Moisture, Density and Volume Change Relationships Of Clay Soils Expressed as Constants of Proportionality

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The project's purpose was to devise a method for establishing emperical relationships between volume change and density, and/or volume change and moisture content.

The soil samples employed were homoionic soils prepared from a Warsaw soil by leaching portions of the soil with suitable electrolytes containing one of the cations chosen, namely hydrogen, aluminum, ferric, and calcium ions.

The prepared soils were tested in various combinations of density and moisture content conditions for swell characteristics.

Additions of organic compounds were investigated to determine the influence of natural soil organic matter on swell properties of the prepared homoionic soils. Lignin was used to represent natural soil organic matter in equilibrium with soil microbial activity. Hypotheses derived from the investigation are given.

● SUBGRADE RESEARCH was initiated in the United States about 1925. Failures of pavements designed to ultimate standards by engineers were investigated to determine contributing factors other than pavement deficiencies. Improved construction methods, thicker pavements, and perfected materials did not prove to be the solution to the pavement failures.

Studies conducted in Michigan (1) indicated that more than half of the pavement failures were contributed to by subgrade failures. These subgrade failures resulted from differential expansion or settlements of the subgrade materials. Studies (2) of flexible road surfaces also proved that the subgrade was a contributing factor to road surface failures. Later investigations (3,4) established definite correlations between concrete pavement failures in the form of crack patterns and the soil texture of the subgrade soil materials.

Pavement pumping, blow-ups, faulting, and longitudinal cracking has also been closely correlated to subgrade soils and soil characteristics (5,6). Investigations and studies of pavement failure have indicated that the failed sections are the consequence of conditions of excessive moisture and resulting loss of cohesion; high percentages of fines, silts, or fine sands and resulting ice lense formations with heaving; excessive volume change, shrinkage, or swelling, resulting from moisture variations or the physical or chemical alteration of the soil constituents. Swelling may

also result from the removal of earth surcharge; however, this condition is not pertinent to this study.

The presence of excessive moisture in the subgrade is one of the most important factors in eliminating the susceptibility of the soil body to volume change.

The presence of organic material in the soil body further complicates the stabilization of the subgrade material. The organic material is accepted to be compressible and easily decomposed by soil microorganisms. The organic matter is also believed to possess a capacity of absorbing considerable moisture. There are very few known facts concerning the effects that varying proportions of organic materials in the soil have on the strength and stability of the subgrade. In general, organic materials have been considered detrimental and their elimination from subgrade soils has been practiced, except in very minor amounts. The following are the essential facts used as the basis of this study:

1. The clay and colloidal fraction of a soil are capable of base exchange and adsorption activities, both of which are surface phenomena (7).

2. Cohesive soils contain sufficient proportions of clay and colloidal materials to provide for surface phenomena to influence the properties of the total soil body.

3. Water molecules are dipoles attracted by ions through polarization and orientation in the clay mineral fraction, either on the broken bonds or between oxygen planes (8).

4. The character of the adsorbed ions saturating the exchange positions of the clay mineral and colloids determines the amount of water that will be taken up under optimum conditions during swelling (9).

5. Principles of base exchange and adsorption allow the surface character of soil colloids to be altered by chemical means so that the water-attractive character of the colloid's surface may be altered to water-repellent properties (9).

6. Soil organic compounds may have a base exchange capacity (10,11).

7. The organic matter in a soil is protected by the clay minerals, and the clay minerals have been found to inhibit peptization of various proteins (12).

8. The exchange positions and adsorption points of a clay mineral may be filled with organic cations instead of easily hydrated cations or water molecules, which would normally occupy them (13).

9. Of the organic materials found in soils, lignin has been determined to be the most resistant to microbial decomposition (14).

10. An excess of organic material in a soil beyond that adsorbed by the clay and colloids can in itself become an agent for absorbing water molecules and result in swelling of the soil mass.

This study was carried out under these stated premises, to begin to evaluate the effects produced by varying exchangeable bases and organic matter additions on volume change, density, and moisture content and to establish emperical relationships between the variables.

TABLE 1

MECHANICAL ANALYSIS OF UNTREATED SOIL

Analysis	Particle Size (mm)	Cumulative % Passing
Sieve (US Standard Sieve):		
1- to 1 1/2- in.	-	100.0
1- in.	-	100.0
3/4- in.	-	98.7
3/8- in.	-	96.7
No. 4	4.8	94.2
No. 10	1.98	89.8
No. 20	0.833	86.3
No. 40	0.417	73.8
No. 60	0.246	64.0
No. 140	0.104	56.6
No. 200	0.074	55.2
Hydrometer		
	0.032	54.6
	0.020	52.4
	0.012	43.9
	0.009	40.2
	0.0061	36.5
	0.0032	29.4
	0.0013	26.9

MATERIALS

The soils chosen for study were typical of some of the road building soils available in various locations of southeastern Michigan. A description of the soil is given in Table I, with the grain-size distribution shown in Figure 1. The samples obtained were taken from the B and C horizon and were a yellowish-brown to reddish-brown coherent gritty loam.

Cationic modifications of the raw soil were made to produce a homoionic soil. The procedure adopted was that previously used by Winterkorn (15). The process consisted of leaching the soil with electrolyte containing the desired cation in enough concentration to saturate the base exchange capacity of the soil. It must be assumed that the process results in base saturation.

Homoionic soils of "hydrogen," "aluminum," "ferric," and "calcium" were produced by leaching the raw soil with the corresponding chlorides and subsequently washing the treated soils with distilled water until the washings were tested as free of the chloride ions.

