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FABRIC-PROPERTY RELATIONSHIPS IN FINE GRANULAR MATERIALS

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Abstract—In this investigation fabric-property relationships were studied in a silty fine sand sized crushed basalt—an artificial 'soil' that has previously been used to simulate lunar soil. The fabric was characterized by measuring preferred orientations of grains, and pore size distribution was determined by mercury intrusion porosimetry. When deposited by pouring, the grains acquired strong preferred orientations in the horizontal direction and formed pores between 1 and 30 μm dia. Densification by static or dynamic compaction resulted in near random grain arrangement and pore sizes between 0·1 and 10 μm dia.

Strength in direct shear and one-dimensional compressibility with the associated lateral stresses were measured. The strength was up to 30 per cent higher when the sample was sheared normal to the preferred orientation of grains than when the shearing was parallel to the orientation direction. This is to be expected, as shearing across the preferentially oriented grains should involve breakage or reorientation of many grains. At a given initial void ratio the compressibility of statically compacted specimens was larger (up to 30 per cent higher axial strain) than that of dynamically compacted specimens at very low stresses. At higher stresses both samples exhibited equal compressibility, suggesting that the grains become more randomly arranged at low void ratios (comparing samples of equal initial void ratios).

INTRODUCTION

The mechanical behavior of an aggregation of discrete units partly depends upon the nature of single individuals and their mutual interactions. A practical and useful approach for studying fabric-property relationships in particulate materials is to characterize the fabric in terms of a directly measurable parameter such as grain orientation. The mechanical properties of the mass can be compared with the fabric for determining possible relationships (or lack of them) between fabric and mechanical behavior.

The structure of clay soils in relation to their strength, compressibility and permeability has been studied extensively. Correlations have been found between the grain orientation and engineering behavior (Mitchell, 1956). Clay particle orientation was correlated with engineering properties of illites (Quigley, 1962) and kaolinite (Sloane and Nowatzki, 1967). Recent studies on cohesive soils point to the need for considering the interaction of multiple-grained units consisting of packets of several clay plates (Barden *et al.*, 1970).

Studies of fabric-property relationships in granular soils are more recent, particularly in connection with engineering problems. This is because most granular soils are composed of nearly equant particles that are not expected to form preferred orientations. Also, it has been believed that the engineering behavior of a given sand was controlled almost entirely by density (Terzaghi and Peck, 1968). It is now known, however, that granular soils that have relatively large numbers of flat or elongated particles can be mechanically anisotropic (Lafeber and Willoughby, 1971). Even in soils with equant, sand-sized particles the mechanical properties at any given density may differ significantly for different depositional and stress histories (Morgan and Gerard, 1971). Samples of wind-deposited loess showed grain orientation and strength anisotropy related to the prevalent wind direction (Matalucci *et al.*, 1969). Laboratory-prepared samples have different fabrics and mechanical anisotropy depending on the method of preparation (Oda, 1972).

Purpose and scope

This investigation was aimed at determining if soils composed of granular materials in the silt and fine-sand size range can have different fabrics when deposited in different ways, and whether the mechanical properties reflect the grain arrangement. The investigation did not include any consideration of such soils as sand–mica mixtures, in which a small amount of flat mica flakes causes large changes in properties (Terzaghi, 1931; Moore, 1971).

An artificially crushed basalt was used to simulate soil in the present investigation. The fabric was characterized by determination of grain orientation and by measurement of the pore size distribution. The mechanical properties studied were strength in direct shear, and one-dimensional compressibility with the measurement of the associated lateral stresses.

SOIL FABRIC

Definition

The term 'fabric' is used to describe the basic framework or arrangement of individual constituents of an assemblage consisting of different components. However, the term as applied to soils has had slightly different connotations in soil science, geology and engineering. The current usage in pedology is to define fabric as that element of soil structure which deals with particle arrangement; whereas the broader term 'structure' includes the size and shapes of mineral grains and interparticle voids (Brewer, 1964). Sedimentary petrologists also use the word in the narrow sense of arrangement or orientation (random or preferred) of the elements that compose a rock (Pettijohn, 1957). In igneous or metamorphic petrology the term fabric includes the orientation of grains as characterized by their crystal lattice (Verhoggen *et al.*, 1970).

In engineering, the picture is somewhat more diffuse, as the application of fabric studies is relatively recent. From the earliest time of its introduction into the soil engineering literature, the word fabric has been used interchangeably with the wider terms structure and microstructure (Casagrande, 1932; Lambe, 1953), and the synonomy has continued to this day (Sides and Barden, 1971). In the present study, fabric has the broader sense that includes the arrangement and spatial distribution of pores as well as the mineral grains.

Test material

The material studied (Lunar Soil Simulant No. 2) was a basalt quarried from Napa County, California, and crushed to the particle size distribution given in Fig. 1. X-ray diffraction analysis of powder samples indicated that the principal minerals were plagioclase feldspars, olivine and pyroxene (Hardcastle, 1972). The average s.g. of solid particles is 2·89 and maximum and minimum bulk densities are 1·82 g/cm^3 and 1·36 g/cm^3 as determined by ASTM Standard Test, D 2049 (ASTM, 1972).

