Mechanisms controlling volume change of saturated clays and the role of the effective stress concept

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The Authors are to be congratulated for their investigation into the volume change behaviour of saturated clays and the interpretation of the results in terms of the interparticle electrical attractive and repulsive forces.

I should like to add a few words regarding the replacement of pore-water by organic fluids. During the investigation of shear-induced microstructures of kaolinite (Foster and De, 1971; De, 1972a, 1972b, 1973, 1975) using a transmission electron microscope, a similar replacement of pore-water by direct and indirect methods was used. The object was to solidify the kaolinite samples by resin impregnation for electron microscopic investigation. The usual sizes of the samples were small compared with those of the Authors i.e. 60 mm × 25 mm × $\frac{2}{3}$ mm thick. However, samples as large as 150 mm × 100 mm × 10 mm thick were used for the above purpose.

The direct method was to submerge a sample in a bath of either methanol or acetone for 24 hours or more, so that the organic fluids could diffuse in and replace the pore-water. For a large sample, two or more changes of fresh organic fluid were needed.

The indirect method was to submerge a sample in a bath of water containing a low concentration of methanol for 24 hours and then to increase the concentration of methanol every day until 100% methanol was reached. The 100% methanol was subsequently replaced by acetone in a similar way before proceeding to the resin-impregnation. Usually the 100% acetone stage was repeated several times to ensure 'complete' removal of any pore-water.

The success of replacement of pore-water, including the adsorbed water, was judged indirectly by proper resin-impregnation. The indirect method was fully successful; the direct method using acetone could be acceptable whereas the same method using methanol was hardly satisfactory. Although a proper resin-impregnation is a measure of success of replacement of pore-water including the adsorbed water, the converse is not true, and as the indirect method is lengthy and time-consuming an alternative rapid and effective method was needed.

From the experiments it can be concluded that the adsorbed water can be removed primarily by diffusion and considerable time can be saved by replacing the free pore-fluid as quickly as possible.

To replace the free pore-water as quickly as possible, a procedure was followed which was very similar to that used by Alexander Steinbrecht and Klaus-Dieter Ernst (1967) for impregnation of tissues. It was based on the principle that even a very viscous liquid showed streaming movement if the container was rotated in an oblique plane, and if the rotation was slow enough for gravitation to act against adhesion forces in the most efficient way. For the impregnation of undisturbed kaolinite samples, it was necessary to have a very low angle of rotational inclination, as high angle of rotation would destroy the undisturbed samples. The angle of rotational inclination was selected to be 3° and the rotational speed was 2 rpm. The above procedure was adopted as the samples were small. For larger samples, the Authors' method is definitely superior. The object of this procedure was to replace the free pore-fluid.

The acetone was drained off and fresh acetone was added until it topped the sample. It was left overnight or longer depending on the actual size of the sample, so that diffusion could take place. This is very fast compared with other methods and very effective for medium dense to dense soil samples. The resin-impregnation was excellent. It is necessary to point out here that samples not left overnight for diffusion to take place, did not impregnate satisfactorily.

Therefore, it may be concluded that only a flow method of replacement of pore-fluid by organic fluids may not be very effective for difficult samples such as montmorillonitic clays or natural clays, as it does not allow time for diffusion to take place. It would be very interesting to know the Authors' comment on the above method and their research experience, if any.

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The Authors are to be congratulated upon a well-conceived investigation within a difficult field of study, from which valuable conclusions have been drawn. There are, however, a few points which may be questioned.

One serious deficiency in the basic data is lack of information regarding pH, cation exchange capacities and types of cation associating with the clay minerals, as they introduce important factors governing microsctructure. Associating cations are especially relevant to the nature of the adsorption phase which plays a major role in particle interaction. This omission minimizes the authority of the Authors' statement

> 'The use of black cotton soil (*instead of montmorillonite*) has in no way brought limitation to study the desired phenomena.'

Double layer theory which is invoked was developed for dilute suspensions, and is not strictly applicable to closely packed particle assemblies.

Considerable care has been exercised in an endeavour to obtain uniform fabric. However, if it is accepted (Burland, 1971) that yielding occurs as a result of microstructural changes, and that a virgin consolidation line is a locus of yield points then the fabric of any one overconsolidated soil is related to both its preconsolidation pressure and its void ratio at that pressure. It may then be questioned whether the 40% variation in void ratio at the constant preconsolidation pressure of 8 tons/ft^2 (Figs 2(a) and 2(b)) does not indicate a corresponding variation in fabric. Furthermore the method of remoulding by mixing material with remoulding fluid for the replacement tests would not necessarily produce a fabric similar to that possessed by the compacted oven-dried soil used for primary consolidation. It is nevertheless acknowledged that the implied deficiencies in contriving constant fabric do not necessarily invalidate the main conclusions drawn.

The shear strength relationships are significant, although it is noteworthy that for the four fluids possessing the lowest dielectric constants there is a large range of shear strengths (Figs 6(a) and (b)) especially for the kaolinite. Furthermore the void ratios associated with all four of these fluids at the preconsolidation pressure (Figs 2(a) and 4(a)) are virtually the same. It is clear therefore that some additional factor other than dielectric constant and fabric is influencing shear behaviour.

The suggestion that flocculation takes place, as a result of replacing one pore-fluid with another in a consolidated material having a void ratio 0·9 (Fig. 10), raises questions. Flocculation is a phenomenon normally associated with suspensions in which particles have sufficient freedom of movement to assume different modes of association. It is also, especially in kaolinite, governed by pH, about which nothing is stated. Presumably it is possible to envisage the occurrence of the necessary slight concomitant accommodating movements of interlocked particles in a comparatively dense assemblage, although the evidence provided appears a little slender.

The appearance of curves 2 and 3 (Fig. 10) are so similar to that of Fig. 9 curve 1, when plotted to the same scale, that a further explanation of the material behaviour reflected by these curves seems possible. The microstructure of the kaolin which was initially remoulded with water was, it is suggested, predetermined at that stage in its history. Furthermore, although the water was subsequently exchanged with carbon tetrachloride the fabric could conceivably have remained virtually unchanged because the carbon tetrachloride failed to dislodge the few molecular layers of water which not only remained within the adsorption phase but were sufficient to determine microstructural behaviour.

These comments by no means deny the main conclusions, but will serve it is hoped, to stimulate further thought on the matter.

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The effect of increasing strength with depth on the bearing capacity of clays

DAVIS, E. H. and BOOKER, J. R. (1973). *Geotéchnique*, **23**, No 4, 551–563.

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The Authors are to be commended for their excellent analysis of the bearing capacity of clay ($\phi = 0$) when the shear strength increases linearly with depth. I have also studied this problem. A purely kinematic solution to the problem was constructed (Salençon, 1968, 1969) using Prandtl's orthogonal net of zero-extension lines; the following upper bounds were obtained:

smooth rigid footing

$$Q/B = C_0(\pi+2+\rho B/C_0) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

rough footing

$$Q/B = C_0(\pi+2+2\rho B/C_0) \quad \text{for} \quad \rho B \leqslant C_0/2 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$Q/B = C_0(\pi+3+\rho B/C_0-C_0/4\rho B) \quad \text{for} \quad \rho B \geqslant C_0/2 \quad . \quad . \quad . \quad . \quad (3)$$