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# DIRECTIONAL VARIATION OF ELASTIC WAVE VELOCITIES IN ORIENTED CLAY

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**Abstract** – Sonic anisotropy of clay resulting from particle orientation was studied by means of velocity measurements on anisotropically consolidated kaolinite. Samples were prepared from a kaolin–water slurry under consolidation pressures ranging from 80 to 400 psi, with two distinct stress histories. Directional velocity measurements were made over a wide range of water contents as saturated samples were allowed to dry by evaporation to water contents below the shrinkage limit. Directional variation was most pronounced with partial saturation, when directional velocities differed by as much as a factor of two. The degree of sonic anisotropy is seen to correlate with variation in the shrinkage limit, showing a systematic dependence on particle orientation, but no unique relation to consolidation stress exists because of the overriding influence of stress history.

## INTRODUCTION

UNDISTURBED natural deposits of clay soils usually exhibit some degree of anisotropy of particle orientation, as a result of environmental effects on the process of sedimentation, diagenetic processes, or a combination of these. The fabric and structure of clays has been the subject of an increasing amount of study in recent years, largely because of a growing concern with the directionality of such soil properties as shear strength and stress–strain relations. The purpose of the present study is to examine the sonic anisotropy of a clay with an oriented structure and the possible application of phase velocity directionality as an indicator of anisotropic soil structure.

The experimental program consisted of a series of directional wave velocity measurements on prismatic samples of kaolinite with an oriented fabric at water contents above and below the shrinkage limit. Test specimens were trimmed from larger samples prepared by consolidation in a large-diameter consolidometer in order to produce a clay structure with a predictable direction of preferred particle orientation.

## WAVE PROPAGATION IN POROUS MEDIA

### *Isotropic media*

In the interior of a solid, two types of wave propagation are possible: (a) a longitudinal, or compression wave, in which particle displacements are in the direction of the advance of the wave; and (b) a transverse, or shear wave, in which displacements are perpendicular to the direction of wave advance. A third wave type, the Rayleigh Wave, may be generated at a free surface. The compression wave has the highest velocity of propagation (phase velocity) and is the first to arrive at a detecting transducer, and therefore is the wave most conveniently used in experiment. The velocity $v_c$ of the compression wave in an infinite, linearly elastic, homogeneous, isotropic medium is given by:

$$v_c = \left(\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}\right)^{1/2} \tag{1}$$

where $E$ is Young's Modulus, $\rho$ is the mass density, and $\nu$ is Poisson's ratio. The compression wave velocity may also be expressed in terms of the bulk and shear moduli $K$ and $G$:

$$v_c = \left(\frac{K+4G/3}{\rho}\right)^{1/2}. \tag{2}$$

Wave propagation in a statistically isotropic, fluid-saturated, porous, elastic solid has been treated theoretically by Biot (1956), who found that three types of waves are propagated in the interior of such a medium. These consist of a single type of transverse, or shear wave, and two kinds of compression waves. The wave with the highest velocity of propagation, and thus the first to arrive at a detecting transducer some distance from the source, is a compression wave which is propagated through the fluid phase. This wave is propagated at a velocity higher than that in a free

*Present address: 6 Gates Court, Auburn, Mass., U.S.A. 01501 fluid because of coupling with the solid elastic structure. The Biot theory was used by Hardin (1961) to compute theoretical velocities for a saturated quartz sand; these are also shown by Richart, Hall and Woods (1970).

The effect of incomplete saturation of the porous medium can be examined qualitatively by considering the velocity of wave propagation in a suspension of solid particles in a fluid medium. The velocity $v_c$ of propagation of the compression wave is given for this simple case by:

$$v_c = \sqrt{\frac{K_m}{\rho_m}}$$

where $K_m$ and $\rho_m$ are the bulk modulus and density, respectively, of the mixture. The compressibility $K_m$ is given by the *Wood Equation* (Wood, 1930):

$$\frac{1}{K_m} = \frac{e}{1+e}\left(\frac{1}{K_w}\right) + \frac{1}{1+e}\left(\frac{1}{K_s}\right) \qquad (4)$$

in which $K_w$ and $K_s$ are bulk moduli of the water and solid, respectively, and $e$ is the volume ratio of voids to solid (void ratio). In fresh water at 20°C, the compression wave velocity in water is about 4800 ft/sec, while in most saturated soils it is between this value and about 7000 ft/sec. In soils with high void ratios, however, the velocity may be lower than in free water.

In partially saturated soils, the velocity is drastically reduced because of the strong effect of even a small amount of air on the bulk modulus of the mixture. Richart, Hall and Woods (1970) consider this effect in a mixture of 0·1% of air bubbles in water, applying the Wood Equation, and show that the wave propagation velocity is reduced from about 4800 ft/sec to about 1200 ft/sec.

