Compaction and Compression Characteristics Of Micaceous Fine Sands and Silts

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Residual soils developed from metamorphic and igneous rocks frequently contain large amounts of mica, which is considered detrimental, because such may be excessively compressive. However, the critical percentages of mica for various soil types have not been determined.

Laboratory tests on synthetic and natural micaceous soils indicate that soils containing less than 10 percent mica and compacted to modified Proctor densities show no significant changes in dry density or compressibility. With increasing mica content, the dry density decreases and the compressibility increases. The presence of fine mica has a greater influence on compressibility than coarse mica. Correlation of results between synthetic and natural soils appears to be good.

• PLACEMENT of pavement sections and foundation elements on compacted local soils is common practice; however, in certain areas the local soils are considered unsuitable for this purpose. Many engineers consider micaceous soils to be unsuitable. Much of their distrust can be traced to the few articles on micaceous soils that have appeared in the literature. In discussing the influence of particle shape on compressibility, Terzaghi and Peck (11) presented compression curves for sands containing 10 and 20 percent mica which indicated a highly compressible material. Although the compression curves were useful to demonstrate a point, the results have been misinterpreted by many. The relative densities of the micaceous soils were not given, but presumably they were low. Rengmark (6) attributed the poor conditions of road surfaces in Sweden to the inferior performance of base materials which contained substantial quantities of mica. Nevertheless, not all the literature is of a negative nature. Sowers (10) indicated that well-compacted fills of micaceous sandy silts and silty sands make satisfactory foundation material, but cautioned that high densities must be obtained.

Micas are members of the phyllosilicate family of minerals, and as such they display a typical platey shape. The mica group contains many species, but muscovite and biotite are the most common varieties and have the widest distribution. Muscovites are most abundant in metamorphic rocks, whereas biotites occur in igneous, metamorphic, and sedimentary rocks. Soils formed during weathering of these rocks still contain mica bands and sheets, but they are ultimately broken down into smaller units. Mica contents of 20 to 30 percent are not uncommon, and bands of 100 percent mica have been observed. Mica flakes, or plates, in soil are usually small and of fine sand and silt sizes. Reported mixtures have generally been classified as nonplastic micaceous sandy silts or micaceous silty sands.

This investigation was undertaken to understand better the influence of mica content on the compression characteristics of nonplastic sandy silts and silty sands. Changes in compressibility caused by increasing mica contents were examined, and critical contents below which effects were slight were determined. Differences caused by substi-

Paper sponsored by Committee on Stress Distribution in Earth Masses.

TABLE 1

DESCRIPTION OF MATERIALS USED

Sample	Source	Specific Gravity	Classification and Description
Sandy silt	Little Gap, Pa.	2.69	Sandy silt with some clay; liquid limit approximately 20, determined by one blow-count method; nonplastic; low dry strength
Silty sand	Wallington, N. J.	2.66	Red silty sand; capable of being compacted to high densities; nonplastic; slight amount of dry strength
Fine sand	Paramus, N. J.	2.70	Fine sand with trace of silt; nonplastic; no dry strength
Coarse mica	A & T Mineral Services, Springfield Gardens, N. Y.	2.84	Muscovite; effective grain size from sand to clay, but predominantly of sand and silt sizes; coarse textures
Fine mica	Charles Wagner, Inc., Phila., Pa.	2.89	Muscovite (Concord mica); effective sizes predominantly in low silt range; extremely fluffy when dry; greasy to the touch; adhesive when wet
Micaceous silty sand (natural)	Longwood Gardens Estate, Kennett Sq., Pa.	2.76	Nonplastic micaceous silty sand; residual soil formed from a micaceous schist; mineralogical composition primarily quartz, feldspar, and mica; slightly dry strength; mica content estimated at 30%, principally among fine sand and silt sizes

tuting differing mica sizes, and variation of density and of moisture content were also studied. The influence of mica content on the moisture density relationship was also studied.

MATERIALS

Synthetic micaceous soils were used for the major portion of this study because naturally occurring soils of varying mica content, equal mineral composition, and equal grain-size characteristics would be difficult, if not impossible, to obtain. Thus, to investigate the influence of mica content alone, soils with known particle gradations and mica contents were created by combining nonmicaceous soils and mica. Descriptions and sources of materials used are given in Table 1.

Three nonmicaceous soils were selected on the basis of their similarity to the granular portion of known micaceous soils. The grain-size distribution curves of the selected soils are shown in Figure 1. All three soils are in the fine sand to silt range. Nonplastic soils were chosen because the observed natural micaceous soils were predominately nonplastic, and further it was considered inadvisable to include the influence of clay in this study because of the anticipated difficulty in evaluating the influence of mica in plastic soils. The X-ray diffraction patterns for the three soils are shown in Figure 2.

Micas to be mixed with the nonmicaceous soils were chosen on the basis of grain size and mineral purity. A coarse and a fine mica were selected to determine the effect of mica size. Gradation curves for these materials are shown in Figure 3. Descriptions and sources of the mica used are given in Table 1. The X-ray diffraction patterns for the two micas are given in Figure 4.

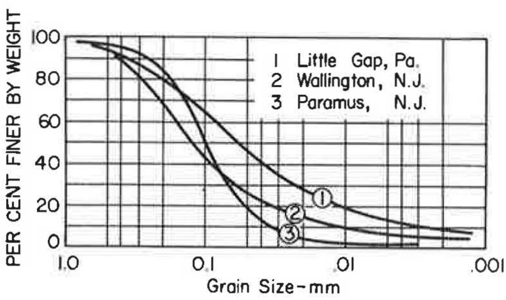

Figure 1. Gradation curve, nonmicaceous soils.

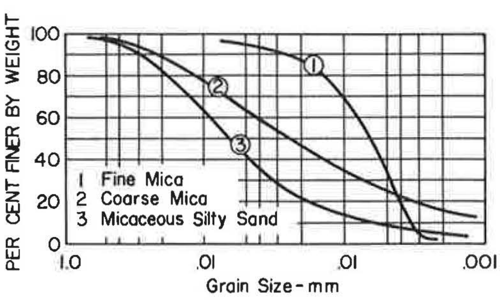

Figure 2. Gradation curve, micas and micaceous soil.

