seals placed on the subgrade. Later tests were made using a damp sand base which would be more nearly comparable to types of subbases often used under concrete pavements. With the exception of the series in which curing was studied all other slabs were made in the laboratory. The details of the proportions, slump, etc., for the concretes are given in Table 14.

When ice was frozen on the slabs, $CaCl_2$ was applied to the surface at the rate of 2.4 pounds per square yard. After the ice was completely thawed, the surface was washed and fresh water left on the surface to await another freezing.

During the winter of 1951-1952, 19 cycles were obtained, and during the winter of 1952-1953, only 17 cycles, and in the winter of 1953-1954, 34 cycles.

The slabs were rated periodically for surface scale. The ratings were based on visual observation of the extent and depth of scale. The numerical significance of the rating system used was the same as that shown for the small laboratory exposed slabs.

DISCUSSION OF LABORATORY TEST SERIES

Effect of Air Content - Part 1

In this group of laboratory tests the object was to study the effect of increasing the air content beyond the maximum 6 percent limit now generally permitted for concrete for pavements. Since the maximum size of aggregate used with the 6- by 12- by 2-inch slabs was ¾ inch, this necessitated a higher air content for a given degree of durability than is required by a normal paving mix containing aggregate graded up to 2 inches. This increase in air requirement has been shown by a number of investigators[1] to be necessary in maintaining the level of durability.

Two different proportions were used, one containing 6 and the other 7 sacks of cement per cubic yard. The slump of the concrete was maintained at 2 to 3 inches. Where entrained air was desired, neutralized Vinsol resin was used to produce the quantity of air specified.

Table 3 shows the scale ratings of the surfaces of the slabs containing various percentages of air. These ratings are reported at 30, 42, 50 and 60 cycles when the tests were discontinued. Some tests were discontinued sooner because of the condition of the slab. The slabs having a cement content of 6 sacks per cubic yard had a maximum air content of 13 percent instead of the 7 to 8 percent which was planned.

The surface condition of the slabs after various cycles of exposure to calcium chloride action is well illustrated in the photographs in Figures 3 and 4.

Figure 3 shows the condition of the surface of concrete made with 6 sacks of cement per cubic yard and various air contents ranging from 1.5 to 13.0 percent. In each case the three slabs in a vertical column were identical in composition and treatment. Under each column is shown the air content of the fresh concrete.

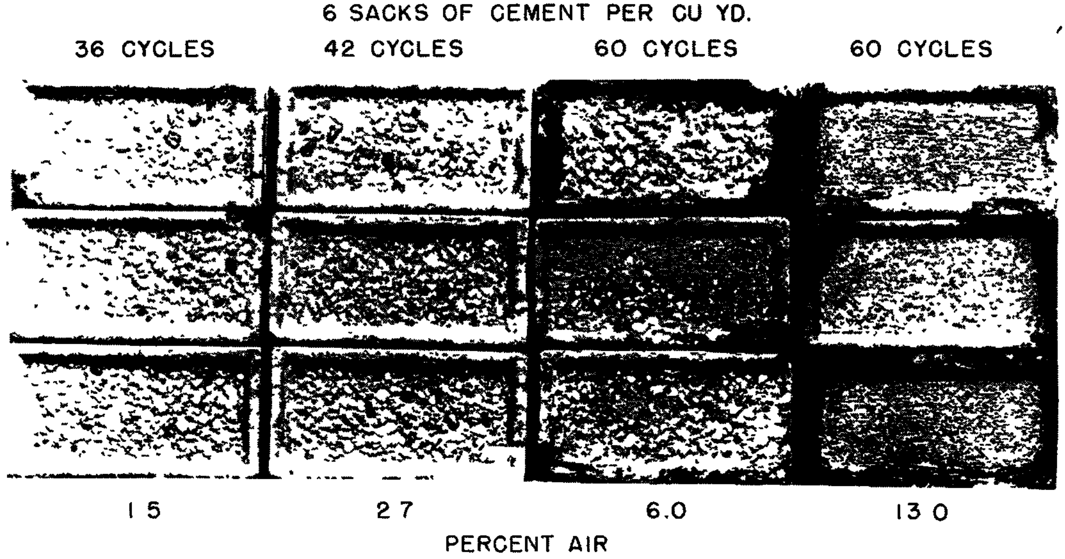

Figure 3. Effect of percentage of entrained air on resistance of concrete to scaling. Laboratory freezing and thawing with $CaCl_2$.

The slabs in which no air-entraining admixture had been added (1.5 percent air) were removed from test at 36 cycles because the surfaces were rated 10 after 36 cycles (see Table 3) and the entire slab was almost completely disintegrated. Likewise the test of the concrete that contained only 2.7 percent air was discontinued after 42 cycles, at which time they were rated 10. It is interesting to note that at 60 cycles 6 percent of entrained air which is the maximum for most specifications was not enough to give adequate protection (rating of 8) for this type of exposure. However, 6 percent delayed the start of scaling and the rate of disintegration was less. The slabs shown in Figure 3 containing 13.0 percent were rated 2 after 60 cycles which is little more than the start of scaling. The high air content was accidental as it was not the intention to exceed 8 percent. The test was made even though it was realized the strength and wear resistance would be seriously affected by the very high air content.

Figure 4 shows the slabs made with concrete containing 7 sacks of cement per cubic

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[1] Effect of Entrained Air on Concretes Made with So-called "Sand-Gravel" Aggregates, by Paul Klieger, Journal American Concrete Institute, October 1948.

TABLE 7

EFFECT OF OILS ON PROPERTIES OF CONCRETE MIX DATA FOR STRENGTH SPECIMENS

Mix by dry Weight	Admixture Amount	Admixture Type	Cement	Water	Slump	Air[a]	Weight of plastic concrete
Pounds	Gal. /sk		Sk. /cu. yd.	Gal. /sk.	Inches	Percent	Pcf.
94-195-350		None	6.0	5.6	2.7	1.1	153.2
94-195-350	⅓	Paraffin base oil	6.0	5.5	3.2	1.0	152.8
94-190-350	⅔	Paraffin base oil	6.0	5.3	2.7	1.2	152.3
94-195-350	⅓	Asphalt base oil	6.0	5.5	2.7	1.0	152.6
94-190-350	⅔	Asphalt base oil	6.0	5.3	2.8	1.0	152.1
94-180-350	⅓	Used crankcase oil	5.8	5.3	3.1	6.4	145.0
94-170-350	⅔	Used crankcase oil	6.0	5.1	2.5	5.0	146.4

Materials used: Cement brand A; siliceous sand F.M. = 2.70; crushed limestone coarse aggregate 1½-inch maximum size.

[a] Air content determined by ASTM tentative method C 231-49 T.

yard. The range in air content was from 1.5 to 7.2 percent. For a given air content the concretes containing 7 sacks of cement per cubic yard were only slightly more resistant than the 6 sack concretes.

The conclusion that can be drawn from the results of these tests is the importance of using as high an air content as possible without jeopardizing unduly strength or wear resistance. The tests also show that the air content is far more important in its influence on resistance to scaling than the cement content.

Effect of Surface Treatments - Part 2

In this group a study was made of the effect of coatings of crankcase oil, undiluted and diluted with various percentages of gasoline on scaling. The effect of time of application of the oils on start of scaling was also investigated.

Observations made in the field on actual pavements indicate that scaling was

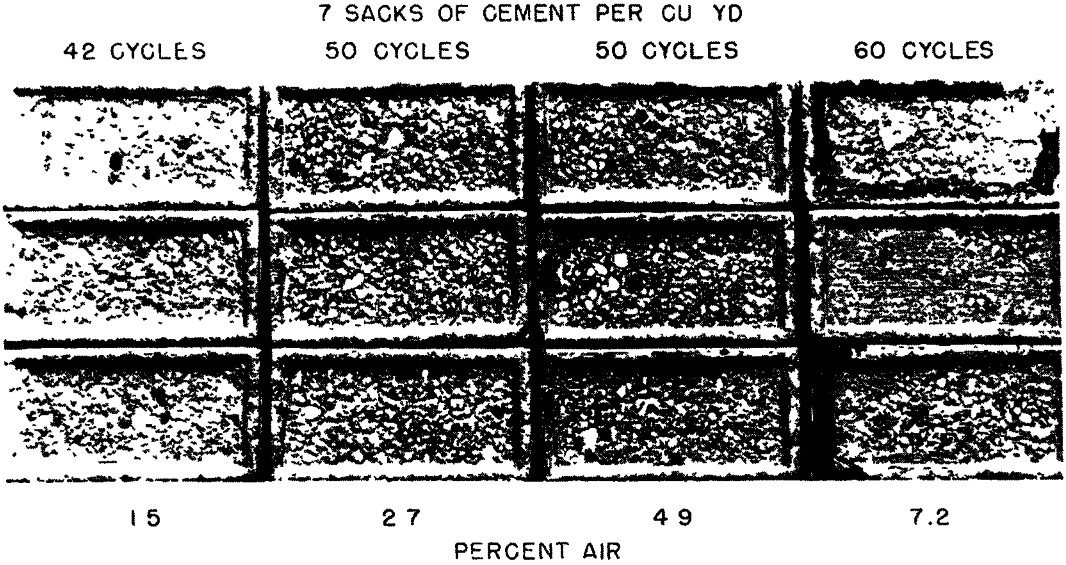

Figure 4. Effect of percentage of entrained air on resistance of concrete to scaling. Laboratory freezing and thawing with $CaCl_2$.