*Anisotropic media*

Directional variation of velocity in rocks has been studied by Thill, Willard and Bur (1969), who compared directional velocity distributions with rock fabric as determined from optical studies of thin sections, in marble, granite, and pumice specimens. The greatest degree of sonic anisotropy was found in pumice, where it was associated with elongation of vesicles with preferential orientation, and was found to have orthorhombic symmetry. Kaarsberg (1959) used wave velocity measurements with X-ray diffraction methods in a study of shales, and found directional variations which were attributed to structure resulting from the essentially one-dimensional consolidation process.

Nacci and Taylor (1967) made unidirectional velocity measurements on sedimented and consolidated Kaolinite specimens with varied structure, obtained by varying the environment of sedimentation, in order to relate velocity to the soil structure. They concluded, in part, that particle orientation appears to be of primary importance in controlling the longitudinal wave velocity, and that dispersed clay (with the most highly oriented structure) gives the highest velocity.

## EXPERIMENTAL PROGRAM

*Material tested*

The clay used was a white Georgia kaolin mined in Twiggs County, Georgia, and marketed commercially as "Hydrite R" by the Georgia Kaolin Company. Some of its index properties are: liquid limit 53%, plastic limit 35%, and specific gravity 2·61. The grain size distribution is such that approximately 97% of the particles are below 5$\mu$ equivalent diameter, and 60% are smaller than 1$\mu$.

*Apparatus*

Samples for this study were prepared in a large-volume slurry consolidometer (Fig. 1) which was specially developed to obtain samples for clay fabric studies. The sample is contained in a teflon-lined cylinder and loaded by a pneumatically actuated piston. The bottom of the sample chamber and the bottom face of the piston are surfaced with

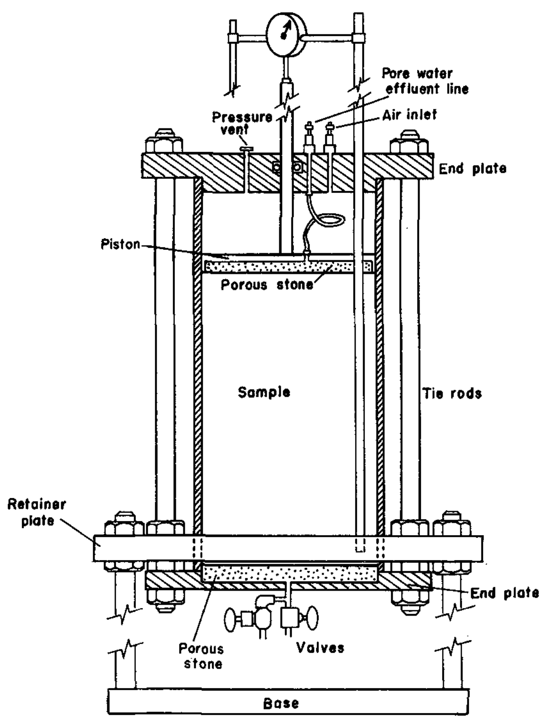


Fig. 1. Slurry consolidometer.

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porous stones to provide drainage. This device has been described in some detail by Sheeran and Krizek (1971). Samples obtained are cylinders 8 in. in diam., and of variable length.

Pulse velocities were measured with a commercial electronic system, the V-scope, which combines a pulse generator, source and receiver transducers, and oscilloscope. The time required for a pulse to travel through the specimen is measured to the nearest microsecond, and the propagation velocity is obtained by dividing the gage length (i.e. the appropriate specimen dimension adjusted for shrinkage) by the travel time. The output frequency is rated at 20 kHz.

Each transducer unit consisted of a rochelle salt crystal immersed in castor oil, in an aluminum case with a rubber membrane over the open end. The cases were cylindrical, with diameters of 4·5 in. and heights of approximately 2·5 in. The output transducer was mounted on a lever action consolidometer frame so that a constant axial pressure of approximately 3 psi was applied to the soil specimen through the transducers during each velocity measurement. The input transducer rested on a vertically adjustable base directly below the transmitting unit. A rubber pad was placed beneath the base for vibration isolation.

Precise shrinkage measurements were also made, by means of a surveyor's level with an optical micrometer. This instrument has a displacement range of 0·500 in. and can be read directly to the nearest thousandth of an inch. Markers were placed in the soil samples with points of embedment approximately 1·20 in. apart, in directions both perpendicular and parallel to the consolidation stress direction. Flat pointers attached to opposing markers provided reference points with a spacing within the 0·5 in. operating range of the optical micrometer. Measurements of changes in the distances between the tips of opposing pointers reflected the shrinkage or expansion of the sample due to drying.