Natural micaceous soils were used to compare the compression characteristics of these materials with those of the synthetic samples. The gradation curve for the natural soil is shown in Figure 3, with material description and source included in Table 1, and X-ray pattern in Figure 5. X-ray patterns of synthetic soils are given on Figure 5 for comparison. The mica peaks can be located by comparing these patterns with those in Figure 4.

The average specific gravities of the materials used in the study are given in Table 1.

TEST PROCEDURE

To provide synthetic micaceous soils of known mica contents, proportioned weights of representative materials were mixed manually until a uniform texture was obtained. Soils and mica were mixed to yield test samples in the proportions shown in Table 2.

The mica content of natural micaceous soils was determined by the point count method (2). The type of mica was checked by X-ray diffraction procedures and the characteristics of the mica were noted by optical observations. The moisture density relationship was obtained for all samples using the modified Proctor test (AASHO T-180-57).

Samples were compacted and testing in floating ring consolidometers. For most tests polished zinc chromate plated steel rings 1.75 in. high and 4.0 in. in diameter were used, but a few tests were performed using Teflon-lined stainless steel rings. Porous stones were provided at upper and lower boundaries to insure proper drainage during compression.

The major portion of the testing program was concerned with the evaluation of compressibility of each material at its maximum density as determined by the modified Proctor test. To determine the effect of moisture on a sample of given mica content and maximum density, compression tests were run on samples at three different moisture contents: (a) at optimum moisture, (b) significantly below optimum moisture, and (c) above optimum moisture. The dry density was maintained within 1 percent for all tests of a given material.

TABLE 2

SYNTHETIC MICACEOUS SOILS

Soil	Source	Coarse Mica[a] (%)	Fine Mica[a] (%)
Sandy silt	Little Gap, Pa.	0, 3, 6, 12, 25, 50, 100	0, 6, 12, 25, 50
Silty sand	Wallington, N. J.	0, 6, 12, 25, 100	—
Fine sand	Paramus, N. J.	0, 6, 12, 25, 50, 100	—

[a]Percentage of mica content by weight in total sample.

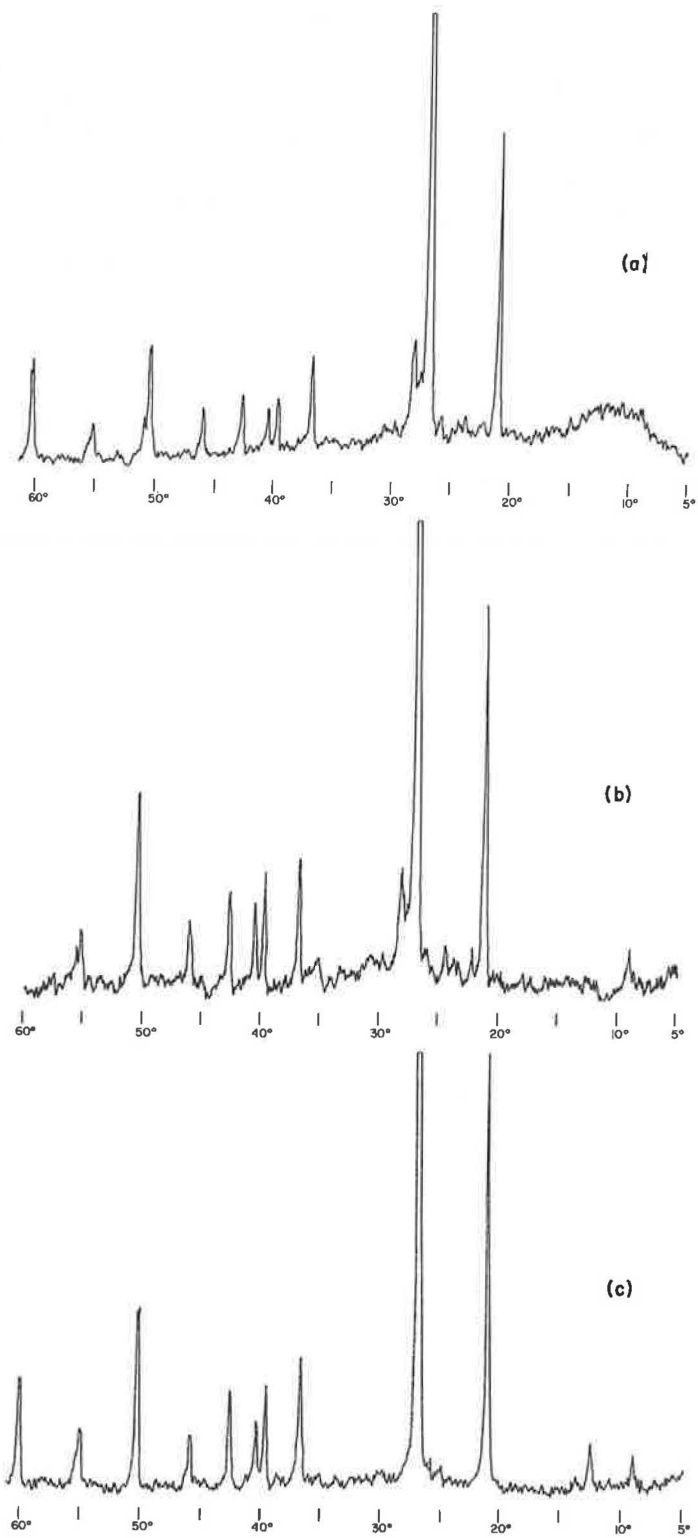

Figure 3. X-ray diffraction patterns of soils used: (a) Paramus fine sand; (b) Wallington silty sand; (c) Little Gap sandy silt.

