REPORT ON A STUDY OF CALCIUM CHLORIDE AS A STRENGTH ACCELERATOR IN PORTLAND CEMENT CONCRETE

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Prepared for Presentation at the 30th Annual Meeting of
Highway Research Board
Washington, D. C.
January 11, 1951

51-04

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November 1950

REPORT ON A STUDY OF CALCIUM CHLORIDE AS A STRENGTH ACCELERATOR IN PORTLAND CEMENT CONCRETE - CALIFORNIA CEMENTS

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SYNOPSIS

The role of calcium chloride in accelerating the hardening of Portland Cement Concrete has been a subject of considerable interest and study throughout at least the last thirty years, and a number of reports on extensive work in this field have been published in the Proceedings of the Highway Research Board, The American Society for Testing Materials, and elsewhere.

The necessity for further tests on the effects of this agent, might, therefore, appear superfluous.

However, none of the published reports on the subject include certain information which may on occasion be of considerable importance.

For instance, none of the reports start with comparative compressive strengths at earlier than 24 hours; test data relating to effect on volume change is meager and conflicting and except for the paper by Leroy C. Stewart of the Dow Chemical Co. (ASTM Vol. 26, 1926), there is very little published data relating to the effects of calcium chloride on flexural strength.

Although all tests reported disclosed the effectiveness of calcium chloride as a strength accelerator, there is a paucity of published data regarding the long time effects of different percentages of this agent, not only on strength, but likewise on volume change and durability under various weathering conditions.

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A desire for an answer to these questions with relation to all of the cements manufactured in California was the occasion for the several series of tests described.

Because it is believed that the data developed may be of general interest, this report has been compiled.

The report covers tests conducted throughout a period of over 25 years involving hundreds of specimens, over 20 different brands and types of cements, variable test conditions and repeat tests to check previous tests.

The results of the most recent tests may be summarized as follows:

1. There was a very definite acceleration in compressive strength for all California cements.
2. Except as hereinafter noted the compressive strength of the concrete at all ages and conditions of cure was greater with than without $CaCl_2$.
3. Under moist room initial curing at 70° F. the calcium chloride increased the initial shrinkage as well as the subsequent volume change under wetting and drying cycles; the increase being relatively slight with 2% but sometimes excessive with 4%, particularly in the case of some of the Type III cements.

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4. When stored at 100° F. and 30% R.H. immediately after fabrication, the setting shrinkage was less with the $CaCl_2$ than without, but the subsequent total shrinkage and wet-dry volume changes substantially paralleled the specimens in which no $CaCl_2$ had been used.

5. The compressive strengths were not materially affected by the initial and subsequent curing and wetting and drying procedure regardless of the type of cement or percentage of $CaCl_2$ except in one case where the volume change of one of the Type III cements with 4% $CaCl_2$ was the greatest.

6. When initially cured in the moist room for seven days the modulus of rupture and modulus of elasticity during the subsequent wet-dry cycles was as a rule lowered by the Calcium Chloride but the differential was not material except in the case of the Type III cements.

7. When initially cured under what may be considered adverse conditions, the calcium chloride was apparently beneficial with relation to the modulus of rupture as well as compressive strengths.

8. The fact that under initial thorough water curing conditions calcium chloride apparently increases the initial shrinkage and induces subsequent greater wet-dry volume changes, indicates the sparing use of this additive when high tensile strength is important or rusting of reinforcing steel may be

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facilitated by the infiltration of moisture through surface cracks.

Early Studies

"Concrete" magazine in September 1919 reported on an investigation on the use of calcium chloride started at least as early as 1918 by the U.S. Bureau of Standards for the U.S. Engineers Office at Memphis, Tennessee.

In the fall of 1920 a cooperative series of tests to study and report on accelerators for concrete was undertaken by ASTM Committee C-9, the Structural Materials Research Laboratory of the Lewis Institute in Chicago (Forerunner of the Portland Cement Association) and a number of other cooperating federal, state, city and producer laboratories.

The first reports on this cooperative series were a comparatively brief report by Committee C-9 in 1923(1), and a more lengthy report by Duff A. Abrams in 1924 on the work done at the Lewis Institute. Abrams was at that time Professor in charge of the Structurals Materials Research Laboratory of the Institute. His excellent report was published in the 1924 Proceedings of ASTM(2).

The report contained a bibliography of previous publications reporting studies on the effect of calcium chloride, starting with an article on "Influence of Calcium Chloride on Portland

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(1) Report of Cooperative Series of Tests on Accelerators, Proceedings, Amer. Soc. for Test. Matls., V. 23, Part 1, p. 223 (1923).

(2) Calcium Chloride as an Admixture in Concrete, Proceedings, American Society for Testing Materials, V. 24, Part ii, p. 781 (1924).

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Cement" by E. Candlot in 1889. Obviously cement technicians had been aware of the attributes of calcium chloride as an accelerator prior to 1889.

About the same time (1923) H. F. Clemmer and Fred Burggraf at that time respectively Engineer and Assistant Engineer of Materials for the Illinois Highway Division, reported on an extensive investigation begun in Illinois in 1921 on the use of Calcium Chloride as a curing agent and as an accelerator in the setting of concrete.(3)

H. S. Mattimore, at that time Engineer of Tests for the Pennsylvania State Highway Commission, in discussing the report by Messrs. Clemmer and Burggraf recited his observations covering a period of ten years.

In 1926, Mr. Leroy C. Stewart, Chemical Engineer for the Dow Chemical Company reported on tests to determine the effect of Calcium Chloride on transverse strength of concrete cured at various temperatures.(4)

Later the Calcium Chloride Association established a fellowship at the U.S. Bureau of Standards to study the reactions of Calcium Chloride with cements. Progress reports on these studies were presented at the Thirteenth Annual Meeting of the Highway Research Board, December 1933, and at the Fourteenth Meeting of the following year by the late Paul Rapp, Research Associate of the National Bureau of Standards for the Calcium

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(3) An Investigation on the Use of Calcium Chloride as a Curing Agent and Accelerator of Concrete, Proceedings, Am. Soc. Testing Materials, V. 23, Part II, p. 296 (1923)

(4) Effect of Calcium Chloride on Transverse Strength of Concrete Cured at Various Temperatures; Proceedings, Am. Soc. Testing Materials, Vol. 26, Part II, p. 451 (1926).

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Chloride Association.[5]

A final report by Rapp was published in the Journal of Research of the National Bureau of Standards in 1935.[6]

Rapp's work dealt primarily with the effect of calcium chloride on the compressive strength of concrete cured at several temperatures within the range 40° to 90° F.

In order to study strengths of similar concrete, stored at temperatures within the range 20° to 40° F. and likewise volume change resulting from wetting and drying, the Calcium Chloride Association Fellowship was re-established in 1939 with Jason C. Yates in charge.

Yates reported on this later series in two papers published in the Proceedings of the Highway Research Board in 1941.[7]

Further studies on the effect of calcium chloride as a curing medium and on the corrosion of steel were reported in 1946 by H. C. Vollmer, Research Associate, Calcium Chloride Fellowship and published in the Highway Research Board Proceedings.[8]

The above listed projects cover the principal studies on the effects of calcium chloride on concrete reported in the Proceedings of National Societies engaged in research. Numerous other articles have appeared in print, particularly in "Concrete",

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(5) Proceedings Highway Research Board, Thirteenth Annual Meeting, p. 291, (1933), and the Fourteenth Meeting, p. 341 (1934).
(6) Research Paper RP 732, Journal of Research, Nat. Bureau of Standards, V. 14, April 1935, p. 499.
(7) Proceedings Twenty-first Annual Meeting Highway Research Board (1941) p. 288 and 294.
(8) Proceedings Twenty-seventh Annual Meeting, Highway Research Board (1947) p. 189.

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describing the results of studies by state and other agencies. All agencies were unanimous in reporting the compressive strength accelerating effects of calcium chloride.

CALIFORNIA STUDIES

In the work of the California Division of Highways occasionally a relatively high strength in a few hours is desired.

Typical cases of this nature are: (a) maintenance patches or minor replacements of short sections of concrete pavements where it is desired to open to traffic in a few hours; (b) in winter where low or freezing overnight temperatures are anticipated; and (c) sea wall construction along the coastal shores where it is desired to construct relatively small units between tides.

Mortar tests in 1929 and 1939 on a number of California cements, using up to 5% calcium chloride, confirmed earlier tests indicating that, in so far as compressive strengths are concerned, as high as 5% calcium chloride can be safely used.

However, as the 1929 and 1939 tests had been to determine the effects of $CaCl_2$ in mortars only and no studies had been made of other effects, such as volume change and modulus of rupture, a more extensive 6 sack concrete series was started in 1944 including all California brands and types of cement being manufactured at that time.

The 1944 series included ten California brands of Types I, II and III with a total of 19 cements.

All cement manufacturers in California were requested to submit samples of all of the types manufactured. On the

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basis of the manufacturers ratings the cements were grouped as Type I, II and III. Subsequent chemical analyses however, disclosed that the manufacturers classifications were in error in several cases. Thus of the Type I classified cements one (cement 3-I) was likewise a true Type II cement, based on compound analysis, whereas the cement of the same manufacturer furnished as Type II was found to be high in C_3S. All of the rated Type II cements contained less than 8% C_3A but three contained over 50% C_3S. Therefore, in tabulating and illustrating the test data the original segregation has been left but with the designation "Group" instead of "Type." (Table 1)

The test specimens in the 1944 series consisted of (a) 6" x 12" cylinders of six sack concrete, and 0% to 5% Calcium Chloride (one set stored in the moist room and another set in the open on the roof of the laboratory) and (b) 2" x 2" x 6-1/4" bars (5" between gage points); (Max. 3/4" aggregate and 2% and 4% $CaCl_2$) for length change, modulus of rupture and compression tests. The percent of cement in the bars was the same as in the minus 3/4" portion of the six sack concrete mix, or the equivalent of 6.75 sacks of cement per cubic yard.

To study the effects of calcium chloride under good and bad initial curing and subsequent atmospheric weathering, one set of the bars was cured in the moist room for seven days and then exposed on the roof of the laboratory until start of the wet-dry length change tests. A second set was placed in an oven at 110° F. and 30% R.H. immediately after fabrication and kept there for seven days after which exposure was in the open, similar to the first set.

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Bar specimens were removed from the molds and initial length measurements were made at 24 hours on the moist room initially cured specimens and at six hours on the oven initially cured specimens.

Pressure of other work delayed starting the wet-dry cycles until late summer of 1945 at which time the bars averaged 320 days age.

Seventeen alternate wet at 70° F. and dry at 110° F cycles of variable length (Figs. 4 to 14) were then started and continued for a period of approximately 200 days after which the bars were tested for modulus of rupture and the ends of the broken bars in compression at an average age of 520 days.

In general all previous tests to determine the effect of calcium chloride on compressive strength were confirmed; namely higher compressive strength at all ages, up to 520 days at least. (Tables 2, 3, 4 and 5).

However, with regard to volume change and modulus of rupture the story was different, as will be most readily noted from a study of Tables 4 to 8 and Figs. 4 to 16. The calcium chloride generally induced greater length changes in the initially moist room cured specimens which with some cements (particularly the finely ground Type III), became excessive under the 17 wet-dry cycles.

Compressive strengths and moduli of elasticity (compressive and dynamic) were determined at 4, 8 and 24 hours; 7 and 28 days; 6 months and one year on the 6" x 12" cylinders in the 1944 series. Some of the cylinder specimens were cured in the moist room for the entire period and others exposed to the atmosphere on the roof of the laboratory after seven days in the moist

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room. (Tables 2, and 3, and Figs. 1 and 2).

Six sack concrete mixes (1-1/2" maximum size coarse aggregate) were used with an average slump of 1-1/2".

An effort was made to determine the setting as well as long time shrinkage of the 2" x 2" bars. To accomplish this, the screws holding the accurately spaced pins at each end of the specimens were loosened shortly after the specimens were fabricated. Regardless of precautions, however, the setting measurements were very erratic, in many cases indicating disturbance and hang up of the pins.

However, by discarding the obviously erroneous readings and averaging the others, it is believed that certain trends are indicated with sufficient accuracy to justify recording as a part of this report. (Table 6 and Fig. 3).

The subsequent long time length change measurements (Tables 7 and 8 and Figs. 4 to 14) were based on the initial set length as zero.

This series of tests was sandwiched with other routine tests and research in other fields being carried on at the same time. Because of the pressure of other work, no fixed wet-dry schedule was followed; this phase of the operations being conducted as opportunity afforded.

All outdoor exposure specimens were stored on the roof of the laboratory throughout the winter following fabrication and until late in the following summer, length change measurements being made at infrequent intervals to determine effect of moisture from rain and maximum shrinkage from thorough drying during the hot dry weather of the summer (the humidity

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on high temperature days usually being less than 20).

Before the second winter, and when the specimens were thoroughly dry, the series of wetting and drying cycles was started, the time intervals conforming with the demands of other work, first at 28 days and then at seven days and finally several cycles of 14 to 17 days (a total of seventeen cycles) just prior to the final measurements which included Dynamic E, modulus of rupture and compressive strength at an average age of 520 days.

As will be noted from Table 6 and Fig. 3 the initial or setting shrinkage was increased by the calcium chloride under 100% humidity and normal temperature (70° F.) storage; whereas when the storage conditions are what may be considered adverse such as relatively low humidity (30%) and moderately high temperatures (110° F.) the initial or setting shrinkage was materially retarded by the calcium chloride.

Subsequent shrinkage on thorough drying over a long period (300+ days) and under variable atmospheric conditions was about the same, with or without the calcium chloride, for the specimens initially stored in the moist room for 7 days but with a moderate increase in shrinkage of the specimens initially stored in the oven for 7 days (Fig. 4 to 14).

There were two very interesting developments from the wetting and drying cycles: (1) the specimens initially cured for seven days in the moist room developed substantially greater subsequent volume change in the wetting and drying cycles, than the specimens initially oven cured; (2) the calcium chloride

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specimens initially cured in the moist room had a greater wet-dry length change than those without calcium chloride; whereas, the initially oven cured specimens developed relatively low subsequent volume change whether with or without calcium chloride. The calcium chloride specimens, which developed greater wet-dry length changes when initially moist room cured than those without calcium chloride showed about the same length changes with calcium chloride as without when initially oven cured. The Type III cement specimens initially moist room cured for seven days developed excessive expansion during the wet-dry cycles ultimately leading to lower strength (particularly lower modulus of rupture) and even to failure (Fig. 16(a)) with calcium chloride, particularly with 4%.

It would appear from the results of these tests that the calcium chloride minimizes the initial (setting) shrinkage under adverse high temperature-low humidity initial weathering, but has little effect on the subsequent shrinkage under normal atmospheric weathering conditions.

