EFFECT OF SOIL AND CALCIUM CHLORIDE ADMIXTURES ON SOIL-CEMENT MIXTURES

By Miles D. Catton and E J Felt, *Portland Cement Association*

SYNOPSIS

This report shows that some sandy surface soils which react poorly with cement, and therefore require high cement contents for hardening, can be improved to react in the normal manner by adding to the sand an admixture of clayey soil, or by adding a small quantity of calcium chloride This work reinforces the advisability of recognizing the soil series and horizon of soils according to the system devised by the old Bureau of Chemistry and Soils, U S Department of Agriculture, in order to recognize soil differences that are chemical rather than physical.

Compressive strength, wet-dry and freeze-thaw test data are given showing the effect of the soil and calcium chloride admixtures on a number of poorly reacting sandy soils. Data are also given showing the effect of calcium chloride upon normally well reacting soils.

Practical application in field construction of the methods developed in the laboratory for economically treating these poorly reacting sandy soils is also discussed. Several field projects have demonstrated that soil admixtures can be added effectively and efficiently Similar field projects involving the addition of calcium chloride are needed to define the details of construction methods While no practical difficulties are anticipated, the final answer to the effectiveness and economy of adding calcium chloride in the field, as differentiated from these laboratory findings, must await demonstration and proof

Construction costs are analyzed for poorly reacting sandy soils with indications that the costs may be excessive when cement alone is used However, the admixture of clayey soil or calcium chloride to these soils, with accompanying reductions in cement requirements, will often result in costs similar to those prevailing on projects where these special problems are not present.

The results of this investigation further the development of soil-cement and are of immediate importance to the Military in the construction of soil-cement roads and airport runways The research data on cement and soil reactions are of significance and value to the cement and concrete technician but these phases are not discussed in this report.

The cement content required to harden a soil to produce satisfactory soil-cement varies both with the texture of the soil and its chemical makeup. For instance, the average normally reacting sandy soil requires the addition of 8 or 10 per cent cement by volume for adequate hardening. In contrast to this, there are a number of poorly reacting sandy soils (principally surface soils) existing in certain parts of the United States that require cement contents by volume as high as 16 to 26 per cent and more All these sandy soils are closely related from a physical standpoint, but they apparently are quite different chemically

To vividly show the difference in the reaction with cement of a "poorly reacting" sandy soil and a "normally reacting" sandy soil, compressive strength data of soil-cement specimens composed of two representative sandy soils are plotted in Figure 1. The specimens were compacted to maximum density at optimum moisture content. Gradation and other data describing these two soils are shown in Table 1.

According to Table 1, these two sandy soils are physically practically identical from a soil-cement viewpoint However, they are vastly different in their reaction with cement Figure 1 shows that Soil 2a–6 (a normally reacting soil) from Berkeley County, South Carolina, has a 28-day compressive strength of more than 1000 lb per sq in. with 10 per cent cement, whereas Soil 3564 (a poorly reacting soil) from Berrien County, Michigan, has a corresponding strength of only about 90 lb. Further, the data indicate that a cement content of 8 per cent would give a well hardened soil-cement base with Soil 2a–6 In contrast, Soil 3564 would require 18 per cent or more cement to give a satisfactorily hardened base.

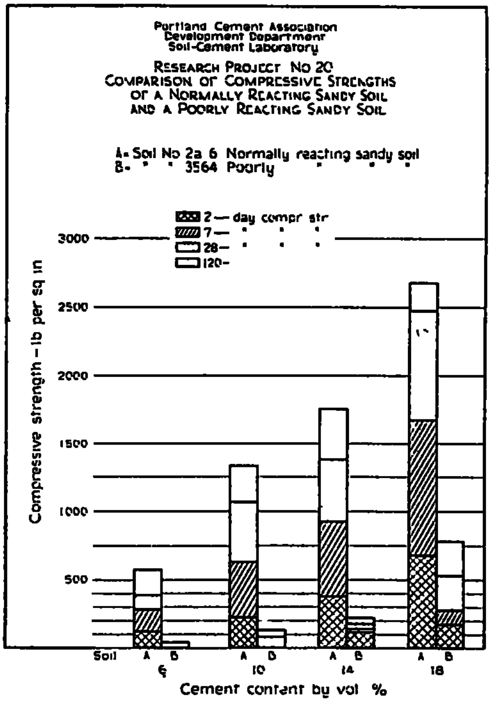


Figure 1

Obviously, a simple, inexpensive method of improving soils of this latter type so that they will react with lesser quantities of cement is acutely needed.

HISTORY

The first experience with these slow hardening or poorly reacting sandy soils occurred in 1936 when a sand soil from Wisconsin failed to react with cement in the normal manner. Research at that time indicated that the poor reaction of the sand might be due to (1) a deficiency of "fines" and (2) the presence of a deleterious material (probably organic matter). To overcome these deficiencies, tests were made to investigate the effect of adding a portion of fine textured (silty clay) soil A mixture of 80 per cent sand and 20 per cent silty clay by weight reacted very well with 10 per cent cement, and a fine project, described in previous Proceedings of the Highway Research Board,[1] was built using this soil mixture.

In December, 1936, an article by D I. Sideri of Moscow, Russia, appeared in Soil Science, " . . On the Bonds Uniting Clay With Sand, and Clay With Humus " At about this same time consideration was being given to the possibility that the poor reaction of the Wisconsin sand was due more to the presence of organic materials in the sand, than to poor gradation Sideri's article fits in with this hypothesis since as he put it "Humus is irreversibly absorbed by clay . " , and, "The binding of humus with clay is due to selective orientation of humus particles on clay . . ." In contrast to this, Sideri continues, "Hence the organic substance of soil can be readily separated from sand " Therefore, since organic matter is held lightly by sand, it appears likely that when clay is added to a sand, it may absorb the organic from the sand by a phenomenon similar to base exchange. Then as the organic matter is held tightly by the clay it will not be free to react with cement added

TABLE 1

GRADATION AND TEST CONSTANTS SOILS 2a–6 AND 3564 COMPRESSIVE STRENGTHS SHOWN IN FIGURE 1

Soil No	Gradation—Per Cent of Total			Organic Content[a] p p m	Physical Test Constants		Textural Class	U S P R A Soil Group
	Sand		Silt & Clay 0 05 to 0 000		L L.	P I		
	2 0 to 0 25	0 25 to 0 05						
	mm	mm	mm					
2a–6	26	57	17	500	14	N P	Loamy Fine Sand	A-2
3564	63	21	16	11,000	15	N P	Loamy Coarse Sand	A-2

[a] Organic content based on colorimetric tests essentially the same as "Standard Method of Test for Organic Impurities in Sand for Concrete" A S T M Designation C 40 – 33 Includes organic materials soluble in a 3 per cent sodium hydroxide solution Additional discussion on "organic" content of soils is given in "Research on The Physical Relations of Soil and Soil-Cement Mixtures" by Miles D Catton, *Proceedings*, Highway Research Board, Vol 20, 1940

[1] Guy H Larson, "Experimental Soil-Cement Road in Wisconsin," *Proceedings*, Highway Research Board, Vol. 17, Part II, 1937.

to the sand-clay mixture All of this, of course, fits into the question, as to why the Wisconsin sand-silty clay mixture reacted well with cement, whereas the sand itself did not.

Further to explore this problem of poorly reacting sandy soils, experiments were conducted during 1938 to determine the effect of washing such poorly reacting soils with water, hydrogen peroxide, ether, alcohol, hydrochloric acid, and sodium hydroxide. Tests were also made to investigate the effect of additions to the sand soils of calcium hydroxide, calcium oxide and calcium carbonate, and of the addition of portland cement in two increments, the first being permitted to hydrate in the loose moist soil, prior to the addition of the second increment. Other tests were made in which the sand was "burned" to a white heat. Later on in 1940 and 1941 exploratory tests were made to determine the effect of sodium silicate, sodium chloride and high early strength cement.

Although some of these treatments and materials were very beneficial in improving the soils so that they reacted better with portland cement, no practical, economical methods for treating the soils with chemicals were evolved. These studies showed, however, that the poor gradation of the sands was of secondary importance as an answer to the question why these sands react so poorly with cement. Rather, the presence of organic matter in the sand, or the presence of deleterious films on the sand, were indicated to be the principal reasons for the poor reactions

SCOPE OF PRESENT REPORT

Although the Wisconsin soil study showed that an addition of clayey soil to a poorly reacting sand was beneficial, the research was of limited extent Therefore, in 1939 through 1941 additional detail studies were made along this line, investigating the addition of admixture soils to poorly reacting sand soils from northeastern and southeastern states. Illustrative data from these tests are given in this report, Part I.

Since the use of chemicals to improve these poorly reacting soils warranted further study, additional tests were started late in 1941 in which small percentages of iron chloride were added to slow hardening sandy soil-cement mixtures. These tests were followed by similar work investigating calcium chloride.

A review of all these data showed that of all the materials, calcium chloride proved practically as effective in all instances where any of the other materials were effective, and in addition, was effective in a number of cases where the other materials were ineffective. Further, the cost of treating the sands with calcium chloride was indicated to be equal to or less than the cost of other forms of treatment.

The fact that calcium chloride was beneficial as an admixture to poorly reacting sands in a number of instances, plus the question as to how it might effect normal soils, was of sufficient importance to warrant a detailed investigation of the following factors (The other materials previously discussed may warrant further study as admixtures at a later date):

1. To what extent can calcium chloride be depended upon to help poorly reacting soils?
2. How will the addition of calcium chloride effect soils that harden normally?
3. How much calcium chloride should be added to the various soils for optimum physical and economic benefit?
4. Is the benefit from calcium chloride temporary, or is it of lasting effect?
5. What will be the effect of lengthy damp mixing periods, such as is common in the usual mixed-in-place procedure of field mixing, on soil-cement-$CaCl_2$ mixtures?

The results of the investigation, to explore the effect of calcium chloride on the strength and durability of soil-cement mixtures covering a wide range of soils, are given in this report, Part II Thus this report consists of two parts (I) the results of a few representative tests to show the effects of the addition of soil admixtures to poorly reacting sandy soils, (II) the results of comprehensive tests to show the effect of the addition of calcium chloride to both poorly reacting soils and normally reacting soils

Materials and Methods of Test

Soils Data from tests using 22 soils, representing much of the United States, are included. Six of these react with cement in a normal manner, ten are poorly reacting sandy or sandy-gravelly soils, and require abnormally high cement contents unless specially treated, and five are admixture soils. Some of the ten poorly reacting soils contained material retained on the No. 4 sieve, but to simplify laboratory procedure this coarse material was not included in the test specimens.

Cement. The cement consisted of a single mixture of equal parts of four popular brands of normal portland cement. Throughout the report cement contents are always expressed as a percentage by volume of the compacted soil-cement or soil-cement-calcium chloride mixtures. In this respect, a bag of cement which weighs 94 lb. is assumed to have a volume of one cu. ft. The expression 10 per cent cement by volume indicates the presence of 0.1 of a cubic foot of cement (or 0.1 of a bag, 9.4 lb.) in a compacted cubic foot of soil-cement. Likewise, 14 per cent by volume indicates 0.14 of a bag (13.16 lb.) of cement in a compacted cubic foot of soil-cement.

TABLE 2

GRADATION AND OTHER TEST DATA FOR SOILS, COMPRESSIVE STRENGTH DATA OF WHICH ARE SHOWN IN TABLE 4 AND FIGURE 2

Soil No.	Soil Horizon	Gradation—Per Cent of Total				Organic Content p p m	Physical Test Constants		Textural Class	U S P R A Soil Group
		Sand		Silt	Clay					
		2 0 to 0 25	0 25 to 0 05	0 05 to 0 005	0 005 to 0 000		L L	P I		
		mm	*mm.*	*mm*	*mm*					
887-2	"A"	16	84	0	0	36,000	21	N P	Fine Sand	A-3
891	"B"	10	90	0	0	2,500	22	N P	Fine Sand	A-3
578	"C"	28	29	27	16	None	24	N P	Sandy Loam[a]	A-2
902	"A"	52	36	7	5	10,000	16	N P	Coarse Sand	A-2
997	"C"	27	52	11	10	700	18	N P	Fine Sandy Loam	A-2

[a] This is a white-grey calcareous material called Florida Limerock

Calcium Chloride. The $CaCl_2$ used in the tests was a commercial product bought on the open market, rated 77–80% $CaCl_2$. Later tests showed it to be 79 5 per cent solids. In all tests reported herein, the $CaCl_2$ was added to the soil-cement mixtures as a percentage by weight of the oven-dry soil in the mixture.

Mixing Water. Water from the Chicago supply was used.

Test Methods. Prior to molding test specimens, moisture-density tests were conducted on representative mixtures in accordance with A.S.T.M. Method D558-40T. From these data interpolations and extrapolations were made so that compressive strength, wet-dry and freeze-thaw test specimens could be molded at optimum moisture content and maximum density.

Wet-dry and freeze-thaw tests were conducted on the standard size specimens 4 in. in diameter and 4 6 in. in height, according to A.S.T.M. Methods D559-40T and D560-40T, except that the tests were extended to 36 cycles in Part II of this report. Compressive strength tests were made on specimens 2 in. in diameter and 2 in in height, cured in a standard moist room and broken at the selected age after 1 hr. soaking in water.

PART I

RESULTS OF SOIL ADMIXTURE TESTS

Compressive strength, wet-dry and freeze-thaw data are available on tests made on a considerable number of poorly reacting sand soils to which soil admixtures have been added. A limited amount of compressive strength data have been selected and presented to illustrate particularly valuable points which aid in understanding the effect of different soil admixtures on poorly reacting sands. Strength data are presented, rather than wet-dry and freeze-thaw data, since they make possible rapid qualitative comparisons of cement and soil reactions.

GENERAL EFFECT OF ADMIXTURE SOIL

Table 2 shows the gradation and other data for five soils from Florida Three of these, 887-2, 891 and 902, are poorly reacting sandy soils, and two soils, 578 and 997 are well reacting soils used as an admixture with the other three. Table 3 and Figure 2 show the effect on compressive strength of mixing the soils in the proportions noted.

With soil 891 the very low compressive strength of 70 lb. per sq in. was obtained with 16 per cent cement at seven days. However, by adding 25 per cent soil 578 this seven-day compressive strength was raised to 615 lb. show a similar beneficial influence from adding the admixture soil to the sand soils.