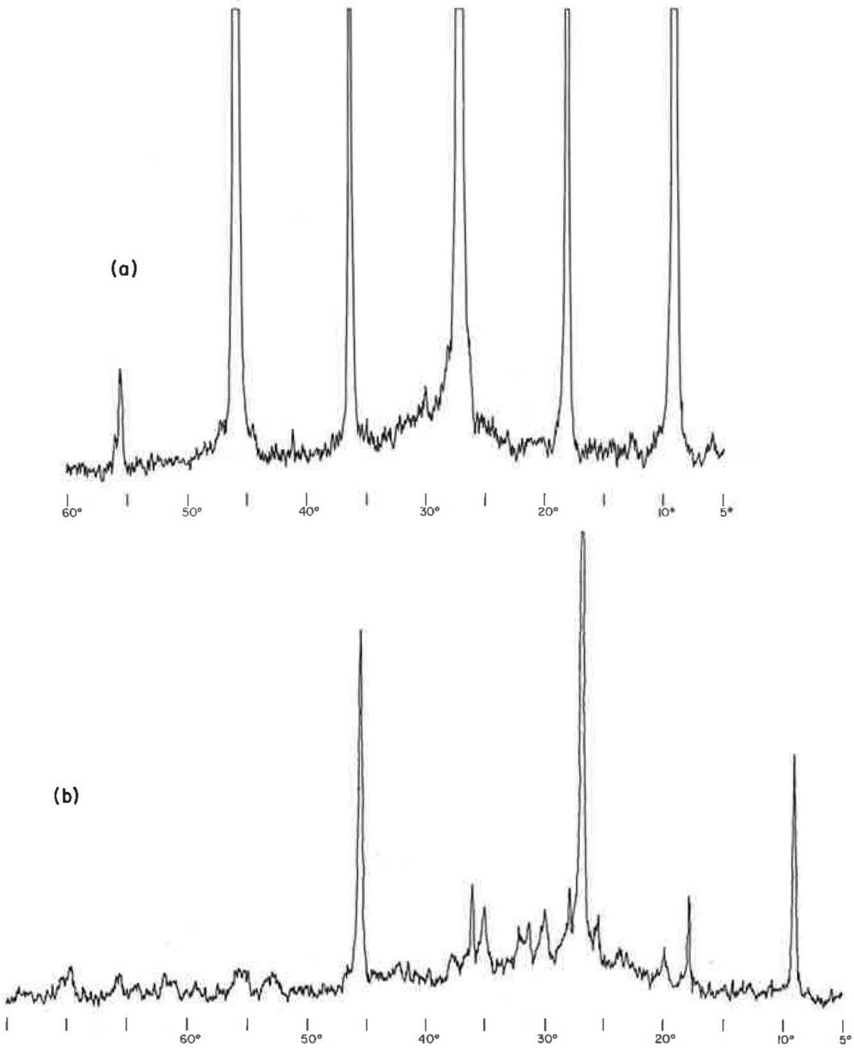

Figure 4. X-ray diffraction patterns of micas used: (a) fine mica; (b) coarse mica.

A minor portion of the testing program dealt with the influence of density on the compression characteristics of the more micaceous mixtures. Minimum densities were determined using the methods suggested by Yemmington (1) and Burmeister (1). Standard Proctor densities were determined using the AASHO T-99-57 procedure. Compression tests were performed on selected soils with mica contents of 25 and 50 percent at their minimum and standard Proctor densities.

RESULTS

The major portion of this study was concerned with the compression characteristics of micaceous soils compacted at modified Proctor density. Modified Proctor density was chosen as a standard because it represents a density commonly required, or used as a reference, on many projects. A soil that is excessively compressive after being compacted to modified Proctor density would normally be rejected. To ascertain the influence of density on the compression characteristics of the highly micaceous soils, a portion of the study was used to investigate this.

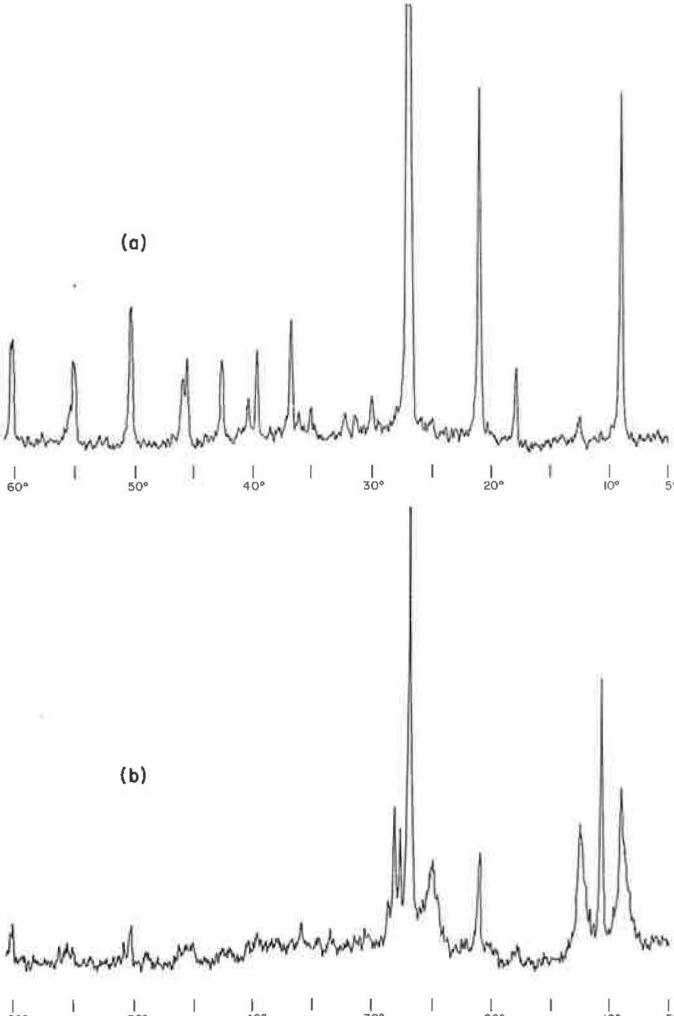

Figure 5. X-ray diffraction patterns of micaceous soils: (a) Little Gap sandy silt plus 25 percent coarse mica; (b) Longwood Gardens micaceous soil.

Moisture-Density Relationships

The influence of coarse mica content on the maximum modified Proctor densities and optimum water contents is significant (Figs. 6, 7, and 8). The trend is for the density and moisture contents to remain essentially constant for coarse mica contents of less than 10 percent. A variation of density of not more than 1 percent was obtained for all soils regardless of the soil type. As mica content is increased beyond 10 percent, decreases in maximum density and increases in optimum water content occur, the changes becoming greater with high mica content. The greatest change in density occurred with the silty sand soil mixture. The maximum densities of all three soils underwent an average reduction of 6 percent by the addition of 25 percent coarse mica.

