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A simplified testing procedure for evaluating the undrained shear behaviour of anisotropically consolidated clay

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Abstract

A simple procedure has been developed to estimate the undrained shear behaviour of anisotropically consolidated clay without special triaxial apparatus. The proposed testing procedure requires no special cell, and its simplicity, speed and economy are well suited to evaluate the undrained shear behaviour after Ko-consolidation. The comparison of data from three methods shows no significant difference in undrained shear behaviour evaluations. Finally, the experimental results obtained by the present method are found to be reasonable in engineering practice. The type Ⅱ test can be readily used by practicing engineers. Although applicable to only a particular soil type, the procedure appears to be sufficiently accurate for practical purposes.

Key words: cohesive soil, consolidated undrained shear, earth pressure at rest, laboratory test, shear strength, test procedure.

Introduction

Most commercial laboratories conduct routine isotropically-consolidated triaxial tests(CIU), whereas most in-situ natural clay deposits exist under anisotropic states of stress, corresponding to CAU conditions. Therefore, the mechanical behaviour of anisotropically cohesive soils have become of increasing importance as the number of embankments and other earth structures being designed and constructed on soft ground have increased. However, unless a device has specialized features as seen in Fig.1 (Nakase and Kamei, 1983; Kamei, 1985), Ko consolidation with no lateral strain is a difficult and time consuming procedure to implement. In addition, the anisotropic consolidation phase of triaxial test specimens is generally time consuming and expensive, especially if Ko conditions are maintained. It has also become standard procedure in CIU tests to use an effective confining pressure equal to the estimated in situ vertical stress. Consequently, it has become routine practice to consolidate the specimens isotropically (Kc=1) before shear to failure.

At this stage, it is advantageous to represent the undrained shear behaviour of Ko-consolidated cohesive soils in a simple manner, using conventional triaxial apparatus which closely resembles that used in engineering practice. A new test (TypeⅡ: SCIDU and TypeⅢ: SCIPCC) which can dramatically reduce the cost associated with the undrained shear behaviour of Ko-consolidated cohesive soils, is described in this paper. The major advantage of this technique is its simplicity because it does not requires special triaxial apparatus. It also has a low initial cost and requires neither time measurement nor stress control during consolidation.

The purpose of this paper is to investigate whether it is possible to estimate the undrained shear behaviour of Ko-consolidated cohesive soil using standard triaxial apparatus, and if so,how accurate these estimations are. Results using the proposed testing procedures are presented and compared to data from special triaxial apparatus for Ko-consolidation.

Experiments

Sample and testing programme

The undisturbed clay(Y-38) used in the present study was sampled at 16～18 m depth from a site south-west of Tokyo Bay. The index properties of the soil sample is shown in Table 1. Fig.2 shows the grading curve of the specimen. All tests were consolidated undrained triaxial shear tests with pore pressure measurements. These undrained shear tests were performed under strain-con-

