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Significance of the Test for Contraction of Mortar in Air with Respect to Performance of Cements in Concrete

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16. ABSTRACT

California Division of Highways has developed a Method of Test for Expansion in Water and Contraction in Air of Portland Cement Mortar, Test Method No. Calif. 527-A, (Dec. 1, 1959). Effective with projects released for advertising on and after September 5, 1961, the following additional requirement for Portland cement has been included in the Special Provisions for each project.

"In addition to the requirements for Portland cement as specified in Section 90-1.02A of the Standard Specifications, mortar, containing the Portland cement to be used and Ottawa sand, when tested in accordance with Test Method No. Calif. 527, shall not expand in water more than 0.010 percent and shall not contract in air more than 0.048 percent."

The Standard Specifications for Portland cement to which reference is made above, require the use of Type II low-alkali cement.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

SIGNIFICANCE OF THE TEST

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61-03

MATERIALS & RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

October 18, 1961

Mr. L. R. Gillis
Assistant State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is a report on:

Significance of the Test

for

Contraction of Mortar in Air

with Respect to

Performance of Cements in Concrete

Study made by. . . . . .Technical Section
Under general direction of . . . . . . Bailey Tremper
Under direct supervision of. . . . D. L. Spellman and
W. E. Haskell
Report prepared by . . . . Bailey Tremper and
W. E. Haskell

Yours very truly

F. N. Hveem
Materials & Research Engr.

cc:JEMcMahon
M.Harris

Significance of the Test for Contraction of Mortar in Air with Respect to Performance of Cements in Concrete

California Division of Highways has developed a Method of Test for Expansion in Water and Contraction in Air of Portland Cement Mortar, Test Method No. Calif. 527-A, (Dec. 1, 1959). Effective with projects released for advertising on and after September 5, 1961, the following additional requirement for portland cement has been included in the Special Provisions for each project.

> "In addition to the requirements for portland cement as specified in Section 90-1.02A of the Standard Specifications, mortar, containing the portland cement to be used and Ottawa sand, when tested in accordance with Test Method No. Calif. 527, shall not expand in water more than 0.010 percent and shall not contract in air more than 0.048 percent."

The Standard Specifications for portland cement to which reference is made above, require the use of Type II low-alkali cement.

The significance of the mortar test for contraction has been challenged by Swayze[1] and others. Swayze contends

Significance of the Test on
Contraction of Mortar in Air with Respect to
Performance of Cements in Concrete

California Division of Highways has developed a [illegible] "Test for Expansion in Water and Contraction in Air of Portland Cement Mortars" Test Method No. Calif. 527-A ([illegible]). Effective with projects released for advertising on and after September 5, 1961, the following additional requirement for portland cement has been included in Special Provisions for each project:

"In addition to the requirements for portland cement as specified in Section 90-1.02A of the Standard Specifications, mortar containing the portland cement to be used and Ottawa sand, when tested in accordance with Test Method No. Calif. 527, shall not expand in water more than 0.10 percent and shall not contract in air more than 0.048 percent."

The Standard Specifications for portland cement to which reference is made above, require the use of Type II modified cement.

The significance of the mortar test for contraction has been challenged by Swayze [illegible] and others. Swayze contends that drying shrinkage tests of 3x3x10-inch (gage length) specimens containing portland cement in concrete mixtures provide a significant measure of the performance of the cement in concrete under service conditions. He believes that drying at 73 F and 50 percent relative humidity of such specimens for a period of one year is necessary to develop information relative to the performance of cements in service. Swayze made tests of 1x1x10-inch mortar bars of some 40 cements by a method resembling Calif. 527-A. From the results of these tests and related tests of concrete specimens, he concluded that mortar bars do not provide a realistic measure of the performance of cement in concrete. In a discussion of Swayze's paper, Tremper(1) contended that the Swayze mortar data do in fact provide a significant index of the performance of portland cement in concrete.

Others have questioned Calif. 527-A because the water-cement ratio is considerably lower than that customarily used in most concrete and for other reasons. The Working Committee on Volume Change and Soundness of ASTM Committee C-1 has promoted an investigation of the mortar test following a recommendation by a Task Group that Calif. 527-A with minor modifications be used as a basis of study in which the results would be compared with those obtained

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... results would be compared with those obtained in drying concrete test specimens for periods up to 24 weeks.

The tests described in this report were made to furnish data to the Working Committee on Volume Change and Soundness as well as to obtain information on the performance of Type II, low-alkali cements manufactured in California.

Selection of Test Cements

Samples of one sack each were obtained from 8 of the 12 producing mills in California. The mills selected to furnish the cements were those from which contraction values lower than 0.040 percent by Calif. 527-A were anticipated and those from which higher values were a reasonable expectation.

Upon receipt, each cement was thoroughly mixed, sieved through a No. 20 sieve and stored in 1-gallon containers with friction lids until used for testing.

Scope of Tests

Chemical analysis and specific surface of the cements were determined. Chlorides were determined in

addition to the customary oxides. The method of analyses for chlorides which is believed to be accurate, is detailed in the Appendix of this report. With one exception, the cements are reported to contain less than 0.01 percent of chloride radical.

Mortar tests for expansion and contraction were made in accordance with Calif. 527-A. Each of the cements was tested by this method on a single day which constituted one round. Three rounds each on a separate day were made yielding 12 specimens of each cement. Calif. 527-A requires that the water used in mixing the mortar be adjusted to produce a flow of 100 to 115 percent. Some investigators have expressed the opinion that the mortar should contain a constant water-cement ratio. For this reason, two rounds of tests were made subsequently in which the W/C was held constant and the flow was allowed to vary. Calif. 527-A gives requirements for temperature and relative humidity in the drying room. Investigations have shown that the rate of drying and the amount of contraction are influenced by the velocity of air in the drying room. In the tests made for this report, the drying room was so operated that the evaporation of moisture from an atmometer* was maintained

* Working drawings and details of operation of the atmometer are available on request.

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at 3 ± 0.5 ml per hour.

Tests for drying shrinkage of concrete were made with each of the cements. The aggregates used in making these tests were graded up to 1-inch and were obtained from a bar in the American River near Sacramento. None of the aggregate was crushed. The aggregates were taken from a large stock maintained at the laboratory and were sieved into sizes from 1-inch to No. 50 and recombined for each batch to produce the grading shown in Table 2. Proportions were adjusted to yield a cement factor of 6 sacks per cubic yard and a slump of 3 inches. The concrete was not air-entrained. Each batch contained sufficient concrete to permit tests for slump, yield, air content and to mold three 3x3x10-inch (gage length) bars. One round consisted of batches containing each of the 8 cements. Four rounds were made, each on a different day yielding 12 specimens of each cement for shrinkage measurements. Bars were standard cured in the molds for 24 hours. They were then removed from the molds and stored in the fog room at 73 F to the age of 7 days. They were then measured for length and subjected to drying in the same room that was used for the mortar bars. Length changes were measured after 7, 14 and 28 days of drying.

Calif. 527-A gives criteria for eliminating the

results of individual specimens that do not meet the specified uniformity requirements. None of the specimens was eliminated for this reason. In assessing the uniformity of concrete shrinkage results, the criterion was adopted that any specimen the shrinkage of which departed from the average by more than 0.004 percent, should be discarded in computing the average result. Of the 284 measurements for length change that were made, 23, or 8 percent, were eliminated in computing averages. Actually the elimination made little change in the final result. Average results were computed to the nearest 0.0001 percent to provide 3 significant places for statistical study.

Data of the Tests

The data of the tests are given in the following tables and figures.

Tables.

1. Chemical analysis and specific surface of cements
2. Grading of aggregates used in concrete tests
3. Properties of the fresh concrete

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Figures:

Discussion

Drying shrinkage of the concrete is shown graphically in Figure 1. The results are plotted against the

logarithm of time of drying. It will be noted that all cements except No. 5 gave substantially straight lines. There is a definite break in the curve for Cement 5. In the manufacture of cement in the mill that produced Cement 5, hydrochloric acid is introduced into the kiln feed to assist in volatilizing alkalies in the production of low-alkali cement. The chemical analysis of this cement (Table 1) shows that it contains 0.11 percent of chloride radical which evidently was not driven out of the clinker as it was burned. It is possible that the presence of chlorides in this cement is responsible for the departure from linearity in the plotted curve.

In correlation studies between mortar and concrete results, the concrete results have been first considered to be the independent variable. The reason for this treatment is that concrete tests are considered by many to be more indicative of performance in service. The objective was to learn how well the observed mortar tests correlate with those predicted from the concrete tests.

Plots of mortar versus concrete are shown in Figure 2. The regression curves are of the form:

$$M = a\,C_n + k \qquad (1)$$

Where M = contraction of mortar by Calif. 527-A
C_n = shrinkage of concrete after drying for n days
a = a coefficient
k = a constant

The values of "k" are fairly large indicating an intercept on the "M" axis. It has been pointed out that unless the intercept is close to zero, the equation may not well represent the behavior of other cements having contractions higher or lower than were encompassed in the range of the test cements. The coefficient of correlation for C_7 is 0.68, which is significant at about the 93 percent level. The coefficients of correlation for C_{14} and C_{28} are 0.57, which is not significant at the 90 percent level.

The ability of the mortar tests to predict concrete shrinkage were studied by calculating regression equations of the form:

$$C_n = a\ M + k \qquad (2)$$

The relationship is shown by the solid line curves of Figure 3. The values of "k" are again quite large.

Equations of the form:

$$C_n = a\ M \qquad (3)$$

were calculated for best fit by the method of least squares and they are shown by broken lines in Figure 3.

The relative precision of equations (2) and (3) are indicated by the standard errors of estimate which are

The values of "K" are fairly large indicating [illegible] on the "M" scale. It has been pointed out that unless the intercept is close to zero, the equation may not well represent the behavior of other cements having [illegible] higher or lower than were encountered in the range of the [illegible] cements. The coefficient of correlation [illegible] is 0.65 which is significant at about the 95 percent level. The coefficients of correlation for C11 and [illegible] are 0.4?, which is not significant at the 90 percent level.