Fine mica has a slightly greater effect than coarse mica on both dentisy and optimum moisture content, as shown in Figure 8. The decrease in dry density brought about by the addition of 10 percent mica was about 4 percent. As mica content is increased beyond 10 percent, maximum density decreases and optimum moisture content increases, but to a greater extent than with coarse mica.

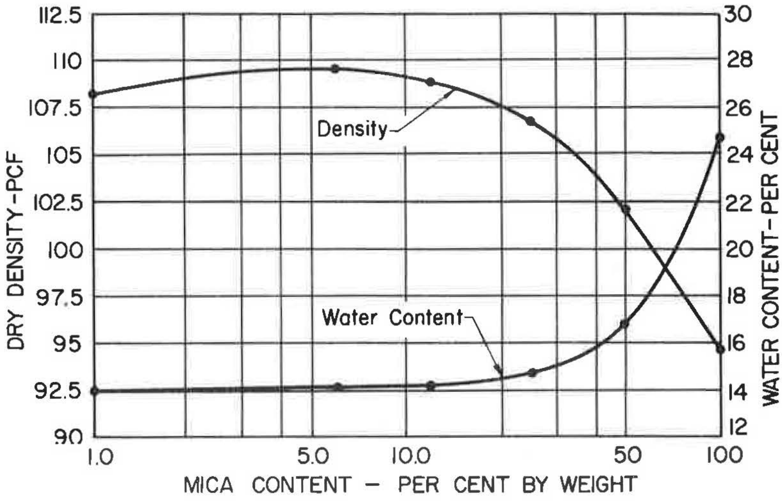

Figure 6. Density and water content vs mica content, Paramus fine sand.

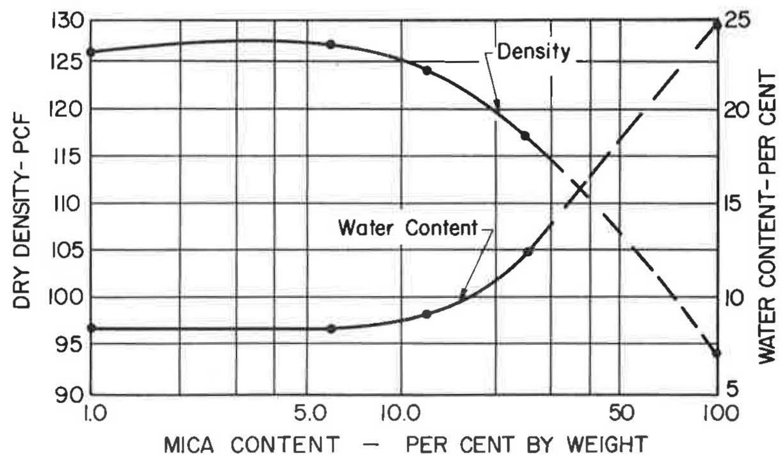

Figure 7. Density and water content vs mica content, Wallington silty sand.

To explain the variations of density and optimum moisture, the specific gravity and shape of the nonmicaceous and micaceous materials were considered. In each case, the specific gravity of the mica was greater than for the nonmica (Table 1). The nonmica particles are approximately equidimensional, whereas the mica particles are plate-like with high surface area to volume ratios.

At low mica contents, the mica flakes are sparsely distributed and do not interact to any degree. For the coarse mica-soil mixtures, a mica particle may simply replace an individual granular particle or fill an existing void, thus contributing to a higher density. As the quantity of mica flakes increases, so does the possibility of creating more void spaces, thus decreasing the dry density of the soil. Individual mica particles are capable of spanning over voids instead of filling them. If mica flakes abound in sufficient number to interact, the bridging phenomenon is further augmented.

When fine mica is considered, the number of flakes for a given weight is much greater than for coarse mica. Thus, contact between flakes is increased with corresponding increases in void ratio. Soil particles are too large to fill the small but numerous openings. Hence, when fine mica is added to a fine sand or silt, a decrease in

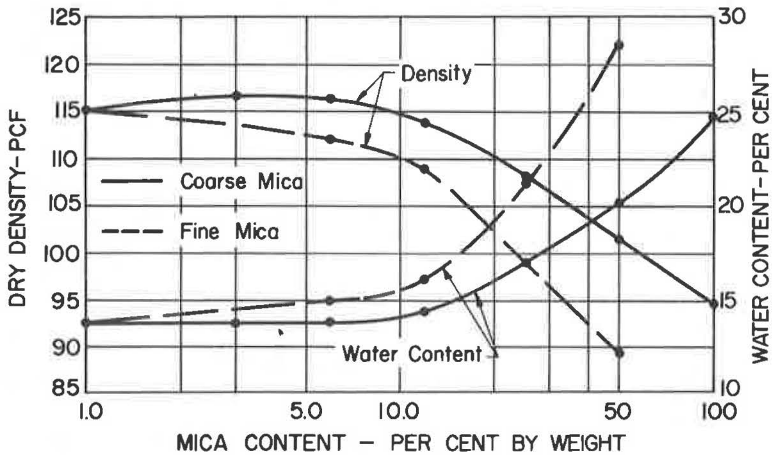

Figure 8. Density and water content vs mica content, Little Gap sandy silt with some clay.

density occurs even at low mica contents. Changes in void ratio with variation in mica for the soils used are given in Table 3.

Optimum water content increases with increasing mica content and the amount of optimum moisture is greater for the fine mica mixtures. Thus, the optimum moisture is a function of the specific surface of the micas.

Compression Tests

For the series of compression tests, densities at the start of the test conformed to the maximum Proctor densities. The soils were dynamically compacted in the compression rings, because Schultze and Moussa (7) found that sands compacted dynamically are more compressible than statically compressed sands. Thus the compression values obtained in this study are probably the greatest that can be anticipated. The results of the compression tests are given in Figures 9, 10, 11, 12, and 13.

