

# The reaction of clays to sampling stress relief

W. M. KIRKPATRICK and A. J. KHAN (1984). *Géotechnique* **34**, No. 1, 29–42

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The Authors have investigated the effects of undrained stress relief during sampling on the subsequent behaviour of two normally consolidated clays, manufactured from kaolin and illite powders. Important conclusions were reached regarding the effect of storage time on the samples' strengths and stiffnesses. Recommendations were made for methods of reconsolidating samples so that in situ behaviour is reproduced.

We are writing to advise caution in applying some of these findings more generally to natural clays, at least to those of low plasticity, and to suggest a reconsideration of the methods proposed for the reconsolidation of samples.

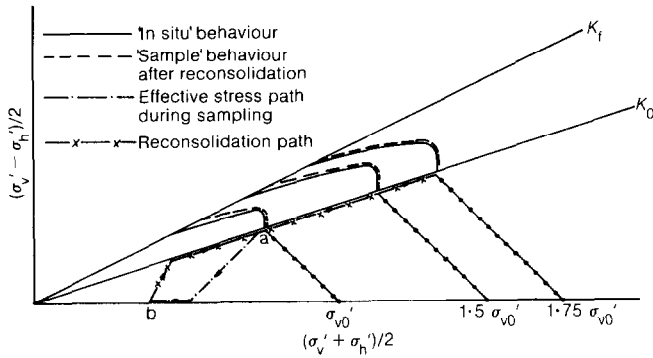
During research into the generalized behaviour of low plasticity clays we have carried out some investigations similar to those described by the Authors. In particular, we have compared the 'sampled' and 'in situ' behaviour of the soil. The low compressibility of low plasticity clays makes them suitable for consolidating within the triaxial cell from a slurry and subsequently testing them to establish the behaviour of soil which has not been subjected to a sampling cycle (El-Ghamrawy, 1978); this has been referred to as the 'in situ' behaviour, but omits ageing and other post-depositional changes which might influence true in situ behaviour. We find that in the normally consolidated soil the features of 'in situ' behaviour are not fully recovered by anisotropic reconsolidation of samples to the in situ stresses. There are differences in stiffness and post-peak behaviour; the differences in post-peak stress path are illustrated in Fig. 1. The effects of a sampling cycle are only fully removed when reconsolidation is continued to  $\sigma_{vc}' > 1.75\sigma_{v,max}'$ ; the match in stress paths between in situ material and material reconsolidated to  $\sigma_{vc}' = 1.75\sigma_v'$  is shown in Fig. 1. This finding is consistent with that on which the SHANSEP approach (Ladd & Foott, 1974) is based.

Although Fig. 1 shows that 'in situ' behaviour is not fully recovered by reconsolidation to the in situ stresses, the match between 'in situ' and 'reconsolidated' soil is acceptable up to peak

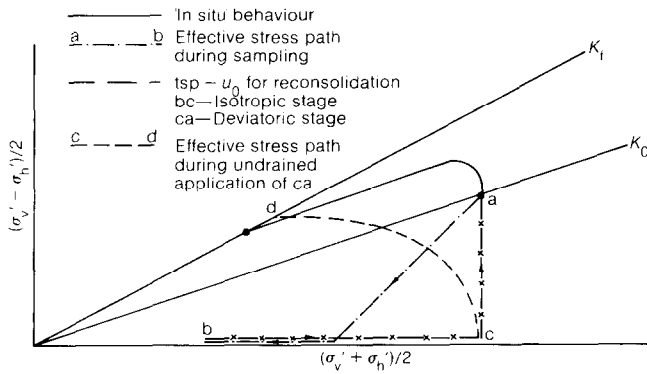
strength. However, this match is only achieved if an anisotropic reconsolidation path with continuous stress changes is adopted. Such a reconsolidation path is relatively straightforward using the hydraulic triaxial cell (Bishop & Wesley, 1975) but is time consuming. Perhaps we must now accept extended testing times if we are to increase the relevance of the data that we obtain from laboratory tests on soil elements.