Lignin was chosen to represent the organic matter in equilibrium with the soil microbiological activity. It was assumed that, by the use of lignin, no further organic decomposition would take place in the soil.

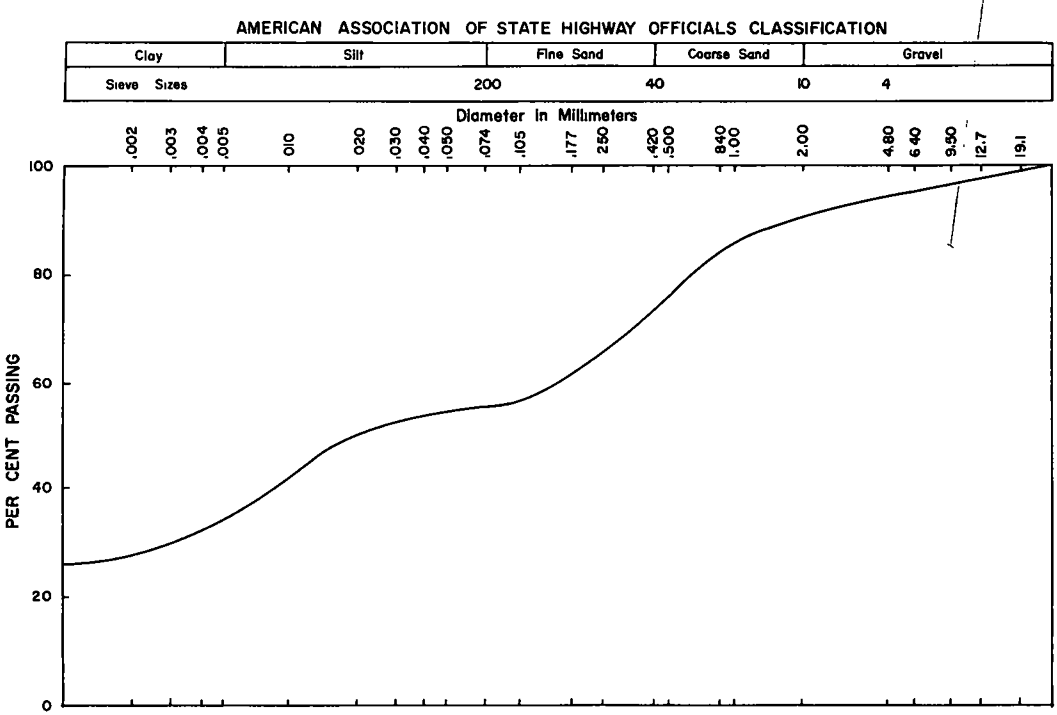

Figure 1. Particle size distribution of Warsaw soil sample (Horizons B and C).

METHODS OF TESTING

The homoionic soils used were air dried to a uniform moisture content and fractioned to insure that all the material passed a No. 4 sieve.

The method of testing adopted for the swell studies was the standard method for the determination of volume change of soils, first proposed by W. K. Taylor (16) of the Bureau of Public Roads and designated in the AASHO Standard Specifications as T 116 - 54.

The apparatus used in these studies was devised from a Soiltest consolidometer body and frame to which a perforated piston was added. A micrometer guage was used to measure the upward movement of the perforated piston as it was forced upward by the swelling action of the soil. The soil sample was maintained at the moisture level of saturation throughout the entire tests. The apparatus was modified from the standard AASHO designation, which accommodates a 4-in. diameter sample 1.5625 in. thick, to a much smaller sample, which after compaction to near-Proctor standards was 2 1/2 in. in diameter and 1 in. thick. The diameter thickness ratio is thus maintained.

A calculated weight of the desired soils were compacted to approximately 120 pcf, dry density, at varying moisture contents from 9 to 14 percent. This compaction was done with static loading to insure uniformity.

Readings were recorded at 15-min intervals for the first hour, then hour intervals for the next 5 hours, and twice daily for the remaining

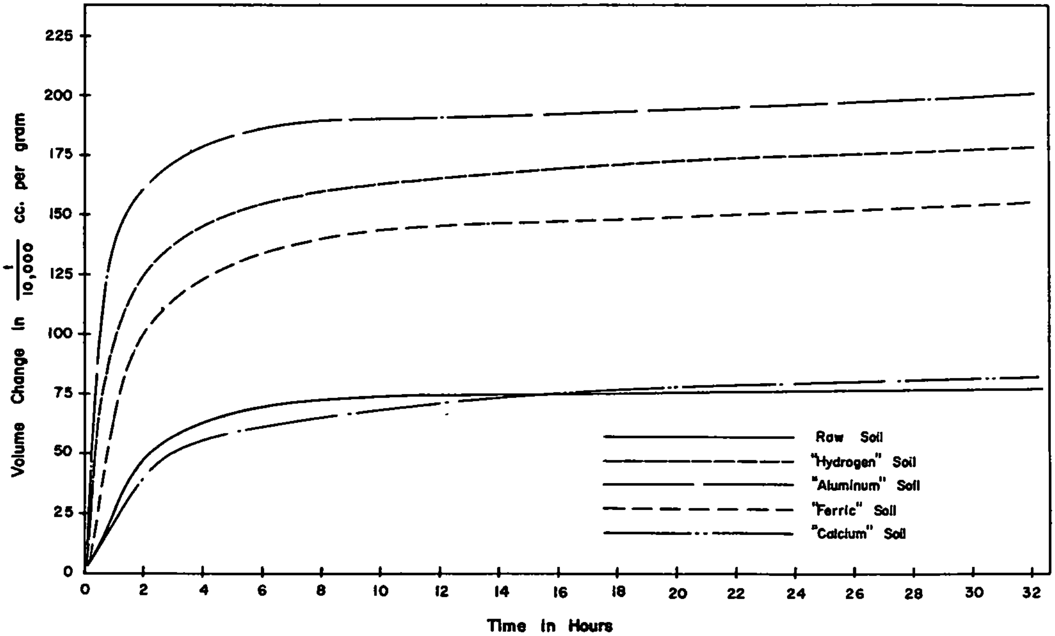

Figure 2. Swelling of homoionic soils compacted at their respective optimum moistures and densities.

