Stabilization of Bank-Run Gravel by Calcium Chloride

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Specimens of different moisture contents without calcium chloride and with varying percentages of added calcium chloride were prepared. Each sample was tested for its density, its bearing capacity, and its ability to swell under saturation and shrink in open air. Two kinds of gravel specimens were prepared: one to represent the upper limits of fines, usually used in road construction; the other one was prepared by washing fines from these samples to represent the lower limit of fines. Calcium chloride was used in percentages of 0.1, 0.5, and 1.0.

Four main types of experiments were conducted on washed and unwashed gravel: (1) modified Proctor tests at different moisture and calcium chloride contents; (2) California Bearing Ratio tests at different moisture and calcium chloride contents; (3) CBR-penetration tests of dried and soaked samples prepared with a constant compactive effort and with varying percentages of calcium chloride; and (4) pH tests on samples with different percentages of calcium chloride.

The addition of calcium chloride resulted in higher optimum dry densities both washed and unwashed bank-run gravel. The addition of calcium chloride will result in either a higher optimum density or an equal density at a lower compactive effort. If a high compactive effort was used, the washed material gave higher densities and higher CBR values than the unwashed material. The addition of calcium chloride had little effect under these conditions. If a low compactive effort was used, the unwashed material gave higher densities and the addition of calcium chloride had an appreciable effect. CBR values were lower for the washed sample regardless of whether calcium chloride was used. Base exchange occurs upon addition of calcium chloride, as shown by a drop in pH.

Addition of calcium chloride caused a loss in CBR values on immediate testing at low compactive efforts and at moisture contents above the optimum. However, calcium chloride caused a gain in CBR at high compactive effort and moisture contents below optimum. The addition of calcium chloride reduces the loss in CBR of soaked samples with a comparatively large percentage of fines. The CBR of the washed sample were about the same for all soaked samples regardless of calcium chloride content. Curing of specimens indicated that any loss in CBR caused by addition of calcium chloride is at least partially recovered by the curing process. Soaking of the samples lowered their CBR values. Drying the samples raised their CBR value. Drying followed by soaking gave higher CBR values than immediate soaking.

Calcium chloride is most effective on gravels containing an appreciable amount of material passing 200 mesh. The effect is minor when the fine content is below 5 percent.

● SOIL stabilization refers to the technique by which an increase in the bearing capacity of soils can be attained. Since there is no generally accepted engineering test for "stability" of soils, the magnitude of the dry density obtained by a standard procedure is often used as a measure of the degree of stabilization of the soil mass. The moisture content and the type of soil are among the most-important factors affecting this technique. In this study, stabilization of a bank-run gravel with calcium chloride was studied, and by experimentation the effects of calcium chloride under different moisture conditions and compactive efforts were observed.

Scope

The technique of soil stabilization has many applications in earth structures where a control of the physical properties of materials is desirable. This technique may be satisfactorily applied in the construction of bases and subbases of paved or unpaved roads and in treating the surfaces of unpaved roads.

APPROACH TO THE PROBLEM

The nucleus of this study was directed toward the effects of calcium chloride on the clay and colloidal fractions of the gravel. Specimens of different moisture contents without calcium chloride and with different percentages of added calcium chloride were prepared. Under these conditions each sample was tested for its density, its bearing capacity and its tendency to swell under saturation and to shrink in open air.

Two kinds of gravel specimens were prepared: one to represent the upper limit of fines usually used in road construction; the other one was prepared by washing fines from this material to represent the lower limit of fines.

THEORETICAL ASPECTS

Soils are dispersed systems which are composed of three phases: solid, liquid, and gaseous.

Solid elements can be of mineral or organic constitution and of various sizes and shapes. Their range is from coarser sizes of sands and gravels to the finer particles of silts, coarse clays, and fine clays. Particle size is related to the physical properties of soil elements. The surface activity in smaller fractions of soils is greater. This relationship establishes the clayey elements as active fractions and the coarser material as the skeleton of the soil system. The relationship of the amount of surface area per unit of mass is an important soil property which is known as the specific surface. The classification of various soil textures into groups on the basis of their effective diameters is an important measure of the chemical and physical behavior of soils. But, also, it is of special interest to know the specific surface of each of these groups. The relationship of particle size and the specific surface is important.

The surface of a colloid can be considered as "active mass" which constitutes the monomolecular surface layer. In colloids the mass ratio of total mass of a particle to its active mass is small and this mass is related to particle size and specific surface. A colloidal system is a heterogeneous system in which the surface molecules (active mass of the solid) are important and the inert mass is inactive and can be largely disregarded. The other active portion of this system is the dispersion medium which may be composed of water, or water plus air.

Specific surface increases as the size of the soil particles decreases. Therefore in smaller-sized particles the extent of the interfaces between particles, and their surface activity, is greater. This fact causes the plasticity of clays. Internal pores or channels increase the specific surface. Control of the surface phenomena of clays can control soil plasticity and help to stabilize the soil material.