### *Test program*

Samples with anisotropic fabric were prepared by one-dimensional consolidation of a clay–water slurry. The initial slurry was a mixture of kaolin with distilled water at a water content of approximately 100%, vacuum treated to remove entrapped air. After 24 hr storage, the slurry was transferred under partial vacuum to the consolidometer.

In the consolidation process, an initial load of 10 psi was followed by load increments each equalling the total previous load. Free drainage was provided through filter paper and porous stones in the piston and base of the consolidometer. Pore pressure measurements, made by closing the drainage lines for 3 hr and determining the resulting pressure build-up, indicated that the pore pressure under any load increment dissipated to less than 0·05 psi before the succeeding load increment was applied. Prior to removal, samples were allowed equilibration time of at least 24 hr after the last load increment was applied.

Final vertical consolidation pressures ranged from 80 to 400 psi. The samples obtained underwent two distinct stress histories, as a result of a loading plan in which after a desired consolidation pressure was reached, the lower half of the sample was extruded from the consolidometer and cut off, and the remaining half was reloaded to a higher pressure. The reloaded samples were kept at the previous maximum load for a period of not less than 24 hr before the next load increment was applied. The group of samples removed at the first load release are referred to as Group A; those portions which were reloaded to higher consolidation pressures are called Group B. Six samples, of 8 in. dia. and approximately 2 in. height, were obtained in each group. Void ratio vs pressure curves for these samples are shown in Figs. 2a, 2b.

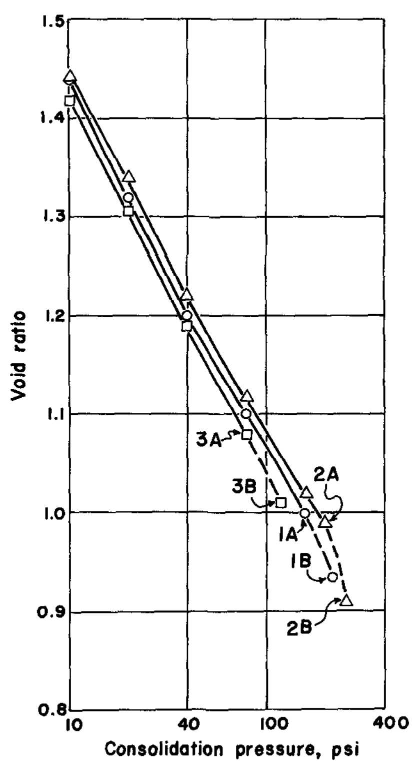
Consolidated samples were cut and trimmed in a high-humidity chamber in preparation for velocity measurements. Four test specimens were trimmed from quadrant sections of each extruded sample, being taken from the central portion to avoid possible nonuniformities near the boundaries. The test specimens were prismatic, approx. $1{\cdot}7 \times 1{\cdot}7 \times 3{\cdot}0$ in. with one of the short dimensions representing the original vertical direction (the direction of the major consolidation stress). Thus, determinations of vertical and horizontal velocities could be made from measurements across the 1·7 in. sides. Radial isotropy in horizontal directions was verified by velocity measurements on the original cylindrical samples.

Following the initial dimensional, weight, and velocity measurements on the samples immediately after preparation, they were air-dried for a short time to produce a reduction in water content. The samples were then wrapped in plastic and placed in storage to allow time for equilibration of the moisture distribution. Each day, after approximately 20–22 hr in storage, the samples were unwrapped, re-weighed, and subjected to the same measurements. At each moisture content, velocity readings were taken with the source transducer alternately placed on either side of the sample, providing two measurements in each direction. Shrinkage measurements were also made as described earlier. This experimental procedure was repeated daily until the samples reached a constant weight. They were then oven dried and final weights were obtained to establish original moisture contents.