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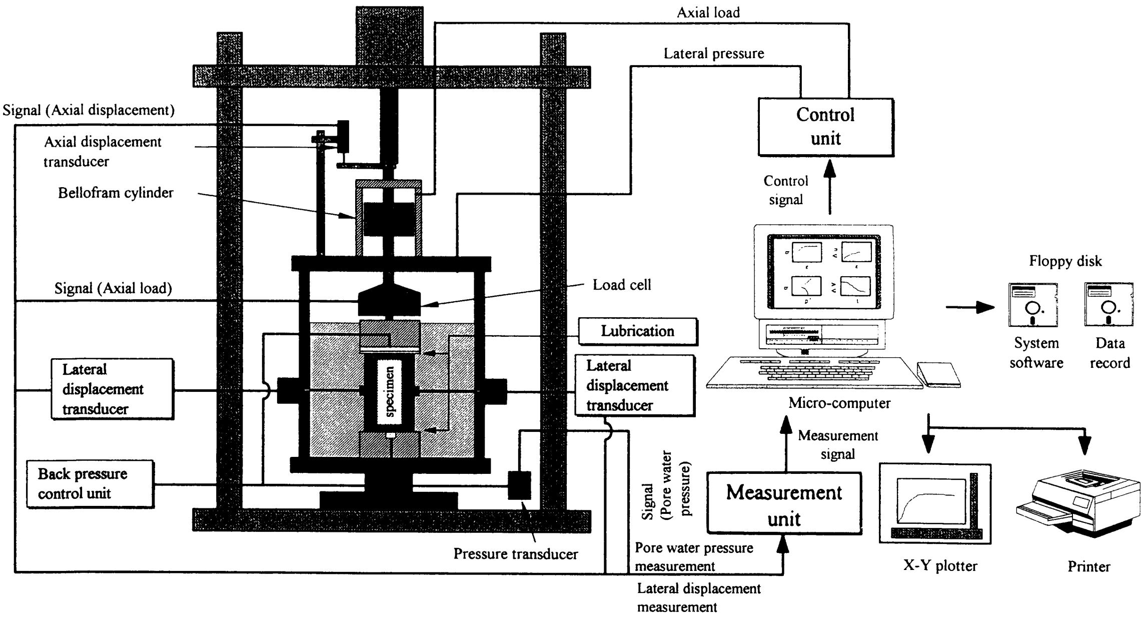

Fig. 1 Schematic diagram of automated Ko-consolidated triaxial apparatus.

Table 1 Index properties of soil studied.

ρ_s(g/cm^3)	w_L(%)	w_P(%)	PI	Sand(%)	Silt(%)	Clay(%)
2.656	77.8	39.8	38	5	49	46

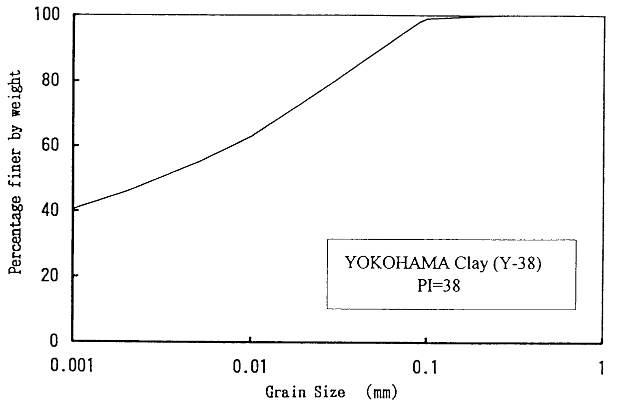

Fig. 2 Grain size distribution curve of sample.

trolled during shear to failure. Fig.3 shows the stress paths used in the present study. Three series triaxial tests were prepared for each of the soils considered : Ko-consolidated (Type I : CKoU) and anisotropically consolidated(Type II : SCIDU and Type III : SCIPCC). The Type II and Type III proposed in the present study are convenience and simplicity of testing procedures for the evaluation of the undrained shear behaviour of Ko-consolidated cohesive soil, although Ko conditions are not maintained during consolidation. For isotropically consolidated specimens, the effective confining pressure was usually applied in one stress increment(0.67 p_o : SCIDU or p_o : SCIPCC), while for anisotropic consolidation, drained shear and mean effective principal stress(p′) at constant were applied to the point of completion of Ko-consolidation(q_o) because of convenience and simplicity of the testing procedures(p_o is the mean effective stress at the point of the completion of the Ko-consolidation, and q_o is the principal stress difference at the point of the completion of the Ko-consolidation). It is important to note that testing procedures used in this study are limited to the evaluation of undrained shear behaviour of anisotropi-