Clay, from a chemical point of view, can be defined as a material formed from decomposition of feldspars and similar silicates. Clays are able to unite with water to form a partially gelatinous state and exert a binding action upon coarser particles in soil. Finer clays are colloidal materials in which particles smaller than 2 microns in size predominate. As colloids, clays are composed of dispersed formations of mineral or organic fragments. These fragments are essentially crystalline and rarely amorphous. Crystalline elements are built up of units of alumina and silica. The alumina unit contains two sheets of closely packed oxygen atoms or OH groups. Aluminum atoms hold three oxygen atoms or OH groups from each sheet. In the silica unit there is one sheet of oxygen atoms. Each silicon atom is surrounded by three oxygen atoms from one sheet, and one oxygen atom from the other sheet. The latter oxygen atom is also shared by the alumina sheet and helps to link the silica sheet to the alumina sheet. According to the arrangements of these sheets, there are two basic groups of clay minerals, the kaolin group and the montmorillonite group. The former type is built up of one silica sheet to one alumina sheet; the latter type of mineral consists of a crystal lattice which is composed of two silica sheets to one alumina sheet.

The binding ability of colloids makes them important cementing agents in the formation of aggregations of soil particles. Dehydrated colloidal oxides of iron and alumina are especially responsible for the stable aggregation of the lateritic soils. By dehydration, as the film of water which coats the clay particles becomes thinner, the particles approach to each other to form aggregations. Aggregation in the colloidal state is created by electric charges (potential) and by envelopes of bound water, which affect the stability of colloids.
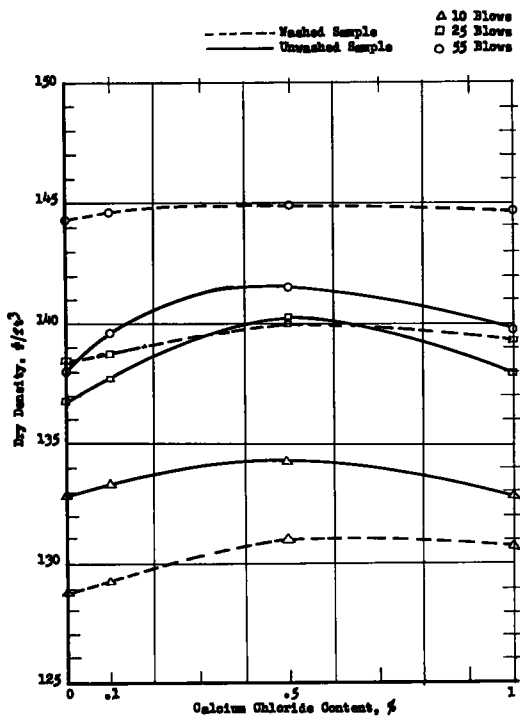

Figure 1. Optimum dry densities of bank-run gravel of various percentages of calcium chloride.

Most clay particles are negatively charged and have a tendency to migrate toward positively charged units. The migration velocity depends upon the strength of the charge. At higher potentials there is a repulsion among particles, at lower potentials the tendency toward repulsion diminishes, and after collision (resulting from Brownian movement) the particles coalesce and settle out as floccules.

The surface behavior of a solid particle in touch with water tends to create certain layers which are formed by the accumulation of differently charged particles. The solid (in the case of clay) develops a negatively charged surface formed by OH^- ions adsorbed from the water, according to C. E. Marshall.

As a counterbalance, H^+, or other positively charged ions, will be attracted to the surface to form a positively charged layer. This arrangement creates a Helmholtz double layer, which leads to a difference of electrical potential between the solid and the H^+ layer. The OH^- layer, being nearer to the surface, is fixed and the H^+ layer is weaker and movable. This original Helmholtz concept of a movable H^+ ion layer can be modified and two distinct types of behavior can be noticed in the H^+ layer. Ions nearer to the negative OH^- layer can be considered fixed and others are dispersed throughout the liquid phase surrounding the solid and can be considered as a diffused layer. This allows a variation in electrical potential across the interface. The potential occurs not through the OH^- layer but through the H^+ double layer, and it can be considered as consisting of two parts. The first part is between the surface (OH^- layer) and the fixed (compensating) H^+ layer, the second part is between the fixed positive layer and the body of the solution. This second type of potential is the electrokinetic potential (or zeta potential) and is measured from the fixed layer to an infinite distance in the solution.

Zeta potential is largely responsible for the stability and the electrical effects observed in clay colloids. The balancing of the surface charges creates more nearly neutral surfaces; this lowers the zeta potential and the electrical effects. In the absence of the electrical charge, collisions from Brownian movement tend to lead to a greater binding action between the particles. Therefore, the isoelectric point (zero zeta potential) may be reached and coagulation between particles may set in. At this stage the clay is stabilized and will not exhibit extreme swelling and shrinkage, and the particles may be closely packed. The neutralization of the surface can be attained by introducing enough positive ions into the fixed positive layer to equal the charges between the fixed layers of OH^- and H^+. This can be done by base exchange. A salt, such as calcium chloride, can be injected into the soil water and calcium ions will replace the H^+ ions in the fixed positive layer

around the colloidal particle. This mechanism creates the base exchange concept in which, by replacing original surface ions by other introduced ions the surface, characteristics of a clay colloid may be altered. During this base exchange, because of the smaller ionic radii of the calcium ions as compared to hydrogen ions, it is possible to introduce more calcium than the number of H^+ ions replaced. In addition, the charge of each ion is twice as great. After the critical (isoelectric) point is reached, a further accumulation of calcium ions may create an excess of positive charges in the fixed positive layer; hence a less-stable system may be created. It can be concluded that at the isoelectric point the zeta potential and the distance between particles will be a minimum. This results in more-densely packed particles in the soil and a maximum density, which is related to the bearing capacity of the soil.