The [illegible] of the mortar tests to predict concrete shrinkage were studied by calculating regression equations of the form

[illegible] = a + KM (2)

The relationship is shown by the solid line curves in Figure [illegible]. The values of "K" are again quite large. Equations of the form

$C_n = aM^b$ (3)

were calculated for best fit by the method of least squares and these are shown by broken lines in Figure 3 [illegible].

The relative precision of equations (2) and (3) [illegible] indicated by the standard error of estimate which are shown below, both in terms of numerical values and as percentages of the observed values of concrete shrinkage.

Equation	Standard Error of Estimate Numerical	Percent	
$C_7 = 0.41\ M + 0.006$	0.0017	7.4	(2)
$C_7 = 0.54\ M$	0.0021	9.1	(3)
$C_{14} = 0.63\ M + 0.011$	0.0035	8.7	(2)
$C_{14} = 0.89\ M$	0.0038	9.3	(3)
$C_{28} = 0.65\ M + 0.023$	0.0036	6.5	(2)
$C_{28} = 1.18\ M$	0.0041	8.2	(3)

The tabulation shows that predictions of concrete shrinkage made in accordance with the derived regression equations, type 2, are somewhat more precise but not greatly so, than those derived from type 3 equations. The precision of prediction from the type 3 equations is in all cases, less than 10 percent of the observed values of concrete shrinkage.

Table 7 shows standard errors of estimate both as numerical and percentage values as determined by type 3 equations of the above data and from available data reported by the Applied Research Section of the Portland Cement Association[2], the Research Laboratory of Ideal Cement Company[3], and M. A. Swayze [1].

The shrinkage of concrete specimens as reported by [illegible] in terms of numerical values and percent [illegible] values of concrete shrinkage [illegible]

	Standard Error of Estimate		
	Numerical	Percent	[illegible]
[illegible]	0.007	9. [illegible]	
(42)	0.0[illegible]	[illegible]	1[illegible]
(43)	0.0038	[illegible]	
(42)	0.0038	[illegible]	
(48)	0.004	6.[illegible]	

[illegible] shows that prediction of concrete shrinkage [illegible] with the derived regression equations [illegible] [illegible] the predictions are greater than [illegible] from Lyman's equation. The prediction of [illegible] for the type "E" equations is in [illegible] [illegible] of the observed values of concrete shrinkage [illegible] standard error of estimate both as [illegible] percentage) such as determined by type [illegible] [illegible] the same data and from [illegible] data reported [illegible] [illegible] Research Laboratory of the Portland Cement [illegible] [illegible] the Research Laboratory of Ideal Cement [illegible] [illegible] Swayze (11) [illegible] [illegible] experiments as reported [illegible]

Swayze is much lower than found by other investigators. Had Swayze's concrete shrinkage values been higher, the standard error of estimate computed on a percentage basis would have been lower. Nevertheless, the numerical values of standard error of estimate as derived from Swayze's data are much higher than those derived from the data of other investigators. Possible reasons for the high standard errors of estimate of Swayze's data are discussed in Tremper's[1] discussion of his report.

Neglecting the results of Swayze, the remainder of the data given in Table 7 indicates a reasonable expectation that the shrinkage developed by different cements in concrete can be predicted within 10 percent by contraction tests of mortar performed in accordance with Test Method No. Calif. 527-A.

The relationship of concrete to mortar tests as found by the several investigators is shown in Figure 4.

Constant W/C Mortar

Some investigators have expressed the opinion that the results of mortar tests would be more significant if they were made with a constant water-cement ratio and

variable flow. Evidently this opinion is based on the belief that variations in W/C of mortar to produce constant flow are not related to water requirements for constant slump of concrete.

Figure 5 shows the relationship between the W/C of mortar for constant flow and the W/C of concrete for constant slump as found for the eight test cements. The coefficient of correlation, r, is 0.69, which is significant at the 94 percent level. The data for these eight cements therefore show that there is a significant relationship between water requirements in mortar and concrete. Among the eight cements, the W/C required for constant slump of concrete varied from 0.553 to 0.583, a difference of 0.03. Had the W/C of the mortars been held constant, it would not have reflected the W/C required in concrete accurately.

To explore the matter further, two rounds of mortar were made with a constant W/C of 0.378. The results are given in Table 8. It will be noted that the percent flow of the mortar varied from 94 to 120. The differences in flow and contraction from the results obtained in constant flow mortar are also shown in this table. The latter data are plotted in Figure 6. The correlation is not significant indicating that variations in W/C or flow within the range encompassed by this study had no certain effect on

contraction. If significance is, nevertheless, ascribed to the regression curve as plotted in Figure 6, it is indicated that a variation of 0.01 in W/C affects the observed contraction by only about 0.0003 percentage point. The fact that the regression curve does not pass through the origin of the chart means that the contraction results of the constant W/C tests were as an average about 0.0012 lower than those obtained in the constant flow series.

A similar finding is indicated in the results of co-operative tests for contraction of mortar in air by 12 laboratories (not yet reported). In this study, different laboratories found different W/C's for the same flow. The differences in W/C used by the laboratories was not clearly reflected in the observed results of contraction.

The results obtained to date therefore, indicate that the use of a constant W/C and variable flow would produce contraction results that are equivalent to those obtained in constant flow mortar. It should be noted however, that despite the fact that the cements were all of the same type, the variations in flow of constant W/C mortar were quite large. Were the use of constant W/C mortar extended to other types of cement, it seems highly probable that the consistency in some cases could be either too dry or too [illegible] significance is, nevertheless, ascribed to the [illegible] curve as plotted in Figure 6, it indicates that a variation of 0.01 in W/C affects the observed [illegible] by only about 0.0003 percentage points. The fact that the contraction curve does not pass through the [illegible] and the slight [illegible] means the contraction results of the constant W/C tests were on an average about 0.0012 [illegible] than those obtained in the constant flow series.

A similar finding is indicated in the results of [illegible] for contraction of mortars in air by 12 [illegible] (not yet reported). In this study, different [illegible] found different W/C's for the same flow. The [illegible] in W/C used by the laboratories was not clearly [illegible] in the observed results of contraction.

The results obtained to date therefore indicate that [illegible] a constant W/C and variable flow would produce [illegible] essentially equivalent to those obtained in [illegible] flow [illegible]. It should be noted, however, that [illegible] the fact that the cements were all of the same [illegible] in the flow of constant W/C mortar were [illegible] the use of constant W/C mortar extended to [illegible] of cements, it seems highly probable that the [illegible] may in some cases be either too dry or too [illegible] wet for proper molding of test specimens. In turn, this condition could have a significant effect on observed contraction results which might not correlate well with the shrinkage of concrete.

REFERENCES

1. Swayze, M.A., "Volume Changes of Concrete", presented at meeting of ASTM Committee C-1 at Denver, Colo., Dec. 6, 1960. Discussion by Bailey Tremper. Both the paper and discussion are scheduled for publication in "Materials, Research and Standards"

2. "Progress Report on Studies of Shrinkage of Paste, Mortar and Concrete", by Applied Research Section, Portland Cement Association, April, 1961

3. Interoffice report by D. L. Crawford and I. L. Lynn, Ideal Cement Company Research Laboratory, June 20, 1961

REFERENCES

1. [illegible], M. A., "Volume Changes of Concrete", presented at meeting of [illegible] Committee C-1 at Denver, Colo., Dec. 6, 1960, discussion by Bailey [illegible]. Both the paper and discussion are scheduled for publication in "Materials, Research and Standards".

2. "Progress Report on Studies of Shrinkage of Paste, Mortar and Concrete", by Applied Research Section, Portland Cement Association, April, 1961.

3. Interoffice report by J. L. Crawford and I. K. Lyman, Ideal Cement Company Research Laboratory, June 20, 1961.

TABLE 1

Composition and Specific Surface of Cements

Cement No. Lab. Ref.	1 14892	2 14891	3 14902	4 14900	5 14924	6 14923	7 14942	8 14922
SiO_2	23.2	22.9	21.8	23.1	21.5	23.1	22.5	23.0
Al_2O_3	3.9	4.1	4.5	4.1	5.3	4.0	3.9	4.7
Fe_2O_3	3.8	2.6	3.1	2.5	4.6	3.6	2.6	2.7
CaO	63.7	63.9	62.3	64.4	63.1	64.3	62.7	64.5
MgO	1.8	2.5	3.8	2.4	1.7	1.6	3.6	1.7
SO_3	2.00	1.74	2.07	2.08	2.43	2.33	2.18	2.00
Ig. Loss	0.9	1.4	1.7	0.9	1.0	0.8	2.0	0.8
Insol. Res.	0.05	0.1	0.05	0.1	0.1	0.1	0.1	0.1
Na_2O	0.29	0.13	0.30	0.30	0.39	0.12	0.37	0.17
K_2O	0.17	0.60	0.26	0.27	0.03	0.30	0.17	0.50
Cl*	<0.01	<0.01	<0.01	<0.01	0.11	<0.01	<0.01	<0.01
Na_2O Equiv.	0.40	0.52	0.47	0.48	0.41	0.32	0.48	0.50
C_4AF	12	8	10	8	14	11	8	8
C_3A	4	7	7	7	6	5	6	8
C_3S	46	50	47	50	43	47	48	46
C_2S	32	28	27	29	29	31	29	31
SS (Blaine)	3461	3378	4329	3223	3651	3396	3626	3041
Residue on No. 325	95.2	95.2	90.0	88.4	91.5	88.7	98.1	97.1

*Expressed as percentage by weight of chloride radical

TABLE 2

Grading of Aggregates Used in Concrete Mixtures

Sieve Size	Percent Passing
1"	100
3/4"	90
3/8"	64
No. 4	50
" 8	41
" 16	29
" 30	19
" 50	7