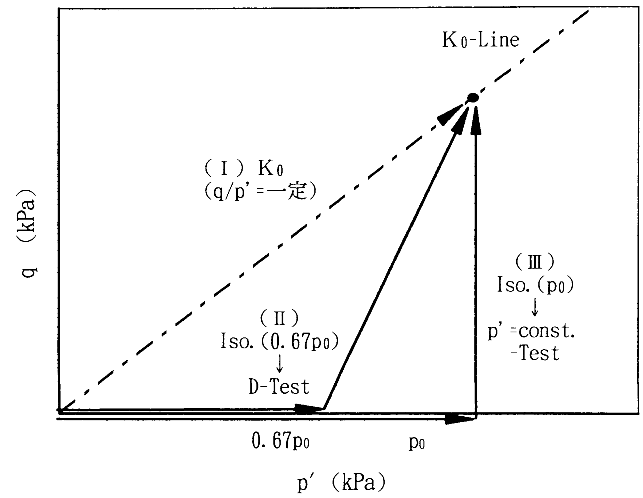

Fig. 3 Stress paths used in the present study.

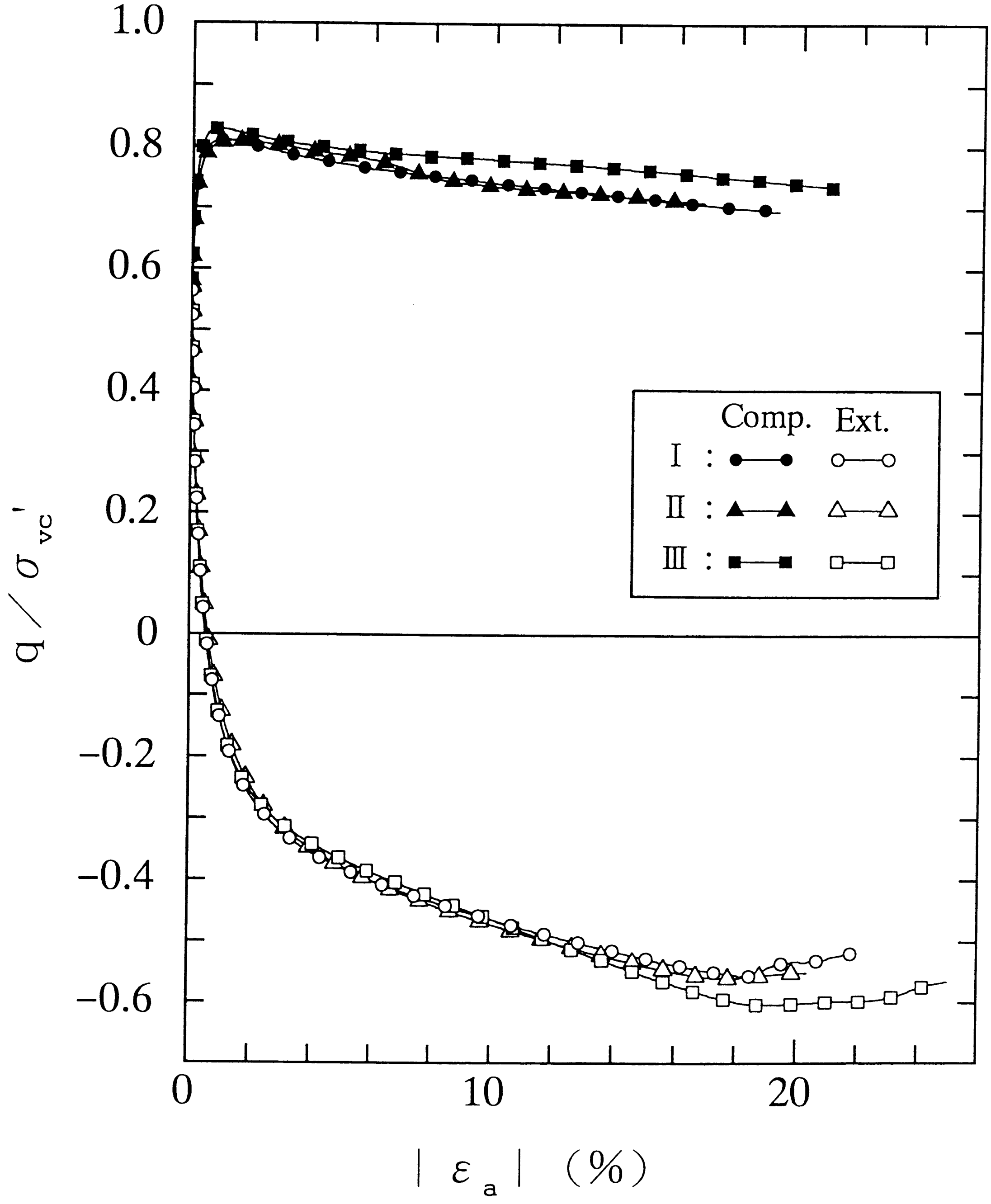

Fig. 4 Comparisons of stress–strain behaviour obtained from three types of anisotropic consolidation process.

Table 2 Summary of triaxial test results.

		Initial Cond.		After Cons.			Triaxial Test Results				
		w_n(%)	e_0	w_c(%)	e_c	K_c	c_u(kPa)	ε_f(%)	E_{50}(kPa)	A_f	c_u/p
I	Comp.	82.2	2.18	68.8	1.82	0.43	116.3	1.04	33900	0.51	0.41
	Ext.	79.9	2.13	67.9	1.81	0.43	78.8	−18.19	30630	0.80	0.28
II	Comp.	78.3	2.08	66.9	1.78	0.43	114.0	1.51	42550	0.56	0.41
	Ext.	77.9	2.07	67.0	1.78	0.43	78.9	−17.89	26960	0.77	0.28
III	Comp.	84.3	2.24	66.1	1.76	0.43	117.3	0.85	47300	0.40	0.42
	Ext.	86.8	2.31	68.8	1.83	0.43	84.0	−18.87	29560	0.76	0.30