TABLE 1

DENSITY VALUES AT DIFFERENT COMPACTIVE EFFORTS, WATER-CONTENTS, AND CALCIUM CHLORIDE CONTENTS

% CaCl₂	Moisture (%)							Compactive Efforts (Blows/layer)
	3	4	5	6	7	8	9	
Unwashed								
0 0				131 7	132 9	130 6	129.6	10
0.1				130 6	133 4	130 7	130 4	10
0 5				132 4	134.2	133.9	129 8	10
1 0				132 8	130 0	132 8	130 6	10
0.0			136 0	136 8	135 2	132 4		25
0 1			137 5	137 7	135 8	132 9		25
0 5			138 8	140 3	136 6	133 2		25
1.0			137 6	137 9	136 2	133 6		25
0 0	139 2	138.0	136 1	135 0				55
0 1	139.3	139 5	136 4	136.2				55
0.5	140 2	141 5	137 0	136 8				55
1 0	139 7	139.8	136 8	136 9				55
Washed								
0 0			124 6	128 5	128 9	127 1		10
0.1			124.5	128.6	129 2	127 3		10
0.5			125 9	128 8	131 0	132.7		10
1 0			125 0	128 6	130.6	129.1		10
0.0		131 5	135 1	138.5	136 8			25
0.1		132 0	135 3	138 8	136 8			25
0 5		135 3	136 4	140 0	137.2			25
1.0		132 6	135.8	139.3	136 9			25
0.0	141.0	144 3	139 9	138.0				55
0.1	139 9	144 6	139 9	137.8				55
0.5	138 1	144.9	142 8	138.5				55
1 0	140 2	144 7	141.6	138 0				55

Soils, irrespective of their origin or source, have potential acidic properties; that is, they may contain hydrogen ions which can be replaced by other positive ions; these H^+ ions can be neutralized with various alkalis to form salts. The concentration of its H^+ ions in solution determines the strength of the acidity of soil. Therefore, the study of the pH value is important. The measurements can be done either by electrometric or by colorimetric methods.

EXPERIMENTAL WORK

Materials

The soil sample was taken from the working face of a gravel pit located about 2 miles south of Newfield, New York, just off the south side of Route 13. Material from the same pit was used by James W. Spencer of Cornell University for the construction of a test road near Newfield. This test road contained sections stabilized by calcium chloride; these sections performed well.

The gravel was screened through a $\frac{3}{4}$-inch screen; only the portion passing the $\frac{3}{4}$-inch screen (about two thirds of the entire material) was used in the experiments.

The approximate mineralogical content of the gravel portion between $\frac{1}{4}$ and $\frac{3}{4}$ inches was as follows:

shale---------------- 50%
sandstone------------ 40%
igneous-------------- 5%
limestone and misc.--- 5%

The mineralogical composition of the clay fraction was approximately 50% illite and 50% montmorillinite, determined by x-ray diffraction.

The material as taken contained a high percentage of fines—near the upper limit of bank-run gravel for road construction. In order to provide a second sample low in fines, with all other variables remaining constant, half of the original sample was washed (stirred with water, followed by decantation). The gradation of the unwashed sample follows:

Sieve No.	Unwashed Gravel % Passing
4	62
8	49
14	39
28	34
48	24
100	18
200	12

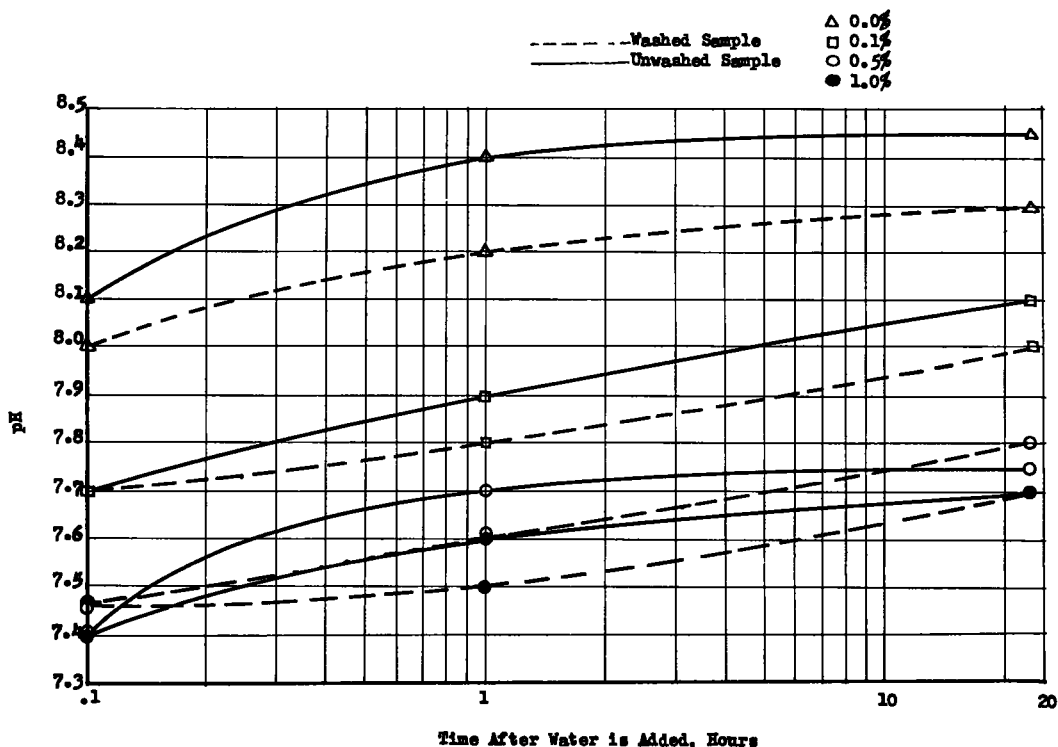After washing, the sample contained 5 percent material passing a 200-mesh sieve.