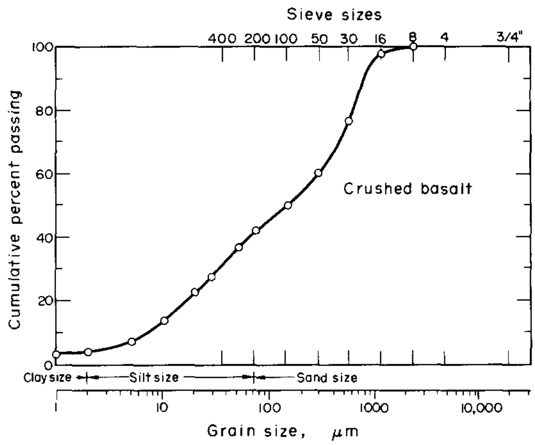

Fig. 1. Grain size distribution of crushed basalt.

For evaluating particle shape characteristics a representative sample was separated into six size fractions by sieving. Each fraction was loosely spread on a horizontal transparent surface and photographed in silhouette. The grain photographs were then used for determining angularity and length to width ratio. A value of roundness was assigned to each grain by visually comparing it with charts based on Wadell's criteria (Müller, 1967). Length to width ratios were determined for each grain by direct measurement on tracings prepared from photographs. Weighted mean values of shape characteristics were then computed for the entire sample. The crushed basalt grains were quite angular, with a mean roundness of about 0·1 (with a scale of values from 0·1 for very angular to 1·0 for very rounded). A photograph of a typical fraction of the basalt sample is shown in Fig. 2. The mean length to width ratio for the entire sample was 1·64, with a distribution as shown in Fig. 3.

Sample preparation

Loose samples for fabric study were prepared by vertical pouring, and the dense samples either by tapping the sample holder on a hard bench top (dynamic compaction), or by slow loading with a flat piston (static compaction). The bulk density of each sample was computed from the known container volume and the weight of crushed basalt that was poured in. This as-prepared sample density was then used in computing the relative density D_r, defined by

$$D_r = \frac{D_{max}}{D} \times \frac{D - D_{min}}{D_{max} - D_{min}} \times 100\%,$$

where D is the bulk density of the sample, and D_{max} and D_{min} are the maximum and minimum densities that can

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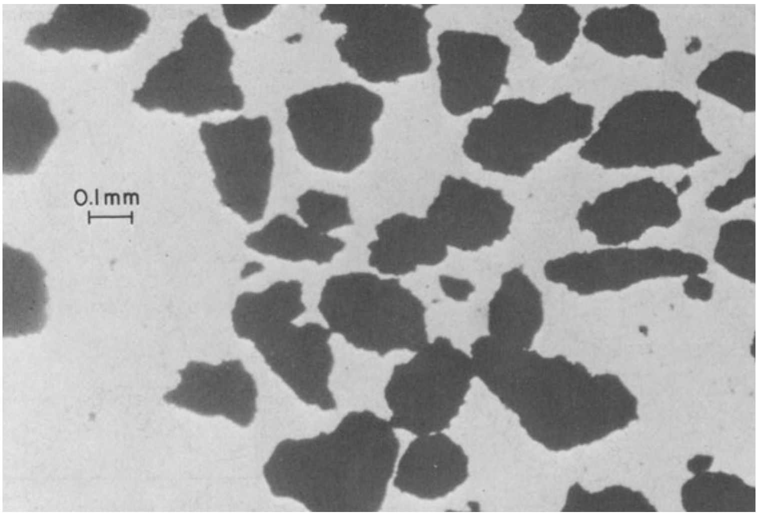

Fig. 2. Photomicrograph of crushed basalt grains, 150–300 μm size fraction.

be determined by standard test methods (see earlier section on test soil). The relative density is an important parameter for defining the state of compaction of a granular material in relation to its engineering properties (Terzaghi and Peck, 1968). The values of relative density are routinely used for defining the state of compaction of granular soils or sands both in nature and in the laboratory.

Grain orientation

A comprehensive description of the grain orientation of a granular soil sample would involve reconstruction of a complex, three-dimensional spatial arrangement of individual grains and multi-grained units. Such spatial grain orientation can be approximated by looking at thin slices or sections separated by precisely known distances.

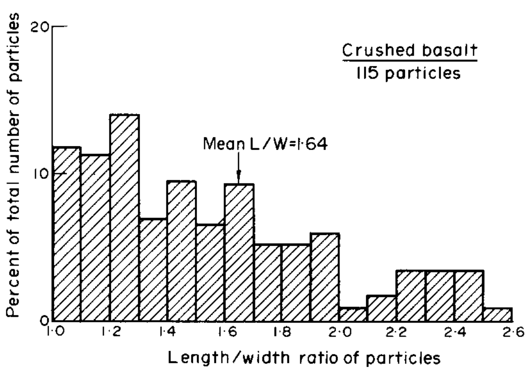

Fig. 3. Grain shape distribution of crushed basalt lunar simulant (whole sample); results based on study of 115 particles.

Alternately, particle orientation can be characterized by studying the apparent long axes that are seen in sections or ground surfaces. This method is of sufficient accuracy for mineral grains with three dimensional shape generally so irregular that the characterization of long axes of most grains is not precise (Dapples and Rominguez, 1964). By comparison, the apparent grain shapes in two-dimensional ground surfaces are nearly ellipsoidal, and long axes can be estimated with sufficient accuracy. The particle aggregate characteristics determined on two dimensional ground surfaces can be related to the three-dimensional properties experimentally (Windisch, 1970) or statistically (Underwood, 1970). In this study the two-dimensional particle arrangement was directly compared with bulk mechanical behavior and no attempt was made to determine the three-dimensional arrangement.

