EFFECT OF CALCIUM CHLORIDE ON READINGS OF A VOLUMETER INCLOSING PORTLAND CEMENT PASTES AND ON LINEAR CHANGES OF CONCRETES

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SYNOPSIS

This paper represents in part the results of work done by representatives of the Calcium Chloride Association at the National Bureau of Standards in studying the effects of calcium chloride on various properties of portland cements and concretes. Since volume change of concrete has been suggested as the explanation of some of the observed cracking and subsequent disintegration of many concrete structures, the possibility that additions of calcium chloride might decrease changes in volume resulting from wetting and drying appeared to warrant investigation.

The same cements were used in both parts of this investigation These cements included eight normal portland cements, two white and one high-early-strength cement.

Part I of the investigation deals with the behavior of portland cement pastes, with and without the addition of calcium chloride, the cement pastes being inclosed in rubber bags and immersed in a volumeter using water as the measuring liquid The level of the water was read at intervals starting with ten minutes from the time cement and water were mixed to form the paste, and continuing up to one year

Conventional length measurements on 4 by 4 by 30-in bars, made from 1:2·4 (by volume) concrete, with and without additions of calcium chloride and subjected to different types of exposure with respect to relative humidity and temperature, are reported in Part II of the paper. The exposures included (Series 1) 270 days at 70±2°F and relative humidity of approximately 100 per cent; (Series 2) one year additional exposure for the same specimens which had been used in Series 1, with the same temperature as in Series 1 but with a relative humidity of from 50 to 65 per cent, (Series 3) one and one-half years' exposure with uncontrolled temperature (50 to 100°F) and uncontrolled relative humidity (30 to 80 per cent).

Among the conclusions presented are:

Additions of calcium chloride to the normal portland cement pastes decreased the burette readings in comparison with the readings at corresponding ages for cement pastes containing no calcium chloride. In terms of percentage of the average burette readings at equivalent ages for the normal portland cement pastes containing no calcium chloride, the average values for pastes containing one per cent calcium chloride were 88 0 and 95 5 per cent at one day and one year respectively. The corresponding average values for pastes containing 2 per cent calcium chloride were 71 and 89 per cent.

All concretes made from the normal cements in Series 1 expanded in length relative to the length at the age of 24 hours. Calcium chloride decreased the amount of the expansion. At 270 days the average expansion of the eight concretes made from the normal portland cements and containing one per cent calcium chloride was 87 per cent of those containing no calcium chloride, the corresponding figure for the two per cent addition was 78 per cent.

In Series 2 the calcium chloride in general decreased the linear shrinkage observed at one year, the average differences in length for the concrete made from the eight normal portland cements where one per cent and two per cent calcium chloride were used being respectively 93 per cent and 82 per cent of the corresponding difference for concretes made without calcium chloride.

In Series 3 all concretes shrank in comparison with the 24-hour lengths. The effect of the calcium chloride was to reduce the linear shrinkage of concretes made with normal portland cements compared with the same concretes made without calcium chloride. At 545 days the linear shrinkage of the concretes made from the eight normal portland cements and containing one per cent calcium

chloride was 92 per cent of the shrinkage of the corresponding concretes without calcium chloride; the corresponding figure for the concretes containing 2 per cent calcium chloride was 86 per cent.

In continuation of the study pertaining to the "Effect of Calcium Chloride on Portland Cements and Concretes," inaugurated in 1932, and on which a report[1] was rendered by Rapp in 1935, dealing with heat of hydration, workability, and strength of cement mixtures, a fellowship was re-established at the National Bureau of Standards by the Calcium Chloride Association in June of 1939. Some of the specific problems to be undertaken in this program included studies of the effects of calcium chloride on the rate of strength development of concrete during low temperatures, on the volume change of cements and concretes, and on the sonic modulus of elasticity of concrete. A report was rendered relative to the low temperature study in December, 1941.[2] This paper pertains to the volume change of portland cements and concretes and is presented in two sections dealing respectively with cement pastes and concretes.

PART I

VOLUME CHANGE OF PORTLAND CEMENTS

Materials

The eight normal portland, two white and one high-early-strength cements used in the present investigation were from the same sources as the corresponding cements previously considered by Rapp. In addition one natural and a blend of natural and normal portland cements were included in this program.

The calcium chloride used was a standard commercial product complying with the A.S.T.M. standard specification D98. The amounts added to the cement are reported as percentages of commercial calcium chloride by weight of cement.

Testing Procedure

The cement and water were thoroughly mixed for 2-min. in the proportion of 200 g. of cement to 70 g. of water or calcium chloride solution. After mixing, the paste was introduced into a modified pressure gun having a suitable nozzle to permit injection into a rubber membrane. Following injection of 230±2 g. of cement paste into the rubber membrane and tying, the membrane and its contents were placed in a fixed position in a one-quart glass jar which was partially filled with distilled water. The top, which was fitted with a burette, was then placed, the glass jar sealed with a mixture of paraffin and wax, and additional distilled water immediately added to fill the jar and the burette. Extreme care was taken to prevent the formation of air bubbles. Following the filling of the container with water, the "zero" reading was recorded. This reading was taken within 10-min. following initial contact of the cement and water, and additional readings were made at suitable intervals over 1 yr. It was found that for any respective set of data, the average deviation from the mean was within a range of ±0.04 ml. for changes in burette readings of from 2 to 9 ml.