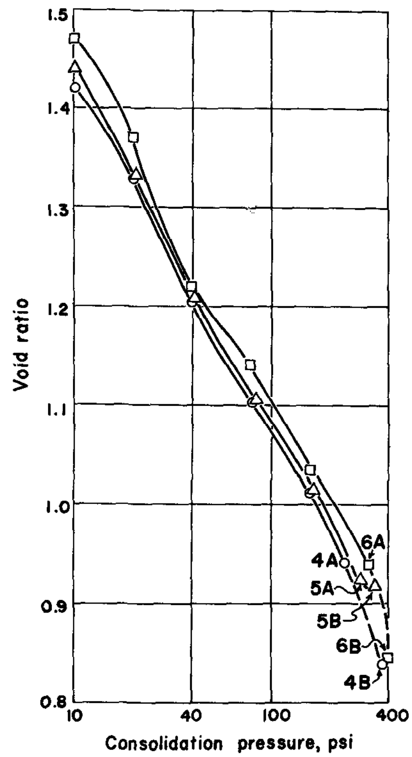
## EXPERIMENTAL RESULTS

### *Shrinkage*

A representative example of shrinkage measurements is shown in Fig. 3, in which relative values of linear dimensions are plotted against moisture content for sample 4A. Similar curves were obtained for each of the twelve samples tested. As Fig. 3 shows, the shrinkage rate was generally higher in the vertical direction (perpendicular to the plane of predominant particle orientation), although a reliable quantitative description of this relation could not be obtained. All samples were at moisture contents very near the shrinkage limit upon removal from the consolidometer, and the portion of the curve depicting the normal shrinkage was confined to a relatively narrow range of moisture contents. For those samples consolidated to the higher consolidation pressures, the initial part of the shrinkage curve could only be approximated by using one or two points together with the average slope from the less-consolidated samples. Shrinkage observations were also used to obtain a shrinkage limit value for each sample.




(a)




(b)

Fig. 2. Void ratio vs. pressure curves: (a) Samples 1–3, (b) Samples 4–6.

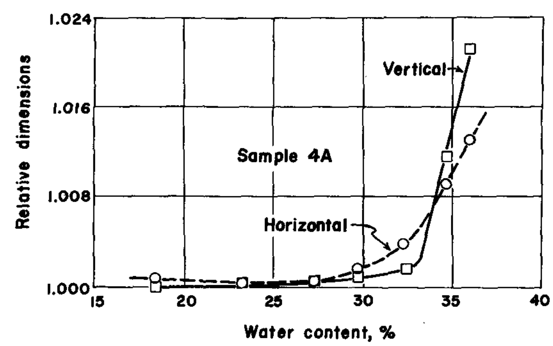



Fig. 3. Typical shrinkage curves.

Lambe (1958, 1960) and Yong and Warkentin (1966) have noted that low shrinkage limit values are associated with soil samples with a relatively high degree of particle orientation. The concept of the shrinkage limit appears at first sight to be quite straightforward, but there are some divergences of viewpoint to be found in the literature, and shrinkage limit determinations vary somewhat according to the definition used. Scott (1963),

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Wu (1966), and Means and Parcher (1963) describe the shrinkage limit as the moisture content at that point of drying where there is no further volume decrease with evaporation of porewater. Capper and Cassie (1963) base its determination on a graphical construction imposed on a moisture content versus volume curve, as shown in Fig. 4. Yong and Warkentin (1966) maintain that the point of "unsaturation" where air enters the voids has a physical significance and the moisture content at that point is the shrinkage limit. In this study, the method of Capper and Cassie was used with the linear shrinkage curves, thus avoiding difficulties due to the slight expansion which kaolinite typically undergoes upon oven drying. In general, the vertical shrinkage curves were more clearly defined than the horizontal, and thus were used in the determination of shrinkage limit.

The shrinkage results are summarized, along with velocity data in Table 1.

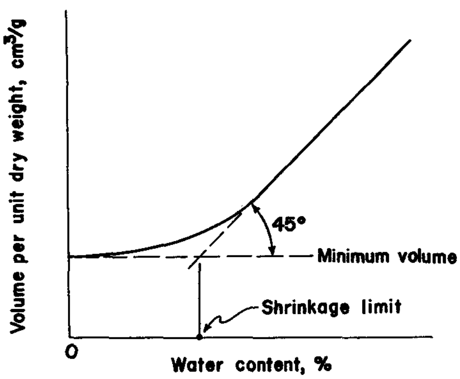


Fig. 4. Graphical determination of shrinkage limit.

*Velocities*

Velocity measurements at initial moisture contents yielded values of vertical velocity near that in free water (4860 ft/sec at 70°F). Horizontal velocities, parallel to the planes of particle orientation, were usually some 200–300 ft/sec greater, so that the average velocity ratio $v_x/v_y$ was approx. 1·05.

The behavior of velocities and velocity ratio with drying was typically as shown in Fig. 5. Characteristically, after reaching maximum values at water contents in the neighborhood of the shrinkage limit, velocity values dropped sharply with further drying while velocity ratios increased. An obvious interpretation of the decrease in velocity is that it is associated with a decrease in the bulk modulus of the soil as desaturation begins. Consequently, the velocity curves can be used to estimate the shrinkage limit from an estimate of the water content at which the steep downward trend begins. This value corresponds in concept to the shrinkage limit contemplated by Yong and Warkentin, and it can be expected to be somewhat higher than that defined by the method of Capper and Cassie. The construction arbitrarily used with the velocity versus water content curves was to draw a straight line midway between the horizontal and vertical velocity curves in their steep portion, and to determine the water content at which it intersected a horizontal line at the velocity of compression wave propagation in water, approximately 4860 ft/sec (see Fig. 5). Results are given in Table 1.

