THE ROLE OF CALCIUM CHLORIDE IN COMPACTION OF SOME GRANULAR SOILS[1]

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SYNOPSIS

Results are reported for 90 compaction runs on six typical A-2 soils, one plastic and one friable from each of three States, Alabama, North Carolina, and Virginia. Runs were made using 0, 0.5, 1, 2, and 3 percent of calcium chloride admixture. Compactive efforts used were 6-in. drop with the standard hammer, 12-in. drop with the standard hammer, and 18-in. drop with the 10-lb hammer. Other details of the procedure were held constant. The Proctor mold was used and plasticity needle readings were taken.

The results indicated that a substantial saving in compactive effort required to obtain a specified density is effected by the addition of calcium chloride. For some soils, the maximum density obtained without admixture was reproduced with about 50 percent of the compactive effort when 3 percent of admixture was used. Penetration curves indicated a noticeable increase in workability with successive additions of the chemical.

The problem of stabilization is an ever present one in the design and construction of soil roads and shoulders, bases and sub-bases for flexible and rigid-type highway pavements, airport runways and taxi-ways, and earth dams and other embankments. There are four factors fundamental to stabilization: gradation, water content, compaction, and plasticity. In three of these factors (water content, compaction, and plasticity) calcium chloride is believed to have a definite influence.

The principle aims of stabilization are to make the soil as dense as possible and to prevent the thickness of the moisture film from changing. The use of calcium chloride as an aid in maintaining the moisture film is fairly well accepted. It reduces the rate of evaporation during dry weather and absorbs water from the atmosphere during periods of high humidity. Densification also serves to control the moisture content by reducing the voids which may become filled with water.

Available information is not conclusive as to the exact role of calcium chloride in compaction. The general expectancy has been that it will reduce the amount of compactive effort required to obtain a definite degree of compaction of a certain soil and that it will contribute toward greater density with constant compactive effort. There are more data to support these trends than to refute them, but variations in soils, in percentages of admixture, and in application and mixing conditions make quantitative predictions uncertain.

Examination and study of the available information on the effect of calcium chloride in stabilization of granular soils led to the following conclusions:

1. Calcium chloride can be expected to contribute to a greater density with a constant compactive effort for a given soil.
2. Calcium chloride can be expected to reduce the compactive effort required to obtain a desired degree of compaction.
3. Insofar, then, as increased density is an indication of greater stability, calcium chloride contributes to the stabilization of a soil.
4. The amount of expected increase in density and the amount of calcium chloride to add to obtain the maximum effect cannot be accurately determined except by tests on the particular soil.
5. The cause of the effect which calcium chloride has in stabilization is largely unknown. Several factors which are thought to have an influence on the action, or which are conceded to have an influence, but with uncertainty as to the action, are:
   a. Increased surface tension of calcium chloride solutions over that of water.
   b. Decreased vapor pressure of calcium chloride solutions over that of water.

[1] Prepared for the Committee on Soil Calcium Chloride Roads.

c. Hygroscopic and deliquescent properties of calcium chloride solutions.

d. Base exchange in the clay fraction.

It was with the hope of finding quantitative data on the role of calcium chloride in compaction and of finding what the action of calcium chloride in compaction is that the study reported here was undertaken. Objectives were to determine what, if any, increase in maximum density results from compacting with additions of calcium chloride and what effect calcium chloride has on the compactive effort required to obtain a specified density. The work was confined to granular soils similar in type and origin in an attempt to eliminate one of the many variables. The project was supervised by the Committee on Soils-Calcium Chloride Roads of the Highway Research Board and was carried on in the soils laboratory of the civil engineering department of the University of Maryland.