The tests were conducted in such a manner that the effect of only one variable, namely the percentage of calcium chloride, could be studied. The initial temperatures of the materials and the temperature of the room in which the test specimens were stored throughout the observation period were maintained at 70±2°F.

The average burette readings for three specimens of each of the mixes containing 0, 1, and 2 per cent of commercial

[1] *Journal of Research,* National Bureau of Standards, 14, 4 (1935); RP782; also *Proceedings,* Highway Research Board, Vol. 14, p. 341 (1934).

[2] See page 288, this volume.

calcium chloride by weight of the cement, respectively, are given in Table 1.

Test Results

(1) For the normal portland cement pastes containing no calcium chloride, the average burette reading at one year was 9.78 ml. with a minimum of 8.50 (cement J) and a maximum of 11.05 ml. (cement C).

(2) For the normal portland cement pastes containing no calcium chloride, the average burette reading at one day was 33.4 per cent of the burette reading at one year. The reading at 3 days was slightly less than 50 per cent of that at one year and the 75 per cent reading occurred between the 14th and 28th day.

(3) For the normal portland cement pastes containing no calcium chloride, the change in burette readings per day ranged from 3.27 ml. (first day) to a minimum of zero (average for the final 4 months).

(4) Additions of calcium chloride to the normal portland cement pastes decreased the burette readings in comparison with the readings at corresponding ages for the cement pastes containing no calcium chloride. For the normal portland cement pastes containing 1 per cent of calcium chloride the average burette reading at one year was 9.34 ml. with a minimum of 8.11 (cement J) and a maximum of 10.12 ml. (cement H). Without exception, the normal portland cement pastes containing 2 per cent of calcium chloride gave lower burette readings at corresponding ages than did the pastes containing one per cent calcium chloride. The average reading at one year was 8.68 ml. with a minimum of 7.91 ml. (cement J) and a maximum of 9.48 ml. (cements B and C). In percentage of the average burette readings at equivalent ages for the normal portland cement pastes containing no calcium chloride, the average values for pastes containing one per cent of calcium chloride were 88.0 and 95.5 per cent at one day and one year respectively. The corresponding average value for pastes containing 2 per cent of calcium chloride were 71 and 89 per cent.

(5) The effect of calcium chloride was to increase the time required for reaching burette readings of a given magnitude.

(6) For the normal portland cement pastes containing 1 per cent of calcium chloride, the change in burette readings ranged from 2.88 ml. per day (first day) to 0 00024 ml. per day (average for last four months). The corresponding range for cement pastes containing 2 per cent of calcium chloride was from 2.33 to 0.00032 ml. per day. From the age of 14 days on, the rate of gain in burette readings for pastes containing calcium chloride either did not significantly differ from or exceed that for pastes without calcium chloride at corresponding age intervals.

(7) Behavior of the pastes of white portland cements differed from that of the normal portland cement pastes only in that the burette readings were significantly less for ages exceeding two days for the white cements.

(8) Tests made on a single high-early-strength cement indicate that an addition of 1 per cent of calcium chloride lowered the burette readings somewhat more than the amount observed for the normal portland cements with a similar addition. An addition of 2 per cent of calcium chloride, however, produced less effect than did the addition of 1 per cent. The burette reading at one year, although slightly less than the corresponding reading on the cement without calcium chloride, much exceeded the corresponding average reading for the normal portland cements, either with or without calcium chloride.

Part II

Linear Changes of Concrete

In addition to the work on cement pastes reported in Part I, certain work was done to determine the effects of calcium chloride on change in length of concrete

TABLE 1

Effects of Calcium Chloride Upon the Burette Readings Observed on Eight Samples of Normal Portland, Two Samples of White and One of High-Early-Strength Cement During the Period of From One Day to One Year

(Burette readings in ml Each value is an average for 3 specimens)