As previously noted, mix densities start to fall below mica-free densities after the coarse mica content exceeds 10 percent. For these materials, the initially large void

TABLE 3

CHANGES IN VOID RATIO WITH MICA CONTENT[a]

Weight	Coarse Mica						Fine Mica, Sandy Silt	
	Fine Sand		Silty Sand		Sandy Silt			
	e_o	$\% \Delta e$	e_o	$\% \Delta e$	e_o	$\% \Delta e$	e_o	$\% \Delta e$
0	0.556	x	0.312	x	0.453	x	0.453	x
3	x	x	x	x	0.448	-1	x	x
6	0.557	x	0.330	+6	0.478	+5	0.510	+13
12	0.565	+2	0.355	+14	0.505	+11	0.554	+22
25	0.612	+10	0.439	+41	0.501	+31	0.686	+55
50	0.710	+28	x	x	0.702	+55	0.960	+212

[a] e_o = void ratio at modified Proctor density; and
$\% \Delta e$ = percent change in void ratio due to mica content.

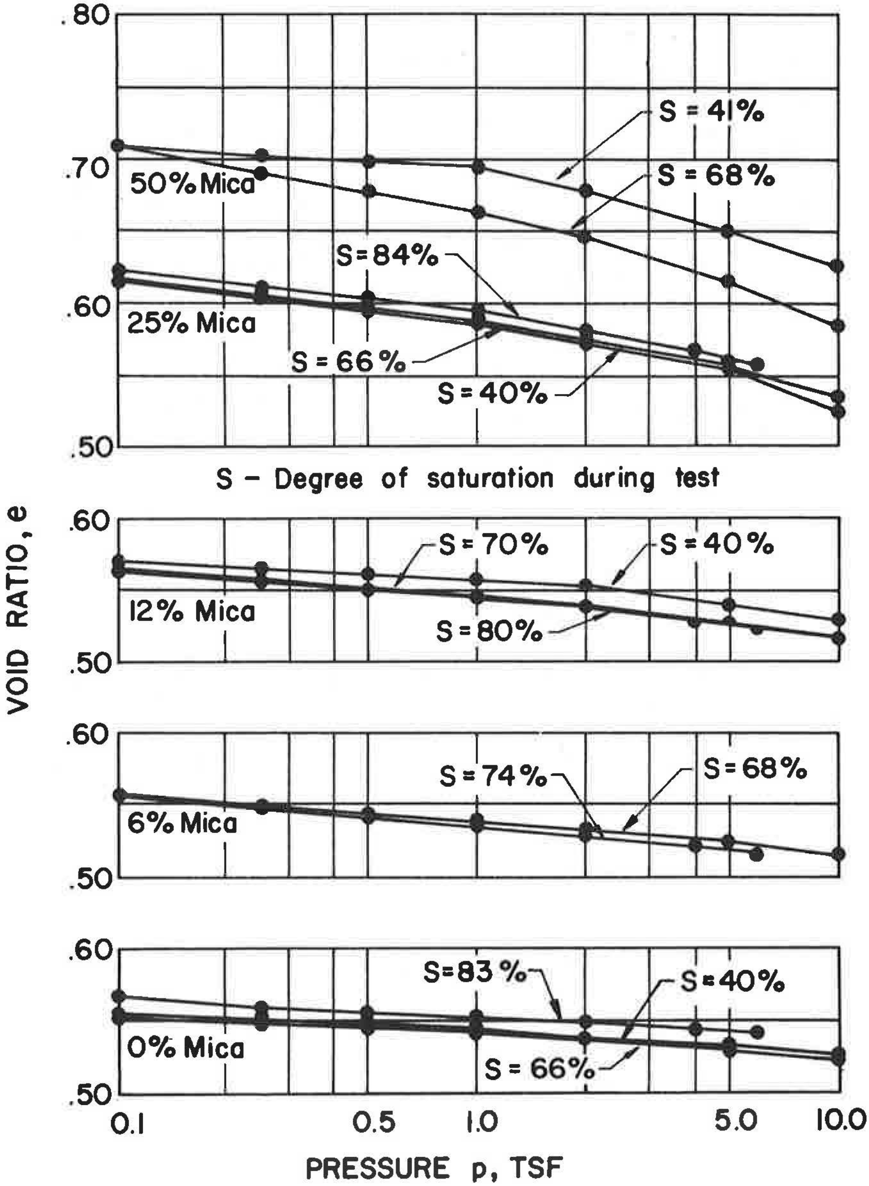

Figure 9. Compression test, Paramus fine sand.

ratios are indicative of greater compressibility. However, even for low mica contents, where densities remain approximately constant, compressibility was observed to increase with mica content.

To facilitate a comparative study, some curves representing the test results of samples not initially at, but very near, maximum density were transposed vertically to start at the void ratio corresponding to the maximum density. Such curves are shown as dashed lines. Actual results are included, but points have not been connected.

For all the samples tested, a break was observed in the e-log p-curve, this leads to the speculation that the compaction effort had the effect of a precompression load. Two tendencies were noted: (a) with a given soil, the break occurs at lower pressures for higher mica contents; and (b) in comparing soils at a given mica content, the break occurs at lower loads for soils with higher contents of fines.