TABLE 3

Properties of Fresh Concrete
(Each value is average of tests made on 4 rounds)

Cement	Slump, Ins.	Air %	Unit Wt. Lbs/Cu.Ft.	W/C By Wt.	Cement, Sks/cu.yd.
1	3.1	1.9	150.1	0.569	6.00
2	3.0	1.9	149.9	0.553	6.01
3	3.0	1.9	149.4	0.565	6.01
4	2.9	1.9	149.5	0.575	6.01
5	3.1	2.0	149.3	0.579	6.01
6	2.9	1.7	149.8	0.583	6.01
7	2.9	1.8	149.6	0.562	6.02
8	3.1	1.8	149.4	0.575	6.01

TABLE 2

Gradation of Aggregate Used in Concrete Mixtures

Sieve	Percent Passing
3/4"	100
3/8"	90
No. 4	64
8	50
16	[illegible]
30	[illegible]
50	[illegible]
100	[illegible]

TABLE 3

Properties of Fresh Concrete
(Each value is average of tests made on 4 rounds)

Mix	Slump Ins.	Air %	Unit Wt. lbs/Cu.Ft.	W/C By Wt.	Cement Sks/cu.yd.
1	1.1	1.9	150.1	0.563	6.00
2	1.0	1.9	149.9	0.553	6.01
3	1.0	1.9	149.7	0.565	6.01
4	2	1.9	149.5	0.545	6.01
5	[illegible]	2.0	150.3	0.579	6.01
6	[illegible]	1.7	149.8	0.561	6.01
7	[illegible]	1.8	149.6	0.561	6.02
8	1.1	1.8	149.4	0.555	6.01

TABLE 4

Drying Shrinkage of Concrete Specimens
(Each value is for an individual specimen)

DRYING SHRINKAGE - PERCENT

Cement Number 1	2	3	4	5	6	7	8
			Dried 7 days				
0.019	0.024	0.022	0.024	0.024	0.023	0.025	0.028
.023	.024	.025	.024	.031	.022	.023	.025
.022	.026	.024	.024	.028	.018	.023	.025
.025	.026	.024	.023	.029	.019	.023	.029
.023	.024	.023	.022	.029	.020	.022	.026
.024	.024	.024	.025	.031	.019	.027	.025
.020	.020	.019	.022	.024	.016	.021	.025
.020	.022	.019	.021	.026	.016	.022	.023
.021	.022	.018	.017*	.027	.015	.020	.023
.022	.023	.023	.021	.024	.020	.022	.024
.022	.023	.021	.022	.028	.017	.023	.025
.022	.022	.023	.023	.026	.018	.023	.024
.0219	.0233	.0221	.0226	.0273	.0186	.0228	.0252
			Dried 14 days				
.033	.038	.038	.038	.045	.036*	.041	.044*
.039	.040	.038	.037	.051	.034	.039	.037
.037	.042*	.038	.039	.051	.032	.038	.040
.039	.039	.037	.034	.048	.033	.036	.044*
.038	.038	.037	.035	.048	.031	.044*	.043
.039	.038	.038	.038	.051	.032	.036	.040
.035	.033	.037	.032	.046	.027	.038	.041
.033	.035	.033	.034	.046	.028	.038	.036
.037	.035	.032	.033	.045	.028	.034	.038
.036	.036	.037	.034	.043	.033	.035	.039
.036	.035	.035	.034	.046	.030	.037	.038
.036	.034	.035	.037	.044	.031	.036	.038
.0365	.0365	.0363	.0354	.0470	.0308	.0371	.0388
			Dried 28 days				
.045	.049	.052	.050	.060	.048*	.056*	.058*
.052	.054*	.051	.049	.065*	.047	.053	.054
.048	.057*	.051	.053	.066*	.045	.052	.055
.050	.052	.051	.049	.062	.045	.053	.059*
.055*	.051	.048	.050	.060	.044	.047	.056
.052	.050	.050	.052	.064	.043	.057*	.053
.048	.046	.047	.045	.059	.038*	.048	.054
.046	.049	.043*	.048	.061	.040	.051	.048*
.050	.049	.042*	.044*	.058	.040	.046*	.052
.049	.048	.050	.047	.057	.044	.047	.050
.049	.047	.048	.045	.059	.042	.050	.050
.048	.046	.044*	.050	.054*	.043	.048	.049
.0488	.0487	.0498	.0486	.0600	.0433	.0499	.0526

*Not included in average

TABLE 5

Mix Data, Expansion and Contraction of Mortars,
Constant Flow
(Each value is for a separate batch, expansion and contraction values are average of 4 specimens from a batch)

Cement Number							
1	2	3	4	5	6	7	8
W/C by Weight							
0.368	0.368	0.380	0.387	0.392	0.384	0.387	0.389
.365	.376	.384	.384	.392	.384	.387	.384
.365	.373	.381	.380	.387	.384	.387	.381
.366	.372	.381	.383	.390	.384	.387	.385
Flow, Percent							
109	104	105	109	108	107	107	110
107	111	111	108	108	107	107	109
110	109	111	109	107	109	107	108
109	108	109	109	108	108	107	109
Expansion, Percent							
.0025	.0038	.0012	.0032	.0030	.0032	.0105	.0020
.0028	.0025	.0022	.0038	.0018	.0028	.0028	.0022
.0025	.0048	.0018	.0030	.0030	.0038	.0030	.0038
.0026	.0037	.0017	.0033	.0026	.0033	.0054	.0027
Contraction - Percent							
.0368	.0450	.0405	.0365	.0460	.0395	.0495	.0455
.0385	.0450	.0385	.0415	.0475	.0400	.0460	.0480
.0368	.0445	.0368	.0373	.0452	.0388	.0432	.0478
.0374	.0448	.0386	.0384	.0462	.0394	.0462	.0471

TABLE [illegible]

Mix Data, Expansion and Contraction of Mortars, Constant Flow

(Each value is for a separate batch, expansion and contraction values are average of 4 specimens from a batch)

	Cement Number						
	[illegible]	3	4	5	6	7	8
W/C by Weight	[illegible]	0.380	0.387	0.392	0.384	0.387	[illegible]
	[illegible]	.384	.384	.392	.384	.387	[illegible]
	[illegible]	.381	.380	.387	.384	.387	[illegible]
	[illegible]	.381	.383	.390	.384	.387	.385
Flow, Percent	[illegible]	105	109	108	107	107	[illegible]
	[illegible]	111	108	108	107	107	[illegible]
	[illegible]	111	109	107	109	107	[illegible]
	108	[illegible]	109	108	108	107	[illegible]
Expansion, Percent	[illegible]	[illegible]	.0032	.0030	.0032	.0103	[illegible]
	.0025	[illegible]	.0038	.0018	.0028	.0028	[illegible]
	[illegible]	.0018	.0030	.0030	.0038	.0030	[illegible]
	[illegible]	.0017	.0033	.0026	.0033	.0057	[illegible]
Contraction, Percent	[illegible]	.0405	.0365	.0460	.0395	.0495	[illegible]
	[illegible]	.0385	.0415	.0475	.0400	.0460	[illegible]
	[illegible]	.0368	.0373	.0452	.0388	.0432	[illegible]
	[illegible]	.0386	.0384	.0462	.0394	.0462	[illegible]

TABLE 6

Summary of Mortar and Concrete
Shrinkage Tests

Values are in percent after drying for period indicated

Cement Number	Mortar,	Concrete		
	4 days	7 days	14 days	28 days
1	0.0374	0.0219	0.0365	0.0488
2	.0448	.0233	.0365	.0487
3	.0386	.0221	.0363	.0498
4	.0384	.0226	.0354	.0486
5	.0462	.0273	.0470	.0600
6	.0394	.0186	.0308	.0433
7	.0462	.0228	.0371	.0499
8	.0471	.0252	.0388	.0526

TABLE 6

Summary of Mortar and Concrete Shrinkage Tests

Values are in percent after drying for period indicated.

Number	Mortar	Concrete		
	4 days	7 days	14 days	28 days
1	0.0374	0.0219	0.0365	0.0488
2	.0448	.0231	.0365	.0487
3	.0386	.0221	.0303	.0493
4	.0384	.0226	.0354	[illegible]
5	.0462	.0213	.0470	.0600
6	.0394	.0186	.0308	.0433
7	[illegible]	.0228	.0371	[illegible]
8	.0441	.0252	.0358	[illegible]

TABLE 7

Precision of Prediction of Concrete Shrinkage from Mortar Tests as indicated by Standard Error of Estimate, S_{xy}

(All mortar tests were made in manner similar to Calif. 527-A. Concrete specimens were 3x3x10-in. (gage length) prisms dried at 73 F and 50%)

Predicted values of concrete shrinkage were calculated from formula X = aY = 0.00 (curve passes through origin)

Description	Value of "a" in equation	Moist Curing, days	Drying days	Std. Error of Estimate	
				Numerical	Percent*
Data of this report involving 8 Type II, low-alkali cements	0.54	7	7	0.0021	9
	0.89	7	14	0.0038	9
	1.18	7	28	0.0041	8
PCA tests involving cements 18, 21 and 24 of LTS series	0.70	3	25	0.0036	9
PCA tests involving cements 12, 31 and 34 of LTS series	0.73	2	26	0.0018	4
Swayze tests involving 40 cements	0.43	3	10	0.0118	50
		3	25	0.0118	35
		3	90	0.0128	27
		3	365	0.0129	21
Ideal Cement Co. Research Lab. 2 Type low alkali cements. Values shown are average differences from calculated shrinkage	0.45	7	7	0.0024	12
	0.70	7	14	0.0033	10

*Percentage values are calculated from numerical values of (difference between predicted and observed shrinkage divided by observed shrinkage) x 100 [illegible] Concrete Shrinkage from Normal Value as [illegible] by Standard Error of Estimate, Eq [illegible]

[illegible] similar to Table 527-A [illegible] specimens [illegible] (gage length) prisms dried [illegible]

[illegible] values of concrete shrinkage were calculated from formula [illegible] curve passes through origin)

Description	Value of n in equation	Moist Curing days	Drying days	Standard Error of Estimate: Numerical	Standard Error of Estimate: Percent
[illegible] II, low [illegible]	0.54	7	7	0.0021	12
	0.89	7	4	0.0028	[illegible]
	[illegible].18	7	28	0.0041	[illegible]
[illegible]	[illegible]	3	28	0.0026	[illegible]
[illegible]	0.75	2	28	0.0018	[illegible]
[illegible]	[illegible]	[illegible]	10	0.0118	50
			28	0.0110	35
			90	0.0128	[illegible]
			28	0.0129	
[illegible]				0.0024	12
[illegible]	0.76		14	0.0093	10

[illegible] are calculated from numerical values of (difference between predicted and observed shrinkage divided by observed shrinkage) x 100

TABLE 8

Mix Data, Expansion and Contraction of Mortars made with Constant W/C of 0.378 by Weight

(Each value is for a separate batch. Expansion and contraction values are averages of 4 specimens from a batch.)