Cement	Calcium Chloride	Time in days									
		1	2	3	7	14	28	90	180	240	365
	%										
Normal cements—A	0	3 41	4 42	5 21	7.52	8 44	9 36	9 84	9 88	9 88	9 92
	1	2 99	3.69	4 00	5 34	7 14	7 51	9 21	9 40	9 40	9 40
	2	2 20	2.71	3.17	4 31	5.10	5 82	7.28	8 00	8 00	8 19
B .	0	3 85	4.82	5.28	6.71	7.49	8 22	9.78	9 90	9 90	9.90
	1	2 99	4 20	4.97	6.39	7.20	7.92	9 69	9 76	9 76	9 76
	2	2.99	4.02	4 77	6 38	7.20	7 84	9 20	9.48	9 48	9 48
C .	0	2 59	2.99	3.69	5.68	7.01	7.98	10 28	11 05	11.05	11 05
	1	2.59	2 99	3.69	4.83	6 80	7 40	9 20	9 71	9.71	9 71
	2	1.91	2.45	3 08	3.69	6.18	6 89	8 30	9.04	9.15	9 48
F	0	3 50	3.97	4.86	5.30	5.34	6.71	9 58	9.82	9 86	9 87
	1	3.05	3.34	4.12	4.35	4 81	6 40	9 49	9 58	9 62	9 62
	2	2.60	2 89	3.86	3.96	4.49	6 30	8 50	8 89	9 21	9 27
H	0	3 86	4 54	5.22	7.74	8.17	8 27	10 37	10.37	10 37	10 37
	1	3.54	4.38	4.90	5.85	6 64	7 73	8 92	10 12	10 12	10 12
	2	3.07	3.37	3.75	5.80	6 62	7 43	8 69	8 81	8 81	8 81
J	0	2 81	3 20	3.93	4 20	5 29	6 50	7 60	8 37	8 40	8 50
	1	2 37	2 96	3 50	4.12	4 99	6 19	7 40	7 91	8 00	8 11
	2	1.83	2 03	2.27	3.12	4 33	5 81	7.26	7 77	7 80	7 91
K	0	2.77	3.50	4 31	5 40	6 70	8.08	9 09	9 15	9 15	9 15
	1	2.50	3.20	3.98	5 21	6 19	7.19	8.20	8 72	8 99	8 99
	2	1 69	2 37	3 07	3 99	5.08	6.19	7 30	7 81	7 99	7 99
Average of 8 normal cements	0	3.27	3.98	4 71	6 15	6.95	7 87	9 42	9.73	9.78	9 78
	1	2.88	3.61	4.22	5.03	6.32	7 25	8.76	9 20	9.31	9 34
	2	2 33	2 83	3.46	4 47	5 60	6 62	7 98	8 51	8 64	8 68
White cements—E	0	3.19	3 97	4 41	4.95	5 38	6.50	7 50	8.00	8 00	8 00
	1	2.28	3.20	3 41	4 19	4 92	6 31	6.85	7 50	7 50	7 50
	2	2 00	2.29	2 72	3 47	4 00	5 38	6 52	7 30	7 30	7.30
G	0	3.45	3.90	4.20	5.10	6 00	6.70	8 50	9 00	9.60	9.60
	1	3.05	3.60	3 90	4 80	5 55	6 40	7 50	8 15	8 20	8.20
	2	2.60	3.10	3.40	4.50	5 50	6.30	7 30	8 10	8.10	8.10
Avg. of 2 white cements	0	3 32	3.93	4 31	5 03	5 69	6 60	8 00	8 50	8 80	8 80
	1	2.67	3.40	3 66	4 50	5.24	6.36	7 18	7.83	7.85	7 85
	2	2 30	2 70	3.06	3 99	4.75	5 84	6.91	7 70	7 70	7 70
High-early-strength cements—D .	0	3 10	3.77	5 16	6 46	7.74	9 21	10 40	10 62	10 62	10 62
	1	1 20	1.90	3 21	4.02	5 02	6.02	6 78	7 40	7.80	7 80
	2	2.48	3.20	3.95	4 96	6.25	8.00	9.73	10 15	10 34	10.34
Natural cement—R	0	2.06	2.24	2.32	3 30	4 05	4 80	6 29	6.70	6 70	6.70
	1	1.50	1.60	1.80	2.99	3 79	4 41	6 19	6 39	6.39	6 39
	2	1 30	1.51	1.60	2.99	3 50	4.20	6 02	6 21	6.21	6 21
Blended cement, 2 pts. R, 5 pts C . .	0	3.08	3.90	4 29	5 51	6.50	7.69	9.25	9.79	9 79	9.79
	1	2.21	2.69	2 99	4.62	6.21	7.29	8 90	9 28	9.28	9 28
	2	2 00	2.17	2.22	4.02	5.00	6.01	7 64	8 18	8.18	8.18

specimens resulting from several different conditions of storage.

Materials

Concretes were made from 11 cements, comprising the 8 normal, 2 white portland, and 1 high-early-strength portland cements reported on in Part I, and were studied in each of the three linear change series of this program. Both the sand and gravel (maximum size 1-in.) were from a Potomac River source and complied with the requirements of Federal Specifications SS-A-281a. The calcium chloride was a standard brand of commercial material complying with the requirements of A.S.T.M. specification D-98.

Program of Research and Testing Procedure

The conditions of exposure for each of the three series of tests were as follows:

Series I. Temperature and humidity controlled by storage in a moist room at 70±2°F with approximately 100 per cent relative humidity.

Series II. Temperature controlled and humidity uncontrolled. Storage in constant temperature room at 70±2°F with relative humidity varying from 50 to 65 per cent.

Series III. Neither temperature nor humidity controlled. In this series the specimens were stored in a laboratory room in which the temperature and humidity varied within wide limits (temperature from 50 to 100°F and relative humidity from approximately 30 to 80 per cent).

The concrete was proportioned 1:2:4 by weight using 6½ gal. of water per sack of cement. The test specimens were 4 by 4 by 30-in. beams cast in 3-gang ¼-in. steel molds, drilled to permit insertion of stainless steel plugs in the ends of the beams for subsequent length change readings.