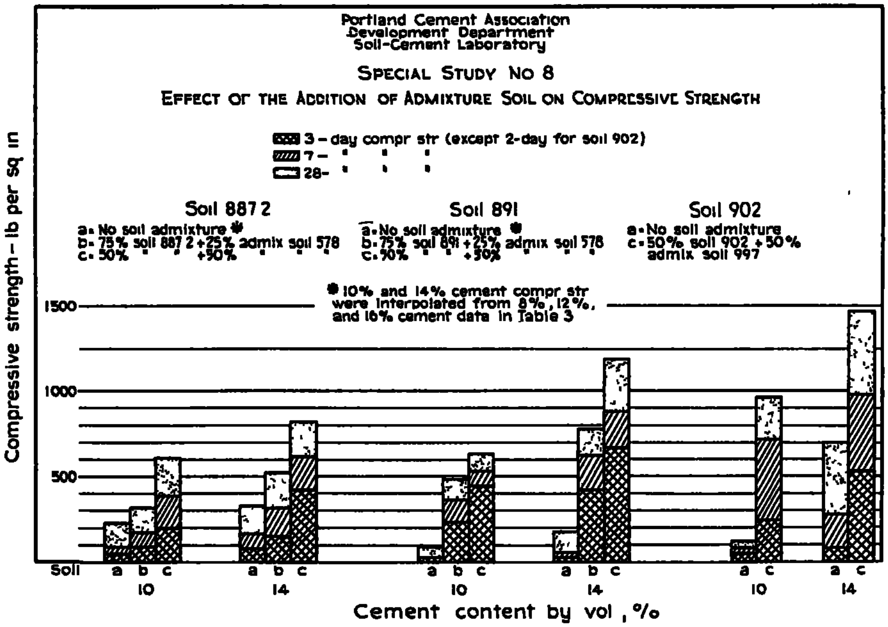


Figure 2

TABLE 3

EFFECT OF "WASHING" AND OF ADDING AN ADMIXTURE SOIL ON COMPRESSIVE STRENGTH OF POORLY REACTING FLORIDA SAND SOILS

Soil No and Soil Mixture Description	Compressive Strength, lb per sq in — Age when Tested, Days — Cement Content by Volume, Per Cent																	
	Three						Seven						Twenty-eight					
	8	10	12	14	16	20	8	10	12	14	16	20	8	10	12	14	16	20
a, 887-2	40		65		75	90	70		125		195	275	115		260		395	525
887-2[a]			420						647						1070			
b, 887-2A = 75% 887-2 + 25% 578		95		150				170		310				320		510		
c, 887-2B = 50% 887-2 + 50% 578		195		415				385		610				600		810		
a, 891a	10		30		10	150	15		30		70	280	90		90		245	545
891[a]			235						615						875			
b, 891A = 75% 891 + 25% 578		235		415				355		615				490		780		
c, 891B = 50% 891 + 50% 578		440		665				525		875				670		1190		
a, 902		50[b]		75[b]				80		280				115		695		
c, 902A = 50% 902 + 50% 997		240[b]		525[b]				705		975				950		1460		

[a] Soil washed in water for one minute, prior to molding specimens
[b] Two-day tests

with 14 per cent cement. Fifty per cent soil 578 further increased the 14 per cent cement strength to 875 lb. Other data in Table 3

Also included in Table 3 are some data showing the effect of washing soils 887-2 and 891. This washing consisted of stirring the soil in water, and then pouring the wash water off after a minute of settlmg. The fact that this washmg vastly improved the soils shows that the relatively poor gradation of the soils (deficient in silt and clay) is not an important factor in their poor reaction with cement.

1543 It will be noted that these three admixture soils represent a wide range in texture Thus the data from the compressive strength tests made using these soils given in Figure 3, show the effect of the texture of the admixture soil upon its effectiveness.

TABLE 4
GRADATION AND OTHER TEST DATA OF SOILS COMPRESSIVE STRENGTH OF WHICH ARE SHOWN IN FIGURE 3

Soil No	Soil Horizon	Gravel	Sand·		Silt	Clay	Organic Content	Physical Test Constants		Textural Class	U S P.R A. Soil Group
		No 4 to No 10 (2 0 mm)	2 0 to 0 25	0 25 to 0 05	0 05 to 0 005	0 005 to 0 000		L L	P. I		
			mm	*mm*	*mm.*	*mm*	*p p m*				
1543	"B"	0	41	51	4	4	1,500	23	N P.	Fine Sand	A-3
1497	"C"	0	0	23	71	6	Trace	27	7	Silt Loam	A-4
1528	"C"	0	0	13	57	30	Trace	29	12	Silty Clay	A-4
1554	"B & C"	3	5	13	32	47	Trace	46	28	Clay	A 7

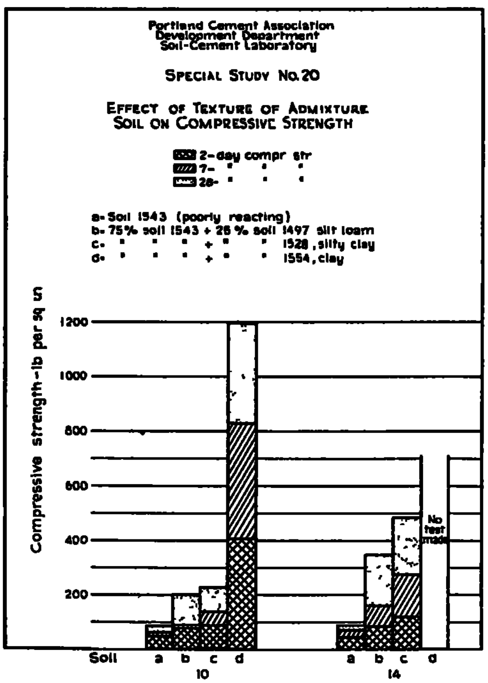


Figure 3

EFFECT OF TEXTURE OF ADMIXTURE SOIL

Table 4 shows gradation and other data for a poorly reacting sand, soil 1543, from New Hampshire, and for three other soils, 1497, 1528 and 1554, used as admixture soils with

Judging from the data in Figure 3, clay soil 1554 is by far the most effective admixture soil The addition of 25 per cent of this soil to 75 per cent soil 1543, raised the seven-day compressive strength (10 per cent cement) of soil 1543 from 55 lb per sq. in to 830 lb This is outstanding The addition to soil 1543 of 25 per cent soils 1497 and 1528 is beneficial, but the data indicate a greater percentage of these admixture soils is necessary for better results

Figure 3 show that the effectiveness of the admixture soils increases as the clay content increases This indicates that it is the clay portion of the soil that combats the evil character of the poorly reacting sand soil 1543. Other available data also show that the heavier textured soils make the best admixtures. However, this isn't necessarily a rule since as shown in Table 3, soil 997 which contains only 10 per cent clay, was a very effective admixture with soil 902.

EFFECT OF SOIL HORIZON AND SOIL ADMIXTURE

Table 5 shows gradation and other data for two poorly reacting sandy soils 1523 and 1524, one well reacting sandy soil 1525, and one admixture silty clay soil 1528; all from Vermont The sand soils were taken from the same soil profile at the depths shown in Table 5 (Note. This soil profile had thin "A" and "B" horizons and is not representative of an average soil profile) Thus compressive strength date for these soils, given in Figure 4 show the effect of soil horizon upon reaction with cement. It is obvious from these data that the greater the depth below ground surface from which the soil was taken, the better corresponding strength of 180 lb. for "B_1" horizon soil 1523.

Figure 4 also shows that admixture soil 1528 improves soils 1523 and 1524 so that they

TABLE 5

GRADATION AND OTHER TEST DATA OF SOILS, COMPRESSIVE STRENGTHS OF WHICH ARE SHOWN IN FIGURE 4

Soil No	Soil Horizon and Depth Below Ground Surface Samples	Gradation—Per Cent of Total					Organic Content	Physical Test Constants		Textural Class	U S P R A Soil Group
		Gravel No 4 to No 10 (2.0 mm)	Sand		Silt 0.05 to 0.005	Clay 0.005 to 0.000		L L	P. I		
			2.0 to 0.25	0.25 to 0.05							
			mm	*mm*	*mm*	*mm*	*p p m*				
1523	"B", 4 to 11 in	3	38	41	14	4	1800	19	N P	Loamy Sand	A-2
1524	"C_1", 12 to 18 in	5	48	41	3	3	300	21	N P	Sand	A-3
1525	"C_2", 22 to 37 in	10	70	19	1	0	Trace	22		Coarse Sand	A-3
1528	"C", 24 to 120 in		0	13	57	30	Trace	29	12	Silty Clay	A-4

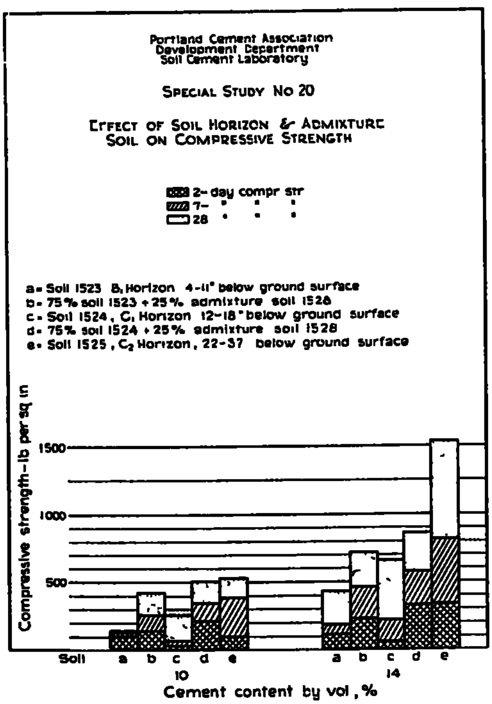


Figure 4

was its reaction with cement For instance, the 7-day compressive strength of 805 lb. per sq in for "C_2" horizon soil 1525 with 14 per cent cement, is vastly superior to the corresponding strength of 215 lb for "C_1" horizon soil 1524, which in turn is greater than the

react fairly well with cement As might be expected, soil 1524 which represents a deeper horizon than soil 1523 and which reacts better with cement than soil 1523 without admixture, also reacts better with cement when mixed with 25 per cent admixture soil 1528.

PART II

RESULTS OF CALCIUM CHLORIDE ADMIXTURE TESTS

The $CaCl_2$ tests included nine soils, four of which are poorly reacting sandy soils and five are normally reacting soils of various textures As shown in Table 6, the poorly reacting sandy soils require 22 per cent or more cement for satisfactory hardening, and the normally reacting soils require 8 to 12 per cent cement.

PLAN OF TESTS

Compressive strength tests at various ages up to 120 days (1 and 5 yr. breaks will be reported later), and A S T M wet-dry and freeze-thaw tests, extended to 36 cycles, were made to measure the effect of commercial $CaCl_2$ upon soil-cement mixtures made from these soils Cement contents ranging from 6 to 26 per cent by volume and $CaCl_2$ admixtures of 0.2, 0.4, 0.6, 1.0, 2.0 and 4.0 per cent by weight of oven-dry soil were investigated.

For soil-cement having a dry density of 112 lb. per cu ft and 12 per cent cement by volume, (11.28 lb. cement per cu ft soil-cement) these percentages of $CaCl_2$ based on weight of cement are 1 77, 3.55, 5 32, 8 87, 17 46 and 34 31 or almost ten times the percentage by weight of soil See Table 7, for additional comparative data Commercial $CaCl_2$ which was 77 to 80 per cent actual $CaCl_2$ was used in all tests and percentages refer to percentages of the commercial product Both zero-hour[2] and four-hour[2] damp mixing times were studied to investigate the effect of the mixing period on the cement and $CaCl_2$ reaction with the soil. A brief review of the testing follows·

TABLE 6
GRAIN SIZE AND TEST CONSTANTS OF SOILS TESTED

P C A Soil No	Required Cement Content	Gradation—Percentage of Total					Physical Test Constants			Textural Class	Organic[b] Content	U S P R A Soil Group
		Gravel[a]	Sand		Silt	Clay						
		No 4 to No 10 (2 0 mm)	2 0 to 0 25	0 25 to 0 05	0 05 to 0 005	0 005 to 0 000	L L	P I	S L			
	vol %		mm	mm	mm	mm					p p.m.	
2a-6	8	0	26	57	6	11	14	N P	20	Loamy Fine Sand	500	A-2
4d	12	0	1	8	67	24	34	14	16	Silty Clay Loam	Trace	A-4
7h	12	2	6	9	36	47	37	18	16	Clay	Trace	A-7
3255-2	8	10	26	33	23	8	21	5	16	Sandy Loam	Trace	A-2
3566	10	12	81	7	0	0	14	N P		Coarse Sand	Trace	A-3
3556	+26	0	11	86	3		10	N P		Fine Sand	11,000	A-3
3564	22	1	62	21	16		15	N P		Loamy Coarse Sand	11,000	A-2
3565	+26	1	68	27	4		19	N P		Coarse Sand	4,000	A-3
3567	+26	0	10	87	3		21	N P		Fine Sand	7,000	A-3

[a] When received from the field some of these soils contained material coarser than the No 4 sieve, but to simplify laboratory technique this coarse material was not included in the test specimens
[b] As determined by the 3% NaOH colorimetric method

TABLE 7
COMPARISON OF CALCIUM CHLORIDE PERCENTAGES BY WEIGHT OF SOIL AND BY WEIGHT OF CEMENT

$CaCl_2$ by wt of soil	$CaCl_2$ by wt of cement, per cent					
	Cement Content by Vol , per cent (Soil-cement-$CaCl_2$ density = 112 lb per cu ft)					
	6	10	14	18	22	26
%						
0 2	3 72	2 13	1 52	1 12	0 87	0 70
0 4	7 45	4 36	2 96	2 25	1 74	1 43
0 6	11 17	6 49	4 41	3 37	2 61	2 13
1 0	18 62	10 85	7 45	6 56	4 35	3 56
2 0	37 06	21 38	14 74	10 99	8 66	7 04
4 0	72 52	42 02	28 86	21 63	16 97	13 79

A. *Moisture-Density Tests*

1 Sufficient A S.T.M. moisture-density tests were made on soil-cement mixtures and soil-cement-$CaCl_2$ mixtures at 0-hr and 4-hr. preliminary mixing, to permit proper interpolation and extrapolation for optimum moisture and maximum density required for molding test specimens for all mixtures

B *Compressive Strength Tests*

1 Standard (zero-hour) mixing. Compressive strength tests were made using all nine soils, investigating 4 to 6 different cement contents ranging from 6 to 26 per cent by volume and six different $CaCl_2$ percentages ranging from 0 2 to 4 0 per cent by weight of oven-dry soil.

2 Four-hour mixing Compressive strength strength tests were made using four soils (two good and two poor), investigating two or four different cement contents and three or four different percentages of $CaCl_2$ All $CaCl_2$ was added during the first two hours of the mixing period, except in tests according to paragraph D.1.

C. *Wet-Dry and Freeze-Thaw Tests*

1. Standard (zero-hour) mixing. Wet-dry and freeze-thaw tests were made using all soils, investigating two to five different cement

[2] Zero-hour mixing refers to the short mixing period given to a soil-cement mixture when molding specimens according to A S T M designation. D559-40T and D560-40T (wet-dry and freeze-thaw tests) Four-hr mixing refers to the mixing period extended to this length of time and used when molding special specimens to investigate the effect of lengthy mixing periods common with "mixed-in-place" construction procedures See p 505 for details

contents with 1, 2, or 3 different $CaCl_2$ percentages for each cement content.

2. *Four-hour mixing* Wet-dry and freeze-thaw tests were made using four soils (two good and two poor), investigating two to four cement contents and 1, 2 or 3 per cent $CaCl_2$ with each cement content.

The $CaCl_2$ in all the foregoing tests was added to the soil-cement mixtures as a part of the mixing water, since this is one of the most practical and simple methods of addition to guarantee good dispersion However, to determine whether the effectiveness of the $CaCl_2$ was dependent upon the manner in which it is added, the following tests were made

D. *Special Tests Varying Manner in which $CaCl_2$ was added*

1. Compressive strength tests were made, with two soils (one good and one poor), investigating three cement contents and one percentage of $CaCl_2$ added in solution or as dry flakes, and by various laboratory methods to simulate field construction procedures The field procedures simulated varied from those encountered with a plant mix, where soil, cement, $CaCl_2$ and water can all be added and mixed in a relatively short time, to a mixed-in-place operation involving prewetting where the soil or soil-$CaCl_2$ mixture is dampened and the mixture permitted to rest undisturbed for approximately 18 hours before adding cement and proceeding with construction.