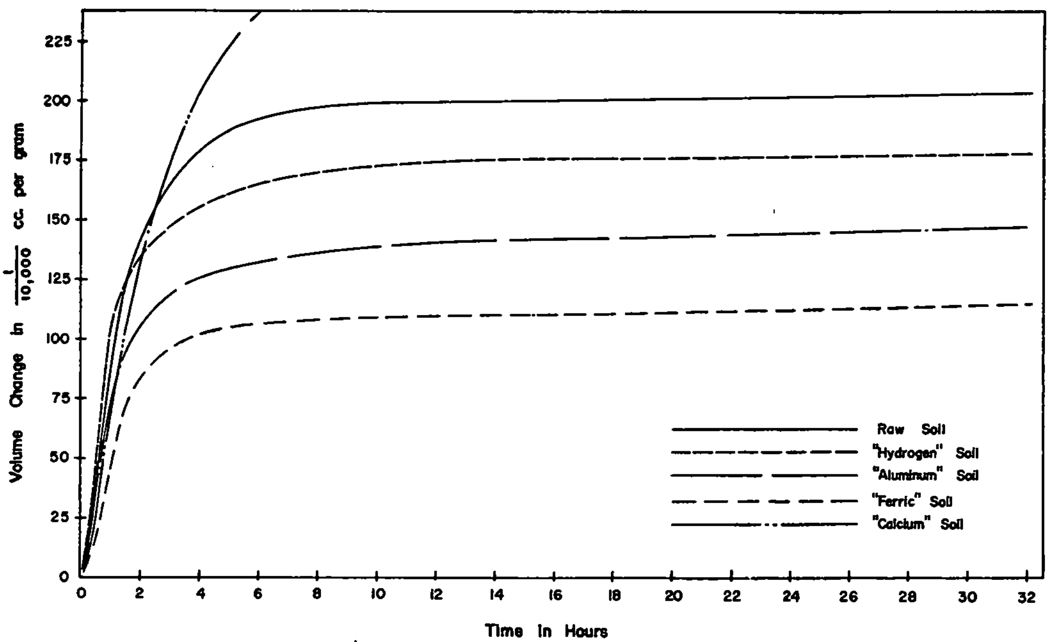

Figure 3. Swelling of homoionic soils compacted at a density of 120 pcf and a moisture content of 13 percent.

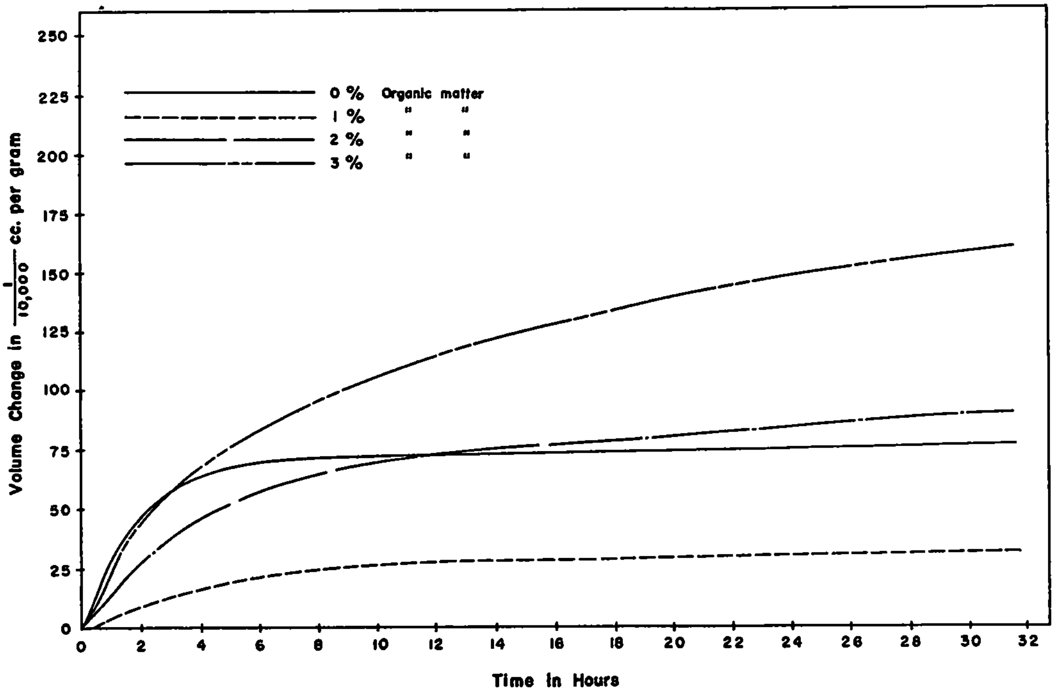

Figure 4. Swelling of "raw" soil at various percentages of lignin.

period that appreciable movement occurred. Readings were terminated on a given sample when the vertical movement of the piston did not exceed 0.001 in. in an 18-hour period.