The wet-dry length changes of 2" x 2" x 6-1/4" bars of concrete (max. 3/4" aggregate. 6.75 sacks of cement per cubic yard) when subjected to alternate cycles of immersion at 70° F. and oven drying at 110° F. are shown in Figs. 4 to 14. Initial measurement was made of the (a) Specimens on removal from forms

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after 24 hours storage in moist room at 70° F. and of the (b) Specimens on removal from forms after six hours in oven at 110° F., relative humidity 30%. After an initial curing period of seven days in the moist room for the (a) specimens and 7 days in the oven for the (b) specimens, all specimens were stored in the open on the roof of the Laboratory until the start of the wet-dry cycles. The first measurement indicates the shrinkage during this outdoor exposure period. All measurements starting at average age of 320 days indicate departure from the initial set measurements.

Figs. 5 to 14 show length changes for each brand and type cement of which the averages are shown in Fig. 4.

All bar specimens were tested for modulus of rupture and modified cube compressive strength at the conclusion of the wet-dry cycles, the average age being as shown on the respective figures. The modulus of rupture and compressive test data are shown in the two columns to the right of the plotted length change data.

As will be noted, the length changes in the wet-dry cycles in the case of the specimens initially cured for seven days in the moist room were greater with the calcium chloride additions than without, the final expansion being substantial with 4% calcium chloride regardless of type of cement, but particularly in the case of the Type III cements, where, as will be noted, a material reduction in flexural strength developed.

The initial oven cure at 110° F., however seemed to temper the concrete with the result that the wet-dry length changes were of a low order, even with 4% $CaCl_2$, and there was little,

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if any, reduction in flexural strength induced by the $CaCl_2$. As will be noted the effect of any high ultimate expansion of the initially moist room cured specimens was reflected in lower modulus of rupture. There was little, if any, adverse effect, however, on the compressive strength; the ultimate compressive strengths of the 4% $CaCl_2$ additions almost invariably being higher than without $CaCl_2$ regardless of initial cure.

That these results are not accidental is evident from a study of the data which show the test results for each brand and type cement. The same pattern is apparent throughout although some cements are affected to a greater extent than others.

The indications from this series are that under normal construction operating conditions where, particularly in hot weather, the concrete temperature and moisture conditions during the early curing periods may, on occasion, more nearly conform with the treatment of the Series (b) Specimens than the ideal moist room cure illustrated by Series (a), the actual concrete performance will, in all probability, fall somewhere between the two extremes.

1945 Series

Because the 1944 series was necessarily limited in scope through the large number of cements tested (nineteen) a new series was started in 1945 limited to but one standard cement of the 1944 series (Cement 1-I) but with variable cement content and water cement ratio.

These later tests were further limited to 2 x 2 x 6-1/4" bars, 3/4" maximum size aggregate, the proportions of cement

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being on the basis of 4.50 sacks, 6.75 sacks and 9.00 sacks per cubic yard of the 3/4" top size aggregate portion of standard 4, 6, and 8 sack concrete mixes.

Two slumps - 1-1/2" and 3" were used. One set of specimens was initially cured in the moist room for 24 hours and then in the oven for an additional six days. The other set in the oven for seven days from the start. Both sets were then stored in the laboratory at normal laboratory temperature and relatively low humidity for 12 weeks (84 days) when opportunity presented for a long time series of 28 day wet (70° F.) and dry (110° F.) cycles (nineteen total) after which (age 616 days) all specimens were tested for modulus of rupture, dynamic modulus and compressive strengths, as well as wet-dry length changes.

Following are a few comments on the results of this 1945 series of tests on the Type I cement tested (Brand 1 - Type I):

(1) No cracking, spalling, or evidences of disintegration was seen in any of the specimens.

(2) The effect of calcium chloride upon the initial drying shrinkage was very apparent. For all mixes and storage conditions, the initial drying shrinkage increased with increasing percentages of the salt.

(3) Subsequent wet-dry length changes were less with the calcium chloride in the 4.5 sack mixes but greater in the case of the 6.75 and 9.0 sack mixes.

(4) Compressive strengths at 616 days after the wet-dry cycles were substantially greater for the calcium chloride additions.

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(5) The modulus of rupture and dynamic modulus of elasticity averaged moderately lower for the calcium chloride additions than without.

1950 Series

As recited above, the results of the 1944 and 1945 tests indicated greater shrinkage and greater wet-dry volume change of concrete containing calcium chloride when initially cured under moist room conditions at 70° F. but less differential shrinkage and less wet-dry volume change when initially exposed to relatively high temperatures (100-110° F.) and relatively low humidity conditions (30% R.H.).

At the same time, although the compressive strengths, up to one year at least, were not adversely affected by the addition of 2% to 4% calcium chloride, regardless of curing conditions, the modulus of rupture was apparently adversely affected to an extent depending on the volume change under alternate wet-dry cycles.

It was, therefore, deemed desirable to make a check of this tendency through a supplementary series of tests. Time available and the expense involved did not appear to justify repeating with all of the cements included in the original series, particularly for the reason that, except for the fine ground Type III cements which are infrequently used, and seldom, if at all in combination with calcium chloride, no substantial differences in performance as between the different brands of cements had been observed in the tests started in 1944.

A check series of tests was, therefore, started in 1950 limited to Brand 1, Type I, five and six sack mixes, 0%, 2% and

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4% calcium chloride, but with a modified curing or storage procedure.

The test specimens in the 1950 series consisted of 6" x 12" cylinders for standard compression tests and 3 x 3 x 11-1/4" beams for modulus of rupture, compression (modified cube on beam ends) and length change measurements.

Storage of different sets of specimens prior to and during the test periods was as follows:

1. 6" x 12" cylinders and 3" x 3" bars continuous moist room storage at 70° F.
2. Bars moist room 60 days then alternate wet (70° F.) Dry (100° F.) cycles.
3. Cylinders and bars at 100° F. protected from material, if any, moisture loss for seven days then stored on Laboratory roof until final test.
4. Bars same as in (3) until age 60 days then alternate wet (70° F.) - dry (100° F.) cycles.

The results of this (1950) series are shown in Figs. 18 to 20.

The essential data and conclusions derived from the 1944 Series were confirmed, to wit:

1. Wet-dry volume changes of the 60 day moist room cured specimens were in proportion to the percentage of calcium chloride.
2. Early drying shrinkage and subsequent volume change of the specimens initially cured at 100° F under good moisture conditions was likewide increased

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by the $CaCl_2$ but with less range than in the case of the moist room cured specimens thereby confirming the results of the 1944 Series with regard to the effect of initial curing conditions on the subsequent performance.

3. Greater wet-dry volume change of the initially moist room cured specimens than with the specimens initially cured at 100° F.
4. Lowered modulus of rupture with calcium chloride after a succession of wet-dry cycles when initially cured in moist room at 70° F. but as a rule either increase in modulus or less differential with $CaCl_2$ when initially cured at 100° F.
5. Increase in compressive strength with $CaCl_2$ regardless of initial cure and subsequent treatment.

ACKNOWLEDGEMENTS

The author wishes to express appreciation to the staff of the Materials and Research Department for their assistance; particularly to Associate Materials and Research Engineer W. E. Haskell for the excellence of his work in designing the bar mixtures and his meticulous care in fabricating and performing the numerous variety of tests on the bars; also to Associate Materials and Research Engineer L. P. Kovanda for work done in connection with the design and fabrication of the mixtures for the concrete cylinder tests.

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Table 1 COMPOUND ANALYSES AND FINENESS DETERMINATIONS OF ALL CEMENTS IN THE 1944 CALCIUM CHLORIDE TEST SERIES

Cement Number	C_3S	C_2S	C_3A	Alk. as Na_2O	Autoclave	Specific Surface Wagner	Specific Surface Air Perm.
GROUP I CEMENTS							
1-I	50	25	11	1.05	.070	1845	3530
2-I	29	46	11	0.31	.048	1750	3520
3-I	47	30	6	0.51	.010	1865	3390
4-I	34	40	13	0.58	.115	1950	3700
5-I	42	30	14	0.98	.198	1880	3480
Ave.	40	34	11	0.69	.084	1858	3524
GROUP II CEMENTS							
1-II	45	33	6	0.49	.003	1925	3430
2-II	37	39	5	0.26	-.031	1755	3300
3-II	54	24	6	0.60	.002	1730	3170
5-II	36	42	3	0.43	-.010	1905	3170
6-II	49	23	6	0.62	.048	1865	3320
7-II	51	23	6	0.38	.166	1850	3770
8a-II	50	23	7	0.89	.105	1965	3960
8b-II	44	32	4	0.48	.046	1915	3900
9-II	67	9	5	0.56	.157	1640	3240
Ave.	49	27	5	0.52	.054	1838	3473
GROUP III CEMENTS (HIGH EARLY STRENGTH)							
1-III	46	26	12	1.09	.047	3080	5420
2-III	51	26	6	0.32	-.004	2035	3830
3-III	62	17	7	0.35	-.018	2895	4930
6-III	61	17	6	0.37	-.029	2460	5270
9-III	53	25	7	0.50	.066	2170	4310
Ave.	55	22	8	0.53	.012	2528	4752

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TABLE 2 AVERAGE SHORT TIME COMPRESSION STRENGTH TESTS ON 6" x 12" CYLINDER SPECIMENS OF CONCRETE FROM NINE BRANDS AND THREE TYPES OF CALIFORNIA PORTLAND CEMENTS (TOTAL 19 CEMENTS) AS AFFECTED BY FROM 2% to 5% CALCIUM CHLORIDE

1944 TEST SERIES

SHORT TIME COMPRESSION STRENGTH 6" x 12" CONCRETE CYLINDERS CURED IN MOIST ROOM															
Age	4 Hours					8 Hours					24 Hours				
	PERCENT CALCIUM CHLORIDE														
Cement	0	2	3	4	5	0	2	3	4	5	0	2	3	4	5
GROUP I CEMENTS															
1-I	0	190	365	485	595	0	685	915	1070	1160	980	1840	2350	2185	2200
2-I	0	270	420	490	640	0	710	785	870	930	630	1435	1500	1500	1575
3-I	0	110	225	190	230	0	555	750	780	860	1100	1710	1815	1820	1785
4-I	0	210	345	355	410	0	710	810	795	760	815	1690	1685	1610	1430
5-I	0	95	205	320	365	0	430	735	770	830	550	1540	1885	1670	1695
Ave.	0	175	312	368	448	0	616	799	857	908	815	1643	1847	1751	1737
GROUP II CEMENTS															
1-II	0	180	310	410	410	0	620	805	950	900	685	1550	1760	1825	1795
2-II	0	225	345	435	480	0	715	775	870	970	870	1730	1570	1615	1815
3-II	0	110	230	320	205	0	555	795	890	765	1035	1745	1885	1845	1690
5-II	0	0	0	0	0	0	145	210	445	475	470	1050	1560	1825	1555
6-II	0	220	465	600	540	0	750	1070	1240	1040	1055	1995	2320	2370	2030
7-II	0	155	330	505	485	0	570	985	1080	985	995	1690	1900	2040	1800
8(a)-II	0	145	260	350	410	0	630	845	870	850	650	1815	1840	1760	1595
8(b)-II	0	135	235	380	365	0	635	715	945	925	920	1655	1690	1980	1895
9-II	0	225	405	540	565	0	885	1030	1215	1110	1015	1965	2070	2175	2120
Ave.	0	155	287	393	384	0	623	803	941	891	855	1688	1844	1937	1811
GROUP III CEMENTS (High Early Strength)															
1-III	0	680	1040	1045	1330	570	1645	1785	1865	2000	1665	2705	2855	2905	3000
2-III	0	260	540	735	705	185	1170	1270	1390	1405	1365	2355	2325	2555	2360
3-III	0	455	890	1110	1190	325	1780	1965	2220	2060	2050	3160	3290	3600	3340
6-III	0	480	1010	1425	1385	380	1735	2110	2520	2375	1815	2955	3500	3700	3385
9-III	0	445	840	910	1335	330	1375	1850	1895	2105	1595	2630	2920	2710	3115
Ave.	0	464	864	1045	1189	358	1541	1796	1978	1989	1698	2761	2978	3094	3049
AVERAGES															
GROUP I	0	175	312	368	448	0	618	799	857	908	815	1543	1847	1757	1737
" II	0	155	287	393	384	0	623	803	941	891	855	1688	1844	1937	1811
" III	0	464	864	1045	1189	358	1541	1796	1978	1989	1698	2761	2978	3094	3040
Grand Ave.	0	265	488	602	674	119	927	1133	1259	1263	1123	2031	2223	2263	2196

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TABLE 3 - AVERAGE ONE YEAR COMPRESSION STRENGTH TESTS ON 6" x 12" CYLINDER SPECIMENS OF CONCRETE FROM NINE BRANDS AND THREE TYPES OF CALIFORNIA PORTLAND CEMENTS (TOTAL 19 CEMENTS) AS AFFECTED BY FROM 2% TO 5% CALCIUM CHLORIDE

1944 TEST SERIES

ONE YEAR COMPRESSIVE STRENGTH 6" x 12" CONC. CYLINDERS															
	Moist Rm. Entire Period					Moist Room 10 Days Air 353 Da.-Water 48 Hr.					Moist Room 10 Days Air 355 Da.- Tested Dry				
	PERCENT CALCIUM CHLORIDE														
Cement	0	2	3	4	5	0	2	3	4	5	0	2	3	4	5
GROUP I CEMENTS															
1-I	4965	5155	5985	6250	6125	4215	4180	4960	5210	5580	4860	5160	5750	5640	6370
2-I	4220	6395	5925	6990	6825	3045	3850	4135	3915	4170	3325	4650	4425	5115	5285
3-I	5635	6405	6085	6160	5745	4340	4510	4745	4340	4010	5140	4410	4980	5210	----
4-I	4955	5520	6130	5900	6665	3705	4385	4825	4005	4500	4150	5190	5635	5195	5480
5-I	5690	5600	6125	6495	6435	3840	3650	4455	4230	4495	3975	4335	4685	4970	4955
Ave.	5094	5815	6050	6359	6359	3829	4115	4624	4340	4551	4290	4749	5095	5226	5523
GROUP II CEMENTS															
1-II	4395	6715	7095	6765	7365	4205	4735	4910	5345	5150	5290	5270	5500	6225	5820
2-II	5410	6380	6605	7220	7055	4755	4175	3990	3990	4315	5580	5015	5385	4850	5375
3-II	5885	5830	6350	6025	6300	4385	4245	4385	4170	4805	5455	4915	5605	5115	5285
5-II	4945	6445	6710	7335	6985	4265	4820	4870	5260	4465	4390	5505	5565	4550	5490
6-II	5180	6315	6240	5795	5485	4490	4490	4760	5160	4705	5460	5630	5485	5520	5830
7-II	6320	6455	6985	7610	6510	4960	4370	4390	4845	4255	5075	5340	5860	5530	5735
8(a)-II	4395	5915	6420	6400	5820	3950	4220	4720	3645	4355	4400	4945	5240	4975	5260
8(b)-II	4735	5110	6270	6645	6455	4390	4945	4845	5330	4975	4540	5790	5280	6065	5525
9-II	4990	6630	6525	6310	6870	4570	4885	5670	5365	5210	5405	5280	5350	5470	6250
Ave.	5139	6288	6577	6678	6538	4441	4543	4727	4790	4693	5066	5299	5474	5371	5619
GROUP III CEMENTS (High Early Strength)															
1-III	4535	6125	6155	6605	6665	4165	4355	5230	4930	5070	4565	5085	5435	5785	5775
2-III	4960	6915	7400	7480	6780	3610	4510	4305	4835	4355	5215	5610	5355	5290	5390
3-III	6260	6850	7090	6885	6525	5355	5095	5370	5745	6095	4960	6155	5745	6800	5450
6-III	5215	6710	6460	6575	6955	4125	4460	4955	4870	4870	4735	4975	5240	5720	5795
9-III	5390	6110	6290	6570	6570	4700	5030	4960	5070	5425	5615	6005	5895	6580	5580
Ave.	5276	6542	6679	6823	6699	4391	4690	4964	5094	5163	5018	5566	5534	6035	5598
AVERAGES															
Group I	5073	5815	6050	6359	6359	3829	4115	4624	4340	4551	4290	4749	5095	5226	5523
" II	5139	6288	6577	6678	6538	4441	4543	4727	4790	4692	5066	5299	5474	5371	5619
" III	5276	6542	6679	6823	6699	4391	4690	4964	5094	5163	5018	5566	5534	6035	5598
Grand Ave.	5169	6215	6435	6620	6532	4220	4449	4772	4741	4802	4791	5205	5368	5544	5580