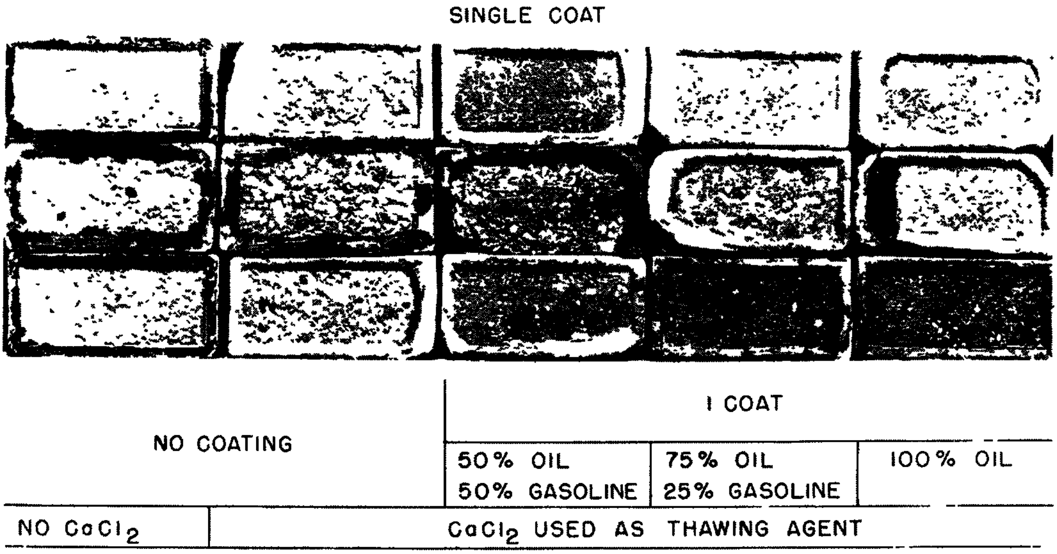

Figure 5. Effect of single coat of mineral oil on resistance of non-air-entrained concrete to scaling after 40 cycles of laboratory freezing and thawing with $CaCl_2$.

less likely to occur on those areas in the middle of the traffic lane containing noticeable oil stain than in the wheel tracks. It is believed that the oil drippings from cars and trucks fill the voids and reduce the absorption of the calcium chloride solution.

The concrete used in the tests was made with non-air-entrained cement and contained 6 sacks per cubic yard. The mix data are given in Table 2.

The slabs in the first section of the group were given a single coating of unused lubricating or mineral oil (SAE No. 10 grade) either undiluted or diluted with gasoline. These surface treatments were quite similar to those used in New York State and reported by Tallamy.[2] The combinations of oil and gasoline used for surface treatment and the scale ratings after 15 and 40 cycles of exposure are given in Table 4. The condition of these slabs after 40 cycles of freezing and thawing is shown in Figure 5.

In the second section of this group specimens were given several coats of oil. Two coats of the undiluted oil were used and three coats of the diluted oils. The concrete would not absorb more than two coats of the undiluted oil within a reasonable period of time (24 hours) without leaving an appreciable residual film on the

TABLE 8

EFFECT OF OILS ON THE STRENGTH OF CONCRETE

Admixture		Air[a]	Modulus of rupture[b]				Compressive strength[c]			
			7 days		28 days		7 days		28 days	
Amount	Type		Str	Ratio	Str	Ratio	Str	Ratio	Str	Ratio
Gal /sk		Percent	psi	Percent	psi	Percent	psi	Percent	psi	Percent
	None	1.1	605	100	765	100	3560	100	4990	100
⅓	Paraffin base oil	1.0	580	96	705	92	3450	97	4660	93
⅔	Paraffin base oil	1.2	605	100	735	96	3450	97	4720	95
⅓	Asphalt base oil	1.0	615	102	730	95	3440	97	4840	97
⅔	Asphalt base oil	1.0	615	102	765	100	3690	104	4990	100
⅓	Used crankcase oil	6.4	495	82	640	84	2720	76	3880	78
⅔	Used crankcase oil	5.0	570	94	720	94	2940	83	4250	85

Each value is the average of four tests

[a] Air content determined by ASTM tentative method C 231-49 T

[b] Specimens were 6 by 6 by 21-inch beams tested in accordance with ASTM standard method C 78-49 Beams tested with side as molded in tension Ratio values for relative strength are based on the strengths for the mix without admixture

[c] Specimens were 6 by 12-inch cylinders tested in accordance with ASTM standard method C 39-49 Ratio values for relative strength are based on the strengths for the mix without admixture

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[2] Control of Concrete Pavement Scaling Caused by Chloride Salts, by B. D. Tallamy, Journal American Concrete Institute, Vol. 20, March 1949, No. 7.

MULTIPLE COATS

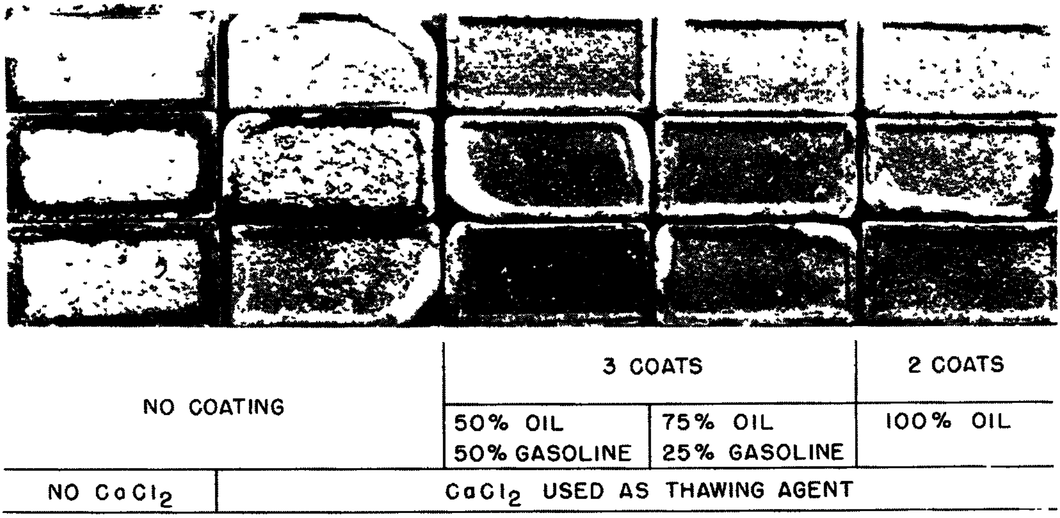

Figure 6. Effect of multiple coats of mineral oil on resistance of non-air-entrained concrete to scaling after 40 cycles of laboratory freezing and thawing with $CaCl_2$.

surface. The condition of these slabs is shown in Figure 6.

The two columns on the left in Figure 5 illustrate the condition of the slabs without surface treatment. $CaCl_2$ was not applied to the slabs shown in the first column from the left and the ice was thawed in laboratory air at about 75° F. These slabs on which no calcium chloride was used showed some action and were given a rating of 4. Calcium chloride was applied to all the other slabs including the three in the second column that were uncoated. The specimens were all subjected to 40 cycles before the tests were discontinued. The uncoated specimens to which $CaCl_2$ was applied were seriously disintegrated at the end of 40 cycles and the surface scale rating was 8.

All of the single coated specimens showed slight scale and one of each group of three identical specimens was badly disintegrated. There was no very marked difference in protection given by the undiluted oil as compared to the different dilutions as indicated by the ratings which varied from 2 to 4.

The surface ratings for the slabs given multiple coats of No. 10 oil or dilutions of the oil with gasoline are given in table 4 and the condition of the slabs after 40 cycles

TABLE 9

EFFECT OF OILS ON PROPERTIES OF CONCRETE

Mix data for freezing, thawing and drying shrinkage specimens

Mix by dry weight	Admixture Amount	Admixture Type	Cement	Water	Slump	Air[a]	Weight of plastic concrete
Pounds	Gal. /sk.		Sk. /cu. yd.	Gal. /sk.	Inches	Percent	pcf.
94-220-320		None	5.9	6.3	3.3	1.2	149.9
94-205 320	2/3	Paraffin base oil	6.0	5.8	3.9	1.3	148.7
94-205-320	2/3	Asphalt base oil	6.0	5.8	3.8	1.3	148.9
94-200-320	1/8	Used crankcase oil	5.9	5.6	4.1	5.2	144.5
94-190-320	2/3	Used crankcase oil	5.6	5.6	4.2	10 ±	137.0

Materials used: cement brand A; siliceous sand, F.M. =2.70; crushed limestone coarse aggregate 1-inch maximum size.

[a] Air determined by ASTM tentative method C 231-49 T.

