Effect of soil properties on cyclic behaviors of intermediate soils in triaxial and torsional tests

M. A. El Mesmary, student member of JSCE, Osaka University
Y. Nabeshima, member of JSCE, Osaka University
T. Matsui, fellow of JSCE, Osaka University
Y. Shinkawa, student member of JSCE, Osaka University

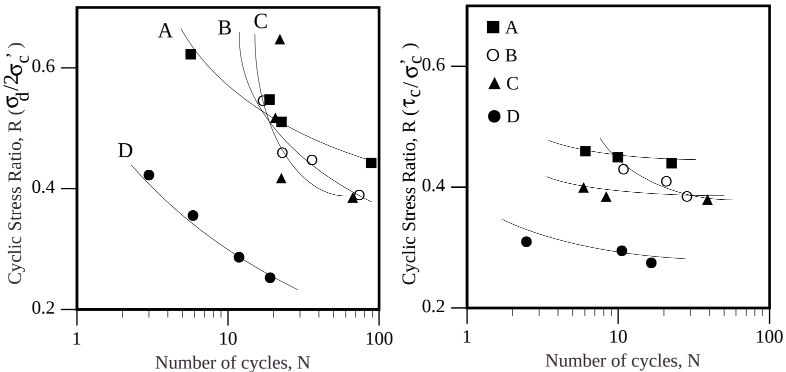
1. Introduction: Since the liquefaction phenomena have been reported due to recent earthquakes in reclaimed deposits which are composed of intermediate soils, their cyclic shear characteristics are highly needed to be elucidated. There is no definite criterion for evaluating the cyclic behavior of such soils. The effect of soil properties on the cyclic strength of intermediate soils has been studied by many researchers using different devices (Ishihara and Koseki 1989, Kuwano et al. 1996, Sato et al. 1996, Guo and Prakash 1999 and Tanaka 1999). The outcome of these studies is that there is confusion on the influence of fine content, clay content, activity and plasticity on the cyclic strength for intermediate soils. In this study, the results of cyclic triaxial and torsional shear tests are compared and the effect of soil properties on the cyclic behaviors of intermediate soils is also discussed.

2. Testing procedure: A series of cyclic triaxial and torsional shear tests was carried out on intermediate soils. They were prepared in the laboratory by mixing sand, silt and clay by weight to control the physical properties of the specimens as shown in Table 1. Both triaxial and torsional specimens were made by moist tamping method.They were prepared at optimum water content and then subjected to compaction energy of 2.4 MPa to achieve the maximum dry density according to the compaction test results. In triaxial tests, solid specimens with 5cm in diameter and 10cm in height were used, while hollow cylindrical specimens with outer and inner diameters of 7.5cm and 4.2cm and 15cm in height were used in torsional tests. The cyclic loading in triaxial and torsional tests was applied under effective cell pressure,σ'_c=98.1kPa and frequency, f=0.1Hz.The deviatoric and shear stresses, σ_d and τ_c were kept constant during stress control cyclic loading in triaxial and torsional tests, respectively. The applied cyclic stress ratio, R in triaxial ($\sigma_d/2\sigma'_c$) and torsional (τ_c/σ'_c) tests in addition to the summarized results are demonstrated in Table 1.

Table1 Properties of tested soils in addition to loading conditions and results.

Soils	P_c (%)	F_c (%)	PI	A	R		$\Delta u/\sigma'_c$		R_u	
					$\sigma_d/2\sigma'_c$	τ_c/σ'_c	(Tri.)	(Tor.)	(Tri.)	(Tor.)
A	19.7	44.2	27.9	1.7	0.623 0.548 0.511 0.443	0.46 0.45 0.44 ---	0.994 1.0 0.999 0.995	0.879 0.85 0.867 ---	0.526	0.442
B	19.3	44.8	12.0	0.7	0.546 0.460 0.448 0.390	0.43 0.41 0.385 ---	0.983 0.987 0.985 0.999	0.877 0.85 0.923 ---	0.492	0.397
C	5.8	45.0	2.6	2.0	0.648 0.518 0.418 0.386	0.40 0.385 0.380 ---	1.0 1.0 0.996 1.0	0.897 0.887 0.866 ---	0.469	0.381
D	31.7	48.5	15.7	0.6	0.423 0.356 0.287 0.253	0.31 0.295 0.275 ---	0.87 0.87 0.952 0.961	0.70 0.884 0.80 ---	0.253	0.275