SPECIAL LABORATORY PROBLEMS

$CaCl_2$ Control· To facilitate the addition of $CaCl_2$ in most of these tests, the chemical was dissolved in water at the rate of 50 g to 100 cc. of solution. Thus it was a simple matter to add $CaCl_2$ to the mixture, since each cc. of solution contained ½ g of commercial $CaCl_2$ However, additional calculations were necessary to determine the quantity of water added with the $CaCl_2$ as this quantity would be a part of total water requirements One cc of solution contained ½ g of commercial $CaCl_2$ but tests showed the $CaCl_2$ to be 79 7 per cent solids and each cc therefore contained 79 7 per cent × 0 5 or 0 3985 g of pure $CaCl_2$ The specific gravity of the solution was 1 28 g per cc and, therefore, the weight of water per cc. of solution was 1 28 − 0 3985 or 0 88 g Thus, each 100 cc. solution was made up of 88 cc water and 40 g. pure $CaCl_2$ These data were used when designing water quantities required to be added to each mixture for molding compressive strength and wet-dry and freeze-thaw specimens

Four-Hour Mixing In accordance with A S T M Test Methods D559–40T and D560–40T (wet-dry and freeze-thaw tests) the specimens are molded immediately after mixing the soil, cement and water Most of this series of tests on the effect of $CaCl_2$ were made by following this procedure However, to see if the effect of $CaCl_2$ would vary with the length of mixing period a number of tests were made with soil-cement-$CaCl_2$ mixtures that were damp mixed 4 hr before compacting specimens Since in these tests the optimum moisture content of the mixture changes with the length of mixing time it was necessary to conduct special moisture-density tests to determine the optimum moisture content and maximum density of the mixtures after the 4-hr damp mixing period

When determining the 4-hr moisture-density relations of a soil-cement mixture, the air-dry mixture is mixed with a small increment of water every 20 min so that at the end of 4 hrs the mixture is about 1 per cent below the zero-hour (standard method A S.T M D558–40T) optimum moisture content During the 20-min interval between the addition of increments of water the mixture rests undisturbed After 4 hr , the damp mixture is packed into the moisture-density mold to obtain the first point on a 4-hr moisture-density curve. Additional density tests are then made at increased moisture contents to develop completely the maximum density and optimum moisture content for the mixture that has had a 4-hr intermittent damp mixing period The 4-hr optimum is usually about 1 to 3 per cent wetter than the zero-hour optimum, and the maximum density is somewhat lower than zero-hour maximum density.

When determining the 4-hr moisture-density relations of soil-cement-$CaCl_2$ mixtures the $CaCl_2$ was added during the first 2 hrs of the 4-hr preliminary mixing period. Thus during the last 2 hr all of the $CaCl_2$ being investigated was in the mix. In all 4-hr mixing tests the water (or water-$CaCl_2$ solution) was added in equal increments at

20 min. intervals, and mixed in for about 1 min.

When molding compressive strength specimens and wet-dry and freeze-thaw specimens after 4 hr damp mixing one-half of the total water required to bring the mixture to 4-hr. optimum and all the $CaCl_2$ were added during the first 2 hr. of mixing Then during the next 2 hr of mixing, the remaining one-half water was added.

PRESENTATION OF RESULTS

Five normally reacting soils and four poorly reacting sandy soils were included to investigate the effect of calcium chloride upon soil-cement mixtures. Comprehensive tests were made using these nine soils In addition, a few exploratory tests were made using three poorly reacting silty soils (these soils have not been mentioned heretofore, data available are limited but are being included since they indicate a trend) Results and an interpretation of the data are presented in the following sequence

1 Data for four poorly reacting sandy soils, Nos 3556, 3564, 3565, and 3567
2 Data for three poorly reacting silty soils, Nos 3611, 3678, and 3679
3 Data for five normally reacting soils, Nos. 2a-6, 4d, 7h, 3255-2, and 3566
4 Data showing effect of $CaCl_2$ when added by five different methods.

Notes on Interpretation of Data

At the present time it is assumed that a soil-cement mixture, to be considered satisfactorily hardened, must meet the following wet-dry, freeze-thaw, and compressive strength criteria

1 Soil-cement losses during 12 cycles of either the wet-dry test or freeze-thaw test (A S T.M Designations· D559-40T and D560-40T) shall conform to the following limits

U S P R A soil classifications A-1, A-2, and A-3, not over 14 per cent.

U.S P R A soil classifications A-4,[3] and A-5,[3] not over 10 per cent

U S P R.A soil classifications A-6,[3] and A-7,[3] not over 7 per cent

[3] Caution should be exercised when testing the heavier-textured soils to see that all scale and "shell" that may have developed on the specimens have been removed before final weighing

2. Compressive strengths shall increase with age and with increases in cement content in the ranges of cement content producing results meeting requirement 1.

Soil-cement mixtures passing these criteria serve as suitable secondary road bases which are generally covered with a relatively thin bituminous wearing surface If the bituminous mat construction is to be postponed for sometime, cement contents higher than those indicated satisfactory by these criteria should be used.

In utilizing these criteria, compressive strength data are first obtained on soil-cement specimens containing various percentages of cement say 6, 10, and 14 per cent by volume. These data show how well the soil is reacting with cement, and aid in the selection of a suitable cement content range to include in specimens for the wet-dry and freeze-thaw tests If the soil is reacting poorly, higher cement contents must be investigated

To develop this idea further and to facilitate interpretation of data, certain assumptions based on previous testing experience have been made as to the relation between compressive strength data and wet-dry and freeze-thaw data It will be apparent from this discussion that the compressive strength criterion alone will not establish the most economic quantity of cement to adequately harden a soil However these assumptions will permit the molding of the minimum number of wet-dry and freeze-thaw specimens after the compressive strength data have once been obtained

Experience has shown that most soil-cement mixtures which satisfactorily meet the foregoing criteria in the A S T M wet-dry and freeze-thaw tests, have a compressive strength at 7-days (the age at which they start the A S T M tests) of more than about 300 lb per sq in The assumption can be made therefore that specimens molded for the wet-dry and freeze-thaw test must include soil-cement mixtures that contain sufficient cement to have a 7-day strength of about 300 lb. per sq. in

This does not mean that any soil-cement mixture having a compressive strength at 7 days of over 300 lb per sq. in will satisfactorily meet the criteria It does mean however, that any mixture this strong has sufficient possibility of being satisfactory to warrant molding wet-dry and freeze-thaw specimens for test On the other hand, if a soil-cement mixture had a 7-day strength of 500 lb. per sq in, test records show it is almost certain to have less soil-cement loss than required to meet the criteria.

From this it is apparent that some lesser and thus a more economical cement content (than required to give a 500-lb strength) is likely to meet the wet-dry and freeze-thaw criteria. However, if a particular soil-cement mixture has a compressive strength at 7 days as low as 150 lb. per sq. in. it very likely would not pass the wet-dry and freeze-thaw tests, and there would be little value in molding test specimens having as low a cement content as in this mixture Even though this same mixture attained a 28-day strength of 600 lb it still likely would not pass the test criteria, since in the A S.T.M. tests, the specimens start in test when they are 7 days old. The basic idea involved in this thought is that unless a soil-cement mixture is reacting well enough in seven days to subsequently withstand the A S T.M soil-cement tests successfully, it should not be used in construction except under special conditions.

Data for the Four Poorly Reacting Sandy Soils

Soil No 3556. This is an unusually poorly reacting surface sand soil from Savannah, Georgia. On the basis of the compressive strength data in Figure 5 it can be assumed that more than 26 per cent cement would be required to harden this soil so that it would pass the wet-dry and freeze-thaw tests. Freeze-thaw and wet-dry data in Table 8, substantiate this assumption and indicate that more than 30 per cent cement is required to adequately harden the soil. However, compressive strength data show through the use of 0.4 to 4.0 per cent $CaCl_2$ the soil can be treated so that 14 per cent cement will adequately harden it For instance the 7-day compressive strength of a 14 per cent cement 0.6 per cent $CaCl_2$ mixture is 450 lb. per sq in.

From a standpoint of economics, study of Figure 5 indicates that a $CaCl_2$ content of 0.4 to 0.6 per cent seems to be the optimum amount, since this quantity gives adequate 7 and 28-day strength results with all cement contents of 14 per cent and over. On the basis of adequate strength at 2 days, 2 per cent is the optimum

As a result of this economic analysis, wet-dry and freeze-thaw specimens were molded using this soil with 12 per cent cement and 1 per cent $CaCl_2$, and 14 per cent cement and 0 5 per cent $CaCl_2$, since compressive strength data indicated that these would be the most economical mixtures that were likely to be sufficiently well hardened to pass test criteria on page 506.

According to the wet-dry and freeze-thaw test data in Table 8, either 12 per cent cement plus 1 0 per cent $CaCl_2$, or 14 per cent cement and 0 5 per cent $CaCl_2$ will adequately harden this soil so that it will pass these tests More detail testing might establish some $CaCl_2$ content with a slightly lower cement content as adequate Exact compressive strength data are not available for these mixtures, but interpolations can be made from available data. On this basis, the 12 per cent–1 per cent mixture would have a strength of about 450 lb. per sq in, and the 14 per cent–0.5 per cent mixture about 430 lb. Since these mixtures cost about the same, and since they have equal resistance to alternate wetting and drying and freezing and thawing and equal compressive strength, there is little choice to make between them.

TABLE 8
WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS[a] DATA
(Based on original oven-dry weight)
SOIL No 3556

Type of Test	Wet-Dry Loss, %		Freeze-Thaw Loss, %			
Specimen	a	b	c	d	e	f
Cement Content by Vol, %	12	14	26	30	12	14
$CaCl_2$ by wt of soil, %	1 0	0 5	0	0	1 0	0 5
12 Cycles	3	2	95	84	2	2
24 Cycles	8	4	100	100	6	4
36 Cycles	11	8			18	15

[a] Losses shown are cumulative

Soil No 3564 This soil is a poorly reacting "A" horizon surface sand soil from Berrien County, Michigan. According to compressive strength data in Figure 6 about 22 per cent cement would be required to adequately harden it The compressive strength for this mixture of 7 days is 370 lb per sq. in. This hypothesis is substantiated by the wet-dry

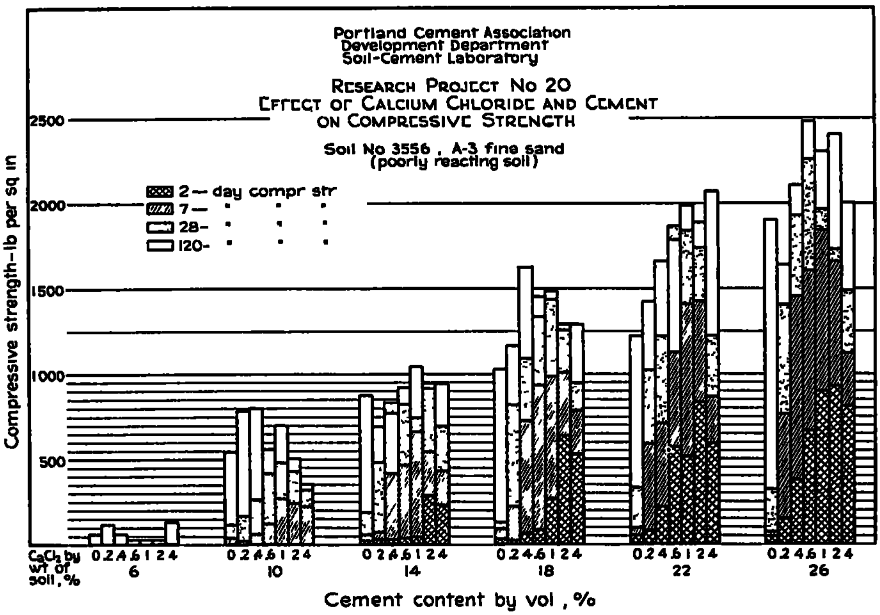


Figure 5

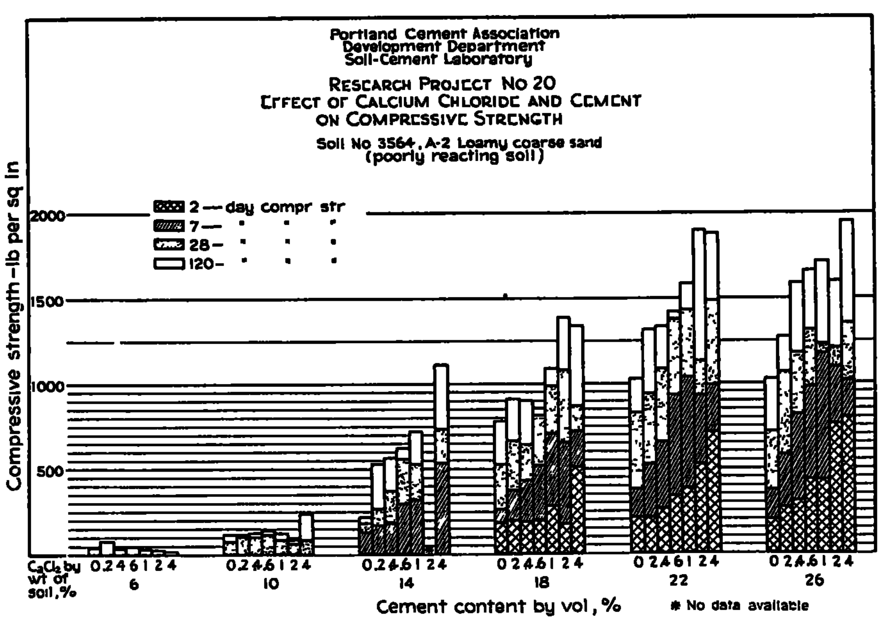


Figure 6

and freeze-thaw data in Table 9 According to these data, 20 per cent cement is not enough to properly harden the soil, whereas 22 per cent is The substantial difference in soil loss in the freeze-thaw test brought about by increasing the cement content only 2 per cent, from 20 per cent to 22 per cent, should be especially noted.

The compressive strength data further show that the use of 1.0 per cent $CaCl_2$ with 14 per cent cement gives a 7-day strength of 315 lb. per sq. in., and 18 per cent cement gives 710 lb. per sq. in. Therefore, on the basis of strength analysis alone, it is indicated that about 14 per cent or 16 per cent cement will properly harden this soil if 1 per cent $CaCl_2$ is used as an admixture. Specimens of this design were molded and subjected to the

TABLE 9

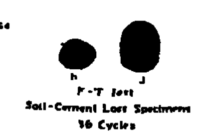
WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS[a] DATA

(Based upon original oven-dry weight of specimens)

SOIL No. 3564

Type of Test	Wet-Dry Loss, %		Freeze-Thaw Loss, %						
Specimen No	a	b	c	d	e	f	g	h	j
Cement Content by Vol., %	20	14	20	22	24	14	16	14	14
$CaCl_2$ by wt. of soil, %	0	1.0	0	0	0	1.0	1.0	2.0	3.0
12 Cycles	1	1	44	2	2	17	9	56	19
24 Cycles	2	3	57	4	3	35	21	71	24
36 Cycles	3	6	69	7	5	46	36	77	28

[a] Losses shown are cumulative.



