III－396 BEHAVIOR OF CLAY SUBJECTED TO UNDRAINED TORSIONAL CYCLIC LOADING AND SUBSEQUENT DRAINAGE

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I Introduction

Under the effect of cyclic loadings, different soil elements beneath a structure may be subjected to triaxial or simple shear conditions (1), and therefore, their behavior may be different. Previous researches on this phenomenon were mostly based on the results from triaxial cyclic tests (2). Undrained torsional cyclic simple shear (TSS) tests have been carried out in order to investigate the behavior of clay under undrained cyclic loading and subsequent drainage. The results were then compared to that from cyclic triaxial tests (TC) on the same clay to see the difference between the two testing conditions.

Table 1 TSS Test Conditions and Results

Test No	e_o	e_c	τ_{cy}/σ_{rc}	f(Hz)	N	$\Delta U_{max}/\sigma_{rc}$	DA_{max}(%)	C_r^*
TCA11	1.681	1.303	0.303	0.1	465	0.384	1.7	0.114
TCA12	1.671	1.348	0.330	0.1	480	0.822	11.1	0.136
TCA13	1.670	1.328	0.363	0.1	143	0.801	12.2	0.124
TCA14	1.660	1.353	0.390	0.1	153	0.789	11.4	0.139
TCA15	1.653	1.329	0.447	0.1	62	0.868	18.2	0.154
TCA16	1.679	1.330	0.475	0.1	18	0.792	11.8	0.136
TCN11	1.657	1.350	0.360	0.1	68	0.501	2.4	0.116
TCN12	1.666	1.344	0.370	0.1	120	0.714	7.6	0.142

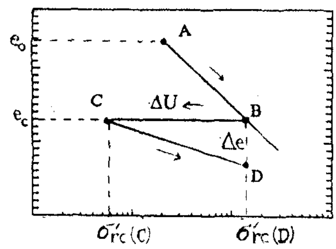

Fig. 1 e–log σ'_{rc} Scheme during Test

II Tested Clay and Test Procedures

Tested clay obtained from one-dimensional preconsolidation of slurry to stress level of 0.5 kgf/cm^2 has basic index properties as: liquid limit 80%, plastic index 40. As presented in Fig. 1, after anisotropic consolidation for 24 hours at the maximum axial stress σ'_{ac} = 1.84 kgf/cm^2 and radial stress σ'_{rc} = 1.0 kgf/cm^2 (Point B), clay was subjected to undrained torsional cyclic loading at different shear stress amplitude, τ_{cy}, and number of cycles, N (up to Point C). The simlpe shear condition during cyclic loading was maintained by keeping unchanged the hollow cylinder specimen's volume, height, and inner cylinder's volume. Accumulated excess pore pressure (ΔU) was measured as an average from the top and bottom of the specimen. After cyclic loading, dissipation of the excess pore pressure was allowed (after 30 min. of curing) until the effective stress reached the value before cyclic loading ($\sigma'_{rc(D)} = \sigma'_{rc(B)}$). In triaxial tests, clay was isotropic consolidated at stress σ'_c = 1.0 kgf/cm^2 before undrained triaxial cyclic loading.

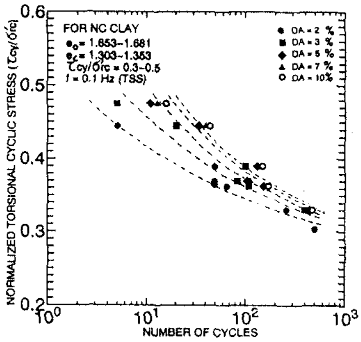

Fig. 2 DA–contour Diagram

III Test Results and Discussions

1. Behavior of Clay during Cyclic Undrained Torsional Simple Shear Condition

Conditions and results of TSS tests are given in Table 1. Torsional cyclic shear stress and excess pore pressure are normalized to effective radial consolidation stress, σ'_{rc}.

In Figs. 2 and 3, the developments of double amplitude shear strain (DA) and normalized excess pore pressure ($\Delta U/\sigma'_{rc}$), respectively, with number of cycles and normalized shear stress (τ_{cy}/σ'_{rc}) are plotted in contour diagrams. Each test of constant shear stress is represented by a set of intersections of a horizontal line throughout the contours.

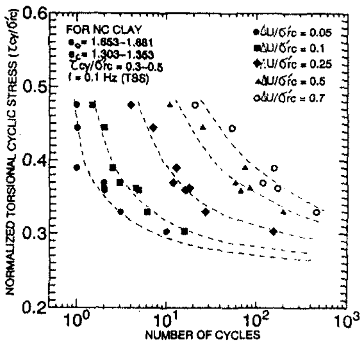

Fig. 3 Normalized Ex.P.Pressure Diagram

Fig. 4 shows that for different tests with maximum double amplitude cyclic shear strain developed to almost the same level,the excess pore pressure increased to almost equal value irrespective of different applied cyclic stress amplitudes. It allows to establish a relationship between normalized excess pore pressure and double amplitude shear strain based on the results from tests of different normalized cyclic stresses (black circles from TSS) as shown in Fig. 5. Drastically increase in excess pore pressure happened at the begining when the DA was up to about 3 %, and then the increase slow down and could not exceed the confining pressure even when the double amplitude shear strain started drastically increasing (when normalized pore pressure about 0.6).

