

- RIEDEL, W. (1929). Zur Mechanik geologischer Brucherscheinungen. *Cbl. Min. Geol. Pal.* **29B**, 354–368.
- SANDER, B. (1930). *Gefügekunde der Gesteine*. 352 pp. Vienna: Springer.
- SANDER, B. (1939). Gefügekunde und ihre Anwendungen. *Z. angew. Miner.* **1**, 285–312.
- SANDER, B. (1948). *Einführung in die Gefügekunde der geologischen Körper (Allgemeine Gefügekunde)*. 215 pp. Vienna: Springer-Verlag.
- SCHMIDT, W. J. (1957). Instrumente und Methoden zur mikroskopischen Untersuchung optisch anisotroper Materialien mit Ausschluss der Kristalle. See Freund (1957) 147–315.
- SKEMPTON, A. W. (1966). Some observations on tectonic shear zones. *Proc. 1st Int. Conf. Soc. Rock Mech.*, Lisbon, **1**, 329–335.
- TURNER, F. J. & WEISS, L. E. (1963). *Structural analysis of metamorphic tectonites*. 545 pp. New York: McGraw-Hill.
- WÄCHTLER, M. (1927). Über die Doppelbrechungserscheinungen in Kolloiden. *Fortschr. Miner. Kristallogr. Petrogr.* **12**, 119–192.
- WIENER, O. (1913). Die Theorie des Mischkörpers für das Feld der stationären Strömung. *Abh. K. sächs. Akad. Wiss. Math.-Phys. Kl.* **32**, 510–604.
- WILLOUGHBY, D. R. (1967). The geometrical description of linear and simple planar features in soils. *Aust. J. Soil Res.* **5**, 21–36.
- WU, T. H. (1958). Geotechnical properties of glacial lake clays. *Proc. Am. Soc. civ. Engrs*, SM 3, 1732, 1–29.

D. Lafeber,  
Division of Soil Mechanics,  
Commonwealth Scientific and Industrial  
Research Organization,  
Australia.  
5 March, 1968.

\* \* \*

The Authors have described experiments to study the effect of shear induced fabric on the resistance of a kaolin clay. Both this Paper and other papers by Morgenstern and Tchalenko (1967 a and b) are valuable contributions in the study of the role of orientation of particles and discontinuities in the mobilization of shear resistance of soils. They have conclusively shown that the birefringence ratio is independent of the thickness of the section and that the carbowax present does not affect this value.

According to Skempton (1964) the shear resistance of clays is reduced due to the preferred orientation of clay particles along the failure plane. The larger the degree of orientation, the nearer the value of residual angle of shear resistance  $\phi'_r$  to  $\phi_\mu$ , the angle of friction for the mineral, which may be considered to be the Hvorslev's angle of friction for the clay in the orientated state. The results obtained by the Authors in the present study are very significant. It is seen that the highly orientated structure of kaolin did not substantially affect the value of  $\phi'_r$  even when the direction of orientation was parallel to the direction of shear, whereas a precut plane reduced it to nearly half the value, which incidentally corresponds to the value of  $\phi_\mu$  for the mineral. This also agrees with the large reduction in  $\phi$  for soils with repeated shearing found by Borowicka (1965). The Authors therefore rightly concluded that although the particle orientation is strong on the average, sufficient local deviations exist to deter failure taking place at the residual strength and a virtually perfect alignment (or discontinuity) is necessary for the same.

In view of this it seems that in the case of a material like kaolin which exhibits a very high order of parallelism of the clay even at low stresses or states (West, 1964), the magnitude of the orientation does not signify that the value of  $\phi_e$  approaches  $\phi_\mu$ . The discontinuities seem to be the cause for this reduction. Studies on clays which do not exhibit such perfect orientation at low stresses are necessary to reveal whether the magnitude of preferred orientation is a measure of  $\phi_e$  and whether at perfect orientation  $\phi_e$  corresponds to  $\phi_\mu$ .

