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# Cyclic Undrained Strength of Sand by Simple Shear Test and Triaxial Test Ⅲ
## (Test Results and Discussions)
## 単純せん断試験と三軸試験による砂の動的非排水強度（Ⅲ）

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### 6. COMPARISON AMONG VARIOUS TESTS

Test results obtained by cyclic undrained triaxial tests and simple shear tests both for wet tamped specimens and for pluviated specimens are compared in this section. For these comparisons, equivalent stress parameters and equivalent strain to both testing methods were selected. For cyclic triaxial tests, conventional stress ratio $\sigma_{dp}/2\bar{\sigma}_c$ in which $\sigma_{dp}$ is single amplitude of the deviatric stress and $\bar{\sigma}_c$ is consolidation effective isotropic stress was adopted. For cyclic simple shear tests, normalized stress ratio $\tau/\bar{\sigma}_{m_c}$, in which $\tau$ is single amplitude of horizontal shear stress and $\bar{\sigma}_{m_c}$ is consolidation mean principal stress, which equals $(\bar{\sigma}_{v_c}+2\bar{\sigma}_{h_c})/3$, was adopted as suggested by Ishihara and Li (1972) and Ishibashi and Sherif (1974). It is important to note that $\sigma_{dp}/2$ and $\tau$ are maximum cyclic shear stress induced in the specimens for cyclic triaxial test and for cyclic simple shear test, respectively. In addition, $\bar{\sigma}_c$ and $\bar{\sigma}_{m_c}=(\bar{\sigma}_{v_c}+2\bar{\sigma}_{h_c})/3$ are mean principal stresses during consolidation for cyclic triaxial tests and for cyclic simple shear test, respectively.

Shear strain in cyclic undrained triaxial tests is 1.5 times axial strain. Therefore, the number of loading cycles corresponding to a specified double amplitude axial strain in a cyclic triaxial test was compared with the number of loading cycles corresponding to a double amplitude shear strain in a cyclic simple shear test which is equal to 1.5 times the specified double amplitude axial strain.

The test results are summarized in Fig. 22 for $D_r=45\%$, in Fig. 23 for $D_r=60\%$ and in Fig. 24 for $D_r=80\%$. In these figures are plotted the numbers of loading cycles

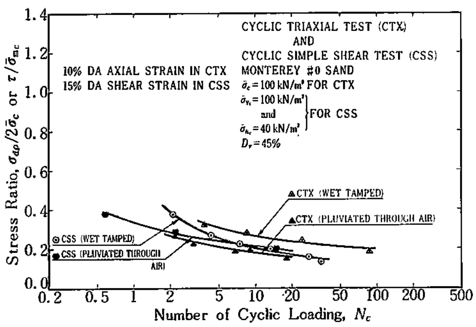


Fig. 22 Summary of Stress Ratio Versus Number of Cyclic Loading to 15% Double Amplitude Shear Strain for $D_r=45\%$

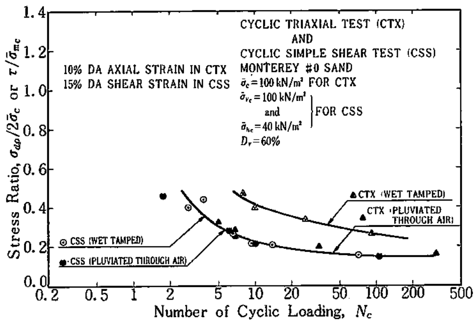


Fig. 23 Summary of Stress Ratio Versus Number of Cyclic Loading to 15% Double Amplitude Shear Strain for $D_r=60\%$

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where 10% double amplitude axial strains were observed in cyclic triaxial test and where 15% double amplitude shear strains were observed in cyclic simple shear tests. From these figures the following results are evident. First, for any density examined in this study, the cyclic triaxial strength obtained for wet tamped specimens was significantly larger than that obtained for specimens which were prepared by pluviating through air. This difference in strength increases with increasing density. Most notably the stress ratio for which 10% double amplitude axial strain is attained in wet tamped triaxial specimens of $D_r=$ 80% (Fig. 24) is much larger for all number of loading cycles observed.

