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Shear Strength Behavior of Kaolinite with Different Microfabrics

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ABSTRACT

Shear strength behaviour of kaolinite with different microfabric is studied by carrying out triaxial and direct shear tests under drained and undrained conditions. All the tests were carried out on normally consolidated samples prepared by slurry consolidation technique. Kaolinite with different microfabric was prepared artificially in the laboratory by using different pore fluids for making the slurry. Distilled water was used as the pore fluid for the preparation of flocculated samples where as a solution of 0.5 N Sodium oxalate was used for the preparation of dispersed samples. It is observed that the shear strength properties of flocculated and dispersed kaolinite vary with the type of tests. In the case of undrained triaxial test dispersed kaolinite is found to have higher peak strength than flocculated. Both flocculated and dispersed samples exhibited similar strength behaviour under drained conditions. Flocculated samples exhibited higher strength when compared to dispersed samples in direct shear tests. It can be concluded that these differences in behaviour are due to the difference in particle arrangement and rearrangement of particles which occur under different loading conditions.

1. INTRODUCTION

Engineering behaviour of clays strongly depends on its microfabric. The term fabric refers to the arrangement of soil particles, particle groups and pore spaces in a soil (Mitchell 1993). The microfabric of naturally occurring clays depends on several factors such as the environment at the time of deposition and the physical and chemical processes in its later history. The two extreme micro fabric arrangements with which clays exist in nature are dispersed arrangement and flocculated arrangement. In the dispersed arrangement, the particles are arranged in highly oriented manner while in the flocculated arrangement the particles are randomly arranged. Dispersed clay exhibits anisotropic behavior as the engineering properties will be different in the vertical and horizontal directions. According to Lambe and Whitman (1979), clays deposited in salt water will have a flocculated structure while that deposited in fresh water will have a dispersed structure.

Many researchers like Ranganatham (1961), Madhav and Rao (1969), Nagaraj (1959), Sridharan et al. (1971), Wang and Siu (2006) and Sachan and Penumadu (2007) have studied the consolidation and shear strength behavior of compacted and reconstituted samples with different microfabric. In the above studies samples of clay with different microfabric were prepared artificially by altering their physico chemical nature by using different pore fluids. Chemicals with divalent cations like Ca^{2+} (eg: Calcium chloride, Calcium hydroxide) were used as flocculating agents whereas chemicals having monovalent cations like Na^{+} (eg: Sodium oxalate, Sodium hexa meta phosphate) were used as dispersing agents.

Shear strength characteristics of soil samples are commonly determined in the laboratory by carrying out direct shear tests or triaxial tests. It is very difficult to control drainage in the case of direct shear tests and drained tests are genarally carried out, though quick tests are often conducted to simulate the undrained conditions. But both drained and undrained tests can be carried out in triaxial apparatus. It is usually found that the effective stress parameters obtained from undrained triaxial tests are same as those obtained from drained triaxial tests.

In the present study, consolidated undrained (CU) triaxial tests, consolidated drained (CD) triaxial tests and drained direct shear tests were carried out on kaolinite samples with different microfabric in order to study the effect of fabric in the shear strength behavior. The effect of microstructure on the stress strain behaviour, pore water pressure response and volumetric response was investigated.

2. SAMPLE PREPARATION

Commercially available kaolinite was used for the study.

The particle size distribution shows that 38% of the particles are in the silt size (0.002mm to 0.075mm) and the clay content (<0.002mm) is 62%. Noramlly consolidated samples were prepared by slurry consolildation technique. Samples with different microfabric were prepared in the laboratory by using chemicals. Distilled water was used as the pore fluid for preparing flocculated samples where as a solution of 0.5 N Sodium oxalate was used for the preparation of dispersed samples. Kaolinite was mixed with the required pore fluid to prepare slurry with a water content of about two times the liquid limit. For triaxial tests the slurry was then consolidated under a vertical pressure of 100 kPa in a cyclindrical mould of 150 mm diameter and 230 mm height. Once the consolidation was over, samples of 38 mm diameter and 76 mm height were extruded from the mould. In the case of direct shear test slurry was poured in the direct shear box and consolidated under a vertical pressure which was less than the required normal stress by 10 kPa. Then the sample was trimmed to a height of 25 mm and reconsolidated under the required normal stress before shearing.