A.S.T.M. soil-cement tests. The results of the freeze-thaw tests given in Table 9, show that the mixture containing 1 per cent $CaCl_2$ and 14 per cent cement to be on the borderline of acceptability and the mixture containing 1 per cent $CaCl_2$ and 16 per cent cement to be satisfactory. The specimen with 14 per cent cement and 2 per cent $CaCl_2$ is not as good as the specimens with 1 per cent $CaCl_2$, and the specimens with 3 per cent $CaCl_2$ are about as good as the 1 per cent specimen. This appears to be an inconsistency. As the importance of the inconsistency was minor compared to the objective of the investigation, no additional tests were made to check it

The compressive strength data as a whole show that the 4-per cent $CaCl_2$ admixture gives a little more effective reaction than lower contents, especially at the early age of 2 days. However, at the end of 7 days, 1 per cent $CaCl_2$ admixture is practically as effective as 4 per cent and even 0 6 per cent gives a good account of itself.

Soil No. 3565 This is a poorly reacting "B" horizon surface sand from Ft. Devens, Massachusetts. Specimens were molded with this soil both in the standard method (called zero-hour mix) and after the soil-cement had been intermittently damp mixed 4 hours (called four-hour mix).

Zero-Hour Mix: According to compressive strength data in Figure 7, more than 26 per cent cement would be required to harden it. $CaCl_2$ is again very effective and 2 per cent with 14 per cent cement gives a 7-day strength of 570 lb per sq. in. Although there are no data for 16 per cent cement specimens, an interpolation can be made which gives a 7-day strength of about 490 lb. for specimens containing 0 6 per cent $CaCl_2$.

Wet-dry and freeze-thaw data in Table 10, show that 14 per cent cement and 1 per cent $CaCl_2$ or 16 per cent cement and 0 5 per cent $CaCl_2$ will adequately harden the soil. However, 12 per cent cement and 1 per cent $CaCl_2$ and 14 per cent cement at 0 5 per cent $CaCl_2$ do not give satisfactory results These data

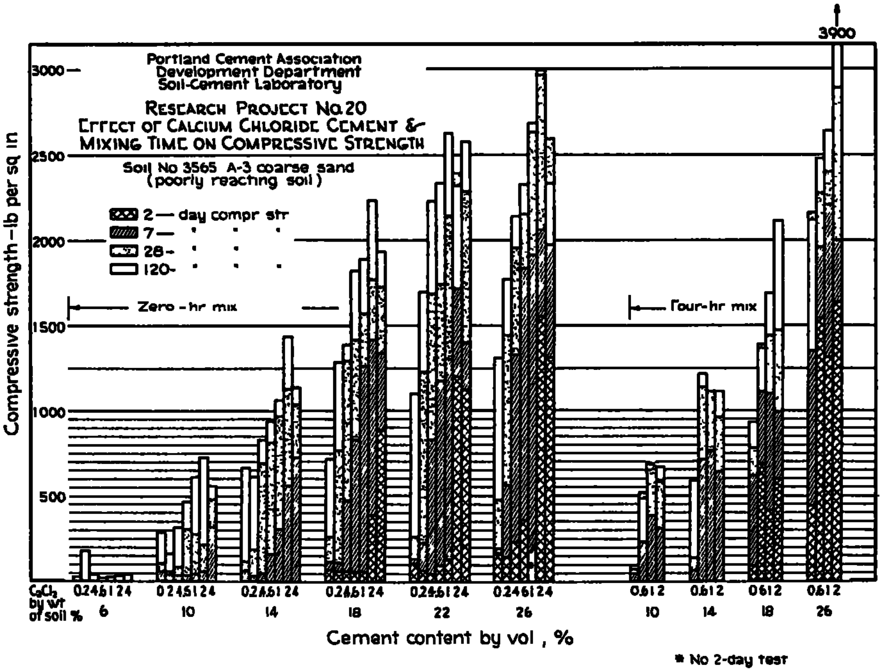


Figure 7

TABLE 10

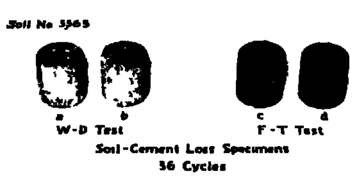
WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS[a] DATA

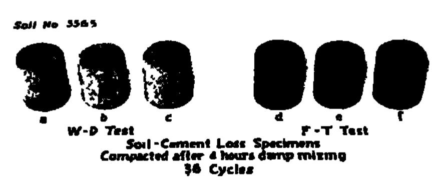
(Based upon original oven-dry weight of specimens)

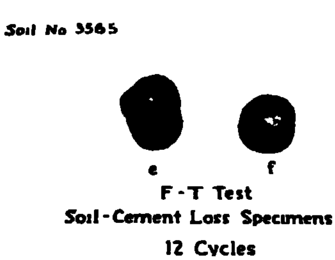
Soil No 3565

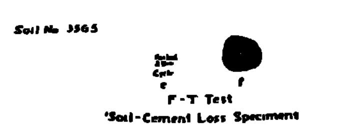
Mixing Time	Zero Hour						Four Hours					
Type of Test	Wet-Dry Loss, %		Freeze-Thaw Loss, %				Wet-Dry Loss, %			Freeze-Thaw Loss, %		
Specimen No	a	b	c	d	e	f	a	b	c	d	e	f
Cement Content by Vol, %	16	14	16	14	14	12	26	14	16	26	14	16
$CaCl_2$ by wt of soil, %	0.5	1.0	0.5	1.0	0.5	1.0	0	1.0	0.5	0	1.0	0.5
12 Cycles	1	1	1	2	48	67	0	3	1	1	2	2
24 Cycles ...	2	3	2	3	79	72	0	4	2	1	4	3
36 Cycles	3	4	3	4	100	74	1	5	3	1	5	3

[a] Losses shown are cumulative









are in close agreement with the compressive strength data

On the basis of the all-around data it appears that specimens containing 1 per cent $CaCl_2$ are slightly superior to those containing 0 5 per cent $CaCl_2$, and might be considered the optimum amount with this soil. For high 2-day strengths 2 per cent $CaCl_2$ is the most effective.

Four-Hour Mix: Previous research has shown that a lengthy damp mix is likely to be beneficial to poorly reacting sandy soils This good as the 0-hr. specimens. These results appear obvious from the compressive strength data This is important since it shows that even with a long damp mixing period a "flash set" of the cement used in these tests does not occur In fact, on the basis of these data, it appears that a 4-hr damp mix is actually a safety factor for these poorly reacting sandy soils.

Soil No. 3567. This is a poorly reacting "A" horizon surface sand from Camp Perry, Florida As was the case with Soil No. 3565,

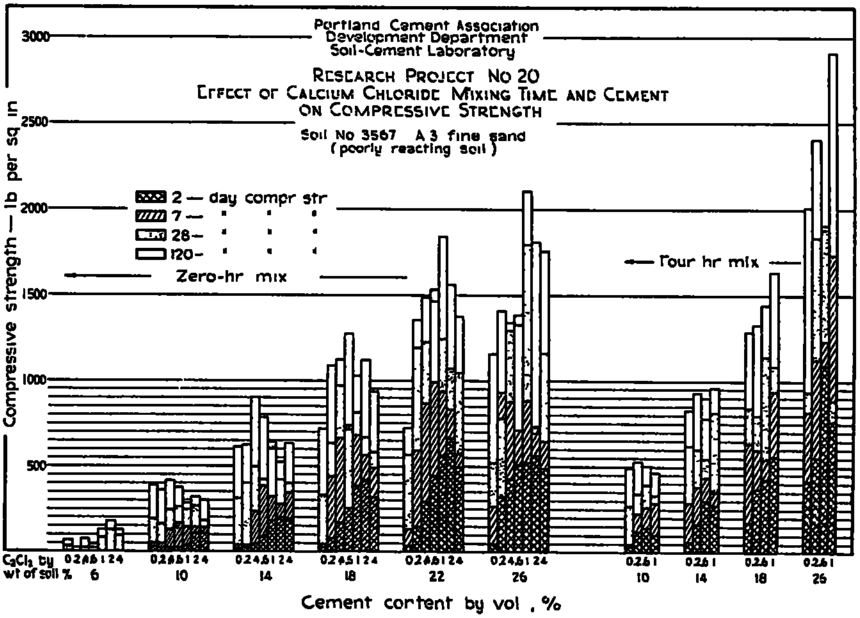


Figure 8

phenomenon is gain shown to be true in the present investigation For instance, at 0-hr. mix, 14 per cent cement and 0 6 per cent $CaCl_2$ gives a 7-day compressive strength of 150 lb per sq in , whereas at 4-hr mix, the same combination gives 710 lb per sq in. Similar data are shown for the soil-cement specimens containing no $CaCl_2$ As an example the 0-hr mix 18 per cent cement specimen has a 7-day strength of 125 lb. per sq. in , and the 4-hr mix has a strength of 615 lb per sq in

It is of interest to note the very high 120-day strength of 3,900 lb per sq in for the 26 per cent cement-2 per cent $CaCl_2$ mixture

The wet-dry and freeze-thaw data for the 4-hr mix specimens show them to be just as both 0-hr and 4-hr mix specimens were tested.

Zero-Hour Mix· According to the compressive strength data in Figure 8, about 26 per cent cement would be required to harden this soil. Again $CaCl_2$ is effective and 14 per cent cement with 0 6 per cent $CaCl_2$ is indicated to be a satisfactory mixture The 7-day strength of this 14 per cent–0 6 per cent mixture is 380 lb per sq in

Wet-dry and freeze-thaw data in Table 11 substantiate this hypothesis and show that 14 per cent cement with 0 6 per cent $CaCl_2$ will adequately harden this soil The data also show that 27 per cent cement without

$CaCl_2$ will make a durable mixture that will pass the wet-dry and freeze-thaw tests

From a standpoint of high early strength at 2 days, 2 per cent $CaCl_2$ is the most effective. However from an over-all standpoint of strength, durability and cost, 0.6 per cent $CaCl_2$ appears to be the optimum quantity.

Four-Hour Mix· As in the case of Soil No. 3565, 4 hr. of intermittent damp mixing is beneficial to this soil. For instance, the 0-hr. mix 18 per cent cement mixture without $CaCl_2$ has a 7-day compressive strength of only 50 lb. per sq. in., whereas the 4-hr. mix specimen has a strength of 635 lb per sq in. The compressive strength of the soil-cement $CaCl_2$ mixtures are likewise increased by the 4-hr mix.

cement to harden, whereas the cement content required to harden the average silt soils is 10 to 14 per cent.

The gradation and physical test constants for these three soils are shown in Table 12, and compressive strength data and freeze-thaw data are shown in Table 13.

Although these data are limited they indicate that $CaCl_2$ improves the reaction of these surface silt soils. For instance, Soil 3611, with 11 per cent cement has a freeze-thaw loss of 47 per cent whereas the 11 per cent cement–1 per cent $CaCl_2$ mixture has only 6 per cent loss. Although the data show little difference in the effect of 1, 2 and 3 per cent $CaCl_2$, the condition of the specimens definitely showed the 2 per cent $CaCl_2$ specimen to be best.

TABLE 11
WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS[a] DATA
(Based upon original oven-dry weight)
SOIL No 3567

Mixing Time	Zero-Hour						Four Hours	
Type of Test	Wet-Dry Loss, %		Freeze-Thaw Loss, %				W-D Loss, %	F-T Loss, %
Specimen No.	a	b	c	d	e	f		
Cement Content by Vol, %	27	14	27	29	14	15	14	14
$CaCl_2$ by wt. of soil, %	0	0 6	0	0	0 6	0 6	0 6	0 6
12 Cycles	1	1	1	1	4	3	3	4
24 Cycles	2	3	2	2	8	5	5	7
36 Cycles	3	5	4	4	14	9	6	9

[a] Losses shown are cumulative

The wet-dry and freeze-thaw data in Table 11, show little difference between the 4-hr. and the 0-hr. mix specimens.

Data for the Three Poorly Reacting Silt Soils

Soils Nos 3611, 3678, 3679. This project was set up to investigate the effect of $CaCl_2$ upon poorly reacting sand soils, but as mentioned on page 506 a few exploratory tests were made on three poorly reacting silty soils. These poorly reacting silty soils require less cement than the average poorly reacting sand soil, and since the occurrence of poorly reacting silty soils is not particularly extensive, they are not as an important a problem as the poor sand soils However, after preliminary tests showed that $CaCl_2$ was very effective with the sands the few tests reported were made to determine how the $CaCl_2$ would effect the silts. These poorly reacting silts are surface soils and require 15 to 20 per cent

TABLE 12
GRADATION AND PHYSICAL TEST CONSTANTS OF POORLY REACTING SILT SOILS

Soil No	Gradation, Per Cent			Physical Test Constants		Texture	U S P R A. Soil Group
	Sand 2 0 to 0 05 mm.	Silt 0 05 to 0 005 mm	Clay 0 005 to 0 000 mm	L L	P I		
3611	16	69	15	31	8	Silt Loam	A-4
3678	15	59	26	36	11	Silty Clay Loam	A-4
3679	35	40	25	35	14	Clay Loam	A-4

Based upon the tests for Soil 3611, 2 per cent $CaCl_2$ was used with Soils 3678 and 3679 in making a few exploratory tests. The data in Table 13 show a slight increase in 7-day compressive strength due to the $CaCl_2$, for both soils and a measurable influence in increased resistance to freezing and thawing for Soil 3678 There is an important question, however, whether the use of $CaCl_2$ will pay economically with these silty soils, particularly if 2 per cent is going to be required. A discussion on costs starts on page 525.

As a whole, these data show that $CaCl_2$ might have some value as an admixture with poorly reacting silty soils. Each case will require individual research to determine the optimum quantity of $CaCl_2$ to use and a special economic study will necessarily have to be made.

TABLE 13

COMPRESSIVE STRENGTH AND FREEZE-THAW DATA FOR POORLY REACTING SILT SOILS

Soil No.	Compressive Strength, lb per sq.in — Age when tested—days: 7 — Cement Content by Vol, Per Cent: 10	7: 14	7: 18	7: 22	28: 10	28: 14	28: 18	28: 22	Freeze-Thaw Losses, Percentage by Wt (12 Cycles) — Cement Content by Vol, Per Cent: 10	11	12	13	14	15	16	18
3611		405	440			435	730			47		18		4		
3611[a]										6						
3611[b]										5						
3611[c]										9						
3678		120	185	250		150	225	395					100		100	
3678[b]		155	225										54			19
3679	200	305			240	490			100		34		3			
3679[b]	225	345							73				11			

[a] One per cent $CaCl_2$ added, by weight of soil
[b] Two per cent $CaCl_2$ added, by weight of soil
[c] Three per cent $CaCl_2$ added, by weight of soil.

Data For The Five Normally Reacting Soils

Soil 2a-6 This is a normally reacting loamy fine sand soil made up of a combination of "B" and "C" horizon material, from Berkeley County, South Carolina. It is slightly slow-hardening at 2 days, but at 7 days has reached a strength comparable with other well-reacting soils of similar texture.