The Authors suggest a two-step procedure for reconsolidating to the anisotropic in situ stress state which is both quicker and, in conventional triaxial equipment, more convenient than  $K_0$  reconsolidation. The procedure involves arriving at the in situ stress state, shown as a in Fig. 2, by first consolidating isotropically, i.e. from the 'as-sampled' state b to c and then applying the deviator component along c to a. We do not believe that this procedure should be adopted, at least for low plasticity clays. Firstly, since these materials are brittle in the normally consolidated state, i.e. they show a peak strength and a drop to an ultimate value (Fig. 1), the suggested procedure, if carried out such that the deviator stage ca, if undrained, can lead to failure of a sample during reconsolidation. This is illustrated in Fig. 2 where cd is the effective stress path for a sample of low plasticity clay which, after sampling from a, has been isotropically consolidated from b to c and then loaded undrained along the total stress path ca. Secondly, as indicated above, we find that the stress-strain characteristics of natural soils are sensitive to their detailed stress history. Isotropic and anisotropic reconsolidation after sampling produce quite different patterns of behaviour.

In common with the Authors, we find a reduction in peak strength of the normally consolidated clay when tested without reconsolidation after sampling. Furthermore, the axial strain to reach peak strength increases to 1–2%, which compares with an axial strain of approximately 0.1% to reach the peak from the in situ state (Jardine, Symes & Burland, 1984). (The initial stiffness is greater after perfect sampling than when shearing from a  $K_0$  stress state.) These changes are relatable to the changes in effective stress in the samples, and they can be ap-



**Fig. 1. 'In situ' versus 'sample' behaviour after anisotropic reconsolidation**

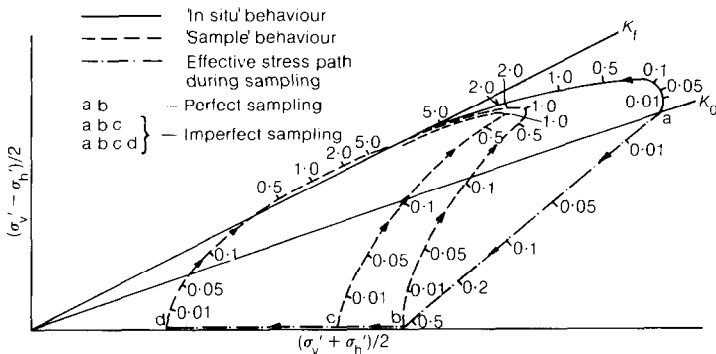


**Fig. 2. Two-stage reconsolidation**

preciated by a simple appeal to the concept of a state boundary surface for the clay (Gens, 1982). Fig. 3 shows the unloading stress paths for three samples, subjected to different levels of sampling disturbance; ab is the effective stress path for 'perfect sampling', and abc and abcd represent increasing sample disturbance. When

tested from their 'as-sampled' stress states of b, c and d, the samples show a peak strength which reduces as their effective stress state after sampling reduces.

We do not find, however, such drastic reductions in strength as those reported by the Authors, nor do we find a pronounced influence of



**Fig. 3. Sample behaviour without reconsolidation (axial strains indicated as a percentage)**

storage time on the initial effective stress in the samples. It appears that natural low plasticity clays are able to retain the suctions induced by stress relief more readily than clays manufactured from single minerals. In specimens taken from 60–70 m below the sea bed from a site in the North Sea, initial effective stresses of approximately 600 kPa have been measured at different times during a two-year period after sampling. In natural clays sampled from deep water offshore, gas exsolution may occur and this can then introduce a storage time effect.

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#### Authors' reply

The discussion refers to three main items which are considered in the order raised.

