Some Drained Tests on Normally Consolidated Cohesive Soils

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In order to investigate the drained shear characteristics of normally consolidated cohesive soils, both Ko-consolidated drained triaxial compression and extension tests were performed on two different soil samples.

The main conclusions from this study are : i) Fully drained triaxial tests were performed on two kinds of normally consolidated cohesive soils properly. In compression tests, shear strength increased with consolidation and shear failure occurred at the strain of approximately 13% for both samples. In the extension tests, on the other hand, the increment of principal stress difference could not be observed clearly after the strain of approximately 5%. ii) M-30, which has more clay franction, shows larger negative dilatancy than M-10. In extension tests, however, the trend was reversed.

Key words: Cohesive Soil/Drained Shear/Plasticity/Stress Path/Test Procedure

1. Introduction

In long term stability problems, the use of strength parameters obtained by the drained shear tests has been recommended[1]. The drained shear test is carried out under the condition that of no pore pressure changes throughout the shear process. This requirement leads to a practical problem since the drained shear test on soils of low permeability can take very long time. In practice, therefore, the drained shear test is sometimes substituted by the undrained test with pore pressure measurements for obtaining strength parameters in terms of effective stress.

The present paper describes the drained shear characteristics of two kinds of cohesive soils observed in Ko-consolidated drained triaxial compression and extension tests.

2. Experiments and Soil Samples

Samples

Two kinds of samples were used, one was Kawasaki clay, and the other was reconstituted cohesive soil made by mixing Kawasaki clay, Toyoura sand and partly crushed Toyoura sand. The two samples were named M-30 and M-10 respectively after their values of the plasticity index PI (Kawasaki clay-mixture series). The preparation method of soil samples has been reported in detail elsewhere[2)3)4)]. There are evidences from triaxial and oedometer tests that properties of Kawasaki clay-mixture series correspond well to that of natural marine clays in Japan having the same PI[4)]. This implies that the results of present tests with Kawasaki clay-mixture series could be used to assess the mechanical behaviour of natural cohesive soils. Ko-consolidated drained triaxial compression and extension tests were performed. These triaxial tests are denoted as $\overline{\text{CKoDC}}$ and $\overline{\text{CKoDE}}$ tests, respectively. Detailed descriptions of triaxial apparatus have been presented elsewhere[2)4)5)]. In the compression test, specimens were consolidated under the Ko condition and then subjected to drained compression by increasing axial pressure, lateral pressure being kept constant during compression process. In the extension test, specimens were consolidated under the Ko condition and then subjected to drained extension by decreasing axial pressure, lateral pressure being kept constant during extension process.

Two different values of vertical effective con-

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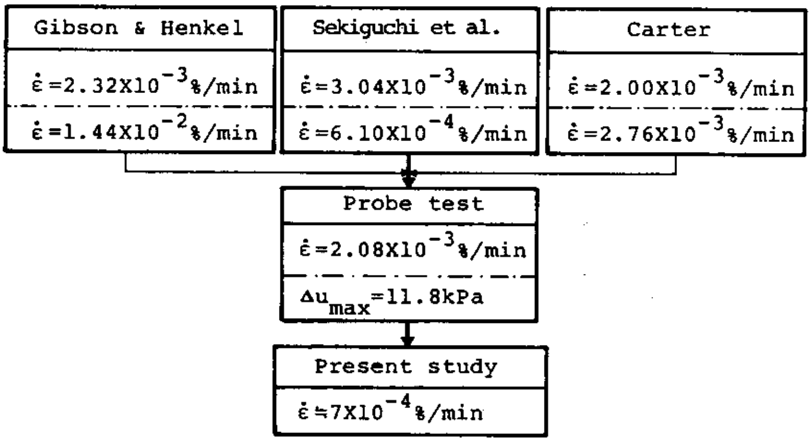
Table. 1 A method of determining axial strain rate for saturated clays



solidation pressures σ'_{VC} were used in the consolidation process : 196kPa and 294kPa in the compression tests, and 196kPa and 392kPa in the extension tests respectively. A back pressure of 196kPa was applied to all the test specimens throughout the consolidation and shear processes. In the present paper, results obtained in the case of σ'_{VC}=196kPa will be shown since this pressure σ'_{VC} was used in the both tests.

The strain rate which satisfied the fully drained condition was examined for the less permeable soil sample of the M-30. The selected strain rate was considered applicable to more permeable soil samples of the M-10 in the present series of experiments. Table 1 shows a sequence of determining the axial strain rate for M-30 under fully drained conditions. The coefficient of consolidation, c_v, was determined by the Bishop and Henkel's equation based on the triaxial test[6].