TABLE 1
PHYSICAL CHARACTERISTICS OF SOILS USED

	Soil					
	Alabama		North Carolina		Virginia	
	Plastic	Friable	Plastic	Friable	Plastic	Friable
Specific Gravity....	2.64	2.66	2.64	2.61	2.66	2.66
Field Moisture Equivalent... %	18.0	18.0	25.0	20.0	22.0	19.0
Liquid Limit.. %	26.0	24.0	30.0	17.0	30.0	19.0
Plastic Limit . %	15.0	NP	21.0	NP	16.0	NP
Plasticity Index .... %	11.0		9.0		14.0	
Shrinkage Limit . .... %	13.0	16.0	18.0	NS	14.0	NS
Percentage of Fines .... %	47.1	46.3	33.0	38.2	57.4	27.7

PROCEDURE

Six selected soil samples were used in the investigation. They were all of the subgrade classification group, A-2. Three of the soils were plastic and three non-plastic. One plastic and one friable sample were selected from each of three states, Alabama, North Carolina, and Virginia and were furnished by members of the committee. Routine tests on the soils were performed by the laboratory of the Virginia Department of Highways. Results of these tests are tabulated in Table 1 and the grain size distribution curves are plotted in Figure 1. These results show the samples to be typical A-2 soils.

By quartering and by use of the sample splitter, five or more samples of about 3000 grams each were obtained from each of the six soils. One sample was used for compaction with no admixture and one additional sample for each different percentage of admixture. Percentages of admixture used were 0, 0.5, 1.0, 2.0, and 3.0. These percentages are expressed in terms of dry weight of soil The chemical was added to the soil in solution, thoroughly mixed, and partially dried before compaction.

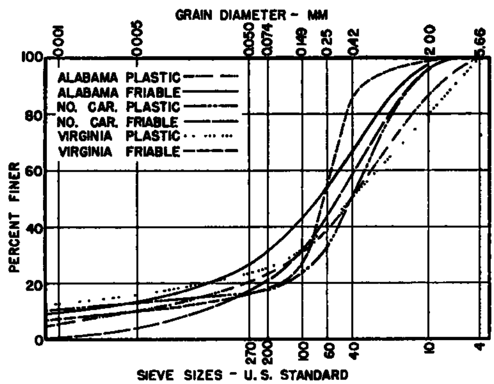

Figure 1. Grain Size Distribution Curves of Soils Used

Three different compactive efforts were used: a 6-in. drop with the 5.5-lb hammer, 12-in. drop with the 5.5-lb hammer, and 18-in. drop with the 10-lb hammer. These hammers, all with 2-in. diameter striking faces, are shown in Figure 2. The standard Proctor mold was used for all compaction runs. Each mold was compacted in three equal layers with 25 blows on each layer. Thus the only variable in compactive effort was the number of in.-lb of energy per blow.

Each sample was subjected to three compaction runs: first, the series of runs required to obtain the usual compaction curve with the 6-in. drop; second, the runs with the 12-in. drop; and, third, the series of runs with the 18-in. drop. After the runs with the 6-in. drop, the sample was dried to a low moisture content, pulverized, and then the series with the 12-in. drop was run. The sample was then dried, pulverized, and re-run using the 18-in. drop. The sample was then discarded and a new sample used for each percentage of admixture.

The Proctor plasticity needle was used to obtain a measure of the penetration resistance of each compacted sample. Figure 3 is an illustration of the equipment used in a compaction run.

