Stress-Strain Behaviour of Fissured Stiff Clays

Comportement Contrainte-Déformation d'Argiles Fissurées

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SYNOPSIS Problems of the stress-strain behaviour, one of the most important in foundation engineering, have generally been solved on the basis of an ideal elastic soil. However, most undisturbed soils are neither ideal elastic nor ideal plastic, but depart from the elastic-plastic theory. For the description of soil behaviour two values of stresses are necessary, the peak stress τ_f and the residual stress τ_r. Fissured over-consolidated clay, like Hannover clay, showed that such soils do not always yield continuously after reaching the peak point. Besides different values of peak stresses were obtained from the same undisturbed sample for the same effective stress. Laboratory investigations, in situ measurements and recent studies with the stereoscan electron microscope emphazised once more that fissured clays are very complex materials. The stress-strain behaviour of such soils depends mainly upon factors such as:

1. Extent, inclination, orientation, shape and amount of fissures.
2. Way of boring for getting samples as well as time of relaxation till laboratory tests are run.
3. Geological history of over-consolidation (pre-stress history).

For that reason investigations with undisturbed and remoulded soil specimens were started to get some comparative results. The paper describes some of recent investigations of the fissured over-sonsolidated Hannover clay (northern region of GFR) and show that the Mohr-Coulomb failure criterion is not directly applicable in all cases for such soils.

INTRODUCTION

It has been realised that fissures have a sensitive influence on measured strengthes of soils, which essentially do not behave as ideal soils. In spite of this knowledge the obtained average strengthes, measured on 78 mm high and 38 mm in diameter specimen or 60 x 60 mm in shear box tests are used in every-day engineering designs. Some of the most widely used relationships of stress-strain behaviour are shown in Fig. 1.

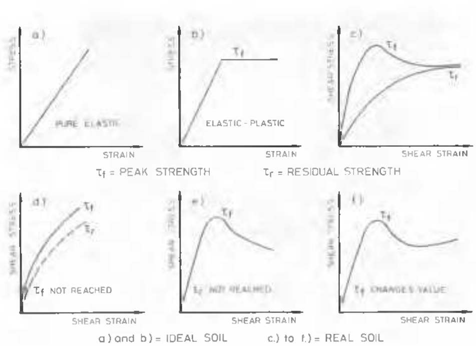

Fig. 1 Stress-strain curves for ideal and real soils

SHEAR STRENGTH AND SOIL PROPERTIES

Some typical results from tests on triaxial (76 x 38 mm) and on direct shear specimens (60 x 60 mm) taken from the same block sample (about 400 x 400 x 150 mm) of fissured Hannover clay are shown in Fig. 2 and 3.

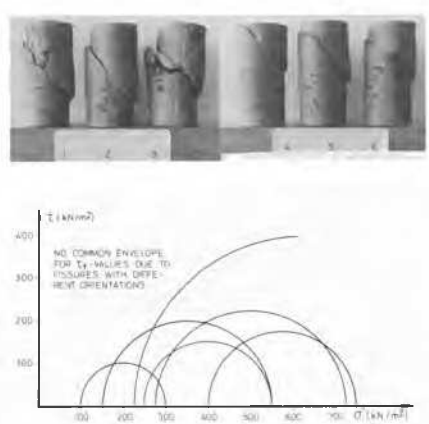

Fig. 2 Shape of failure and results of the corresponding triaxial tests

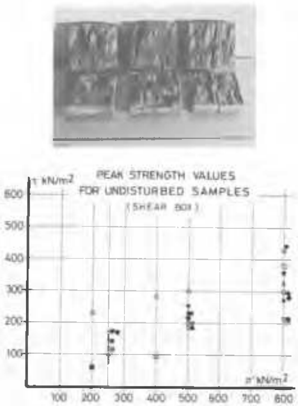

Fig. 3 Shape of failures and results of the corresponding shear box tests

It was expected that specimens with a single fissure must have the lowest strength and those without fissures, or with fissures perpendicular to the longitudinal axes must have the highest strength. This phenomena could'nt be generally confirmed in the conducted tests as shown in Fig. 2. A comparison of some laboratory with in situ tests showed also that the values measured on the small specimens were not convenient and not representative. The laboratory values were on the safe side but not economically for engineering designs. There are some suggestions from authors introducing e.g. an "empirical factor" to adjust the obtained laboratory results of fissured clay with "in situ values". This should be however only applied if the engineer could not find any other sophisticated solution. Such empirical factors may add more confusion to the uncertitude we have already in soil mechanics and need a high experience about foundations' engineering. In addition to that such factors would depend also e.g. on the type of test, used equipment, experience of technicians, amount of fissures etc.
Tests to determine the influence of the mentioned different parameters are very expensive and require a long period of time. In the last decade several investigations concerning the behaviour of London clay have been published. Unfortunately the obtained results cannot be generalized as London clay is'nt identical with other fissured clays which have different geological ages and pre-stress history.
Some index soil properties of fissured Hannover clay (mean values) are given in Tab. 1.