As shown by the wet-dry and freeze-thaw data in Table 14, the soil is satisfactorily hardened with 8 per cent cement. Soil losses at 12 cycles are 5 and 7 per cent respectively for the wet-dry and freeze-thaw test Ten per cent cement gives a mixture very resistant to alternate wetting and drying and freezing and thawing, as shown by soil-cement losses at 36 cycles of only 7 and 9 per cent respectively.

Specimens containing 0.5 per cent $CaCl_2$ and 7 and 9 per cent cement were tested to compare with 8 and 10 per cent cement specimens (without $CaCl_2$). The decision to use 0 5 per cent $CaCl_2$ was based on the compressive strength data in Figure 9, which shows maximum 7-day strengths with 0.4 to 0.6 per cent $CaCl_2$ (Also, according to the cost analysis on page 525, 0 5 per cent $CaCl_2$, on the basis on 120 lb density of soil-cement, and 9 per cent cement, costs 4 4 cents per sq yd. of pavement, or somewhat more than the 3 cents for 1 per cent of cement per sq. yd of pavement) From a cost standpoint, if $CaCl_2$ were to be practical, the 7 per cent cement-0.5 per cent $CaCl_2$ mixture should be better than the straight 8 per cent cement mixture, and the 9 per cent-0 5 per cent $CaCl_2$ mixture should compare favorably with 10 per cent cement mixture. The data in Table 14 show that the best mixtures are those containing cement alone, although the $CaCl_2$ mixtures are almost as good

Also included in Table 14 are data showing the relative volume change due to wetting and drying and freezing and thawing of straight soil-cement specimens as compared to soil-cement-$CaCl_2$ specimens. According to these data there is relatively little difference between the volume change characteristics of the two types of mixtures

On a strength basis at early ages, the cement-$CaCl_2$ mixtures are probably better than the straight cement mixtures of equal cost. At later ages there is relatively little difference between the mixtures

Therefore, since the straight cement mixtures have a slight advantage in the wet-dry cluded that the use of $CaCl_2$ with this soil would not be practical or economical

TABLE 14

WET-DRY AND FREEZE-THAW VOLUME CHANGE AND SOIL-CEMENT LOSS DATA

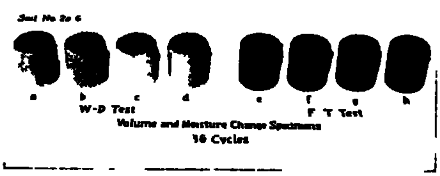
(Volume change is based upon original volume,[a] and loss[b] data are based upon original oven-dry weight)

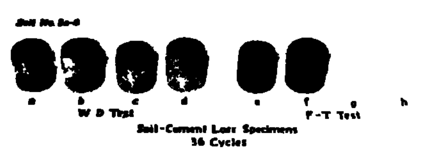
Soil No 2a-6

Type of Test	Wet-Dry, Per Cent								Freeze-Thaw, Per Cent							
	Loss	V. C	Loss	V C	Loss	V C	Loss	V C	Loss	V C	Loss	V C	Loss	V C	Loss	V C.
Specimen No	a	a	b	b	c	c	d	d	e	e	f	f	g	g	h	h
Cement Content by Vol , %	8		10		7		9		8		10		7		9	
$CaCl_2$ by wt of soil, %	0		0		0 5		0 5		0		0		0 5		0 5	
12 Cycles	5	0 0	3	−0 18	8	−0 10	2	−0 10	7	0 0	4	+0 07	9	+0 10	5	+0 21
24 Cycles	8	+0 05	4	−0 14	14	−0 10	3	−0 04	16	+0 16	8	0 0	17	+0 14	13	+0 25
36 Cycles	14	+0 19	7	−0 02	20	+0 10	8	+0 09	22	+0 32	9	+0 26	26	+0 26	14	+0 21

[a] Wet-dry volume change is given at the end of the wetting cycle, and freeze-thaw volume change at the end of the freezing cycle

[b] Losses shown are cumulative





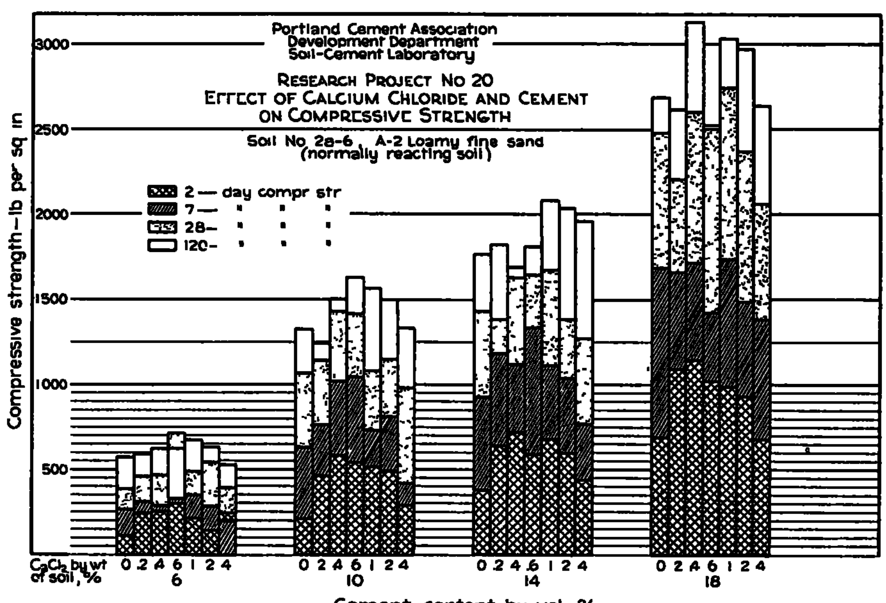


Figure 9

and freeze-thaw test, and since they have adequate strength at early ages (though less than the cement-$CaCl_2$ mixtures), it is con-

Soil 4d This is a normally reacting silty clay loam soil made up of a combination of "B" and "C" horizon materials from McHenry

County, Illinois. Tests were made using this soil both after 0-hour mixing and after 4-hour mixing.

Zero-Hour Mix· In the freeze-thaw test, specimens containing 10 per cent cement develop an outer shell or scale that comes off after 8 or 10 cycles resulting in high soil-cement losses; but with 12 per cent cement a very durable specimen is obtained In the wet-dry test, 12 per cent cement is adequate also, although there is a tendency for the specimens to crack, first at the compaction planes, and then other places

From a durability standpoint, however, it appears that $CaCl_2$ has a slight value For instance, the soil-cement losses for the 12 per cent cement specimen in the wet-dry test are 1, 14 and 21 at the end of 12, 24 and 36 cycles respectively. The 10 per cent cement–1.0 per cent $CaCl_2$ mixture had losses of 0, 4 and 14 per cent respectively. The main difference between these two mixtures was that the $CaCl_2$ specimens cracked less than the straight cement specimen. These mixtures are of about equal cost, with the straight cement mixture being slightly more economical.

TABLE 15

WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS DATA AND VOLUME CHANGE

(Volume change is based upon original volume[a], and loss[b] data are based upon original oven-dry weight)

Soil No 4d

Mixing Time	Zero Hour										Four Hours									
Type of Test	Wet-Dry Loss, %				Freeze-Thaw Loss, %						Wet-Dry Loss, %				Freeze-Thaw Loss, %					
Specimen No	a	b	c	d	e	f	g	h	i	j	a	b	c	d	e	f	g	h	i	j
Cement Content by Vol , %	12	14	10	12	12	14	11	10	12	9	12	14	10	12	12	14	11	10	12	9
$CaCl_2$ by wt of soil, %	0	0	1 0	1 0	0	0	0 5	1 0	1 0	2 0	0	0	1 0	1 0	0	0	0 5	1 0	1 0	2.0
12 cycles	1	0	0	0	1	1	1	2	1	5	13	5	8	3	2	2	2	20	2	9
24 cycles	14	8	4	2	1	1	2	4	2	8	48	26	34	22	50	24	37	52	10	27
36 cycles	21	25	14	12	5	4	5	7	4	13	66	62	60	39	83	63	75	79	21	51
Volume Change, %																				
12 Cycles 24 Cycles 36 Cycles	(1)−1 7		− 73 (2)		− 70 + 67 (3)		−.45 − 31 +.75		− 45 − 79 − 12		− 51 − 51 − 02		− 30 − 23 + 35		− 21 − 02 + 19		− 12 − 04 + 35		+.10 (4)	

[a] Wet-dry volume change is given at end of the wetting cycle, and freeze-thaw volume change at the end of the freezing cycle

[b] Losses shown are cumulative

(1) End of 6 cycles, specimen cracked at compaction plane

(2) No measurements after 12th cycle, specimen cracked at compaction plane

(3) Accurate measurements not possible after 29th cycle

(4) Bottom scaling slightly, no measurements

The effect of $CaCl_2$ upon this soil is shown in the wet-dry and freeze-thaw data, Table 15, and in the compressive strength data, Figure 10 Wet-dry and freeze-thaw tests were made investigationg 0 5, 1 and 2 per cent $CaCl_2$, although according to the compressive strength data in Figure 10 there is relatively no beneficial effect from adding $CaCl_2$ except in the case of the 18 per cent cement specimens at an age of 120 days. Even in this case the $CaCl_2$ is not economically beneficial since it requires 4 per cent $CaCl_2$ to have much effect The cost of such a large amount would be about 30 cents a sq. yd of pavement, which is about equal to the cost of 10 per cent cement and consequently not practical or economical.

Therefore, from a strength standpoint, it is concluded that $CaCl_2$ is not of value when mixed with this soil.

In the freeze-thaw test there was little difference between the specimens, with or without $CaCl_2$, when compared on a cost basis. The $CaCl_2$, however, is effective as shown by the 9 per cent cement–2 0 per cent $CaCl_2$ mixture The losses for this mixture were 5, 8 and 13 per cent respectively at 12, 24 and 36 cycles This shows the effectiveness of the $CaCl_2$ since previous data with this soil not included in this study, show high soil losses at 24 cycles with a straight 10 per cent cement mixture The cost of 2 per cent $CaCl_2$ however, is about 15 cents per sq yd of pavement, which is equal to the cost of about 5 per cent cement.

Since there is little doubt but that a straight 14 per cent cement mixture is better than a 9 per cent cement–2.0 per cent $CaCl_2$ mixture, it is concluded that the use of $CaCl_2$ is not economical or practical with this soil.

Also shown in Table 15, are volume change data for soil-cement and soil-cement-$CaCl_2$ specimens. These data show a slightly greater volume change for the specimens containing $CaCl_2$. For instance the 11 per cent cement-0 5 per cent $CaCl_2$ freeze-thaw specimen changed from a minus 0 30 per cent volume change at 12 cycles to plus 0.35 per cent at 36 cycles, whereas the straight 12 per cent cement specimen changed from minus 0.45 per cent to minus 0 12 per cent during the same periods

Four-Hour Mix· The compressive strength data show little beneficial effect from $CaCl_2$, except in the case of the 14 per cent cement-2 per cent $CaCl_2$ mixture at 120 days.

There is, however, some benefit apparent in the wet-dry and freeze-thaw test data For instance the 14 per cent cement specimen has wet-dry losses of 5, 26 and 62 per cent, after 12, 24 and 36 cycles of test respectively. In comparison to this, the losses for the 12 per cent cement-1 per cent $CaCl_2$ mixture, are 3, 22 and 39 per cent respectively. In the freeze-thaw test the losses for the same mixtures after the same number of cycles, are 2, 24 and 63 per cent and 2, 10 and 21 per cent, again showing some superiority for the 12 per cent cement-1 per cent $CaCl_2$ mix over the 14 per cent straight cement mixture.

Soil 7h. This is a normally reacting clay soil taken from the "B" and "C" horizons, in Lake County, Illinois.

According to Figure 11, the addition of $CaCl_2$ to this soil tends to have a slightly deleterious effect upon compressive strengths up to an age of 28 days. Because of this it was difficult to decide what $CaCl_2$ percentages to investigate in the wet-dry and freeze-thaw tests A choice was made to include tests on 0 4 per cent and 1 per cent $CaCl_2$. Data for these tests in Table 16, show no practical or economical value from the addition of the $CaCl_2$

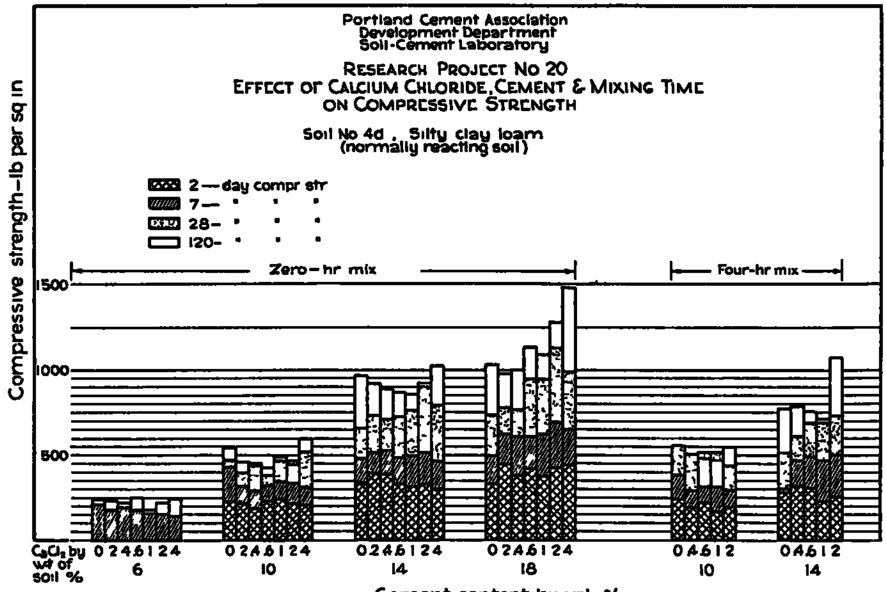


Figure 10

Soil 3255-2. This is a normally reacting sandy loam soil from Marfa, Texas. On the basis of the wet-dry and freeze-thaw data in Table 17, 8 per cent cement is adequate to harden it satisfactorily.

According to compressive strength data in Figure 12, $CaCl_2$ has little beneficial effect upon this soil at the early ages, and no one percentage appears to be the optimum quantity.

Wet-dry and freeze-thaw tests were made investigating the influence of 0.5 per cent $CaCl_2$ with 8 per cent and 10 per cent cement. These data, given in Table 17, show very little difference between the straight cement mixtures and the soil-cement-$CaCl_2$ mixtures. This indicates no practical or economic benefits from adding $CaCl_2$ to this soil.