With continued drying below the shrinkage limit, the velocities and the velocity ratio approached nearly constant values, as shown in Fig. 5. Final

Table 1. Summary of experimental results

| Sample no. | Final consolidation pressure (psi) | Initial moisture content* | Shrinkage limit* from shrinkage measurements | Shrinkage limit* from velocity measurements | Velocity, air-dry horizontal (ft/sec) | Velocity, air-dry vertical (ft/sec) | Initial velocity ratio | Air-dry velocity ratio |
|---|---|---|---|---|---|---|---|---|
| 1A | 160 | 38·2 | 35·3 | 34·5 | 2400 | 1800 | 1·07 | 1·34 |
| 1B | 220 | 35·8 | 33·6 | 34·3 | 2500 | 1650 | 1·11 | 1·52 |
| 2A | 200 | 37·9 | 33·7 | 34·5 | 2560 | 1580 | 1·03 | 1·62 |
| 2B | 260 | 34·9 | 32·7 | 33·2 | 2380 | 1720 | 1·01 | 1·38 |
| 3A | 80 | 41·4 | 34·6 | 34·2 | 2700 | 1380 | 1·04 | 1·95 |
| 3B | 120 | 38·8 | 34·0 | 35·0 | 2400 | 1800 | 1·01 | 1·34 |
| 4A | 240 | 36·0 | 33·0 | 34·3 | 2660 | 1470 | 1·05 | 1·71 |
| 4B | 370 | 32·1 | 30·0 | 32·8 | 2860 | 1530 | 1·03 | 1·86 |
| 5A | 280 | 35·7 | 31·8 | 34·7 | 2850 | 1410 | 1·11 | 2·02 |
| 5B | 340 | 35·2 | 31·8 | 32·5 | 2660 | 1700 | 0·98 | 1·56 |
| 6A | 320 | 36·0 | 33·2 | 34·8 | 2620 | 1730 | 1·07 | 1·52 |
| 6B | 400 | 32·5 | 30·2 | 32·0 | 2870 | 1510 | 1·05 | 1·90 |

*Moisture contents in per cent of oven-dry weight.

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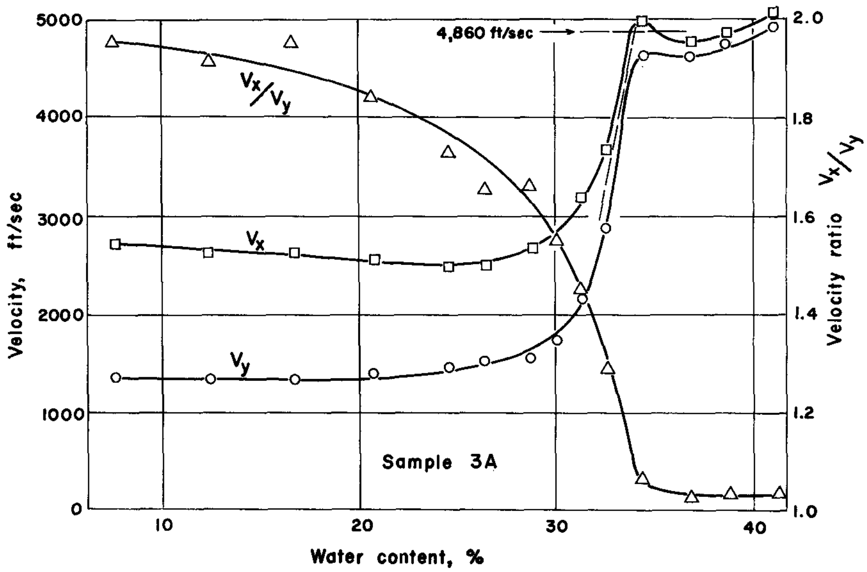


Fig. 5. Typical velocity and velocity ratio curves.

velocity ratio values in air-dry samples varied from 1·34 to 2·02, being generally higher for higher consolidation pressures. The final velocity ratios are also given in Table 1.