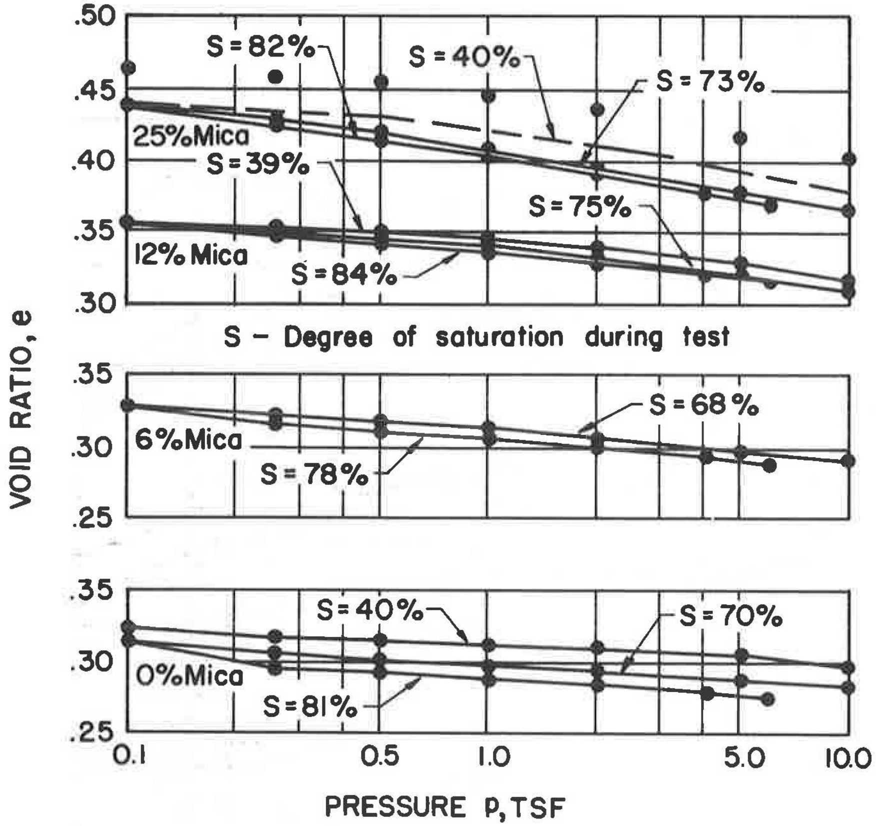

Figure 10. Compression test, Wallington silty sand.

The e-log p-curve is approximately linear in the 2- to 5-tsf range for all samples. In Figure 13, the numerical value of the slope for this loading range is shown as it varies with mica content. For the three soil types, the slope increases with mica content, but the variation between soil types is minor if the same size mica is the additive. Thus, the mica particles have a dominating effect on the compression characteristics, with variations in nonmica particle sizes being of limited influence. This is made more evident when comparing results obtained for the same soil mixed with different sized micas.

Minor variations in compressibility were noted for differing degrees of saturation, the trend was for the compressibility to increase with increasing water content. Probably the addition of water facilitates reorientation of particles under loading.

It may be argued that frictional resistance developed along the consolidation ring may be changed as water content is varied for a given sample. However, there was little evidence of adhesion, and inasmuch as solid friction depends on normal pressures only, ring friction in each case would remain approximately constant because samples were identical except for water content. Further, Leonards and Girault (4) have given evidence that ring friction may be of more importance to the time rate of compression than to the ultimate compression value, and is more pronounced for very low ranges of loading. Nevertheless, it is felt that on a comparative basis, consideration of friction is of little consequence.

Expansion of the samples when unloaded was minor. Volume increases were of the same magnitude for zero and high percentages of coarse mica. Only for soil with 50 percent fine mica was rebound considered notable, an unloading curve for this mixture is shown in Figure 12.

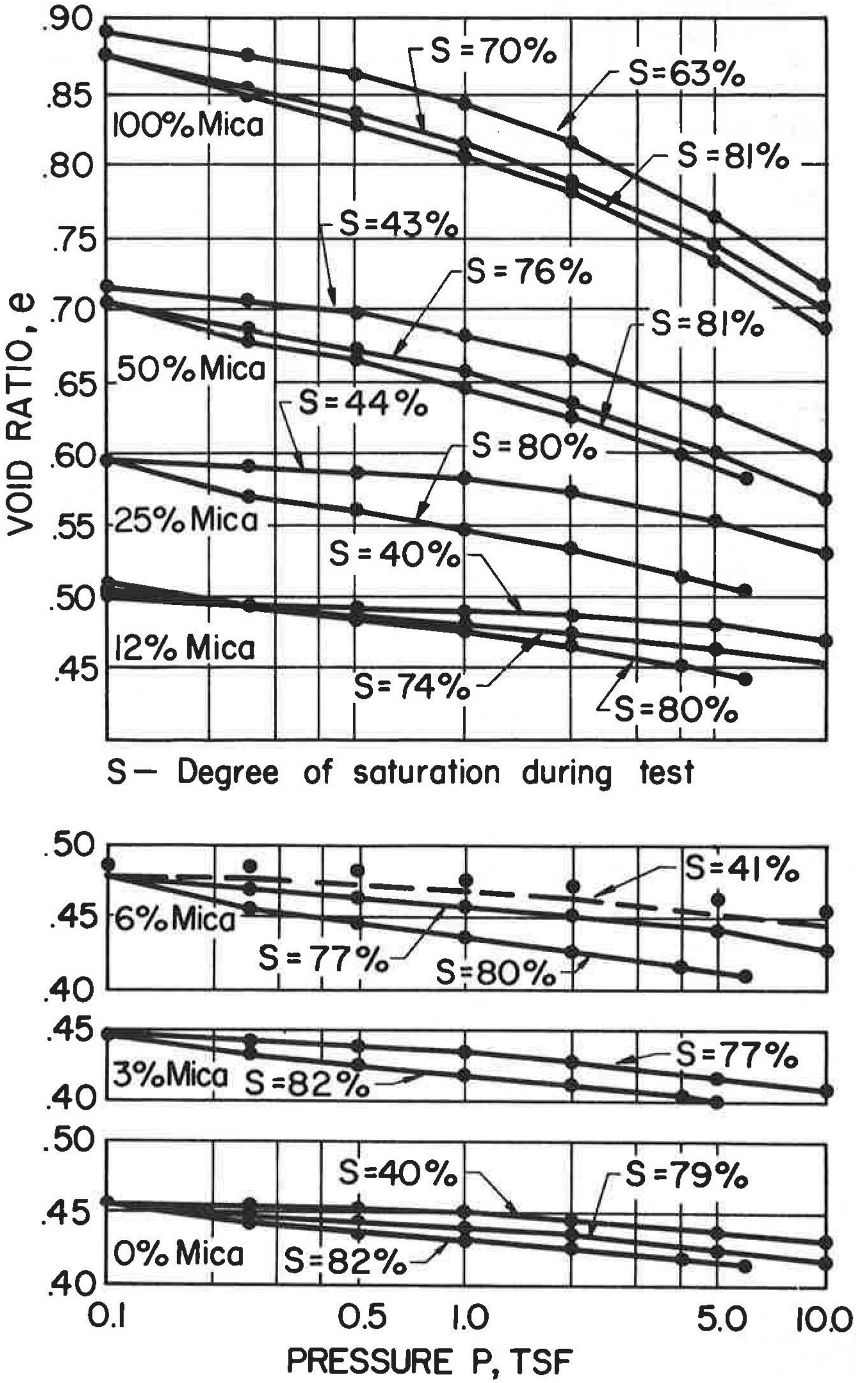

Figure 11. Compression test, Little Gap sandy silt (coarse mica).