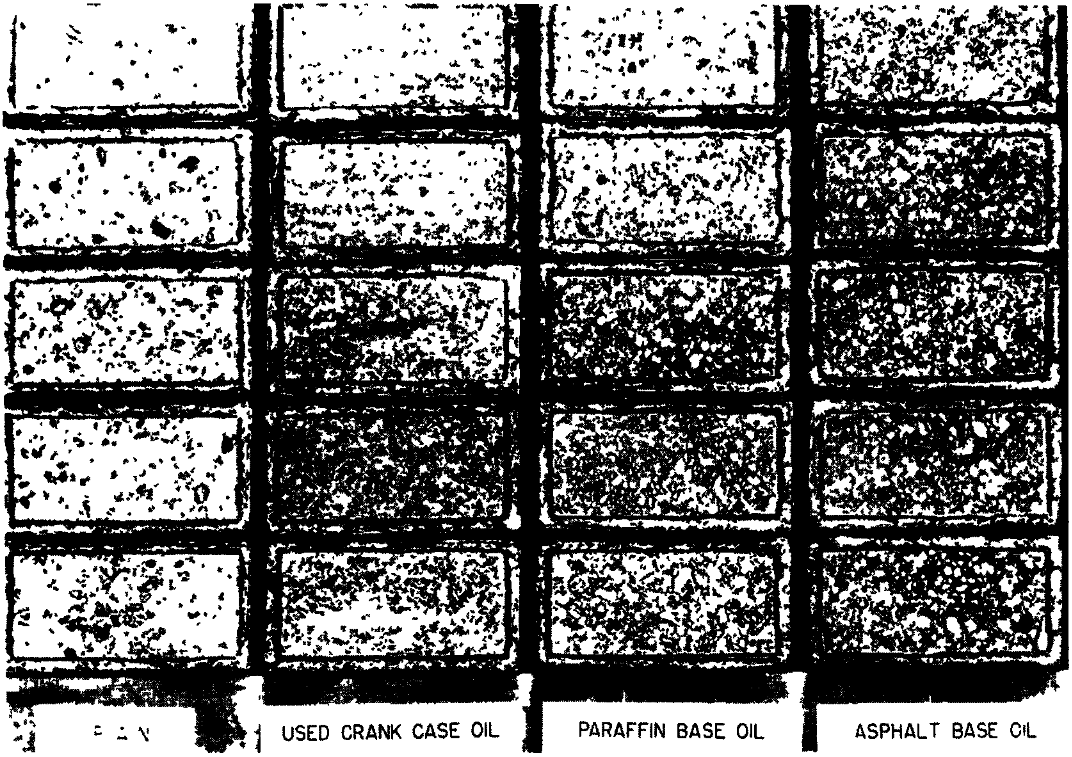

Figure 7. Effect of oil admixtures on resistance of concrete to scaling after 75 cycles of laboratory freezing and thawing with $CaCl_2$

of freezing and thawing are shown in Figure 6. The ratings indicate that at 40 cycles the multiple oil treatment is only a little more beneficial in preventing scaling than the single coating.

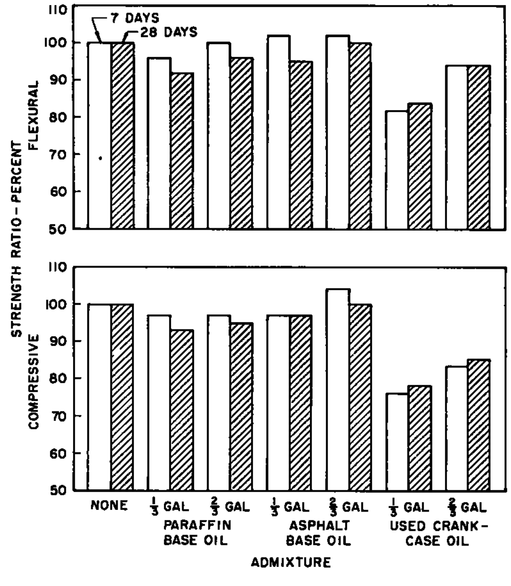

Figure 8. Strength ratio of concrete containing oils.

TABLE 10

EFFECT OF OILS ON THE RESISTANCE OF CONCRETE TO FREEZING AND THAWING IN WATER

Admixture		Air[a]	Loss in N² at cycles						Durability factor[b]	Flexural Strength[c] 3- by 4- by 16-inch beams	
Amount	Type		6	11	25	35	50	70		Control	Fr & th.
Gal./sk			%	%	%	%	%	%		psi	psi
	None	1 2	56						3	970	235(24)
⅔	Paraffin base oil	1 3	32	53					7	1030	305(30)
⅔	Asphalt base oil	1 3	35	54					7	895	285(31)
⅛	Used crankcase oil	5 2	7	12	10	11	14	17	83	905	600(66)
⅔	Used crankcase oil	10 0	6	17	12	12	17	22	78	740	410(55)

Each value is average of tests on three beams

Figures in parentheses indicate the percentage of the strength of the corresponding unfrozen control specimens

[a] Air content determined by ASTM tentative method C 231-49T

[b] Durability factor calcualted at 70 cycles of freezing and thawing

[c] Beams tested with bottom as molded intension (4-inch depth)

Examinations of all the slabs in the series indicate that no type of coating will prevent scaling from becoming progressive after a single break in the surface permits the calcium chloride solution to enter the concrete under the oil-impregnated layer. On pavements in service such breaks in the oil protected surface may be caused by tire chains.

It was proposed in New York State that the oil coat could be applied to plastic concrete in lieu of a membrane curing compound. Therefore, to obtain information on the effect of such application oil was applied to three slabs three hours after molding to simulate the time of application of a membrane curing compound. The other six slabs were given 7 days moist curing. Three of the six were given no further treatment. To the remaining three an oil surface coat was applied after 7 days drying. The ratings of these slabs after 15, 25, 50 and 60 cycles of freezing and thawing are shown in Table 5. The application of oil to the surface of plastic concrete was definitely detrimental and resulted in much more severe scale than similar concrete that received no surface treatment. The slabs on which oil was applied to the plastic concrete were rated 10 and the ones on which no oil was used were rated 6 after 60 cycles of freezing and thawing.

The concrete given an oil treatment after 14 days had far better resistance to scaling than that which received no earlier surface treatment. These slabs were rated 3. These tests indicate that the oil protective coat cannot be applied at an early age and still have value in improving resistance to scaling caused by application of $CaCl_2$.

Effect of Admixtures of Oils - Part 3

In this phase of the investigation, paraffin base oil, asphalt base oil, and used crankcase oil were used as admixtures in concrete.

The mixes and the mix data for the concrete used in this group are given in Table 2. The scale ratings of the slabs are shown in Table 6 after 20, 30, 50, 65, and 75

TABLE 11

EFFECT OF OILS ON THE DRYING SHRINKAGE OF CONCRETE

Admixture		Air[a]	Reduction in length after storage in laboratory air at 72° F. and 50 percent RH for days indicated (expressed in 0.001 percent)						
Amount	Type								
Gal./sk.		Pct.	5 da	20 da.	50 da.	70 da.	100 da	150 da.	180 da.
	None	1.2	6	17	38	40	48	48	48
⅔	Paraffin base oil	1 3	6	16	34	35	36	35	36
⅔	Asphalt base oil	1.3	6	12	31	31	36	35	35
⅛	Used crankcase oil	5 2	8	16	37	37	43	41	41
⅔	Used crankcase oil	10 0	4	17	40	40	47	44	44

Each value is average of tests of three beams

[a] Air content determined by ASTM tentative method C 231-49 T

TABLE 12

EFFECT OF UREA AND INHIBITOR FOR CALCIUM CHLORIDE ON THE RESISTANCE OF CONCRETE SLABS TO SCALING

Part 4 Laboratory Specimens

Thawing agent	Rate of application	Rating after cycles of freezing and thawing indicated		
		10	15	17
	lb. per sq. yd.			
None	-	2	3	3
$CaCl_2$	1	7	10	10
Urea	1	5	8	8
None	-	2	3	3
$CaCl_2$	2	9	10	10
Urea	2	6	8	9
None	-	2	3	3
$CaCl_2$	3	9	10	10
Urea	3	8	9	10
None	-	2	3	3
$CaCl_2$	1	7	10	10
$CaCl_2$ + 1% inhibitor	1	7	8	8
$CaCl_2$ + 5% inhibitor	1	7	8	8
None	-	2	3	3
$CaCl_2$	2	9	10	10
$CaCl_2$ + 1% inhibitor	2	8	9	10
None	-	2	3	3
$CaCl_2$	3	9	10	10
$CaCl_2$ + 1% inhibitor	3	10	10	10

Each value is the average of three tests.
Slabs cured in moist air 14 days and then in laboratory air for 90 days.

cycles of freezing and thawing with $CaCl_2$. Figure 7 shows the specimens after 75 cycles of freezing and thawing.

The paraffin base oil and the asphalt base oil were ineffective in delaying the start of scaling or in controlling the rate of progress of the scaling. As may be seen from the table the slabs containing these oils all showed more scaling at 20 cycles than the slabs made without admixture. At 75 cycles the slabs containing the paraffin or asphaltic base oils were rated 10 the same as the concrete slabs without admixture.

The used crankcase oil was effective in retarding the start of scaling probably because of the air entrained in the plastic concrete. The concrete containing this material was rated 1 after 50 cycles and 4 after 75 cycles.

Since some of the materials used as admixtures are of value in delaying the start of scaling the effect of these admixtures on other properties of concrete is important. To study these properties, concretes containing these admixtures were tested for flexural and compressive strength, durability as measured by freezing and thawing (specimens frozen in water) and volume change due to drying.

The mix data for the strength specimens are shown in Table 7. Seven mixes were used, one a base mix without admixture containing 6.0 sacks of cement per cubic yard of concrete with a slump of approximately 3 inches. The other 6 mixes contained the admixtures and were similar to the base mix except that the sand and water content were reduced to maintain approximately the same slump and cement content.

The ⅓ gallon of oil was selected because it was the amount used in previous tests for waterproofing concrete. Twice the above amount was also used to determine if there were any harmful effects from using more than that recommended.

The air contents of the mix without admixture and of the mixes containing the paraffin and asphalt base oils ranged from 1 to 1.2 percent. The air content for the mix containing $^1/_3$ gallon of used crankcase lubricating oil per sack of cement was 6.4 percent and for the mix containing $^2/_3$ gallons it was 5.0 percent. Air determinations were made using a pressure type air-meter.