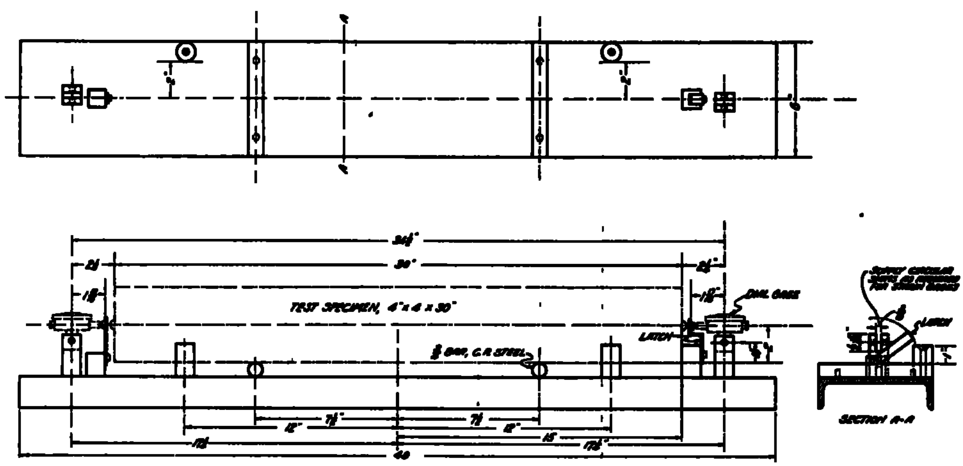

Figure 1. Measuring Device for 4-In. by 4-In. by 30-In. Prisms

An apparatus developed by the National Bureau of Standards was used for determining the length changes of the 4 by 4 by 30-in. specimens. The details of this equipment are illustrated in Figure 1. The gage dials had a travel of 0.3 in. and were read to 0.0001 in. A standard stainless steel reference bar was used to set and check the dials before and after each reading. The apparatus and standard bar were stored and all measurements were made in a room maintained at a temperature of 70±2°F. All specimens were made in triplicate and the values of percentage of change in length, given in Tables 2, 3 and 4 are averages of tests on three specimens.

TABLE 2

Series I. Effects of Additions of Calcium Chloride on the Length Changes of 1:2.4 (By Weight) Concretes Made From Various Cements and Exposed at a Temperature of 70° Plus or Minus 2° F. and a Relative Humidity of Approximately 100 Per Cent. Values Represent Change in Length as a Percentage Difference From the Initial Reading (24 Hours) and Are All Positive (Expansion)

Cement	Calcium chloride	Time in days													
		2	3	7	14	21	28	60	90	120	150	180	210	240	270
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
Normal cements—A	0	.006	.006	008	015	.015	016	.015	.015	.015	.015	.015	015	.015	.015
	1	.003	.005	007	.014	.014	014	.014	.014	.014	.014	.014	014	014	.014
	2	.002	.004	.006	.010	010	012	.012	.012	.012	.012	012	.012	.012	.012
B	0	.005	.008	.009	016	.018	.028	.028	.027	026	.026	026	.026	.026	.026
	1	.004	.006	.007	014	.016	.025	.025	.024	.025	024	025	.025	.025	.024
	2	.003	.005	006	.012	.014	.024	.024	022	.023	.022	.023	.023	.023	.023
C	0	.004	.006	.010	016	.018	.026	.026	026	.025	.025	.024	.024	.024	.025
	1	.003	.005	.009	.013	.016	.021	.022	.022	.023	.022	.022	.022	.022	.022
	2	.002	.004	.007	.010	.014	.019	.020	.020	.021	.020	.020	.021	.021	.021
F	0	.003	.005	.008	.013	014	.014	.015	.014	.014	.014	.014	.014	.013	.013
	1	.002	.004	.007	.012	.013	.013	.013	.013	.013	.013	.013	.013	.013	013
	2	.002	.003	.006	.012	.013	.013	.013	.013	.013	.013	.013	.013	.013	.013
H	0	.006	.007	.012	.015	.021	.024	.023	.023	.023	023	.023	.023	.023	.024
	1	.005	.006	.010	.014	.020	.023	.022	.022	.022	.022	022	.022	.019	.020
	2	.004	.005	.009	.012	.018	.022	.021	.020	.019	.019	.019	.019	.018	.019
I	0	.005	.006	.016	.021	.022	.025	.023	.023	.020	.020	.020	.020	.021	.020
	1	004	.005	.015	.018	.020	.024	.024	.022	019	.018	.018	019	.019	.019
	2	.003	.004	.013	.016	.018	.023	.020	.020	.018	.018	.018	.018	.018	.018
J	0	.004	007	.012	.018	.021	.025	.025	025	025	.025	.025	.025	.025	.025
	1	.003	.006	011	.017	.019	023	.023	.023	.023	.023	.023	.024	.023	.024
	2	.002	.005	.010	.016	.018	.022	.022	.022	.023	.022	022	.023	.022	022
K	0	.003	.006	.011	.018	.026	.026	.026	.026	.026	.026	.027	.027	.027	.026
	1	.002	.003	.009	.016	.025	.025	.025	.025	025	.025	.026	026	.026	.026
	2	.002	.003	.008	014	.025	.024	.024	024	.024	.024	.025	025	.025	.025
Average of 8 normal cements.	0	.004	.005	.008	.014	.018	023	.023	.023	.023	.023	.023	.023	023	022
	1	.003	004	.007	.012	.016	019	.019	.020	.020	020	020	.020	.020	020
	2	.003	.003	.006	010	.014	.018	.018	.018	.018	018	018	018	.018	.018
White cements—E	0	004	.005	.007	.013	013	022	.022	.022	.023	.021	021	.022	.022	.022
	1	.003	004	.006	.012	.012	.020	.020	.020	021	020	020	.020	020	.020
	2	.002	.003	.005	.011	.011	.019	.019	.020	.019	.018	018	.020	.020	020
G	0	.002	.002	.005	.011	014	.018	.019	.019	.020	.021	.022	022	.022	022
	1	.002	002	.005	010	.012	016	018	.018	.019	020	020	020	020	.020
	2	.002	.002	.005	009	.010	.015	.017	.017	018	018	018	017	018	.019
Average of 2 white cements	0	003	.004	.006	012	014	020	021	021	.022	021	022	.022	022	022
	1	.003	.003	006	.011	.012	018	019	019	.020	020	020	.020	020	.020
	2	002	003	005	.010	011	017	018	019	.019	018	.018	019	019	020
High-early-strength cement—D	0	015	016	.023	029	.030	.031	030	.030	030	.030	030	.031	.031	030
	1	009	.013	015	024	024	.024	.025	.025	.025	025	025	025	025	025
	2	005	009	011	.021	.022	025	025	025	.025	025	.025	025	.024	.024