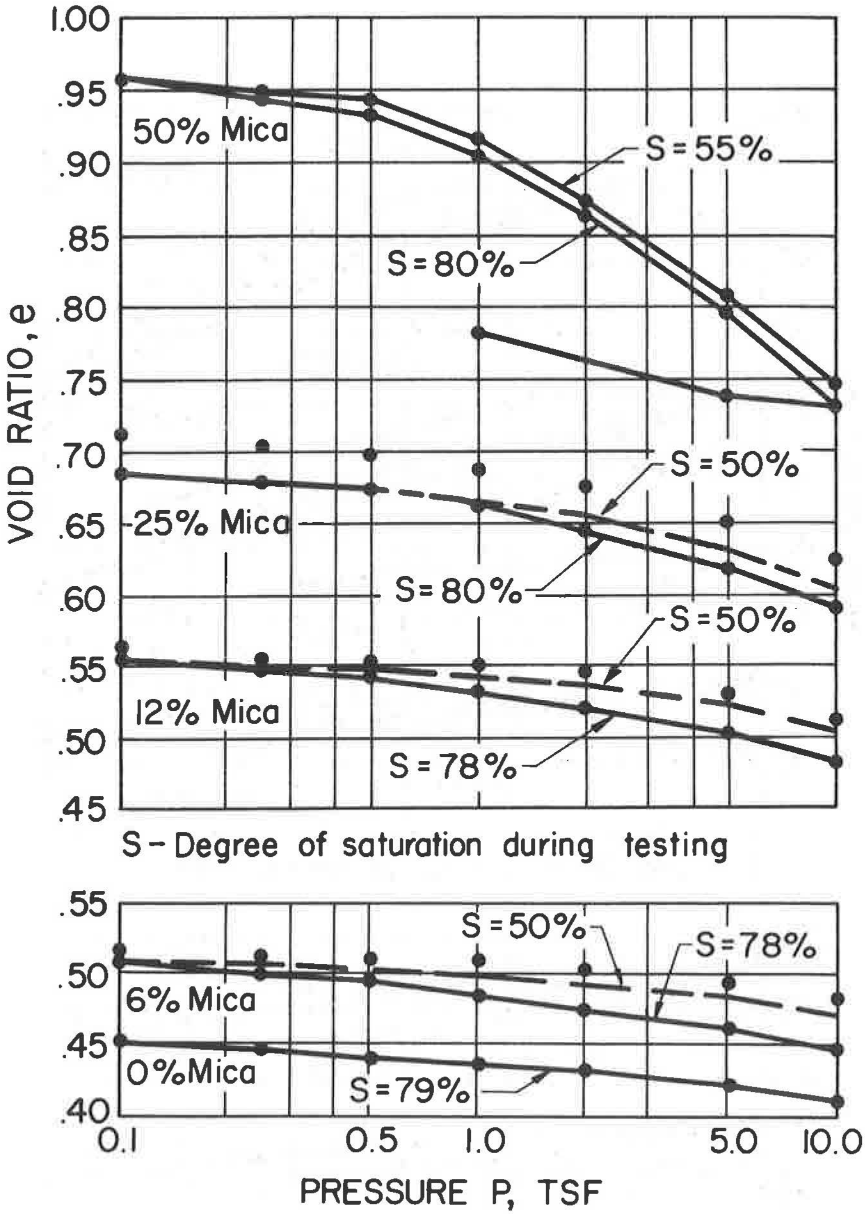

Figure 12. Compression test, Little Gap sandy silt (fine mica).

A natural micaceous soil was used to check the trends observed and the values obtained for the synthetic soils. The e-log p-curve for the natural micaceous soil sample is shown in Figure 14. The value of the slope of the compression curve (2 to 5 tsf) vs mica content is shown in Figure 13. The mica particles are slightly smaller than the coarse mica used, but larger than the fine mica. Consequently, this point would be expected to fall between the extremes determined with the synthetic soils. The close agreement observed leads to the following conclusion: it may be possible to predict soil compression characteristics if mica content, mica sizes, nonmica sizes, and amount of compaction are known.

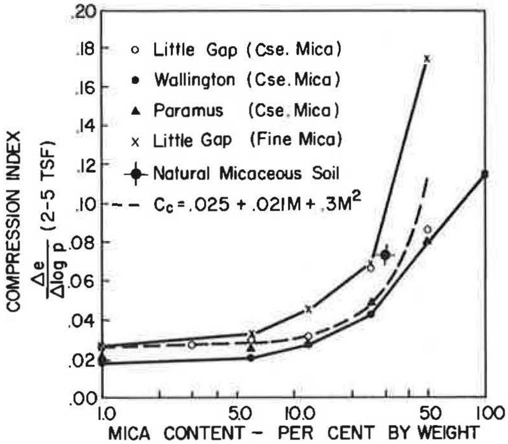

Figure 13. Δe/Δ log p vs mica content (2 to 5 tsf).

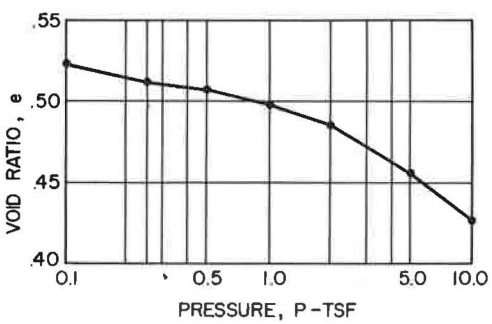

Figure 14. Compression test, Longwood Gardens micaceous soil.