Secondly, it may be seen from Fig. 22 that for $D_r=$ 45%, the simple shear strength of pluviated specimen is slightly less than that of wet tamped specimen. However, it can been seen from Figs. 22 through 24 that there is not a significant difference in cyclic undrained simple shear strength between wet tamped specimens and pluviated specimens for a wide range of relative density. Since the number of different sample preparation method examined in this study is rather limited, a general conclusion about the effect of sample preparation on cyclic undrained simple shear strength can not be derived from the test results by this study. However, it seems apparent that the effects of sample preparation method on cyclic undrained simple shear strength is not similar to that on cyclic undrained triaxial strength.

Finally, it can be seen from these figures that there is not a significant difference among cyclic undrained simple shear strength of wet tamped and pluviated specimen in the term of $\tau/\bar{\sigma}_{mc}$ and cyclic undrained triaxial strength of pluviated specimen in the term of $\sigma_{dp}/2\bar{\sigma}_c$ for $D_r=$ 45%, 60% and 80%.

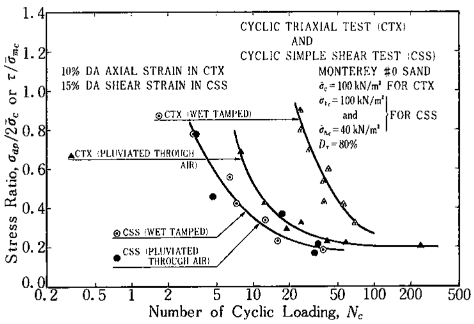


Fig. 24　Summary of Stress Ratio Versus Number of Cyclic Loading to 15% Double Amplitude Shear Strain for $D_r=$ 80%

To see more clearly the difference of strength among different testing methods, several other figures were prepared. Figs. 25, 26 and 27 show the relationship between strength for 15% double amplitude shear strain and relative density for numbers of cyclic loading of 5, 10 and 20, respectively. It can be seen from these figures that except for $D_r=$ 80%, the difference between cyclic triaxial strength

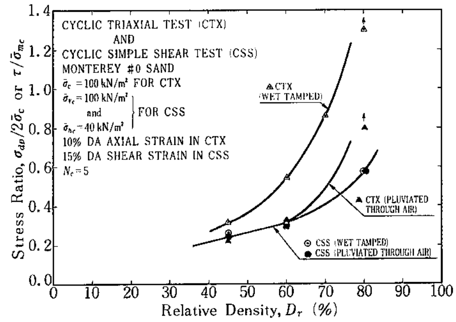


Fig. 25　Summary of Stress Ratio Versus Relative Density for 15% Double Amplitude Shear Strain at Number of Cyclic Loading of 5

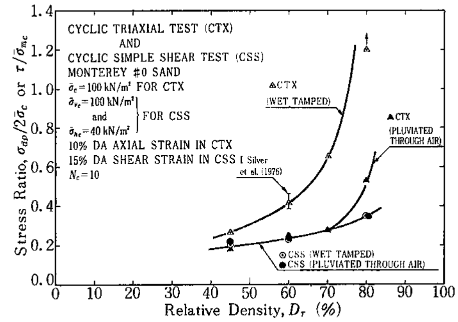


Fig. 26　Summary of Stress Ratio Versus Relative Density for 15% Double Amplitude Shear Strain at Number of Cyclic Loading of 10