The water required per sack of cement for the mixes containing the paraffin base and asphalt base oils were only slightly less than that required for the plain mix for the same slump and cement content. For the mix containing $^1/_3$ of a gallon of used crankcase lubricating oil, it was 0.3 of a gallon less and for $^2/_3$ of a gallon it was 0.5 of a gallon less.

The workability of all of the mixes containing the admixtures was better than that of the plain concrete. This improvement was greater for those mixes which entrained air.

For each mix, eight 6- by 6- by 21-inch beams and eight 6- by 12-inch cylinders were made, two each on 4 different days. Four beams and four cylinders were tested at 7 days and four at 28 days. All specimens were stored continously in moist air until tested.

The results of the strength tests are given in Table 8. The table also shows the ratios of the strength developed with admixtures expressed as percentages of the strengths of the corresponding concrete without admixture. The strength ratios are shown graphically in Figure 8.

It should be noted that the use of the admixtures included in this series resulted in reductions in the 28-day flexural and compressive strengths. The 28-day ratios for the paraffin and asphalt base oils series range from 92 to 100 for flexural strength and 93 to 100 for compressive strength. These reductions would not be considered serious if the use of the admixture results in an improvement in the durability of the concrete.

There was a greater reduction in the strengths of the mixtures containing used crankcase oils. The use of these admixtures resulted in the entrainment of air in the concrete; therefore the strength ratio of 85 percent specified in the Tentative Specifications for Air-Entraining Admixtures for Concrete, ASTM Designation C260-52T will serve as a basis for comparison.

The strength ratios for the mixtures containing $^1/_3$ gallon per sack of cement of used crankcase oil were lower than the ASTM Standard and for those containing $^2/_3$ gallon the ratios were all above 85 percent except the compressive strength ratio at 7 days which was 83 percent. The lower strengths of the $^1/_3$ gallon mixtures are probably due to

TABLE 13

EFFECT OF VACUUM TREATMENT ON THE RESISTANCE OF CONCRETE TO SCALING

Part 5 Laboratory Tests

Cement	Air[a]	Surface treatment	Rating after cycles of freezing and thawing indicated			
			15	25	30	55
Sk. /cu. yd.	%					
6.0	1.7	None	3	9	10	
6.0	1.7	Vacuum	2	3	3	4
6.2	7.4	None	0	2	3	5
6.2	7.4	Vacuum	1	1	1	2
7.0	1.7	None	3	9	10	
7.0	1.7	Vacuum	3	8	8	10
7.1	7.8	None	1	3	3	5
7.1	7.8	Vacuum	0	0	0	0

Each value is average of 3 tests.

Slabs stored in moist air 14 days followed by 21 days in laboratory air.

[a] Air content determined by ASTM tentative method C 231-49 T.

the air content of 6.4 percent as compared to 5.0 percent for the ⅔ gallon mixtures.

The mix data for the freezing and thawing specimens and the volume change specimens are given in Table 9. Five mixes were used, one base mix without admixture, containing approximately six sacks of cement per cubic yard of concrete with a slump of 3.3 inches. The other four mixes contained the admixtures and were similar to the plain mix except that sand and water contents were reduced to maintain approximately the same consistency and cement content.

The mixes and materials used were similar to those used in the strength tests except that the maximum size of coarse aggregate was one inch instead of 1½ inches, and the percentage of sand was increased. The use of a smaller maximum size coarse aggregate resulted in higher air contents in the concretes than those in the concretes used for the strength specimens. The greatest difference was in the mixtures containing ⅔ gallon used crankcase oil. Five percent air was obtained for the concrete (1½-inch maximum size) for the strength specimens and 10 percent for the concrete (1-inch maximum size) for the freezing and thawing specimens. A mixture containing ⅛ of a gallon of used crankcase oil was included in the freezing and thawing series. This mix had an air content of 5.2 percent which is within the accepted limits.

For each mix, nine 3- by 4- by 16-inch beams were made. Three beams were used for freezing and thawing, three were used for control and were tested for flexural strength along with the freezing and thawing specimens and three were used for drying shrinkage tests.

The results of the freezing and thawing tests are shown in Table 10 and Figure 9. The bars (3 by 4 by 16 inches) for the freezing and thawing tests were stored in moist air for 28 days prior to the start of the test.

The freezing and thawing tests were made in a manner similar to that described in the paper: Evaluation of Air-Entraining admixtures for Concrete, by F.H. Jackson and A.G. Timms, Public Roads, Vol. 27, No. 12, February 1954.

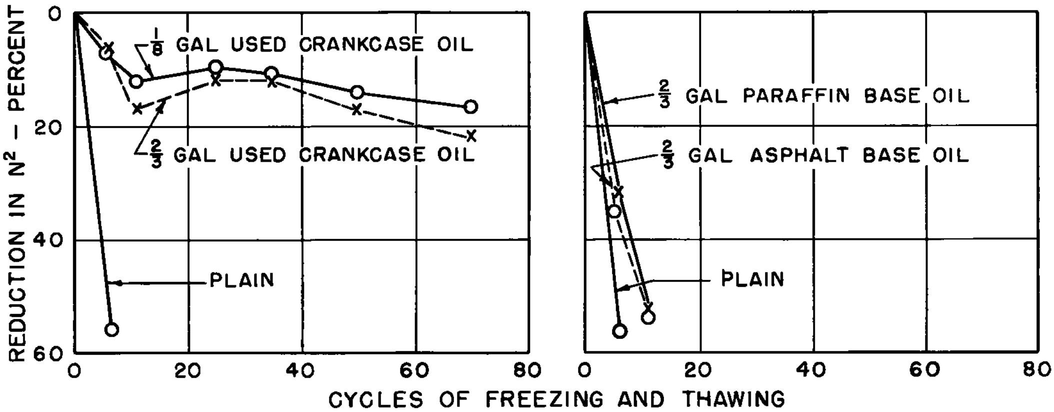

Figure 9. Effect of admixtures of oils on the resistance of concrete to freezing and thawing.

The sonic modulus (N^2)[3] was determined on the specimens prior to freezing and then regular intervals of freezing and thawing and the percentage decrease in N^2 was determined. When a group of specimens showed an average decrease in N^2 of 40 percent, they were considered disintegrated and freezing and thawing was then discontinued and flexural strength tests were made. On the remaining specimens freezing and thawing was discontinued at 70 cycles and flexural strength tests were made.

In Table 10 are given the losses in N^2, the durability factors and the results of flexural strength on both the unfrozen control bars and the bars which had been frozen and thawed. The durability factor (DF) was calculated as follows:

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[3] Application of Sonic Method to Freezing and Tawing Studies of Concrete, by F.B. Hornibrook, ASTM Bulletin No. 101, December 1939, Page 5.

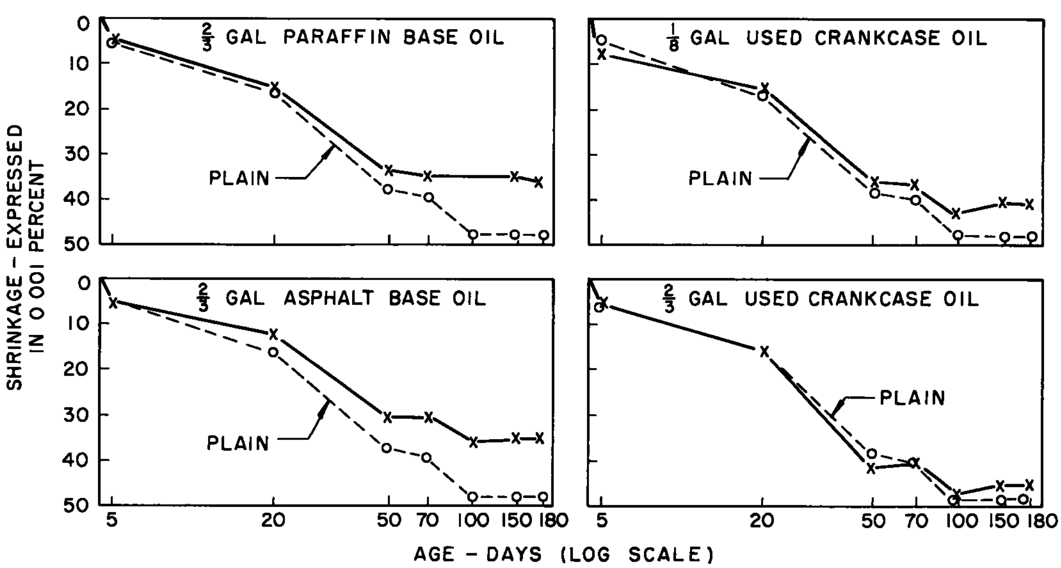

Figure 10. Effect of admixtures of oils on the shrinkage of concrete.

$$DF = (100 - L)\left(\frac{n}{70}\right)$$

where :

L = Loss in N^2 at n cycles

n = number of cycles at which N^2 reaches 40 percent or 70 if loss of 40 percent is not reached by end of test (70 cycles). Durability factors of 70 or greater for the particular conditions of this test are considered satisfactory.

The concrete without admixture showed a loss in N^2 of 56 percent after six cycles of freezing and thawing. The freezing and thawing bars had a flexural strength of 24 percent of the unfrozen control bars. The durability factor was three.