The grain orientation was studied on 1-cm cubes of crushed basalt deposited in a sample holder and then impregnated with epoxy-resin subsequently hardened by polymerization. Horizontal and vertical surfaces of the samples were ground, photographed and enlarged by projecting on a sheet of paper and tracing the grain boundaries, Fig. 4. Each complete tracing had 400 or more grains.

The best estimates of the apparent long axes of elongated grains were drawn on such tracings and their orientations determined by assigning them to one of the eighteen 10° intervals between 0° and 180°. These techniques did not provide the true, three-dimensional orientation but rather the apparent imbrication, as all the ground surfaces studied were vertical. The choice of 10° interval was based on the total number of grains

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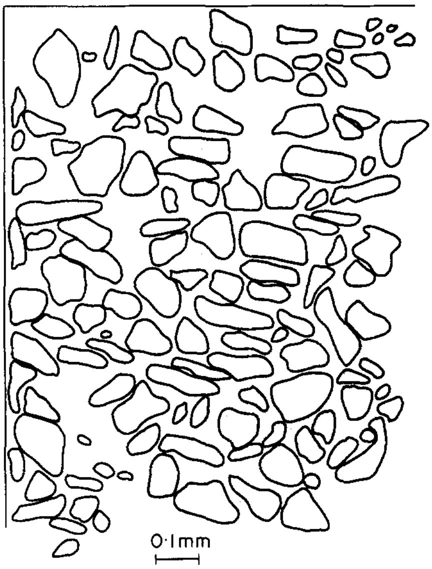

Fig. 4. A portion of tracing made from a photograph of vertical surface of an impregnated crushed basalt specimen.

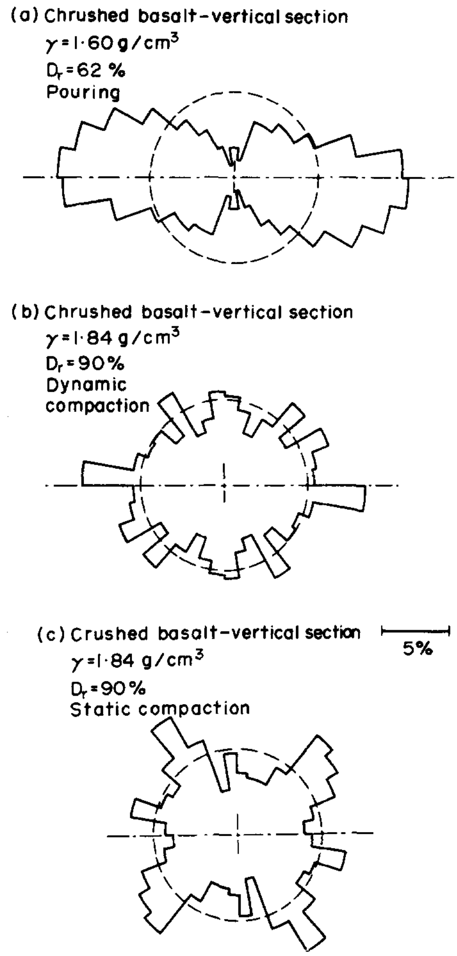

Fig. 5. Particle orientation diagrams for crushed basalt: (a) pouring; (b) dynamic compaction; (c) static compaction.

in the tracing sample and compatibility of confidence level (accuracy) in fabric and property determination. Intervals from 5° to 20° are generally used in similar studies. The number of particles in each of the eighteen intervals was separately totalled, and then computed as percentages of the total number of particles in a tracing. These percentage values were then plotted on polar coordinate graph paper as rose diagrams shown in Fig. 5. If all particles were randomly oriented, the plot would have been a circle such as shown by broken line.

Pore size distribution

The pore size distribution of crushed basalt was determined by mercury intrusion porosimetery, using an Aminco–Winslow type porosimeter (Diamond, 1970; Ahmed *et al.*, 1974). A pressure capacity of 15,000 lb/in^2 and a conventional filling device limited the range of pore sizes that could be studied to between 0·012 and 70 μm. The cohesionless nature of the crushed basalt necessitated the fabrication of a special sample holder, and a design similar to that used by Klock *et al.* (1969) was adopted.

The pore size distributions of loose and dense samples of crushed basalt are plotted in Fig. 6. As might be expected, the pores were much finer than the grains that form the void walls. The effective size (d_{10}) of pores in the loose sample was about one fourth the effective grain size, while the effective pore size in the

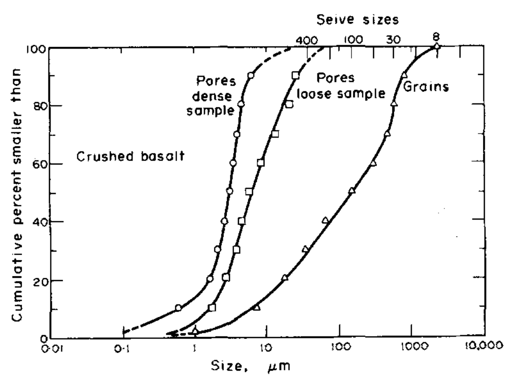

Fig. 6. Grain and pore size distributions for crushed basalt simulant; dense sample: density = 1·91 g/cm^3, D_R = 97 per cent; loose sample: density = 1·60 g/cm^3, D_R = 62 per cent.