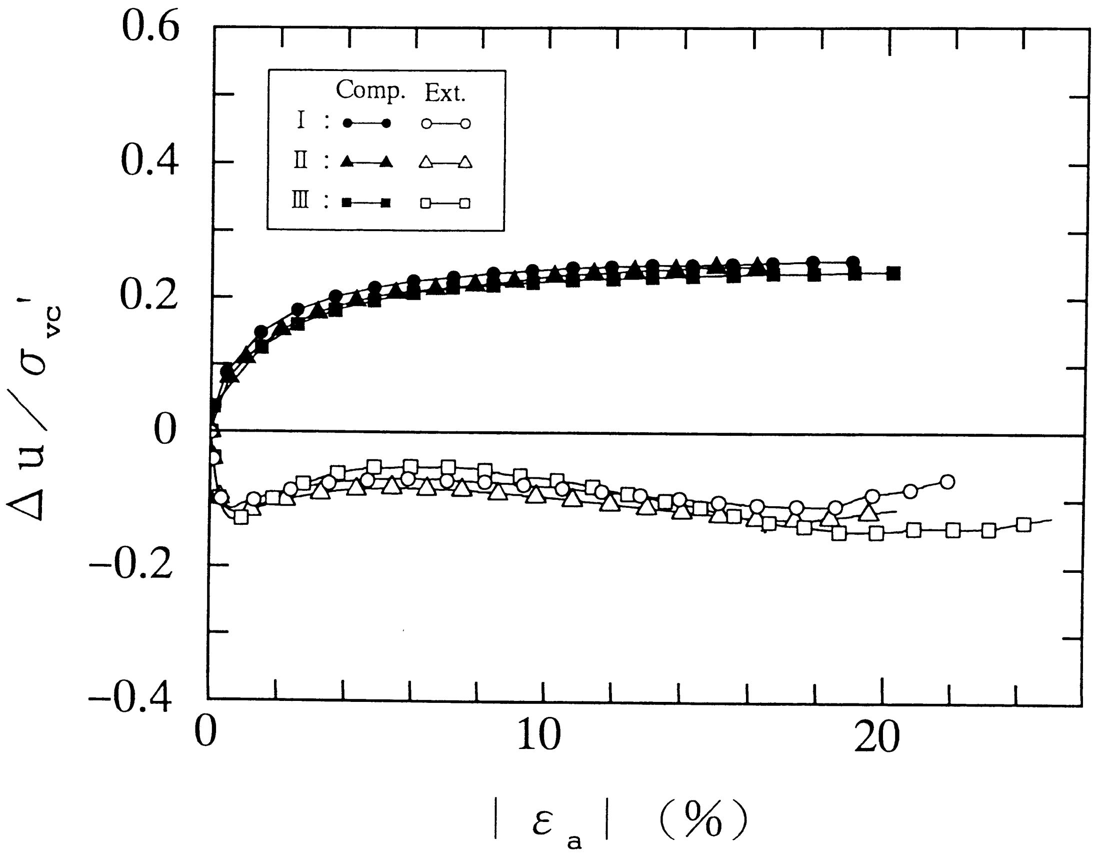

Fig. 5 Comparisons of excess pore pressure Δu–strain behaviour obtained from three types of anisotropically consolidation process.

cally consolidated cohesive soils only.

A vertical effective consolidation pressure of 294 kPa was used in the consolidation process. A back pressure of 196 kPa was applied to all the test specimens throughout the consolidation and undrained shear. For each soil sample, triaxial compression and extension loadings were performed, with a constant rate of axial strain of 0.07%/min.(Kimura and Saitoh, 1983 ; Nakase and Kamei, 1986)

Test results and discussions

Figure 4 compares the stress–strain behaviour, results obtained from three types of anisotropic consolidation processes, where the principal stress difference $q=\sigma_a-\sigma_r$ is normalized by dividing by the vertical effective consolidation pressure σ_{vcr}'. As seen in this figure, there is reasonable agreement between results for stress–strain behaviour of undrained triaxial compression and extension loading for undisturbed Yokohama clay(Y–38), subjected to the three types of anisotropic consolidation process.

Comparison of excess pore pressure Δu–strain behaviour obtained from three types of anisotropic consolidation process is shown in Fig.5, where the excess pore pressure Δu is normalized by dividing by the vertical effective consolidation pressure σ_{vc}'. As seen in this figure, reasonable agreement is obtained from the excess pore pressure Δu–strain behaviour of undrained triaxial compression and extension loadings for undisturbed Yokohama clay(Y–38) subjected to the three types of anisotropic consolidation processes.

Figure 6 compares the effective stress path results from three types of anisotropic consolidation processes, where the principal stress difference $q=\sigma_a-\sigma_r$ and the mean effective stress $p'=(\sigma_a'+2\sigma_r')/3$ are normalized by dividing by the vertical effective consolidation pressure σ_{vc}'. As seen in this figure, there is reasonable agreement between the results for effective stress paths of undrained triaxial compression and extension loadings for undisturbed Yokohama clay(Y–38) for the three types of anisotropic consolidation processes considered. The procedure is sufficiently valid and accurate for practical purposes, and should be used to investigate the undrained