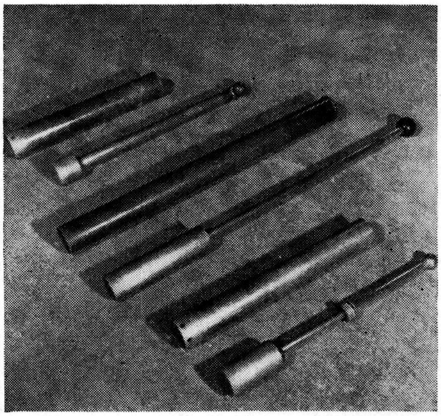

Figure 2. Three Hammers Used in Obtaining Various Compactive Efforts

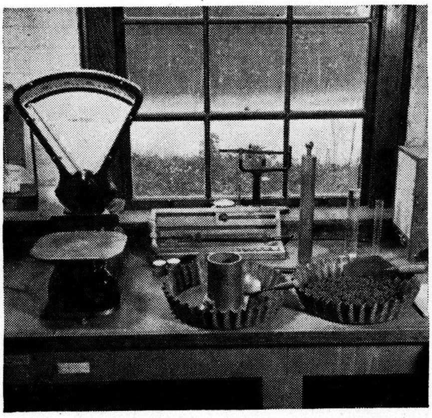

Figure 3. Equipment Used in Compaction Runs

ANALYSIS OF RESULTS

Results of 90 compaction runs were plotted—one curve for each combination of six soils, three compactive efforts, and five percentages of admixture. Figure 4 is a typical example of five runs on one soil with constant compactive effort.

The data plotted are the dry densities during each run against the corresponding moisture contents. Moisture contents were computed in all cases as the ratio of the weight of water (driven off at 105 C) to the weight of the dry solids expressed in percent. By the weight of the dry solids is meant the dry weight of the mixed soil. Thus the dry solids include the soil proper as well as the weight of the added calcium chloride remaining after heating for 12 or more hours at 105 C. The dry density, similarly, is the density of the soil plus the calcium chloride remaining after being oven dried.

The five curves of the group show the relative densities of the sample with varying percentages of admixture and with uniform compactive effort for the same soil. The curves follow the usual pattern of compaction curves, parallel on the dry side and practically coinciding on the wet side, with peaks moving progressively upward and to the left with increasing amounts of calcium chloride. With lighter compactive efforts and lower densities the curves are more rounded. As densities increase, the curves tend to become steeper and have sharper peaks.

The increase in density with increases in percent of calcium chloride used is noticeable in the plot. The lowest curve is that of the soil with no admixture, and the highest curve is that of the soil containing three percent of calcium chloride. The other three curves are found in order of their percentages of admixture between the two extremes.

In the typical plot, the lowest peak occurs at a higher moisture content than the other peaks; the highest peak occurs at a lower moisture content than the other peaks; and the remaining peaks are again distributed between the extremes. This condition follows inevitably from the arrangement of the curves. With the lines well-spaced on the dry side and coinciding on the wet side, the peaks are moved upward and to the left in meeting the succeeding dry-side curves.

Figure 5 shows the complete set of curves of the Alabama friable soil. Here again the greater density obtained with increased amounts of calcium chloride is evident for each compactive effort. The relation between corresponding curves of the three groups for each soil shows the effect of varying the compactive effort.

Figures 4 and 5 are given as typical compaction curves resulting from the data and to give a picture of comparative results. Probably the most rapid means of comparing the maximum dry densities obtained from the various combinations of soil, compactive effort, and admixture is the tabular form given in Table 2. Values in this table were obtained by reading the density at the peak of each of the 90 compaction curves such as those in the figures shown.

There is consistent evidence of increasing values of maximum density with additions of calcium chloride. In all cases the maximum density is shown by the soil containing the maximum percentage of admixture used (three percent). With the 6-in. and 12-in. drops the average increase of maximum density of the soils from compaction without admixture to compaction with three percent calcium chloride was about 5 lb per cu ft. With the 18-in. drop the average increase was about 3 lb per cu ft.

Comparison between the three groups of of values for each soil will show the effect on density of varying the compactive effort. The average increase over the density obtained with the 6-in. drop realized by using the 18-in. drop was about 11 lb per cu ft, varying from 8 for the North Carolina friable to 14 for the Virginia friable. The 12-in. drop produced an average density increase of about 5 lb per cu ft over that obtained with the 6-in. drop.