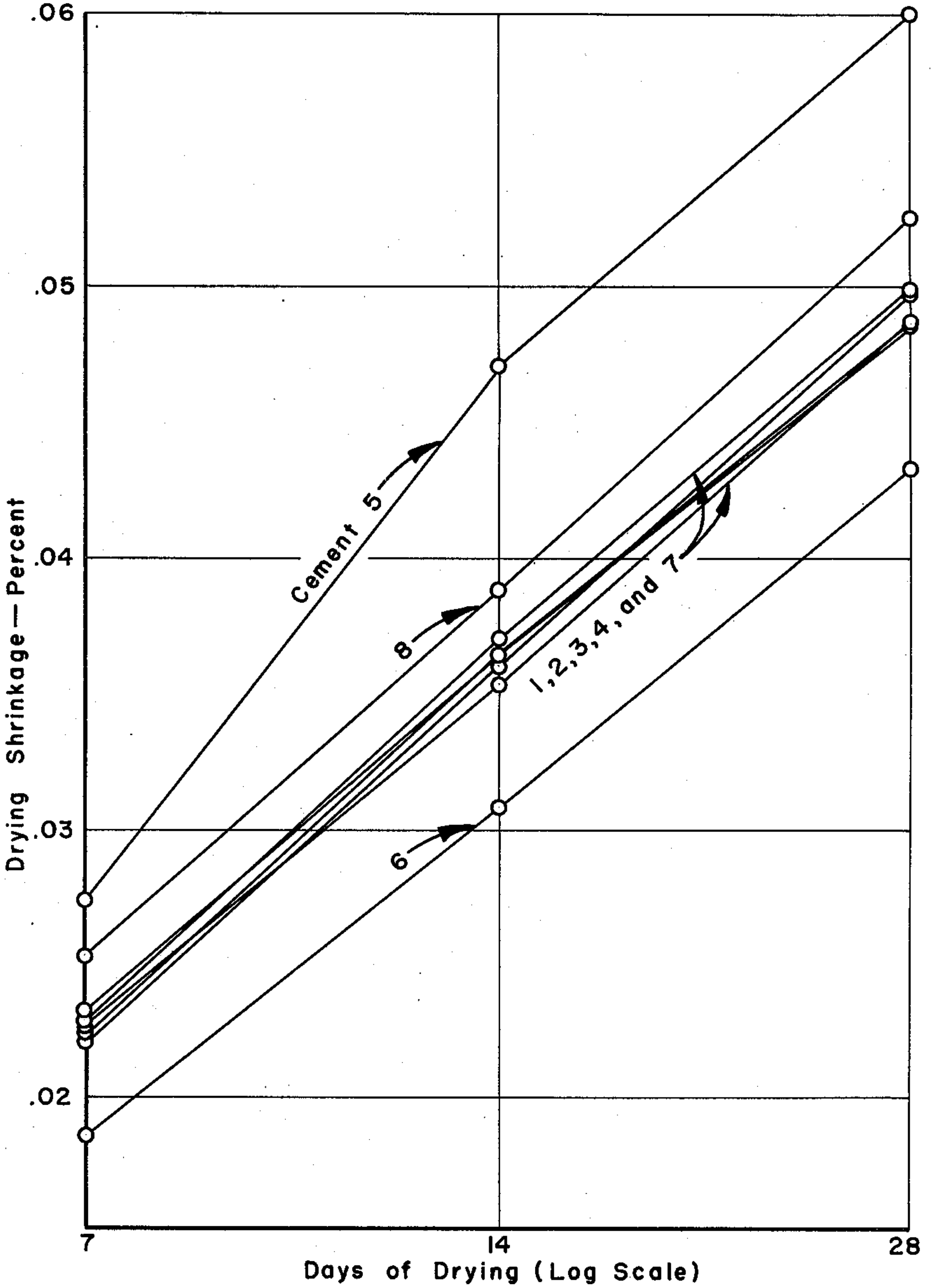
Cement Number							
1	2	3	4	5	6	7	8
Flow - Percent							
121 120 121	109 110 110	104 103 104	103 101 102	94 95 95	95 96 96	97 95 96	104 102 103
Expansion - Percent							
.0015 .0042 .0028	.0015 .0042 .0028	.0012 .0020 .0016	.0028 .0040 .0034	.0012 .0045 .0028	.0010 .0055 .0032	.0018 .0032 .0025	.0000 .0050 .0025
Contraction - Percent							
.0365 .0362 .0364	.0432 .0432 .0432	.0378 .0365 .0372	.0392 .0395 .0394	.0420 .0468 .0444	.0380 .0395 .0388	.0412 .0430 .0421	.0438 .0485 .0462
Change in W/C, constant flow mortar minus constant W/C mortar							
+.012	+.006	-.003	-.005	-.012	-.006	-.009	-.007
Change in Contraction, constant flow mortar minus constant W/C mortar							
-.0010	-.0016	-.0014	+.0010	-.0018	-.0006	-.0041	-.0009

Table [illegible]

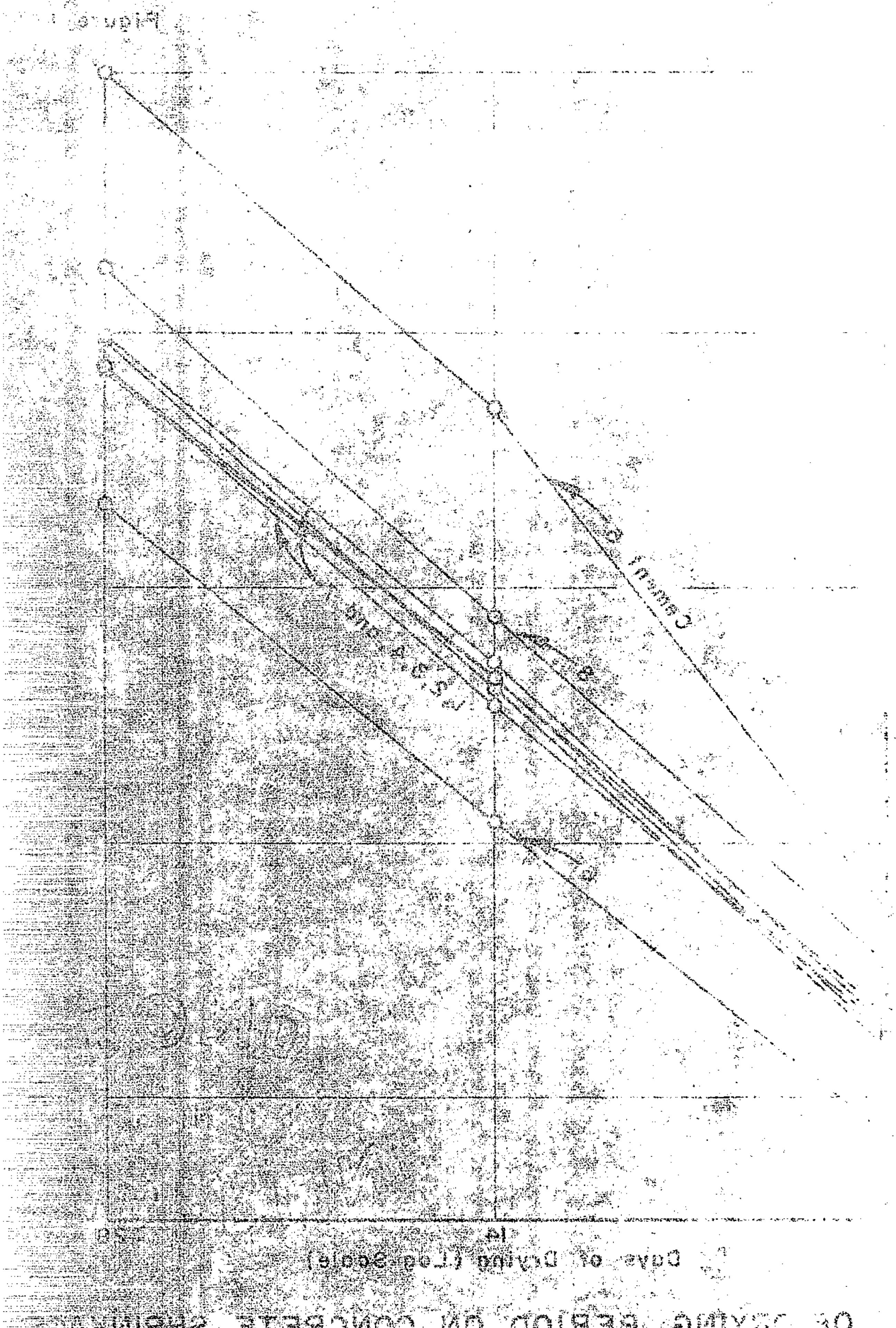
[illegible] Expansion and Contraction of Mortars
[illegible] Constant W/C of 0.379 by Weight

([illegible] for separate batches. Expansion and contraction [illegible] of 4 specimens from a batch.)