An initial attempt to correlate the vertical and horizontal velocities reached in the air-dry state with final consolidation pressures did not reveal any coherent pattern when vertical and horizontal velocities were considered separately. However, the average of the horizontal and vertical velocities showed a consistent tendency to higher values with increasing consolidation pressure. A comparison of velocity ratio $v_x/v_y$ with consolidation pressure (Fig. 6) showed a rather large scatter, but strongly suggested a divergence in trend between samples of Group A and Group B. The curves shown are

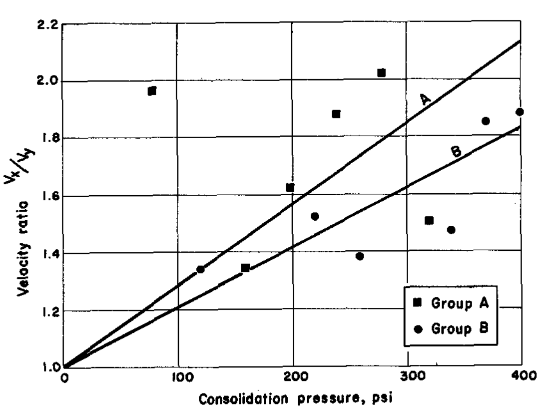


Fig. 6. Velocity ratio vs. final consolidation pressure.

least-squares straight lines, forced through (0, 1·0) on the assumption that zero consolidation pressure would result in isotropy of velocities. The samples of Group A were subjected to monotonically increasing loads until the final consolidation pressure was reached, and generally showed higher velocity ratios than those of Group B, which were unloaded at one point and then subjected to additional higher loads than those previously applied. It is a reasonable inference from this behavior that the more complicated stress histories of the Group B samples resulted in a relatively lower degree of particle orientation. At the same time, most samples of Group B were more highly consolidated than those of Group A at equivalent consolidation pressures, as evidenced by the void ratio-pressure curves of Fig. 2. This can be explained in retrospect as greater amounts of secondary consolidation in Group B samples because their heights were one-half those of the Group A samples, while the time allowed for consolidation under a single load increment was the same. These differences illustrate the profound effect of stress history on the structure of a clay soil, and on properties which are structure-dependent.

As noted earlier, Lambe (1958–1960) and Yong and Warkentin (1966) have observed that clay soils exhibit greater shrinkage with greater degrees of particle orientation. Thus, directionality of wave velocities can be expected to show a systematic relation to the shrinkage limit. Figure 7 represents values of horizontal velocities in air-dry samples for Groups A and B plotted against

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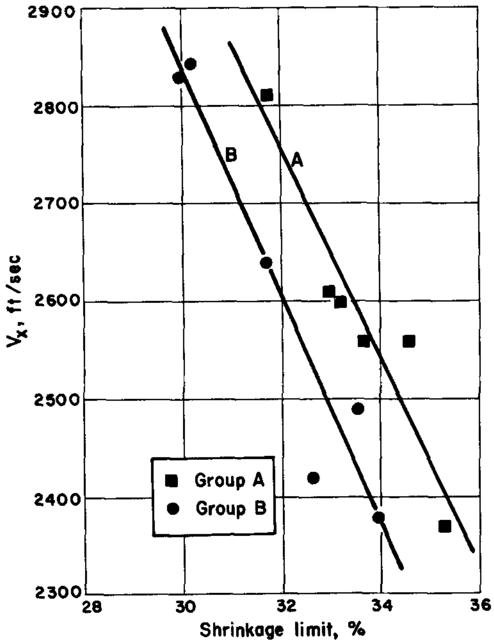


Fig. 7. Air-dry horizontal velocity vs. shrinkage limit.

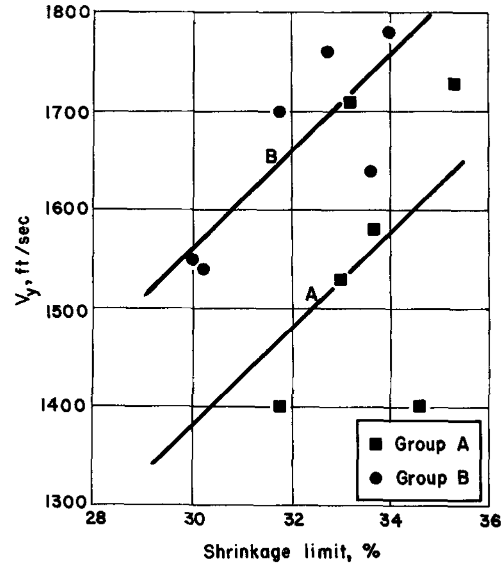


Fig. 8. Air-dry vertical velocity vs. shrinkage limit.

shrinkage limits as determined by the shrinkage measurements. A large systematic variation of velocities over the observed shrinkage limit range is evident for both groups, with the slopes of the lines, which are least-squares fitted, being very nearly equal. The curve for Group B exhibits values of velocity comparable to those in Group A at approximately 1·5 percentage points lower on the shrinage limit. Figure 8 presents dry vertical velocities versus shrinkage limit in the same format, with the least-squares straight lines. Aside from a greater scatter of points in Fig. 8, the obvious difference is a reversal of slope from Fig. 7, indicating the tendency for vertical velocities in the air-dry state to decrease with increased particle orientation. In addition, the displacement of the Group B curve to the left is much more pronounced for vertical velocities, representing about 4 percentage points on the shrinkage limit scale.