Table 3 is a tabulation of the maximum density of the dry soil alone obtained from each of the 90 compaction runs. The values in the table correspond to those in Table 2 but the weight of the calcium chloride is subtracted in each case. The tabulation shows that in general for the 6-in. and 12-in. drops there is significant increase in the density of the dry soil alone as a result of compacting with calcium chloride. For the 18-in. drop there is no significant change in the density of the dry soil alone For all three compactive efforts and for most of the six soils, the maximum effect on the density of the dry soil alone was obtained with one percent of admixture. Use of additional amounts of admixture either caused no appreciable change in the density of the dry soil or resulted in a definite falling off of the density of the dry soil. In most cases, excepting four of the soils under the heavy hammer, three percent of admixture in compaction resulted in a dry soil density greater than that obtained using no admixture. It should be noted that even though in some instances the increase in dry density of the solids as tabulated in

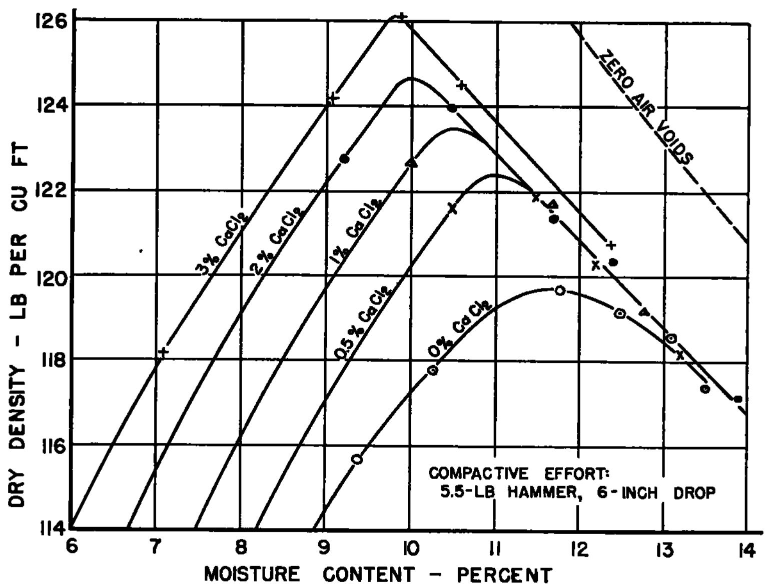

Figure 4. Compaction Curves of Virginia Plastic Soil

Table 2 was due primarily to the calcium chloride added nevertheless that increase in dry density represents a decrease in the volume of the voids in the soil and consequently contributes toward stability by reducing future fluctuations in water content. In some instances with the heavy hammer the void space at the maximum compacted condition was reduced to about one percent, so percent of this base figure and the 180 in.-lb of the 18-in. drop as 545 percent. As every sample was compacted in three equal layers and each layer received the same number of blows, the energy per blow is a direct indication of the variation in compactive effort.

Information available from this type of plot is the saving in compactive effort resulting from the use of calcium chloride as an