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TABLE 4 AVERAGE OF ALL TESTS FOR DYNAMIC MODULUS OF ELASTICITY, MODULUS OF RUPTURE AND COMPRESSIVE STRENGTH OF 2" x 2" x 6-1/4" CONCRETE BARS (3/4" max. size aggregate) CONTAINING 0%, 2% and 4% CALCIUM CHLORIDE BY WEIGHT OF CEMENT*

1944 TEST SERIES

Cement Group	Ave. Age	Dynamic E x 10^{-6}			Mod. of Rupt.			Compr. Strength		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a) Bars initially stored in moist room at 70°F. 7 days then on Lab. Roof and subsequent wet and dry cycles										
I	512	5.34	5.43	5.21	1170	1156	1042	5778	6890	6976
II	536	5.66	5.55	5.43	1312	1147	1017	6794	7658	7399
III	527	5.51	4.95	4.34	1120	964	788	6798	7164	6826
Ave.	525	5.50	5.31	4.99	1201	1089	949	6456	7237	7067
(b) Bars initially stored in oven at 110°F. 7 days - then on Lab. Roof and subsequent wet and dry cycles										
I	514	5.07	5.22	5.60	1028	1008	1116	4974	6750	6728
II	537	5.19	5.50	5.57	992	1127	1076	5406	7030	7083
III	530	5.64	5.60	5.62	1184	1154	1120	6630	7890	7924
Ave.	527	5.30	5.44	5.60	1068	1096	1104	5670	7223	7245

*One set of bars cured in moist room for seven days and the other set in an oven at 110°F. at an average humidity of 30 for the same period (7 days). Both sets then stored in the open on the Laboratory roof for an average of approximately 320 days, then to 17 alternate cycles of immersion in water at 70°F. and drying in the oven at 110°F. over a period of approximately 200 days until breaking test at an average age of 526 days. (Fig. 4).

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TABLE 5 DYNAMIC MODULUS, MODULUS OF RUPTURE AND COMPRESSIVE STRENGTH OF 2" x 2" x 6-1/4" CONCRETE BARS (3/4" Max. size aggregate, 6.75 Sacks cement per cubic yard) containing 0%, 2% and 4% CALCIUM CHLORIDE, TESTS AT AVERAGE AGES INDICATED AFTER WET AND DRY CYCLES.

(a) GROUP I CEMENTS

Cement Number	Age Days	Dynamic E x 10^{-6}			Modulus of Rupt.			Compr. Strength		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a) Bars stored in moist room at 70° F., seven days. Then on Laboratory Roof and subsequent wet and dry cycles.										
1-I	595	5.43	5.71	5.29	1340	1330	970	6000	7580	7000
2-I	519	5.57	5.48	5.58	1370	1240	1240	6080	6640	7430
3-I	505	5.41	5.39	5.43	1180	1100	1110	5890	7030	6790
4-I	471	5.21	5.20	5.05	850	1110	1080	5340	6480	6650
5-I	469	5.09	5.35	4.69	1110	1000	810	5580	6720	7010
Ave.	512	5.34	5.43	5.21	1170	1156	1042	5778	6890	6976
(b) Bars stored in oven at 110° F. first seven days. Then on Laboratory Roof and subsequent wet-dry cycles.										
1-I	590	4.80	5.20	5.80	900	1190	1240	4720	7100	7320
2-I	521	5.53	5.48	5.50	1220	1170	1032	5230	7360	6710
3-I	507	5.54	5.54	5.51	1080	1110	1260	5870	6350	6930
4-I	478	4.78	4.63	5.31	850	1030	920	4130	6110	6680
5-I	476	4.68	5.26	5.87	1090	1040	1130	4920	6830	6000
Ave.	514	5.07	5.22	5.60	1028	1008	1116	4974	6750	6728

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TABLE 5 (CONTINUED)

(b) GROUP II CEMENTS

Cement Number	Age Days	Dynamic E x 10^{-6}			Modulus of Rupt.			Compr. Strength		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a) Bars stored in moist room at 70°F., 7 days, then on Lab. Roof and wet and dry cycles.										
I-II	589	5.83	5.91	5.74	1370	1230	1100	6480	7650	7450
2-II	518	5.66	5.71	5.76	1300	1190	1220	6690	7950	7910
3-II	504	5.59	5.47	5.64	1250	1170	1150	6030	7710	7330
5-II	477	5.68	5.67	5.52	1280	1080	910	7140	7030	7450
6-II	574	5.63	5.53	5.40	1420	1180	1137	6710	7820	7160
7-II	471	5.64	5.51	5.58	1420	1240	1070	6840	7650	7470
8a-II	575	5.63	5.43	5.16	1340	1250	1000	7110	7700	6780
8b-II	581	5.51	5.49	5.44	1300	1050	830	6820	7460	7960
9-II	532	5.78	5.23	4.66	1130	930	740	7330	7950	7080
Ave.	536	5.66	5.55	5.43	1312	1147	1017	6794	7658	7399
(b) Bars stored in oven at 110°F., 7 days, then on Laboratory Roof and subsequent wet and dry cycles.										
1-II	588	5.18	5.88	5.93	880	1320	1020	5270	7430	7860
2-II	520	5.63	5.59	5.82	1150	1200	1210	5390	6960	6820
3-II	506	5.26	5.52	5.54	1130	1400	1180	6060	7710	7540
5-II	475	4.48	5.52	5.48	840	1060	990	4600	6360	6530
6-II	576	5.37	5.42	5.56	750	1130	1140	5750	6950	7200
7-II	477	5.27	5.47	5.54	1300	1240	1060	5380	7110	6230
8a-II	577	4.46	5.10	5.02	700	1040	890	5210	6880	7260
8b-II	583	5.44	5.47	5.61	990	960	1130	5210	6510	6980
9-II	534	5.66	5.57	5.63	1190	1050	1060	5780	7360	7330
Ave.	537	5.19	5.50	5.57	992	1127	1076	5406	7030	7083

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TABLE 5 (CONTINUED)

(c) GROUP III CEMENTS (HIGH EARLY STR.)

Cement Number	Age Days	Dynamic E x 10^{-6}			Mod. of Rupt.			Compr. Strength		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a) Bars stored in M.R. at 70°F - then on Lab. Roof and subsequent wet-dry cycles										
1-III	582	5.44	5.22	4.54	1170	1040	750	6450	7590	7770
2-III	513	5.70	5.49	5.37	1140	960	890	6690	6680	7000
3-III	484	5.47	5.38	5.33	1220	1150	1030	6560	7340	6970
6-III	533	5.43	3.56	2.05	930	560	430	6970	7020	5890
9-III	525	5.52	5.11	4.43	1140	1110	840	7320	7190	6500
Ave.	527	5.51	4.95	4.34	1120	964	788	6798	7164	6826
(b) Bars stored in oven at 110°F. first 7 days - then on Lab. Roof and subsequent wet-dry cycles										
1-III	584	5.27	5.46	5.83	1010	1180	1250	6010	7860	8270
2-III	514	5.66	5.63	5.57	1160	1070	1180	6990	7810	7890
3-III	485	5.91	5.55	5.54	1400	1280	1070	6810	7900	7870
6-III	542	5.82	5.79	5.60	1230	1160	1020	7500	8660	7940
9-III	526	5.53	5.59	5.57	1120	1080	1080	5840	7220	7650
Ave.	530	5.64	5.60	5.62	1184	1154	1120	6630	7890	7924

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TABLE 6 INITIAL (SETTING) LENGTH CHANGES OF 2" x 2" x 6-1/4" MORTAR BARS CONTAINING 0%, 2% and 6% CALCIUM CHLORIDE.

1944 TEST SERIES

Average setting shrinkage of all bars, Cement Groups I, II and III

Percent Calcium Chloride	CEMENT GROUP			Average
	I	II	III	
(a) Initially cured in moist room at 70° F. Bars removed from molds and measured at 24 hours.				
0%	-122	-134	-178	-145
2%	-220	-199	-224	-214
4%	-275	-235	-260	-257
(b) Initially cured in oven at 110° F., 30 R.H. Bars removed from molds and measured at 6 hours.				
0%	-554	-527	-724	-602
2%	-166	-320	-216	-234
4%	-160	-387	-298	-282

NOTE: The pins for measuring length changes were very accurately spaced between gage points and held rigid by set screws prior to fabricating the concrete. As soon as the concrete had stiffened the set screws were loosened in an effort to free the pins from all restraint. The effort was only partially successful, but as there were over 340 specimens total in all groups it is believed that the average of the measurements in each group and for the whole indicates the trend of initial or setting shrinkage as influenced by the calcium chloride and the initial storage conditions.

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TABLE 7 AVERAGE FINAL DRY AND WET BAR LENGTHS IN THE 1944 CALCIUM CHLORIDE TEST SERIES JUST PRIOR TO FINAL TEST AT AVERAGE AGES INDICATED.

Figures Millionths of an inch per inch

1	2	3	4	5	6	7	8	9	10	11
Cement Group	Ave. Age Days	Oven 17 D. at 110° F.			Water 16 D. at 70° F.			Final Range Dry to Sat.		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a)* Bars initially stored in moist room at 70° F. then on Lab. Roof and subsequent wet-dry cycles. Based on initial measurement at 24 hours.										
I	512	-604	-493	-123	-325	-148	+307	279	346	451
II	536	-530	-433	-190	-273	-104	+209	257	329	399
III	527	-421	+187	+860	-113	+736	+1643	308	549	783
Ave.	525	-518	-246	+182	-237	+161	+720	281	408	544
(b)* Bars initially stored in oven at 110° F. first 7 days then on Lab. Roof and subsequent wet-dry cycles. Based on initial measurement at 6 hours.										
I	514	-576	-641	-708	-347	-376	-423	229	265	285
II	537	-484	-619	-708	-269	-386	-452	216	234	256
III	530	-528	-520	-539	-304	-212	-187	224	308	352
Ave.	527	-529	-593	-652	-307	-325	-354	223	269	298

*Length changes shown in Columns 3 to 8 are with relation to the initial measurement on removal from molds at 24 hours for the (a) and 6 hours for the (b) group specimens.

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TABLE 8 FINAL DRY AND WET LENGTHS OF ALL BARS IN THE 1944 SERIES

(a) GROUP I CEMENTS

1	2	3	4	5	6	7	8	9	10	11
Cement Number	Ave. Age Days	Oven 17 D. at 110° F.			Water 16 D. at 70° F.			Range - Dry to Sat.		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a) Bars initially stored in moist room at 70° F. 7 days. Then on Lab. Roof and subsequent wet-dry cycles.										
1-I	595	-600	-467	-460	-340	-153	-113	260	314	347
2-I	519	-633	-613	-400	-360	-260	+ 13	273	353	413
3-I	505	-640	-660	-587	-360	-313	-193	280	347	394
4-I	471	-627	-367	+187	-353	- 20	+633	274	347	554
5-I	469	-520	-360	+647	-213	+ 7	+1193	307	367	546
Ave.	512	-604	-493	-123	-325	-148	+307	279	346	451
(b) Bars initially stored in oven at 110° F. first 7 days then on Lab. Roof and subsequent wet-dry cycles.										
1-I	590	-460	-547	-680	-213	-267	-420	247	280	260
2-I	521	-580	-607	-680	-380	-393	-420	200	214	260
3-I	507	-580	-767	-900	-367	-520	-640	213	247	260
4-I	478	-713	-673	-627	-473	-360	-287	240	313	340
5-I	476	-547	-613	-653	-300	-340	-347	247	273	306
Ave.	514	-576	-641	-708	-347	-376	-423	229	265	285

NOTE: Length changes shown in Columns 3 to 8 are with relation to the initial set length at 24 hours for specimens initially cured in the moist room at 70° F. and at 6 hours for specimens initially cured in the oven at 110° F.

At the end of the wet-dry cycles and just prior to test for dynamic modulus of elasticity, modulus of rupture and compressive strength, all specimens were stored in the oven at 110° F. for seventeen days - measured and then stored in water for sixteen days at 70° F.

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TABLE 8 (CONTINUED)

(b) GROUP II CEMENTS

Cement Number	Ave. Age Days	Oven 17 D. at 110° F.			Water 16 D. at 70° F.			Range - Wet to Dry		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a) Bars initially stored in moist room at 70° F., 7 days, then on Lab. Roof and subsequent wet-dry cycles.										
1-II	589	-607	-587	-593	-353	-313	-313	254	274	280
2-II	518	-533	-540	-140	-280	-247	+220	253	293	360
3-II	504	-567	-560	-547	-307	-233	-153	260	327	394
5-II	477	-507	-413	-187	-240	- 80	+253	267	333	440
6-II	574	-573	-480	- 60	-333	-160	+287	240	320	347
7-II	471	-473	-427	- 80	-193	- 53	+367	280	374	447
8a-II	575	-553	-520	-380	-313	-220	- 20	240	300	360
8b-II	581	-487	-413	-293	-253	-113	+ 33	234	300	326
9-II	532	-473	+ 40	+567	-187	+480	+1207	286	440	640
Ave.	536	-530	-433	-190	-273	-104	+209	257	329	399
(b) Bars initially stored in oven at 110° F., 7 days, then on Lab. Roof and subsequent wet and dry cycles.										
1-II	588	-453	-600	-773	-253	-393	-553	200	207	220
2-II	521	-547	-687	-860	-320	-453	-560	227	234	300
3-II	506	-573	-827	-780	-360	-567	-500	213	260	280
5-II	475	-467	-573	-760	-200	-340	-493	267	233	267
6-II	576	-473	-613	-707	-307	-413	-493	166	200	214
7-II	477	-453	-587	-687	-160	-313	-407	293	274	280
8a-II	577	-427	-660	-673	-260	-453	-433	167	207	240
8b-II	583	-500	-547	-653	-313	-335	-420	187	214	213
9-II	534	-467	-480	-500	-247	-207	-213	220	273	287
Ave.	537	-484	-619	-708	-269	-386	-452	216	234	256

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TABLE 8 (CONTINUED)

(c) GROUP III CEMENTS (HIGH EARLY STR.)