Figure 2. Changes of pH of bank-run gravel with various percentages of calcium chloride at various times after water is added.

Equipment

(1) CBR molds, standard size: 6-inch diameter, 7-inch height; (2) spacer disc, standard size: 6-inch diameter, 2-inch height; (3) CBR mold collars, standard size: 2-inch height; (4) compacting hammer, standard modified AASHO type: 10 lb. weight, height of drop: 18 inches; (5) volume of each cylinder: 0.0818 cu. ft.; (6) hydraulic loading apparatus, 6000-lb. capacity, 3 sq. in. cross-section penetration piston; (7) surcharge weight: 10 lb.; (8) dial gauge, Ames 0.001-inch type; (9) oven, temperature controlled (50 C.); and (10) tripod for height measurements, equipped with a 0.001-inch Ames gauge.

Laboratory Procedure

Four main types of experiments were conducted on washed and unwashed gravel: (1) modified Proctor tests at different moisture and calcium chloride contents; (2) (CBR) California Bearing Ratio penetration tests at different moisture and calcium chloride contents; (3) drying and soaking tests at approximately the optimum moisture content with a constant compactive effort and at different percentages of calcium chloride; and (4) pH tests on samples with different percentages of calcium chloride.

Procedure for Preparing Washed Gravel

Material was placed in a tilted pan and water was constantly applied over it. By frequent stirring the suspended fines were washed away. The material was dried in open air.

Modified Proctor Tests

The equipment consisted of the standard cylinders and the modified Proctor hammer. Each sample, at a particular moisture content, was compacted in five layers with a certain compactive effort. The compactive efforts applied were: 10, 25, and 55 blows per layer. Then the dry density at any particular moisture content was determined. The moisture contents were determined on a dry-weight basis and increments of 1.0% moisture were added until the optimum moisture of the sample

was passed at any particular compactive effort. The resulting dry densities were determined.

California Bearing Ratio (CBR) Penetration Tests

After weighings for the determination of dry densities, the sample was subjected to the CBR-penetration test and the loading intensity at each value of penetration was obtained. From the collected data CBR values for each test at each moisture content were established.

TABLE 2

CBR VALUES AT DIFFERENT COMPACTIVE EFFORTS, WATER CONTENTS, AND CALCIUM CHLORIDE CONTENTS (PERFORMED IMMEDIATELY AFTER PROCTOR TESTS)

%CaCl₂	Moisture Contents (%) 3	4	5	6	7	8	9	Compactive Effort, (Blows/ layer)
					Unwashed			
0.0				25	9	4	2	10
0.1				26	7	2	2	10
0.5				16	7	4	1	10
1.0				15	5	4	2	10
0.0			67	28	9	4		25
0.1			78	38	6	3		25
0.5			56	13	5	2		25
1.0			38	16	3	1		25
0.0	98	40	15	5				55
0.1	97	39	15	5				55
0.5	107	42	16	-				55
1.0	98	39	14	4				55
					Washed			
0.0			8	21	16	17		10
0.1			16	22	33	16		10
0.5			20	29	40	4		10
1.0			18	24	38	4		10
0.0		53	54	76	25			25
0.1		64	65	39	16			25
0.5		69	69	38	9			25
1.0		67	68	35	5			25
0.0	129 (16"p)	129 (.16"p)	22	7				55
0.1	126	129 (.18"p)	36	7				55
0.5	96	193 (10"p)	50	8				55
1.0	92	129 (185"p)	34	7				55

Note. 2-inch penetration was used except when otherwise indicated

Drying and Soaking Tests

Soaked Samples. These samples were prepared with 55 blows per layer compactive effort in five layers using standard CBR molds. The cylinders thus prepared were subjected to soaking in water. The soaking period was 5 days on the average. A penetration test was run on each cylinder. During the entire period of soaking, periodic checks on weight of samples and height of samples were recorded. A 10-lb. surcharge weight was used throughout the soaking and testing procedure.

Dried Samples. They were prepared the same way as the soaked samples. The drying period was about 14 hours, at which time about 30 percent of the water had been evaporated at the constant oven temperature (50 C). Height and weight measurements were recorded as in the case of the soaked samples. After the drying period the samples were soaked in water as for the soaked samples. Height and weight measurements were periodically taken and recorded. A 10-lb. surcharge weight remained on the samples during the drying and soaking periods but not used during the CBR determinations (in order that more than one CBR could be run on one sample). Previous experiments showed that, for this material, nearly identical CBR's were obtained with and without the surcharge weight.

CBR Tests. Three different kinds of CBR tests were performed on the samples which had been dried and soaked as explained above. These tests and their details were as follows: (1) Immediate CBR tests were performed on the compacted samples with various percentages of calcium chloride before they were put in the oven. (2) Tests performed immediately after drying in the oven. (3) Tests performed immediately after the soaking period. (This type of testing applies to the samples which were soaked immediately, and to the ones which were soaked after a period of drying in the oven.)