EVALUATION OF TEST RESULTS

The general effects of the various ions of the homoionic soils on the swell characteristics may be compared to the swell characteristics of the raw soil. Figure 2 shows that the soil samples were compacted at their respective optimum moistures and densities. When the soil samples were compacted at a uniform dry density and moisture content, variations in swell were observed. An example of this is shown in Figure 3, where a uniform dry density of approximately 120 pcf and a moisture content of 13 percent were maintained. When employing optimum moisture and density the Al, Fe, and H soils exceeded the raw soil in swell, and the Ca was slightly lower in swell. When compacting the samples at uniform density and moisture, the Ca soil exceeded the raw soil in swell and the H, Al, and Fe soils were respectively lower than the swell of the raw soil.

The additions of organic matter in the form of lignin varied the effects upon swelling, dependending on the ion of the homoionic soil with which it was incorporated and on the amount of lignin added. In some instances small amounts of lignin decreased the swelling, while greater amounts added to the same soil increased swelling. Figure 4 shows this effect of varying percents of lignin added to the raw soil. Figures 5, 6, 7, and 8 show respectively the effects of varying percents of lignin on homoionic soils of H, Al, Fe, and Ca.

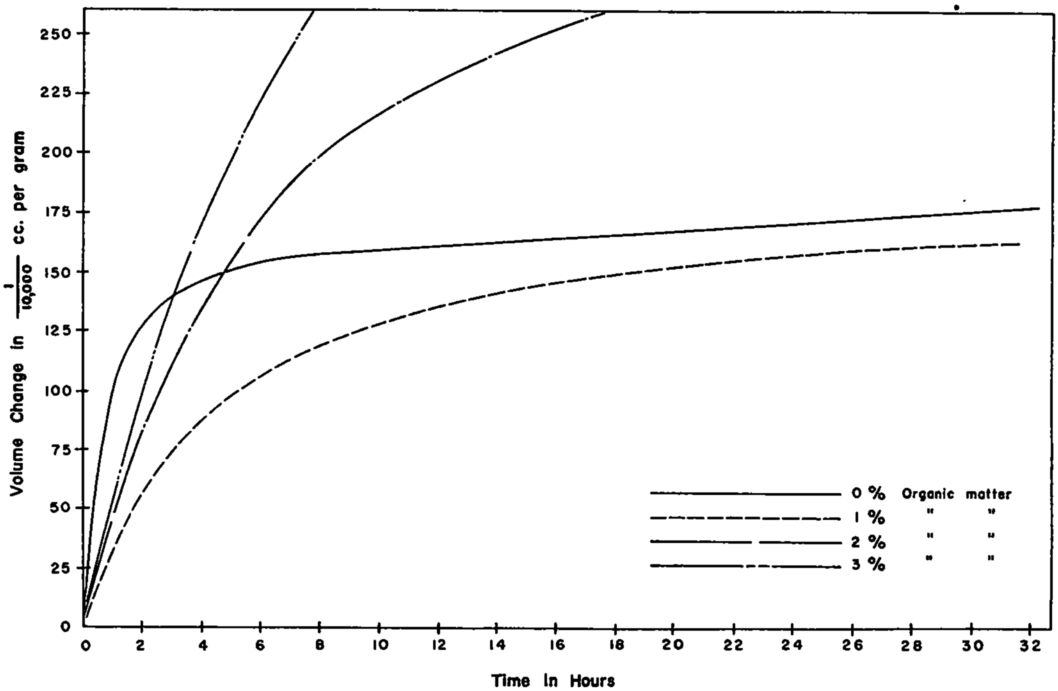

Figure 5. Swelling of "hydrogen" soil at various percentages of lignin.

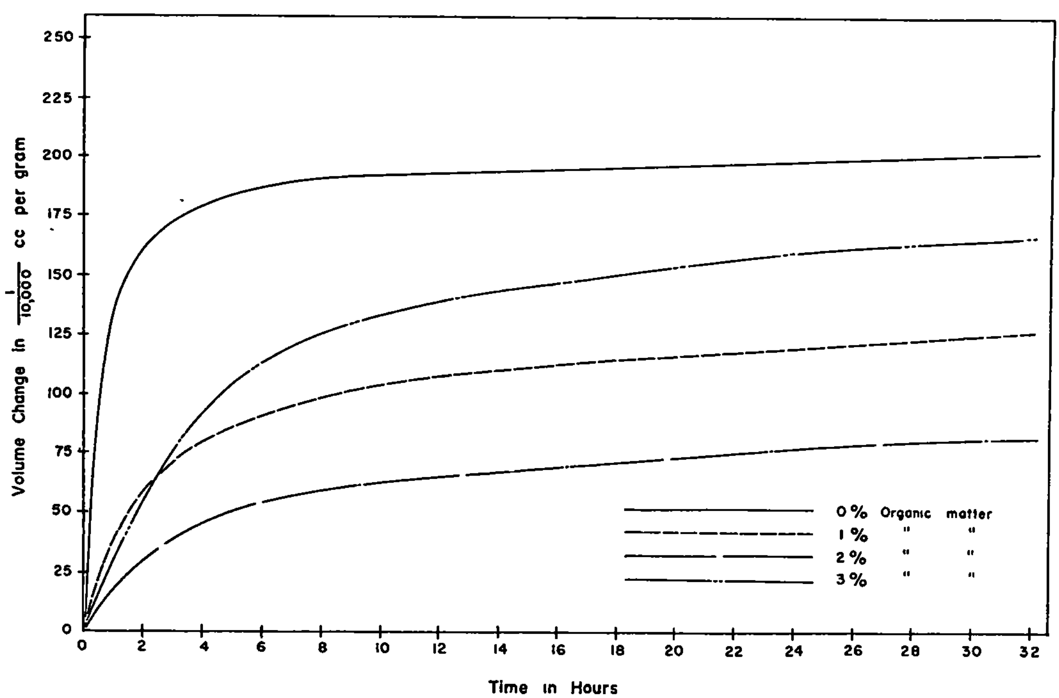

Figure 6. Swelling of "aluminum" soil at various percentages of lignin.