The first point refers to the use of the consolidated undrained test on samples in an attempt to recover the in situ undrained behaviour. In our work we were predominantly interested in peak and pre-peak behaviour and in this respect reconsolidation of samples to the in situ stresses was found to reproduce in them data comparable with the in situ soil. Post-peak behaviour of these reconsolidated samples, however, was found to diverge from that of the in situ soil. In these respects therefore the findings of Hight, Gens and Jardine are in agreement with ours.

In the consolidation the final point in the stress path is known. The second matter in the discussion centres on the different ways or paths in arriving there. We attempted to use procedures which might generally be used within the resources of most commercial laboratories. The stress path control equipment referred to by Hight *et al.* remains perhaps more of a tool of the research laboratory.

In the method of consolidation used by Hight *et al.* it is presumed that the control is such that the effective stresses are made to follow the  $K_0$  line faithfully from start to finish. In our work, step methods were adopted. Two procedures

were involved and it might be useful to enlarge on the description.

In the step method, increments of the pure hydrostatic stress component were applied alternately with increments of the deviatoric component. Drainage was allowed throughout and no following step was applied until the excess pore pressure resulting from the previous step had effectively dissipated.

In the progressive or multistage method the stress path was made to move up the  $K_0$  consolidation line by applying small increments of the stress components. After consolidation under the hydrostatic component the effective stress point lay slightly below the  $K_0$  line. On applying the deviatoric component the stress path would first move above the  $K_0$  line, as a result of the induced pore pressure, but would eventually return to it once this pore pressure had dissipated. The size of the increments were chosen to keep the deviations of the effective stress paths from the  $K_0$  line down to small limits.

This process is slow and is expensive in time and supervision. In the case of the illites 20 steps were used in the tests referred to in the Paper, requiring upwards of 30 days in consolidation.

In the second consolidation method—referred to as the two-step method—the entire hydrostatic component of the final consolidation pressure was applied in one (the first) step, followed by the deviatoric component in the second step. Although in the first step the whole hydrostatic component could be applied immediately, the deviatoric component necessary to bring the effective stress to the  $K_0$  line was applied gradually depending on the build-up of pore pressure. The aim was to keep the effective stress path below the  $K_0$  line until the final point on the stress path was approached. Although the process required some attention the period of consolidation for the normally consolidated soils could be reduced to a quarter of that needed in the progressive method.

As stated in the Paper, the behaviours measured using these two methods, although not identical, were found to be reasonably similar up to peak conditions for the materials tested. It has to be agreed, however, that if a substantial deviator component is applied without drainage being allowed, failure could result. Although this may be costly in wasting an expensive sample, at least there can be no doubt that something is wrong with the test method when it happens.

The third point refers to the amount of strength lost on sampling and its variation with sample age. In common usage, the term 'perfect

sampling' is taken to mean the removal of only the deviatoric stress from an 'in situ' specimen under conditions of no drainage and no physical disturbance. In this case the negative pore pressure induced on 'samples' can be quite small. In our experience the amount of loss of negative pore pressure and related strength will increase as the amount of total unloading increases and will increase appreciably on removal of the total stresses including the hydrostatic component.

Although the mechanism causing the loss of negative porewater pressure is not fully understood, it is possibly related to cavitation in the porewater. Data, as yet unpublished, suggest that this may have some truth and that specimens unloaded from in situ mean effective stresses of 1 atm or less will not suffer much loss of strength from this cause. (Samples from depths less than 5–10 m depending on the position of the water-table would thus be relatively unaffected by stress relief.) The diagrams provided by Hight *et al.* do not contain a scale; therefore

it is difficult to comment on the amount of strength loss in their samples as a result of unloading.

Loss of undrained strength of samples of natural clay with the age of the sample has been noted before (e.g. Kallstanius, 1971; Berre & Bjerrum, 1973). In these cases it is reasonable to assume that the strength losses occurred as a result of a loss of suction in the soils. These authors referred to tests on plastic clays so perhaps there is reason for expecting, as Hight *et al.* suggest, that soils become less sensitive to the behaviour under discussion as their plasticity reduces.

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