EFFECTS OF PRE-SHEAR HISTORY ON REPEATED LIQUEFACTION BEHAVIOR OF DENSE SAND USING HOLLOW CYLINDRICAL TORSIONAL SHEAR APPARATUS

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1. INTRODUCTION

Numbers of studies have been done on evaluating the resistance of liquefaction on sandy grounds while most cases were focused on loose sand since it was well known that liquefaction tended to occur in young sandy deposits during earthquakes. Recently, however, in constructions of some important or special structures such as nuclear power plant, it was realized that the evaluation of liquefaction resistance of dense sand was of great importance as well while such study and data were relatively rare. Due to the ageing effect which includes different liquefaction and consolidation histories, dense sandy ground may show totally different behavior during coming earthquakes. Therefore, in order to evaluate liquefaction characteristics of dense sand as well as the influence of pre-shear history, a series of undrained cyclic shear tests were conducted on dense sand samples that experienced different pre-shear histories.

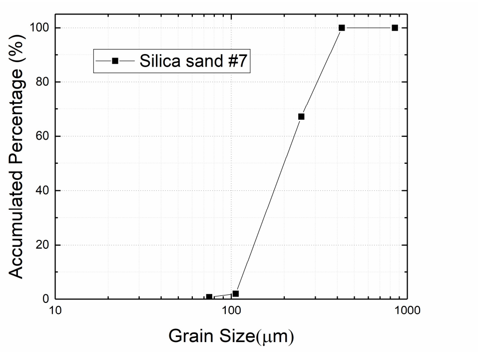

Fig. 1 Grain size distribution of silica sand #7

2. EQUIPMENT AND MATERIAL

Hollow cylindrical torsional shear apparatus was applied in this study while the specimen had the height of 300 mm, the outer diameter of 200 mm and the inner diameter of 120 mm. Silica sand #7 was used to make the specimen which has a specific gravity of 2.648, mean diameter of 0.2 mm, max. void ratio of 1.211 and min. void ratio of 0.700. The grain size distribution of silica sand #7 is shown in Fig. 1.

3. METHODOLOGY

As shown in Fig. 2, the specimen was prepared by air-pluviation method with an initial relative density around 80% and kept under double vacuum for one night for the purpose of better saturation. After being fully saturated on the next day, B value no less than 0.96 was checked with a back pressure of 200 kPa and then the specimen was consolidated in isotropic condition with an initial effective stress of 100 kPa. Different types of pre-shear histories were then applied before the undrained cyclic torsional shear. For the purpose of examining the influence of different pre-shear histories, the main undrained cyclic loading was conducted while keep the height of specimen constant with the same CSR of 1.0, γ_{DAmax} of 7.5%, and constant loading rate of 0.85%/min in all the tests. Moreover, in order to study the influence on the following liquefaction stages, reconsolidation and repeated liquefaction tests were conducted after the first stage of main cyclic shear but no longer with the pre-shear after reconsolidation.

Ishihara and Okada (1978) defined small and large strain history by using the phase transformation line and therefore in this study, two kinds of pre-shear histories were applied: one was small strain histories with large cyclic numbers in drained condition while another kind was isolated undrained liquefaction histories with the γ_{DA} of 2% which representing the large strain history.

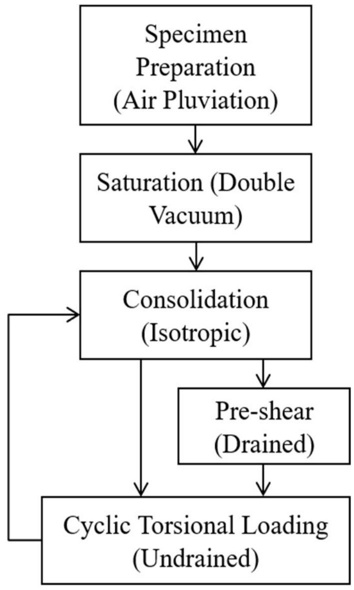

Fig. 2 Flow chart of the test

4. RESULTS AND DISCUSSIONS

As the reference for comparison, a series of repeated liquefaction tests without pre-shear history were conducted. The stress-strain relationship in Fig. 3 shows that under such high CSR of 1.0, γ_{DAmax} was reached after only 2 cycles of torsional shear and the specimen showed the phase transformation (i.e. from negative to positive dilatancy) during the undrained cyclic loading.

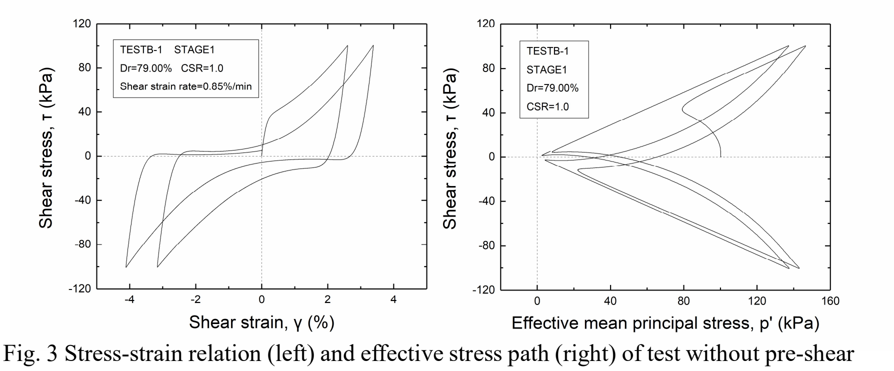

Fig. 3 Stress-strain relation (left) and effective stress path (right) of test without pre-shear

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4.1 Effect of drained small strain pre-shear history

Table 1 shows the detail of tests with different pre-shear histories and their influences on the first stage of liquefaction tests. These tests were put into the same group in that the strain amplitude of these pre-shears were quite limited but the cyclic numbers were large and the pre-shear were conducted under drained condition while keeping the effective stress without obvious change. Relative density of the specimen did not change significantly after these small strain pre-shear, however, the liquefaction resistance showed the increase in varying degrees respectively.

