Variation of liquefaction resistance between liquefaction and reliquefaction processes from the viewpoint of the stress paths

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1. Introduction

Liquefaction disasters attacked many areas in the 2016 Kumamoto earthquakes. The two major shocks were considered as a very important factor for causing the extreme damages in the earthquakes base on the results of field investigations after the earthquakes. The foreshock could be regarded as a kind of pre-shear for the ground while mainshock coming. Some researchers conducted the static triaxial compression tests and torsion tests disclosed that the resistance of soil liquefaction was affected greatly depended on the load conditions in pre-shearing period. (F. Tatsuoka and S. O-hara, etc. 1974,1975, K. Ishihara and S. Okada 1982; B. Ye, J.F. Lu, etc. 2015.)

2. Cyclic triaxial compression tests and results

To the further detect this phenomenon, the cyclic triaxial compression tests was conducted to make the soils suffered by two serious of cyclic loads to simulate the two shocks in the 2016 Kumamoto earthquakes. Toyoura sand was carried for the materials to make it to be liquefied two times in the tests, and detailed conditions were arranged in Table 1.

The sand in each case was prepared carefully by using the CO_2 for achieving a very high saturation degree. Cyclic stress ratio (CSR) $\sigma_d/2\sigma'_0$ was set a same value between first liquefaction and re-liquefaction tests meanwhile the CSR changed in different cases. The subscript "$_1$" and "$_2$" indicates the different conditions measured just before the two cyclic loads applications. It is easy to find that the relative densities increased 5% ~7% in all cases. The sand was compacted by drain consolidation after first liquefaction tests and make the sand denser for second liquefaction tests. However, the liquefaction resistances defined by while the axial strain with both amplitudes was equal to 5% (DA. = 5%) dropped significantly in second tests. In the first liquefaction tests, the liquefaction resistances correspond a linear relationship by different cyclic stress ratio (CSR) in the sand with the similar relative densities. In the second tests, on the contrary, the liquefaction resistances located at Nc = 15 or its vicinity in most cases no matter how much of the CSR and relative density.

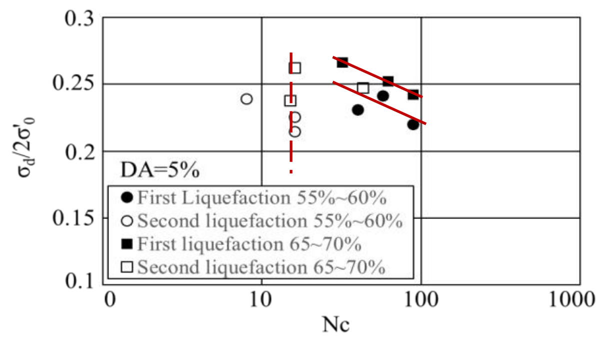

Fig. 1. Comparison for liquefaction resistances of sands in first liquefaction and re-liquefaction

Table 1. Conditions of test materials

	Gs	*e*$_{01}$	*Dr.*$_1$ *(%)*	ρ_{sat1} *(kg/m*^{3}*)*	*B value*	*e*$_{02}$	*Dr.*$_2$ *(%)*	ρ_{sat2} *(kg/m*^{3}*)*	$\sigma_d/2\sigma'_0$
C-1	2.643	0.760	58.4	1933.90	0.954	0.738	64.4	1945.92	0.242
C-2	2.643	0.753	60.4	1937.87	0.939	0.731	66.4	1949.96	0.231
C-3	2.643	0.752	60.6	1938.33	0.976	0.727	67.4	1951.87	0.220
C-4	2.643	0.734	65.5	1948.13	0.961	0.715	70.7	1958.83	0.267
C-5	2.643	0.727	67.4	1951.97	0.960	0.706	73.1	1963.68	0.252
C-6	2.643	0.725	67.9	1952.98	0.958	0.704	73.6	1964.81	0.243

3. Behaviors of stress path in reliquefaction process

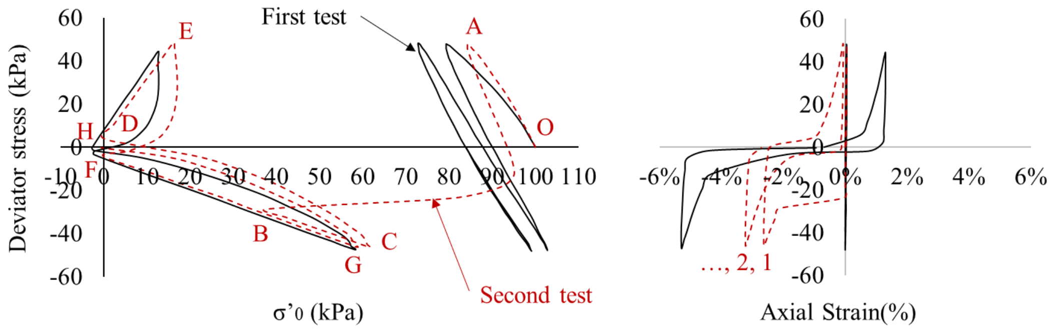

Fig. 2. Example of the stress paths during liquefaction and reliquefaction process