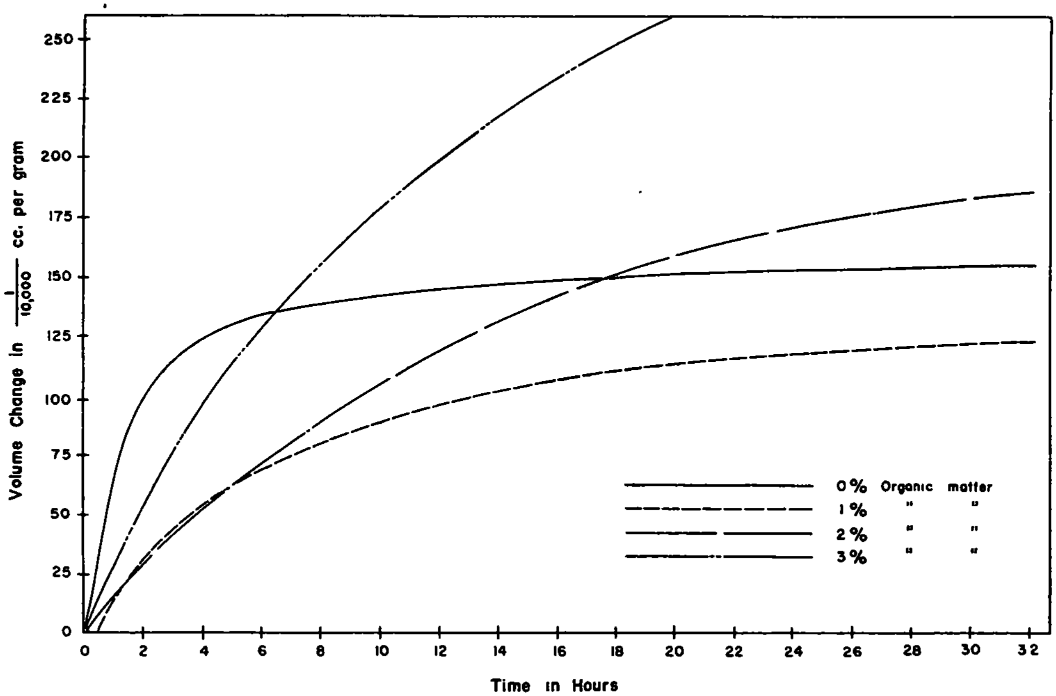

Figure 7. Swelling of "ferric" soil at various percentages of lignin.

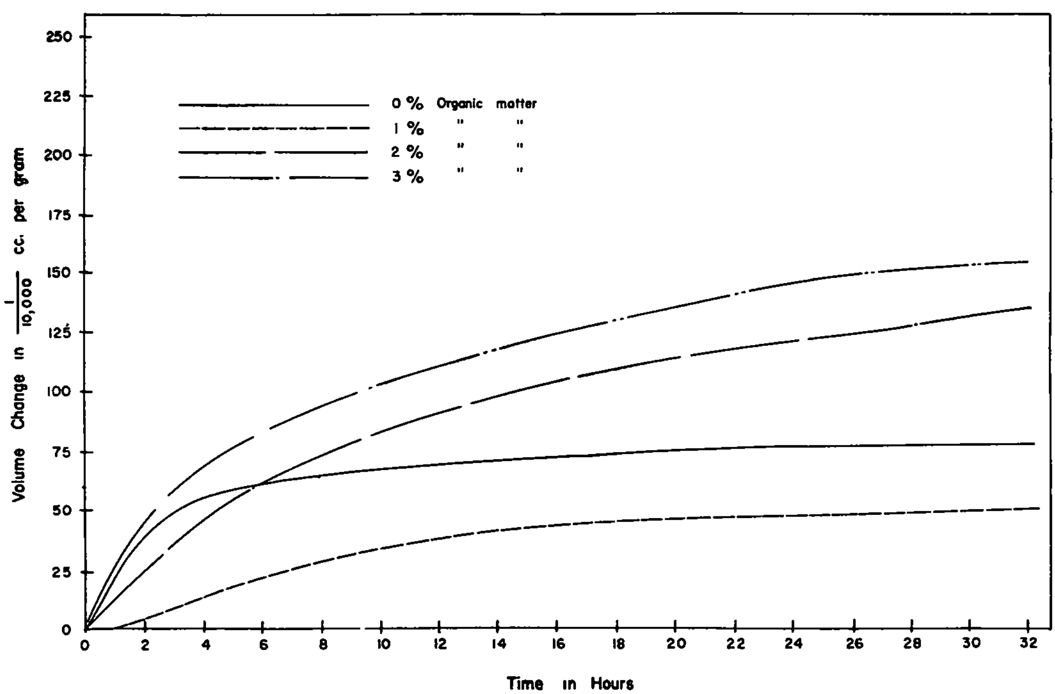

Figure 8. Swelling of "calcium" soil at various percentages of lignin.