Table 1 Details of tests with small strain pre-shear history

Test number	Pre-shear history	Excess pore pressure ratio induced in the 1st cycle	γ_{DA} induced in the 1st cycle	Cycle numbers to cause γ_{DAmax}
B-1	No	78%	5.76%	1.8
B-6	γ_{DA}=0.2% ×100cycles	66%	5.33%	2.16
B-7	γ_{DA}=0.6% ×100cycles	43%	4.25%	3.42
B-8	γ_{DA}=0.6% ×200cycles	2%	1.63%	15.27

4.2 Effect of isolated liquefaction histories

Test B-9 was conducted with another type of pre-shear which included 15 times isolated undrained repeated liquefaction histories with a γ_{DAmax} of 2%. As shown in Fig. 4, this special test was started with the specimen prepared in relatively lower density and finally reached similar relative density of 80% before the main cyclic shear with a γ_{DAmax} of 7.5%. Test results showed the liquefaction resistance in the 1st stage of main cyclic shear was increased sharply but soon dropped in the 2nd stage.

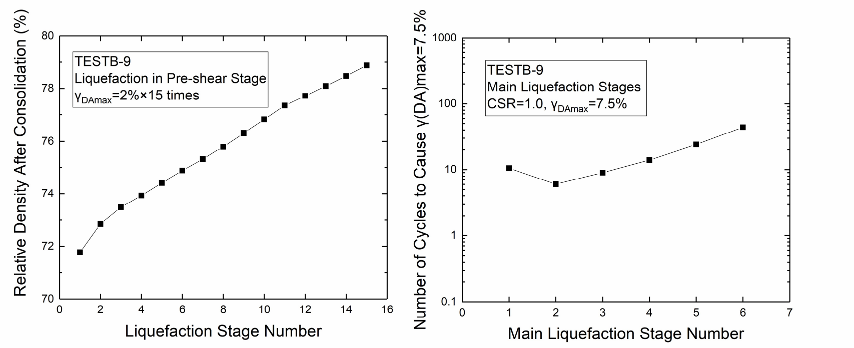

Fig. 4 Density change in pre-shear stages (left)and number of cycles to reach γ_{DAmax} in main liquefaction stages (right) of Test B-9

4.3 Comparison of different pre-shear histories

Fig. 5 shows the relationship between the number of cycles to reach γ_{DAmax} of 7.5% and relative density in different stages of repeated liquefaction tests. Results of test B-6 and B-8 show that when the amplitude and cyclic numbers were small, the effect of pre-shear history was quite negligible while with increases in strain amplitude and cyclic numbers, the liquefaction resistance of the sand specimen increased noticeably. However, the effect of this kind of small strain pre-shear history seemed to exist only the immediately following stage of liquefaction tests in that from the 2nd stage they all showed almost consistent behavior of tests without pre-shear history. Similar results were found by Wahyudi and Koseki (2013) using stacked ring apparatus on loose sand.

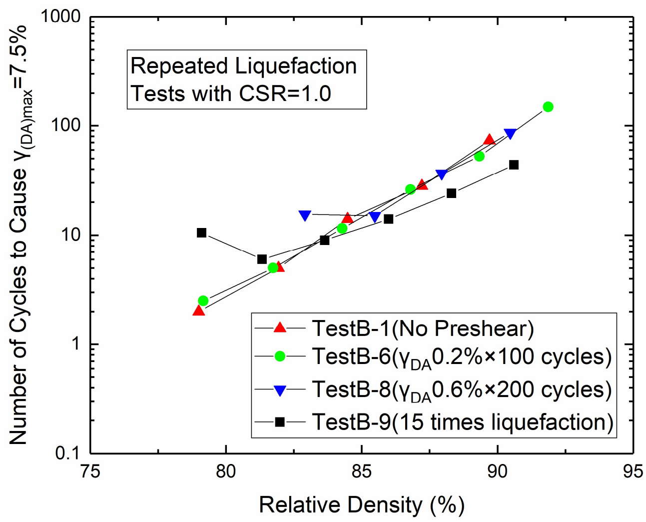

Fig. 5 Relationship between relative density and number of cycles to reach γ_{DAmax} of 7.5%

By contrast, test B-9 with several isolated liquefaction histories behaved differently. The liquefaction resistance in the 1st stage of main cyclic shear was influenced obviously while its following stages seemed to be affected slightly as well. However, it is also necessary to clarify whether all the 15 times liquefaction histories with the γ_{DA} of 2% had effects on the behavior of the specimen in the coming stages of main cyclic loading or the sample was barely affected by the last 1 or 2 stages of pre-shear.

5. CONCLUSIONS

The liquefaction resistance of dense sand is influenced by the pre-shear history considerably and the increase in cyclic numbers of pre-shear seems to have larger effect rather than the increase in strain amplitude. Large strain history seemed to have different effects to the following stages of liquefaction compared with that of small strain history.

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