The concretes containing $^2/_3$ gallon of paraffin base oil per sack of cement and $^2/_3$ gallon of asphalt base oil showed a reduction in N^2 of 53 percent and 54 percent respectively after 11 cycles of freezing and thawing, and the flexural strengths were 30 and 31 percent of the corresponding control bars. The durability factor was 7 for both concretes.

The bars containing $^1/_8$ gallon used oil and $^2/_3$ gallon of used oil showed a loss in N^2 of 17 and 22 percent respectively after 70 cycles of freezing and thawing. The flexural strengths were 66 and 55 percent of that of the unfrozen specimens. However, these concretes contained 5.2 and 10.0 percent air. The durability factors for these bars were 83 and 78 representing very good resistance to freezing and thawing.

The results of the volume change tests are shown in Table 11 and in Figure 10. The bars for the volume change tests were made with stainless steel gauge plugs cast in the ends. They were stored in moist air in the molds for two days. After removal from the molds, they were stored in laboratory air at 72^0 F. and 50 percent R. H. The bars were measured when they were removed from the moist room and then after regular intervals of drying. The percent reduction in length was calculated from these measurements. After 180 days storage, the test was discontinued. All the concretes containing admixtures showed less shrinkage than the plain concrete.

Effect of Urea as a Thawing Agent and Use of a Rust Inhibitor - Part 4

Urea, an organic compound, which is reported to be non-corrosive to metals, has been suggested as a thawing agent to replace the more commonly used chlorides particularly on streets with underground streetcar cables. The tests in this investigation were made to compare the ice-melting properties of urea with calcium chloride and to study the effect of urea on the surface of concrete when used for ice removal.

A comparison was made of concrete slabs on which no thawing agent was used with slabs on which either $CaCl_2$ or urea was used. The rate of application of the thawing agent was varied from 1 to 3 pounds per square yard of exposed surface of the slab.

Table 12 shows the scale ratings at 10, 15, and 17 cycles of freezing and thawing and Figure 11 shows the slabs after 17 cycles. The slabs shown in the figure were thawed with 2 pounds per square yard of either salt applied to the surface of the slabs.

In general, the rate of application of the thawing agent appeared to have only a slight effect on the scale resistance of the concrete. After 10 cycles, the slabs on which 1 pound of $CaCl_2$ was used had a rating of 7 and the ones on which 2 or 3 pounds of $CaCl_2$ were used had ratings of 9. After 15 cycles all specimens on which $CaCl_2$ was used had a rating of 10.

The specimens on which urea was used, in general, showed slightly less scaling than those on which $CaCl_2$ was used. The use of smaller amounts of urea per square yard of surface caused less depth of scaling and also appeared to retard the start of scaling slightly as may be seen from the ratings in Table 12.

The rate of thawing of the ice on the slabs on which urea was used appeared to be slower than the thawing rate when $CaCl_2$ was used.

The slabs on which no thawing agent was used showed only light scale after 17 cycles of freezing and thawing in the air of the laboratory.

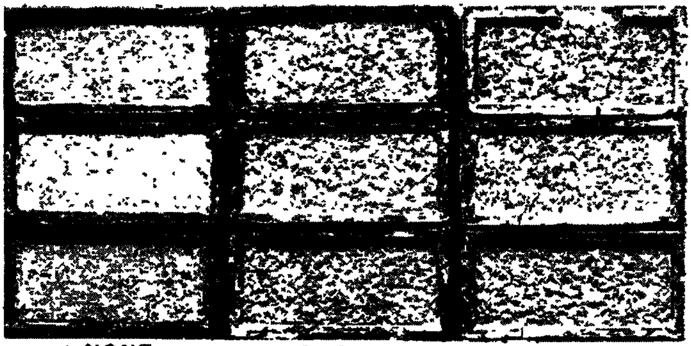

Figure 11. Effect of thawing agent on the resistance of non-air-entrained concrete after 17 cycles of laboratory freezing and thawing.

It is claimed that the corrosive effect of $CaCl_2$ on steel such as automobile fenders can be greatly retarded by inhibiting the action with buffer materials.

Two different percentages of an inhibitor were mixed with $CaCl_2$ and applied to the surface of the concrete slabs. The mixture containing 1 percent inhibitor by weight of the $CaCl_2$ was used at three different rates of application, 1 pound, 2 pounds, and 3 pounds per square yard, and the mixture containing 5 percent inhibitor was used only at the rate of 1 pound per square yard of surface.

In Table 12 are shown the relative scaling ratings determined after 10, 15, and 17 cycles of freezing and thawing. It will be noted that any retarding of the scaling action of the concrete caused by calcium chloride and the inhibitor was so slight that its use would have no practical significance with respect to scaling of cements. There appeared to be no difference in the extent of scaling on the slabs between those on which mixtures of 1 percent and 5 percent inhibitor were used with the thawing agent.

Effect of Vacuum Treatment - Part 5

It has been demonstrated that the use of vacuum mats consolidates plastic concrete with the consolidation probably being greater at the surface than in the body of the concrete.

Vacuum treatment was applied to two types of concrete, air-entrained and non-air-entrained. Two cement contents, 6 and 7 sacks per cubic yard, were used with and without air. The details of the mixes and the air contents are shown in Table 2.

The method of using simulated the commercial method of application to flat slabs using a vacuum pad and pump. The scale ratings are given in Table 13.

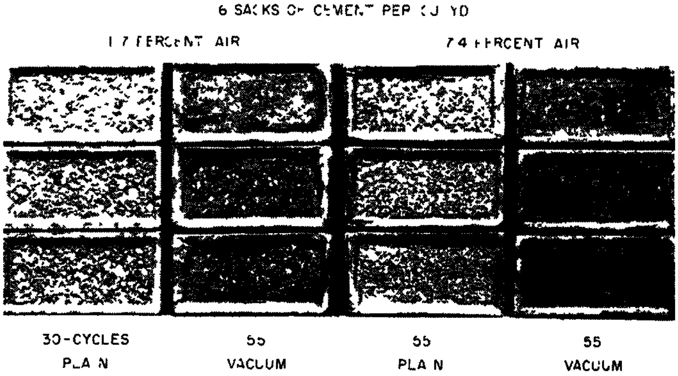

Figure 12. Effect of vacuum surface treatment on resistance to scaling of concrete after indicated cycles of laboratory freezing and thawing with $CaCl_2$

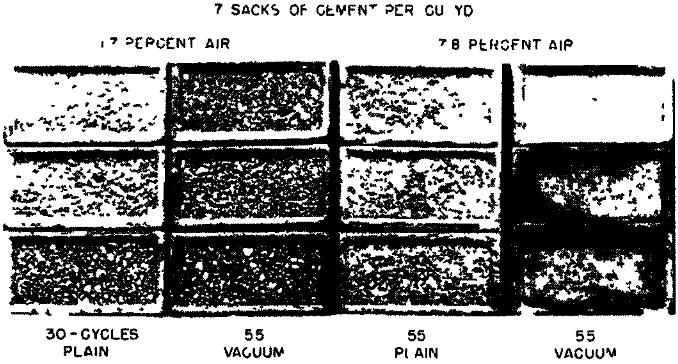

Figure 13. Effect of vacuum surface treatment on resistance to scaling of concrete after indicated cycles of laboratory freezing with $CaCl_2$

The non-air-entrained concrete containing 6 sacks of cement per cubic yard and subjected to a vacuum treatment showed a much improved surface resistance to the action of the chloride as compared to the untreated concrete. The slabs made from concrete containing 6 sacks of cement, non-air-entrained, and untreated were rated 10 at 30 cycles, whereas those with the vacuum treatment were rated only 4 after 55 cycles. Photographs of the slabs for the concrete containing 6 sacks of cement per cubic yard are shown in Figure 12 and for the 7-sack concrete in Figure 13.

In the case of the concrete containing 7 sacks of cement without entrained air the improvement was very much less than that observed for similar concrete containing 6 sacks of cement per cubic yard. The vacuum treated slabs were rated 8 at 30 cycles and 10 at 55 cycles as compared to the 6-sack concrete rated 3 at 30 cycles and 4 at 55 cycles. This is in agreement with other tests of vacuum placing of concrete because it has been observed that the leaner mixes are compacted more because of the greater quantity of water removed.

It was found that concretes with air entrainment and containing both 6 and 7 sacks of cement per cubic yard were greatly improved in resistance to the chloride attack by use of the vacuum method. This was not anticipated as it was believed that the

TABLE 14

MIX DATA FOR SLABS EXPOSED OUTDOORS

(16- by 24- by 4-inches deep)

Concrete	Mix by dry weight	Cement	Water	Slump	Air
	Pounds	Sk. /cu. yd.	Gal. /sk.	Inches	%
Non-air-entrained	94-215-315	6.0	6.1	3.0	1.8
Air-entrained	94-200-315	6.0	5.6	3.0	6.0

Figures given in above table are average values for parts 1 to 4 inclusive. In part 2, 33⅓ percent of the cement was replaced by equal solid volume of flyash.

Materials used: Type 1 cement brand A and B; siliceous sand, F.M. = 2.70; crushed limestone coarse aggregate 1-inch maximum size.

vacuum treatment would not benefit air-entrained concrete because such concrete has inherent resistance in the first place and secondly the vacuum treatment would lower the air content at the surface. The only explanation that appears reasonable is the probable reduction in the water-cement ratio at the surface of the concrete.