soil parameters	w [%]	w_P [%]	w_L [%]	I_C —	γ [kN/m³]	clay [%]	silt [%]	sand [%]	φ [°]	c [kN/m²]
note	range	range	range	range	average	d ≤ 0.002	d ≤ 0.06	d > 0.6	range	range
undisturbed	20.3 - 24.7	20.8 - 23.4	52.3 - 53.8	1.01 - 1.09	21.0	50 -	44 -	6 -	14.5 - 15.5	35.0- 150.0
remoulded	24.6 - 26.8	20.8 - 24.0	48.9 - 52.3	0.81 - 0.98	19.3	58	32	10	19.0- 21.0	10.0- 40.0

Tab 1

BEHAVIOUR OF UNDISTURBED AND REMOULDED SOILS

To describe the behaviour of the fissured Hannover clay the author considered some other aspects in his studies as e.g.:

a) Stress-strain behaviour in the shear box.
b) Behaviour of remoulded samples.
c) Shape of failure plane or area after shearing with the scanning electron microscope by magnification up to 16.000 x.
d) Validity and application of Mohr-Coulomb criterion for undisturbed and remoulded highly fissured over-consolidated clays.

Due to this brief contribution, the author can only summarise the results of tests and comment the degree of clay particles disturbance by examination of the microstructure of samples after shearing. More details will be given in a special publication.

The soil behaviour in the shear box was nearly identical with that in triaxial tests. No linear relation was found between τ_f and σ for undistrubed (intact) specimens (see Fig. 2, 3). Differences up to 100 % in τ_f-values for the same effective stress σ have been observed (compare specimens in Fig. 3). As shown the undisturbed clay (boundary areas of specimens) has an open structure and the platey clay particles appear relativly in dense peds. Some areas revealed a less open structure. Several groups of particles are in parallel alignment and the alignment direction does'nt differ too much from group to group. The shear zone ist very narrow and no deformations were observed beyond this area (compare also Fig. 7 and 9).

The results of shearing tests (triaxial and shear box) with remoulded samples were very satisfactory and showed nearly homogenous behaviour (Fig. 4) and a better interpretation of parameters for design.

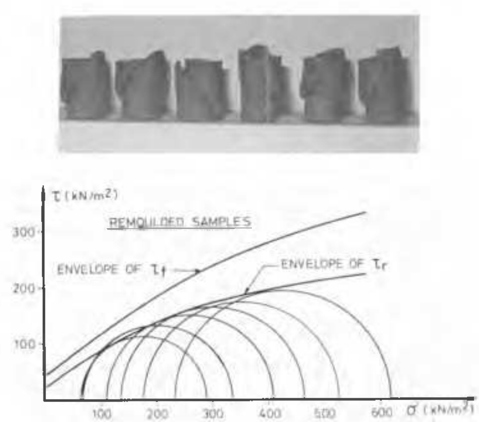

Fig. 4 Results obtained with remoulded samples

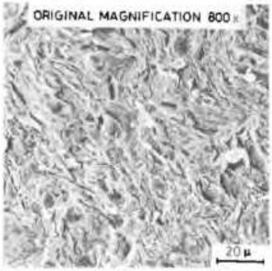

Fig.5 Remoulded specimen,subject to shear box testing. Typical particle arrangement outside the shear plane area. Nearly parallel orientation of clay particles, arrangement as "fabric units". Predomination of parallel-orientation running diagonally from top left to bottom right of the picture.

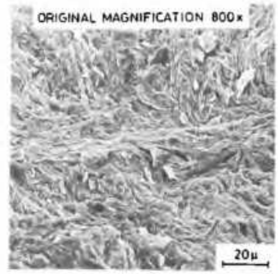

Fig.6 Remoulded specimen, subject to shear box testing. Shear plane running in the middle (nearly horizontally) from left to right. Note initial structure on top and bottom and viz. the structure change in the critical zone.