Gibson and Henkel's method is based on the consolidation theory[7]. The upper and lower values in the table correspond to the maximum and minimum drainage length of the specimen respectively.

Sekiguchi et al.'s method is based on the elasto-viscoplastic model and finite element method, and the calculated value is given in a upper value[8]. Furthermore, the decrease in efficiency of a drains, situated in lateral direction of specimens, is to result in a lower value.

Carter applied a finite element method and Biot type's consolidation analysis to Modified Cam Clay Models[9]. The value in the upper and lower column was obtained for the Weald clay and M-30 respectively.

As a result of the above investigation, the preliminary drained shear tests were conducted at a rate of $\dot{\varepsilon}$≒2.08X10^{-3}%/min for the M-30 specimens, which were isotropically consolidated under σ'_{VC}= 196kPa. In the test, the maximum excess pore pressure of 11.8kPa was observed. This pore pressure was considered a little too large as that in the drained test, therefore, it was decided to employ the strain rate of $\dot{\varepsilon}$≒7X10^{-4}%/min, a third of the rate adopted in the preliminary tests, for the drained shear test on the M-30 as well as the M-10. In the test, the maximum observed excess pore pressure was 0.49kPa.

3. Test Results and Discussion

Stress Paths

Figs. 1 and 2 show the stress paths of two kinds of samples of the M-30 and M-10. As the stress

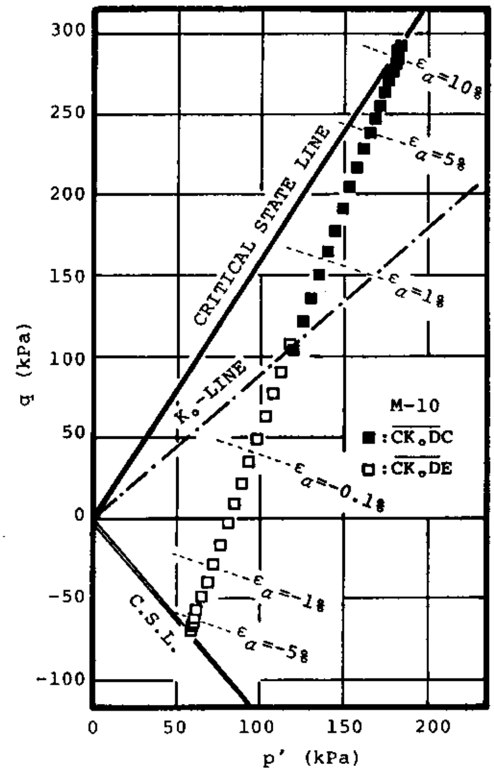


Fig. 1 Typical stress paths of M-30 in $\overline{\text{CKoD}}$ tests (σ'_{vc} = 196kPa)

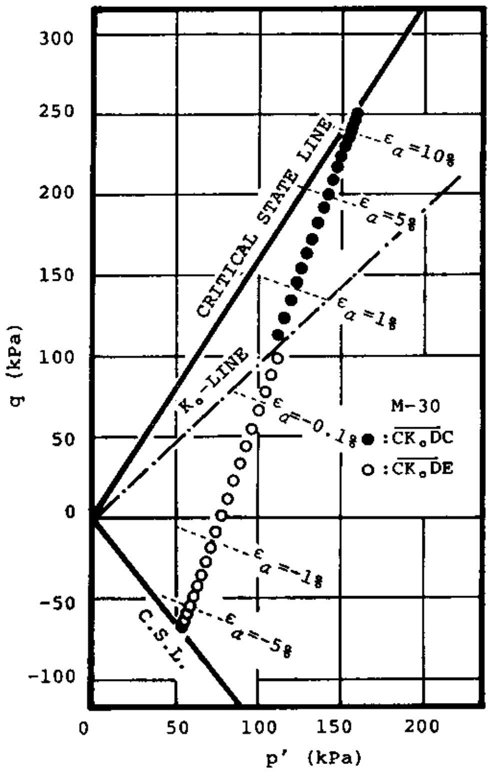


Fig. 2 Typical stress paths of M-10 in $\overline{\text{CKoD}}$ tests (σ'_{vc} = 196kPa)

paths of two specimens are straight in q : p' space and rise at a slope of one in three from the point of completion of Ko consolidation, no significant amount of excess pore pressure (less than 0.49kPa) had ever developed and the fully drained tests seem to be carried out properly. Stress paths of both specimens approach the critical state line at the strain of approximately 10% in the compression tests and approximately 5% in the extension tests.