DISCUSSION OF OUTDOOR TESTS

Effect of Type of Air-Entraining Admixture - Part 1

As mentioned earlier in this report, the concrete specimens for the outdoor exposure test were 16- by 24- by 4-inches deep. The concrete contained approximately 6 bags of cement per cubic yard and the maximum size of aggregate was 1 inch. Further details of the concrete proportions are given in Table 14. Two cements were used, a high and low alkali cement; see Table 1 for chemical analyses of the cements. The specimens exposed outdoors during the winter of 1951-1952 were cast in watertight wooden molds with metal bottoms. The concrete specimens were made in the laboratory during the spring of 1951, and cured in the moist room until the summer of 1951. They were then placed outdoors and in the fall when freezing was expected the surfaces were covered with from ¼ to ½ inch of water. The water was held on the

Figure 14. Exposure area - spring 1954.

surface by the raised edge around the specimen. On those slabs tested during the winter 1951-1952, 19 cycles of freezing and thawing were obtained. Any freezings that occurred on week-ends are not included in the tests because in general no salt application was made on either Saturday or Sunday during this series. Figure 14 shows the exposure plot photographed in the spring of 1954. Figure 15 shows the method of examining and removing any loose mortar before rating the slab. The same scale of rating was used for the large slabs as for the small laboratory slabs. A rating of 5 or more was considered major scaling.

One slab was made for each admixture tested. As a basis of comparison two non-air-entraining slabs were made. The thawing agent used was $CaCl_2$ and it was applied at the rate of 2.4 pounds per square yard in a manner similar to that used on the laboratory specimens.

Figure 15. Examination of slabs for scaling.

Table 15 shows the ratings of the slabs after 7, 12, and 19 cycles. The different admixtures have been arranged in the table in seven groups corresponding to the grouping in the evaluation tests of air-entraining admixtures described in a previous report and with the same identification numbers.[4]

The non-air-entrained concretes used as a basis of comparison had light scale over most of the surface and some moderately deep scale at 7 cycles (rating of 7) and both were badly scaled (rating of 10) at the end of 19 cycles.

TABLE 15

EFFECT OF AIR-ENTRAINING ADMIXTURES ON RESISTANCE OF CONCRETE TO SCALING-PRELIMINARY TESTS CEMENT BRAND-A METAL BASE-OUTDOOR EXPOSURE

Admixture	Air	Rating at cycles of freezing and thawing indicated			Modulus of rupture 4- by 4- by 16-inch beams[a]
		7	12	19	
No.					psi
Base mix - no air-entraining admixture					
0	1.1	6	8	10	905
0	1.3	5	7	10	755
Salts of wood resin					
1	5.5	1	1	2	830
2	6.2	1	1	1	710
3	6.4	1	2	2	650
4	5.2	1	2	2	810
5	5.6	0	1	3	775
6	5.0	1	4	6	800
7	4.5	0	1	2	830
Snythetic detergents					
12	6.4	1	3	6	705
13	5.0	1	2	4	780
14	4.0	4	8	10	815
15	4.8	3	8	10	770
16	4.8	3	7	10	750
17	4.8	2	7	10	750
26	5.4	1	6	10	790
Salts of sulfonated lignin					
18	5.8	0	1	1	940
20	6.7	0	1	1	870
21	6.4	0	1	1	925
22	3.2	0	1	1	1080
Salts of petroleum acids					
11	6.5	0	0	1	790
27	5.0	2	4	6	860
Salts of proteinaceous materials					
24	5.1	3	5	8	790
25	5.6	2	6	9	750
Fatty and resinous acids and their salts					
8	4.2	1	1	1	860
9	5.6	0	1	1	815
10	4.8	0	1	2	810
28	6.4	1	1	2	825
Organic salts of sulfonated hydrocarbons					
23	5.3	0	1	1	810

Slabs made February 1951 stored in moist air about 100 days.

Outdoor freezing and thawing with $CaCl_2$ for 19 cycles during the winter of 1951-52.

[a] After 19 cycles of freezing and thawing each slab was sawed into five 4- by 4- by 16-inch beams. The beams were tested by center loading on a 12-inch span with the top as molded in tension.

With one exception, the use of air-entraining admixtures consisting of salts of wood resin resulted in concretes having very good resistance to the action of $CaCl_2$. The

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[4] Evaluation of Air-Entraining Admixtures for Concrete, by F. H. Jackson and A. G. Timms, Public Roads, Vol. 27, No. 12, February 1954.

TABLE 16

EFFECT OF AIR-ENTRAINING ADMIXTURES ON RESISTANCE OF CONCRETE TO SCALING-PART 1-CEMENT BRAND A-METAL BASE-OUTDOOR EXPOSURE

Admixture	Air	Rating after cycles of freezing and thawing indicated			
		12	17	39	51
No	%				
Base mix - no air-entraining admixture					
0	1.8	6	10	10	10
0	2.1	1	5	10	10
0	1.8	8	10	10	10
0	1.9	6	10	10	10
0	1.0	8	10	10	10
Salts of wood resin					
1	6.1	1	1	1	2
2	7.3	1	1	3	6
3	6.0	1	1	2	2
4	6.1	1	3	6	7
6	4.9	1	1	1	2
7	6.3	1	1	1	1
30	5.7	1	1	1	1
31	4.0	1	2	2	3
32	6.4	0	1	1	1
Synthetic detergents					
12	6.7	1	2	2	4
14	5.4	1	1	2	3
17	6.3	0	1	3	5
26	8.4	0	1	1	1
26[a]	5.6	1	1	7	9
Salts of sulfonated lignin					
18	7.0	1	1	1	2
19	3.7	1	1	1	2
21	5.1	1	1	1	2
Salts of petroleum acids					
11	7.4	0	1	2	4
27	6.5	1	1	1	1
Salts of proteinaceous materials					
24	5.5	1	1	4	9
25	6.3	0	1	3	6
Fatty and resinous acids and their salts					
8	7.6	0	1	1	3
9	6.8	1	1	1	2
10	6.7	0	1	1	2
Organic salts of sulfonated hydrocarbons					
23	7.5	1	1	1	2
Miscellaneous					
33	5.7	1	1	1	2
34	5.7	1	1	1	2

Slabs made February to May 1952, stored in moist air 30 to 120 days, then stored in exposure area

Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952-1953 for 17 cycles and winter of 1953-1954 for 34 cycles.

[a] Repeat of admixture No 26 with corrected amount of air.

TABLE 17

EFFECT OF AIR-ENTRAINING ADMIXTURES ON RESISTANCE OF CONCRETE TO SCALING-PART 1-CEMENT BRAND B-METAL BASE-OUTDOOR EXPOSURE

Admixture	Air	Rating after cycles of freezing and thawing indicated			
		12	17	39	51
No	%				
Base mix - no air-entraining admixture					
0	1.0	4	8	10	10
0	2.1	8	10	10	10
0	1.1	8	10	10	10
0	1.1	8	10	10	10
0	0.6	3	10	10	10
Salts of wood resin					
1	5.7	0	1	1	1
2	5.8	1	1	2	3
3	6.5	1	1	2	2
4	6.0	1	1	2	3
6	6.6	1	1	2	2
7	5.1	1	1	2	3
30	7.8	2	2	2	2
31	5.6	1	2	2	3
32	6.4	1	1	1	2
Synthetic detergents					
12	5.6	0	1	1	2
14	4.6	1	2	2	2
17	4.9	1	5	7	8
26	4.8	1	1	1	1
Salts of sulfonated lignin					
18	5.5	1	1	1	1
19	2.8	2	4	5	7
21	5.5	0	1	2	2
Salts of petroleum acids					
11	6.7	1	1	1	1
27	4.1	1	1	1	3
27[a]	5.1	1	1	2	2
Salts of proteinaceous materials					
24	4.3	1	2	4	8
25	4.1	1	1	2	6
Fatty and resinous acids and their salts					
8	8.4	1	1	1	1
8[b]	4.3	1	1	1	5
9	5.6	1	1	2	2
10	5.5	1	1	1	2
Organic salts of sulfonated hydrocarbons					
23	5.6	1	1	1	3
Miscellaneous					
33	4.5	1	2	2	2
34	6.9	1	1	1	1

Slabs made March to June 1952 Stored in moist air 30 to 100 days, then stored in exposure area.

Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952-53 for 17 cycles and the winter of 1953-54 for 34 cycles.

[a] Repeat of admixture 27 with correct amount of air.

[b] Repeat of admixture 8 with correct amount of air.

one exception, admixture No. 6, was rated 6 at the end of 19 cycles.

The use of the air-entraining admixtures consisting of synthetic detergents in concrete was ineffective in reducing scaling. The concretes had poor resistance with all but two showing complete scaling of the surface (rating of 10) at 19 cycles. Even the two exceptions were rated 4 and 6 at 19 cycles.

Admixtures of the sulfonated lignin type were effective in preventing major scaling up to 19 cycles at which time the tests were discontinued. All specimens were rated 1 at 19 cycles.

There were only two admixtures in the group of salts of petroleum acids. One of these in concrete had good resistance to scaling and the other admixture in this group was intermediate (rating of 6 at 19 cycles) between those which scaled very badly and those that had good resistance.

Neither of the two admixtures made from salts of proteinaceous acids had much value in reducing scaling of concrete even though these admixtures entrained air comparable with the other air-entraining admixtures. At the end of 19 cycles the surfaces of the concretes were nearly as bad as those concretes containing no air-entraining admixtures. However, major scaling was delayed to 10 or 12 cycles.

The four admixtures consisting of fatty and resinous acids and their salts were very effective and all the concretes in which they were used showed excellent resistance to $CaCl_2$ attack. Likewise the admixture containing organic salts of sulfonated hydrocarbons was of value in concrete in preventing scaling caused by the surface application of $CaCl_2$.