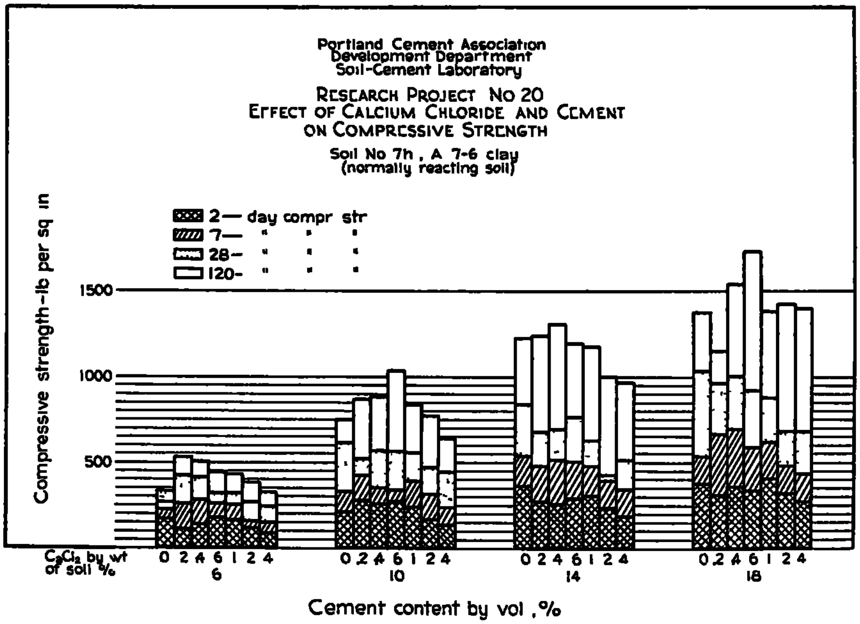
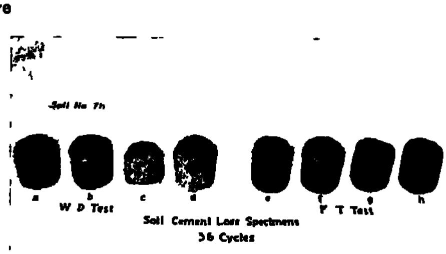


Figure 11

TABLE 16
WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS[a] DATA
(Based upon original oven-dry weight)
SOIL No. 7h

Type of Test	Wet-Dry Loss, %				Freeze-Thaw Loss, %			
Specimen No	a	b	c	d	e	f	g	h
Cement Content by Vol, %	12	14	12	12	12	14	12	12
$CaCl_2$ by wt of soil	0	0	0 4	1 0	0	0	0 4	1 0
12 Cycles	2	2	2	2	2	2	3	3
24 Cycles	4	4	4	4	4	4	6	6
36 Cycles	7	7	20	7	8	6	14	11

[a] Losses shown are cumulative



Soil 3566. This is a normally reacting coarse sand soil of "C" horizon origin from

Fort Devens, Massachusetts It was taken from the same area as Soil 3565 but from a horizon lower in the ground.

Both 0-hour and 4-hour tests were made using this soil.

Wet-dry and freeze-thaw data in Table 18 show that 10 per cent cement will adequately harden this soil. To determine the effect of $CaCl_2$ specimens were tested containing 0 5 per cent $CaCl_2$ and 9 and 11 per cent cement.

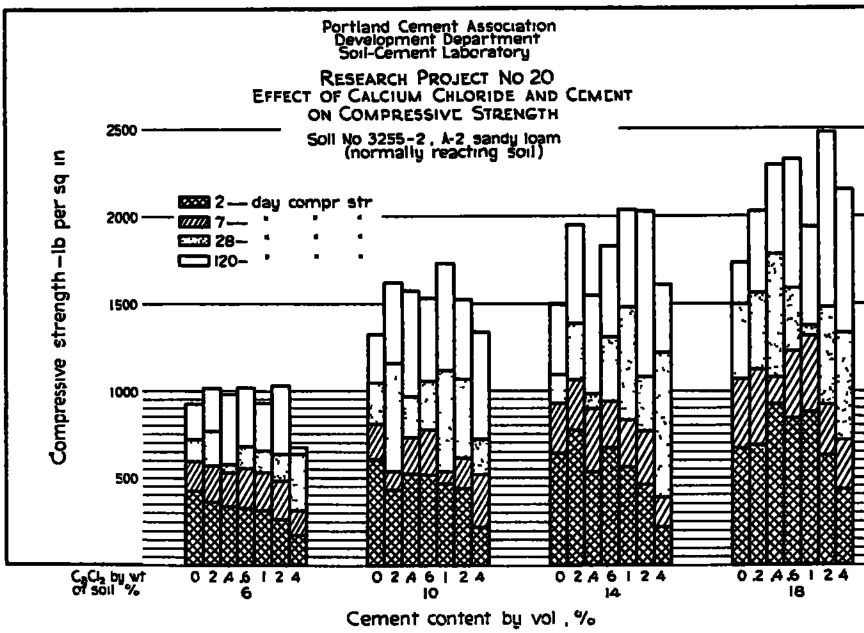


Figure 12

TABLE 17

WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS[a] DATA

(Based upon original oven-dry weight)

SOIL NO 3255-2

Type of Test	Wet-Dry Loss, %		Freeze-Thaw Loss, %			
Specimen	a	b	c	d	e	f
Cement Content by Vol, %	8	10	8	10	8	10
$CaCl_2$ by wt of soil, %	0	0	0	0	0 5	0 5
12 Cycles	6	3	4	2	2	1
24 Cycles	11	7	6	4	5	3
36 Cycles	19	13	9	7	9	4

[a] Losses shown are cumulative

Zero-Hour Mix The compressive strength data in Figure 13 show some increase in strength due to the addition of $CaCl_2$ in the range from 0 2 to 0.6 per cent. The increase, however, is not particularly significant, since the straight soil-cement mixtures are strong enough when containing sufficient cement for adequate durability.

The data in Table 18 show that these specimens were less resistant to the wet-dry and freeze-thaw tests than the specimens of slightly less cost containing 10 and 12 per cent cement For instance, at 12 cycles, the freeze-thaw specimens containing 10 per cent cement has a soil-cement loss of 7 per cent whereas the 9 per cent cement–0.5 per cent $CaCl_2$ has a loss of 14 per cent

Four-Hour Mix Compressive strength data in Figure 13 and wet-dry and freeze-thaw data in Table 18, show little difference between the straight soil-cement specimens, and the soil-cement-$CaCl_2$ specimens. In the compressive strength tests some slight increases are obtained with $CaCl_2$ but in the wet-dry and freeze-thaw tests there is a slight advantage in favor of the straight soil-cement mixtures over the soil-cement-$CaCl_2$ mixtures of equal cost.

In light of all the test data for this well reacting sand soil, it can be concluded that the addition of $CaCl_2$ is neither practical nor economical.

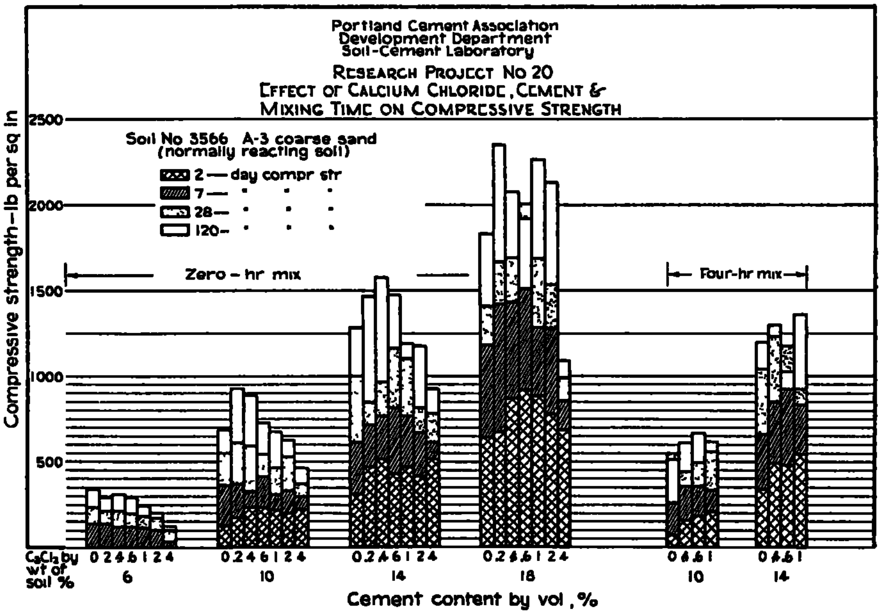
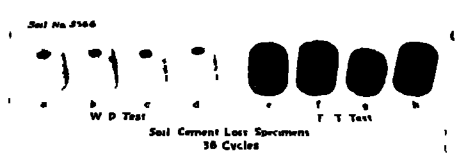


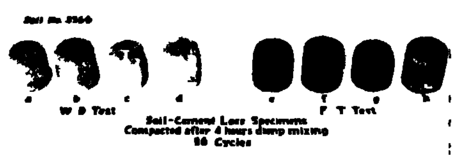
Figure 13

TABLE 18
WET-DRY AND FREEZE-THAW SOIL-CEMENT LOSS[a] DATA
(Based upon original oven-dry weight)
Soil No 3566

Mixing Time	Zero Hour								Four Hours							
Type of Test	Wet-Dry Loss, %				Freeze-Thaw Loss, %				Wet-Dry Loss, %				Freeze-Thaw Loss, %			
Specimen No	a	b	c	d	e	f	g	h	a	b	c	d	e	f	g	h
Cement Content by Vol, %	10	12	9	11	10	12	9	11	10	12	9	11	10	12	9	11
$CaCl_2$ by wt of soil, %	0	0	0 5	0 5	0	0	0 5	0 5	0	0	0 5	0 5	0	0	0 5	0 5
12 Cycles	12	3	17	6	7	3	14	3	9	4	9	3	11	4	12	3
24 Cycles	14	4	23	8	10	4	22	4	14	6	16	6	20	7	24	6
36 Cycles	19	5	29	10	13	5	27	5	15	7	20	7	27	10	35	10

[a] Losses shown are cumulative





Data Showing Effect of $CaCl_2$ As Compared to Method of Adding

It is logical to expect that the method of adding $CaCl_2$ to a soil-cement mixture would have some effect upon the results obtained To explore this question, compressive strength tests were made using two sand soils, a good one (Soil 3566) and a poor one (Soil 3565), in which the $CaCl_2$ was added in the following different ways

1 No $CaCl_2$ added.

2. $CaCl_2$ added in solution, as part of the

mixing water, after dry mixing the soil and cement.

3. $CaCl_2$ added as dry flakes to the air-dry soil-cement mixture, water added and specimens molded immediately.
4. $CaCl_2$ added in solution to the soil, and the soil-$CaCl_2$ mixture prewetted to two per cent moisture below optimum about 18 hours before adding cement and necessary additional water for molding specimens.

Of these various methods, No. 2 was the simplest and therefore, since these special tests showed that this method was fairly representative and was not necessarily the most effective, it was chosen as the method to use in making all routine $CaCl_2$ tests involving 0-hr mixing time Likewise, method 7 was used for making routine tests involving a 4-hr. mixing period.

The data showing the effect of the method of adding $CaCl_2$ are shown in Figures 14 and

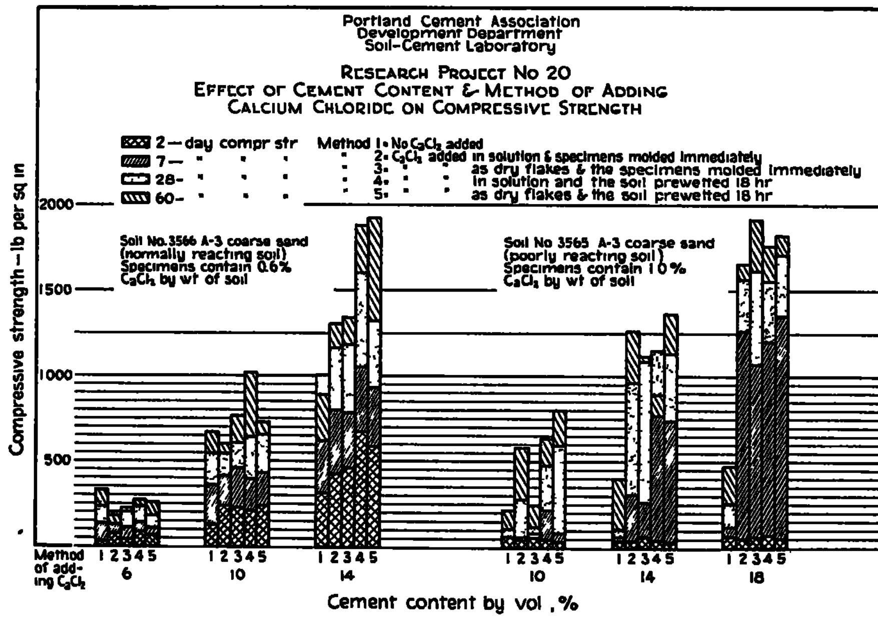


Figure 14

5 $CaCl_2$ added as dry flakes to the soil, and the soil-$CaCl_2$ mixture prewetted to 2 per cent moisture below optimum about 18 hr before adding cement and necessary additional water for molding specimens.

In these tests the specimens were molded using the standard mixing procedure called 0-hr mix. To explore the effect of a 4-hr. mix under two different conditions, methods 6 and 7 were employed.

6 $CaCl_2$ added in flakes and soil-$CaCl_2$ mixture prewet 18 hours as in Method No. 5 above, but a 4-hr. mixing time used before molding specimens.
7. $CaCl_2$ added in solution as part of the mixing water, during the first 2 hr. of a 4-hr. mixing period.

15. Figure 14 shows data for methods No 1 to 5, and Figure 15 shows a comparison of data for method 6 and method 7. The latter data are taken from other 4-hr. mixing tests given in Figures 7 and 13. (In Figure 15, 4-hr. tests in which no $CaCl_2$ was added are identified as method 1a.)

According to Figure 14, methods 4 and 5 are the most effective with both the normally reacting Soil 3566 and the poorly reacting Soil 3565 Methods 2 and 3 give about the same results with normal Soil 3566 and in the case of poor Soil 3565, method 2 is generally better than No. 3. Since interest is directed at poor Soil 3565 rather than normal Soil 3566, it can be concluded that methods 2, 4 and 5 give better results than method 3.

The data in Figure 15 show that the $CaCl_2$ can be safely added the day before construction and prewetted, even though a 4-hr. damp mix is used during construction. Again, particular attention is directed at the data for poor Soil 3565. With this soil, as much as 2 per cent $CaCl_2$ was added and prewet, before adding cement and damp mixing four hours, without deleterious effect. However, with normal Soil 3566, 2 per cent $CaCl_2$ had a decided deleterious effect upon the compressive strength. Since this soil is a normally reacting soil and $CaCl_2$ would not likely be added to it in practice, this latter fact is not of major significance The data are a warning, however, to use discretion when adding $CaCl_2$ to soil-cement mixtures Other data in Figures 7, 8, 10 and 13 show that a 4-hr. damp mixing period is not harmful, when the $CaCl_2$ is added in solution during the first 2 hr. of mixing.

From this information it can be concluded that maximum effectiveness of the $CaCl_2$ is likely to be obtained by adding the $CaCl_2$ either in solution or in flake form to the soil and prewetting the day before construction. However, if equipment is available for adding the $CaCl_2$ in solution in the mixing water, this method is satisfactory; or, if for some reason, it becomes necessary to add the $CaCl_2$ in flake form at the same time the cement is added, this method too will give good results. This latter method, however, is the least preferred of all methods.