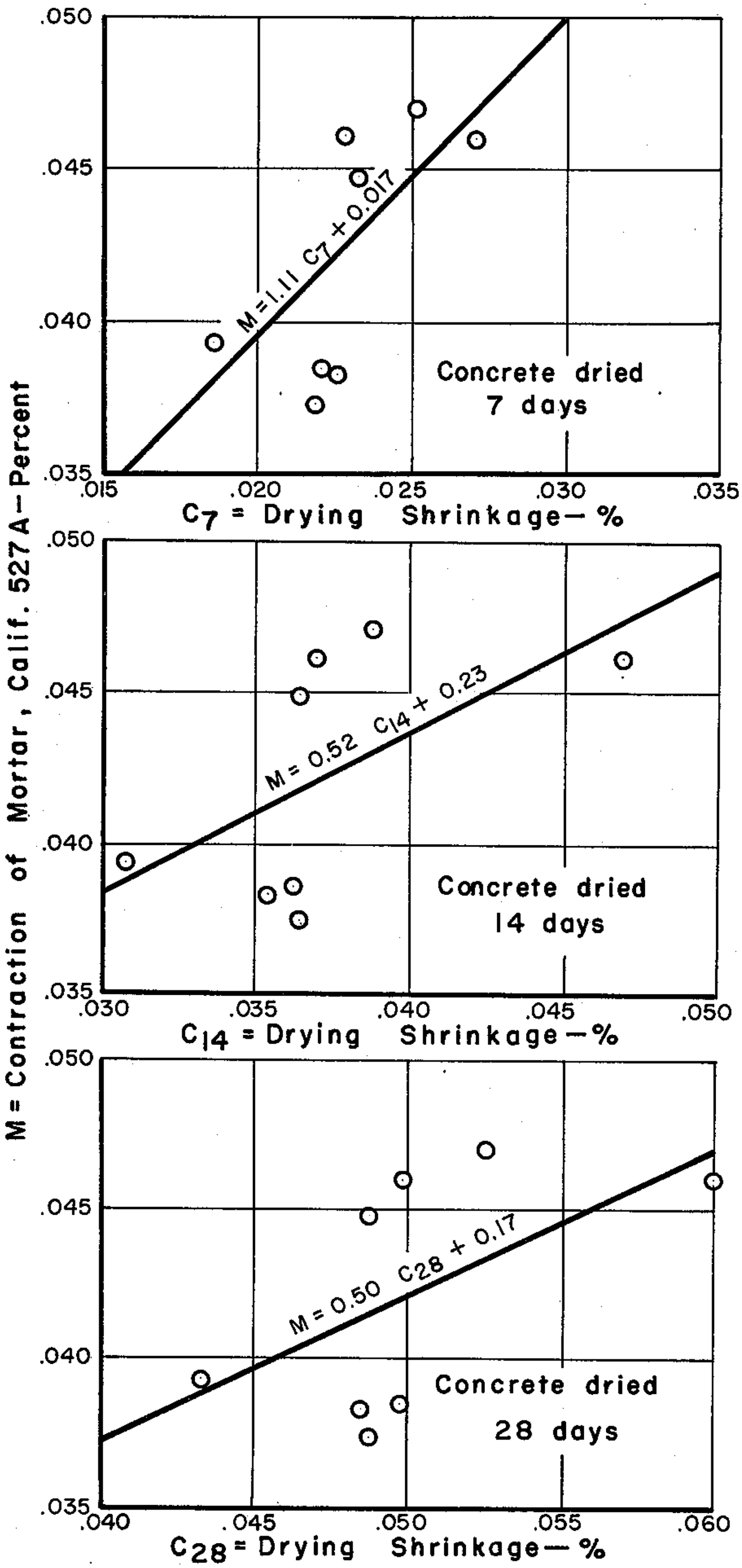
Cement Number	[illegible]	7	6	5	4	[illegible]	[illegible]	1
Flow - Percent								
	109	97	95	94	103	104	[illegible]	[illegible]
	[illegible]	98	96	95	101	103	[illegible]	[illegible]
	103	96	96	95	102	104	[illegible]	[illegible]
Expansion - Percent								
	.0028	.0018	.0010	.0012	.0028	[illegible]	[illegible]	[illegible]
	.0036	.0022	.0055	.0045	.0040	.0020	[illegible]	[illegible]
	.0035	.0029	.0032	.0028	.0034	[illegible]	[illegible]	[illegible]
Contraction - Percent								
	.0400	.0412	.0380	.0412	.0382	.0376	[illegible]	[illegible]
	[illegible]	.0408	.0392	.0408	.0307	.0365	[illegible]	[illegible]
	[illegible]	.0429	.0388	.0414	.0394	[illegible]	[illegible]	[illegible]
Change in W/C, constant flow mortar minus constant W/C mortar								
	-.007	-.009	-.006	-.012	-.005	-.005	[illegible]	[illegible]
Change in Contraction, constant flow mortar minus constant W/C mortar								
	[illegible]	-.0041	-.0006	-.0018	-.0014	[illegible]	-.0015	[illegible]



EFFECT OF DRYING PERIOD ON CONCRETE SHRINKAGE

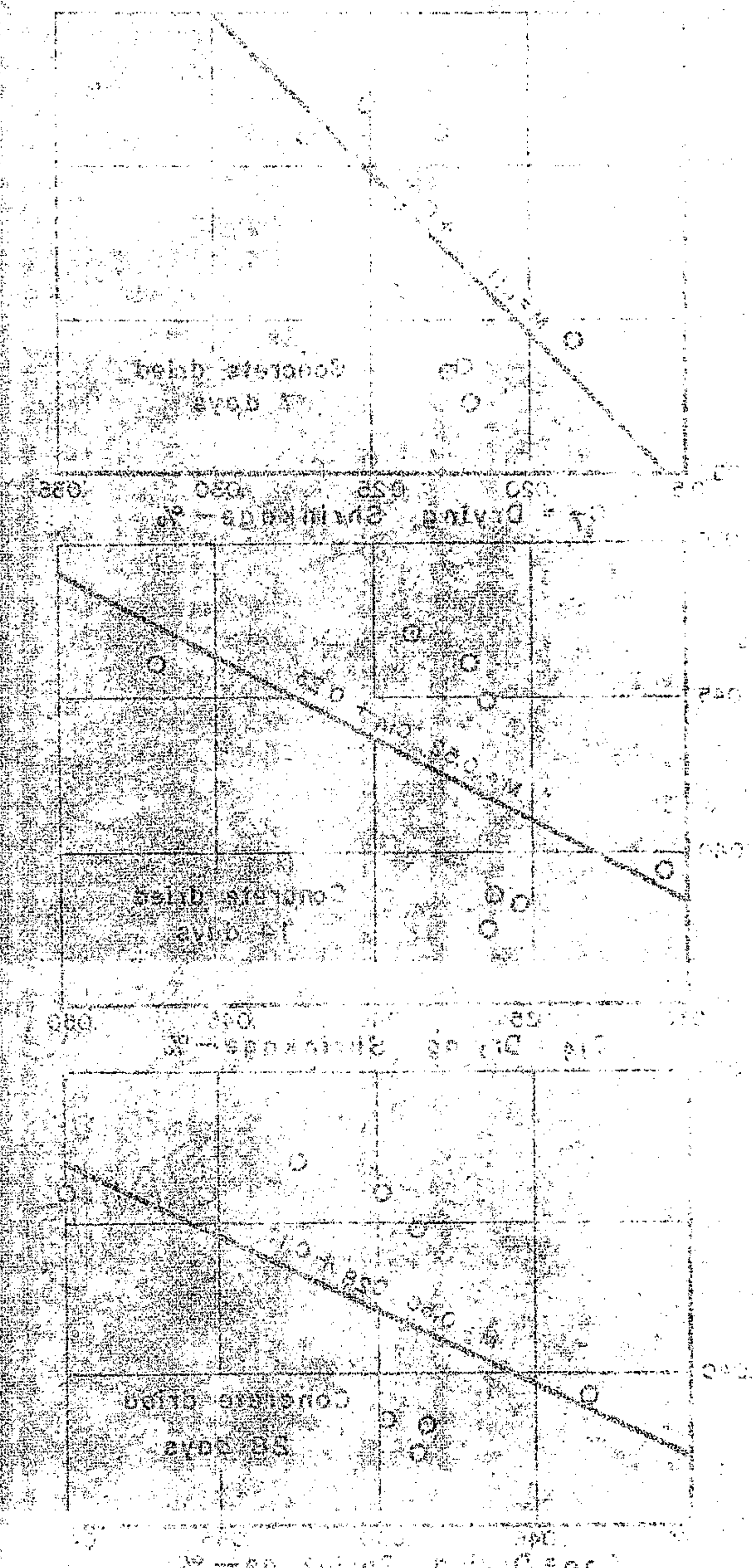


OF DRYING PERIOD ON CONCRETE SHRINK...

