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THE EFFECT OF CALCIUM CHLORIDE ON THE COMPACTIVE EFFORT AND WATER RETENTION CHARACTERISTICS OF SOILS

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SYNOPSIS

The results of the tests reported herein were obtained in the soils laboratory of the Joint Highway Research Project, Purdue University. The greater portion of the tests were made on four local materials consisting largely of fine-grained glacial drift soils from both the Wisconsin and Illinoian ages. The remaining tests were performed on 21 soil samples from nine southern states.

The soils were tested with an admixture of calcium chloride ranging in amount from ¼ percent to 1½ percent by weight of dry soil. In the compaction tests the compactive effort was varied from 5 to 90 blows of the Proctor hammer.

A total of 156 compaction tests were made; 81 of these tests were made on the raw soil and 75 were made on various combinations of the soil plus calcium chloride. In most cases the compacted densities of the soil-calcium chloride mixtures were higher than those of the soil alone. However, a portion of the increase in density was attributed to the weight of the admixture that was added to the soils.

The test results indicated that the compactive effort required to produce a given density of soil was decreased, for most of the soils, by the use of calcium chloride and also that the calcium chloride was most effective at low compactive efforts.

Tests were made to determine the effect of calcium chloride on the pH of soils. The results showed that the pH of the soil-calcium chloride mixtures were less than those of the same soils with no calcium chloride.

Several of the soils were tested to determine the effect of calcium chloride on their plasticity. The results indicated calcium chloride lowered both the liquid and plastic limits of some of the soils.

The results of load-penetration tests showed that the penetration resistance of the specimens containing the admixture were somewhat less than the penetration resistance of the soil alone.

To determine the effect of calcium chloride admixture on the water retention characteristics of soils, a series of drying tests was performed. The results of these tests indicated calcium chloride retarded the drying out of the soils when subjected to accelerated drying. The results of drying and re-wetting tests showed that the moisture contents of the specimens containing calcium chloride were lower after the drying and wetting cycle than those with no calcium chloride.

Calcium chloride has been used on highway work as a dust palliative and as a stabilizing agent due to its moisture retention and surface tension properties. However, the available data have not been conclusive as to its effect on the various physical properties of soils.

In the past few years some work has been done along this line. The data indicate that the incorporation of calcium chloride as an admixture in a soil makes it possible to attain higher densities with the mixture, for a given compactive effort, than is possible with the soil alone. However, inconsistencies in the test results have indicated the need for further study of the effect of calcium chloride on the compaction characteristics of soils.

Hogentogler, Jr. (*1*)[1] found that the results of tests made on three soils indicated calcium chloride was effective in increasing the compacted density of soils. Woods and Gregg (*2*) reported a similar study made on fifteen different soils from the northern and western states. Johnson (*3*) reported, "Calcium chloride in percentages up to at least three percent will cause an increase in the wet and dry density of soil. This effect is more noticeable with the lighter compactive efforts." He also reported that calcium chloride causes a decrease in the penetration resistance of soils.

It was the purpose of this study to expand the work already done on the effect of calcium chloride on the compaction characteristics of soils and, in addition, to perform tests to determine the effect of calcium chloride on the water retention characteristics of soils. Also, several tests were run to determine the effect of calcium chloride on the penetration resistance, plasticity, and pH of soils.

MATERIALS

The soils tested composed a wide variety of materials relative to soil texture, origin, and location. A diversified type of sampling was used in order that the soils might be obtained from as many soil areas as possible. In most cases the soils sampled represent not only the immediate area from which the sample was taken, but also, a larger area that covered all or parts of several states. For example, the Ruston and the Memphis soil samples were both obtained in Kentucky; however, by referring to Figure 1 it can be seen that both these samples represent materials which occur in an area of wide extent.

A complete listing of the soils tested is shown in Table 1. It will be noted that in most cases a pedological type of classification was used. This type of classification is necessarily comprehensive and does not designate closely the type of material from which the soil is derived. For example, soils 1960S and 1961S are both designated as Cecil. However, the first soil listed as Cecil was derived from granite while the other was derived from gneiss. Likewise, soils 1966S and 1967S are both designated as Lowell. Soil 1966S was derived from shale and soil 1967S was derived from limestone.

Soil No. 1945S (Crosby) is representative of a large area that extends through the Central States. This soil occurs on the level to undulating terrain of the Late Wisconsin drift area which, because of the minimum amount of grading required, is often selected as a satisfactory site for airport and highway construction.

Of the first four soils tested, three were obtained from the same location and are all designated as Illinoian drift. It will be noted, however, that each was sampled at a different depth. Soil No. 1946S represents the "A" horizon and is a silt. This soil is in many respects similar to wind-blown silt (Memphis). Figure 2 shows the grain size distribution of these two materials to be approximately the same.

Soil No. 1947S is from the plastic "B" horizon of the Illinoian drift. The liquid limit and plastic index values of this soil are indicative of its plastic nature.

The Illinoian drift parent material (soil No. 1948S) contained some granular material as is shown by its grain size curve. All these soils occur extensively throughout the northern and central states.

Eight soils were sampled in the coastal plain region. These soils defined the two extremes relative to grain size. Soil 1955S (a white coastal plain sand) was by far the most granular of all the soils tested. However, the coastal plain soils were for the most part highly plastic.

Six soils of the Piedmont region (soils 1957S to 1962S) were tested. The Piedmont region extends from Alabama north along the eastern edge of the coastal plain, into the southern portion of Pennsylvania. The soils in this region are developed from granites, schists, gneiss, slate, and other metamorphic rocks. One of the predominating characteristics of several of the soils sampled in this region is the high amount of mica flakes which they contained.

[1] Italicized figures in parentheses refer to list of references at the end of the paper.

This was particularly true of the sample of Louisa (Soil No. 1959S).

The remaining soils sampled, with the exception of soil 1968S, were derived from sedimentary rocks and were obtained in Alabama, Virginia and Kentucky. Of these soils, four were derived from limestone; however, they differed in that they were derived from various types of parent rock.

Soils 1968S was a sample of Illinoian drift found south of the Ohio River in Kentucky. This soil was not unlike the Illinoian drift obtained in Indiana.

PROCEDURES

The materials were air dried and sieved through a No. 4 sieve. In all cases, with the exception of the granular materials used in the drying tests, that portion of the soil which did not pass a No. 4 sieve was discarded at the outset in accordance with the accepted procedure for preparing compaction samples (7).

A standard Proctor cylinder and compaction device was used for all the compaction tests. A hand-operated mechanical device regulated the distance through which the tamper was dropped in compacting the soil. The height of drop was kept at a constant value of 12 in. for each of three compacted layers.

The compactive effect was varied by the number of blows delivered by the compaction hammer. For the first series of tests—those performed on the four local materials—the compactive effort used was 5, 15, 45, and 90 blows of the 5.5-lb. Proctor compaction hammer. After the tests on the raw soil were completed, new tests were run similar to those on the raw samples except that calcium chloride was added to the soil in amounts ranging from $\frac{1}{4}$ to $1\frac{1}{2}$ percent. In the case of the Crosby soil, the calcium chloride contents were $\frac{1}{4}$, $\frac{1}{2}$, and $1\frac{1}{2}$ percent while with the three Illinoian drift samples, $\frac{1}{4}$, $\frac{3}{4}$, and $1\frac{1}{2}$ percent calcium chloride was used.

Whenever calcium chloride was used as an admixture it was incorporated in the water used at the start of each test, thus insuring that all the calcium chloride was mixed in the soil for the entire test. In all cases the percentage admixture was calculated on the basis of the dry weight of the soil.

Four tests were made on soil No. 1947S, using an 11-lb. hammer and 5, 15, 45, and 90 blows. No calcium chloride was used in this short series of tests.

The Memphis and Ruston soils were tested under conditions of two compactive efforts (15 and 45 blows) and with two percentages of calcium chloride (1 and $1\frac{1}{2}$ percent).

Compaction tests were made on the remaining southern soils using 5, 15, and 45 blows of the compaction hammer. The 15-blow tests were then duplicated on each of the soils, with the exception that a one percent admixture was incorportated in the soil.