Key words: sandy soil, cyclic triaxial compression test, reliquefaction, liquefaction resistance, stress path.
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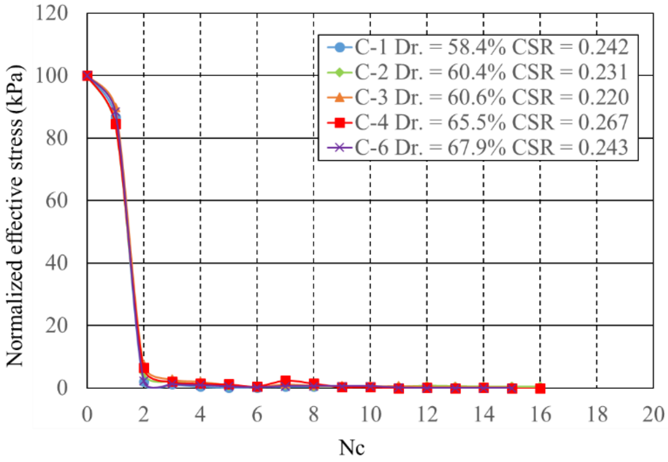

Fig. 3. Variation of minimum effective stress in each load cycles during reliquefaction process

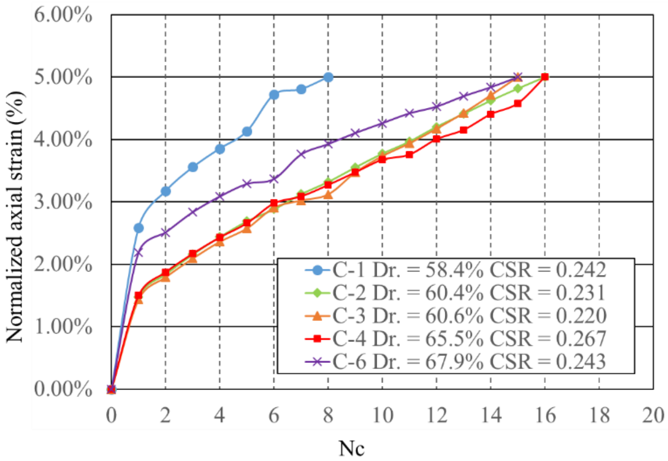

Fig. 4. Variation of maximum axial strain in each load cycles during reliquefaction process

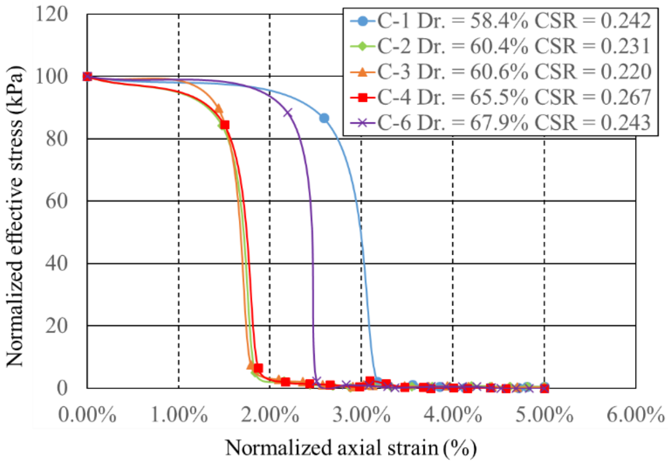

Fig. 5. Variation of maximum axial strain in each load cycles during reliquefaction process

In order to explain the reasons for the greatly drooping of liquefaction resistance in reliquefaction process, as the first step, the stress path in the second test process is very worthful to discuss to find what happened of the sand during this process. The stress path of effective stress and axial strain varied with deviator stress was made at first. For eliminating the distractions form too many cyclic loads during test process, the tress path drew from the first two load cycles and last cycle in first processes were carried with black solid line in Fig. 2. And the paths from the first two load cycles in reliquefaction process were drew with red dash line in this figure. Concerned about the left graph, the stress path developed along with “O→H’ within the two load cycles. It could be found that the effective stress decreases very fast at the tensile direction of the cyclic load in the first load cycles. Meanwhile the effective stress approximately reduces to zero at the final state of second load cycle. The generated minimum effective stress in each load cycles were arranged in Fig. 3. Although the different test conditions were given to different cases, the variation of effective stresses exhibit the same results. They dropped very quickly with a similar rate between the first and second load cycles. At the same time, the generated maximum axial strain in each load cycles depended on the right graph in Fig. 2. were arranged in Fig. 4 as well. The results showed different behaviors with the effective stress. The greatest axial strain produced within first load cycle, however, the increasement became relative gently and kept a variation rate with the near linear relationship until it arrived at DA. = 5%. The relations between the effective stress and axial strain were arranged in Fig. 5., where indicates the similar results.

Conclusions

Several sandy soils with very high saturation degrees were conducted by liquefaction and reliquefaction tests under cyclic compression apparatus. The results indicate majorly: a) Liquefaction resistance dropped greatly in reliquefaction process; b) The effective stress decreased significantly within first two load cycles during reliquefaciotn process; c) however, the greatest axial strain occurred within the first load cycle.

Acknowledgments

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