For mica contents up to 50 percent, the compression index in the 2- to 5- tsf range for micaceous sands and silts compacted to maximum Proctor densities may be estimated from:

$$C_c = 0.025 + 0.021M + 0.3M^2 \quad (1)$$

in which M is the mica content expressed as a fraction. For mica contents of 5 to 50 percent, the compression index may be approximated more easily, but with accuracy, by

$$C_c = 0.01 + 0.2M \quad (2)$$

Minimum and Standard Densities

Because the higher mica contents had a significant influence on the modified Proctor densities, a limited study of the soils was undertaken. For determining the influence of the type and amount of mica alone, only one type of nonmicaceous soil was used in the synthetic mixtures. Two procedures were used to determine minimum density because of the lack of a standard procedure for this test. The results of these tests are given in Table 4. In all cases the minimum density decreased with increasing mica content. Exceedingly low minimum densities were obtained using high percentages of fine mica of uniform size. The minimum density of the 50 percent fine mica soil was about three-tenths of the modified Proctor density. The effect

TABLE 4

DRY DENSITIES OF MICACEOUS SOILS

Sample	Mica %	Mica Type	Min. Density (pcf) Bur. (1) Method	Min. Density (pcf) Yem. (1) Method	Proctor Density (pcf) Standard	Proctor Density (pcf) Modified
Little Gap sandy sandy silt	T25	Coarse	60.1	62.2	107.1	108.4
		Fine	51.8	52.5	96.6	98.7
	T50	Coarse	56.9	60.5	98.8	101.2
		Fine	25.5	26.9	88.8	90.2
Longwood Gardens micaceous soil	—	—	70.2	69.2	104.6	114.6

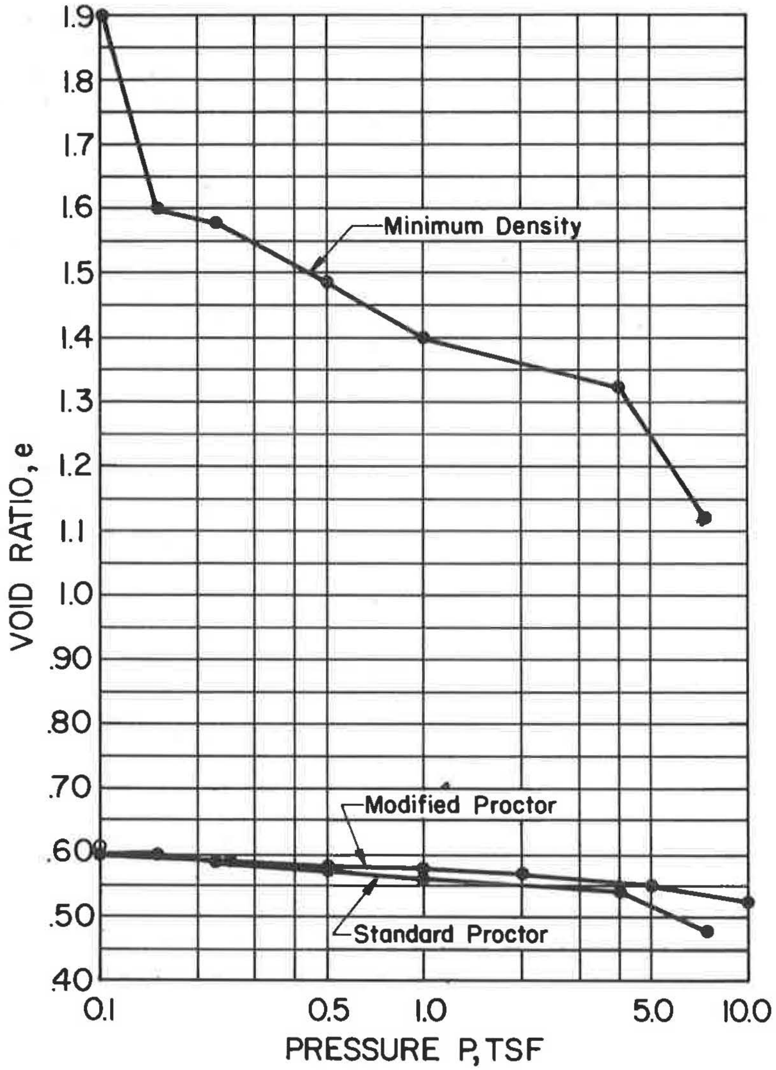

Figure 15. Compression test, Little Gap sandy silt plus 25 percent coarse mica.

of coarse mica on the minimum density values was not as great as the fine mica, but it was still significant. The influence of 25 percent fine mica was essentially the same as 50 percent coarse mica. A 50 percent coarse mica content resulted in a minimum density of approximately one-half the modified Proctor density. The influence of mica on the minimum density of the natural micaceous soil was essentially the same as that exhibited by the synthetic micaceous soils.

The standard Proctor densities for the synthetic micaceous soils were slightly less than their modified Proctor densities. This was not the case for the natural soil. No reason can be given for this fact, other than a difference in sample. A second sample, taken at the same time and location as the sample used in the minimum and modified Proctor densities, was used for the standard Proctor density. The grain-size distributions were similar.

Compression at Lower Densities

A minor testing program to illustrate the influence of the density of micaceous soils on their compression characteristics was undertaken with one micaceous mixture. The results of this testing are shown in Figure 15. Because the modified and the standard Proctor densities of this soil are nearly the same, their compression characteristics are very similar and may be taken as being equal. The slight difference in amount of compression at high loads is probably due to the higher moisture content of the standard Proctor sample. The high compressibility of the low density sample illustrates the need for density control with micaceous soils.

CONCLUSIONS

The presence of mica in a nonplastic soil can have a pronounced effect on its density, this is due principally to the particle shape of the micas. With a given compactive effort, increasing mica content in excess of about 10 percent causes dry densities to decrease and optimum moisture contents to increase. Differences between dry densities for soils with less than 10 percent mica are very minor—about 1 percent for coarse mica or only slightly greater; about 4 percent for fine mica. Minimum density also decreases with increasing mica content. Very low minimum densities may be obtained when fine mica is present in quantity. The effect of coarse mica is still significant. Minimum density values from 0.3 to 0.6 of the modified density values may be obtained when the mica content exceeds 25 percent.

The compressibility of nonplastic micaceous soils increase with increasing mica content. Soils containing fine mica are more compressible than those with coarse mica. Moisture has a slight effect on ultimate compression of micaceous soils; however, compression increases with the degree of saturation. Compressibility of well-compacted soils with up to 50 percent coarse mica and up to 30 percent fine mica may be tolerable. The compression index of nonplastic micaceous soils with mica contents up to 50 percent and compacted to the modified Proctor density may be estimated by Eq. 1. Close control over density is needed to limit the amount of compression of micaceous soils.

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