Load-penetration tests were made on three of the soils. The type of test used was similar in many respects to the California bearing ratio test. The materials were compacted in molds 6 in. in diameter to a height of $4\frac{3}{8}$ in. by a 10.4-lb. impact hammer dropped from a height of 12 in. on each of three compacted layers. Previous investigations have shown that the compactive effect produced by this means is approximately equal to that of the standard Proctor device. The number of blows was varied according to the number of blows used in the compaction tests.

Before the start of each penetration test, enough water to bring the moisture content of the soil to a value near the optimum, as determined in the compaction tests, was added to the soil. Here again, when calcium chloride was incorporated as an admixture, it was mixed with the water used at the start of the test. The soil and water were mixed by hand for at least ten minutes. As the soil was placed in the cylinder, a small amount of it was taken from each layer for moisture determinations.

Each specimen was allowed to take up water from both the top and bottom for a period of four days before being tested for penetration resistance. Swell readings were taken at the start and completion of the soaking period. A soaking surcharge weighing 10 lb. was used in all of the tests.

The procedure followed in the penetration test was that of the California bearing ratio test. The specimens were penetrated at the rate of 0.05 in. per min. with a piston having an end area of 3 sq. in. Before the test was started, a load of 10 lb. was placed on the piston and all the dials were set at zero. The load at each 0.1-in. penetration, up to 0.5-in. penetration, was recorded.

Liquid and plastic limit tests were performed on several of the soils, with and without calcium chloride admixture. The standard procedure was followed with the exception that when calcium chloride was used it was mixed with the water at the start of the test.

To determine the effect of calcium chloride on retarding drying of soils, two granular materials (a clean pit-run gravel, and a mixture of soil and coarse sand), a sample of Crosby, and a sample of Ruston were placed in a pan. Each was mixed with a quantity of water greater than optimum, and allowed to dry under an electric fan at room temperature. The moisture contents of the specimens were determined at frequent intervals.

Tests were made on soils Nos. 1945S, 1949S, and 1950S to determine the effect of calcium chloride on the drying and rewetting characteristics of soils. In this series of tests the soils were compacted in cylindrical molds, 2 in. in diameter and 6 in. high. They were first dried out at a constant temperature at 120 F. and then subjected to capillary moisture. Moisture determinations were made at frequent intervals during the drying and rewetting process.

The pH values of the soils with and without calcium chloride were determined by means of a Leeds and Northrup glass electrode pH indicator.

RESULTS

Compaction Tests—A total of 156 compaction tests were performed; 81 of these tests were made on the raw soil and 75 were made on the various combinations of soil plus calcium chloride. The results of the compaction tests were plotted in the form of the usual moisture-density compaction curves.

The density values used in analyzing the data were in every case maximum densities representing the peaks of the compaction curves. Moisture contents and dry densities were calculated on the basis of the dry soil plus the calcium chloride contained in the soil.

The general trend of the data indicated that for a given compactive effort the density of a soil-calcium chloride mixture was higher in most cases than that of the soil alone. However, this was not consistent, for in some cases the density of the soil-admixture combination was less then that of the soil alone; in some other cases the lower percentages of calcium chloride resulted in higher densities than did higher percentages of the admixture.

Figures 4 and 5 show a summary of the compaction tests made on the four local materials. Here density is plotted against compactive effort on a semi-log plot. The solid lines connect the points that represent the results of the tests made on the soils with no admixture.

The curves indicate that the compactive effort required to produce a given density was less when calcium chloride was employed as an

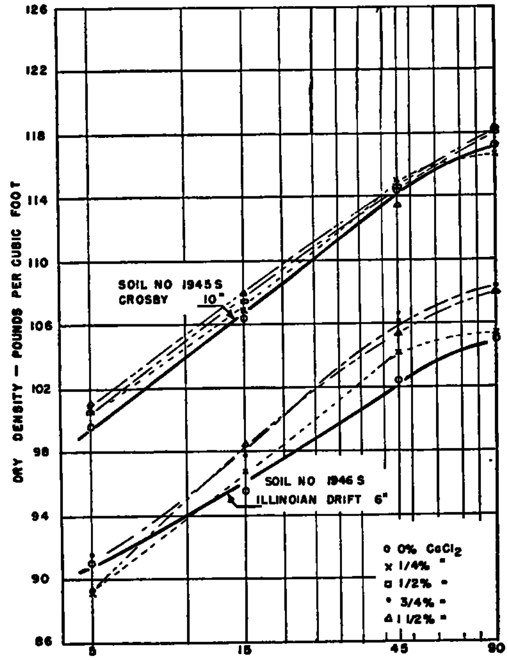


Figure 4. Effect of Calcium Chloride on Compaction—Soils 1945 S–1946 S

admixture than when no calcium chloride was used. In several cases the densities of the soil-calcium chloride mixtures were less than those of the soil alone. This was particularly true of the five blow tests made on soil No. 1946S.

Also, the increases in density were not always progressive—an increase in the percentage of admixture did not always result in a corresponding increase in dry density. This can be seen by noting that the curves for the various calcium chloride contents crossed one another. In the majority of the tests, however, the densities of the soil-calcium chloride mixtures were higher than those of the soil alone, and the compactive effort curves for the mixtures were higher than those for the raw soil, indicating a saving of compactive effort when calcium chloride is used as an admixture.

Figure 5 also shows the results of the tests made with the 11-lb. compaction hammer. The compactive effort curve for the 11-lb. hammer is seen to parallel very closely that of

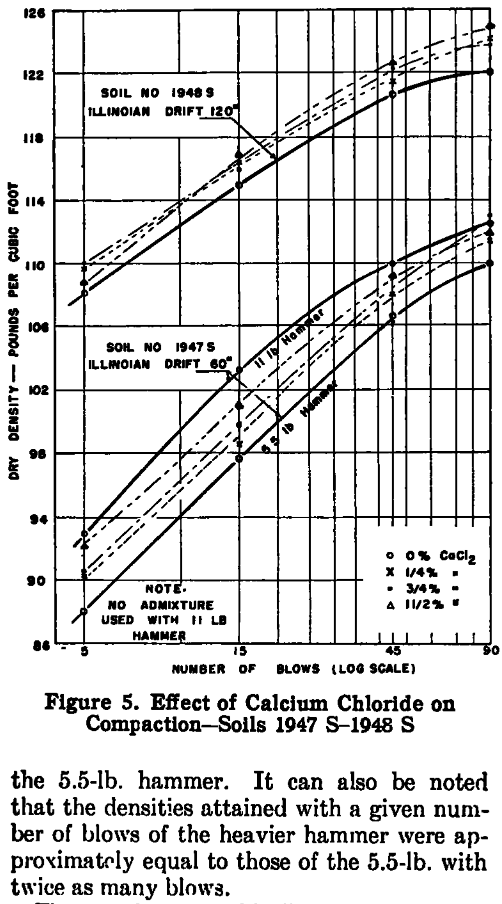


Figure 5. Effect of Calcium Chloride on Compaction—Soils 1947 S–1948 S

the 5.5-lb. hammer. It can also be noted that the densities attained with a given number of blows of the heavier hammer were approximately equal to those of the 5.5-lb. with twice as many blows.

Figure 6 shows graphically the results of the tests made on six of the southern soils. These curves are typical of those developed for each of the 21 southern soils. With the exception of soil No. 1962S, the densities of the soil-calcium chloride mixtures compacted by 15 blows of the hammer were higher than those of the raw soil compacted by the same number of blows. In two cases (soils Nos. 1958S and 1959S) the densities resulting from 15 blows and 1 percent calcium chloride were equal to those of the raw soil compacted by 25 blows.

The densities of the soils with and without the admixture are shown in Tables 2 and 3. The densities of the specimens tested with calcium chloride were corrected by deducting the weight of the calcium chloride. These tables indicate that the increase in density resulting from adding calcium chloride to a soil was due in part to the weight of the admixture contained in the soil. However, in most cases the increase in density was more than the amount attributable to the weight of the admixture. The increases in weight of dry soil per cubic foot resulting from the admixture are also shown in Tables 2 and 3. Of the tests made on the four local materials, the greatest increases in weights of dry soil resulted from the 5-blow tests made on soil No. 1947S. The largest increases in densities for soil No. 1945S were under conditions of compaction of 5 blows, while with soil No. 1946S maximum increases were shown at 15 blows. With soil Nos. 1949S and 1950S the largest increases were shown for the lowest compactive effort used on these soils (15 blows). Soil No. 1948S increased in dry density the largest amount when calcium chloride was used with 90 blows. However, the results of previous investigations (*4*) indicate that with this granular material and 90-blow compaction, it is possible that other factors effected these densities. In all cases but the latter, the calcium chloride admixture was most effective at low compactive efforts.