GENERAL DISCUSSION OF CALCIUM CHLORIDE TESTS

The presentation of the preceding data readily show,

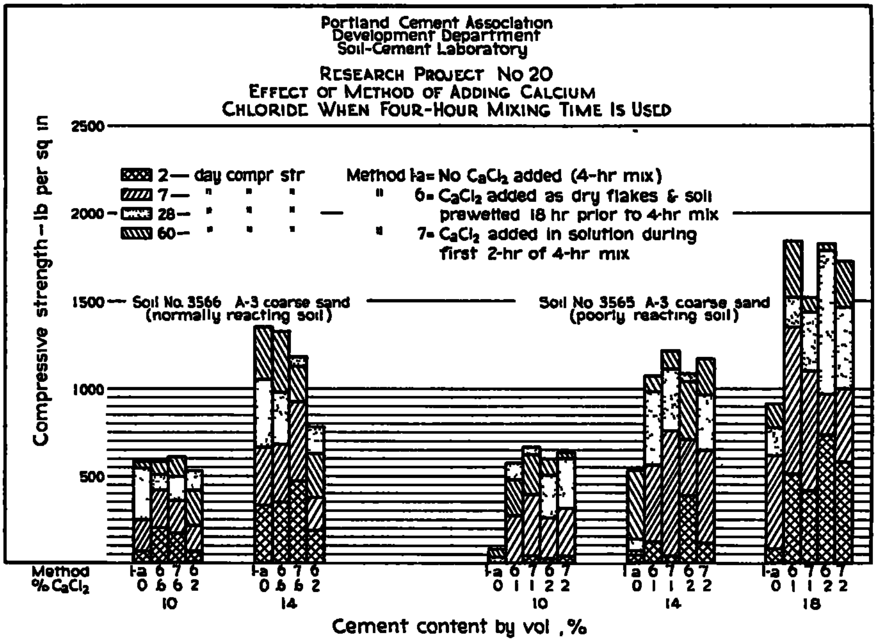


Figure 15

(1) That $CaCl_2$ is very effective in improving the cement reaction with poorly reacting sandy soils; and

(2) That $CaCl_2$ has a minor effect upon the reaction of cement with normally reacting soils.

Poorly Reacting Sandy Soils

The extent to which $CaCl_2$ is effective with these poorly reacting soils is shown in Table 19

According to Table 19, Soils 3556 and 3567 are the most responsive to $CaCl_2$ treatment. To explore the reason for this it is first necessary to explore the reasons why the soils are so poorly reacting Without doubt, the major reason is the presence of organic matter in some form of decomposition and may or may not occur as a coating on the soil grains. All these soils are surface sands taken from areas where the rainfall is relatively high and where the natural vegetation has been or is principally forest. Experience has shown that these soils are the most difficult to harden of all sands Sandy surface soils from areas where the rainfall is light and vegetation is principally herbaceous or grasslike, react normally with cement.

TABLE 19

EFFECT OF $CaCl_2$ IN REDUCING CEMENT CONTENT FOR HARDENING POORLY REACTING SANDY SOILS

Soil No	Organic Content	Cement Content to Harden, per cent by Vol [a]		
		Without $CaCl_2$	With $CaCl_2$, per cent by wt of soil	
			0 6	1 0
	p p m			
3556	11,000	+30	14	12
3564	11,000	22		16
3565	4,000	+26	16	15
3567	7,000	+27	14	

[a] Based upon wet-dry and freeze-thaw test data

As shown in Table 19, Soils 3556 and 3564 contain 11,000 p.p.m. organic matter[4] compared to 4,000 and 7,000 p p m. respectively for Soils 3565 and 3567. Since Soil 3564 responds to treatment with 22 per cent cement, whereas Soil 3556 requires +30 per cent, it is apparent that the actual amount of organic matter present is not of prime importance so long as it is high and is of a certain type This is further shown by the fact that Soil 3565 (4,000 p.p.m. organic) requires +26 per cent cement, whereas Soil 3564 (11,000 p.p.m.) requires only 22 per cent cement.

It is also realized that the gradation of the soil will have a direct influence upon its reaction with cement and resulting compressive strength. Based upon the best gradation and greatest density, see Figure 16 and Table 21, best compressive strengths would likely be obtained with Soil 3564 or 3565 (assuming organic influence constant) Table 20, giving compressive strengths of these four sandy soils with 1 0 per cent $CaCl_2$, and 18 per cent cement, permits analysis of this point.

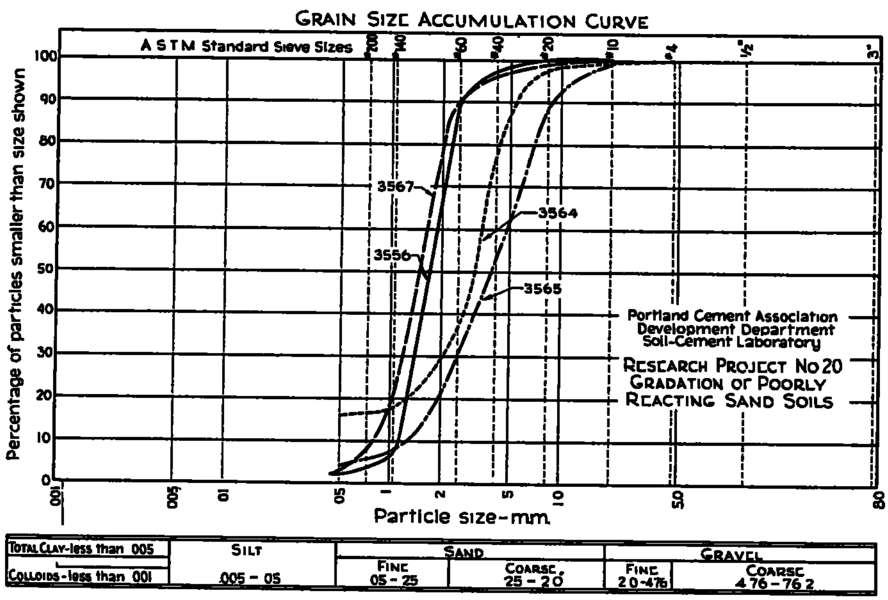


Figure 16

According to Table 20, Soils 3565 and 3556 are by far the strongest, whereas the best graded and most dense soils are 3564 and 3565.

[4] As determined by sodium hydroxide colorimetric test See references cited, Table 1.

TABLE 20
COMPARISON OF COMPRESSIVE STRENGTHS

Soil No.	Maximum Density	Compressive Strengths, lb per sq in — 18% Cement by Vol, 1% $CaCl_2$ by wt of soil	
		7 Days	28 Days
	lb per cu ft.		
3556	115±	975	1,500
3564	118±	710	980
3565	118±	1,260	1,560
3567	114±	675	810

The soils with the most organic matter (11,000 p p.m.) are 3556 and 3564. From these comparisons it is difficult to evolve any relation between gradation, density, organic content, and cement reaction with $CaCl_2$ present.

The question as to why $CaCl_2$ improves these poorly reacting soils is, of course, of interest If it is assumed that the poor reaction is due to the presence of organic matter in the soil, then it is logical to assume that the soil could be improved by either removing the

TABLE 21
MOISTURE-DENSITY RELATIONS
(Used for interpolating and extrapolating optimum moisture and maximum density for all soil-cement and soil-cement-$CaCl_2$ mixtures)

Soil No	0-hr. Tests				4-hr. Tests			
	Cement Content	$CaCl_2$ by wt of Soil	Maximum Density	Optimum Moisture	Cement Content	$CaCl_2$ by wt of Soil	Maximum Density	Optimum Moisture
	Vol, %	*%*	*lb per cu ft*	*%*	*Vol, %*	*%*	*lb per cu ft*	*%*
2a-6	7.98	0	121 1	9 7				
	12 11	0	122 7	9 6				
	16 01	0	123 5	9 5				
	7 95	0 6	120 7	9 5				
	8 01	2 0	121 6	9.6				
4d	13 71	0	107 2	17 8	13 52	0	105 5	18 0
	13 61	0 6	106 2	18 0	13 52	0 6	105 5	18 5
	13 81	2 0	107.9	17 6	13 71	2 0	107 0	17 5
7h	14 02	0	108 9	18 2				
	13 79	2 0	107 1	18.7				
	13 71	4.0	106 5	19 1				
3255-2	8 09	0	116 9	13 7				
	14 23	0	118 3	13 5				
	8 06	0.6	116 6	13.0				
	8 09	2 0	117 0	13.5				
3564	10 00	0	117 1	12 8				
	15 93	0	117 1	13 2				
	21 85	0	117 1	12 8				
	16 16	0.6	117 7	12 3				
	16 20	2 0	118 0	12 3				
3565	9 99	0	115 6	12 0				
	15 46	0	117 0	11.9				
	22 33	0	117 0	11 9				
	14 23	0 6	118 0	11 5	13 83	0	114 6	11 9
	14 37	2 0	119 1	11 3	13 97	0 6	115 6	11.6
3566	7 78	0	115 6	10.0	7 62	0	113 2	11 2
	13 77	0	118 6	9 3	13 57	0	117.3	10 7
	7 74	0.6	114 4	10 5	7 62	0 6	113 2	10 5
	7 85	2 0	116 5	10 2				
	14 00	2 0	121 0	8 9	13 31	0 6	116.8	10.0
3556	10 00	0	113 1	11 1				
	15 91	0	114 1	10 8				
	21 91	0	115 3	10 7				
	10 50	0 6	111 6	11 0				
	10 57	2 0	112 4	11 0				
	21 96	0 6	115 6	11 0				
	21 89	2 0	115 2	11 5				
3567	9 87	0	112 0	10 6				
	15 76	0	113 3	10 8	13 66	0	110.2	11 7
	13 98	0 6	113 9	10.5	14 02	0 6	113 1	11.1
	14 04	2 0	114 4	10.8				

organic material or rendering it inactive to cement by some chemical action. Obviously, the $CaCl_2$ does not remove the organic, so therefore, it must inactivate it. (Research has shown that it is possible to improve some of these poor sand soils by removing the organic matter by washing the soil in water, as shown by Table 3, or in a solution of sodium hydroxide, or of hydrochloric acid.)

In concrete work under ordinary temperatures, the use of $CaCl_2$ is limited to 2 per cent by weight of cement. This small quantity it appears that the action of the $CaCl_2$ is at least two-fold.

1. It hastens the hydration of the cement.
2. It reacts chemically with the organic matter in the soil rendering it partially inactive (Other research has shown that CaO and $Ca(OH)_2$ will also improve poorly reacting sandy soils, but the quantity likely to be necessary is not indicated as economical)

Four-Hour Mixing Period. As previously mentioned a 4-hr. damp mixing period is apparently helpful in soil-cement-$CaCl_2$ mixtures,

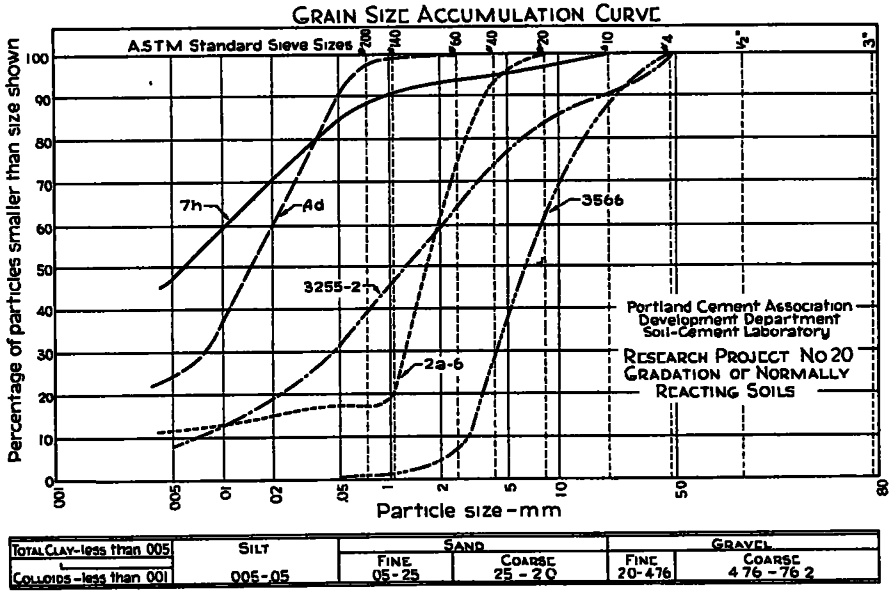


Figure 17

increases the rate of hydration so that high strengths are obtained at early ages Why $CaCl_2$ is an accelerator is not clearly known, and information from concrete-$CaCl_2$ research is not of particular value in determining why $CaCl_2$ reacts the way it does in soil-cement For one thing, the quantity of $CaCl_2$ required to aid these poor sands is many times the amount of $CaCl_2$ used in concrete work For instance, according to Table 7, 2 per cent of $CaCl_2$ by weight of soil in a mixture containing 14 per cent cement and having a density of 112 lb per cu ft. is equal to 14 74 per cent by weight of cement Available concrete-$CaCl_2$ information indicates that such a high $CaCl_2$ content in concrete would be harmful

From the available data and this discussion the same as in straight soil-cement (with poorly reacting sand soils) The reason for this perhaps can be attributed to the scouring action during the mixing period which helps to dislodge the deleterious organic film on the sand grain This gives the cement a better foundation on which to stick and thus results in a better soil-cement mixture

Normally Reacting Soils

As will be seen in Figure 17 and in Table 6, the five normally reacting soils included in this study cover a wide range in types, including a corase sand, a loamy fine sand, a sandy loam, a silty clay loam and a clay

The reaction of $CaCl_2$ upon normally reacting sandy soils might be considered similar to its reaction upon concrete That is, it accelerates the cement hydration and gives higher early strengths. However, since the normal soil has sufficient strength when it is mixed with an amount of cement required to give adequate durability, the value received from the $CaCl_2$ is not in keeping with the cost of the material.

In the case of the silt soil included in this study, the use of $CaCl_2$ was not decisively helpful in economical quantities in either wet-dry, freeze-thaw or compressive strength tests. With the clay soil included, $CaCl_2$ had little or no effect upon compressive strength at early ages, and only a minor beneficial effect at later ages. In the wet-dry and freeze-thaw tests, the $CaCl_2$ was ineffective in the economical quantities tested.

Effect of $CaCl_2$ On Moisture-Density Relations

Data from A S T.M. moisture-density tests, with and without $CaCl_2$ in the soil-cement mixtures, are shown in Table 21. As shown by these data, the difference in maximum density between soil-cement mixtures and soil-cement-$CaCl_2$ mixtures ranges within about 2 lb. per cu ft There is no definite trend as to the effect of the $CaCl_2$; sometimes the addition is accompanied by a decrease in density and sometimes by an increase.

The difference in optimum moisture content between the soil-cement mixtures and soil-cement-$CaCl_2$ mixtures is ordinarily less than one percentage point

It can be concluded from these data that the addition of $CaCl_2$ to the soil-cement mixtures had practically no effect upon the moisture-density relations, regardless of whether the soil was principally sand, silt or clay.

COSTS OF ADMIXTURE TREATMENTS

For an investigation of this type to have practical value, it is necessary that the cost details be fully developed before starting laboratory tests. To make the addition of $CaCl_2$ worth while in soil-cement mixtures, it is necessary that an amount of cement equal to or greater than the cost of the $CaCl_2$ must be saved and still get comparable results In fact, the research project was set up under the impression that by use of $CaCl_2$ with poorly reacting sandy soils, a substantial saving in construction costs would be realized by reducing cement costs considerably in excess of the cost of the $CaCl_2$. As shown by the test data obtained, this result has been realized.