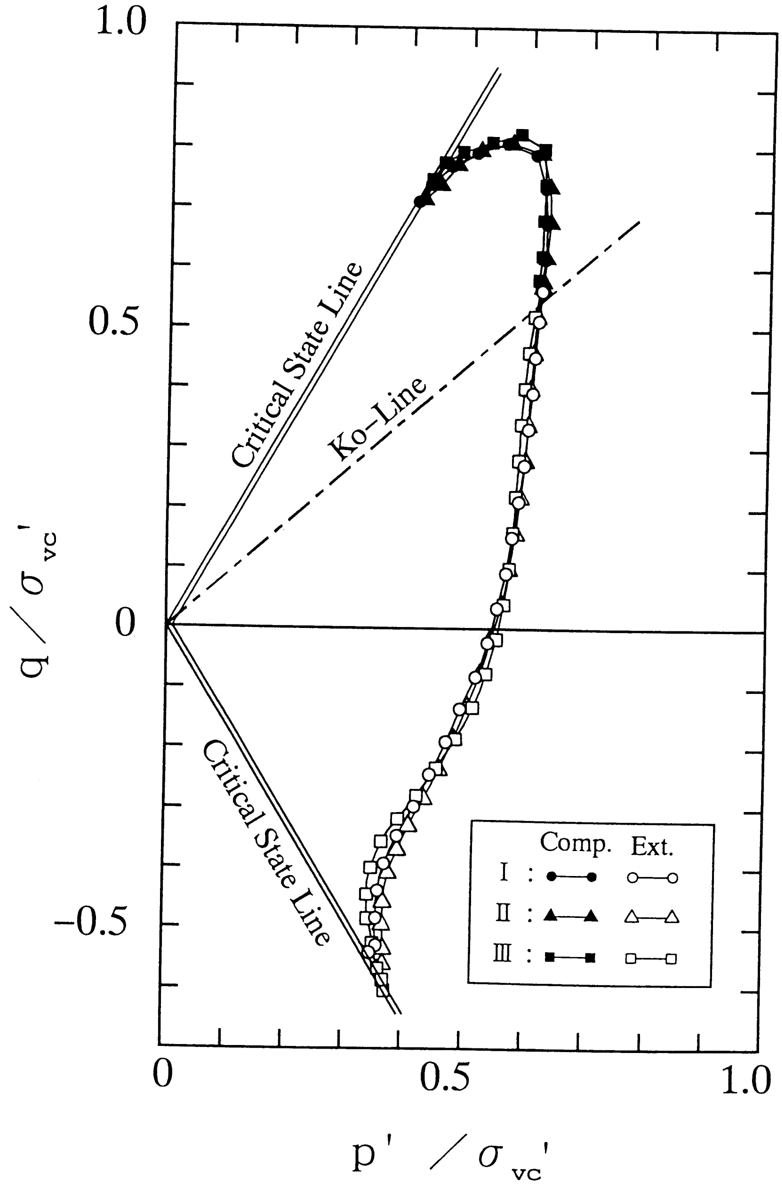

Fig. 6 Comparisons of effective stress path obtained from three types of anisotropic consolidation process.

shear behaviour of Ko–consolidated cohesive soil. The typeⅢ(SCIPCC) test, however, is time–consuming and impractical for commercial testing. The weakness of this method lies in its neglect of the Ko conditions during consolidation, however, a limitation that the typeⅡ approach has overcome is to reduce the cost significantly. The applicability of the proposed methods to other soils will constitute further research. Table 2 shows the summary of triaxial test results.

The combination of the proposed method and the shear provide an extremely rapid, easy, reliable and economic means of evaluating the undrained shear behaviour of Ko–consolidated cohesive soils.

The author is fully aware of the limitations of the proposed testing procedure, and it should be regarded only as a first approximation.

Conclusions

A simple procedure has been developed to estimate the undrained shear behaviour of anisotropically consolidated clay without special triaxial apparatus. The proposed testing procedure requires no special cell, and it is a simple, rapid and economical way, to evaluate the undrained shear behaviour after Ko–consolidation. The comparison of data from three methods shows no significant difference in undrained shear behaviour evaluations. To this end, the experimental results obtained by the present methods are found to be reasonable in engineering practice. The type II test can be readily used by practicing engineers. Although relevant to only a particular soil type, the procedure appears to be sufficiently accurate for practical purposes.

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（要　旨）

亀井健史，1995．異方圧密粘土の非排水せん断挙動に関する簡便法の提案，島根大学地質学研究報告，14．

自然地盤上に構造物を建設する際の破壊と変形のメカニズムを高精度に解析するためには，原位置での土要素の異方力状態を正確に再現したKo圧密状態からのせん断試験結果を適用する必要がある．しかしながら，実務における三軸試験では三軸試験装置の機能・試験者・コスト・試験時間の制約等の観点から，ほとんどの場合等方圧密条件下での試験が実施されている．

上記の点に着目し，本研究では三種類の異方圧密過程の違いが，その後の非排水せん断特性に及ぼす影響を検討している．その結果，通常の三軸試験装置を用いることによっても，本研究で提案している応力経路を土要素に作用させることにより，異方圧密粘土の非排水せん断挙動を評価できることを示唆している．