Additions of any lignin to a hydrogen soil increased swelling over the raw soil. Additions of 1 percent to the raw, ferric, and calcium soils reduced swell, whereas over 1 percent additions increased swelling. The aluminum soil would tolerate additions of lignin up to 3 percent without any increase in swell, and 2 percent lignin had only one half the swell of the nonadditive homoionic aluminum soil.

It can be generally stated that, for two soil samples compacted at the same dry density, the volume change for that compacted at the lower moisture content is greater. In correlation to moisture content, in any two samples of a given soil compacted at equal moisture contents but with varied densities, the one compacted at the greater dry density will exhibit the larger volume change.

To express the relationships of the moisture-density effects on swelling of soils, constants of proportionality in the form of exponential curves were developed.

The development of the constants of proportionality were based on the following considerations:

1. For two samples compacted at the same density, the one with the lower moisture content indicates greater swelling.

2. For two samples compacted at the same moisture content and occupying the same volume, the sample with the higher dry density has the greater swelling.

3. In the computations, D_2 always refers to the density of the sample at the higher moisture content, and w_2 refers to its moisture content.

The relationships and defination of the constants are as follows:

$$K_1 = f\ (D_2/D_1)$$

$$K_2 = f\ (w_1/w_2)$$

$$K_3 = f\ (t)$$

$$K_4 = (K_1)\ (K_2)$$

$$K = (K_4)\ (K_3)$$

Therefore $K = (K_1)\ (K_2)\ (K_3)$

S_1 and S_2 are corresponding swellings, and are expressed as:

$$S_2/S_1 = f\ (D_2/D_1,\ w_1/w_2,\ t)$$

If the densities of the two samples are equal:

$$S_2/S_1 = f\ (w_1/w_2,\ t)$$

If the moisture contents of the two samples are equal:

$$S_2/S_1 = f\ (D_2/D_1,\ t)$$

If the time of swell is equal for the two samples:

$$S_2/S_1 \;=\; f\,(D_2/D_1,\ w_1/w_2)$$

If the densities, moisture contents and time of swell are equal:

$$S_1 \;=\; S_2$$

The curves in Figures 9, 10, 11, and 12 show the plots of proportionality constant "K" varying with the time in hours.

The swell of two samples at varying moisture contents is determined on the basis of a proportionality constant "K" as follows:

$$S_2/S_1 \;=\; K$$

K is a function of percent moisture and time, K_2 and K_3, respectively, only because the density K_1 is a constant at 120 pcf. The swell of the samples, S_1 and S_2, are expressed in cubic centimeters per gram of dry soil in each sample and are based on the original sample volume.

The curves are indicative of an exponential expression for a given comparison of swell characteristics of a soil. The variations of curves for a given soil may be attributed to the effects of moisture percent upon the swell characteristics of the soil and it is evident that there

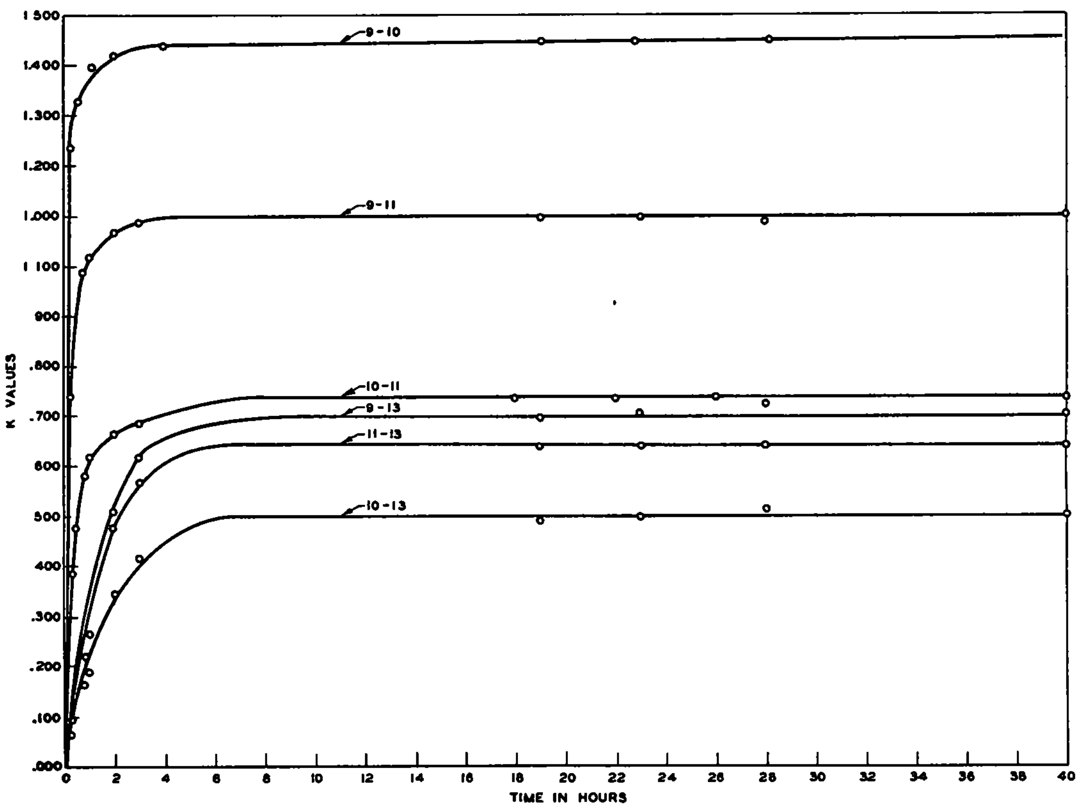

Figure 9. Swell of "hydrogen" soil at various moisture contents expressed as proportionality constant "K".