Similarly, in the majority of cases, the lower percentages of calcium chloride caused greater increases in dry weights of soil than did higher percentages. For example, the lowest percentages of admixture used with soils 1945S, 1948S, 1949S, and 1950S resulted in the largest increases in weight of dry soil. With soils 1946S and 1947S the largest increases were shown by ¾ percent calcium chloride and 1½ percent calcium chloride respectively.

Effect of Calcium Chloride on the pH of Soils—The results of this series of tests are listed in Table 4. In all cases the addition of calcium chloride to a soil caused a corresponding decrease in the pH value of that soil. This was true even though the pH of the calcium chloride itself showed it to be basic. With the exception of soils, 1945S, 1952S. 1954S, and 1969S, the soils used in this investigation were acid. The highest pH recorded was 7.4 (Soils 1945S and 1952S, see Table 4). As can be seen in Table 4 a large portion of the decrease in pH took place with the low percentages of admixture.

results indicated that there was a tendency for the calcium chloride to lower both the liquid and plastic limits of some of the soils tested. However, this was not consistent inasmuch as

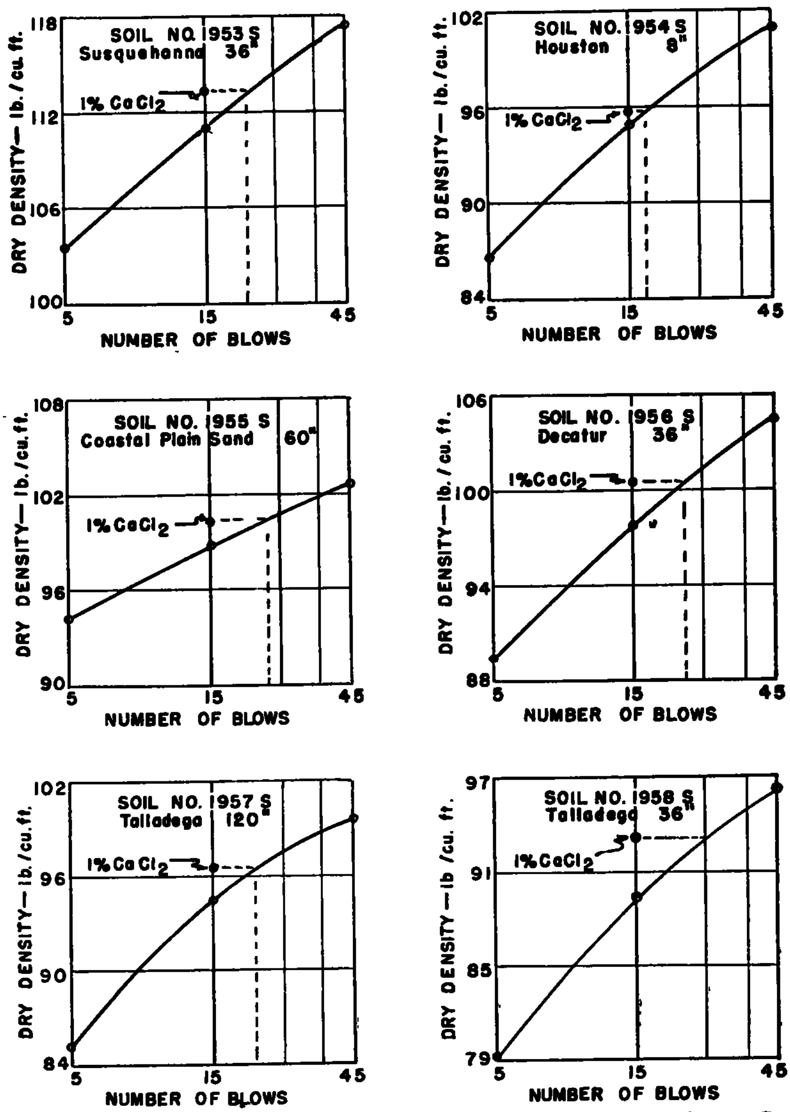


Figure 6. Effect of Calcium Chloride on Compaction—Soils 1953 S–1958 S

none of the values for soils Nos. 1945S and 1946S were changed appreciably by the admixture. Also, while the plastic limit of some of the soils was changed by the admixture, the liquid limit was changed for others. Of the 19 tests made on soils with the admixture, 15

Liquid and Plastic Limit Tests—The results of this series of tests are listed in Table 5. The

TABLE 2
SUMMARY OF COMPACTION TESTS MADE ON SOILS 1945S–1950S

Calcium chloride	5 Blows Dry Weight[a]	5 Blows Increase	15 Blows Dry Weight	15 Blows Increase	45 Blows Dry Weight	45 Blows Increase	90 Blows Dry Weight	90 Blows Increase
			Soil No. 1945S Crosby 10 in.					
per cent	*lb. per cu. ft.*	*lb. per cu. ft.*	*lb. per cu. ft.*	*lb. per cu. ft.*	*lb. per cu. ft.*	*lb. per cu. ft.*	*lb. per cu. ft.*	*lb. per cu. ft.*
0	99.5		106.2		114.5		117.2	
0.25	100.5	1.0	106.5	0.3	114.7	0.2	116.2	−1.0
0.5	100.0	0.5	106.5	0.3	113.9	−0.6	117.4	0.2
1.5	99.5	0.0	106.3	0.1	111.8	−2.7	116.5	−0.7
			Soil No. 1946S Illinoian Drift 6 in.					
0	91.2		95.0		102.5		104.8	
0.25	88.7	−2.5	96.3	1.3	103.8	1.3	104.9	0.1
0.75	90.8	−0.4	97.1	2.1	105.9	3.4	107.5	2.7
1.5	87.9	−3.3	97.0	2.0	103.6	1.1	105.2	0.4
			Soil No. 1947S Illinoian Drift 60 in.					
0	88.0		97.8		106.4		110.0	
0.25	89.9	1.9	98.2	0.4	107.7	1.3	111.4	1.4
0.75	89.8	1.8	99.0	1.2	105.6	−0.8	112.2	2.2
1.5	90.7	2.7	99.7	1.9	107.9	1.5	110.3	0.3
			Soil No. 1948S Illinoian Drift 120 in.					
0	108.0		115.2		120.6		122.0	
0.25	103.2	1.2	116.2	1.0	121.1	0.5	123.9	1.9
0.75	109.1	1.1	115.1	−0.1	121.5	0.9	122.8	0 8
1.5	107.7	−0.3	115.0	−0.2	120.9	0.3	122.9	0.9
			Soil No. 1949S Ruston 168 in.					
0			105.2		112.5			
1.0			106.1	0.9	112.6	0.1		
1.5			105.8	0.6	111.1	−1.4		
			Soil No. 1950S Memphis 24 in.					
0			98.2		106.1			
1.0			99.1	0.9	106.3	0.2		
1.5			98.5	0.3	105.8	−0.3		

[a] Densities of soils with $CaCl_2$ admixture corrected by deducting the weight of $CaCl_2$.

TABLE 3
SUMMARY OF COMPACTION TESTS MADE ON SOILS 1951S–1969S

Soil No.	Calcium Chloride	Dry Density[a] at 15 Blows	Increase	Soil No.	Calcium Chloride	Dry Density at 15 Blows	Increase
	Per- cent	*lb. per cu. ft.*	*lb. per cu. ft*		*Per- cent*	*lb. per cu. ft.*	*lb. per cu. ft.*
1951S	0	93.8		1961S	0	86.5	
	1	93.0	−0.8		1	87.8	1.3
1952S	0	86.7		1962S	0	103.5	
	1	86.1	−0.6		1	101.0	−2.5
1953S	0	111.3		1963S	0	96.8	
	1	112.0	0.7		1	98.5	1.7
1954S	0	95.0		1964S	0	104.1	
	1	94.8	−0.2		1	105.4	1.3
1955S	0	98.9		1965S	0	91.5	
	1	99.0	0.1		1	91.5	0.0
1956S	0	97.8		1966S	0	96.8	
	1	99.5	1.7		1	96.8	0.0
1957S	0	95.5		1967S	0	88.1	
	1	95.6	0.1		1	89.6	1.5
1958S	0	89.2		1968S	0	101.5	
	1	92.2	3.0		1	102.3	0.8
1959S	0	99.9		1969S	0	103.8	
	1	101.9	2.0		1	104.7	0.9
1960S	0	117.1					
	1	116.1	−0 5				

[a] Densities of soils with $CaCl_2$ admixture corrected by deducting weight of $CaCl_2$.