TABLE 3

OPTIMUM DRY DENSITIES AT DIFFERENT PERCENTAGES OF CALCIUM CHLORIDE

	Dry Densities pcf		
	Unwashed		
%CaCl₂	10 blows	25 blows	55 blows
0.0	132.9	136.8	138.0
0.1	133.4	137.7	139.5
0.5	134.2	140.3	141.5
1.0	132.8	137.9	139.8
	Washed		
0.0	128.9	138.5	144.3
0.1	129.2	138.8	144.6
0.5	131.0	140.0	144.9
1.0	130.6	139.3	144.7

Height Measurements

The equipment consisted of a standard tripod and an Ames 1/100-inch dial. Each cylinder was carefully oriented during the measuring and the tripod always was placed

at the same marked points to avoid any reading error. Also, during the measurements a possibility of any jarring of the perforated cylinder plates made it necessary to record the height immediately and again after the cylinder was put in its resting place following weighing: the following height measurement was based on the latter reading.

OBSERVATIONS

Density tests were conducted on the same sample at four different moisture contents, chosen according to the compactive effort used. Water was added after each test to make up the necessary moisture for the next test. The ideal approach, in the case of abundant soil
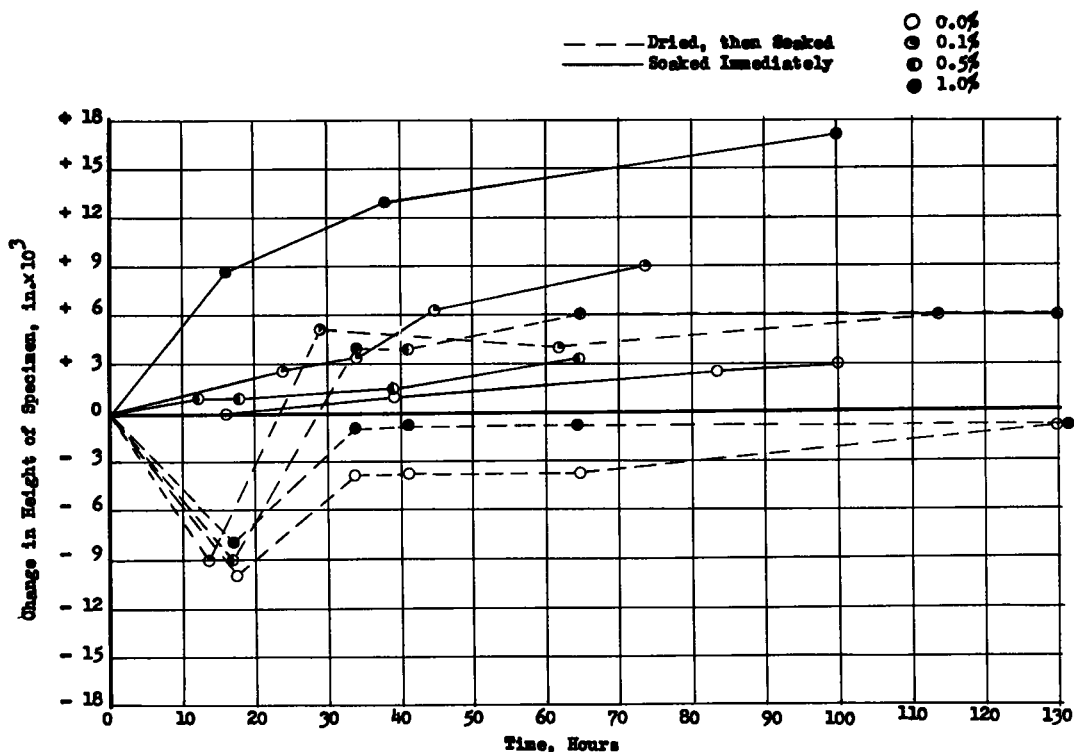
Figure 3. Shrinking and swelling of unwashed bank-run gravel with oven drying and soaking at various percentages of calcium chloride.

Weight Measurements

Periodic determinations of weight were made during the drying and during the soaking periods.

The pH tests were conducted on the samples at different percentages of calcium chloride at various time intervals after addition of the calcium chloride. An electrometric type of pH meter (glass electrode) was used.

Measurements were made of changes in moisture content and height of specimens in all four concentrations of calcium chloride, for both washed and unwashed gravel, during the soaking period and during a cycle of drying and soaking. The results are shown in Figures 3, 4, 5, and 6.