3. EXPERIMENTAL PROGRAMME

Triaxial tests were carried out as per the specifications given in IS 2720 part (12). Side drains were used for easy saturation and consolidation of samples. Saturation of samples was carried out by back pressure saturation ensuring the value of pore pressure coefficient B above 0.95. After saturation, samples were consolidated under the required confining pressure. Volume change of sample was monitored with time and time taken for 100% consolidation (t_{100}) was obtained using the relationship between volume change and $\sqrt{t}$. In order to ensure equalization of pore pressure in the case of undrained conditions and dissipation of excess pore pressure in the case of drained conditions, rate for shearing was obtained based on the value of t_{100} as suggested in Head (1998). In the case of CU tests time of failure (t_f) was taken as 1.8 x t_{100} where as for CD tests t_f was taken as 14 x t_{100}. Time taken for consolidation was higher in the case of dispersed samples and hence they were sheared at a slower rate when compared to flocculated samples. In CU tests pore pressure at the bottom of the sample was measured using a pressure transducer. In the case of CD tests drainage was allowed from the bottom of the sample and was measured using a GDS make standard pressure controller.

Direct shear tests were carried out as per IS: 2720 part (13). Porous stones and grid plates were used at top and bottom. Drainage was allowed during shearing and the test was carried out with a slower rate to ensure full dissipation of excess pore water pressure. Rate of shearing was obtained based on the coefficient of consolidation (c_v) value of the samples obtained from oedometer tests as suggested in IS 2720 part (13). For direct shear tests also, dispersed samples where sheared at a slower rate than the flocculated samples.

4. RESULTS AND DISCUSSIONS

Consolidated Undrained Tests

Fig. 1 shows typical CU stress-strain response curves of flocculated and dispersed samples for a confining pressure of 200 kPa. It can be seen from the figure that dispersed samples exhibits a peak stress followed by a strain softening behavior whereas flocculated samples exhibits strain hardening behavior which is the characteristic of normally consolidated clays. Reason for such a behavior can be explained as the initial resistance against compression offered by the parallely oriented particles in case of dispersed samples, up to the peak stress. Later at higher strain levels the occurrence of slipping of particles leads to the strain softening behavior. Sachan and Penumadu (2007) and Wang and Siu (2006) reported similar behaviour. It can also be seen from the figure that ultimate strength, at larger strains, of flocculated and dispersed samples are almost similar.

Variation of excess pore pressure with strain for flocculated and dispersed samples under CU conditions at a confining pressure of 200 kPa is presented in Fig. 2. It can be seen from the figure that both type structures of clays have similar pore pressure pattern indicting no role of microfabric on the nature of pore pressure build-up and dissipation in clays.

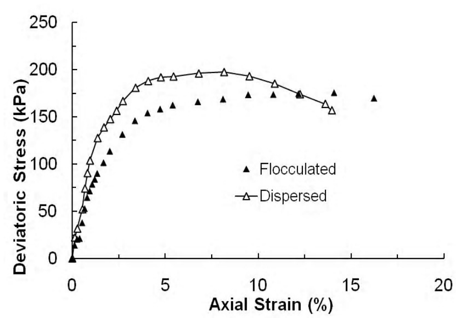

Fig. 1: Stress-Strain Graphs of Flocculated and Dispersed Samples Subjected to CU Test Under a Confining Pressure of 200 kPa

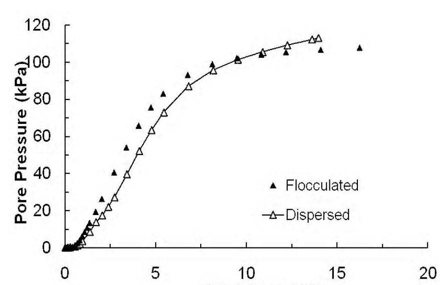

Fig. 2: Variations of Pore Pressure with Axial Strain for Flocculated and Dispersed Samples Subjected to CU Test Under a Confining Pressure of 200 kPa