TABLE 3

SERIES II. EFFECTS OF ADDITIONS OF CALCIUM CHLORIDE ON THE LENGTH CHANGES OF 1:2.4 (BY WEIGHT) CONCRETE MADE FROM VARIOUS CEMENTS AND EXPOSED AT A TEMPERATURE OF 70° PLUS OR MINUS 2° F. WITH RELATIVE HUMIDITIES RANGING FROM 50 TO 65 PER CENT. VALUES REPRESENT CHANGE IN LENGTH AS A PERCENTAGE DIFFERENCE FROM THE INITIAL READING (24 HOURS) OF SERIES I AND ARE POSITIVE OR NEGATIVE AS INDICATED. (THE READINGS FOR ZERO TIME ARE THE 270 DAY VALUES FOR SERIES I)

Cement	Calcium chloride	Time in days												
		0	3	7	14	21	28	60	90	120	240	270	330	365
		%	%	%	%	%	%	%	%	%	%	%	%	%
Normal cements—A	0	+.015	+ 008	+ 007	+ 000	− 008	− 008	− 011	− 018	− 021	−.029	− 029	− 027	−.024
	1	+ 014	+ 009	+ 007	+ 001	− 004	− 006	− 010	− 015	− 020	−.027	− 027	− 026	−.024
	2	+ 012	+.008	+ 006	+ 001	− 004	− 006	− 009	− 015	− 020	−.027	−.027	− 024	−.025
B.	0	+ 026	+.017	+ 013	+.012	+ 005	+ 001	−.001	− 011	−.014	− 020	− 020	− 025	−.023
	1	+ 024	+.018	+ 017	+.013	+.007	+ 007	−.001	− 001	−.001	−.012	− 012	− 018	−.017
	2	+.023	+ 018	+ 018	+ 014	+.006	+.007	−.001	− 001	− 001	−.011	−.011	−.017	−.013
C .	0	+ 025	+ 016	+.016	+ 010	+ 008	− 005	− 005	−.006	− 006	−.014	−.014	−.015	−.013
	1	+ 022	+.015	+.014	+ 010	+ 005	− 007	− 008	− 008	−.008	−.015	−.015	−.015	−.015
	2	+.021	+.018	+.015	+.010	+ 006	.000	.000	−.004	−.006	−.013	−.013	−.015	−.011
F	0	+.013	+ 003	−.004	− 007	− 014	− 014	− 013	− 017	−.023	−.032	−.032	− 035	−.033
	1	+.013	+.007	+ 002	−.004	− 007	− 010	−.011	− 014	− 022	− 030	−.031	− 034	−.031
	2	+.013	+ 012	+ 004	−.003	− 006	−.009	−.010	−.013	− 021	−.029	−.028	−.029	−.024
H .	0	+.026	+ 015	+ 013	+ 006	.000	− 002	− 008	−.009	− 011	−.016	− 017	−.016	−.018
	1	+.020	+ 012	+ 011	+ 005	−.003	− 004	−.010	− 012	−.013	− 020	−.021	− 020	−.021
	2	+.019	+ 013	+ 011	+ 004	−.002	− 002	−.009	−.011	− 013	−.019	− 018	−.016	−.022
I	0	+.020	+.015	+.009	+ 004	+.003	− 003	− 006	−.007	−.012	−.019	−.020	−.021	−.019
	1	+.019	+.016	+ 009	+ 003	+.003	− 002	−.006	−.007	− 011	−.016	−.016	−.017	−.018
	2	+ 018	+ 016	+ 009	+.006	+ 004	− 002	−.006	− 007	− 011	− 017	− 017	−.015	−.013
J . .	0	+.025	+ 020	+ 012	+ 009	+.004	+ 003	− 003	− 008	−.008	−.012	−.013	−.017	−.016