I have studied the role of soil structure on Hvorslev's angle of friction in the case of a montmorillonitic clay (Narain and Ayyar, 1967). In the experiments triaxial compression tests were conducted on different states of the clay. After failure the soil structure was measured from the slices cut out of the failure zone. Three methods, namely shrinkage

ratio, orientation factor and X-ray diffraction patterns, were used. The thin sections were prepared in a manner similar to that used by Pusch (1964). The technique of measurement was similar to that used by Wu (1958). The area of measurement was larger (0.80 mm dia.) and thin sections (5 microns thick) were used on account of the considerably low sensitivity of the photocell and amplifier used. These studies revealed that there was no significant preferred orientation at the time of failure (within the strains attained) and that slight differences in  $\phi_e$  obtained for the samples were in accordance with the structure (greater for random and less for the orientated structure). Studies on a kaolinite clay showed that the extent of preferred orientation during shear is greater in this clay than in the case of the montmorillonitic clay. This is also corroborated by the observations of thin sections of kaolinite in shear failure (Goldstein, Misumsky and Lapidus, 1961). The Authors have stated that the thin section used by them is essentially the same as that for rock samples. I experienced difficulty in fixing the sections on glass slides since Canada balsam could not be used hot and the adhesive used should not dissolve or react with carbowax. This was solved by using cold Canada balsam on microtomed sections. I should like a clarification of the procedure used by the Authors.

I agree with the statement that while a continuous band of strongly orientated particles may exist in the case of some clays, the concept of a single thin zone of orientated clay particles is an unwarranted oversimplification in all clays. It appears that they are likely to form in clays which have a lower cohesion component ( $C_e$ ) than with other clays. Studies on montmorillonitic clays will be necessary to clarify the role of bonds in the development of preferred orientation. Unfortunately the optical determination of the orientation in the case of these clays is difficult due to the higher absorption of light and unknown degree of accuracy of optical characteristics of these minerals. These may possibly be overcome by the use of thin microtomed sections and the highly sensitive selenium photocell and amplifier used by the Authors.

In conclusion, I feel that further structure studies are necessary. These are required to explain the apparent contradiction between the findings of Schmertmann and Osterberg (1960) that friction increases with strain and Skempton (1964) that friction decreases on prolonged shearing. While it is possible that a certain amount of strain is necessary to mobilize full friction with the formation of a tight structure, on prolonged shearing the bonds may break and discontinuities may develop resulting in a steep reduction of  $\phi$  to the residual value. The extent to which these happen may vary with the nature of the soil.

## REFERENCES

- BOROWICKA, H. (1965). The influence of the colloidal content on the shear strength of clay. *Proc. 6th Int. Conf. Soil Mech.* **1**, 175-178.
- GOLDSTEIN, M. N., MISUMSKY, V. A. & LAPIDUS, L. S. (1961). The theory of probability and statistics in relation to the rheology of soils. *Proc. 5th Int. Conf. Soil Mech.* **1**, 123-126.
- MORGENSTERN, N. R. & TCHALENKO, J. S. (1967 a & b). The optical determination of preferred orientation in clays and its application to the study of microstructure in consolidated kaolin I and II. *Proc. R. Soc. A* **300**, 218-250.
- NARAIN, J. & AYYAR, T. S. R. (1967). Measurement of soil structure. *Proc. S.E. Asian Reg. Conf. Soil Engng.*
- PUSCH, R. (1964). On the structure of clay sediments. *Nat. Swed. Coun. Buildg Res. Handlingar*, No. 48.
- SCHMERTMANN, J. H. & OSTERBERG, J. O. (1960). The experimental study of development of cohesion and friction with axial strain in saturated cohesive soils. *Proc. Am. Soc. civ. Engrs. Res. Conf. Shear Strength Soils*. Colorado, 643-694.
- SKEMPTON, A. W. (1964). Long-term stability of slopes. *Géotechnique* **14**, No. 2, 77-101.
- WEST, R. (1964). The characteristics of filter pressed kaolinite-water pastes. *Proc. 12th Nat. Conf. Clays Clay Miner.*, 209-222.
- WU, T. H. (1958). Geotechnical properties of glacial lake clays. *Proc. Am. Soc. civ. Engrs* **84**, SM. 3, 1-34.

T. S. Ramanatha Ayyar,  
College of Engineering,  
Trivandrum, India.  
2 April, 1968.