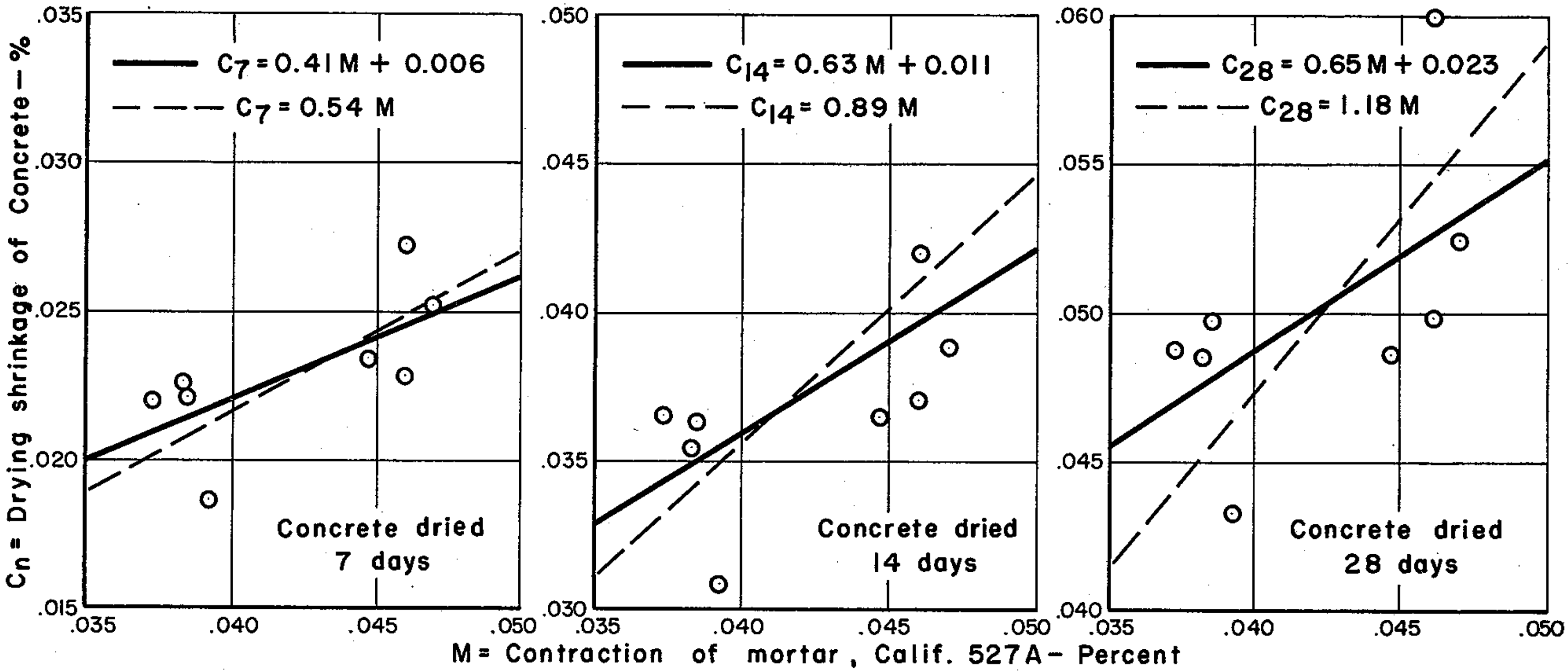


MORTAR CONTRACTION AS A FUNCTION OF CONCRETE DRYING SHRINKAGE

Figure 2



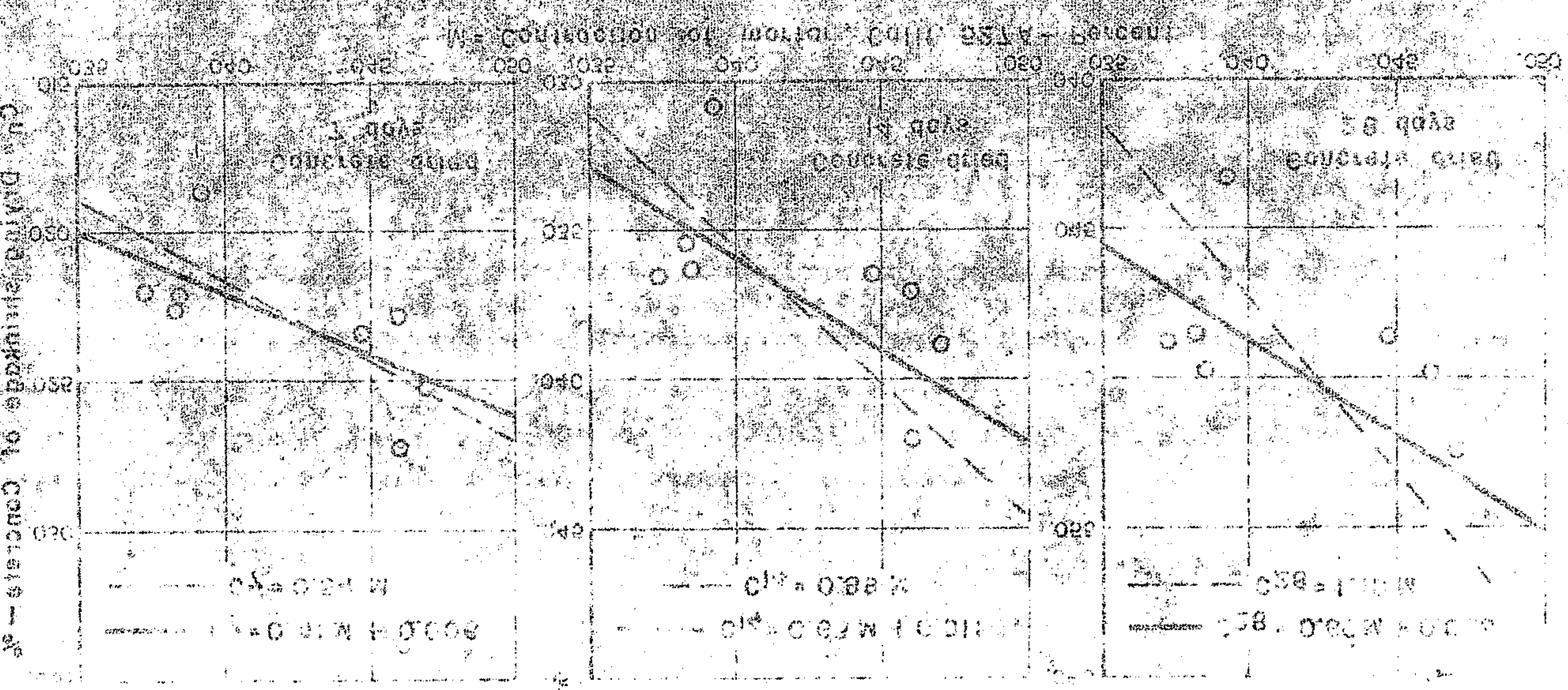
MORTAR CONTRACTION AS A FUNCTION
OF CONCRETE DRYING SHRINKAGE



CONCRETE SHRINKAGE AS A FUNCTION OF MORTAR CONTRACTION

Figure 3

CONCRETE SHRINKAGE AS A FUNCTION OF MORTAR CONTRACTION



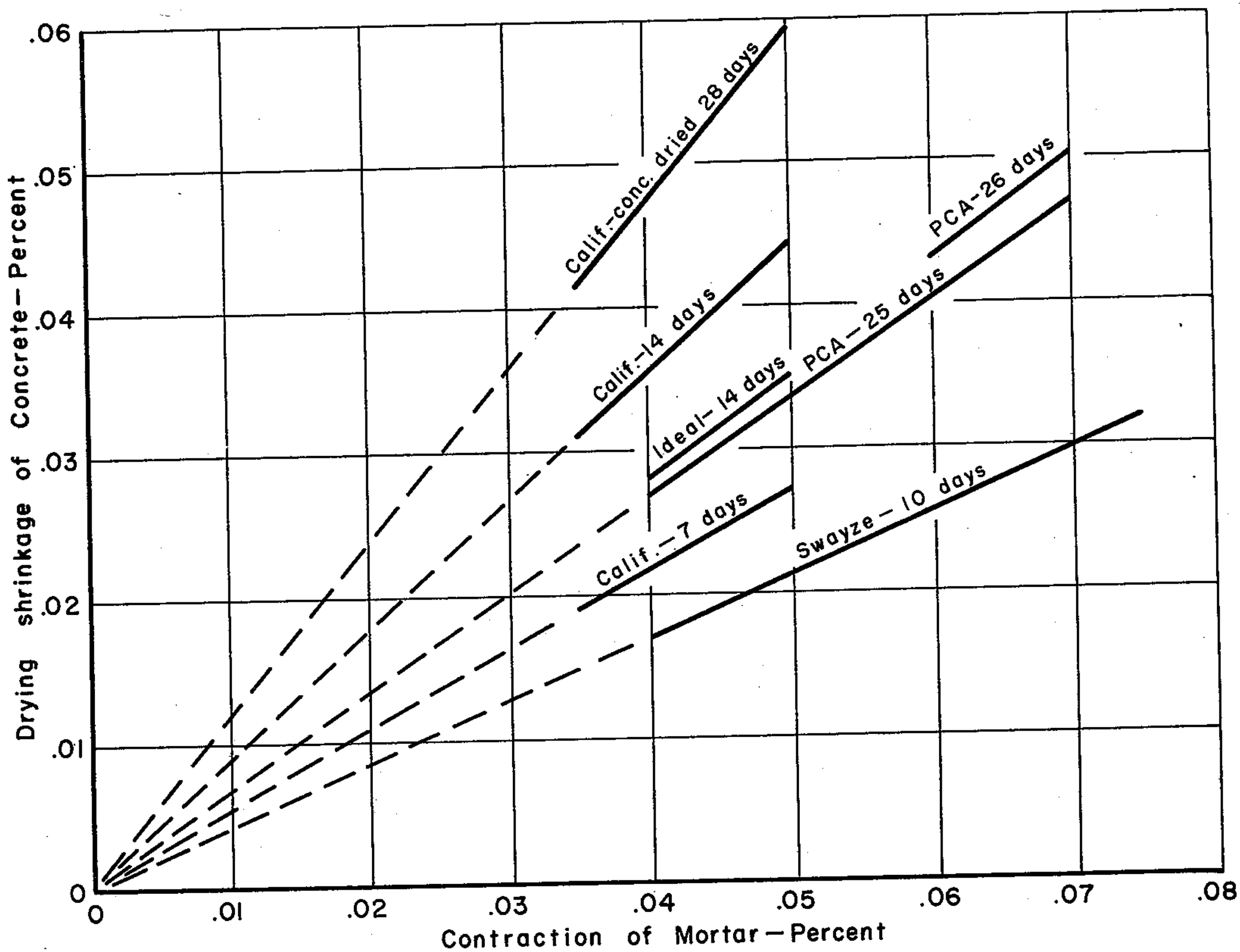
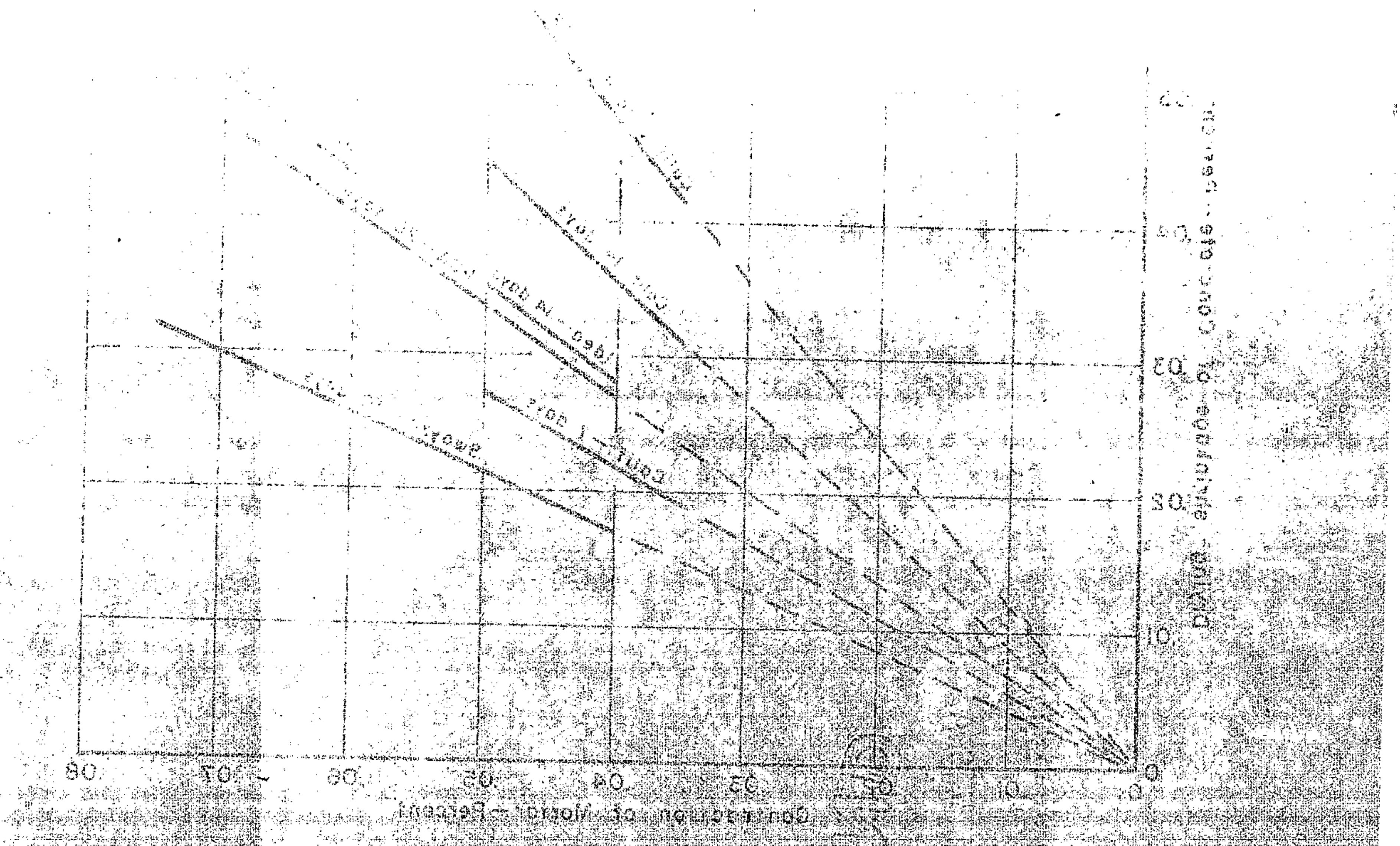