Stress-Strain Characteristics

Fig. 3 shows the stress-strain curves of both specimens. In the compression tests, shear strength has increased with consolidation and shear failure occurred at an axial strain of approximately 13% for both samples. In the extension tests, on the other hand, the increment of principal stress difference could not be observed clearly after the strain of approximately 5%. And the strain at failure of M-30 was larger than that of M-10. In a previous series of undrained tests, it was observed that the strain at failure in $\overline{\text{CKoU}}$ tests was approximately 1% for compression tests and approximately 20% for extension tests[2]. It is known that the c_u/p value increases with an increase in PI in $\overline{\text{CKoU}}$ tests[2], but for $\overline{\text{CKoDC}}$ tests the shear strength of M-10 is larger than that of M-30. In $\overline{\text{CKoDE}}$ tests, the difference in shear strength between M-10 and M-30 is not significant. This means that the void ratio decreases during shear in $\overline{\text{CKoDC}}$ tests, the increase of strength due to interlocking of soil particles of M-30 is smaller than that of M-10. In soil mechanics literature, the ratio of extensive strength to compressive strength is often considered as a measure of the strength anisotropy. In $\overline{\text{CKoU}}$ tests, the extensive strength of M-10, which has the largest strength anisotropy, is approximately 50% of compressive strength[2]. As seen in Fig. 2, in

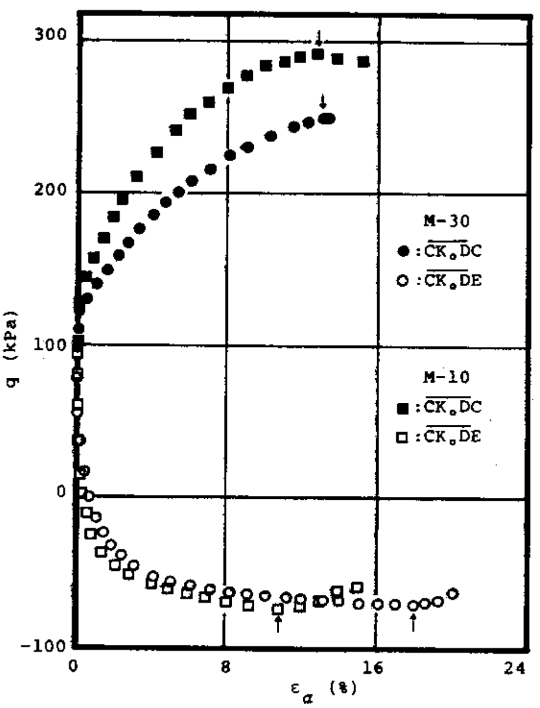


Fig. 3 Typical stress-strain curves in $\overline{\text{CKoD}}$ tests (σ'_{vc}=196kPa)

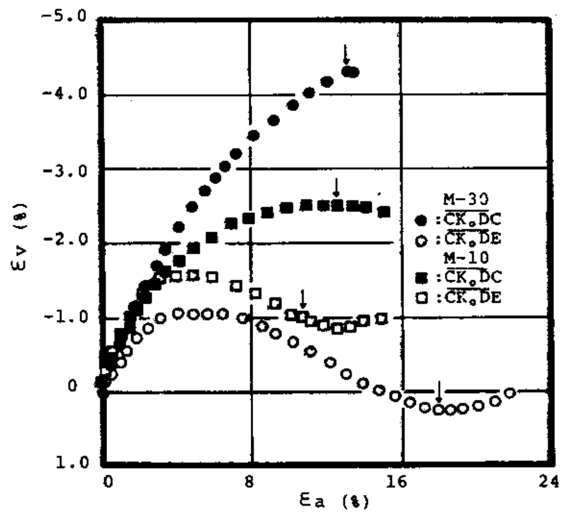


Fig. 4 Typical volumetric strain-axial strain behaviour in $\overline{\text{CKoD}}$ tests (σ'_{vc}=196kPa)

$\overline{\text{CKoD}}$ tests, strength anisotropy increases further and the extensive strength of M-10 reduces to approximately 25% of compressive strength.