2. Recompression Behavior of Clay after Cyclic Loading

Dissipation of the build-up pore pressure causes a recompression of clay. In Fig. 6, the change in void ratio, Δe, is plotted against the logarithmic ratio of effective stress after full drainage of excess pore pressure, $\sigma_{rc(D)}$, to effective stress before drainage, $\sigma_{rc(C)}=\sigma_{rc}-\Delta U$. The slope of the curve give the recompression index, C_r^* of clay during dissipation. Fig. 7 indicates that C_r^* gradually increases with increasing of excess pore pressure, and considerably increases when the latter had exceeded the value of 0.8, correspondingly double amplitude shear strain had been over 10 % (See Fig. 5).

3. Comparison between TSS and TC Tests

In Figs. 5 to 7, all white circles represent for TC tests, while black ones are from TSS. It can be said that the behavior of clay under undrained cyclic triaxial and torsional simple shear as well as during dissipation of excess pore pressure are quite similar. However, since in TC the cyclic loading and consolidation are in the same direction, wheras in TSS cyclic loading was applied in horizontal direction. Correspondingly, in TC, shear strain develops in 45°–plane, but in TSS it is in horizontal one. That may explain why at the same level of excess pore pressure build–up, the DA from TSS tests were much higher compared to that from TC tests as it can be seen in Fig. 5. Consequently, larger shear strain developed under TSS condition and also disturbance in different direction of clay structure may be one of the reasons of higher change in void ratio and correspondingly, higher C_r^* during dissipation for the same amount of excess pore pressure build–up.

IV Conclusions

1. Developed excess pore pressure and shear strain depend on the severity of cyclic loading.
2. Maximum excess pore pressure and corresponding double amplitude shear strain are in direct relation independent of cyclic stress level.
3. Change in void ratio, and thus settlement, is dependent not only on pore pressure build–up, but also on recompression behavior of clay.
4. Recompression index seems to increase drastically when normalized excess pore pressure becomes greater than about 0.8.
5. Behavior of clay under cyclic TC and TSS are similar. But larger shear strain developed under TSS condition may be the reason of higher recompressibility of clay.

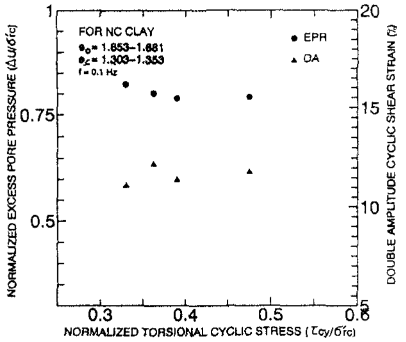

Fig. 4 Normalized Ex.P.P–DA vs. Cyclic Stress

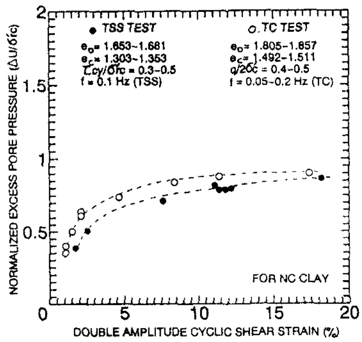

Fig. 5 Normalized Ex.P.P–DA Relationship

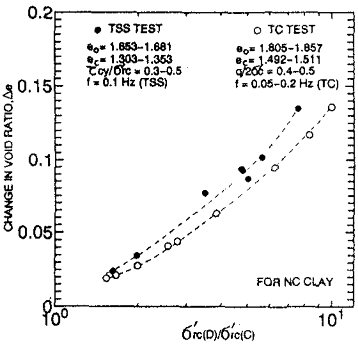

Fig. 6 Change in void ratio–ΔU Relationship

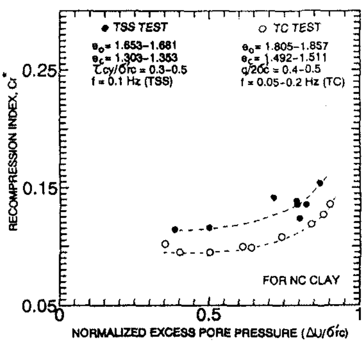

Fig. 7 C_r^*–Normalized Ex.P.P Relationship

References:

1) Anderson K.H. (1988), "Properties of Soft Clay under Static and Cyclic Loading", ICEPRS'88.

2) Matsui T., Bahr M.A., Kotani Y., Hayashi T. (1991), "Post Cyclic Recompression Volumetric Strain of Natural NC Undisturbed Clays", Proc. of 46th annual conf. of JSCE