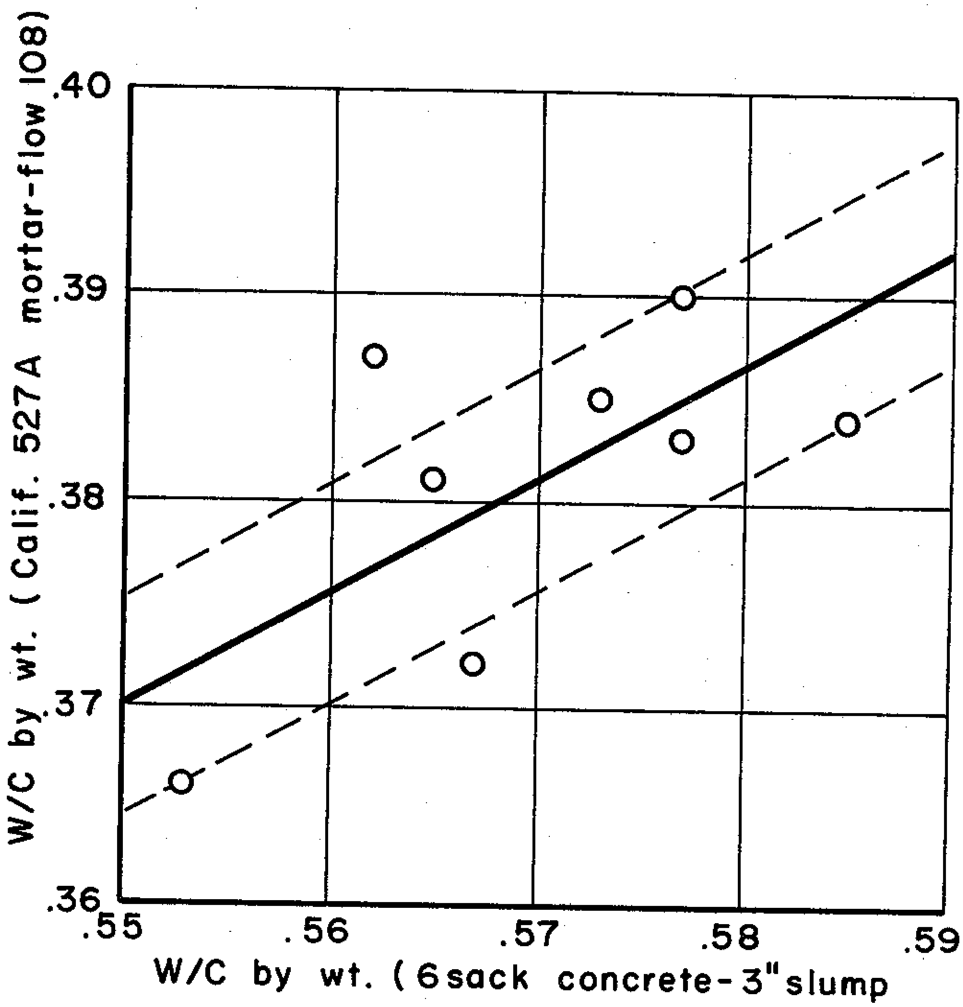
Figure 4

CONCRETE SHRINKAGE AS A FUNCTION OF MORTAR CONTRACTION RESULTS BY SEVERAL INVESTIGATORS

Figure 4

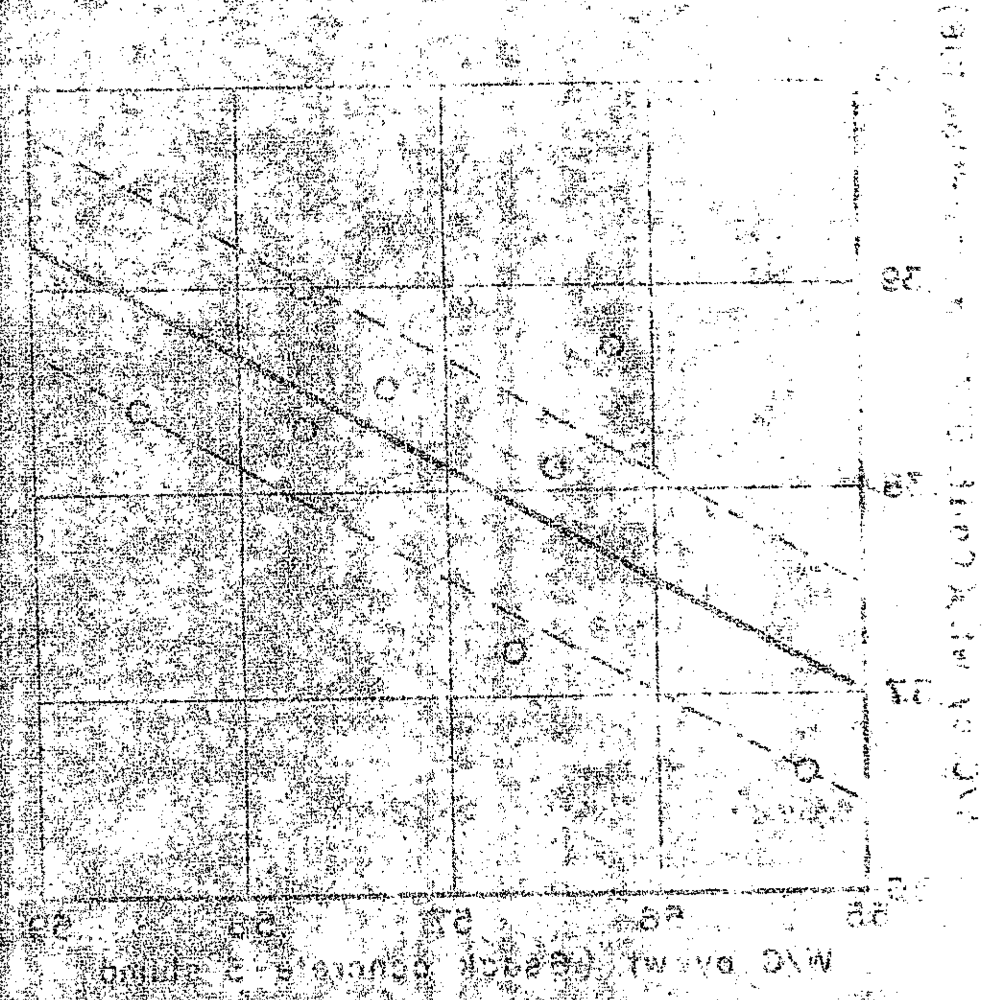


Contraction of Mortar – Percent
Drying Shrinkage of Concrete – Percent

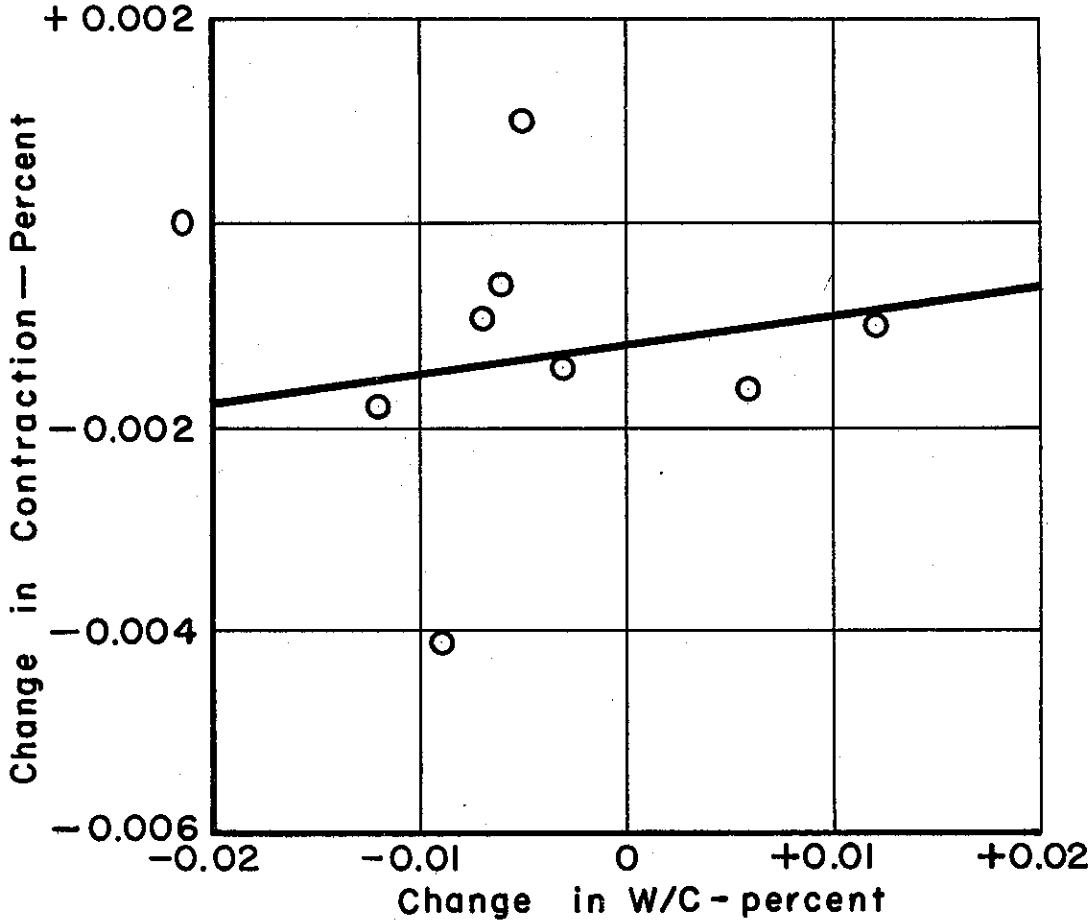


WATER REQUIRED IN MORTAR AND CONCRETE

Figure 5



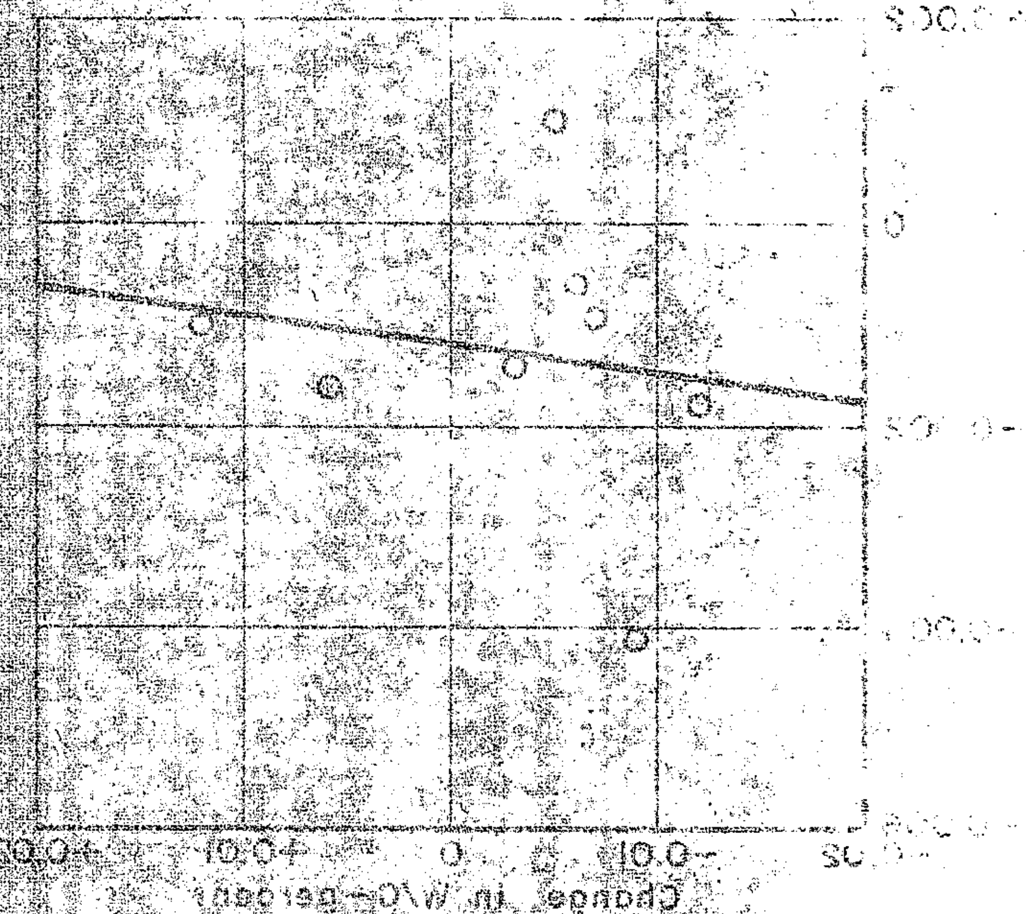
WATER REQUIRED IN MORTAR AND CONCRETE



NOTE: Indicated correlation is not significant

EFFECT OF CHANGE IN W/C OF MORTAR ON CONTRACTION

Figure 6



NOTE: Indicated correlation is not significant

EFFECT OF CHANGE IN W/C
OF MORTAR ON CONTRACTION

APPENDIX

Tentative Method of Determination of Chlorides in Portland Cement

To 10.0 grams of portland cement in a 400 ml beaker, add 100 ml of boiling water and a slight excess of 0.1 N silver nitrate (6.0 ml is an appropriate amount of silver nitrate for cements that do not contain in excess of 0.15 percent chloride). Boil for 2 minutes. Remove from heat and cool slightly. Slowly add 20 ml nitric acid with vigorous stirring and scrubbing. (Effervescence usually occurs as neutrality is approached.) Cover and boil for 2 minutes. Remove from heat and break up any lumps of undissolved cement with the flattened end of a stirring rod. Cool to room temperature and filter through a 12.5 cm, fairly fast paper into a 400 ml beaker. The filtrate should be clear. Wash the residue three times with 1:99 nitric acid. Discard the residue.