These tests are of particular interest because they show that the percentage of entrained air alone may not be the controlling factor in determining the degree of resistance to $CaCl_2$ attack. Some of the concrete having air contents below 4.5 percent showed good resistance and some containing air contents over 5 percent showed rather poor resistance.

After the 19 cycles of freezing and thawing with $CaCl_2$ the slabs were sawed into five 4- by 4- by 16-inch beams. These beams were tested for flexural strength on a 12-inch span with center point loading. The tops as molded (the surface on which $CaCl_2$ was used) were in tension. The strengths were relatively high with only one value below 700 psi. modulus of rupture which indicates that the concrete under the scale was structurally sound.

Because a single slab was made for each condition in the preliminary investigation it was considered desirable to repeat the early work and extend it to cover other variables. In the spring of 1952 most of the same 27 air-entraining admixtures and a few other admixtures received too late to be used the first year were used with each of two different portland cements to make two series of exposure slabs similar to

TABLE 18

EFFECT OF SAND BASES ON RESISTANCE OF AIR-ENTRAINED CONCRETE TO SCALING-CEMENTS A AND B, SAND BASE - OUTDOOR EXPOSURE

	Cement A					Cement B				
Admixture	Air	Rating after cycles of freezing and thawing indicated				Air	Rating after cycles of freezing and thawing indicated			
		12	17	39	51		12	17	39	51
	%					%				
Base mix - without air-entraining admixture										
None	1.1	1	8	10	10	0.6	2	4	8	10
Salts of wood resin										
2	5.0	1	2	2	2	6.0	1	1	1	2
Snythetic detergents										
12	3.7	1	2	2	2	4.5	1	1	1	2
15	6.7	1	2	2	2	4.8	1	1	1	1
Salts of sulfonated lignin										
19	3.5	1	1	2	2	2.6	1	1	2	3
Salts of petroleum acids										
27	4.3	1	2	2	3	4.3	1	1	1	2
Salts of proteinaceous materials										
24	4.5	1	2	2	3	3.7	1	1	2	2
Fatty and resinous acids and their salts										
10	4.3	1	2	2	2	4.2	1	2	2	2
Organic salts of sulfonated hydrocarbons										
23	5.3	1	2	2	3	6.1	1	1	1	1

Slabs made in June 1952 Stored in moist air for 30 days and then stored in exposure area.

Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952-1953 for 17 cycles and during the winter of 1953-1954 for 34 cycles.

TABLE 19

EFFECT OF FLYASH ON RESISTANCE OF CONCRETE TO SCALING-PART 2 - CEMENTS A AND B - METAL BASES - OUTDOOR EXPOSURE

Cement	Flyash[a]	Air[b]	Rating after cycles of freezing and thawing indicated			
			12	17	39	51
		%				
		Non-air-entrained concrete - cement A				
A	None	1.0	5	8	10	10
A	A	1.0	6	8	10	10
A	B	1.0	6	8	10	10
A	X	1.0	7	8	10	10
A	Y	1.0	6	8	10	10
		Air-entrained concrete - cement A				
A	None	4.0	1	2	2	3
A	A	4.6	2	3	3	4
A	B	5.4	3	4	4	4
A	X	4.9	4	6	7	7
A	Y	4.3	4	6	6	7
		Non-air-entrained concrete - cement B				
B	None	1.0	3	8	10	10
B	A	1.0	4	8	9	10
B	B	1.0	4	8	10	10
B	X	1.0	6	8	10	10
B	Y	1.0	5	8	10	10
		Air-entrained concrete - cement B				
B	None	6.8	1	2	2	2
B	A	4.0	1	2	4	4
B	B	3.3	5	6	7	7
B	X	3.9	6	8	8	8
B	Y	5.8	6	8	8	8

Slabs made June 1952. Stored in moist air 30 days then stored in exposure area.

Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952-53 for 17 cycles and during the winter of 1953-54 for 34 cycles.

[a] Where flyash was used, 33⅓ percent of the cement was replaced by an equal volume of flyash.

[b] Air in non-air-entrained mixes calculated - others measured by ASTM tentative method C 231-49 T.

those made the previous year. The two cements are identified as cement A and B. The winter of 1952-1953 was very mild and the 17 cycles obtained were not nearly so severe as those obtained the previous winter. Under the conditions of test all the concretes regardless of the air-entraining admixture or brand of cement gave good resistance after the first year of exposure. These slabs remained in the exposure area during the summer of 1953 and were all tested again during the winter of 1953-1954 and were subject to an additional 34 cycles of freezing and thawing making a total of 51 cycles. Thirty-four cycles were obtained by making tests on Saturdays and Sundays. However, this was also a mild winter with the temperature seldom falling below 25° F.

The ratings of the slabs made with cement A are given in Table 16 and with cement B in Table 17.

It is interesting to note that the extent of scaling at the end of 51 cycles in general was not as severe as that obtained in the earlier test in 1951-1952 where the concrete was exposed to only 19 cycles of severe freezing. The two mild winters and the greater age of the slabs at the time of the second exposure probably accounts for the better resistance of the second series of tests.

Two slabs were made using admixture No. 26 and cement A. In the first the air

TABLE 20

EFFECT OF CURING ON RESISTANCE OF CONCRETE TO SCALING-PART 3 - CEMENT A - SAND BASE AS NOTED OUTDOOR EXPOSURE

Type Base	Initial curing[a]	Surface treatment[b]	Admixture	Rating after cycles of freezing and thawing indicated			
				12	17	39	51
		Non-air-entrained concrete[c]					
Metal	None	None	None	1	1	1	1
do.	do.	do.	do.	1	2	4	6
Sand	do.	do.	do.	0	1	1	1
do.	do.	do.	do.	1	2	2	3
do.	Burlap	do.	do.	0	1	1	1
do.	do.	do.	do.	1	3	3	4
do.	do.	Lubricating oil	do.	0	1	1	1
do.	do.	do.	do.	0	1	1	1
do.	do.	None	Lubricating oil	0	1	1	1
do.	do.	do.	do.	1	1	2	2
do.	Paper	do.	None	0	1	1	1
do.	do.	do.	do.	1	2	4	9
do.	Paper	Lubricating oil	do.	0	1	3	5
do.	Memb. A	None	do.	1	1	1	1
do.	do.	do.	do.	0	1	1	4
do.	Memb. B	do.	do.	1	1	1	1
do.	do.	do.	do.	0	1	1	2
do.	Lubricating oil	do.	Lubricating oil	0	1	2	2
do.	do.	do.	do.	1	1	1	5
do.	do.	do.	do.	0	1	2	3
		Air-entrained concrete[d]					
Metal	None	None	Vinsol resin	0	1	1	2
Sand	do.	do.	do.	0	1	1	1
do.	Burlap	do.	do.	1	2	2	2
do.	do.	do.	Used crankcase oil	1	1	1	1
do.	Paper	do.	Vinsol resin	0	1	1	1
do.	Memb. A	do.	do.	0	1	1	2
do.	Memb. B	do.	do.	0	1	2	2
do.	Used crankcase oil	do.	Used crankcase oil	0	0	2	2

All slabs made outdoors in July 1952 and removed from molds after 3 days and then stored in exposure area.

Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952-1953 for 17 cycles and the winter of 1953-1954 for 34 cycles.

[a] Curing applied after 1½ hours of placing of slab and if removed, removed after 3 days.

[b] Surface protective treatment applied after 28 days.

[c] Air content of non-air-entrained concrete approximately 2 percent.

[d] Air content of air-entrained concrete approximately 4½ percent.

TABLE 21

EFFECT OF VACUUM SURFACE TREATMENT ON RESISTANCE OF PLAIN AND AIR-ENTRAINED CONCRETE TO SCALING - PART 4 - CEMENT A - OUTDOOR EXPOSURE

Air	Type Base	Surface treatment[a]	Rating after cycles of freezing and thawing indicated			
			12	17	39	51
%						
1.0	Metal	None	1	1	8	10
1.0	do.	do.	1	4	10	10
1.0	do.	Vacuum	1	2	4	6
1.0	do.	do.	1	4	7	10
1.0	Sand	None	1	1	9	10
1.0	do.	do.	1	4	10	10
1.0	do.	Vacuum	1	1	2	4
1.0	do.	do.	0	1	2	3
2.6	do.	None	1	1	2	4
2.6	do.	Vacuum	0	1	2	2
3.2	do.	None	1	1	2	2
3.2	do.	Vacuum	0	1	1	1
5.2	do.	None	0	1	2	2
5.2	do.	Vacuum	0	1	1	1
6.1	do.	None	1	1	2	2
6.1	do.	Vacuum	0	1	1	1
7.0	do.	None	1	1	3	3
7.0	do.	Vacuum	0	1	1	2
10.0+	do.	None	0	1	1	1
10.0+	do.	Vacuum	0	0	0	0

All slabs cured with wet burlap for 3 days then stored in exposure area. Slabs made outdoors in September 1952.

Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952-1953 for 17 cycles and the winter of 1953-54 for 34 cycles.

[a] Vacuum applied to surface of plastic concrete for ½ hour.

content was 8.4 percent which was greater than intended. For this reason another slab was made with an air content of 5.6 percent. The slabs with 5.6 percent air were badly scaled (rating of 9) at 51 cycles whereas the slab with 8.4 percent had a rating of 1 at 51 cycles. This is an indication that slight differences in air contents may account for differences in the scaling on different slabs containing the same admixture. However, when this admixture was used in concrete with cement B and the air content was only 4.8 percent the resistance to attack by $CaCl_2$ was very good.