1	2	3	4	5	6	7	8	9	10	11
Cement Number	Ave. Age Days	Oven 17 D. at 110° F.			Water 16 D. at 70° F.			Range - Dry to Sat.		
		PERCENT CALCIUM CHLORIDE								
		0	2	4	0	2	4	0	2	4
(a) Bars initially stored in moist room at 70° F., then on Lab. Roof and subsequent wet-dry cycles.										
1-III	582	-453	-180	+293	-193	+227	+793	260	407	500
2-III	513	-540	-253	+ 60	-233	+153	+587	307	406	527
3-III	484	-420	-313	-113	- 87	+ 87	-327	333	400	440
6-III	533	-293	+1520	+2880	+ 47	+2540	+4567	340	1020	1687
9-III	525	-400	+160	+1180	-100	+673	+1940	300	513	760
Ave.	519	-421	+187	+860	-113	+736	+1643	308	549	783
(b) Bars initially stored in oven at 110° F. first 7 days, then on Lab. Roof and subsequent wet-dry cycles.										
1-III	584	-533	-460	-667	-287	-153	-327	246	307	340
2-III	514	-513	-700	-700	-300	-413	-420	213	287	280
3-III	485	-587	-567	-513	-353	-273	-147	234	294	366
6-III	542	-500	-327	-300	-300	+ 13	+ 93	200	340	393
9-III	526	-507	-547	-513	-280	-233	-133	227	314	380
Ave.	530	-528	-520	-539	-304	-212	-187	224	308	352

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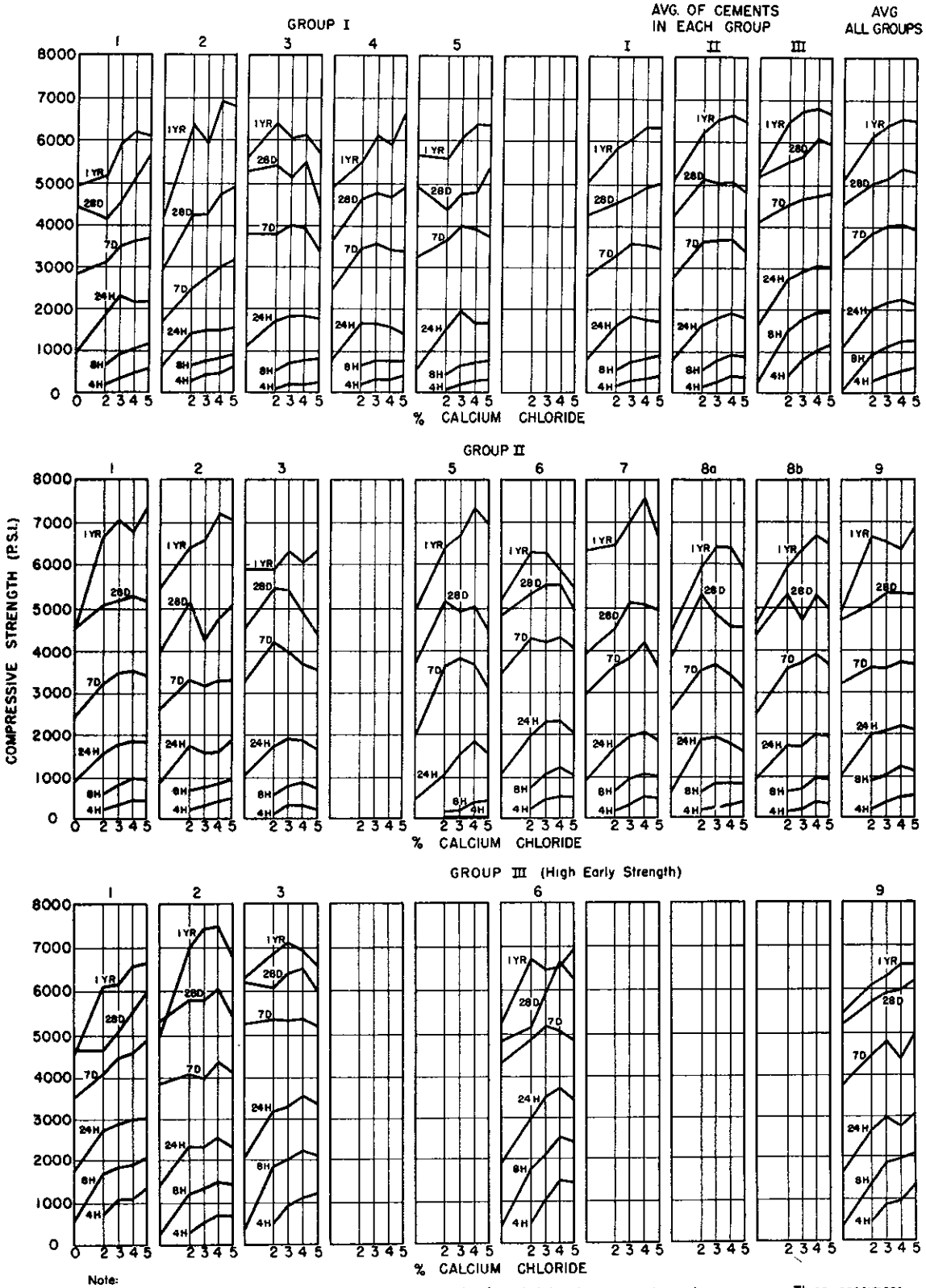
Fig 1 EFFECT ON COMPRESSIVE STRENGTH OF 0% TO 5% CALCIUM CHLORIDE IN A SIX SACK CONCRETE MIX. ALL SPECIMENS 6"X12" CYLINDERS, CURED IN THE MOIST ROOM AT 70°F FOR ENTIRE PERIOD. 1944 TEST SERIES.



Note:
Erratic results for individual cements probably due to the fact that breaks represent single specimens Three specimens were cast for each mix but one specimen in each set was cured 10 days in the moist room, 353 days on the roof of the laboratory and 48 hours in water The third specimen was cured 10 days in the moist room and 355 days on the roof of the laboratory, then broken dry See Table 3 and Fig 2 for test data

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Fig. 2 AVERAGE ONE YEAR COMPRESSION STRENGTH TESTS ON 6"x12" CYLINDER SPECIMENS OF CONCRETE FROM NINE BRANDS AND THREE TYPES OF CALIFORNIA PORTLAND CEMENTS (TOTAL 19 CEMENTS) AS AFFECTED BY FROM 2% TO 5% CALCIUM CHLORIDE.

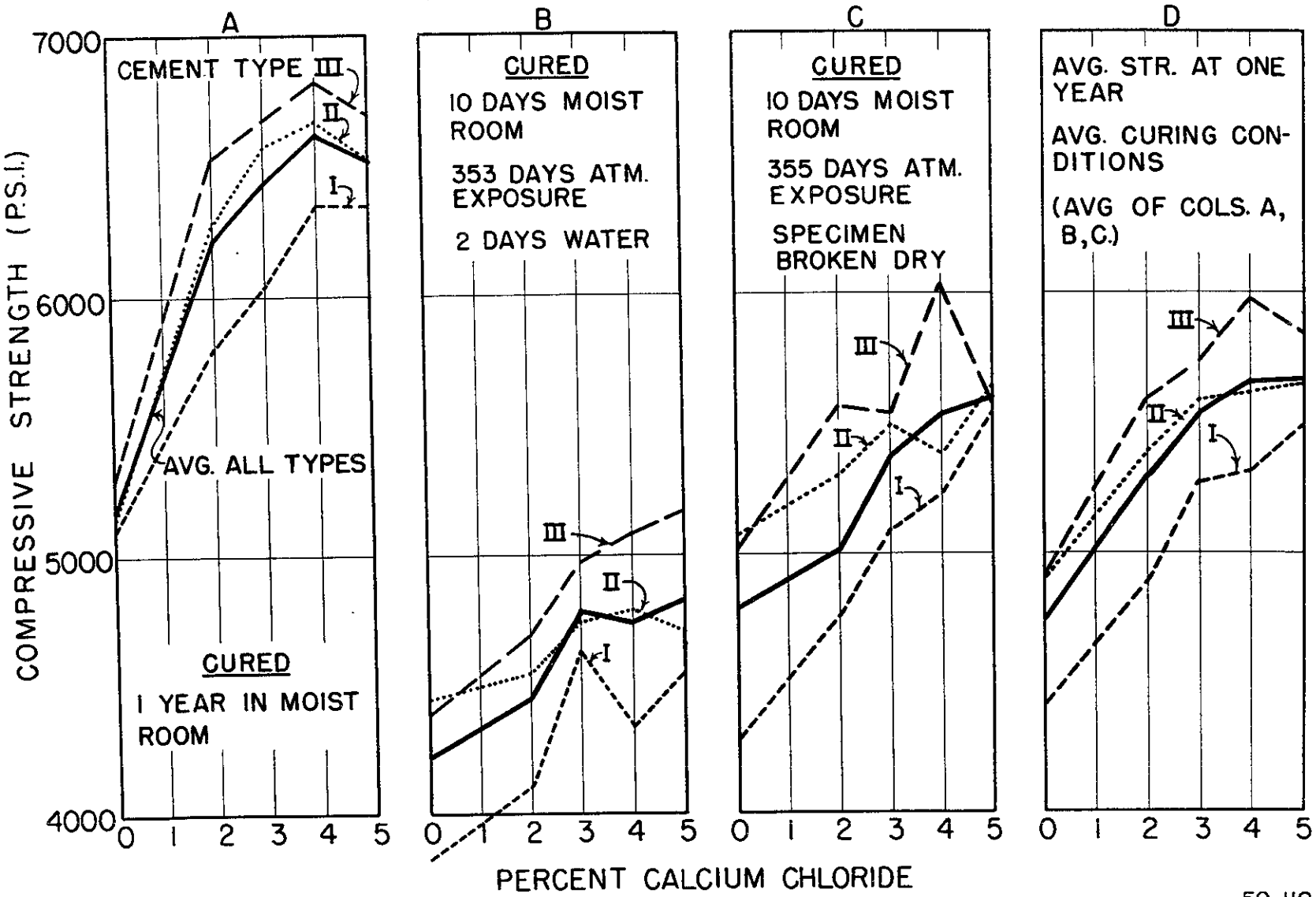

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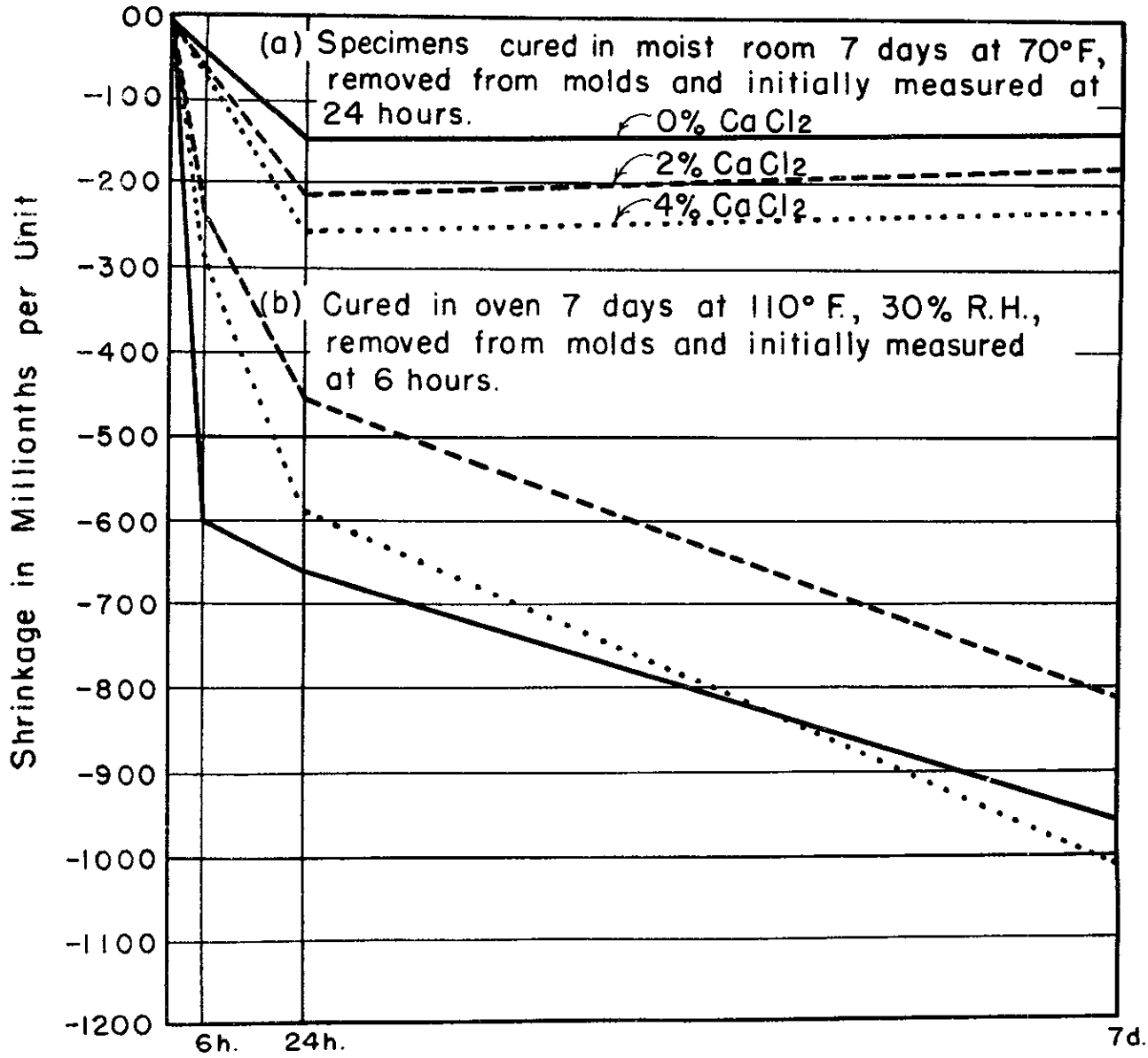
Fig. 3 Initial and Seven Day Shrinkage of 2"x2"x6¼" Concrete Bars with 0%, 2% and 4% Calcium Chloride Additions, by Weight of Cement.