TABLE 4
EFFECT OF CALCIUM CHLORIDE ON THE pH OF SOILS

Soil	Calcium Chloride Added	pH	Soil	Calcium Chloride Added	pH
	Percent			*Percent*	
1945S	0	7.4	1958S	0	4.7
	0.25	7.0		1	3.6
	0.5	6.6	1959S	0	4.6
	1.5	6.5		1	3.9
1946S	0	6.2	1960S	0	5.4
	0.25	5.4		1	4.5
	0.75	5.2	1961S	0	5.5
	1.5	5.1		1	3.4
1947S	0	4.4	1962S	0	4.5
	0.25	3.6		1	4.2
	0.75	3.4	1963S	0	4.8
	1.5	3.1		1	3.7
1948S	0	5.2	1964S	0	4.5
	0.25	4.4		1	3.4
	0.75	4.3	1965S	0	6.3
	1.5	4.3		1	5.6
1949S	0	6.3	1966S	0	7.3
	1	5.5		1	6.6
	1.5	5.4	1967S	0	4.8
1950S	0	5.0		1	3.7
	1	3.7	1968S	0	5.0
	1.5	3.6		1	3.7
1951S	0	5.4	1969S	0	7.1
	1	4.8		1	6.7
1952S	0	7.4	Distilled Water	0.25	9.0
	1	6.8		0.5	9.8
1953S	0	5.2		0.75	10.0
	1	3.9		1.0	10.2
1954S	0	7.3		1.5	10.3
	1	6.7			
1955S	0	5.3			
	1	4.1			
1956S	0	5.1			
	1	3.5			
1957S	0	4.9			
	1	4.0			

TABLE 5
EFFECT OF CALCIUM CHLORIDE ON THE PLASTIC AND LIQUID LIMITS OF SOILS

Soil No.	Calcium Chloride	L.L.	P.L.	P.I.
	Percent			
1945S	0	33.2	18.7	14.5
	0.25	33.2	18.4	14.8
	0.5	33.1	18.8	14.3
	1.5	31.6	18.4	12.2
1946S	0	28.6	20.5	8.1
	0.25	27.6	20.0	7.6
	0.75	28.8	20.8	8.8
	1.5	28.2	19.7	8.5
1947S	0	42.6	17.2	25.4
	0.25	43.7	19.6	23.1
	0.75	42.1	19.4	22.7
	1.5	40.5	18.1	22.4
1948S	0	22.3	13.3	9.0
	0.25	21.2	12.6	9.6
	0.75	20.2	12.6	7.6
	1.5	19.9	11.6	8.3
1949S	0	31.0	14.2	16.8
	1	29.0	13.2	15.8
	1.5	29.9	14.1	15.8
1950S	0	44.3	27.2	16.1
	1	40.2	18.1	22.1
	1.5	41.8	22.2	19.6
1954S	0	43.9	27.3	16.6
	1	40.9	27.3	13.6
1960S	0	23.5	18.1	5.4
	1	20.0	15.9	4.1
1969S	0	32.4	16.5	15.9
	1	30.1	16.2	13.9

showed a decrease in the liquid limit values from that of the raw sample, 13 showed a decrease in the plastic limit values, and 13 showed a decrease in the plastic index.

Penetration Tests—To arrive at an overall picture of the effect of calcium chloride on the sample are shown in Figure 7. The results of all the load-penetration tests are listed in Table 6.

It will be noted that in most cases the addition of calcium chloride caused a slight decrease in penetration resistance. The ex-

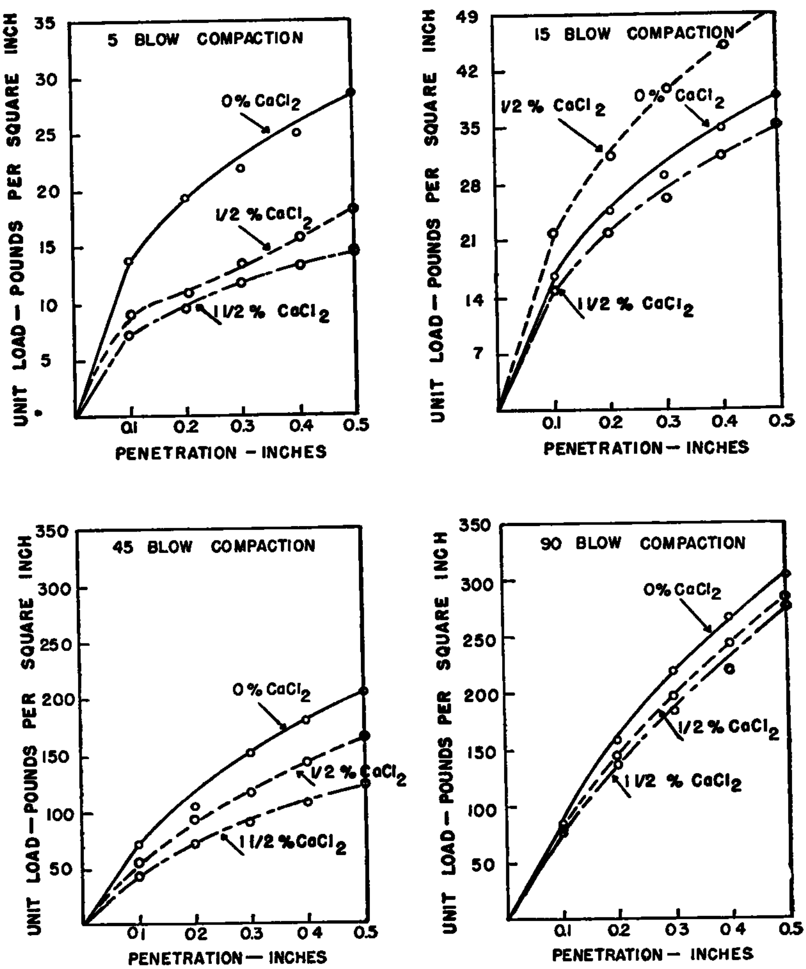


Figure 7. Load-Penetration Curves For Soil No. 1945 S Crosby 10 in.

penetration resistance of soils as measured by the California bearing ratio test, three soils were tested. These three soils represented a wide variety relative to a soil texture. They were (1) Crosby (silty clay), (2) Memphis (wind blown silt), and (3) Rustan (sand clay). Load-penetration curves for the Crosy ceptions to this were the tests made on the Crusby and Ruston soils under conditions of density produced by 15 blows of the compaction hammer. In all other cases the penetration resistance of the specimens that contained calcium chloride as an admixture were less than those of the raw soil alone. This was true even though (with the exception of the 1½ percent calcium chloride, 45-blow, Crosby sample) the densities of the specimens with calcium chloride were higher than those with no calcium chloride.

The explanation for this can be found in part in Table 6. It will be noted that there was a greater tendency fot the specimens with calcium chloride to swell during the soaking period than for those with no calcium chloride. However, the moisture contents of these specimens after soaking were, for the most part, less than those of the specimens which contained no calcium chloride. This was probably due to the higher densities of the specimens with calcium chloride as an admixture.

Drying, Drying and Rewetting Tests—The results of the drying tests are shown in Figures 8 and 9. Two of the materials used in this series of tests were granular materials. The pit-run gravel contained approximately 6 percent finer than a No. 200 mesh sieve, and the maximum size of the aggregate was ¾ in. In contrast the soil-coarse sand mixture contained approximately 15 percent finer than a No. 200 mesh sieve, and all the sand was finer than ¼ in. The Crosby and Ruston samples used were those incorportated in the compaction and penetration test series.