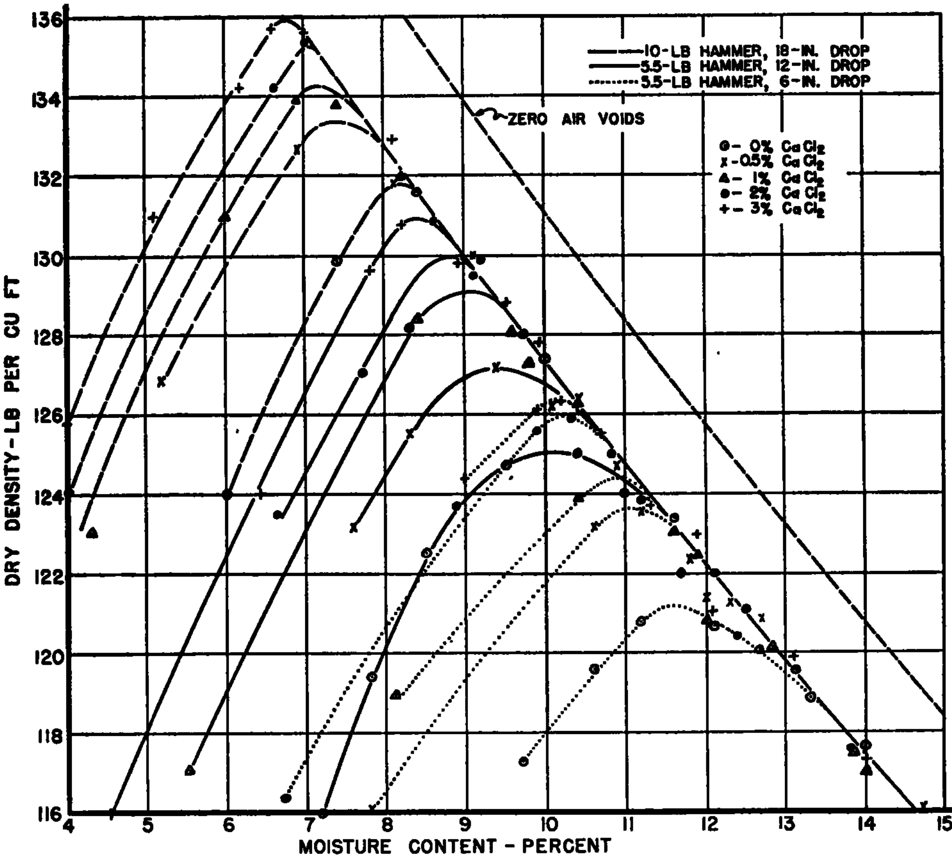

Figure 5. Compaction Curves for Alabama Friable Soil

that the soil would be able to retain but little more water than its optimum.

The maximum densities obtained from each combination of variables (the data in Table 2) were plotted on semi-logarithmic paper against an index of the compactive effort used. Figure 6 shows this plot for two of the soils. The 33 in.-lb of energy per blow of the 6-in. drop was used as the base figure. The 66 in.-lb of the 12-in. drop was plotted as 200 admixture. The dotted lines on the plot of the Alabama plastic soil show the compactive effort required to obtain 100 percent standard density when using the various percentages of admixture. A similar examination for 100 percent modified AASHO density is illustrated on the plot for the Alabama friable soil. The summary of this analysis is given in Tables 4 and 5.

Table 4 lists the percentages of standard compactive effort required with various percentages of admixture to obtain 100 percent standard density. The figures in the table subtracted from 100 will give the saving in compactive effort resulting from the use of each percentage of calcium chloride. The average saving of compactive effort by using 0.5 percent of admixture on the six soils was about 19 percent. The average saving for the six soils was about 31 percent with one percent of admixture. Use of 2 percent of admixture brought a saving in effort of about 43 percent, and by using 3 percent of calcium chloride an average saving in compactive effort required to obtain 100 percent standard compaction was about 52 percent. Less than half the effort was required to obtain the same density. The sample which responded least to this treatment was the Virginia friable soil.

TABLE 2
DRY DENSITY AT MAXIMUM

Calcium Chloride	Soil					
	Alabama		North Carolina		Virginia	
	Plastic	Friable	Plastic	Friable	Plastic	Friable
	6-in. drop, 5.5-lb hammer					
%	*Pounds per cubic foot*					
0	119.1	121.0	116.5	119.5	119.8	114.4
0.5	122.5	123.7	117.4	120.6	122.4	115.0
1	123.3	124.4	118.3	121.7	123.7	116.0
2	123.9	125.7	120.0	122.8	124.9	117.0
3	125.4	126.5	121.2	123.5	126.2	118.1
	12-in. drop, 5.5-lb hammer					
0	125.6	125.2	121.4	122.0	123.6	121.2
0 5	127.0	127.2	122.4	123.9	126.5	121.8
1	128.0	129.0	123.3	125.1	128.3	122.4
2	128.7	129.8	124.1	125.7	130.4	123.4
3	129.4	131.0	125.0	126.4	131.3	125.6
	18-in. drop, 10-lb hammer					
0	132.9	131.7	127.7	127.3	133.3	129.3
0.5	133.6	133.1	126.6	128.1	133.8	129.8
1	134.2	134.2	128.3	129.8	134.2	130.9
2	134.8	135.5	129.4	130.9	135.0	131.6
3	135.4	136.0	130.1	132.0	135.7	132.1