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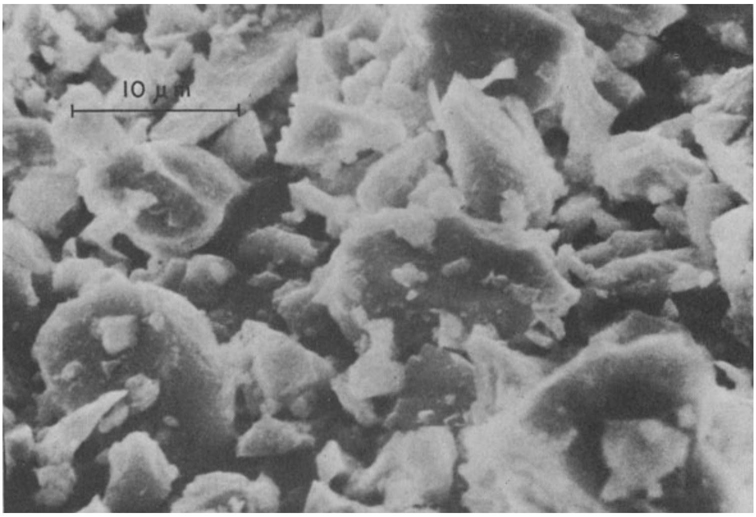

Fig. 7. Scanning electron photomicrograph of loose crushed basalt; surface seen initially horizontal.

dense sample was only about one tenth of the d_{10} grain size. In fact, virtually all the pores in the dense sample were finer than the d_{10} grain size.

One phenomenon that causes the pores to be so much finer than the grains is the way grains become arranged to form void spaces. For instance, as is known from studies of molecular structure (Sienko and Plane, 1961), the diameter of a void between three equal spheres is approx 1/5 dia. of the individual spheres. This is also borne out by design of drainage filters (Sowers and Sowers, 1971). A scanning electron photomicrograph shows that even in a loose specimen the voids formed between grains are much smaller than the grains themselves, Fig. 7.

The pore size distribution is also more uniform than the grain size distribution, Fig. 6. The uniformity coefficient, d_{60}/d_{10} is 40 for the grains, but only about 4 for the pores.

The densification brought about by dynamic compaction (tapping the sample holder on a hard-topped table) caused a reduction in the median pore diameter, d_{50}, from 6 μm in the loose state to 3 microns in the dense condition. The reduction in overall pore space was mainly due to reduction in the number of pores larger than 10 μm in diameter. In the loose sample, 35 per cent of the pores were larger than 10 μm dia., in the dense sample only about 2 per cent.

Pore size distribution curves are more precise if coordinates customary for porosimetry are used, Fig. 8, than the cumulative plots. The former represent the actual intruded volume rather than the percentages of a whole which sometimes do not agree with the total pore volume computed on the basis of bulk sample volume and the specific gravity of solids, thus introducing an unknown sliding error in the cumulative percentage values. Figure 8(a) is a re-plot of pore size distribution from Fig. 6.

As the finer portion of the sample had considerably large grain surface area, it also formed a large proportion of the void walls, Fig. 7. The finer 35 per cent of a crushed basalt sample was separated at the No. 270 sieve (52 μm) and its pore size distribution determined, Fig. 8(b). Much of the pore volume (over 85 per cent) in both loose and dense conditions lies within pores 1 and 10 μm dia. During densification, the number of pores larger than 2 μm was greatly reduced, and the resulting dense sample contained pores mostly between 1 and 2 μm. It is not known if some form of 'micro-sorting' occurs during densification.

Dynamic and static compaction as alternate means of densification are compared for samples of approximately the same density, Fig. 8(c). The statically compacted specimen had a greater proportion of large (7–10 μm) pores (26 vs 2 per cent in the dynamically compacted specimen). Since static compaction did not produce a specimen quite as dense as did dynamic compaction, the former results were normalized to the void ratio of the dynamically compacted specimen. The difference in the pore size distribution shown in Fig. 8(c) indicates that the proportion of pores larger than 10 μm dia. was greater in the statically compacted than in the dynamically compacted specimen.

Summary of fabric results

The fabric of crushed basalt was studied by determining the grain orientation and pore size distribution

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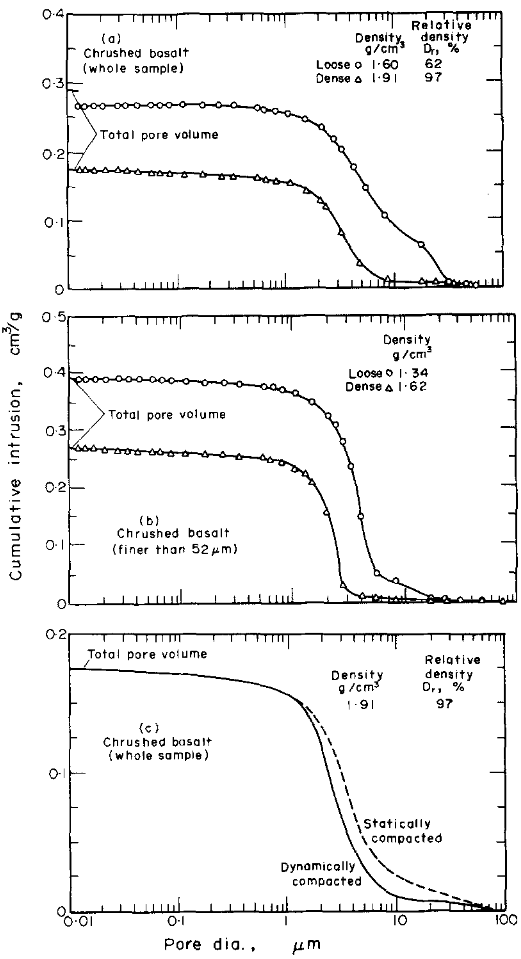

Fig. 8. Pore size distribution of crushed basalt; (a) loose and dense samples; (b) fine fraction (passing 52 μm); (c) differences due to compaction method.

of small (1–2 g) samples deposited in different ways and at different porosities. When deposited by pouring (loose condition) the grains acquired strong preferred orientations in the horizontal direction. The pores were mostly between 1 and 30 μm dia. in the loose sample.