TABLE 4

CBR VALUES FOR SOAKED AND DRIED SAMPLES

% CaCl₂	Immediate	Oven-Dried	"Soaked" After Oven-Dried	"Soaked"
Unwashed				
0 0	16	113	39	5
0 1	14	111	40	8
0 5	36	111	47	8
1 0	9	44	20	22
Washed				
0 0	81	129 (225"pen)	68	35
0 1	73	129 (225"pen)	67	34
0 5	71	127	67	34
1 0	53	119	64	26

Note All results are at 0 2-inch penetration unless otherwise indicated

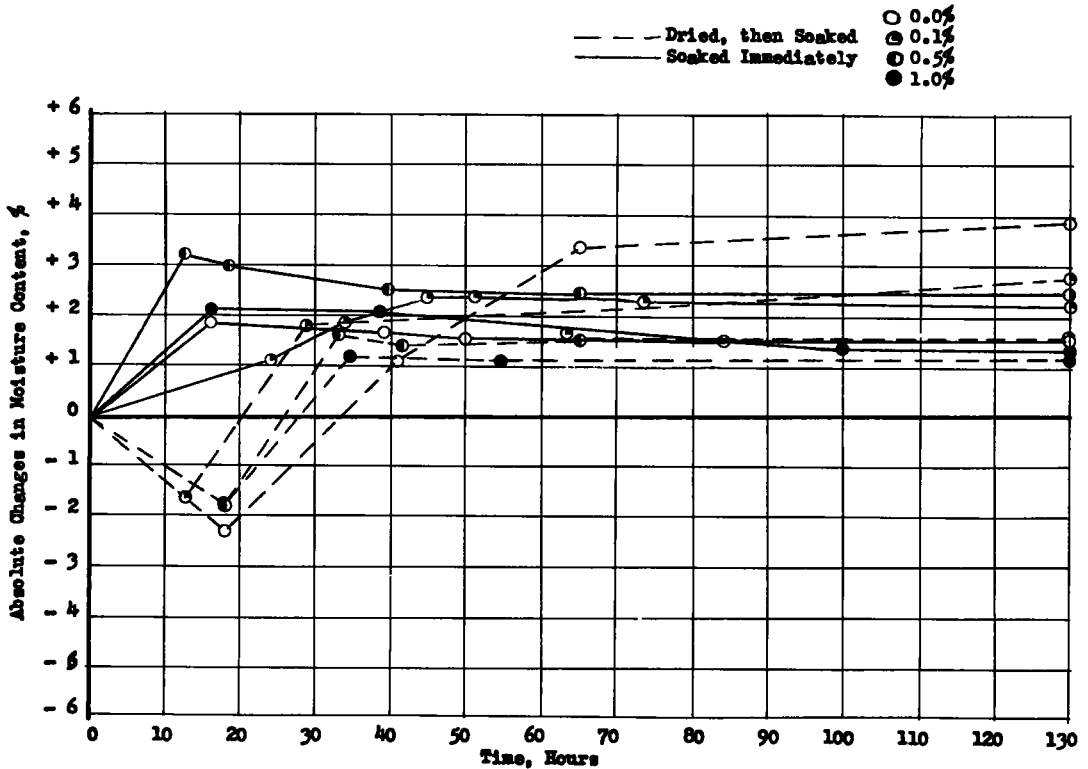material, would be to prepare a fresh sample for each different moisture con-

Figure 4. Change of moisture content of unwashed bank-run gravel
with oven drying and soaking at various percentages of calcium
chloride.

tent. This latter method would give more-accurate (comparable) CBR results. However, this would require four times the amount of soil material. The most serious shortcoming of the method used was that the gradation of the material changed considerably with compaction; the amount of the middle-range-size particles increased while the percentage of coarser material decreased. The results shown below were obtained with material from the same pit.

Sieve No.	Percent Passing Fresh Sample	Percent Passing Used Sample*
4	49	65
8	32	46
14	22	33
28	16	23
48	10	12
100	6	6

*The sample was subjected four times to a compaction test of 25 blows/layer in 5 layers (compaction with a standard modified Proctor hammer).

Also, the control of water content would be more accurate if the suggested

latter method were used. Therefore, comparisons of the obtained densities and the CBR values have limitations. At the same moisture content and at the same compactive effort, the results from two different percentages of calcium chloride can be accurately compared, because for these cases any changes in gradation would be the same, resulting from similar previous compaction.

The addition of calcium chloride was done in solution and the water forming the salt solution was part of the initial moisture added to the soil. Four different percentages of calcium chloride were used: 0. 0, 0. 1, 0. 5, and 1. 0.

In the soaking and drying tests the most-important factors were the sensitivity of the measuring instruments (such as the gauge and the weighing apparatus) and the curing conditions for the samples. The humidity and temperature should be carefully controlled, and they should be nearly constant during the entire series of tests.