A comparison of the results obtained with the two cements used indicates that the slabs containing type B cement were not as severly attacked as those made from type A. In the group of wood resins the concretes containing admixtures 2 and 4 showed ratings of 3 for type B cement at the end of 51 cycles, and the same admixture made with type A cement had scale ratings of 6 and 7 respectively. In the case of concretes containing synthetic detergents all the slabs with cement A showed extensive scaling except the one containing 8.4 percent air, whereas with those made with cement B only one of the four slabs showed more than slight (rating 2) scaling.

The concrete slab containing cement B and admixture No. 19, "sulfonated lignin," and having an air content of 2.8 percent had a rating of 7 whereas all the other slabs with higher air contents containing this admixture had ratings of 2 or less. The lack of resistance to salt action of the one slab in this series may be attributed to the low percentage of entrained air.

The concretes containing salts of petroleum acids, fatty acids and resinous acids and their salts and the miscellaneous air-entraining admixtures showed satisfactory resistance when used with both cements.

The concretes containing slats of proteinaceous materials showed major scaling with both cements.

One or two representative air-entraining admixtures of each group was used in concrete cast on a sand base. Comparable slabs were cast for both cements A and B. The ratings of these slabs are shown in Table 18. Only one slab with cement B had a rating of 3, two had a rating of 1 and the others all were rated 2 at 51 cycles.

The following tabulation from data in Tables 16, 17, and 18 shows a direct comparison between metal and sand bases:

Rating at 51 Cycles

Admixture	Cement A		Cement B	
	Metal base	Sand base	Metal base	Sand base
0	10	10	10	10
2	6	2	3	2
12	4	2	2	2
19	2	2	7	3
27	1	3	3	2
24	9	3	8	2
10	2	2	2	2
23	2	3	3	1

In general, the action of calcium chloride is less severe on air-entrained concrete that is cast on a sand base than when the concrete is cast in a water-tight metal based mold that does not allow any of the water to escape from the plastic concrete.

Effect of Flyash Used as a Replacement for Portland Cement - Part 2

Four flyashes, a fine and coarse flyash from each of two sources, were each used to replace 33⅓ percent of the cement in a 6-sack mix. The flyashes (A and B, Table 19) from one source had carbon contents of less than 1 percent and those from the other source (X and Y, Table 19) carbon contents of 5 and 11.2 percent. From each source the finer material had the lower carbon content. Two cements were used, cement A and cement B. Cement B had a very low alkali content and cement A a high alkali content. See Table 1 for a comparison of the chemical analyses and calculated compound composition.

The concrete for the exposure slabs was cast in molds with metal bases. Two types of concrete were used, non-air entrained and air-entrained concrete.

The ratings at 12, 17, 39, and 51 cycles are shown in Table 19 and photographs at 51 cycles are shown in Figure 16.

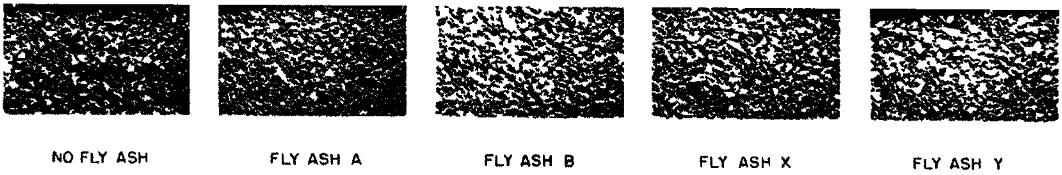
The plain concretes without air-entrainment and without flyash replacements for part of the cement had very poor resistance to attack by the chloride salt. None of the flyashes used as replacements for part of the cement were effectual in improving the resistance of non-air-entrained concrete to attack by calcium chloride.

Entrained air greatly increased the resistance of the plain concrete. In air-entrained concrete all the flyash replacements for cement were detrimental to the resistance to scaling of the concrete, as indicated by the ratings of 4 to 8. The alkali content of the cement appeared to have had no relation to the resistance of the resulting concrete to attack by calcium chloride used for ice removal. The extent of attack by the calcium chloride did not appear to differ much with the brand of cement used or with the flyash used as a replacement for cement.

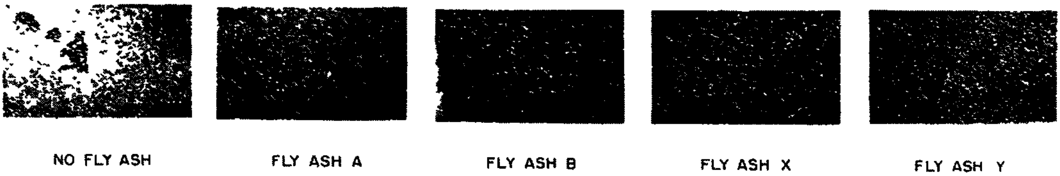
Effect of Type of Curing - Part 3

Table 20 gives the ratings of concrete slabs cured by different methods. Portland cement A was used in all slabs. The slabs were cast outdoors in wood molds on sand bases. The slabs remained in the molds for 3 days, they were then removed from the molds, the sides painted and the slabs placed in the exposure area. Two rounds of slabs were made for the non-air-entrained concrete on different days, and one round for the air-entrained concrete. For purposes of comparison slabs given no curing were cast in molds with metal bases and with sand bases.

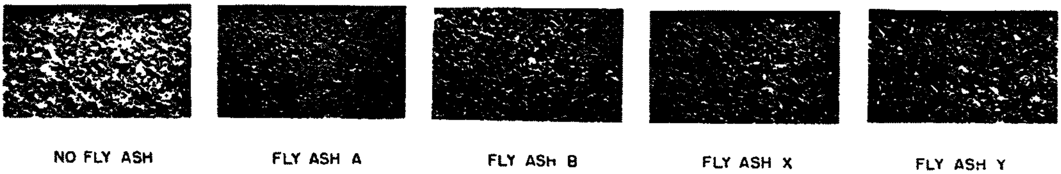
Considerable difference in resistance was observed between the two rounds of test slabs, regardless of curing treatment. All the slabs in round one, even the slab given no curing, showed better resistance than those cast in rounds two except burlap plus oil. This difference in rounds is a common experience in curing studies carried out under the humidity conditions which prevail in the Washington area. Because of the greater attack on the slabs in round 2, differences due to curing are more apparent. In the discussion that follows only the second round is considered.



CEMENT - A NON-AIR-ENTRAINED CONCRETE



CEMENT - A AIR-ENTRAINED CONCRETE



CEMENT - B NON-AIR-ENTRAINED CONCRETE

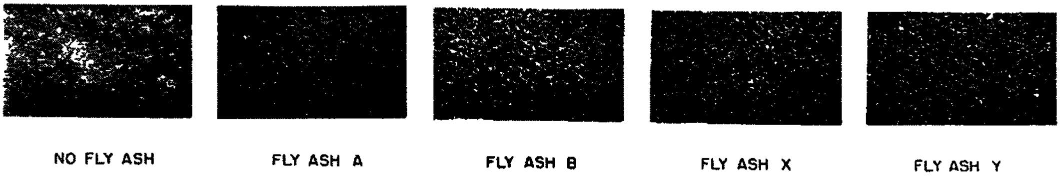


Figure 16. Effect of flyash on resistance of concrete to scaling test panels photographed 1954 after 51 cycles of outdoor freezing and thawing with $CaCl_2$.

In general, the different methods of curing had little effect on the scale resistance of the resulting concrete.

Wet burlap curing for 3 days followed by a lubricating oil surface treatment at 28 days was effective in reducing scaling. Concrete containing an admixture of lubricating oil and cured 3 days under wet burlap was also effective in reducing scaling.

With air-entrained concrete little or no scaling occurred and it is not possible to distinguish between the relative effect of any of the curing methods tried.

Effect of Vacuum Treatment - Part 4

Comparisons were made between the regular method of finishing concrete and the vacuum method. The ratings of the slabs after various cycles are shown in Table 21. These specimens were made and cured outdoors. After curing under wet burlap for three days the sides were waterproofed and the slabs were then placed in the exposure area.

Non-air-entrained concrete was cast in molds with metal bases and in molds with damp sand bases. One-half of the specimens cast in each type base were finished in the regular manner by brooming and the other half were subjected to vacuum finishing using a vacuum pad covering the entire surface of the concrete. A vacuum of 18 to 25 inches of mercury was applied for about 30 minutes. The vacuum pad was removed and the specimen given a final trowel finish. The vacuum-placed slabs were covered with wet burlap 1 hour after they were cast and the others were covered after 2 hours.

The concrete cast in molds with metal bases and subjected to vacuum treatment had about the same resistance to scaling as that placed by the conventional methods. One of the two vacuum-placed specimens had a little better resistance than the other. In the case of the non-air-entrained concrete cast in molds with sand bases there was a marked improvement in the resistance to scaling of the vacuum placed specimens. It seems likely that the metal base mold inhibits the removal of the water normally withdrawn by the vacuum process.

The air-entrained concrete specimens for vacuum treatment were cast on sand bases. The air content varied from 2.6 to over 10 percent. The lowest air content of 2.6 percent for the untreated concrete had a rating of 4 at 51 cycles while the comparable vacuum treated concrete had a rating of 2. The untreated concrete with an air content of 10+ percent had a rating of 1 and the corresponding treated concrete had a rating of 0. In every case the vacuum placed concrete had a slightly greater resistance to the action of calcium chloride than its untreated counterpart.

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