	1	+ 024	+.021	+ 017	+ 014	+.010	+ 008	+ 004	+ 001	− 002	−.007	− 012	−.017	− 014
	2	+.022	+.020	+ 016	+.013	+ 010	+ 006	+ 006	+ 001	000	−.007	−.010	− 015	−.013
K .	0	+.026	+ 021	+ 016	+ 014	+ 012	+ 008	+ 007	+.006	+ 005	− 004	− 004	− 009	−.006
	1	+ 026	+ 022	+ 017	+ 015	+.013	+.008	+ 007	+ 006	+.006	− 004	− 004	− 007	−.006
	2	+.025	+ 022	+.021	+.019	+ 016	+ 012	+.012	+ 008	+ 007	− 001	−.002	− 007	− 003
Avg of 8 normal cements . .	0	+ 022	+ 014	+ 010	+ 006	+.001	− 003	− 005	−.009	− 011	−.018	− 019	−.021	− 019
	1	+ 020	+ 015	+ 012	+ 007	+.003	− 001	− 004	−.006	− 009	− 016	− 017	− 019	−.018
	2	+.018	+ 016	+ 013	+ 008	+ 004	+ 001	− 002	− 005	− 008	− 015	− 016	− 017	− 016
White cements—E	0	+.022	+.017	+ 011	+.005	+ 003	− 007	− 005	− 008	− 009	−.012	− 020	− 022	−.016
	1	+.020	+.016	+.010	+.005	+ 002	− 006	− 006	− 009	− 009	−.013	− 021	− 022	− 017
	2	+.020	+.017	+.017	+ 006	+ 004	− 003	− 004	− 007	− 010	−.012	− 016	− 021	− 016
G..	0	+.022	+ 014	+.012	+ 006	+ 003	+ 002	+ 000	− 009	−.010	− 016	− 017	− 019	− 021
	1	+.020	+ 013	+ 013	+ 008	+ 002	+ 000	− 001	−.009	− 011	− 016	− 016	− 016	− 020
	2	+ 019	+.014	+ 012	+ 007	+ 001	+.001	−.001	−.008	−.012	− 016	− 016	−.016	−.019
Avg of 2 white cements	0	+.022	+.016	+.012	+ 006	+ 003	− 003	− 003	− 009	− 010	− 014	− 019	− 021	− 019
	1	+ 020	+.015	+ 012	+ 007	+.002	− 003	− 004	− 009	− 010	− 015	− 019	− 019	− 019
	2	+.020	+ 016	+.015	+.007	+ 003	− 001	− 003	− 008	−.011	− 014	− 016	− 019	− 018
High-early-strength cement—D	0	+.030	+ 024	+ 019	+ 011	010	+ 003	− 002	−.004	− 007	− 012	− 011	−.009	− 009
	1	+ 025	+ 018	+ 015	+ 008	.008	− 003	−.004	−.004	− 004	− 013	− 019	−.013	− 013
	2	+ 024	+ 016	+.014	+ 006	005	− 002	− 005	− 005	−.006	− 016	−.021	−.016	− 016

TABLE 4

SERIES III. EFFECTS OF ADDITIONS OF CALCIUM CHLORIDE ON THE LENGTH CHANGES OF 1.2.4 (BY WEIGHT) CONCRETE MADE FROM VARIOUS CEMENTS AND EXPOSED TO UNCONTROLLED TEMPERATURES RANGING FROM 50° TO 100° F. AND TO UNCONTROLLED RELATIVE HUMIDITY RANGING FROM 30 TO 80 PER CENT. VALUES REPRESENT CHANGE IN LENGTH AS A PERCENTAGE DIFFERENCE FROM THE INITIAL READING (24 HOURS) OF THIS SERIES AND ARE ALL NEGATIVE (SHRINKAGE)