1944 Test Series
Average of 19 cements. (All types)
(See Table 6)



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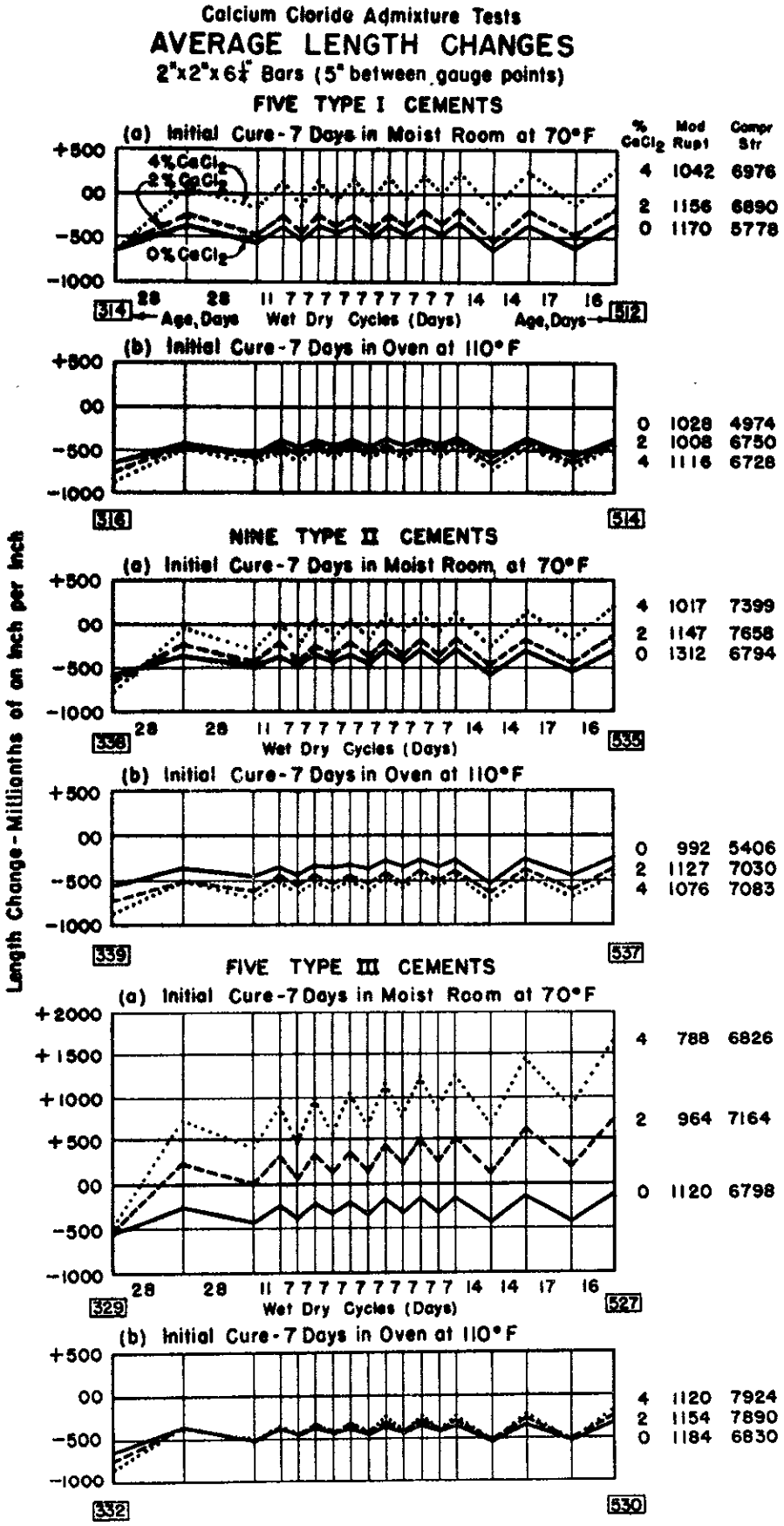