Modified failure envelopes for flocculated and dispersed samples are given in Fig. 3. In the graph $s = (\sigma_1' + \sigma_3')/2$ and $t = (\sigma_1' - \sigma_3')/2$, where $\sigma_1' - \sigma_3'$ is the peak deviatoric stress. Peak angle of internal friction (ϕ_{peak}) obtained for dispersed sample (28.7°) is slightly higher than that of flocculated samples (27.5°).

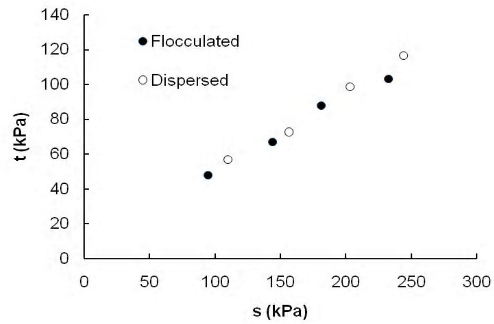

Fig. 3: Modified Failure Envelopes of Flocculated and Dispersed Samples Subjected to CU Test

Consolidated Drained Tests

Typical stress-strain curves for flocculated and dispersed samples under CD conditions at a confining pressure of 200 kPa are presented in Fig. 4.

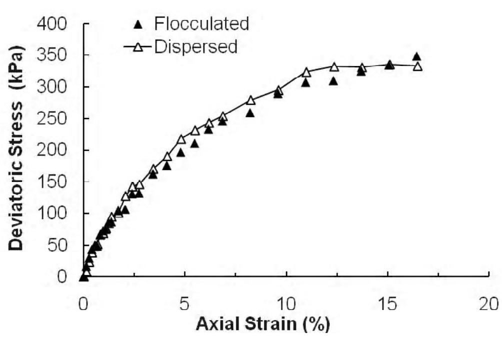

Fig. 4: Stress-Strain Curves of Flocculated and Dispersed Samples in CD Tests Under a Confining Pressure of 200 kPa

Unlike in the CU conditions dispersed sample did not show a peak stress and strain softening behavior at CD conditions. Both flocculated and dispersed samples shows similar strain hardening behavior under drained conditions.

The reason for such a behavior may be that fabric rearrangement is possible during shearing in the case of CD conditions. As drainage and volume change is allowed during shearing in the case of CD test, particles will be free to rearrange, leading to their similar stress-strain behavior. As a consequence, we can expect a different volume change behavior for flocculated and dispersed samples during CD tests. Variation of volumetric strain with axial strain for samples with different microfabric under CD conditions at a confining pressure of 200 kPa is given in Fig. 5. It can be seen from the figure that volume change in the case of flocculated samples is higher than that of dispersed samples.

Modified failure envelopes for flocculated and dispersed samples subjected to CD tests are given in Fig. 6. It can be seen from the figure that both flocculated and dispersed samples have almost same failure envelopes. Both flocculated and dispersed samples were found to have an angle of internal friction (ϕ) of 28°.

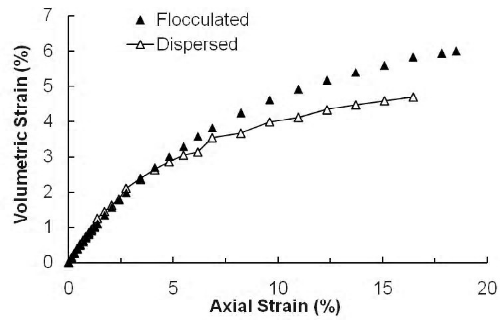

Fig. 5 Variations of Volumetric Strain with Axial Strain of Flocculated and Dispersed Samples Subjected to CD Test Under a Confining Pressure of 200 kPa