The relatively great scatter in the vertical velocity measurements, as compared to horizontal velocity measurements, is attributable in part to shrinkage cracks parallel to the plane of particle orientation which occurred erratically during drying. Such cracks also would naturally result in lower average values of vertical velocity. This observation suggests that development of oriented shrinkage cracks on a microscopic scale may explain the tendency for vertical velocities to be lower in association with lower shrinkage limits, and hence with greater degrees of particle orientation.

The ratios of horizontal to vertical velocity in the air-dry state are plotted against shrinkage limits in Fig. 9, which again indicates strong directionality of wave propagation. As before, the curves shown are the mathematically fitted straight lines. Because of the opposite trends of horizontal and vertical velocities with the degree of particle orientation, the effect is amplified in the ratio of the two.

## CONCLUSIONS

The results of this study show that, for the material examined, directional variation in velocity of wave propagation does occur. The velocity is highest in paths which lie in the plane of maximum preconsolidation stress, and thus of expected particle alignment. In saturated samples, the velocities observed were only slightly greater than that in free water, but the velocity in the plane of expected particle orientation was consistently higher than that in the perpendicular direction, with a velocity ratio averaging about 1·05.

On drying to moisture contents below the shrinkage limit, the velocity contrast is significantly magnified, and it is greater in samples in which a higher degree of particle orientation is indicated by the value of the shrinkage limit. While both horizontal and vertical velocities were observed to decrease sharply with desaturation of the sample, the velocity perpendicular to the plane of expected particle orientation diminished to a

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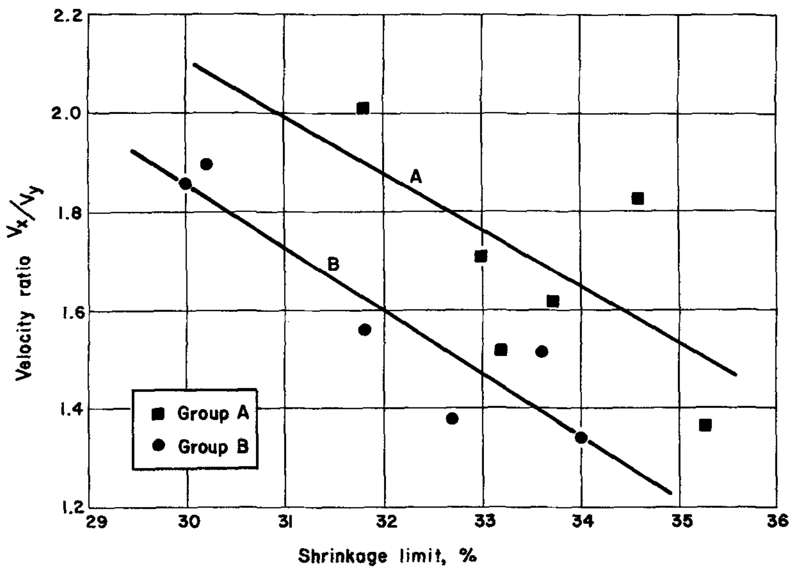


Fig. 9. Air-dry velocity ratio vs. shrinkage limit.

greater degree. This was possibly due in part to the development of microscopic shrinkage cracks parallel to that plane. Velocity ratios in air-dried samples were seen to be as great as 2·02, and to have a systematic relation to the value of the shrinkage limit, which has been shown by other writers to be dependent on the degree of particle orientation. The abrupt change in velocity as desaturation of the sample occurred was seen to provide a sensitive indication of the shrinkage limit.

The stress history exerts a dominant influence on the soil structure. In the samples studied, the effects of differences in stress history were strong enough to prevent the final consolidation pressure being used as an index of soil fabric. However, within groups with an essential similarity in stress history, there was a general consistency in trends of behavior.

## REFERENCES

Biot, M. A. (1956) Theory of propagation of elastic waves in a fluid-saturated porous solid—I. Low-frequency range: *J. Acoust. Soc. Am.* **28**, 2, 168–178.

Capper, P. L. and Cassie, W. F. (1963) *The Mechanics of Engineering Soils*. Mackay, London.

Hardin, B. O. (1961) Study of elastic wave propagation and damping in granular materials: Ph.D. Dissertation, Univ. of Florida.

Kaarsburg, E. A. (1959) Introducing studies of natural and artificial argillaceous aggregates by sound propagation and X-ray diffraction methods: *J. Geol.* **67**, 447–472.

Lambe, T. W. (1958) The structure of compacted clay: *J. Soil Mechanics and Foundations Division*, American Society of Civil Engineers, **84**, No. SM2, Paper 1654, 1–34.