3. Results and discussion: The outcome of the test program is illustrated in Fig. 1 where the cyclic stress ratio, R is plotted against the number of cycles, N to cause 5% double-amplitude, DA axial and shear strain in triaxial and torsional tests, respectively. The solid lines in Fig. 1 give the cyclic strength curve or liquefaction curve for each soil. Although the tested soils have almost the same fine content F_c, the cyclic strength curves are located differently. This is contrary to that given by Sato et al. (1996) who found that the cyclic strength decreased with the increase of fine content. It can be noticed that the rate of decreasing R with number of cycles in triaxial tests is bigger than that in torsional tests. The cyclic strength, R_u or the cyclic stress ratio to cause DA=5% axial or shear strain in 20 cycles of loading is decided from Fig. 1 for both triaxial and torsional tests. The effect of such soil properties as fine content F_c, clay content P_c, activity A and plasticity index PI on the cyclic strength in both triaxial and torsional tests is shown in Fig. 2. It can be seen in Fig. 2(a) that the fine content is unable to judge the cyclic strength. In the range of clay content and activity tested in this study, the cyclic strength tends to decrease as increasing clay



(a)Triaxial tests (b)Torsional tests

Fig. 1 Variation of cyclic stress ratio with number of cycles to cause 5% DA axial and shear strain in triaxial and torsional tests.

Keywords: Cyclic loading, Intermediate soil, Soil properties, Triaxial and torsional tests. Address: 2-1 Yamadaoka, Suita, Osaka, 565-0871

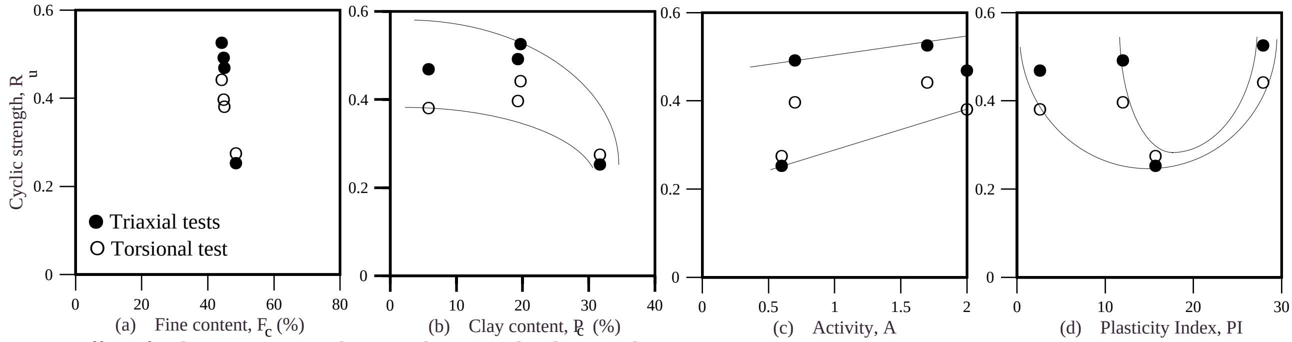


Fig. 2 Effect of soil properties on cyclic strength in triaxial and torsional tests.

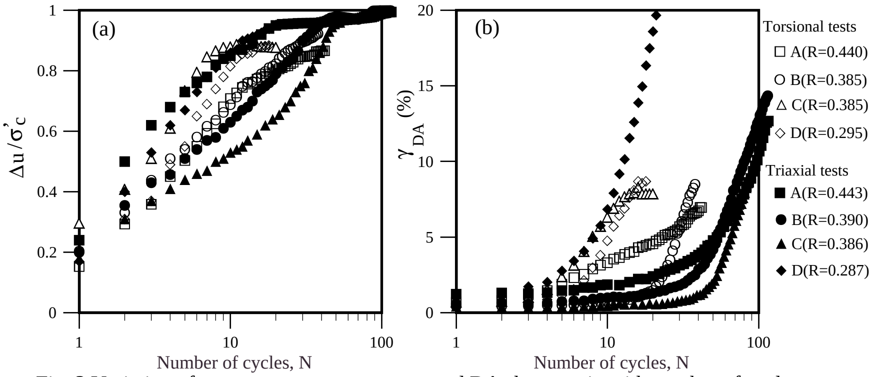


Fig. 3 Variation of excess pore water pressure and DA shear strain with number of cycles during cyclic triaxial and torsional tests.