With cements that are low in iron, add a few drops of ferric solution as an indicator. Titrate with 0.1 N ammonium thiocyanate solution, that has been standardized against the silver nitrate solution, to the first permanent red color.

Calculate chlorides as chloride radical by the following formula:

formation of
ement

group of ... content ... Mercury

... slight excess of 1 N

... 0 ml is an appropriate amount of water

... must do not contain excess of HCl

... boil for 2 minutes. Remove from heat

... and 2 ml nitric acid with

... stirring and scratching (after vessels and)

... is uncapped) cover and boil for

... Remove from heat and press on any lumps

... with the flattened end of a stirring

... decant and filter through

... paper into a 100 ml beaker. The filtrate

... Wash the residue three times with 1 N

... the residue

... remains that ... a few drops

... solution as ... with 1 N

... that has been extended

... solution, in the filtrate

... ert

... chlorides ...

Tentative Method of Determination of Chlorides in Portland Cement

$$\% \text{ chloride radical} = \frac{(A \times n) - (B \times m) \times F \times 100}{\text{Wt. of sample in grams}}$$

Where

A = ml of $AgNO_3$

n = normality of $AgNO_3$

B = ml of NH_4SCN

m = normality of NH_4SCN

F = conversion factor to Cl = 0.03546

$(A \times n - B \times b) \times E \times 100$ ... in grams

A = ml of $AgNO_3$

n = normality of $AgNO_3$

B = ml of NH_4SCN

b = normality of NH_4SCN

E = conversion factor to Cl = 0.03546