Figure 8 indicates that the addition of calcium chloride to granular materials greatly retards their drying. For example, the pit run gravel dried from 8-percent moisture to optimum moisture (6 percent) in 10 min. The use of increasing amounts of calcium chloride retarded the drying, until with 1½ percent calcium chloride, the time required for the material to dry from 8 to 6 percent moisture was approximately 50 min., or five times as long as that of the raw sample. It will be noted that in each case the greatest portion of the drying occurred during the first part of the test.

Similarly, drying of the soil-coarse sand mixture was retarded by the addition of calcium chloride. In this case the original samples

TABLE 6
SUMMARY OF LOAD PENETRATION TESTS

Soil	Compaction No. Blows	Calcium Chloride	Dry Density	Moisture Before Soaking	Moisture After Soaking		Swell	Penetration	
					Top 1 in.	Ave.		Unit Load at 0.1-in. pen.	Unit Load at 0.5-in. pen.
		Percent	*Lb. per cu. ft.*	*Percent*	*Percent*		*Percent*	*psi*	*psi*
1945S Crosby	5	0	98.6	23.0	23.0	22.8	0.09	14.0	28.0
	5	0.5	100.2	22.2	22.6	22.4		8.3	17.3
	5	1.5	102.0	22.3	(23.0)	22.7		7.0	14.6
	15	0	105.0	18.9	21.8	21.0	0.34	16.0	38.0
	15	0.5	107.9	18.2	20.2	19.7	0.44	22.0	55.8
	15	1.5	108.0	19.5	20.5	19.6		14.6	35.3
	45	0	113.1	15.8	17.1	16.9	0.44	71 6	212.0
	45	0.5	115.1	15.0	17.9	16.8	0.79	50.6	166.6
	45	1.5	112.9	16.7	18.6	17.3	0.57	42.3	124.0
	90	0	117.2	14.7	15.9	15.4	0.54	87.6	308.5
	90	0.5	117.5	14.1	16.7	15.4	0.48	70 0	281.0
	90	1.5	118.5	14.3	18.2	15.2	0.07	72.3	280.5
1949S Ruston	15	0	106.5	18.7	20.3	20.0	0.39	32 6	72 0
	15	0.5	107.5	18.5	20.2	20.0	0.46	38.3	81.3
	15	1.5	108.2	17.9	21.2	18.5	0.69	41.0	95.0
	45	0	112.0	17.0	20.0	18.7	0.55	73.3	188 6
	45	1	113.5	16.6	19.7	17.5	0.78	47 0	157.0
	45	1.5	113.9	16.6	20.3	17.6	0.74	53 0	172.0
1950S Memphis	15	0	98.0	23.8	28.8	26.6	0.63	25.0	90.0
	15	1	99.0	21.8	26.9	24.9	0 82	28.3	74 6
	15	1.5	99.4	22.5	27.9	25.8	1.10	26.6	68.6
	45	0	104.2	19.1	24.6	23.2	0.75	89.6	212.3
	45	1	106 4	18.5	26.8	23.9	1.71	53.0	163 0
	45	1.5	108.2	17.6	27.7	23.8	1.92	31.6	94.3

contained 10 percent moisture at the start of the test. The specimen with no calcium chloride dried from 10 percent moisture to the optimum of 8 percent moisture in 20 min. results. In particular, the zero-percent Crosby sample dried out slower than did the ¼- or ¾-percent samples. Also, in the case of the tests on the Ruston samples, the moisture

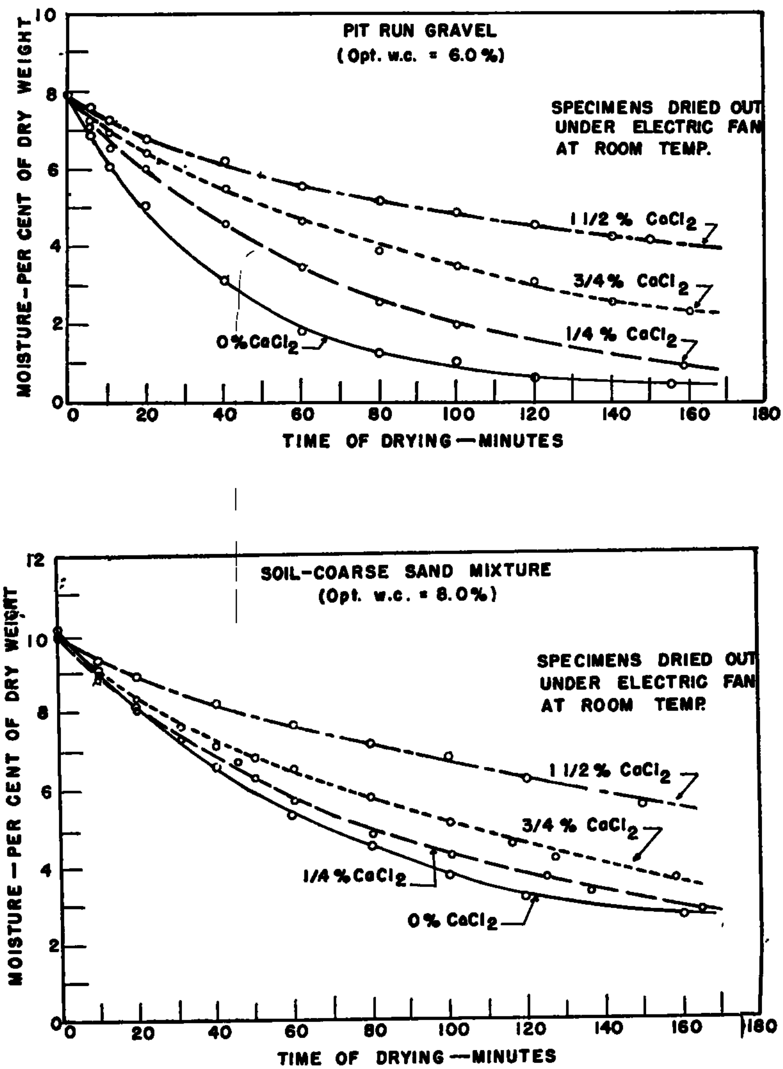


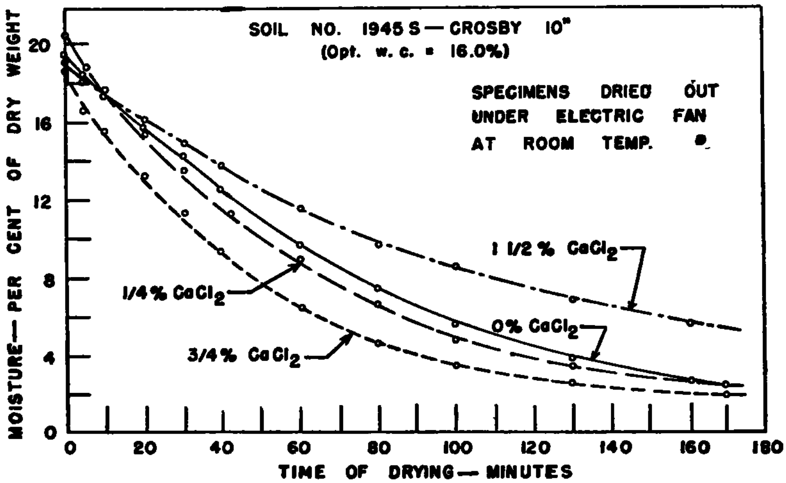
Figure 8. Effect of Calcium Chloride on Retarding Drying of Two Granular Materials

However, when 1½ percent calcium chloride was incorporated this drying time was increased to 48 min.

Figure 9 shows the results of the drying tests made on a sample of Crosby and Ruston. Neither of these materials showed consistent content of the ¼-percent calcium chloride sample was higher at the completion of the test than that of the ¾-percent sample.

The effect of calcium chloride on the water retention characteristics of soils is further shown in Figure 10. In this series of tests the samples were compacted into small cylindrical molds. The densities as shown on the graphs were approximately equal to those obtained by the 15- and 5-blow Proctor tests.