Fig.7 Remoulded specimen, subject to shear box testing. This picture is partial magnification of Fig.6 . Shear plane running from left to the right. Note nearly parallel (horizontal) particle orientation in the critical zone. Initial structure on top and bottom of the critical zone like in Fig. 5 .

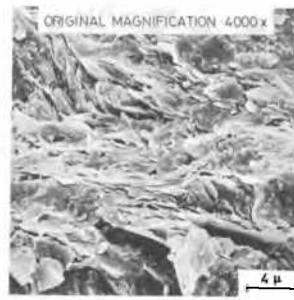

Fig.8 Remoulded specimen, subject to shear box testing. This picture is partial magnification of Fig.7. Note configuration of critical zone, sharp limited to the adjacent areas with nearly initial particle structure. Shear 2 mm/h horizontal strain.

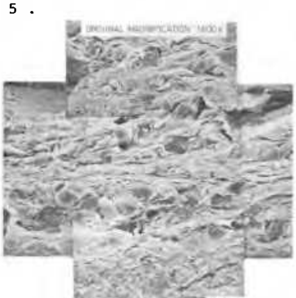

Fig. 9 Undisturbed specimen,subject to triaxial testing. Shear plane running in the middle from left to right(horizontally).Note nearly initial particle structure on top and bottom of the critical zone. This initial structure is without specific particle orientation(randomly oriented structure),compare with Fig.7.

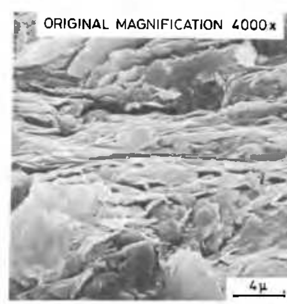

Fig.10 Undisturbed specimen,subject to triaxial testing. This picture is partial magnification of Fig.9 .Note the specific parallel particle orientation in the critical zone in comparison with the adjacent areas. The shear plane(horizontal) can be good identified.Shear 1 mm/min vertical strain.

If the interpretations put forward in this contribution and those of Fig. 5 to 10 are correct, there is a sort of conflict between the assumption of the Mohr-Coulomb criterion and the results of undisturbed fissured samples. This criterion may be applied in cases of soils in which a plane of failure occurs within the sample only due to a maximum of stress and not e.g. due to the influence caused through fissure orientation.

CONCLUSIONS AND COMMENTS

The Mohr-Coulomb criterion of failure predicts the plane on which failure occurs. For all granular and normally consolidated soils the obtained results with this criterion are quite satisfactory. But especially for fissured over-consolidated clay the prediction seems not to be reliable for direct application. For that reason a description of material behaviour as well as comparative results with remoulded clay specimens must be carried out additionally for such complex materials to determine the shear strength properties. For fissured clay the failure criterion can be applied only for the tested sample but the obtained results must not be representative for the whole soil in nature.

It is essential to regard each investigated type of fissured clay (e.g. London, Mexico, Bangkok, Frankfurt or Hannover clay) as a special soil and not to generalise the results and values for all other types. Such studies can only be useful and valuable when they are in conjunction with foundation engineering design and with the corresponding measurements in situ.

The design of temporary and permanent works can be observed with different perspectives. The fissured Hannover clay is a very complex material and cannot be described in all cases with the Mohr-Coulomb criterion. The author considers that the estimation of shear parameters for the design of temporary works (nearly two years) can be reliable by laboratory tests on the condition of reducing the statistical values between 85 and 90 % (factor of safety for intact materials $\eta = 1.20$ to 1.1). For permanent works caution should be exercised in using the values of laboratory tests for the full-scale strength as it could decrease in function of the time up to 60 % of the measured value in laboratory. This depends mainly on the time interval that the clay specimen remains under stresses lower than the original stresses in situ (pre-stress history).

The author considers that using the peak strength values of remoulded fissured clay specimens for permanent works without reduction involves not too much confusion for the designer as no danger is expected that the average values in situ will be much lower. Another way of approach is using the residual strength of undisturbed specimens whereby the statistical average value could be sure enough as design parameter without reduction.

Both ways using the residual strength or peak values of remoulded specimens have shown a better approach to the Mohr-Coulomb criterion as peak values of naturally undisturbed specimens of over-consolidated fissured clays. By highly fissured clay differences up to 100 % in peak strength have been observed (in laboratory tests). It is encouraging to observe the new developments of geotechnics concerning the study of fissured and over-consolidated clays.

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