TABLE 3
DENSITY AT MAXIMUM OF DRY SOIL ALONE

Calcium Chloride	Soil					
	Alabama		North Carolina		Virginia	
	Plastic	Friable	Plastic	Friable	Plastic	Friable
	6-in. drop, 5.5-lb hammer					
%	*Pounds per cubic foot*					
0	119.1	121.0	116.5	119.5	119.8	114.4
0.5	121.9	123.1	116.8	120.0	121.8	114.4
1	122.1	123.2	117.1	120.5	122.5	114.8
2	121.5	123.2	117.6	120.4	122.5	114.7
3	121.7	122.8	117.7	119.9	122.5	114.7
	12-in. drop, 5.5-lb hammer					
0	125.6	125.2	121.4	122.0	123.6	121.2
0	126.4	126.6	121.8	123.3	125.9	121.2
1	126.7	127.7	122.1	123.9	127.0	121.2
2	126.2	127.3	121.7	123.2	127.8	121.0
3	125.6	127.2	121.4	122.7	127.5	121.9
	18-in. drop, 10-lb hammer					
0	132.9	131.7	127.7	127.3	133.3	129.3
0.5	132.9	132.4	126.0	127.5	133.1	129.2
1	132.9	132.9	127.0	128.5	132.9	129.6
2	132.2	132.8	126.9	128.3	132.4	129.0
3	131.5	132.0	126.3	128.2	131.7	128.2

TABLE 4
PERCENTAGE OF 5.5-LB, 12-IN. DROP COMPACTIVE EFFORT REQUIRED TO OBTAIN 100 PERCENT PROCTOR COMPACTION WITH VARYING PERCENTAGES OF CALCIUM CHLORIDE

Soil	Percentage of Calcium Chloride				
	0	0.5	1	2	3
	%	%	%	%	%
Alabama Plastic	100	80	70	60	52
Alabama Friable	100	75	60	46	40
No. Car. Plastic	100	85	73	61	48
No. Car. Friable	100	73	61	50	42
Virginia Plastic	100	77	64	52	42
Virginia Friable	100	94	83	75	66

TABLE 5
PERCENTAGE OF 10-LB, 18-IN. DROP COMPACTIVE EFFORT REQUIRED TO OBTAIN 100 PERCENT MODIFIED AASHO COMPACTION WITH VARYING PERCENTAGES OF CALCIUM CHLORIDE

Soil	Percentage of Calcium Chloride				
	0	0.5	1	2	3
	%	%	%	%	%
Alabama Plastic	100	90	81	74	66
Alabama Friable	100	79	64	51	46
No. Car. Plastic	100	88	79	72	62
No. Car. Friable	100	75	59	48	40
Virginia Plastic	100	92	84	74	63
Virginia Friable	100	95	84	76	71

Percentage savings only slightly less in magnitude are evidenced in Table 5. This table presents the percentage of modified AASHO effort required to obtain 100 percent of modified AASHO compaction with different percentages of calcium chloride. Here the Alabama plastic soil, as well as the Virginia friable responsed less to the treatment than did the other samples. With 0.5 percent calcium chloride the average saving in compactive effort for the six soils was about 14 percent. The savings with the additional increments of calcium chloride were about 25, 34, and 42 percent of modified AASHO effort respectively.

From the standpoint of field procedure, these data are important. They indicate that a specified compaction may be obtained with fewer trips of the roller if calcium chloride is used, but the data do not show how many trips may be saved since the variable in that instance is the number of passes whereas the number of "passes" or blows was held constant in this work and the energy per blow varied. The variable in field work that does correspond to varying the energy per blow in the laboratory determination is the weight of the roller. With other dimensions of the roller being held constant, the energy expended on the soil per trip would presumably be in direct proportion to the weight of the roller. Thus, a saving of 50 percent in the required compactive effort when using three percent calcium chloride would indicate that a specified density which required a certain number of trips with a certain roller with no admixture in the soil could be obtained by the same number of trips with a roller only half as heavy. This may provide considerably more flexibility in equipment required for a compaction contract.