Cement	Calcium chloride	Time in days																	
		2	7	21	28	90	120	150	210	240	270	330	365	395	425	455	485	515	545
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Normal cements—A	0	.004	.007	.010	.015	.035	.038	.039	.043	.040	.029	.033	.033	.035	.035	.035	.038	.039	.039
	1	.003	.004	.009	.011	.032	.036	.038	.040	.038	.028	.028	.029	.033	.034	.035	.035	.039	.038
	2	.002	.003	.007	.010	.025	.035	.036	.038	.037	.027	.030	.030	.030	.033	.033	.033	.038	.037
B	0	.006	.014	.038	.039	.046	.044	.044	.044	.042	.042	.044	.045	.045	.045	.047	.047	.050	.051
	1	.004	.012	.032	.034	.045	.043	.042	.040	.038	.038	.040	.044	.044	.044	.045	.045	.045	.047
	2	.002	.010	.030	.032	.039	.041	.040	.036	.035	.035	.041	.045	.041	.043	.044	.044	.044	.043
C..	0	.007	.020	.028	.030	.029	.053	.053	.049	.048	.050	.052	.052	.062	.062	.060	.059	.059	.057
	1	.005	.015	.027	.030	.027	.051	.047	.045	.046	.047	.052	.052	.059	.057	.057	.055	.055	.056
	2	.004	.014	.025	.027	.025	.043	.041	.042	.043	.037	.051	.052	.057	.054	.053	.053	.053	.053
F.O.. . .	0	.005	.016	.028	.036	.046	.046	.046	.046	.046	.052	.050	.054	.056	.055	.060	.054	.056	.058
	1	.004	.010	.024	.032	.041	.044	.044	.044	.042	.041	.045	.052	.048	.052	.050	.051	.052	.053
	2	.003	.008	.019	.027	.039	.040	.041	.042	.041	.038	.041	.048	.050	.050	.048	.048	.050	.051
H.... ..	0	.006	.016	.029	.038	.044	.046	.043	.040	.042	.048	.050	.057	.056	.057	.056	.054	.054	.054
	1	.003	.010	.022	.030	.041	.042	.037	.038	.040	.044	.046	.049	.052	.052	.052	.050	.050	.050
	2	.002	.008	.019	.026	.034	.035	.035	.034	.033	.039	.045	.046	.050	.050	.050	.048	.048	.048
I.. ..	0	.006	.013	.025	.028	.043	.046	.047	.046	.046	.036	.042	.048	.048	.049	.049	.051	.050	.050
	1	.004	.011	.023	.024	.042	.044	.045	.043	.043	.034	.040	.039	.040	.047	.048	.050	.048	.048
	2	.002	.010	.019	.020	.034	.042	.043	.040	.040	.033	.037	.038	.038	.045	.047	.047	.045	.045
J.... ..	0	.007	.014	.030	.040	.046	.047	.040	.046	.047	.037	.039	.046	.046	.048	.045	.050	.050	.049
	1	.004	.009	.023	.030	.044	.041	.039	.036	.037	.035	.037	.042	.043	.042	.043	.045	.045	.045
	2	.002	.006	.017	.024	.035	.035	.034	.033	.031	.031	.032	.038	.037	.040	.040	.040	.040	.040
K... ..	0	.006	.015	.036	.049	.048	.045	.040	.040	.040	.040	.046	.048	.049	.049	.049	.049	.050	.050
	1	.005	.012	.023	.037	.041	.043	.039	.038	.039	.039	.041	.046	.047	.047	.047	.046	.047	.047
	2	.003	.010	.021	.034	.038	.039	.038	.036	.036	.037	.040	.044	.045	.043	.043	.043	.043	.043
Avg. of 8 normal cements	0	.006	.018	.028	.033	.042	.044	.045	.042	.041	.041	.046	.048	.049	.049	.049	.049	.050	.051
	1	.004	.012	.022	.029	.039	.041	.041	.040	.039	.038	.041	.044	.046	.047	.047	.047	.047	.047
	2	.003	.009	.020	.026	.035	.038	.038	.034	.034	.034	.038	.042	.043	.043	.043	.043	.044	.044
White cements—E	0	.006	.017	.040	.048	.047	.045	.047	.041	.041	.046	.048	.050	.048	.054	.053	.054	.054	.054
	1	.005	.012	.038	.041	.041	.043	.042	.039	.040	.042	.046	.049	.047	.053	.053	.053	.053	.053
	2	.003	.010	.030	.036	.038	.040	.040	.038	.038	.037	.043	.045	.044	.050	.050	.050	.050	.050
G	0	.004	.014	.020	.024	.027	.030	.025	.025	.025	.027	.029	.028	.029	.027	.026	.026	.026	.026
	1	.002	.012	.019	.019	.024	.029	.024	.022	.023	.025	.025	.025	.025	.023	.025	.024	.024	.024
	2	.001	.010	.016	.018	.023	.027	.022	.020	.022	.024	.022	.020	.020	.021	.022	.022	.022	.022
Avg of 2 white cements . .	0	.005	.016	.030	.036	.037	.038	.036	.033	.033	.037	.039	.039	.039	.041	.040	.041	.041	.041
	1	.004	.012	.029	.030	.033	.036	.033	.031	.032	.034	.036	.037	.036	.038	.039	.039	.039	.039
	2	.002	.010	.023	.027	.031	.034	.031	.029	.030	.031	.033	.033	.032	.036	.036	.036	.036	.036
High-early-strength cement D ..	0	.006	.011	.020	.026	.046	.048	.049	.046	.045	.045	.045	.043	.045	.045	.052	.054	.050	.051
	1	.004	.009	.018	.024	.040	.044	.045	.045	.044	.041	.040	.041	.042	.044	.052	.049	.045	.048
	2	.003	.007	.017	.019	.039	.043	.044	.044	.044	.041	.040	.040	.039	.042	.049	.047	.043	.045

Initial readings for Series I and III were made 24 hr. after casting the specimens. Observations on the specimens subjected to the exposure condition of Series I were made through 270 days. The same specimens were then given the exposure described under Series II. The initial readings (zero time) for Series II (Table 3) were those made at 270 days for Series I and the percentage changes in length were calculated with reference to the 24-hr. reading reported for Series I. Series II was continued for one year. All values in Table 2 are positive (increase in length compared with initial reading) whereas in Table 3 the readings are in part positive and in part negative as indicated The tests representing the exposure condition of Series III (Table 4) were made on new specimens and all readings are negative (shrinkage in length). The Series III readings were continued for one and one-half years.