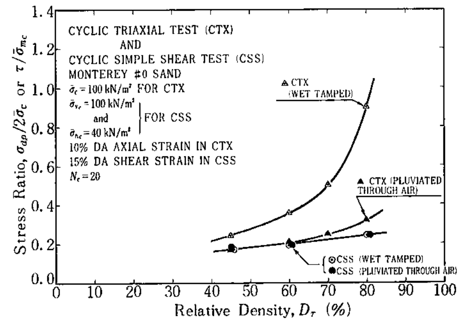


Fig. 27　Summary of Stress Ratio versus Relative Density for 15% Double Amplitude Shear Strain at Number of Cyclic Loading of 20

and simple shear strength is not significant for pluviated specimens. In addition, these figures show that the difference between cyclic triaxial strength and cyclic simple shear strength is significant for specimens for wet tamped specimens. This difference is more considerable for denser wet tamped specimens. The ratio of cyclic triaxial strength to cyclic simple shear strength for wet tamped specimens and pluviated specimens as a function of double amplitude shear strain are shown in Fig. 28 for number of cyclic loading of 10 and in Fig. 29 for number of cyclic loading of 20. The ratio increases with the increase in double amplitude shear strain. However, the ratio for pluviated specimens of $D_r =$ 45% and 60% is almost unity for numbers of cyclic loading of 10 and 20, irrespectively of the value of strain.

All these facts obtained from this study show that the relationship between cyclic undrained triaxial strength and cyclic undrained simple shear strength is not as simple as suggested in the previous papers (Peacock and Seed (1968), Finn et al (1970), Ishihara and Li (1972), Seed and Peacock (1971) and Seed (1979)). This relationship is apparently functions of sample preparation method, density, definition for failure and number of cyclic loading at least. However, it is likely that specimens of $D_r = 45\%$ and 60% reconsitituted by pluviating through air have a similar strength both for cyclic triaxial test and for cyclic simple shear test, irrespectively of density, number of cyclic loading and double amplitude strain used for defining failure. The laboratory sample preparation method of pluviating through air is much more similar to the way of depositing in flood plains or in uncompacted hydraulic fills than the method of wet tamping. Therefore, it may be anticipated that if undisturbed specimens obtained from alluvial deposits or uncompacted hydraulic fills were tested both with cyclic simple shear apparatus and with cyclic triaxial apparatus, strength would be very similar for both testing methods if the test results were summarized as in Figs. 22 through 24. However, for undisturbed specimens obtained from artificial fills which were made by a kind of tamping, different strength may be obtained depending on the method of testing, cyclic triaxial test or cyclic simple shear test.

To date, a considerable amount of cyclic undrained triaxial tests have been performed for undisturbed specimens obtained from alluvial sandy deposits and uncompacted hydraulic fills (Seed, Mori and Chan (1975), Ishihara, Silver and Kitagawa (1978) and Tatsuoka et al (1978)). It does not seem unreasonable from the test results obtained by this study to convert cyclic undrained triaxial strength to cyclic undrained simple shear strength for loose to medium sandy specimens which were obtained from alluvial deposits or uncompacted hydraulic fills, as suggested by Ishihara and Li (1972) and Ishibashi and Sherif (1974). In this case, equivalent cyclic undrained simple shear strength $\tau/\bar{\sigma}_{vc}$ is obtained from cyclic undrained triaxial strength $(\sigma_{dp}/2\bar{\sigma}_c)$ as

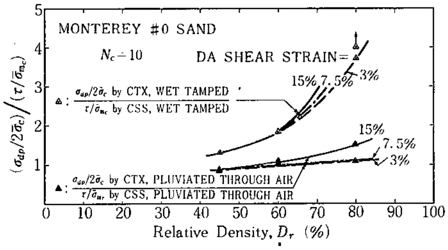


Fig. 28 Ratio of Cyclic Triaxial Strength to Cyclic Simple Shear Strength for Number of Cyclic Loading of 10