Upon densification the grains became randomly oriented, and the pore sizes were reduced to between 0·1 and 10 μm dia. The method of densification seemed to affect both the grain orientation and the pore size distribution. Dynamic compaction (tapping the sample holder) produced a near random grain orientation and a fine pore size distribution. Static compaction was less efficient in reducing pore diameter. The grain orientation in a statically compacted specimen showed a weak bimodal preferred orientation at nearly 45° from the horizontal.

PROPERTY RESULTS

Since fabric study of artificially crushed basalt indicated a preferred orientation of grains when poured loosely, with somewhat larger pores in statically compacted specimens than in dynamically compacted specimens, it appeared that there might be measurable strength anisotropy. In addition, differences in the proportions of large pores could affect the compressibility. Therefore, tests were done to investigate these effects.

Strength in direct shear

A special direct shear box was fabricated for measurement of the strength both along and across the direction of preferred orientation of grains. The box could be opened either from the top or side to pour soil to form a cubical sample (side = 44 mm). The sample could be sheared either along or across the initial direction of deposition, Fig. 9.

The crushed basalt was poured from a low height (2–3 mm) into the shear box with the aid of a funnel. In the case of samples poured from the top, the loading cap was placed on the sample, two halves of the shear box were disconnected and the sample sheared. When a sample was prepared by pouring from the side, the side opening was closed and the shear box tilted to restore the normal position. The top plate was then removed and the test carried out as for the top-filled specimens, Fig. 9.

The results of two series of shear tests are summarized in Fig. 10. The abscissa shows density as well as relative density of samples because mechanical properties such as shear strength and compressibility are far more dependent on relative density than on the bulk density of soils (Terzaghi and Peck, 1968). In one series of four tests the samples were prepared by pouring from the top. The four tests were at different densities and resulted in curve a, Fig. 10. Another series of six tests was carried out on samples poured from the side of the shear box to obtain curve b. The measured shear strength was greater when samples were sheared across the plane containing the preferred orientation direction of grains, than when they were sheared along it, Fig. 10.

No strength tests were carried out on the statically or dynamically compacted specimens. Both methods impart mechanical energy to the sample and result in residual interlocked stresses (Sowers, 1957). The interlocked stresses lead to indeterminate and anisotropic initial state of stress in the sample in a rigid sample holder such as that used for strength tests in this study.

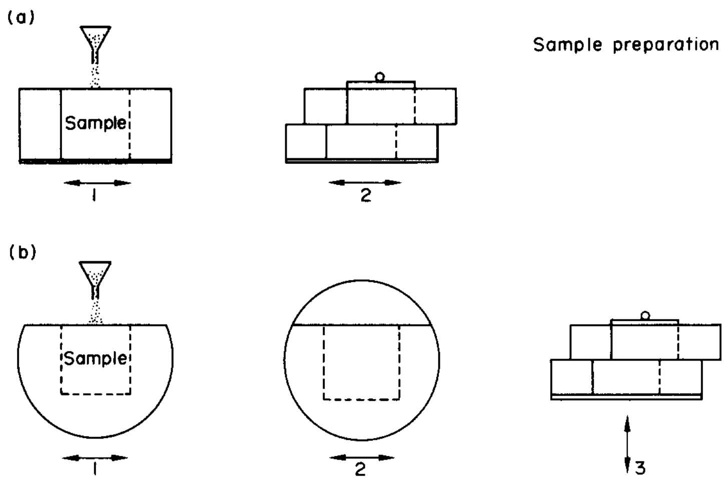

Fig. 9. Sequence of sample preparation for top and sidefilled specimens in direct shear; arrows show the direction of preferred grain orientation; (a) top-filled specimen: 1-pouring, 2-shearing; (b) side-filled specimen: 1-pouring, 2-closing the side, 3-shearing.

The influence of grain orientation alone could not be studied in samples densified by mechanical compaction.

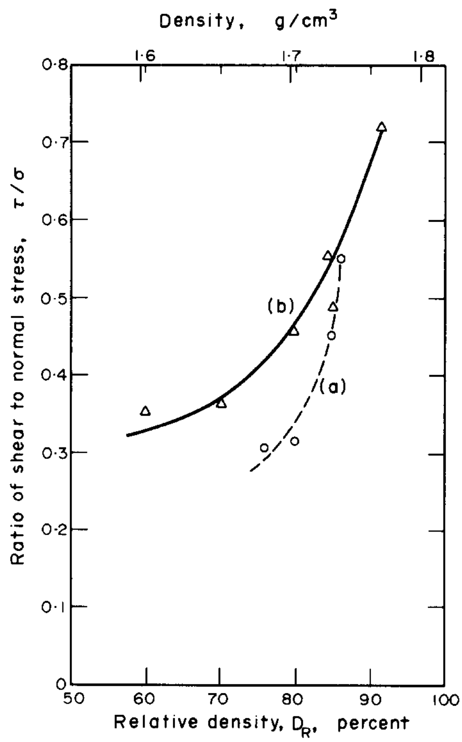

Fig. 10. Summary of direct shear test results on pluviated samples of crushed basalt: (a) top-filled, sheared along grain axes; (b) side-filled, sheared across grain axes.