A comparison of the curves resulting from the treated and untreated samples of equal densities—zero admixture, 15-blow density, and 1 percent admixture, 5-blow density—



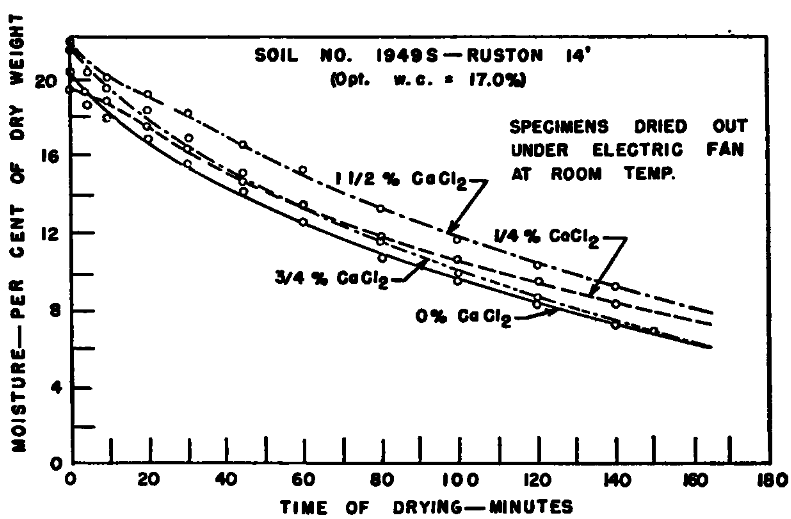


Figure 9. Effect of Calcium Chloride on Retarding Drying of Soils 1945 S and 1949 S

In every case when calcium chloride was used as an admixture, the moisture contents of these samples were less at the end of the drying and rewetting period than those of the raw samples. However, the densities of the treated samples were higher than those of the untreated samples.

shows that these two specimens took up approximately the same amount of water during the wetting cycle.

SUMMARY OF RESULTS AND CONCLUSIONS

Based on the data obtained in this study, the results and conclusions are summarized as follows:

1. The results of the compaction tests indicated that, for most of the soils tested, the use of calcium chloride decreased the compactive effort required to produce a given density of soil. In most cases this effect was found to be greatest for the lower ranges of compactive effort used. Also, the lower percentages of calcium chloride appeared to be more effective than did the higher percentages.

2. Calcium chloride in percentages up to 1½ percent consistently lowered the pH of the soils tested.

3. The results of the tests for the effect of calcium chloride on the plasticity of the soils indicated that calcium chloride lowered both the liquid and plastic limits of some of the soils tested.

4. The results of the load-penetration tests performed on three of the soils indicated that calcium chloride lowered the penetration resistance of the soils a small amount.

5. Calcium chloride retarded the drying out of soils when subjected to accelerated drying. The results of the drying and rewetting tests showed that the moisture contents of the specimens containing calcium chloride were lower after the drying and wetting cycle than those with no calcium chloride. This was probably due in part to the higher densities of the specimens which contained calcium chloride.

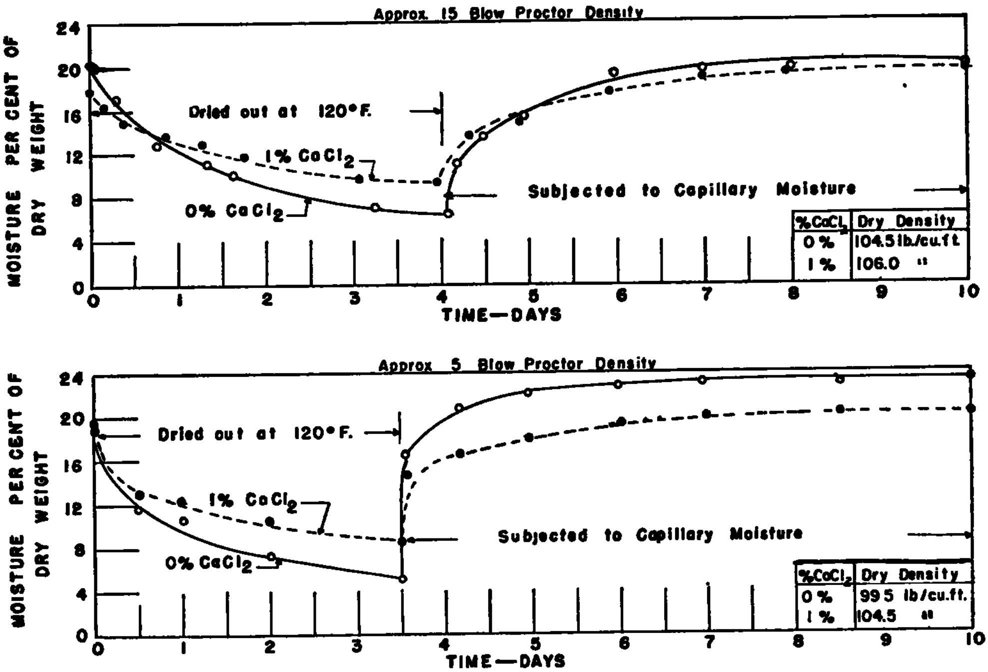


Figure 10. Effect of Calcium Chloride on Drying and Rewetting Soil No. 1945 S Crosby 10 in.

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DISCUSSION

J. A. Knight. The following discussion presents the results of a series of tests carried out through the summer and fall of 1947. As the first tests did not provide a comparison between calcium chloride treated and untreated samples a further set of tests was completed.

TABLE A

Sieve No.	Percent Passing	Size-Microns by Hydrometer	Percent Passing
3 in.	100	39.1	12.3
2 in.	97.2	27.8	11.0
1½ in.	93.8	17.8	10.0
1 in.	90.0	10.3	7.9
¾ in.	86.2	7.2	6.0
⅜ in.	79.2	5.2	5.3
No. 4	73.7	2.6	4.3
No 10	60.5	0.5	2.4
No. 20	37.4		
No. 40	27.2		
No. 60	17.8		
No. 140	16.2		
No. 200	15.8		

The purpose of these tests was to demonstrate in the laboratory the benefits to be derived from calcium chloride treatment of soils in secondary roads where a large proportion of the compaction must be obtained under traffic with no control over moisture content.

Samples—Two bags of pit run gravel were obtained from a gravel pit near Barrie, Ontario, which had been used by the Ontario Department of Highways in rebuilding Highway No. 27. These were mixed together, air dried, the clods of the fine material broken up, and the whole sample subjected to the tests described below.

Mechanical Analysis—Sieve and hydrometer analysis on the sample gave the results shown in Table A.

Standard Proctor Compaction Test—A standard Proctor compaction test was made on un-

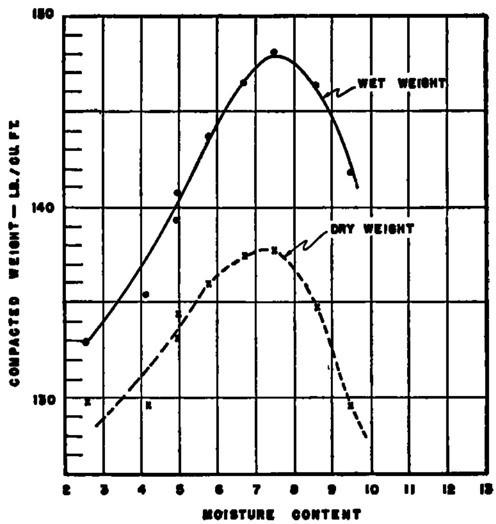

Figure A. Standard Proctor Compacted Density-Moisture Characteristics—Pit Run Gravel.

treated material passing the No. 4 sieve. This test was made using a 4- by 4.6-in. cylindrical mould and a tamper of 5½-lb. weight dropped through 12 in. 25 times on each of three layers of soil. The results obtained in this test are presented graphically in Figure A.