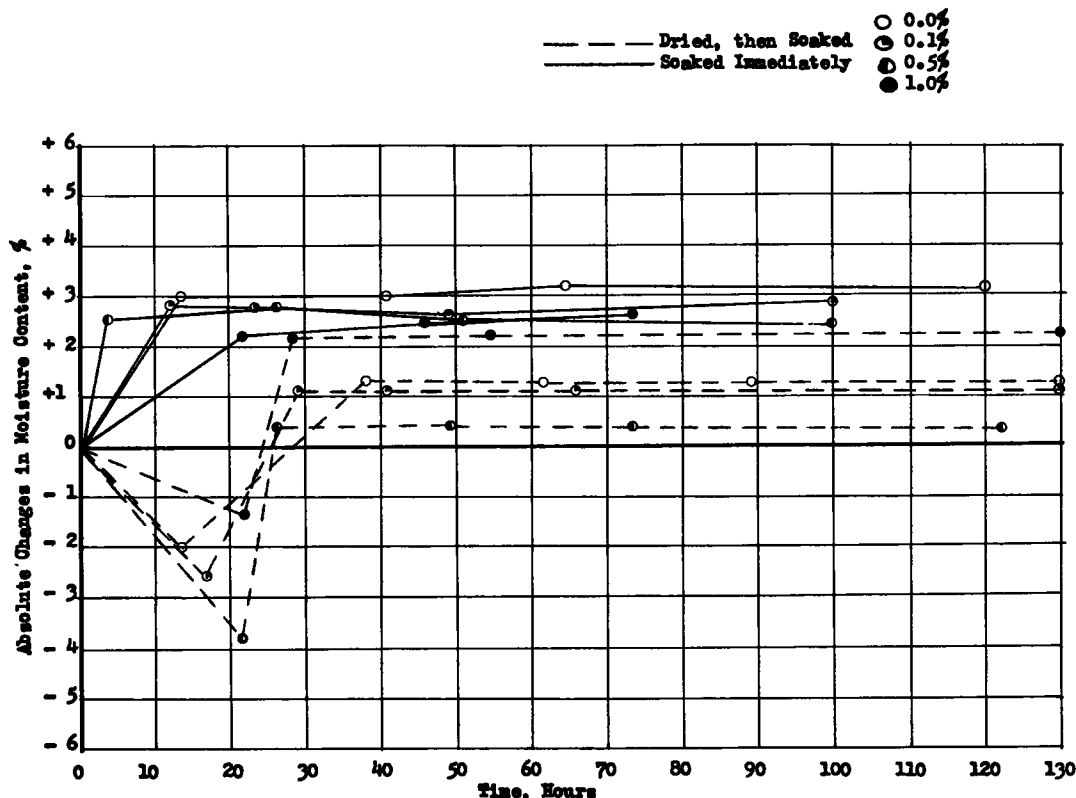The CBR results were based on 0. 2-inch penetration, since the values at this

Figure 5. Change of moisture content of washed bank-run gravel with oven drying and soaking at various percentages of calcium chloride.

point were always higher than 0.1-inch penetration. As checks, some of the tests were repeated and nearly the same results were obtained. One factor affecting this (except for dried specimens) was that the top of a CBR sample was wetter and had a higher percentage of moisture; the percentage of moisture decreased from the top of the specimen downward. In case of any disturbances in the center of the top of the. specimens occurring during the removal of the samples from the cylinders, the CBR was run on the undisturbed side of the top, without a surcharge weight. Tests showed that the presence or absence of the surcharge weight had little effect on CBR's for this material.

The fact that the addition of calcium chloride lowered the pH shows that base exchange occurred. Apparently 0.5 percent of calcium chloride gives nearly maximum base exchange—calcium for hydrogen.

CBR values (0.2-inch penetration) were calculated on the basis of the value of standard stress[1] which is based on crushed stone. Some values of CBR, especially in the cases with maximum compactive effort, were above 100 percent.

The tests involving drying, followed by soaking, of the specimens were run in an effort to determine any possible effect of curing on the CBR's of the material at various calcium chloride contents. This condition of the alternate dyring and wetting is one which must occur in the field. The one cycle used was extreme in rate of change of moisture, but should indicate the trend of results in the field.

The data presented in Figures 3, 4, 5, and 6 showed little trend as affected by percentage of calcium chloride. The changes in height shown are extremely small and within experimental error. The procedure involved lifting the specimens in and out of a water bath and tilting them to pour off excess water for a weight determination. This handling could dis-

[1] CBR (%) = $\frac{\text{stress from test}}{\text{standard stress}}$ x 100, standard stress = 1500 psi. for 0.2 inch penetration.

turb the specimens slightly, although great care was used. It should be noted, however, that each curve follows a specific trend (is not erratic), indicating that the data are reliable. There is a tendency for greater swelling, and immediate soaking, for larger percentages of clacium chloride. This tendency is eliminated, largely or completely, by a drying cycle before immersion.

type of base and base exchange capacity, would have been helpful in interpretation of the results.

The increase in density from 138 to 141.5 pcf. (for unwashed gravel, 55 blows, 0.5% calcium chloride) would reduce the void space by about 12% on a relative basis (from 160 down to 14% of the total volume). This might be a significant factor in resistance to freeze-thaw action.
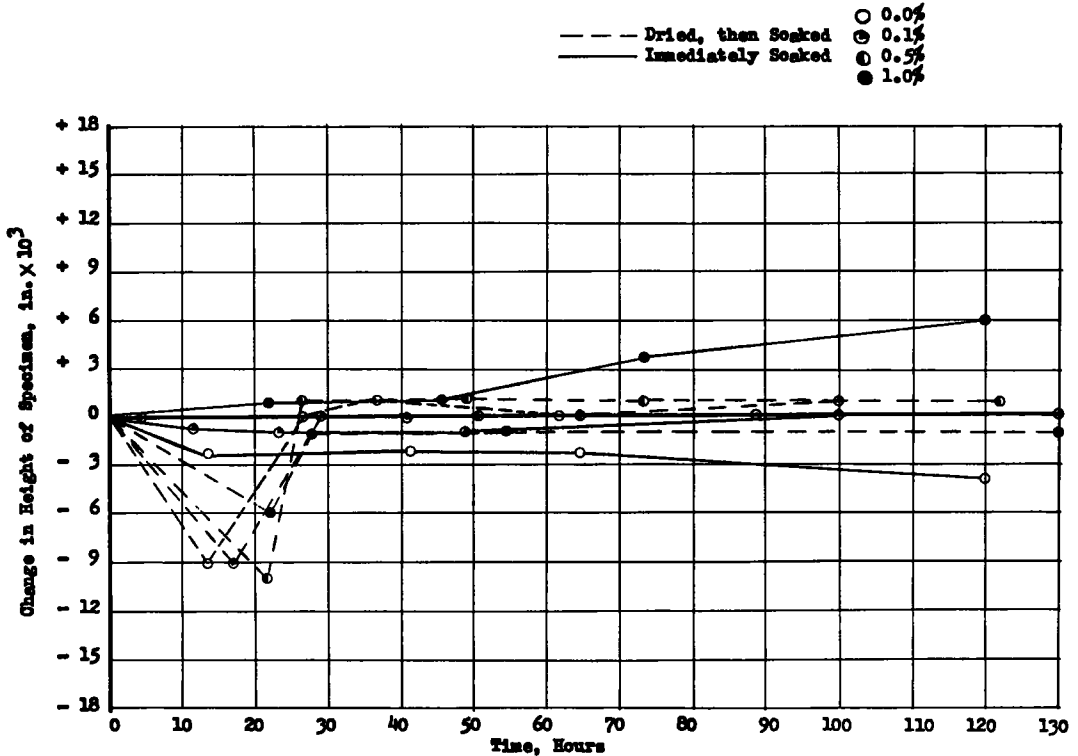