Compressibility

Since samples densified by vibration had different pore size distribution and particle orientations than samples densified by static compaction, a study was made to determine if these differences had any effect on the compressibility.

One-dimensional compressibility was measured using a ring compressionmeter type of device capable of measuring both vertical deformation and lateral stress (Mahmood, 1973). The lateral stress measurement capability permitted use of mechanical compaction as the state of stress could be defined by direct measurement. The chamber consisted of a cylinder fabricated by joining together alternating rings of steel and rubber-impregnated cork, Fig. 11. This particular construction made it compressible in the vertical direction yet rigid against lateral deformation.

Crushed basalt was poured into the ring chamber and then densified either by static compaction or by dynamic compaction. The static compactive effort was applied by slow loading with a piston. For dynamic compaction, the sample was placed on a vibrating table. While this method of compaction does not duplicate the 'tapping' that was used in the fabric study, it is similar to vibration in that both methods impart dynamic, oscillatory mechanical effort.

At small axial stresses the statically compacted specimen showed strains larger than those measured in the vibrated sample, although both samples had equal strains at the larger stresses, Fig. 12. At all levels of axial stress slightly higher radial stresses were measured in the vibrated sample, Fig. 13.

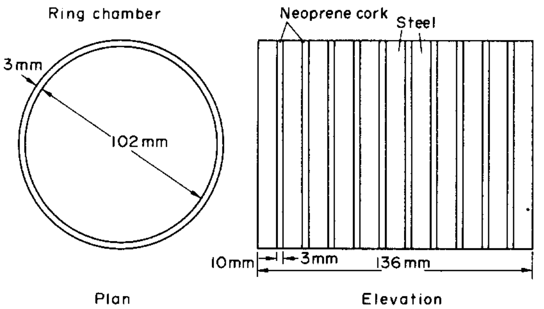

Fig. 11. Schematic diagram of ring chamber.

DISCUSSION

Fabric

The fabric study showed that granular materials composed of silt and fine sand-sized crushed basalt grains acquire different fabrics when different methods of sample preparation are used. Pouring resulted in the grains acquiring an arrangement such that their long axes were preferentially oriented in the horizontal direction or normal to the direction of free fall, Fig. 5(a). Arthur and Menzies (1972) describe experiments with aluminum discs poured through water that resulted in a plate-like alignment normal to the direction of pouring. One way in which the orientation of poured sand grains can be explained is by considering the behavior of a flat ellipsoid tumbling in free fall (Jizba, 1971). On a horizontal surface, more ellipsoids are likely to come to rest with their long axes normal to the direction of free fall. The effect of decreasing grain size is to increase the influence of such surface forces as fluid drag in comparison to the body forces. If particles in every size range had a constant shape, this would mean that in the silt-sized granular soils the coarser grains will tend to be preferentially oriented on pluviation, whereas the finer grains will be randomly oriented. However, in natural sediments, quartz particles less than 100 μm in size appear to become flatter with decreasing size (Krinsley and Smalley, 1973). Hence it is likely that even fine granular soils might acquire preferred orientation.

Samples densified by dynamic or static compaction have been subjected to stresses, and the grains do not maintain the initial or primary fabrics developed during sedimentation (pouring). The grains arrange themselves in order to best resist the applied stresses. In sands the dynamic compactive effort applied during tapping or vibration causes the interparticle stresses to pulsate. This results in the periodic reduction of energy barriers that are formed by interlocking and friction between particles (Youd, 1970), leading to densification

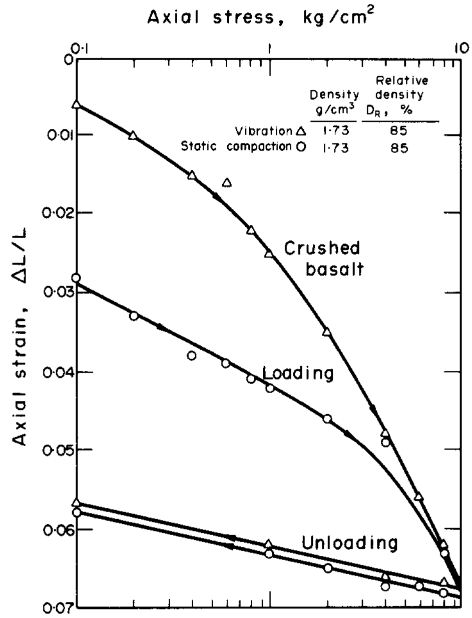

Fig. 12. One-dimensional compression behavior of crushed basalt.

of the sand mass. In silts, interparticle adhesion may also contribute to this energy barrier. Equilibrium between surface forces and body forces can sometimes lead to metastable grain structures (Terzaghi, 1956).

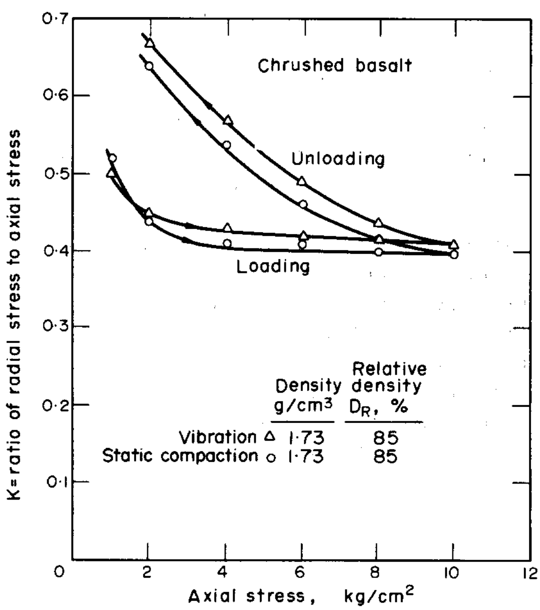

Fig. 13. Relationship between axial stress and the ratio of radial to axial stress in crushed basalt lunar simulant samples densified by vibration and static compaction.