Volumetric Strain-Strain Characteristics

Fig. 4 shows the relation between volumetric and axial strains. The shapes of the curves are similar to those of the excess pore pressure-strain behaviour[2], giving experimental evidence of the close relationship of the volumetric strain in drained tests and the excess pore pressure in the undrained tests. The compression tests, M-30, which has more clay fraction, shows a larger negative dilatancy than that of M-10. In the extension tests, however, the trend is reversed and M-10 shows larger negative dilatancy than that of M-30.

Where the volume of specimen is decreasing during shear energy correction is not necessary. If there is an increase in volume during shear, on the other hand, the energy correction must be considered[10]. In the present experiment, therefore, the energy correction is not needed in the compression tests. In extension tests, the volume continues to decrease until $\varepsilon_a \fallingdotseq 5\%$, then it tends to increase slightly for larger strains. The drained shear strength, however, did not increase significantly for the larger strains. The energy correction, therefore, was not adopted in the results shown in this paper.

Angle of Drained Shear Resistance

The failure criteria generally adopted in triaxial testing of soils are either the condition of the maximum principal stress difference or the maximum principal effective stress ratio. In the case of the drained test, the two criteria coincide. In Fig. 5, the angle of drained shear resistance, ϕ_d, is plotted against the angle of shear resistance, ϕ', for both failure criteria, together with published data[11][12]. Results of the present experiment seem to confirm a general trend that the ϕ_d almost coincides with the ϕ' determined by the condition of the maximum principal effective stress ratio.

4. Conclusions

Drained shear characteristics of normally consolidated cohesive soil samples of Kawasaki clay-mixture series (M-30 and M-10) were studied by

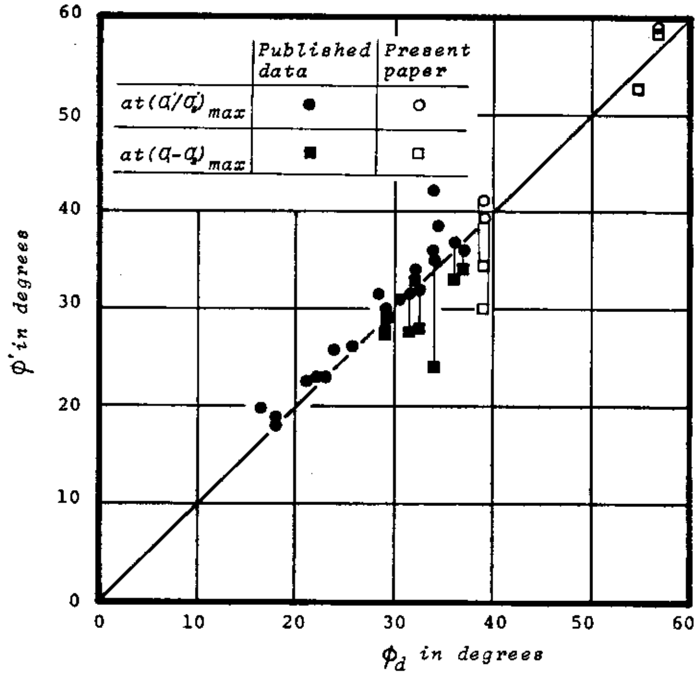


Fig. 5 Relationship between ϕ' and ϕ_d

Ko-consolidated drained triaxial compression and extension tests, i. e., $\overline{\text{CKoDC}}$ and $\overline{\text{CKoDE}}$ tests. The conclusions from this study are :

1) Fully triaxial drained tests were performed on two kinds of normally consolidated cohesive soils properly. In the compression tests, shear strength increased with consolidation and shear failure occurred at an axial strain of approximately 13% for the both samples. In the extension tests, on the other hand, the increment of principal stress difference can not be observed clearly after the strain of approximately 5%.

2) In the compression tests, M-30, which has more clay fraction, showed larger negative dilatancy than M-10. In extension tests, however, the trend was reversed and M-10, which has more silt-sand fraction, showed larger negative dilatancy than M-30.

3) The drained angle of shear resistance almost coincided with the undrained angle of shear resistance in terms of effective stress determined by the condition of the maximum principal effective stress ratio.

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Notation

$\overline{\text{CKoDC}}$	= Ko-consolidated drained compression test
$\overline{\text{CKoDE}}$	= Ko-consolidated drained extension test
M	= letter M is named after their plasticity index in Kawasaki clay-mixture series
p'	= mean effective stress : $(\sigma_a'+2\sigma_r')/3$
q	= principal stress difference : σ_a-σ_r
ε_v	= volumetric strain
ϕ_d	= angle of drained shear resistance
ϕ'	= angle of shear resistance in terms of effective stress

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