Figure 6.   Shrinking and swelling of washed bank-run gravel with oven drying and soaking at various percentages of calcium chloride.

Calcium chloride is known to affect rate of drying of soils. In this experiment, the rate and extent of drying were extremely severe; they were chosen to measure the effect of exaggerated curing on CBR values. As a result, a good measurement of effect of calcium chloride on drying rate was not obtained. However, a general trend of reduction of drying rate with increasing percentage of calcium chloride can be noted by extrapolating all drying curves to the same drying time.

Further analysis of the fine portion (passing No. 200 mesh), showing types and amounts of the clay minerals and their

TABLE 5

CHANGES OF pH WITH TIME AT VARIOUS PERCENTAGES OF CALCIUM CHLORIDE

Unwashed Aggregate				
%CaCl₂	Time Interval			
	5 min	1 hr	22 5 hours	6 days
0 0	8.1	8 4	8 45	8 3
0.1	7 7	7.9	8 1	7 9
0 5	7 4	7 7	7 75	7.7
1 0	7 4	7 6	7 7	7.6

Washed Aggregate			
% CaCl₂	Time Interval		
	5 min	1 hr	23 0 hours
0 0	8 0	8.2	8.3
0 1	7 7	7 8	8.0
0.5	7.45	7 6	7 8
1.0	7 45	7 5	7 7

CONCLUSIONS

1. The addition of calcium chloride resulted in higher optimum dry densities of both washed and unwashed bank-run gravel. The greatest increases were obtained with 0.5% of calcium chloride; amounts smaller or larger than this gave densities intermediate between those for no chemical and for 0.5% chemical. The amount of increase was appreciable, being a maximum of 3.5 pcf. for unwashed gravel at intermediate compactive effort (25 blows Proctor).

2. The addition of an optimum amount of calcium chloride will result in either a higher optimum density or an equal density at a lower compactive effort.

3. In the sample tested, if a high compactive effort was used, the washed material (few fines) gave higher densities and higher CBR values than the unwashed sample and the addition of calcium chloride had little effect. However, if a low compactive effort was used, the unwashed material (many fines) gave higher densities and the addition of calcium chloride had an appreciable effect. In the latter case, CBR values measured immediately (no curing period) were lower than for the washed sample, regardless of whether or not calcium chloride was used.

4. Base exchange occurs upon addition of calcium chloride, as shown by a drop in pH. The reaction is not complete in five minutes, but is substantially complete in one hour. A greater amount of base exchange occurred in the sample with more fines; this is correlated with the greater density obtained for this material. The amount of base exchange increases with increase in amount of calcium chloride added; however, 0.5% gave almost as much effect as 1%. This is in accord both with the theory of reduction of zeta potential by base exchange and with experimental density results.

5. In general, addition of calcium chloride caused a loss in CBR values on immediate testing (no curing) at low compactive efforts and at moisture contents above the optimum. In general, addition of calcium chloride caused a gain in CBR values on immediate testing (no curing) at high compactive efforts and at moisture contents below the optimum. The increase was usually greatest for 0.5% calcium chloride, as it was for dry density.

6. The addition of calcium chloride reduces the loss in California Bearing Ratio of soaked samples with many fines. The bearing capacities of the washed gravel were about the same for all soaked samples, regardless of calcium chloride content (from 0.0% to 1%). The bearing capacities were about the same (very small reduction caused by calcium chloride and its retained water) for all samples after they were dried to approximately one half optimum moisture content and they were substantially equal after the dried samples were soaked.

7. Curing (that is, drying followed by soaking) of specimens indicated, on the basis of few tests, that any loss in CBR values (determined by immediate testing after molding) caused by addition of calcium chloride is at least partially recovered by the curing process.

8. Soaking of the samples lowered their CBR values. Drying of the samples raised their CBR values. Drying followed by soaking gave higher CBR values than immediate soaking, even though the final moisture contents in the two cases were about the same.

9. Calcium chloride is effective for increasing density, only on gravel containing an appreciable amount of material passing 200 mesh. The effect is minor when the fines content is below 5%.

Acknowledgment

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