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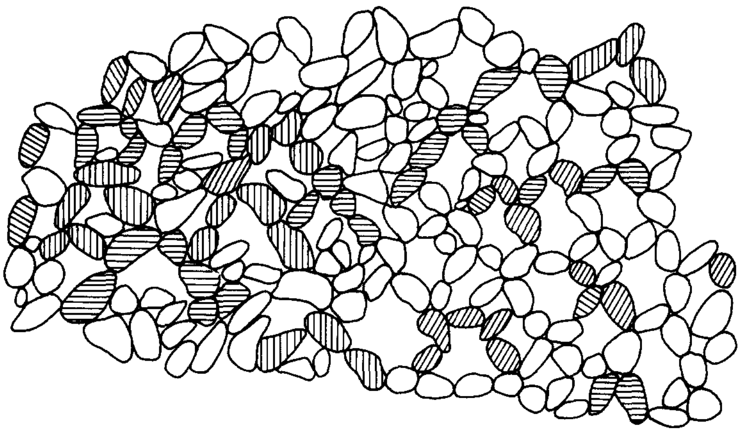

Fig. 14. A two-dimensional schematic arrangement of simple arches in a statically compacted specimen.

The nature of applied stresses in both vibratory and tapping compaction is cyclic and does not make the particles acquire any preferred orientations. Therefore, it is quite probable that the dynamically compacted specimens would not exhibit any preferred grain orientation, Fig. 5(b). The vibratory compactive effort is, however, applied to the soil through the base or top and the side walls of a sample holder, and the sample geometry can have an influence on the grain arrangement. It is possible that a differently shaped sample from that employed in the compressibility measurement might exhibit some preferred grain orientation on vibratory densification.

During static compaction, the soil mass is deformed one-dimensionally, and the grains resist densification by mineral friction, interlocking and reactions developed in the interparticle contacts. Any elastic deformations of grains themselves are recoverable, and the densification takes place by slippage on contacts, sliding and some overturning of grains into voids. Particle crushing also takes place at high stresses. Under applied stresses the grains rearrange from a loose condition into some form of simple arches, an arrangement mechanically very efficient in resisting load (Timoshenko and Young, 1967). The grain orientation diagram shows a weak bi-modal preferred orientation, Fig. 5(c), perhaps representing a rudimentary arch system, a two-dimensional schematic of which is shown in Fig. 14. No evidence of arching could be seen in the grain orientation photographs. This type of particle arrangement is intermediate between the single-grained and a honeycomb (Casagrande, 1932), and would also explain the presence of large pores in a statically compacted specimen, Fig. 8(c). The particle alignment along mutually conjugate planes also points to the presence of incipient failure planes in the soil mass due to the applied vertical load. Maximum shear stresses act on 45° planes (Terzaghi, 1943), and the particles probably align parallel to the shear planes (Morgenstern and Tchalenko, 1967).

Fabric-property relationships

In direct shear the failure takes place on a predetermined plane, Fig. 9. A sample in which the grains are preferentially oriented across this failure plane would be stronger, as a greater cross-section of solid matter will lie across the plane. This strength anisotropy was demonstrated by the direct shear tests at the low densities. In denser samples, however, both side- and top-poured samples have nearly the same strength. This result would seem to support the idea that in the very dense condition the grains probably tend towards random orientation.

The samples sheared across the preferred orientation were stiffer than those sheared along the preferred orientation of grains. The stress to deformation ratio at 50 per cent of peak strength was higher in the former (sheared across) than in the latter (sheared along) at all densities, Table 1. This shows that even though the effect of preferred orientation on peak strength is less pronounced at high densities, the stress-deformation properties are still influenced by fabric anisotropy.

The compressibility results show that at very small loads the vibrated sample was better able to resist deformation than the statically compacted specimen.

Table 1. Effect of grain orientation on ratio of stress to deformation at 50 per cent peak strength (Values in kg/cm^2/cm)

Relative density (per cent)	Relationship between preferred grain orientation and direction of shearing	
	Sheared along	Sheared across
70	0·50	0·90
75	0·71	1·41
80	0·80	1·71

The grains in the latter specimen probably required a small deformation before the postulated arches could become activated. After that, however, the specimen showed only small changes in strain with increasing axial stress, although specimens prepared by both methods of compaction had identical initial void ratios at the beginning of loading in the compression test. The vibrated sample had been brought to this initial void ratio by vibratory compaction. To prepare the statically compacted specimen a static load (approx 5 kg/cm^2) was applied and then removed and the sample allowed to rebound. It was the void ratio after rebound that was recorded as the initial void ratio. When the loading for the compression test was started, the statically compacted specimen showed a relatively large axial deformation at a small load, probably to regain the loss of density in the upper most portion of the sample that had occurred during rebound. The rebound in the two samples was nearly equal, suggesting that the grains were rebounding from a similar, dense arrangement.

CONCLUSIONS

(1) Fine granular materials such as crushed basalt are susceptible to different grain arrangements and pore size distributions when deposited in different ways.

(2) Poured samples at low densities acquire preferred orientations normal to the direction of pouring. At high densities achieved by dynamic or static compaction the grains are nearly randomly oriented and the pore sizes are reduced.