Fig. 4

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND I

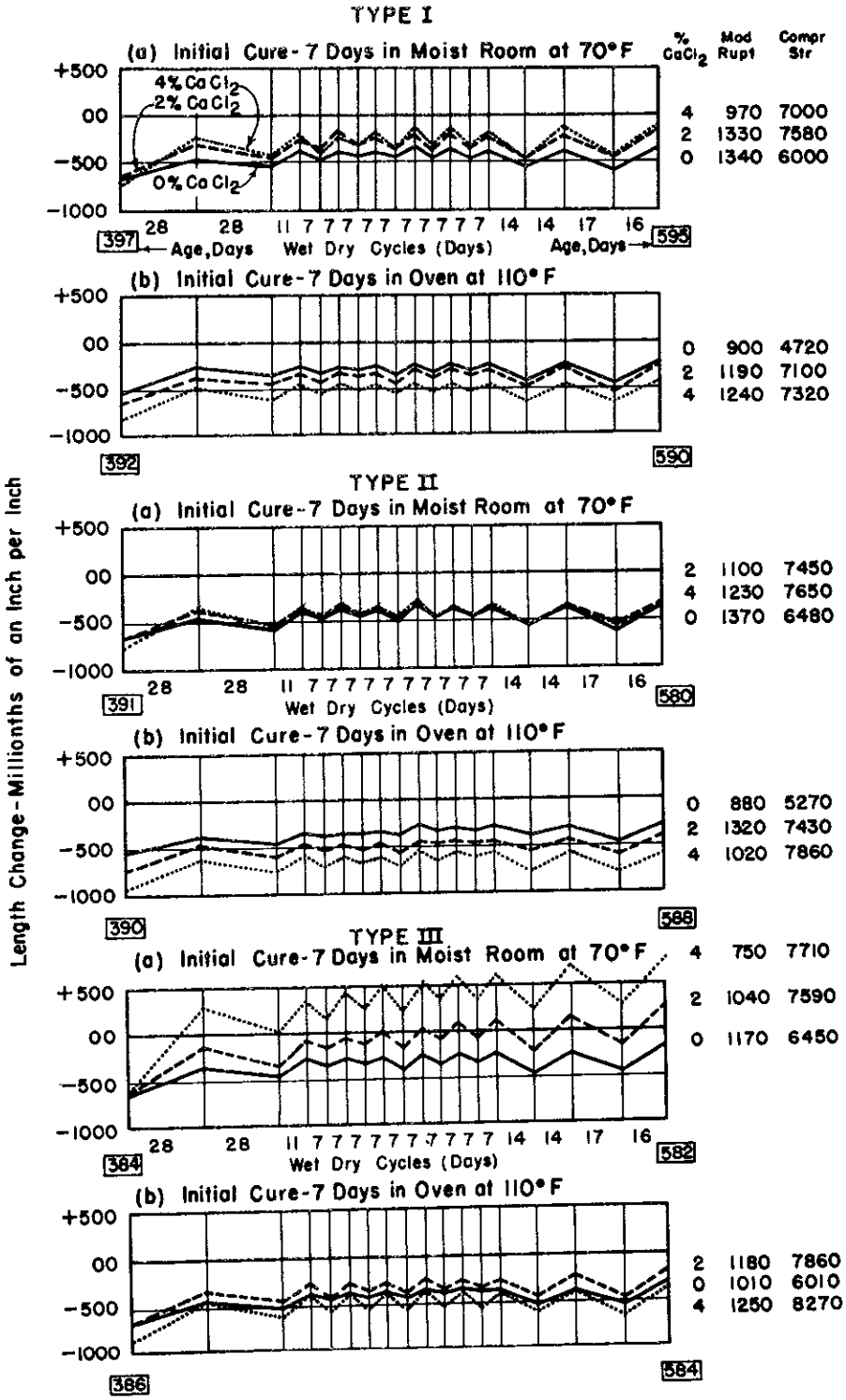

Fig. 5

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 2

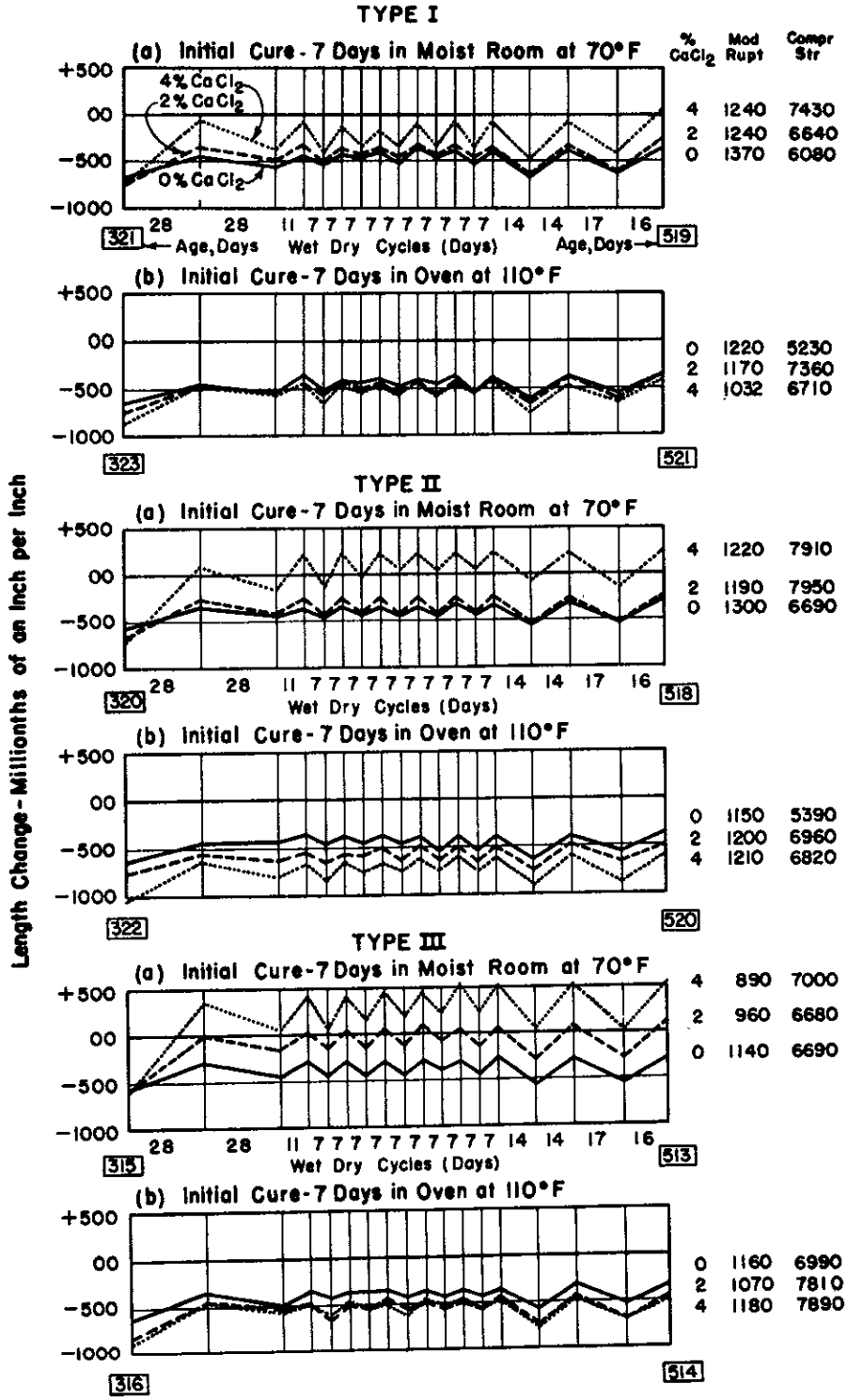

Fig. 6

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 3

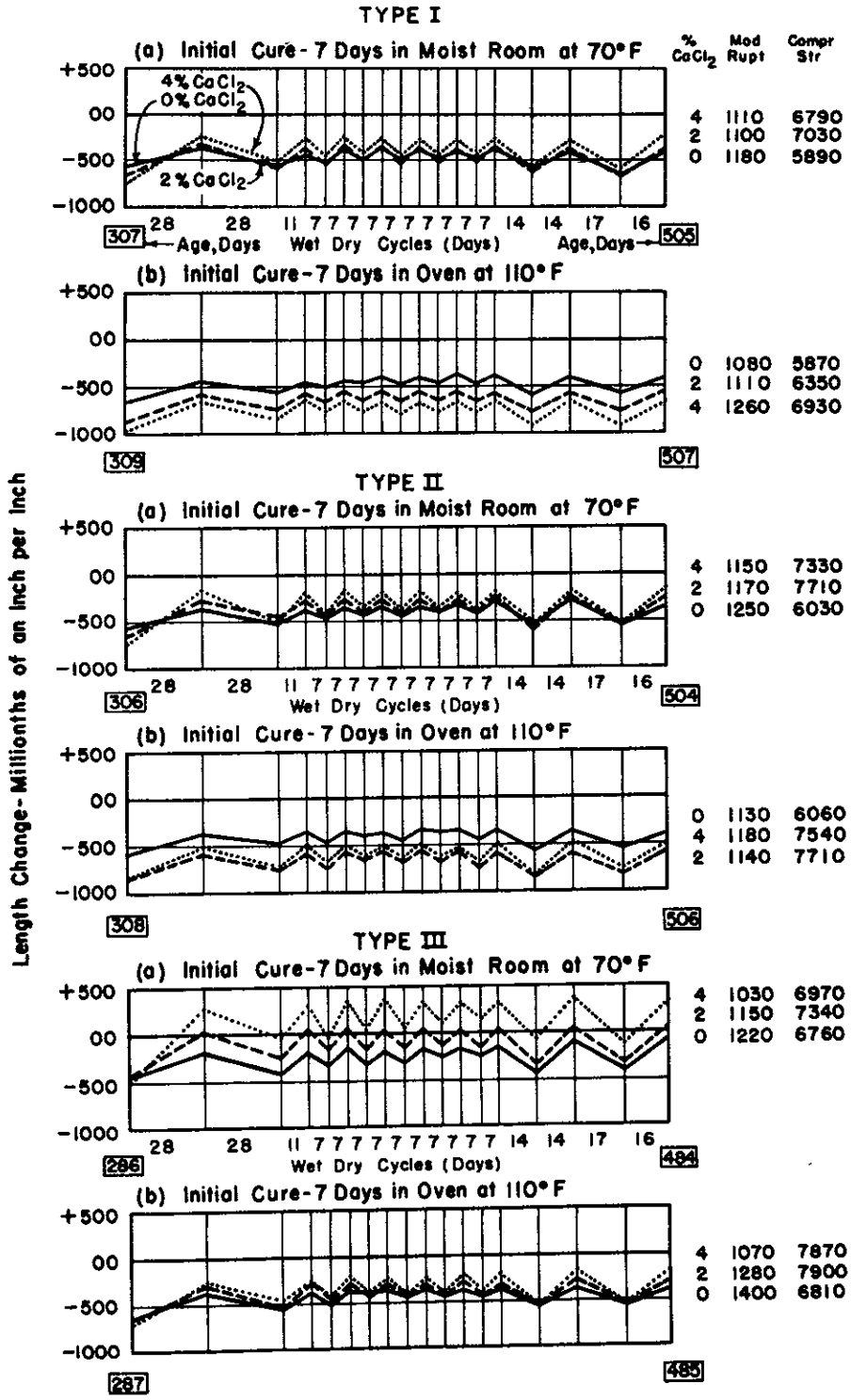

Fig. 7

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 4

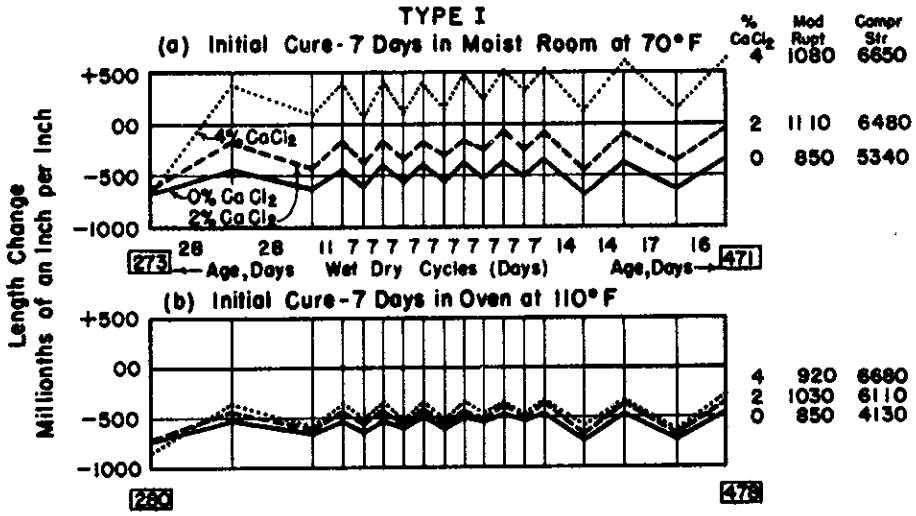

Fig. 8

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 5

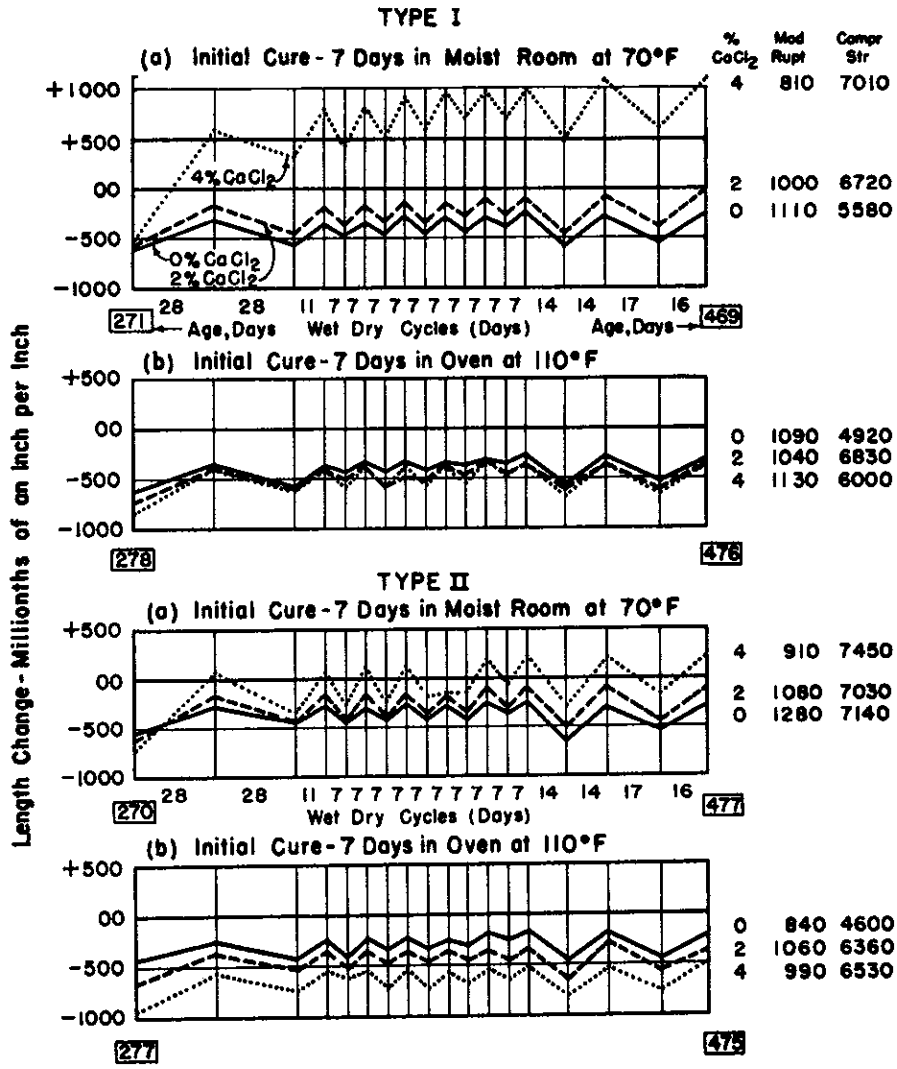

Fig. 9

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 6

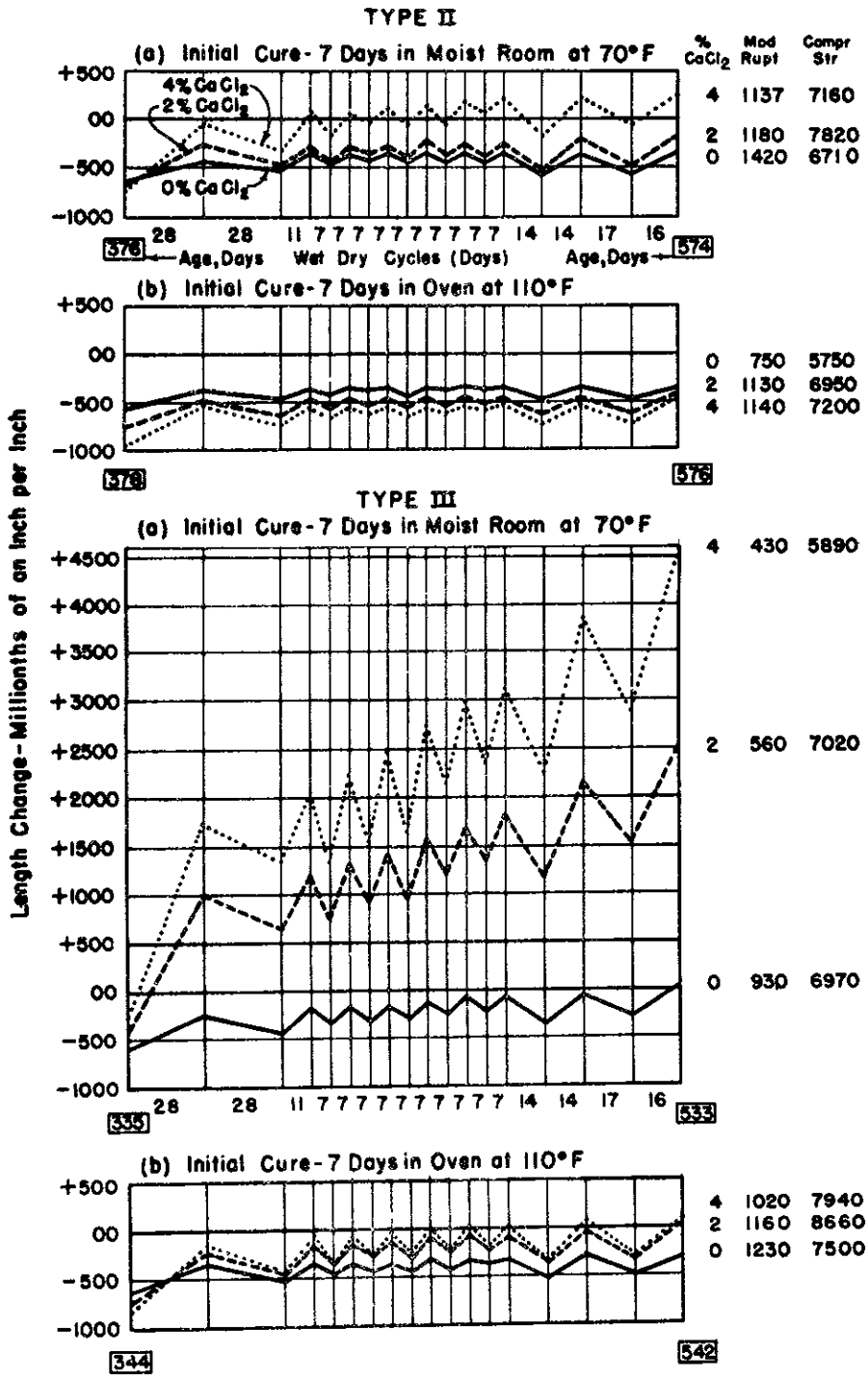

Fig. 10

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 7

TYPE II

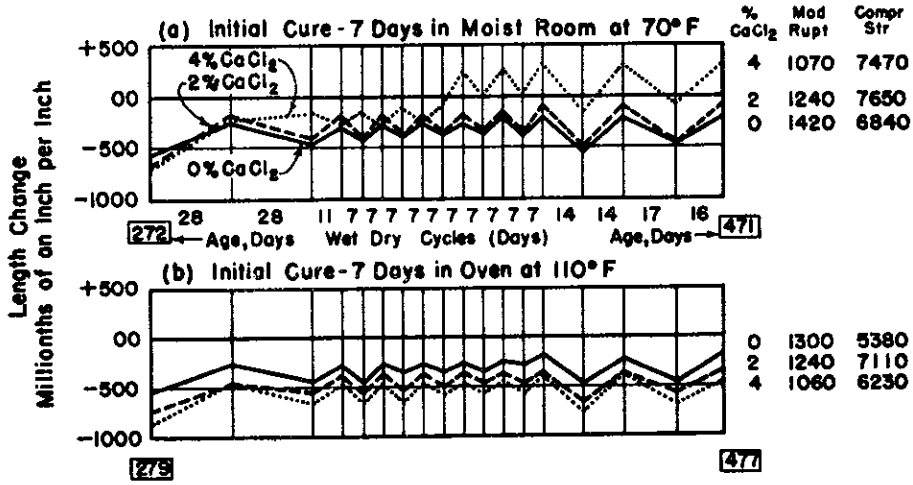

Fig. 11

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 8a

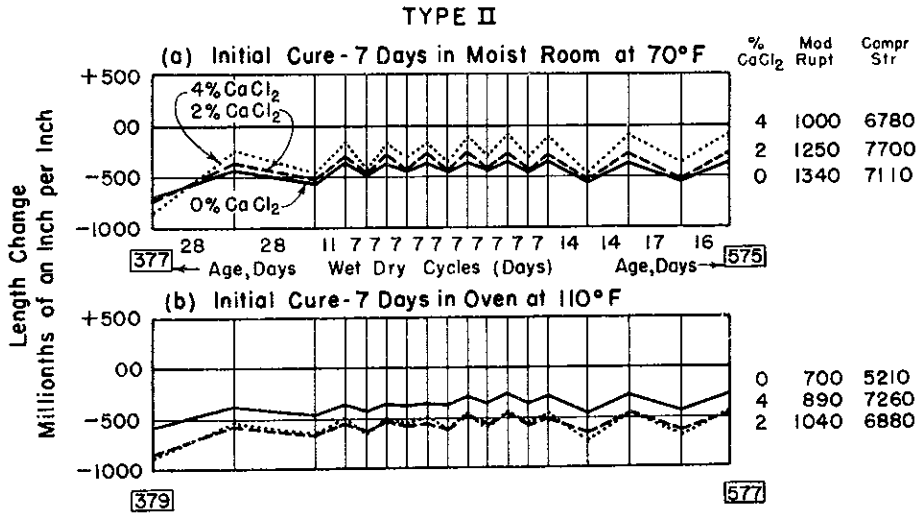

Fig. 12

Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 8b

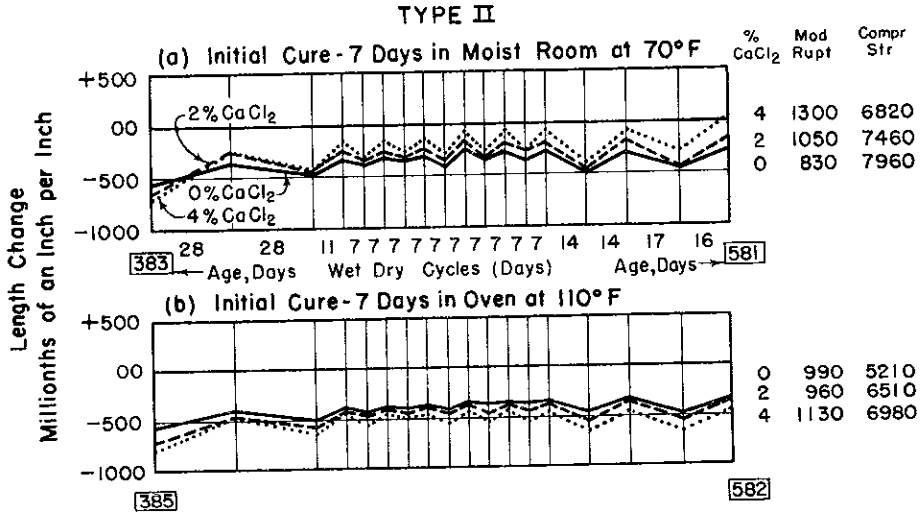

Fig. 13

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Calcium Cloride Admixture Tests

Length Changes 2"x2"x6¼" Bars (5" between gauge points)