The following costs of $CaCl_2$ (Table 22) in carload lots was obtained from the Dow Chemical Company, Chicago in the spring of 1943.

The following costs for portland cement (Table 23) were taken from *Engineering News-Record*, April, 1943.

In arriving at a logical cost for $CaCl_2$ applied to the soil-cement in field construction the assumption was made that $10 a ton would be ample for truck hauling from the rail siding and for adding to the soil If an average

TABLE 22
COST OF CALCIUM CHLORIDE

Dollars per ton, Carload lots

Boston	Atlanta	Jacksonville	Detroit	St Louis	Omaha	Roswell, N M
21 50	25 50	25 50	18 50	23 00	22 00	30.00

TABLE 23
COST OF PORTLAND CEMENT

Dollars per bbl, paper bags

Boston	Atlanta	Chicago	Cincinnati	St Louis	Dallas	Seattle
2 50	2 52	2 45	2 31	2 52	2 27	2 75

figure for the $CaCl_2$ at the siding is taken at $25 a ton, the total cost becomes $35 a ton, or 1 75¢ a pound Using these figures as a basis, the cost of 0.6 per cent commercial $CaCl_2$ will average about 5¢ a sq. yd. of 6-in pavement. This is a conservative figure and in most instances where $CaCl_2$ will have an advantage (the northeast, southeast, and north central United States) the actual cost may be less than 5¢ per sq. yd.

A price for cement was taken at $2 65 a barrel, which figures 3¢ for 1 0 per cent cement per sq. yd of 6-in compacted pavement ($2\,65/376 \times 4\,5 \times .01 \times 94 = \$0\,0298$).

Thus, it is seen that if the use of 0 6 per cent $CaCl_2$ will save 2 per cent cement, the economics of the treatment will be sound. Actually, of course, to make the $CaCl_2$ application practical, a greater quantity than 2 per cent cement would have to be saved

As an illustration; Soil 3566 included in these tests, will not harden satisfactorily with

26 per cent cement which would cost approximately 78¢. However, by adding 1 per cent $CaCl_2$ to the soil it will harden with 14 per cent cement Thus it is seen that approximately 8¢ worth of $CaCl_2$ (1 per cent) will save approximately 36¢ (12 per cent) worth of cement to reduce construction costs 28¢ per sq yd, a substantial amount. Total material costs would thus be about 50¢ per sq yd. of pavement. In return for this 50¢ a base material would be obtained having excellent durability, with a compressive strength of about 650 lb. per sq. in. at 7 days, and about 1,000 lb. at 120 days. In the first case where cement costs alone would be more than 78¢, soil-cement likely would not be considered economical in comparison with other types of pavement. However, in the case using $CaCl_2$ the project would be entirely economically feasible.

There also are other solutions that might be cheaper than the $CaCl_2$ treatment. For instance, one of the best ways to handle the poorly reacting soils is to cover them up with good soil. Soil 1525 is vastly superior to Soil 1523 Since the soils come from the same location (except depth below ground surface) it would be economical to borrow Soil 1525 and use it to cover Soil 1523, for soil-cement construction Ordinarily, if the poor soil condition is recognized prior to grading operations, this is a simple matter, since then it is only necessary to go deeper in the ground for good soils Thus where there is a "cut" of a few feet, enough good soil will be obtained to cover the poor soil lying on the surface of the ground. Such selective grading likely will cost less than any other method of handling these poor soil conditions.

Also, as shown in Part I, another way to improve these poor sand soils is to dilute them with a well reacting soil. A number of excellent soil-cement jobs have been built using this method. Uusually best results are obtained with the smallest quantity (about 25 per cent) of admixture soil if a friable clayey soil is used If it is economical to use larger quantities (as much as about 50 per cent) of admixture, limerock, limestone and other soil materials make very satisfactory admixtures.

Each job is an individual problem, and will need be worked out separately, analyzing the cost of the various methods of handling poor soil conditions.

SUMMARY AND CONCLUSIONS

The preceding data show that poorly reacting sandy surface soils can be improved so that they react with cement in approximately a normal manner; (1) by diluting the sand with an admixture of clayey soil or limerock; and (2) by adding to the sand a small percentage of $CaCl_2$ Throughout the report special attention has been given the soil horizon from which the samples were taken. This points up the advisability of recognizing soil series and soil horizons according to the system devised by the "Bureau of Chemistry and Soils,"[5] U. S. Department of Agriculture.

Soil Admixture Series

In so far as an admixture of soil is concerned, the data indicate that one-fourth admixture of soil to three-fourths poorly reacting sandy soil will give a mixture likely to react satisfactorily with economical quantities of cement, providing the admixture soil is relatively clayey. If a lighter textured admixture soil or limestone, limerock or similar material is used, approximately a 50–50 mixture of soils may be required to obtain a well reacting material for soil-cement The percentage of admixture soil required will vary not only with the type and character of the material, but also with the degree to which the sand soil reacts with cement Thus it is likely that a poorly reacting sand soil requiring 18 per cent cement for hardening can be improved with an admixture soil more readily than a poor sand requiring 26 per cent cement for hardening

Data show that by the use of the soil-admixture treatment a poor sandy soil requiring 18 per cent cement can be improved so that the soil mixture can be hardened with 8 to 10 per cent cement.

One phase of this admixture problem that has not been completely investigated, but which is under study, is the effect of adding a coarse textured material such as gravel or crushed stone to both poorly reacting and normally reacting soils. A report on this phase will be prepared when the study is completed

[5] Now the Bureau of Plant Industry.

$CaCl_2$ Admixture Series

The primary purpose of this series was to discover the effect of $CaCl_2$ upon the reaction of cement with both poorly reacting sandy surface soils and normally reacting soils. This has been accomplished Approximately 100 wet-dry and freeze-thaw specimens were tested; and when all tests are done, over 4,000 compressive strength specimens will have been broken

The improvement in cement reaction resulting from the addition of small percentages of $CaCl_2$ to the poorly reacting sandy soils tested is very outstanding. As an illustration, soils included in these tests that would not harden with 26 per cent cement would, after the addition of 1 per cent $CaCl_2$ harden with about 14 per cent cement.

The only negative reaction to be obtained from these data is that the $CaCl_2$ does not make these unusually poorly reacting soils so good that they will react favorably with about 10 per cent cement rather than 14 per cent

The value of $CaCl_2$ increases to an optimum as the amount added increases and then its benefit decreases. With the average poorly reacting sandy soil tested, optimum all-around benefit from cost, compressive strength and durability viewpoints, is obtained with about 0 6 to 1.0 per cent $CaCl_2$ by weight of dry soil Good results are obtained with 0 4 to 2 0 per cent and even up to 4 0 per cent with some soils, but there is a trend for the higher percentage to be less helpful than smaller amounts Also, of course, the cost of the higher percentages would likely make their use uneconomical.

An average quantity of $CaCl_2$ of 0 6 per cent by weight of dry soil is equivalent to 2 7 lb to 3 2 lb per sq yd of soil-cement pavement 6 in. in compacted thickness, when the weight of soil per cu ft. of soil-cement varies from 100 to 120 lb.

The addition of $CaCl_2$ is a simple operation in the laboratory. About the same test results are obtained whether $CaCl_2$ is (1) added in solution in the mixing water after mixing soil and cement, or (2) added in wetting the soil the day before adding cement, or (3) added as flakes and mixed in the soil followed with some water addition and mixing the day before adding cement. When (4) added as flakes as the soil and cement are mixed together, and followed immediately with water addition and mixing, the test results are not quite as uniformly good, but still the $CaCl_2$ is effective.

Whereas the effect of $CaCl_2$ upon poorly reacting sandy soils is definitely beneficial, $CaCl_2$ addition is of little or no value with normally reacting soils. For instance, with silty and clayey soils there is little effect from the $CaCl_2$; but in general, with sandy soils, there is an increase in compressive strength at early ages with the addition of $CaCl_2$. However, since the strength of the plain soil-cement is usually adequate, no economic benefit is generally obtained from adding $CaCl_2$. This is brought out by the fact that wet-dry and freeze-thaw data from normally reacting soils show that adequately hardened soil-cement mixtures (without $CaCl_2$) have equal or better resistance to moisture and temperature change than the soil-cement $CaCl_2$ mixtures of equal cost This is on the basis that if $CaCl_2$ is added, the cement content must be reduced to hold the cost equal.

On page 499, five questions are listed that were to be answered by this study. These questions and their indicated answers are as follows.

1. *Question:* To what extent can calcium chloride be depended upon to help poorly reacting soils?

Answer: Four poorly reacting sandy soils, representative of three soil areas (southeast, northeast and north central) in the United States, were included in the investigation. In every case the addition of $CaCl_2$ was very beneficial in improving the soil so that it could be hardened with considerably less cement In some instances the quantity of cement saved was 50 per cent or more of the quantity required to harden the untreated sand soil. Compressive strengths and resistance to alternate wetting and drying and freezing and thawing were definitely increased by the use of $CaCl_2$. With these soils, the use of $CaCl_2$ appears both economical and practical.

2 *Question·* How will the addition of calcium chloride effect soils that harden normally?

Answer: Five normally reacting soils were included in the study. The addition of $CaCl_2$ to the soils of sandy character generally resulted in an increase in the compressive strength, but the increase was not generally of practical significance. In the case of the silty and clayey soils, $CaCl_2$ had practically no beneficial effect. Soil-cement-$CaCl_2$ specimens of all normally reacting soils did not have greater resistance to alternate wetting and drying and freezing and thawing than plain soil-cement specimens of equal cost. With these soils, the use of $CaCl_2$ does not appear to be either ceonomical or practical

3 *Question:* How much calcium chloride should be added to the various soils for optimum physical and economic benefit?

Answer: The optimum quantity of $CaCl_2$ added to poorly reacting sand soils was of the order of 0 6 to 1.0 per cent by weight of soil. Generally, 0.6 per cent was adequate. In the case of the normally reacting sandy soils, 0.2 per cent $CaCl_2$ might be considered the optimum quantity, although it would be questionable whether even this small percentage would be economically justified. With normally reacting silty and clayey soils the addition of $CaCl_2$ does not appear economically justified.

4. *Question:* Is the benefit from calcium chloride temporary or is it of lasting effect?

Answer: Available data indicate that the benefit obtained from the $CaCl_2$ is permanent. Compressive strengths continue to increase at an age of 120 days—the oldest tests included in this progress report Of greater significance than this information is the fact that soil-cement-$CaCl_2$ specimens molded early in 1942 and stored outdoors are now over a year old and have withstood the weathering effect of an Illinois winter without any discernable effect

5 *Question:* What will be the effect of lengthy damp mixing periods, such as are common in the usual mixed-in-place procedure of field mixing, on soil-cement-$CaCl_2$ mixtures?

Answer: Lengthy damp mixing for as long as 4 hr had a beneficial effect upon poorly reacting sand soils treated with $CaCl_2$, as well as on the untreated soils Compressive strengths greatly increased when the damp mixing period was prolonged to 4 hr. in contrast to a 0-hr. (about 5 min.) mixing period. The effect of the mixing time upon the action of the $CaCl_2$ added to normally reacting soils was small and not of any practical significance, except in the case where a large quantity (2 per cent) proved deleterious when added to a prewetted sand soil.

CONSTRUCTION SUGGESTIONS

It is suggested that test sections be constructed in the field immediately in which $CaCl_2$ is added to poorly reacting sandy soils prior to the application of cement The following procedures are suggested for initial construction, and for emergency construction in military combat areas

Standard Construction and Testing

Samples of soil representative of the proposed construction shall be taken and tests made to determine the optimum quantities of $CaCl_2$ and cement to be used

Emergency Construction and Testing (Military)

If preliminary tests show that a sandy soil does not harden satisfactorily with 14 per cent cement or less, additional tests shall be made to investigate the effect of $CaCl_2$ upon the soil-cement mixture It is suggested that all tests be made using 1 per cent $CaCl_2$ by oven-dry weight of soil. If it is imperative that construction start before emergency test data are available, and if there is any doubt but that the soil will respond normally with cement, it is recommended that 1 per cent $CaCl_2$ by weight of soil, and 14 per cent cement by volume be added to practically insure a satisfactory reaction.

Method of Adding $CaCl_2$

Tests In making test specimens under normal conditions the $CaCl_2$ may be added in solution as part of the mixing water.

When making tests under emergency construction it may be easier to add the $CaCl_2$ to the soil in the form of dry flakes. Part of the mixing water should then be added and the $CaCl_2$ dissolved. Cement may then be added, followed by the remaining portion of the mixing water Excess rubbing of the mixture should be avoided.

Construction In many instances, it is believed that simplest construction will involve the addition of $CaCl_2$ in the form of dry flakes. Least interference with normal construction operations will be obtained by adding the chemical the day before soil-cement construction. After adding the $CaCl_2$ some water may be required to dissolve it. The soil-$CaCl_2$ mixture should then be mixed to obtain uniform distribution.

If equipment is available, uniform application of $CaCl_2$ will be obtained by adding it in solution, either as part of the mixing water during soil-cement processing, or as part of the water used to prewet the soil the day before soil-cement construction.

It will be necessary to learn from field experience, which is now lacking, the most efficient and economical procedures to follow on construction. Experience with concrete and soil-cement paving construction indicates that adding calcium chloride in the field should present no particularly difficult or costly procedures.

The data in this report include the results of compression tests at various ages of a number of poorly reacting sandy soils containing various cement contents (without $CaCl_2$ admixture). It will be noted that the cement appears to be practically inactive for a considerable period of time after which it begins to harden the soil-cement specimens in a more normal manner, a cement phenomenon not generally known. This and other important observations can be made on cement hydration in poorly reacting sandy soils but since this paper is devoted primarily to determining successful treatment methods for soil-cement, they are not analyzed and discussed at this time. However, the cement and concrete technician will find considerable new and valuable information in the cement and raw soil data that will throw additional light on some of his special research and construction problems.

ACKNOWLEDGEMENT

The detail laboratory work for this research was performed by Ensign E. G. Robbins, C.E.C , U.S N.R , with the assistance of E. J. Deklotz and F. L. Goodman.

ROADWAY AND RUNWAY SOIL MECHANICS DATA

By Henry C. Porter, *Research Engineer*
Texas State Highway Department

SYNOPSIS

The data presented are a continuation of those reported in the soil-water-phenomena discussion at the Highway Research Board 1941 and 1942 meetings.

(1) *Method of Preparing Soil Specimens for Physical Tests:* Because too much time was required for making various moisture content tests with 1/30 cu. ft. cylinder specimens, experiments were made with small specimens molded in 20 cu cm. pat cups.

It appears that a consolidated specimen of cohesive clay soil has characteristics not very different in a general way from other building materials. No doubt moisture content fluctuations cause greater changes in a consolidated clay soil structure than in many of the other materials; but it seems that consolidated specimens of clay soil can be prepared and tested for structure durability and other properties in somewhat the same manner as the other materials.

(2) *Density and Strength of a Clay Soil When Consolidated and Saturated.* Experiments showed that the same type of soil compacted to different densities absorbed different amounts of water and ruptured under different loadings. When the soil with plastic index of 22 was consolidated to 72 lb. wet, the amount of water absorbed to become saturated was 46 per cent and the relative rupture load was 11, while the same soil consolidated to 97 lb wet absorbed 21 per cent water to become saturated and the relative rupture load was 129.

Data also showed the soil type made a difference in amount of water absorbed