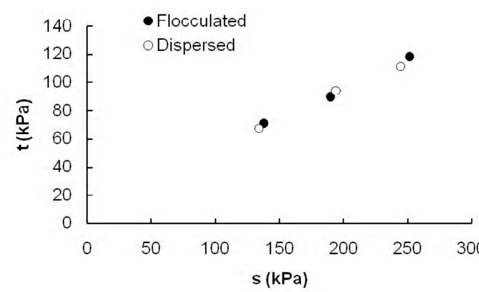

Fig. 6: Modified Failure Envelopes of Flocculated and Dispersed Samples Subjected to CD Test

Direct Shear Tests

Fig. 7 presents the variation of shear stress with horizontal displacement of flocculated and dispersed samples obtained from the direct shear tests under a normal stress of 150 kPa.

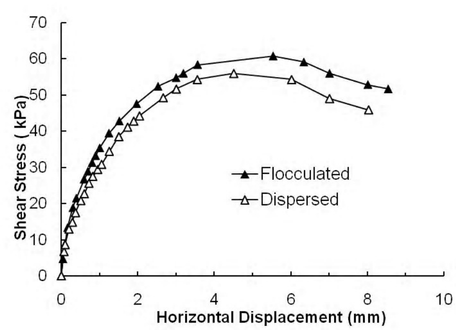

Fig. 7: Variations of Shear Stress with Displacement for Flocculated and Dispersed Samples Subjected to Direct Shear Test Under a Normal Stress of 150 kPa

It can be observed from the figure that flocculated clay samples have higher resistance than dispersed clay samples in contrast to CD triaxial tests where both type samples have similar resistance. It is due to a fact that in the direct shear tests the dispersed samples having horizontal particle arrangement offers less resistance to shearing along the horizontal failure plane whereas flocculated samples offer higher resistance due to its the randomly arranged particles arrangement.

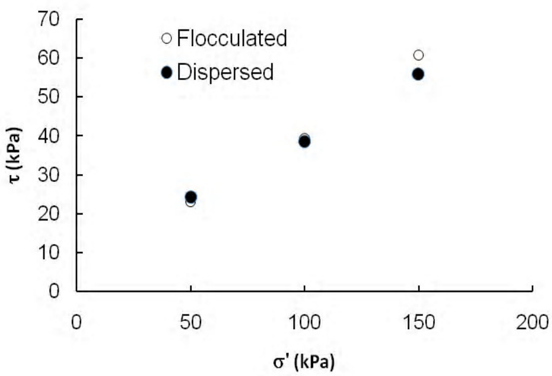

Fig. 8: Failure Envelopes of Flocculated and Dispersed Samples Subjected to Direct Shear Test

Failure envelopes of flocculated and dispersed samples obtained from the direct shear tests are presented in Fig. 8. Fig.8 indicates flocculated samples have slightly higher shear strength than dispersed samples. Angle of internal friction (ϕ) of flocculated sample (22°) and dispersed sample (ϕ = 21°) are found to be less than that obtained from triaxial CD tests.

5. CONCLUSIONS

In the present study consolidated undrained and consolidated drained triaxial tests and drained direct shear tests were carried out on artificially prepared kaolinite samples with different microfabric. Based on the test results the following conclusions are arrived on the effect of microfabric on the shear strength behaviour of Kaolinites;

Dispersed sample exhibits a peak stress and strain softening behavior under CU triaxial conditions whereas flocculated samples exhibits conventional strain hardening stress-strain behavior. Pore pressure pattern is found to be almost same for both flocculated and dispersed samples. Though dispersed samples exhibited a higher peak deviator stress, they were found to have only slightly higher angle of internal friction than flocculated samples. Under CD triaxial conditions flocculated and dispersed samples have similar stress-strain behavior. But volume change during shearing is found to be higher for flocculated samples than dispersed samples. Both flocculated and dispersed samples posses similar shear strength under CD triaxial conditions. In direct shear test, flocculated samples exhibit higher strength than dispersed samples.

It can be concluded that the type of test and drainage conditions significantly affect the shear strength, dilatancy and stress-strain characteristics of kaolinite samples with different microfabric.

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