CEMENT BRAND 9

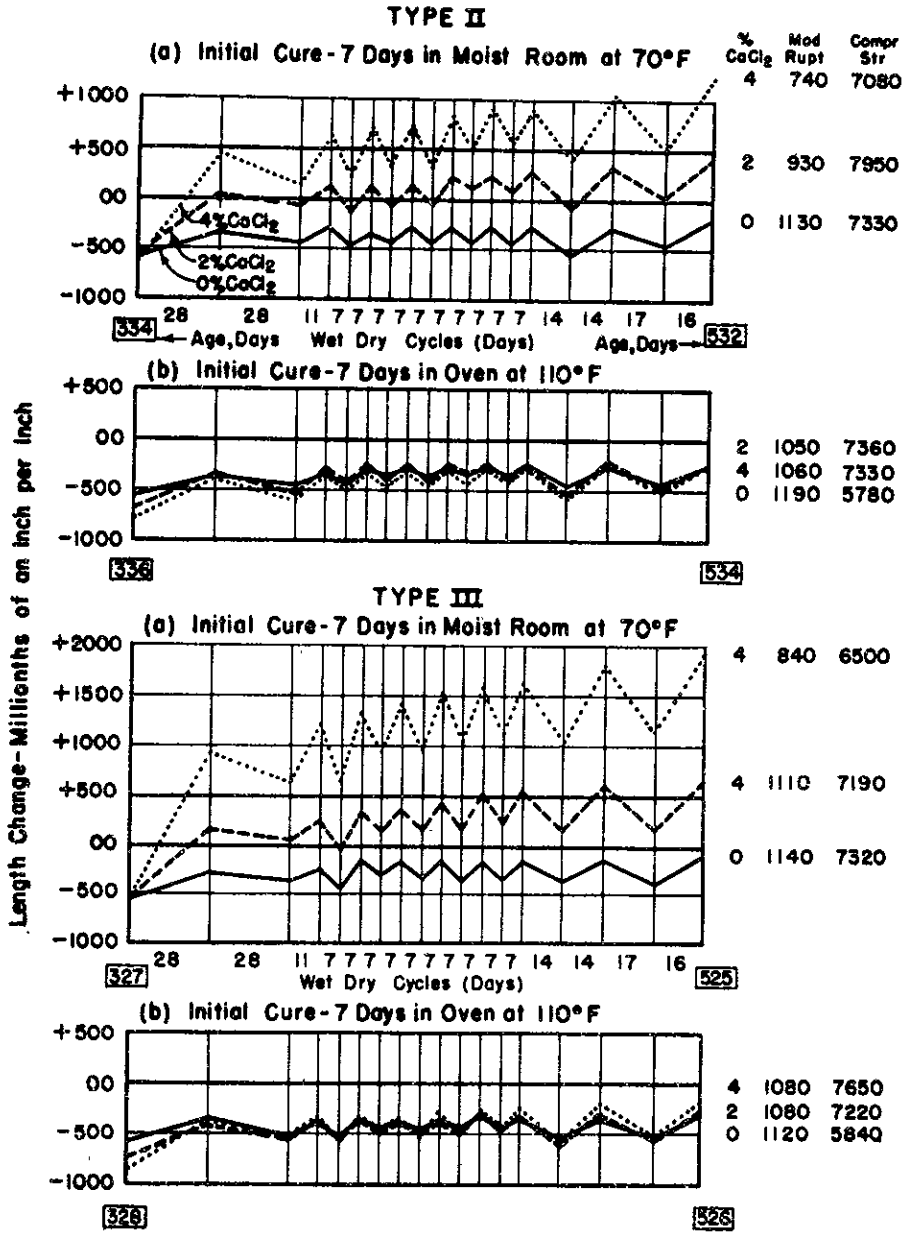

Fig. 14

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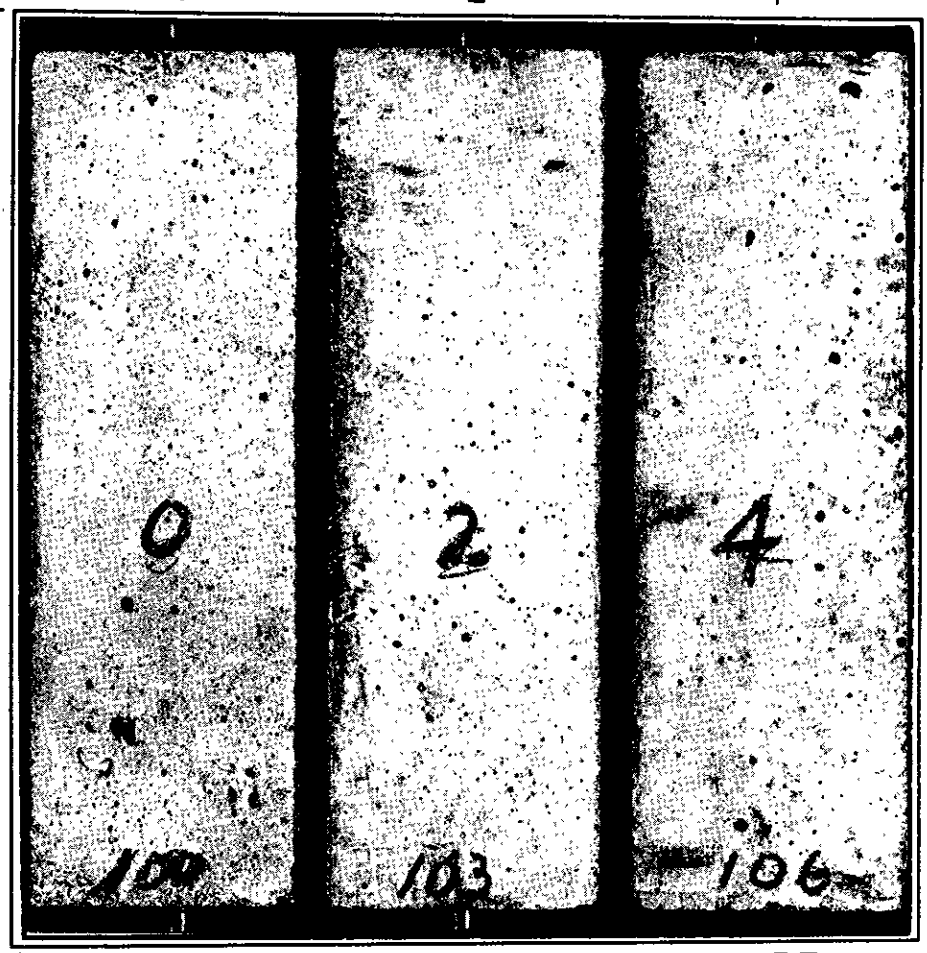
Fig 15 SHOWING CONDITION OF CEMENT 6-II BARS AT AGE 574 DAYS, AFTER NINE CYCLES OF WATER IMMERSION AT 70° F. AND OVEN DRYING AT 110°F.*

Initial cure 7 days in moist room.

% $CaCl_2$	0	2	4



Mod. of Rupt. (p.s.i.)	1420	1180	1137
Compr. Str. (p.s.i.)	6710	7820	7160
Final Sat. Length**	-333	-160	+287

Corresponding strength of specimens initially cured 7 days in oven at 110° F.

Mod. of Rupt.	750	1130	1140
Compr. Str.	5750	6950	7200
Final Sat. Length***	-307	-413	-493

*Compare with corresponding high early strength cement of the same Brand - Fig. 16

**Based on zero at 24 hrs.

***Based on zero at 6 hrs.

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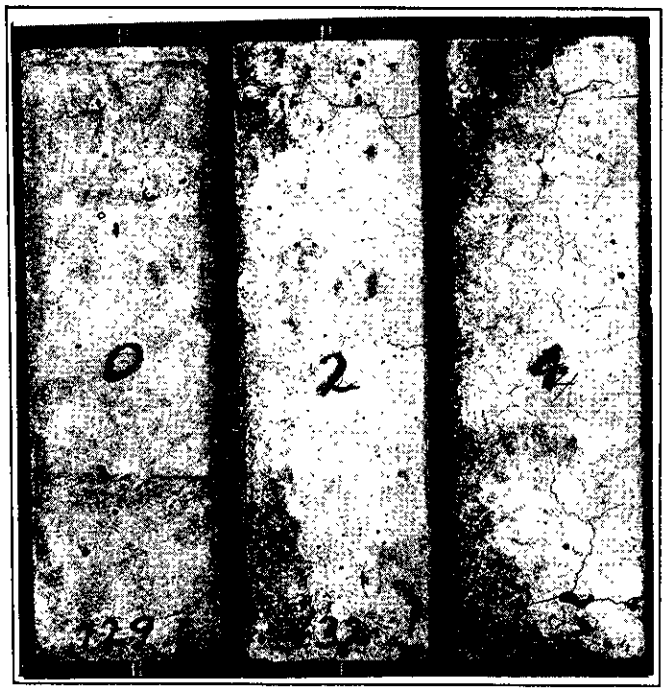
FIG. 16 SHOWING CONDITION OF CEMENT 6-III BARS AT AGE 533 DAYS, AFTER NINE CYCLES OF WATER IMMERSION AT 70° F AND OVEN DRYING AT 110° F.

(a) Initial cure 7 days in moist room.



	0	2	4
Mod. of Rupt. (p.s.i.)	930	560	430
Compr. Str. (p.s.i.)	6970	7020	5890
Final Sat. Length*	+47	+2540	+4567

(b) Initial cure 7 days in oven at 110° F.

	0	2	4
Mod. of Rupt. (p.s.i.)	1230	1160	1020
Compr. Str. (p.s.i.)	7500	8660	7740
Final Sat. Length**	-300	+13	+93

*Based on zero at 24 hrs.
**Based on zero at 6 hrs.

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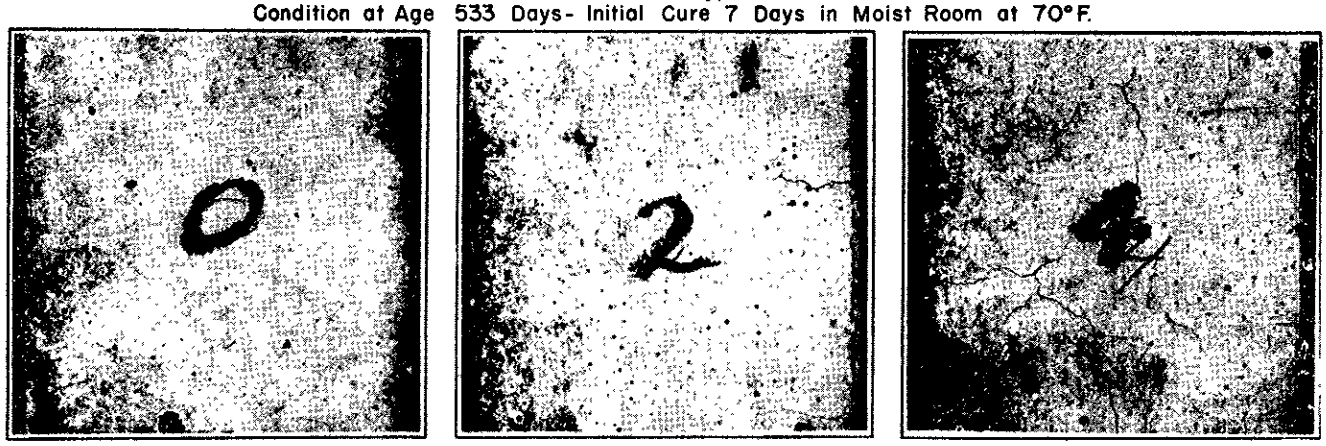
Fig 17 SHOWING CONDITION OF CEMENT 6-II AND 6-III BARS IN THE 1944 TEST SERIES AT AGES AND INITIAL CURING INDICATED, AND AFTER 17 ALTERNATE WET-DRY CYCLES AS SHOWN IN FIG. 10.

CEMENT 6-II (Type II cement.)
Condition at Age 574 Days - Initial Cure 7 Days in Moist Room at 70°F.

0% CaCl 2% CaCl 4% CaCl

CEMENT 6-III (Type III cement.)
Condition at Age 533 Days - Initial Cure 7 Days in Moist Room at 70°F.



0% CaCl 2% CaCl 4% CaCl

CEMENT 6-III (Type III cement.)
Condition at Age 533 Days - Initial Cure 7 Days in Oven at 110° F.

0% CaCl 2% CaCl 4% CaCl

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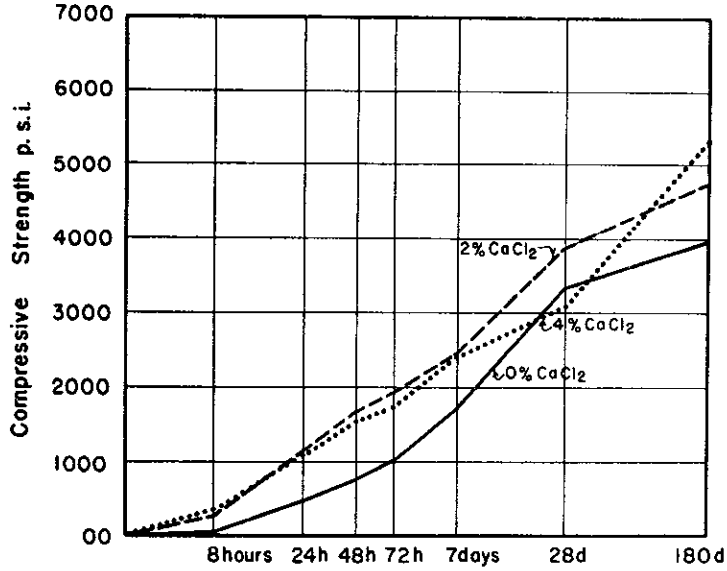
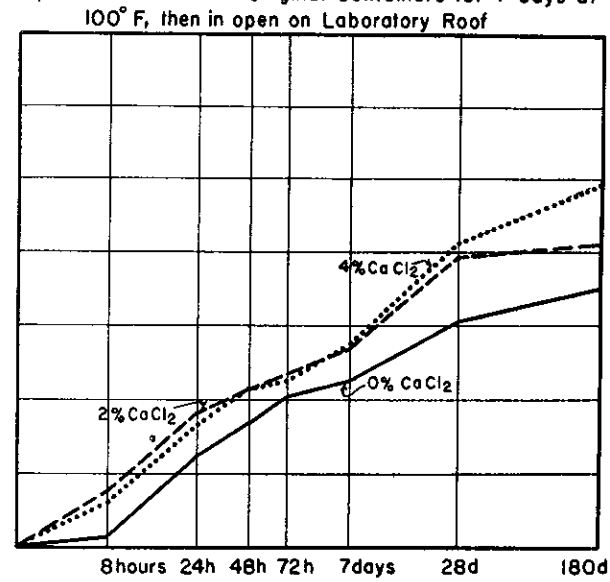
Fig 18 COMPRESSIVE STRENGTH 6"X12" CONCRETE CYLINDERS (CEMENT I-I) 1950 CALCIUM CHLORIDE TEST SERIES
SPECIMENS CURED AS INDICATED

5 SACK CONCRETE

Specimens Stored in Moist Room at 70° F

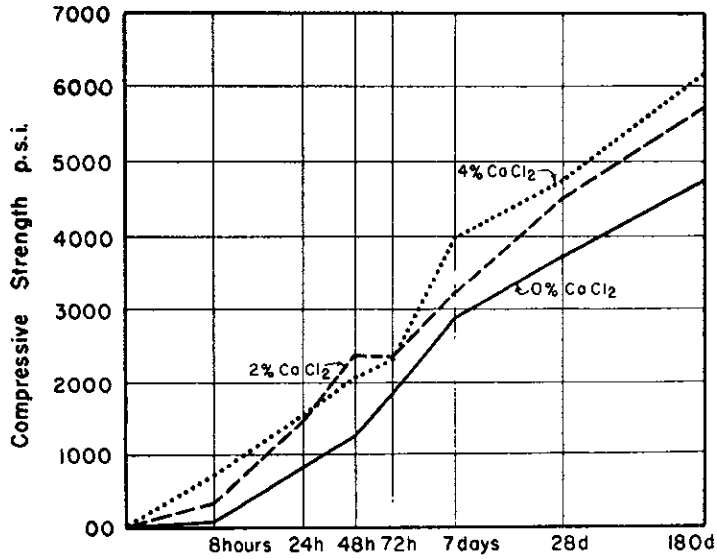


Specimens Stored in Original Containers for 7 days at 100° F, then in open on Laboratory Roof



6 SACK CONCRETE

Specimens Stored in Moist Room at 70° F



Specimens Stored in Original Container for 7 days at 100° F, then in open on Laboratory Roof