content and to increase as increasing activity, as shown in Fig. 2(b) and (c). This tendency is identical for both triaxial and torsional test results. In the lower plasticity range, the increase of PI decreases the cyclic strength while in the higher plasticity range, the increase of PI increases the cyclic strength. This conclusion is also consistent with that given by Guo and Prakash (1999).The development of the excess pore water pressure, $\Delta u/\sigma'_c$ and DA shear strain, γ_{DA} with number of cycles during cyclic loading is shown in Fig. 3 for specimens loaded under almost the same cyclic stress ratio R in both triaxial and torsional tests. The same test results is also summarized in Fig. 4 to demonstrate the variation of γ_{DA} with number of cycles, N at 80%, 85% and 90% of $\Delta u/\sigma'_c$ during cyclic triaxial and torsional tests.The induced pore water pressure during cyclic torsional tests is almost under 90%, while almost 100% pore water pressure can be achieved in cyclic triaxial tests. It can be observed that the higher the clay content, the higher the rate of build-up of pore water pressure and DA strain during cyclic loading especially in triaxial tests. Also it can be noticed that for a certain level of built-up excess pore pressure, the developed DA shear strain in torsional tests is higher or almost equal to that in triaxial tests.

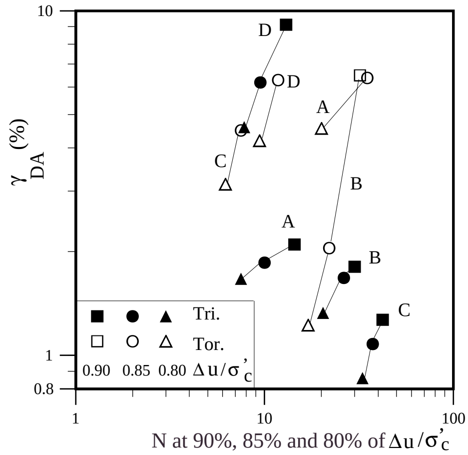


Fig. 4 Comparison between development of induced excess pore water pressure and DA shear strain during cyclic triaxial and torsional loading with number of cycles.

4. Conclusions: 1) The cyclic strength and the development of induced excess pore pressure are different in both triaxial and torsional cyclic loading tests. 2) The fine content is unable to judge the liquefaction strength and the cyclic strength decreases as increasing clay content or decreasing activity. 3) In the lower plasticity range, the increase of PI decreases the cyclic strength, while in the higher plasticity range the increase of PI increases the cyclic strength. 4) The higher the clay content, the higher the rate of build-up of pore water pressure and DA strain during cyclic loading.

5. References: 1) Guo, T. and Prakash, S. (1999). “Liquefaction of silts and silt-clay mixtures.” J. Geotech. Eng. 125(8), 706-710. 2) Ishihara, K., and Koseki, J. (1989).”Cyclic shear strength of fines-containing sands.” Proc. of Earthquake and Geotech. Eng., JSSMFE, Tokyo, 101-106. 3) Kuwano, J., Nakano, H., Sugihara, K. and Yabe, H. (1996). “Factors affecting undrained cyclic strength of sand containing fines.” Proc. of 31th Annual Meeting of Japanese Geotech. Society, 989-990(in Japanese) 4) Sato, M., Ozeki, K., Oda, M., Kazama, H. and Shibata, M. (1996). “Effects of fines on undrained cyclic shear strength of reclaimed sand (Phase-2).” Proc. of 31th Annual Meeting of Japanese Geotech. Society, 975-976(in Japanese) 5) Tanaka, Y. (1999). “Liquefaction properties of well graded course fill materials.” Proc. 9th Int. Offshore and Polar Eng. Conf., Brest, Vol.(1), 562-567.