Lambe, T. W. (1960) Compacted clay: *Transactions*, American Society of Civil Engineers **125**, 682–706.

Means, R. E. and Parcher, J. V. (1963) *Physical Properties of Soils*. Charles E. Merrill, Columbus, Ohio.

Nacci, V. A. and Taylor, R. J. (1967) Influence of clay structure on elastic wave velocities: *Proc., Int. Symp. on Wave Propagation and Dynamic Properties of Earth Materials*, Albuquerque, N.M.

Richart, F. E., Hall, J. R. and Woods, R. D. (1970) *Vibrations of Soils and Foundations*. Prentice-Hall, Englewood Cliffs, New Jersey.

Scott, R. F. (1963) *Principles of Soil Mechanics*. Addison–Wesley, Reading, Mass.

Sheeran, D. E. and Krizek, R. J. (1971) Preparation of homogeneous soil samples by slurry consolidation: *J. Mater. JMLSA* **6**, 2.

Thill, R. E., Willard, R. J. and Bur, T. R. (1969) Correlation of longitudinal velocity variation with rock fabric: *J. Geophys. Res.* **74**, 20, 4897–4909.

Wood, A. B. (1930) *A Textbook of Sound*. Bell, London.

Wu, T. H. (1966) *Soil Mechanics*. Allyn & Bacon, Boston.

Yong, R. N. and Warkentin, B. P. (1966) *Introduction to Soil Behavior*. Macmillan, New York.

**Résumé**—L'anisotropie de l'argile vis a vis des ondes sonores, résultant de l'orientation des particules, a été étudiée au moyen de mesures de vitesse sur une kaolinite consolidée d'une façon anisotrope. Les échantillons étaient préparés à partir d'une pâte eau-kaolin, sous des pressions de consolidation allant de 80 psi à 400 psi, avec deux systèmes de précontrainte distincts. Les mesures de vitesse directionnelle ont été effectuées pour un grand domaine de teneurs en eau puisque les échantillons saturés étaient séchés par évaporation jusqu'à des humidités inférieures à la limite de retrait. La variation directionnelle était la plus forte pour une saturation partielle, avec des vitesses directionnelles pouvant différer d'un facteur deux. Le degré d'anisotropie vis à vis des ondes sonores est à corréler avec la variation de la limite de retrait en montrant une dépendance systématique envers l'orientation des particules; il n'y a pas de relation unique avec la contrainte de consolidation à cause de l'influence prédominante du système de précontrainte.

**Kurzreferat** – Die sich aus der Teilchenorientierung ergebende Anisotropie von Ton wurde untersucht mit Hilfe von Geschwindigkeitsmessungen an anisotropisch konsolidiertem Kaolinit. Es wurden Proben hergestellt aus einer Kaolin-Wasseraufschlämmung mit Versichtungsdrucken, die sich von 80 psi bis 400 psi erstreckten, mit zwei verschiedenen Beanspruchungsverläufen. Richtungsgeschwindigkeitsmessungen wurden über einen weiten Bereich von Wassergehalten durchgeführt, indem man gesättigte Proben durch Verdampfung bis auf Wassergehalte unterhalb der Schrumpfgrenze trocknen liess. Richtungsmässige Unterschiede waren am deutlichstem bei Teilsättigung wo festgestellt wurde, dass sich die Richtungsgeschwindigkeiten bis zu einem Faktor von zwei voneinander unterschieden. Es wird gezeigt, dass sich der Grad sonischer Anisotropie in Korrelation mit der Schrumpfgrenze befindet, mit einer systematischen Abhängigkeit von der Teilchenorientierung, jedoch besteht keine eindeutige Beziehung zur Verdichtungsspannung infolge des überwiegenden Einflusses des Spannungsverlaufes.

**Резюме** — Звуковая анизотропия глины возникающая вследствии ориентации частиц изучается путем измерения скоростей на анизотропически отвердевшем каолините. Из водяного шламма каолина приготовили образцы под давлением консолидации от 80 фунт/дюйм$^2$ до 400 фунт/дюйм$^2$, с двумя резко выраженными ходами развития напряжения. Провели измерения скорости волны в поле давления, зависящей от направления, по широкому диапазону содержания воды в то время как насыщенные образцы высушивались испарением воды ниже предела усадки. Направленная вариация была наиболее заметна при частичном насыщении, когда направленные скорости различались, по крайней мере, на два значения. Степень звуковой анизотропии, кажется, находится в корреляции с разницей в пределе усадки, проявляя систематическую зависимость от ориентации частиц, но не проявляя особой зависимости от напряжения отвердевания вследствие преобладающего влияния хода развития напряжения.