Penetrometer data for two of the soils, Alabama friable and Virginia plastic, from the compaction with the 5.5-lb hammer and 12-in. drop are shown in Figure 7. These curves are presented not as evidence of change of stability with changes in admixture, but as evidence of the workability of the soil at the time of compaction. There have been many informal observations by those who feel that calcium chloride added to the soil makes it more workable.

The reduced resistance of the soil to penetration of the penetrometer may be taken as an indication of an increase in workability of the soil. The curves in Figure 7 show a marked decrease in resistance to penetration with each added increment of calcium chloride at any moisture content The other soils show similar decreases in penetration resistance with increases in calcium chloride content of the soil. Even though the treated soil is denser than the untreated soil, as shown in Table 2, the increased workability reduces the resistance to penetration.

The dashed line crossing the penetration curves in Figure 7 crosses the curves at the approximate optimum moisture content of each of the soil mixtures. Since the optimum moisture content corresponds to the maximum density, the curves show less penetration resistance at maximum density for greater percentages of calcium chloride. So even though additions of calcium chloride contrib-

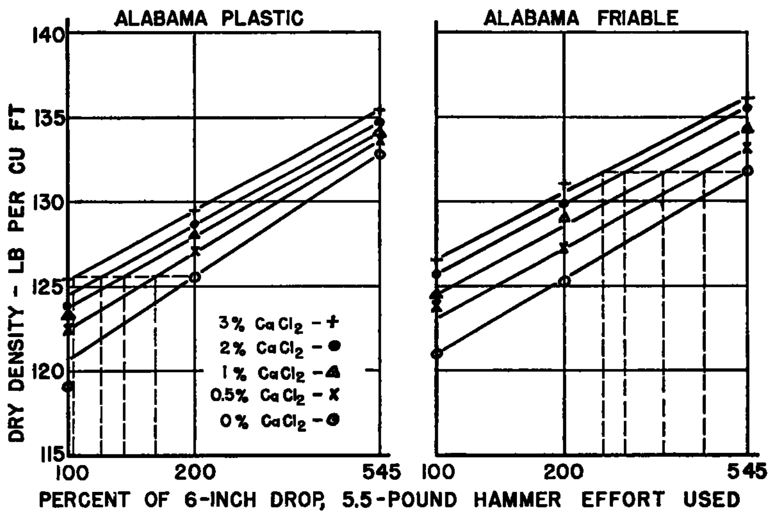

Figure 6. Relation Between Density and Compactive Effort

ute to increased density, there is a corresponding decrease in resistance to penetration of the soil immediately after placing. This decreased resistance to penetration is a measure of the increase in workability resulting from additions of calcium chloride. Increased workability is important for two reasons: first, it means greater ease in placement; and second, it means that there is greater opportunity for traffic during the curing period to further compact the fill and thereby increase the stability obtained.

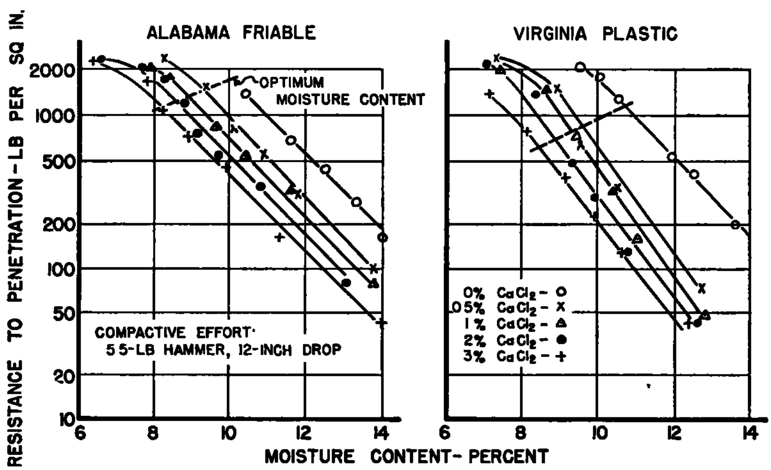

Figure 7. Penetration Curves for Two Soils

CONCLUSION

Analysis of the data in this work leads to the following conclusions for the soils used:

1. Calcium chloride in percentages up to at least 3 percent will cause an increase in the wet and dry compacted density of soils. This effect is more noticeable with the lighter compactive efforts.