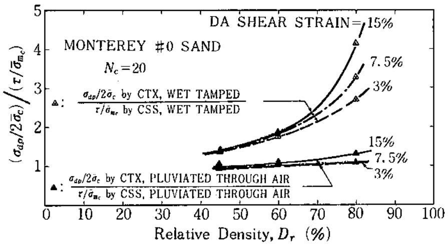


Fig. 29 Ratio of Cyclic Triaxial Strength to Cyclic Simple Shear Strength for Number of Cyclic Loading of 20

$$\frac{\tau}{\bar{\sigma}_{vc}} = \frac{\tau}{\bar{\sigma}_{vc}(1+2K_0)/3} \times (1+2K_0)/3$$

$$= \frac{\tau}{\bar{\sigma}_{mc}} \times (1+2K_0)/3$$

(Eq. 1)
$$= \left(\frac{\sigma_{dp}}{2\bar{\sigma}_c}\right) \times (1+2K_0)/3$$

in which $K_0$ is an estimated in situ coefficient of earth pressure prior to earthquake motion. However, it is likely that Equation 1 is questionable to apply to artificial fills which were made by a kind of tamping. Further investigation using undisturbed specimens will be nessessary to clarify these problems.

There are only a very limited number of other test results which can be compared directly with the test results obtained from this study. For cyclic triaxial test, other test results which were obtained for Monterey No. 0 Sand, the same sample preparation method, the same confining pressure and the same definition for failure were compared with the test results by this study. The cyclic tiraxial strengths of Monterey No. 0 Sand of $D_r = 50\%$ for 5% double amplitude axial strain at cycle 10 for $\bar{\sigma}_c = 100$ kN/m$^2$ which were reported by Mulilis et al (1977) are compared with the test results by this study in Fig. 30. The range of scatter of test results which were obtained by eight organizations is also shown in Fig. 26. The differences which are shown in Figs. 26 and 30 are well with in the scatter of the test results.

The test results by large simple shear tests reported by DeAlba et al (1976) are compared with the test results by this study for initial liquefaction in Fig. 31. Considering different consolidation stress condition between two testing methods and that reported values for large simple shear tests are those after theoretical corrections, difference seems very small despite of the fact that there is a large difference in sample size between these two testing methods.

From these comparisons, it seems that the test results obtained by this study are compared very closely with other test results.

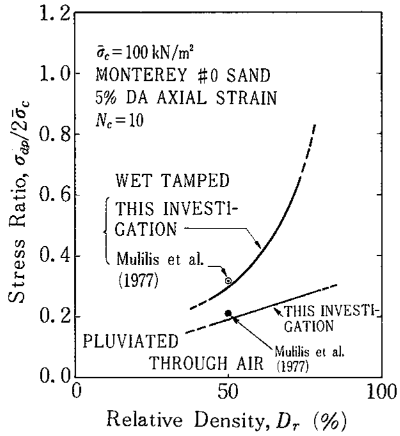


**Fig. 30 Comparison of the Test Results with Other Test Results for Cyclic Triaxial Test**

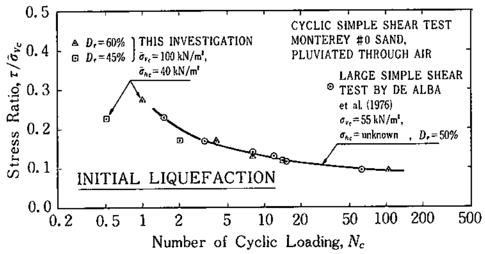


**Fig. 31 Comparison of the Test Results with Other Test Results for Cyclic Simple Shear Test**

## SUMMARY OF UNIFORM LOADING TESTS

The following conclusions were drawn from the test program. First, in triaxial tests, specimens prepared by compacting moist sand showed significantly greater resistance to cyclic undrained shear than specimens prepared by air pluviation. However, in simple shear test, the difference in strengths of specimens prepared by wet tamping and air pluviation was negligible. Therefore, the ratio of cyclic undrained strength under simple shear test conditions to cyclic undrained strength under triaxial test condisions is significantly affected by the sample preparation method. It was also found that for loose to medium specimens prepared by air pluviation cyclic undrained simple shear strength values were almost identical to cyclic undrained triaxial strength values when maximum cyclic shear stress devided by mean effective principal stress at consolidation was used as cyclic stress ratio for both tests. These results show that the cyclic undrained triaxial strength of sand prepared by compacting moist soil may give an overestimate of the liquefaction strength in horizontal sand deposits for which the simple shear simulation is an appropriate measure of cyclic strength.

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