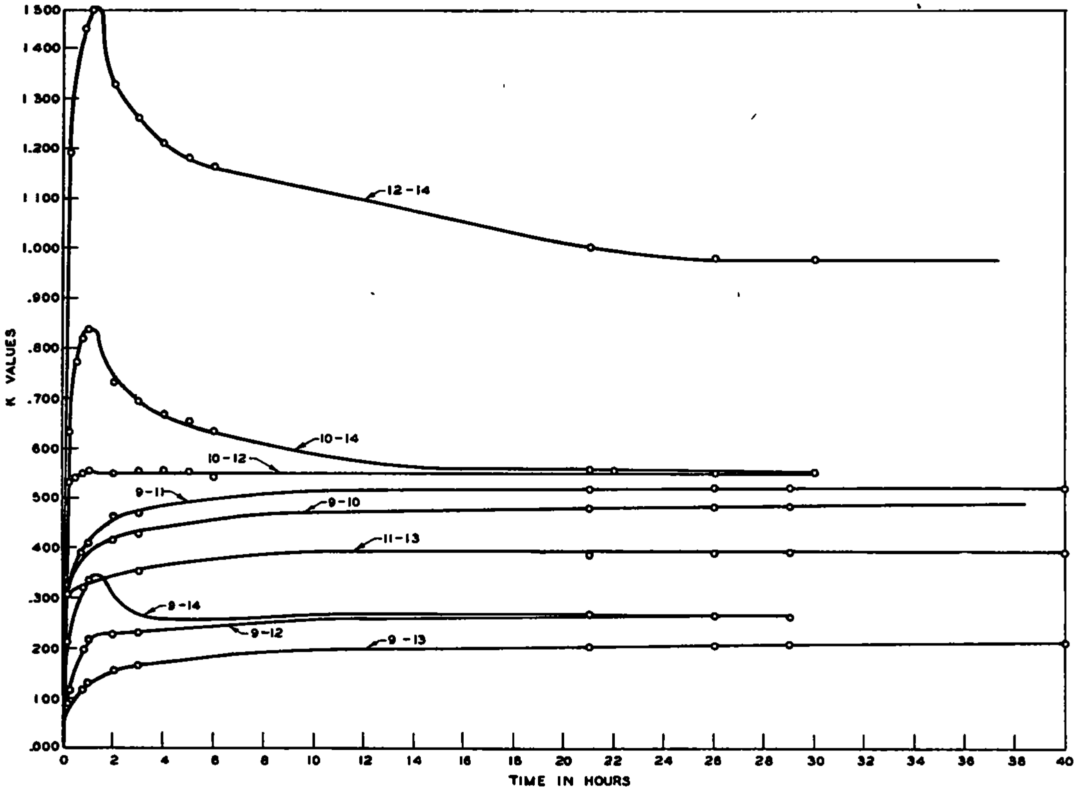

Figure 10. Swell of "aluminum" soil at various moisture contents expressed as proportionality constant "K".

is an optimum moisture content at which soils will possess minimum swell characteristics.

The "K" curves for the various homoionic soils have similarity in shape and character, but variations are attributed to the ion of the homoionic soils. For each of the homoionic soils the shape and character of the "K" curves are characteristic for all comparative moisture percents.

The "K" curves for all the homoionic soils indicate that after approximately 6 hours of swelling tests the relationship of swell of the samples at varying moisture content is constant.

CONCLUSIONS

The following conclusions have been reached at the present stage of this study:

1. An expression in exponential form can be employed to express the relationship of volume change of soil specimens compacted at the same dry density but at varying moisture contents.

2. Relationships of volume change, density, and moisture content are a function of not only the original dry density and moisture content but also of the time subsequent to compaction, type of clay mineral, and the controlling exchange ions.

3. By employing a series of controlled tests it is possible to determine for any given soil a combination of optimum dry density and