Densities and Moisture Contents—

Uniform Compactive Effort. Two 15-lb. batches of minus 4 mesh material were placed in separate drying pans. To one of these pans tests were then made on each batch alternately, allowing a 45-min. drying period under a fan between each test. After nine tests had been completed on each batch, i.e. at the end of the working day, damp cloths were

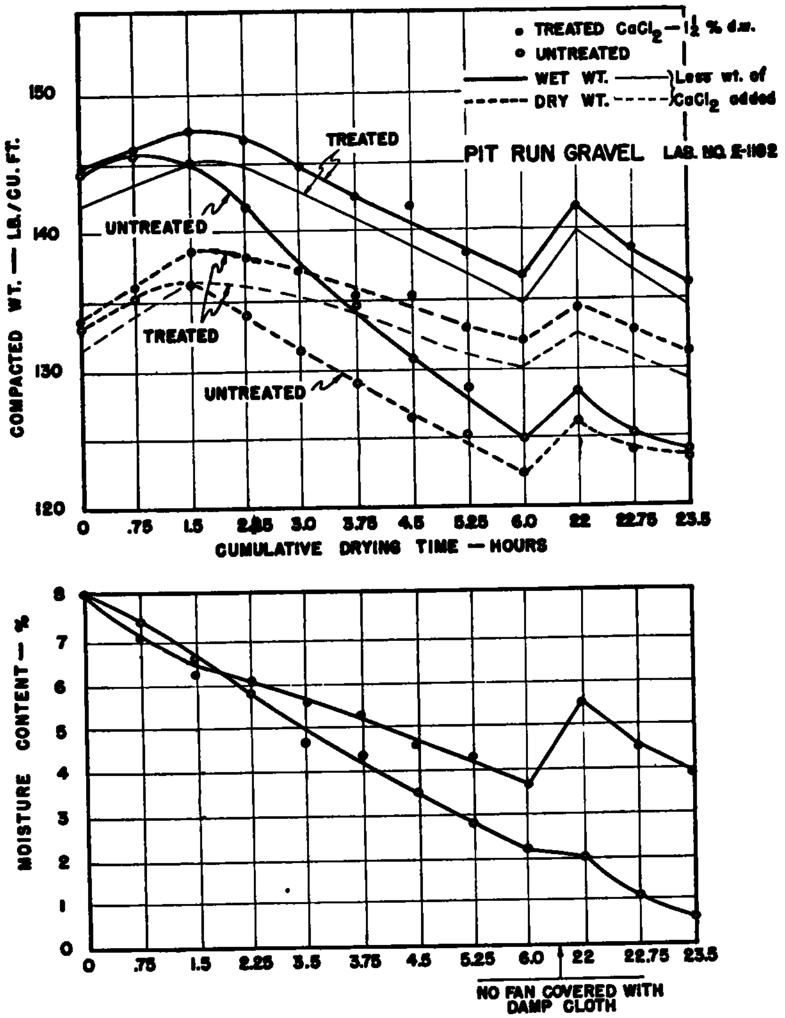

Figure B. Moisture Content and Densities—Uniform Compactive Effort (Standard Proctor)—Fan Dried

calcium chloride was added in an amount equal to 1.5 percent of the dry weight of the soil. The materials in both pans were brought to a moisture content of approximately 8 percent or slightly above the Proctor optimum.

A series of standard Proctor compaction placed over each pan and the tests resumed in the morning.

The densities and moisture contents determined at the conclusion of each test are presented in Figure B. A correction was made on the densities of the treated soil by subtracting from the calculated weights the weight of calcium chloride added. This correction varied from 1.94 to 2.05 lb. per cu. ft.

Increasing Compactive Effort. A second series of tests were run in a manner similar to those described above with the exception that in succeeding compaction tests a heavier compactive effort was employed. Increased compactive effort was obtained for the first six tests by increasing the number of 12-in. blows with the 5.5-lb. tamper from 5 to 160 per layer. In the remaining three tests a 10-lb. tamper with 12- and 18-in. blows was used.

The results of this series of tests are shown graphically in Figure C.

Effect on Cohesive Strength of Increased Density—To demonstrate the improvement in cohesive strength resulting from an increase in compacted density, four compaction tests were made in a standard Proctor mould on untreated soil using different moisture contents and varying the compactive effort. The compacted soil specimens, 4-in. diameter and 4.52 in. in length, were then jacked out of the mould, and subjected to unconfined compressive tests.

The results of the tests are graphically pre-

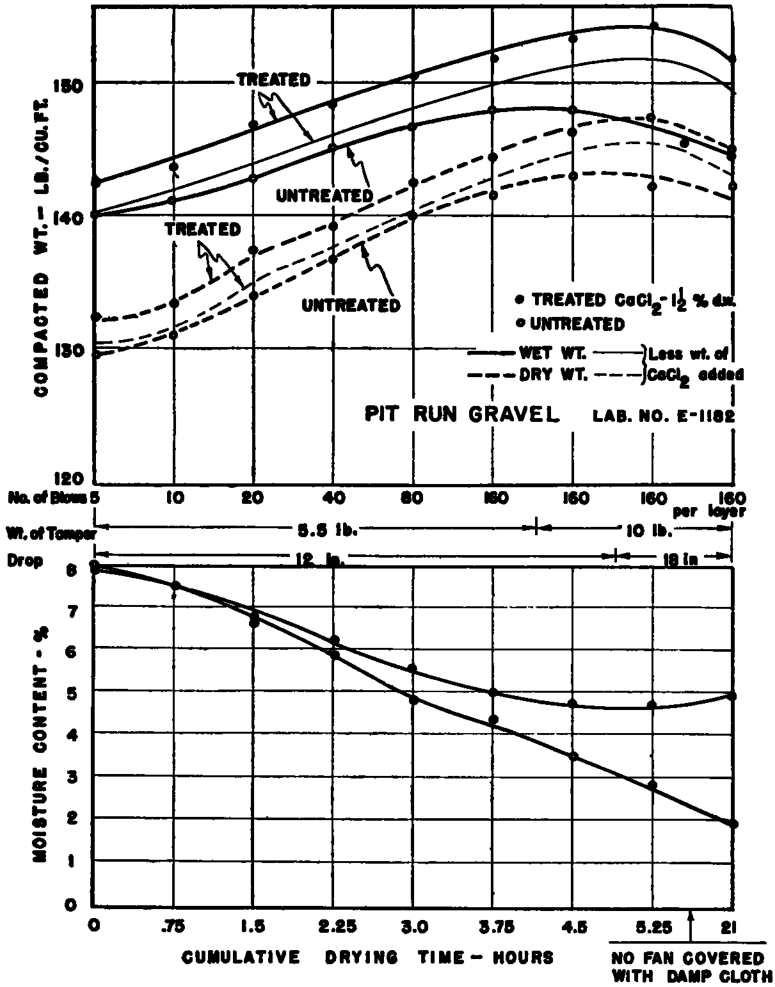

Figure C. Moisture Content and Densities—Increasing Compactive Effort—Fan Dried

sented in Figure D, the compacted weights being plotted on an arithmetic scale and cohesive strength on the logarithmic scale.

2ND SET OF TESTS

The purpose of these tests was to determine in the Laboratory the effect of calcium chloride treatment on the compressive strength of soils.

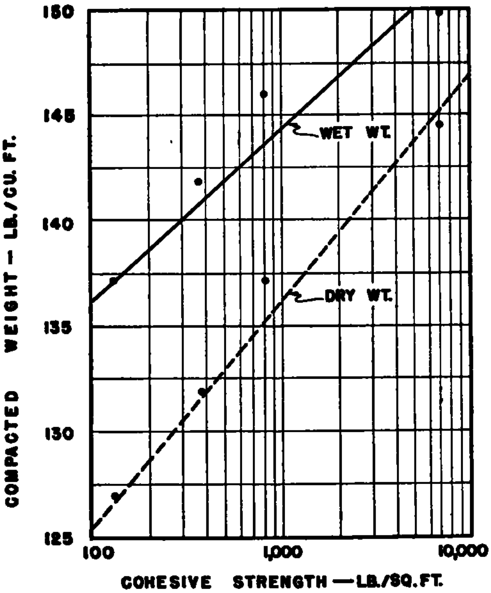

Figure D. Effect of Compacted Density on Cohesive Strength of Soil No. E-1182.

Sample—A sample of gravel was obtained from a Department of Highways pit near Barrie, Ontario. The material was air-dried, the clods broken up and subjected to the following tests.

Mechanical Analysis—The results of the sieve analysis are presented in Table B.