2. Calcium chloride in amounts up to one percent generally will contribute to increased density of the dry soil alone. This effect is less important when the heavy compactive effort is used. Greater percentages of calcium give increased density to the dry solids largely by the amount of the chemical itself. In all conditions tested, the void space is reduced with added increments of admixture.

3. Additions of calcium chloride up to at least 3 percent will greatly decrease the amount of compactive effort required to obtain a specified degree of compaction—as much as 50 percent reduction being evidenced. Translated to field work, this point indicates that much lighter rollers may be used to obtain a given degree of compaction if calcium chloride admixture is used.

4. As evidenced by lowered penetration resistance readings accompanied by increased densities, addition of calcium chloride contributes to increased workability. This workability in turn contributes to ease in placement and to further compaction from traffic during the curing period.

DISCUSSION

E. S. Barber, *Public Roads Administration.* The compaction test results reported in this paper are remarkably consistent and indicate very careful work. The conclusions, however, are not warranted.

Since the arrangement of the soil grains determines the compressibility and water capacity, the real measure of soil compaction is the density of dry soil alone as given in Table 3. When the soil is wet the soluble salts become part of the liquid and their weight has no effect on the soil.

Considering experimental variations, Table 3 shows that varying the amount of calcium chloride has no effect on the real soil density. However, for the 6-in. drop the average densities with 0.5 per cent calcium chloride average 1.3 lb per cu ft higher than the densities when no chloride was used. This difference is apparently not due to the chloride but rather to the fact that the samples with chloride were wet and partially dried before compaction. The results of tests on two samples from Illinois with grading and plasticity similar to those used in this report showed an increase in density of 1.0 and 1.4 lb per cu ft due to wetting and partial drying (with no calcium chloride) before compaction. Thus the data in Table 3 shows that the presence of calcium chloride in the soil water has no effect on the compaction of the soil.

If the penetration data is similarly analyzed, it is found that the calcium chloride has no apparent effect on the soil although it may effect the calculations It is not clear why a decrease in penetration resistance due to increased moisture should not be considered as a decrease in strength.

This discussion applies to compaction where the supply of water is controlled and is not intended to indicate that compaction under traffic would not be benefited by the presence of a deliquescent substance to maintain the soil in a moist condition.

A. M. JOHNSON, *Closure.*—Table III shows average densities with 0.5 percent calcium chloride to be about 1.0 lb per cu ft higher than the densities when no calcium chloride was used when using the 12-in. drop, as compared to an average increase of 1.3 when using the 6-in. drop. It is obvious from the paper that the first runs with the 12-in. drop, including those with no calcium chloride, were made on samples which had been dried back and then rewetted for compaction. Thus the increase in density of the material with the 0.5 percent admixture over the density of the sample with no admixture may be directly attributed to the presence of the admixture. Not obvious in the paper, but a standard part of the procedure, was the fact that the first run (using the 6-in. drop) on each soil with no admixture was made on a sample which had been wetted to about 10 percent moisture, air-dried back to a low moisture content, and then rewetted for compaction. Thus, the conditions for all runs were as nearly uniform as possible and comparative increases in density may be considered to have resulted from the use of the admixture.

The penetration data were offered not as evidence of change of strength with calcium chloride but as evidence of increased workability resulting from use of the chemical. The ultimate useful strength of the soil—as with concrete or bituminous mixes—is not measured by its strength at time of placement but by what it will develop after a period of curing as a result of the relationship of its constituents. Workability and ease of placement tend toward establishing a more desirable relationship of the particles. More research is undoubtedly needed on the effect of calcium chloride on the strength of soils and work of this type is in the plans of the Soils-Calcium Chloride Roads Committee.