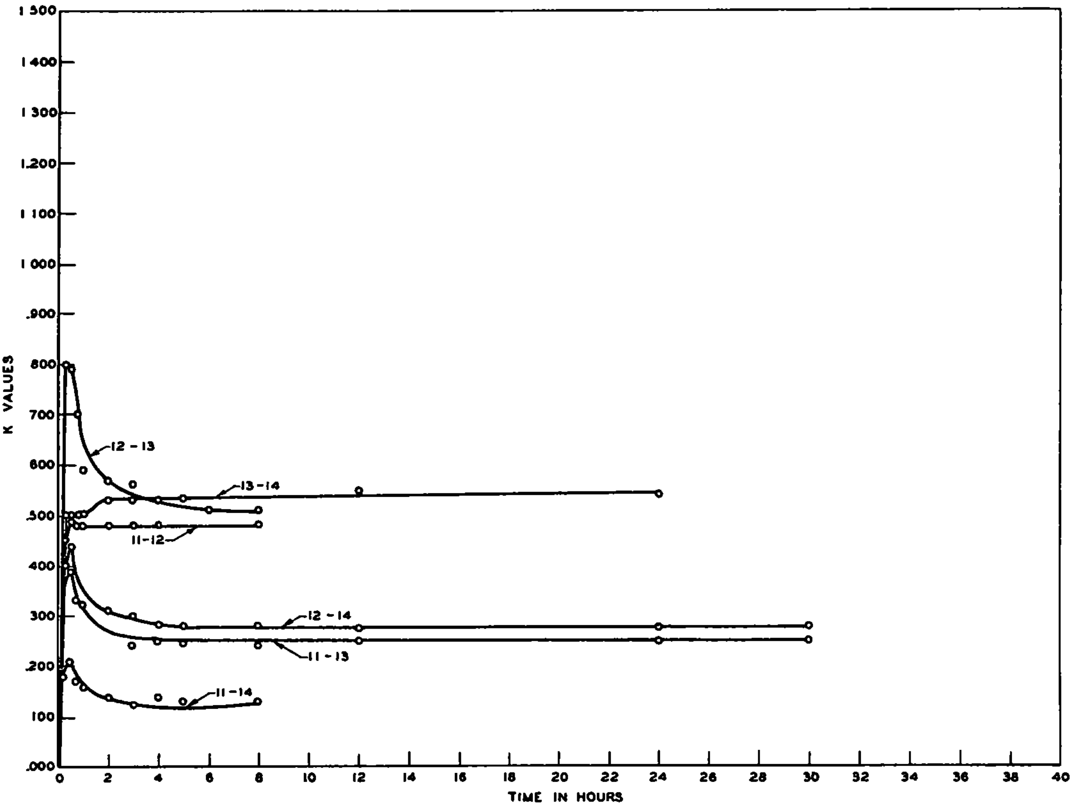

Figure 11. Swell of "calcium" soil at various moisture contents expressed as proportionality constant "K".

moisture content that will result in a minimum volume change subsequent to initial compaction.

4. The additions of organic matter in the form of lignin to the homoionic cohesive soil has a beneficial effect in reducing swell characteristics for soils having aluminum and ferric ions saturating the base exchange capacity of the clay and colloidal portion of the soil. The lignin, if applied in amounts not exceeding that necessary to provide steric hinderance to water dipoles, is effective as a moisture inhibitor, and thus reduces swell.

Further studies are being carried out to determine the following:

1. The relationship between volume changes of samples compacted at varying densities but at the same moisture content. Studies to date have indicated these volume changes may be expressed in the form of an exponential expression.

2. The swell characteristics of sodium and potassium homoionic soils as related to density and moisture content variations.

3. The effects of optimum amounts of organic additives in the form of lignin on the swell characteristics of homoionic soils at uniform density and varying moisture content, and at constant moisture content and varying densities.

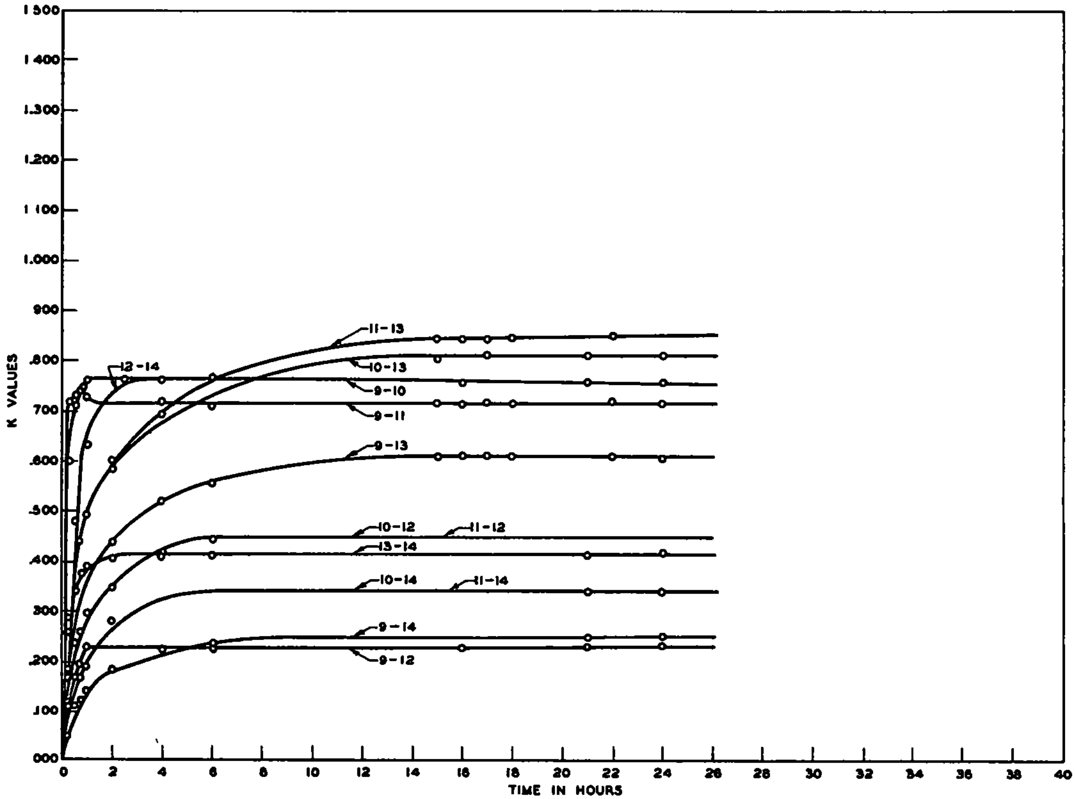

Figure 12. Swell of "ferric" soil at various moisture contents expressed as proportionality constant "K".

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