TEST RESULTS

Series I

(1) When exposed to a relative humidity of approximately 100 per cent at a temperature of 70±2°F all 1:2:4 concretes made from the eight normal portland cements used in this investigation expanded in length relative to the length measured 24 hours after casting. The average increase in length at one year for these eight concretes was 0.022 per cent with a maximum of 0 026 per cent (B and K) and a minimum increase of 0.013 (cement F).

(2) The maximum increase in length took place at 28 days on an average. For cement F expansion had ceased at 14 days.

(3) The effect of calcium chloride was to decrease the amount of linear expansion. The average linear expansion of the eight concretes made from normal portland cements and containing 1 per cent calcium chloride was 87 per cent of those containing no calcium chloride at 270 days. The corresponding value for the two per cent addition was 78 per cent. Calcium Chloride had no effect on the linear expansion of the concrete made from cement F which had a minimum linear expansion among all the cements tested. The differentiation between concretes made with and without calcium chloride became evident at early ages and did not alter with increase in time.

(4) The concretes made from white portland cements did not significantly differ from those made from normal portland cements with respect to amount and time of linear expansion and the effect of calcium chloride on linear expansion.

(5) In studying the effects of calcium chloride on the one concrete made from high-early-strength cement, it was observed that this concrete gave a linear expansion at two days, two and one-half times as great as the next most expansive concretes (cements A and H). At one year this same concrete had expanded 0.030 per cent which exceeded all others in the series. Calcium chloride in the amount of 1 per cent caused a 17 per cent reduction in linear expansion. The addition of 2 per cent produced a decrease of 20 per cent in linear expansion.

Series II

(6) Considering concretes made without additions of calcium chloride and from normal portland cement, an average change in dimension (sum of positive initial reading at zero time and negative reading at one year) of 0.041 per cent was recorded. The maximum change was 0 049 per cent (cement B) and the minimum was 0 032 per cent (cement K). In general, high initial readings were associated with low final readings and vice versa. Cement B supplied one of the exceptions.

(7) Considering concretes made without additions of calcium chloride and from normal portland cements, the change from

positive to negative readings took place between 21 and 28 days on an average. The earliest change was recorded for cement F (between 3 and 7 days) and the most delayed shrinkage was associated with cement K (between 120 and 240 days).

(8) The effect of additions of calcium chloride was in general to decrease the linear shrinkage observed at one year. The average difference in length for the concrete made from the eight normal portland cements where 1 per cent of calcium chloride was used was 93 per cent of the corresponding difference for concretes made without calcium chloride. The corresponding value for a 2 per cent addition of calcium chloride was 82 per cent. Additions of calcium chloride in general lessened the expansion of concretes in Series I and decreased their shrinkage in Series II.

(9) Concrete made from the two white cements did not differ significantly in their behavior from the concretes made from normal portland cements with respect to amount of change in length and effect of additions of calcium chloride.

(10) The concrete made from the one high-early-strength cement gave the greatest linear expansion of all concretes tested when exposed in Series I. These same concretes gave the minimum shrinkage observed under the conditions of Series II. The total range of linear change (sum of expansion and contraction) did not, however, significantly differ from the corresponding range for the concretes made from normal portland cements and white cements. Additions of calcium chloride somewhat increased the linear shrinkage observed on concretes made from the high-early-strength cement; the total range of linear change (sum of expansion and contraction) was not affected by additions of calcium chloride.

Series III

(11) All concretes subjected to the exposure of Series III shrank in comparison with the lengths measured 24-hours after casting. The concretes made from the eight normal portland cements shrank without interruption up to 120 days; thereafter readings varied with humidity although the maximum shrinkages were recorded at 545 days. The average linear shrinkage for the eight concretes made without calcium chloride was 0.051 per cent at 545 days. The maximum linear shrinkage at this period was 0 058 per cent (cement F) and the minimum was 0.039 per cent (cement A).

(12) Concretes made from white cement also shrank though not to the degree observed on the average for concretes made with the normal cements.

(13) The concrete made from high-early-strength cement equalled in shrinkage the average of the eight normal concretes. The corresponding concretes had differed noticeably when exposed in Series II. That the Series III exposure caused considerably greater linear shrinkage on all concretes than did Series II exposure may be explained either by Series III having lower relative humidities at times or by Series I having caused a partially irreversible expansion, all of which was not overcome by the treatment of Series II.

(14) The effect of calcium chloride was to reduce linear shrinkage of concretes made with normal portland cements in comparison with shrinkage observed on the same concretes made without calcium chloride. At 545 days, concretes made from the eight normal portland cements and containing 1 per cent calcium chloride had 92 per cent of the linear shrinkage undergone by the corresponding concretes made without calcium chloride. The corresponding figure for the concretes containing 2 per cent of calcium chloride was 86 per cent.

General

(15) The amount of linear change measured on 1:2:4 concretes (propor-

tioned by weight) made from different portland cements when subjected to various conditions of exposure depends primarily on the nature of the cement used in making the concrete. In general, additions of calcium chloride caused a consistent decrease in linear expansion of the concretes when exposed to high relative humidities and effected a consistent decrease in shrinkage when exposed to low relative humidities. A 2 per cent addition of calcium chloride was in general more effective than a 1 per cent addition in minimizing length changes.