The shear strength of partly saturated soils

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H. D. Schreiner, *Imperial College of Science and Technology*

The consolidation time chosen by the Authors does not appear to have been arrived at by measurement. The soils used have significantly different plasticity and grading characteristics, and it would be expected that the consolidation times should vary accordingly. Data currently being obtained at Imperial College suggest that the equilibrium time for section changes in a sample 30 mm thick with a liquid limit of 125 is of the order of 3 weeks. The Authors have noted that the consolidation time is longer than that used previously, and that this has affected the results. However, they have not shown that 4 days is adequate for full consolidation under applied stress or suction changes.

The apparent curvature of the shear strength versus suction lines is in the region where the suction is lower than the as-compacted suction. This is particularly evident in the Authors' fig. 4 for the Madrid clayey sand, where four sets of tests were performed at suctions greater than the initial suction. Data from a test in an oedometer at Imperial College in which vertical and lateral stress and suction are known indicate that large increases in lateral stress may take place on wetting. The vertical-to-horizontal stress ratio in the shear box may thus vary between tests, which would call into question the validity of using the vertical stress on its own.

Authors' reply

As far as the time for equilibrium is concerned, the criterion that was followed for testing was given in the Note: 'The times of consolidation were such that virtually no vertical movements were observed after the corresponding loading periods'. The Madrid grey clay required 4 days and the same period was applied to the other soils tested, since they were less plastic and had less fines; this was therefore on the safe side. This criterion may be a fair approximation for highly compressible soils but is inadequate for soils of low compressibility. The process of pore pressure equalization may continue for a long time without any appreciable deformation.

The problem is even more difficult for ascertaining the correct rate of shear to be applied if constant suction during the failure process is

desired and this doubt is also clearly expressed in the Note.

Currently the shear test is being run with the standard rates that have been established, i.e. 4 days of consolidation and a rate of shear of 2.4 mm/day. After passing the peak strength, the shear process is discontinued by stopping the horizontal push rod. Then 2 more days for equilibrium with the same nitrogen pressure are allowed for and the shear test is started again. The shear strengths before and after the additional 48 h for equilibrium are compared.

With the Madrid grey clay the test had an overpressure of 3 kg/cm² and 150 kg/cm² suction. The peak strength was attained after 26 h and 19 h later the horizontal push rod was stopped. When the shear test was resumed the shear strength was the same.

Two tests have been run with the Guadalix red clay, both for 3 kg/cm² overpressure. In one test the suction was 139 kg/cm², where the peak strength had been reached after 9 h, and the push rod was stopped 13 h later. No change in shear strength was observed when the test was resumed after 48 h.

The other Guadalix clay test had 3 kg/cm² suction. The peak strength was reached after 12 h and the push rod stopped 10 h later. A temporary increase in shear strength of about 5% was observed but after about 2 h the path of the original curve was resumed.

The number of tests is insufficient to draw any firm conclusions, but the results may be tentatively interpreted as follows. The time for equilibrium of 4 days is sufficiently long from the point of view of the effective stresses for both high and low suctions. The rate of shear is sufficiently slow for high suctions but still slightly fast for low suctions; nevertheless it is adequate for the Guadalix clay. Before the peak strength is reached the pore pressures generated by shear may be much larger than during the post-peak process, but this difference cannot be accounted for by this checking procedure.

The clay mentioned by Schreiner is much more plastic than the Madrid grey clay and the thickness of Schreiner's sample is almost 50% larger than the 22 mm samples used. Therefore it is not surprising that the equilibrium times are much longer. However, the Authors do not discard the possibility of a secondary equilibrium process still taking place during shearing, but with negligible

effects on the effective stresses.

The results given here are for tests on three samples with increasing suctions up to 150 kg/cm². The results obtained so far confirm the main argument of the Note, that there is a clear curvature of the τ versus $u_a - u_w$ relation at constant vertical pressure. The shear strength τ reaches a maximum value and then tends to decrease, but only slowly for the samples and ranges tested. However, these are only tentative conclusions since more data are needed.

During the first tests at high pressures some yielding of the horizontal reaction support of the shear testing machine, which used to be fixed by friction screws, has been observed. The defect has been corrected but may have affected some of the results presented in the Note. Therefore, until the results are checked by repeating some of the tests, it is preferable not to enter into an analysis of the

effect of the initial suction on the curvature or into any other detailed consideration, such as the apparent departure of the results from the parallel constant suction envelopes assumed by Fredlund. Furthermore in the last line of table 1, the term 'time to failure' is better described as 'total shearing time', since the peak strain was in all cases overrun.

The vertical-to-horizontal stress ratio changes in the oedometer with swelling soils has also been investigated in this laboratory with strain gauges in the ring containing the sample in the suction-controlled oedometer. How the sample shrinks and therefore the lateral pressure becomes zero for high values of the suction has also been observed. However, this will not take place either in the Madrid clayey sand or in the Guadalix red clay. The effect has not been analysed in the Madrid grey clay.