Compacted Density—Treated and Untreated Soil—A sample of material passing the No. 4 sieve was subdivided into two batches of 20 pounds each. To one of the two beakers containing 1.1. lb. of water (5.5 per cent of the dry weight of the soil), a quantity of flake calcium chloride was added equivalent to 1½ percent of the dry weight of the soil. After the calcium chloride had dissolved the contents of the beakers were added to the respective batches of soil, henceforth referred to as Treated and Untreated. Soil from each batch was then compacted into separate Proctor moulds under the same compactive effort, i.e. eighty 12-in. blows from a 5½-lb. hammer on each of 3 layers. After recording the compacted densities the cylindrical specimens were jacked from the moulds and subjected to unconfined compression tests. Moisture contents were recorded. During a period of 45 min. between successive tests the soil remaining in the pans was air-dried under a fan. In each succeeding test

TABLE B

Sieve No.	Percent Passing
3 in.	100.0
2 in.	97.2
1½ in.	93.8
1 in.	90.0
¾ in.	86.2
⅜ in.	79.1
No. 4	73.5
No. 10	60.3
No. 20	37.2
No. 40	27.1
No. 60	17.7
No. 140	16.1
No. 200	15.9

increased compactive efforts were employed as follows:

Test No.	No. of Blows per Layer	Height of Blows	Wt. of Hammer
		in	*lb.*
1	80	12	5.5
2	160	12	5.5
3	160	12	10.0
4	160	18	10.0

Results on the moisture contents, compacted density, and unconfined compression strength are presented in Table C. The stress-de-

TABLE C
COMPACTED WEIGHT—MOISTURE CONTENT—COMPRESSIVE STRENGTH TREATED AND UNTREATED SOIL

Test No.	Soil	Moisture Content	Wet Density	Dry Density	Compressive Strength
		%	*lb. per cu. ft.*		*psi.*
1 A	Treated	5.9	149.9	141.5	40.8
1 B	Untreated	5.5	149.3	141.5	67.6
2 A	Treated	5.7	152.5	144.3	49.8
2 B	Untreated	5.2	150.2	142.8	86.8
3 A	Treated	5.3	154.0	146.2	87.2
3 B	Untreated	3.8	148.2	142.8	[a]
4 A	Treated	4.2	150.8	144.8	121.2
4 B	Untreated	1.8	144.3	141.8	[a]

[a] Specimen broke during removal from mould.

formation curves obtained in the compression tests are recorded in Figure E.

Figure F shows the progressive drying which occurs in each batch during the 45-min. drying period between successive tests. In Figure G are plotted the compacted densities obtained in each test for the treated and untreated soil, the latter being corrected for the weight of calcium chloride added. Figure H shows a plot on semi-logarithmic paper of the dry density against the compres-

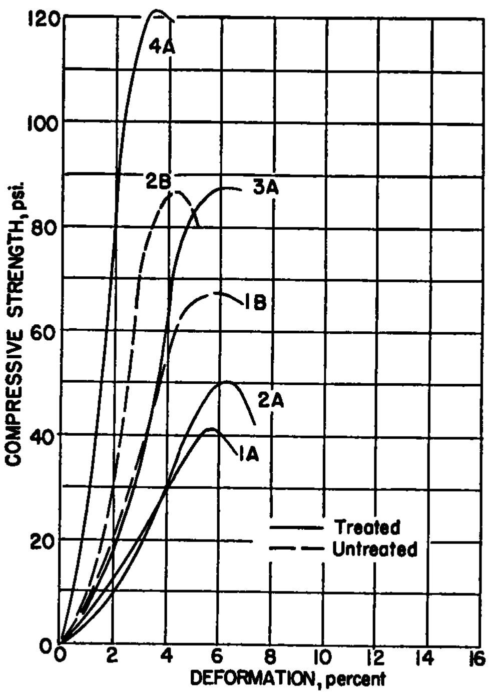

Figure E. Stress-Deformation Curves—Unconfined Compression Tests.

sive strength. It will be noted that for equivalent dry densities the compressive strength of the untreated exceeds that of the treated soil. Figure I shows all samples plotted together in strength-moisture content axes; apparently indicating a direct relationship irrespective of treatment.

Conclusions—In view of the limited number of tests made due to breakage of cylinders on removal from the mould, no definite conclusion can be made. The indications are that when the treated and untreated samples were compacted to the same density, the latter showed the higher compressive strength. However, it should be noted that we were

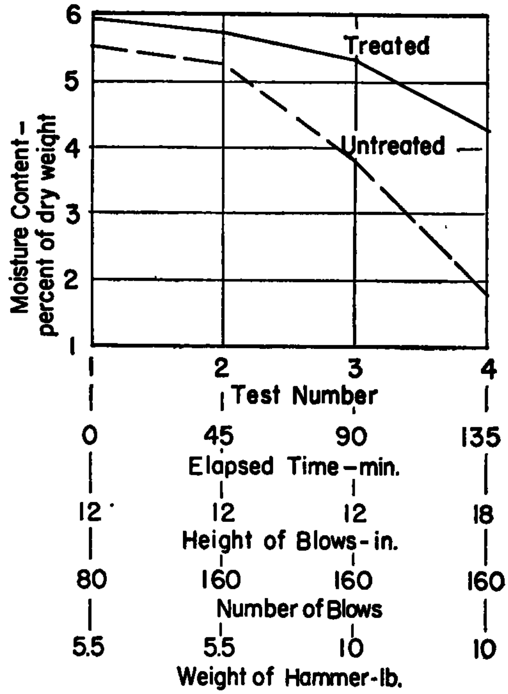

Figure F. Progressive Drying of Treated and Untreated Soils between Tests.

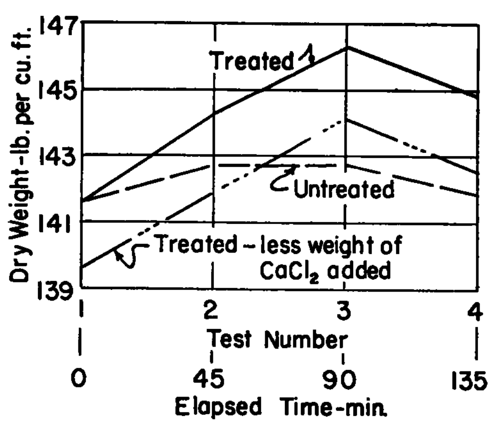

Figure G. Compacted Densities Obtained with Treated and Untreated Soils.

unable to obtain high strength in the untreated samples as they would not retain their form when jacked from the mould indicating a lack of cohesion. The treated samples were intact up to a strength 50 percent in excess of the untreated. The moisture when in calcium brine form seems to be more active than when untreated thus allowing the development of higher strengths.

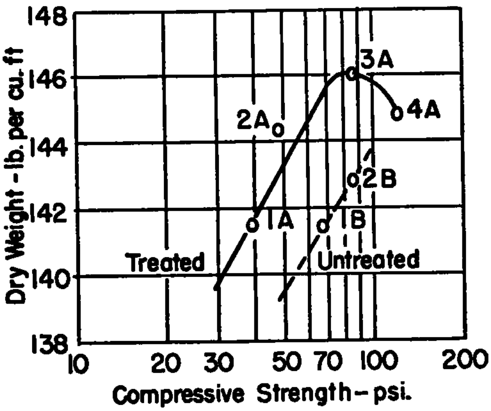

Figure H. Compressive Strength of Compacted Soil Treated and Untreated plotted against Dry Weight.

These tests were not extensive enough to justify the drawing of definite conclusions but they indicate several possibilities and so call for considerable further investigation. I believe that the following conclusions are justified:

1. Calcium chloride when used as an admixture to road gravel decreases the effort needed for compaction, increases the available time during which compaction is possible, and increases the ultimate strength.

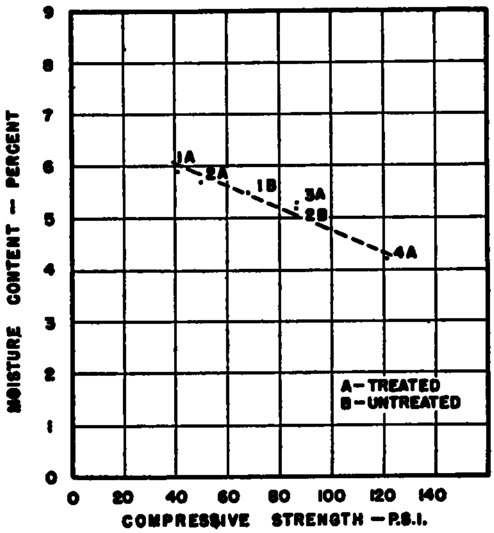

Figure I. Compressive Strength of Compacted Soil Treated and Untreated plotted against Moisture Content.

2. I also believe that the tolerance on density specification is a dangerous practice and that strength control should be on a moisture content strength basis rather than expressed as a percent of specified density.