(3) The shear strength is greater when the samples are sheared across the preferred orientation direction than when sheared along the preferred orientation as more grains are lying across the shear plane in the former case, and greater interlocking of grains results in greater shear strength.

(4) Compressibility is higher in statically compacted specimens at low stresses than in the sample prepared by dynamic compaction. At higher axial stresses the one-dimensional compressibility is the same for both samples as the grains are nearly randomly oriented.

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Résumé—Dans ce travail on a étudié les propriétés d'arrangement particulaire d'un basalte broyé à la dimension d'un sable fin limoneux, un "sol" artificiel qui avait été utilisé auparavant pour simuler un sol lunaire.

L'arrangement a été caractérisé en mesurant l'orientation préférentielle des grains et la distribution des pores a été determinée par porosimétrie au mercure. Quand le dépôt est obtenu en faisant couler la poudre, les grains acquièrent de fortes orientations préférentielles dans la direction horizontale et forment des pores dont le diamètre est compris entre 1 et 30 μm. L'augmentation de densité par compaction statique ou dynamique entraîne un arrangement granulaire presque au hasard et des diamètres de pores compris entre 0,1 et 10 μm.

La contrainte principale de cisaillement et la compressiblité monodimensionnelle ont été mesurées, avec les contraintes latérales associées. Lors du cisaillement normal à l'orientation préférentielle des grains la contrainte était supérieure jusqu'à 30 pour cent à ce qu'elle était lors du cisaillement parallèle à la direction d'orientation. Ce résultat n'est pas inattendu puisque le cisaillement à travers des grains orientés préférentiellement doit entraîner une cassure ou une réorientation de nombreux d'entre eux. Pour un indice de vide initial donné, la compressibilité à faible pression d'échantillons compactés par voie statique est plus grande que celle d'échantillons compactés par voie dynamique (compactabilité axiale jusqu'à 30 pour cent supérieure). Aux pressions plus élevées les deux échantillons ont des compressibilités égales, ce qui suggère que les grains sont arrangés plus au hasard pour les indices de vide bas (la comparaison portant sur des échantillons à indice de vide initial égal).

Kurzreferat—In dieser Untersuchung wurden die Beziehungen zwischen Gefüge und Eigenschaften an einem schluffig-feinsandigen, gemahlenen Basalt untersucht—einem künstlichen 'Boden', der schon früher zur Simulation des Mondbodens benutzt wurde. Das Gefüge wurde durch Messung der bevorzugten Kornorientierung gekennzeichnet und die Porengrößenverteilung durch Quecksilberporosimetrie bestimmt. Wenn ihre Ablagerung durch Schütten erfolgte, nahmen die Körner eine streng bevorzugte Orientierung in horizontaler Richtung ein und bildeten Poren zwischen 1 und 30 μm im Durchmesser. Statische oder dynamische Verdichtung führte zu einer nahezu zufälligen Kornanordnung und zu Porengrößen zwischen 0,1 und 10 μm im Durchmesser.

Der Widerstand bei direkter Abscherung und die eindimensionale Kompressibilität mit den zugehörigen seitlichen Spannungen wurden gemessen. Der Scherwiderstand war bis zu 30 Prozent größer, wenn

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die Scherbeanspruchung der Probe senkrecht zur bevorzugten Orientierung der Körner erfolgte, als bei Abscherung parallel zur Orientierungsrichtung. Dies entspricht der Erwartung, da Abscherung senkrecht zu bevorzugt orientierten Körnern Bruch und Reorientierung vieler Körner beinhalten sollte. Bei einem gegebenen anfänglichen relativen Porenvolumen war die Kompressibilität statisch verfestigter Proben bei sehr geringen Drucken größer (bis zu 30 Prozent höhere axiale Spannung) als die dynamisch verfestigter Proben. Bei höheren Drucken wiesen beide Proben gleiche Kompressibilität auf, was darauf hindeutet, daß die Körner bei niedrigem relativem Porenvolumen eine zufälligere Anordnung erhalten (wenn Proben gleicher anfänglicher Hohlraumanteile verglichen werden).

Резюме — В этом исследовании изучались соотношения «структура-свойства» в илистом измельченном до размера песка базальте, искусственной почве, которая прежде применялась для имитации почвы луны. Характеристика структуры определялась измерением преобладающей ориентации зёрен, а распределение размеров пор определялось ртутной интрузионной порозиметрией. При насыпании зёрна принимали строго преобладающую ориентировку в горизонтальном направлении, образуя поры диаметром от 1 до 30 μм. Статическое или динамическое уплотнение давало почти беспорядочное распределение и размеры пор были между 0,1 и 10 μм. диам. Измерялись прочность на прямой срез и одно-размерная сжимаемость со связанными с нею латеральными напряжениями. Прочность была до 30% выше, когда образец срезался нормально по преобладающей ориентировке зёрен, чем при срезке параллельно направлению ориентировки. Это и предполагалось, так как срез через зёрна преобладающей ориентировки должен был вызывать разрыв или изменение ориентировки многих зёрен; при данном исходном коэффициенте пустотности сжимаемость статически сжатых образцов была больше (до 30% выше осевого усилия), чем динамически сжатых образцов при очень низких напряжениях. При более высоких напряжениях сжимаемость обоих образцов была одинаковой; это указывало на то, что зёрна располагались более беспорядочно при низких коэффициентах пустотности (когда сравнивались образцы с одинаковыми исходными коэффициентами пустотности).