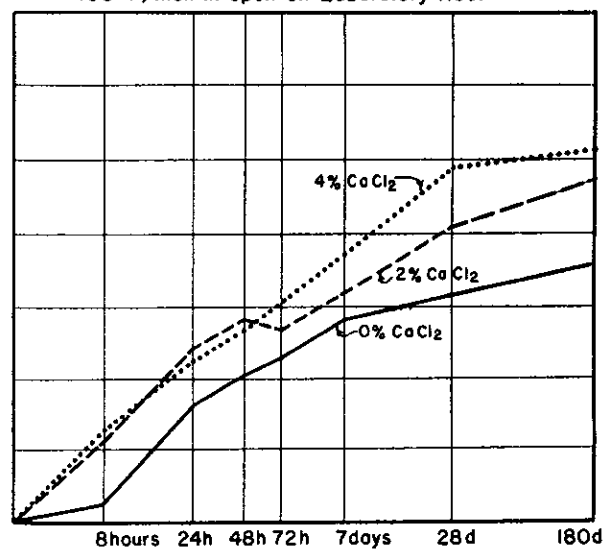


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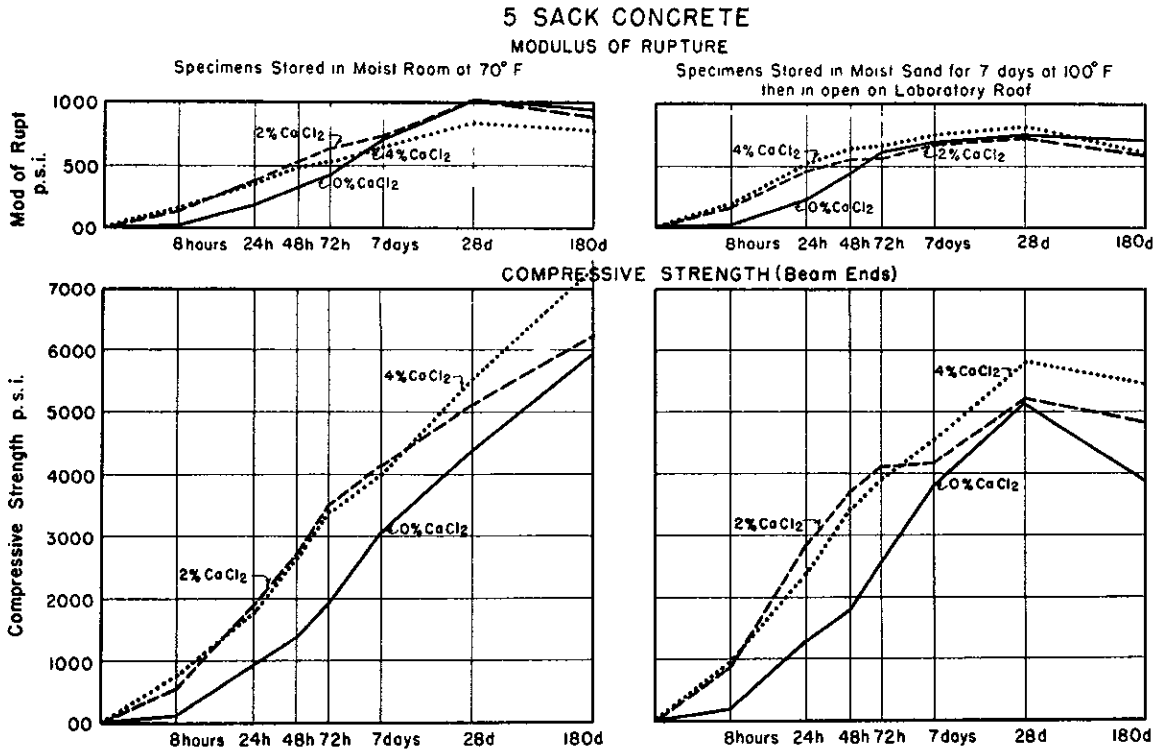
Fig 19 MODULUS OF RUPTURE AND COMPRESSIVE STRENGTH OF 3"X 3"X 11¼" CONCRETE BEAMS (CEMENT I-I)
1950 CALCIUM CHLORIDE TEST SERIES. SPECIMENS CURED AS INDICATED



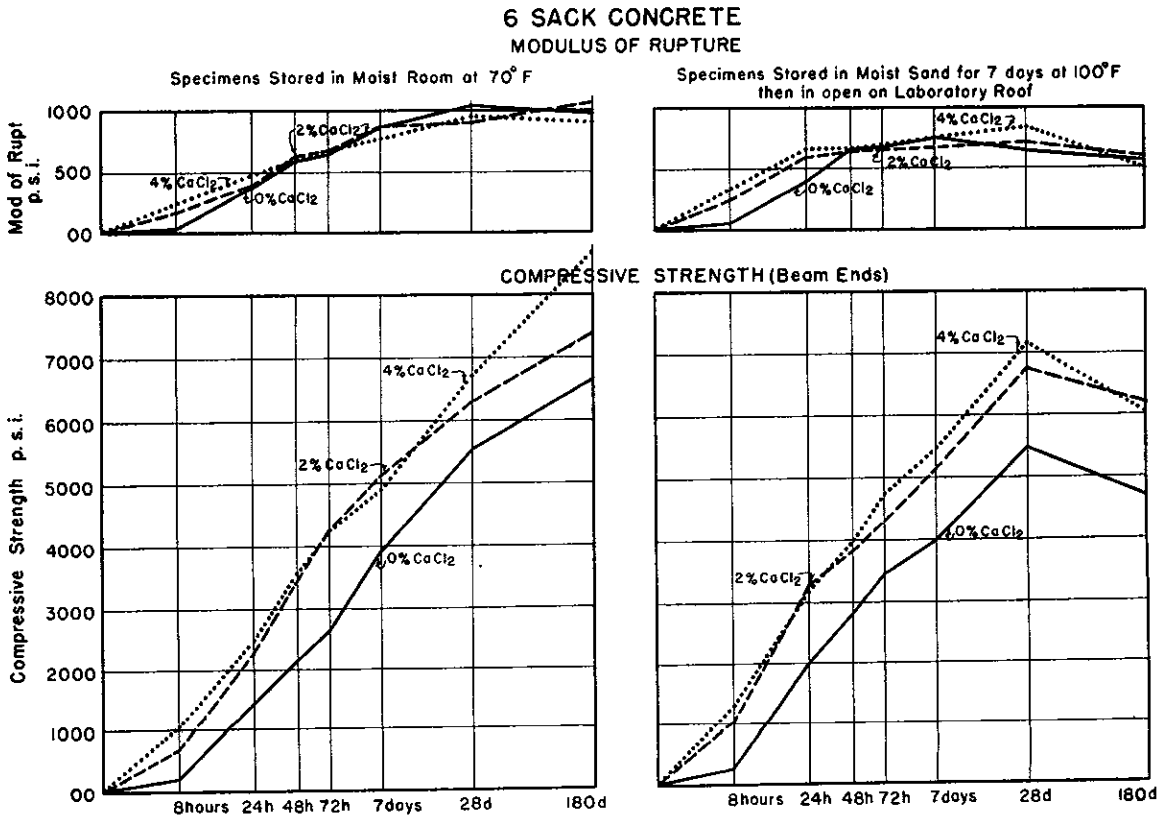


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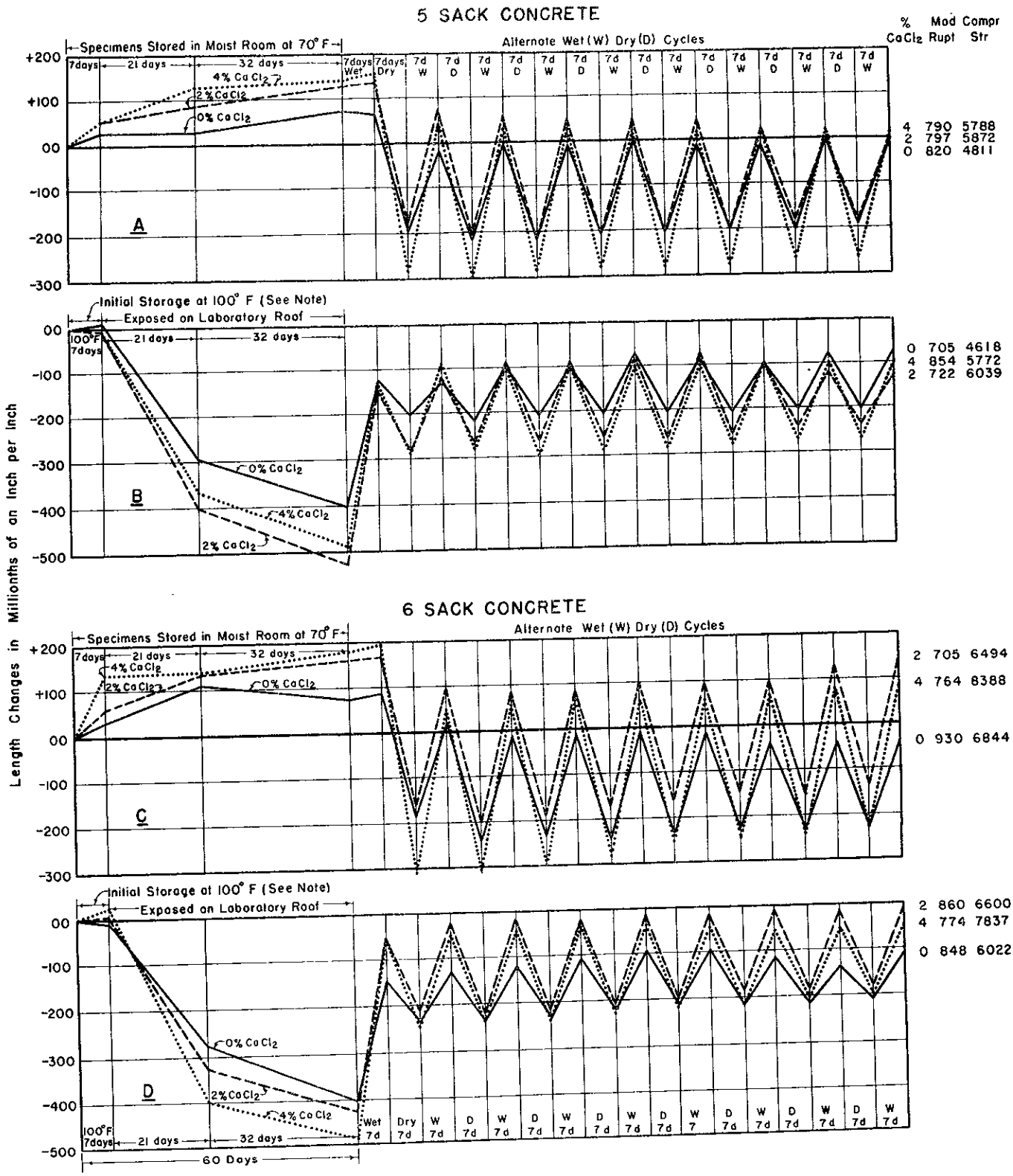
Fig 20 WET-DRY LENGTH CHANGES OF 3"X3"X11¼" CONCRETE BEAMS OF 5 AND 6 SACK CONCRETE (CEMENT I-I)
1950 CALCIUM CHLORIDE TEST SERIES



Note:

All specimens were removed from the molds and initially measured at 24 hours. One set of each mix was then stored in the moist room for 60 days at 70° F and then subjected to 7 day cycles of alternate soaking at 70° F and drying in an oven at 100° F until test for modulus of rupture and compression at age of approximately 6 months. The second set of each mix was stored at 100° F for 7 days in a moist sand bed and with impervious membrane surface seal, then in open on laboratory roof until start of wet-dry cycles at 60 days.

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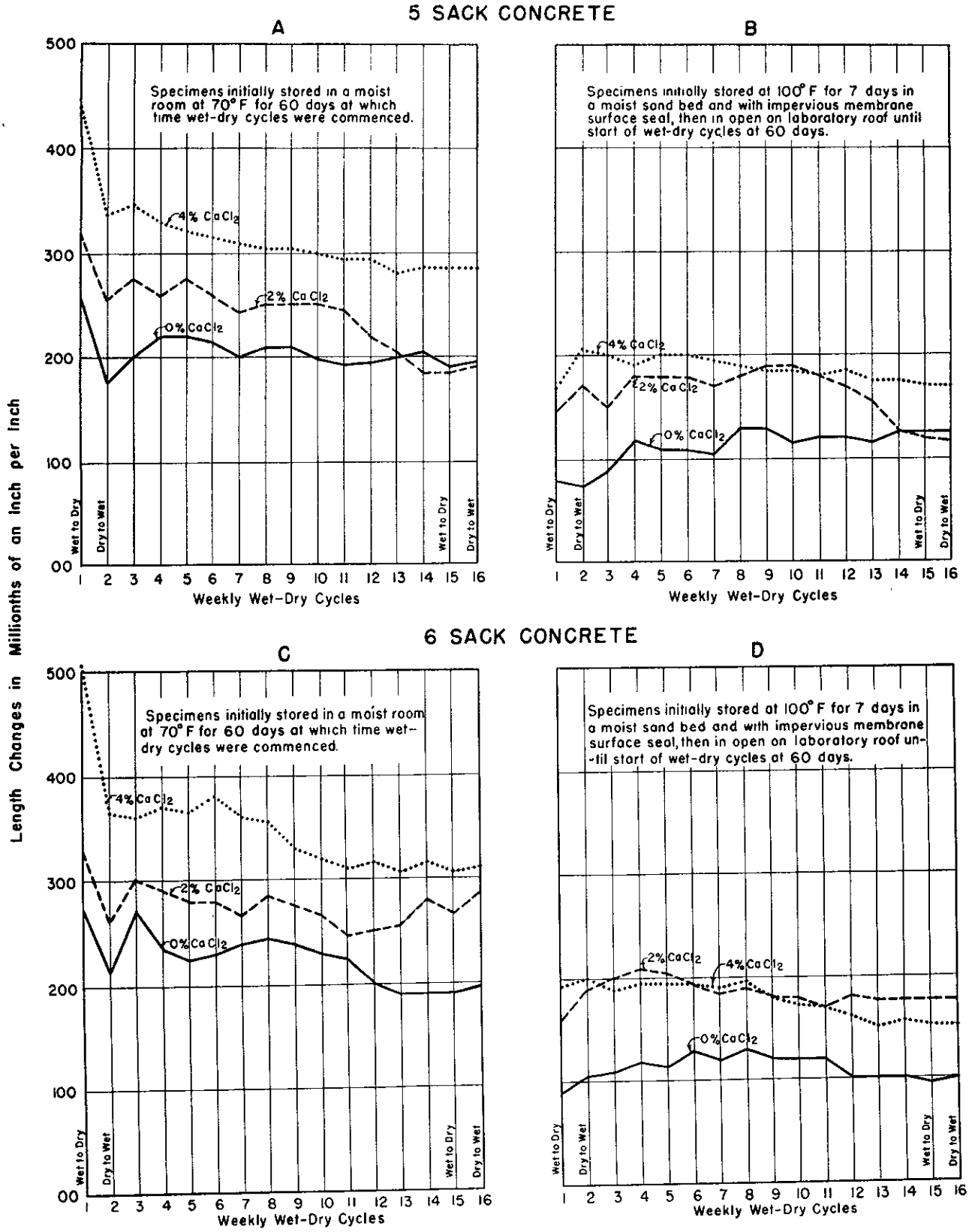
Fig 21 WET-DRY LENGTH CHANGES OF 3"X3"X11¼" CONCRETE BEAMS (CEMENT I-I) IN THE 1950 CALCIUM CHLORIDE TEST SERIES. SPECIMENS ALTERNATELY SOAKED IN WATER AT 70°F AND DRIED AT 100°F-30RH. DATA SHOW LENGTH CHANGES FOR EACH 7 DAY WET-DRY ALTERNATION



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