EFFECTS OF PRE-SHEARING HISTORY ON RE-LIQUEFACTION BEHAVIOR OF LOOSE SAND USING STACKED-RING SHEAR APPARATUS

University of Tokyo, Student Member, ○ Seto Wahyudi
University of Tokyo, Member, Junichi Koseki

1. INTRODUCTION

The issue on re-liquefaction phenomenon, in which soil can liquefy repeatedly from one time to another, has been re-emerged in post 2011 Great East Japan Earthquake. It was reported that liquefaction had re-occurred at 150 sites during the period from year of 745 to 2008 throughout Japan while 60 cases of re-liquefaction were also found in recent 2011 Great East Japan Earthquake disaster (Wakamatsu, 2012). These evidences raised concern among researchers about the potential danger of re-liquefaction that might happen in the future big earthquake. Therefore, this paper is aimed to investigate the effects of pre-shearing history on the re-liquefaction behavior of sand using newly developed machine so called stacked-rings shear apparatus. This new apparatus enables us to project qualitatively the behavior of soil against re-liquefaction in long future.

2. EXPERIMENT PROCEDURES

The stacked-rings shear apparatus is shown in Fig. 1. The normal stress is controlled by pneumatic system while torque is controlled by magnetic-driven motor system. The capacity of normal and torque loads are 30 kN and 1500 N.m, respectively. The specimen is confined in between two stacked-rings, which are inner and outer parts. Each part is composed of 31 pieces of vertically stacked annular ring having the thickness of 5mm. Each ring is free to move in circumferential direction, but constrained in radial direction. The inner and outer diameters of the specimen are 90mm and 150mm, respectively, while the height is 155mm. Air-dried Toyoura sand was used as the test material prepared by air pluviation method. Five specimens having the initial relative density of about Dr_0= 55% (e_0=0.793) were tested. Each of them was sheared with cyclically shear strain double amplitudes of 2%, 3%, 4%, 7% and 10%, respectively.

To conduct a re-liquefaction test, the specimen was consolidated one-dimensionally up to 200 kPa of vertical stress prior to the application of cyclic shear loading. Then, cyclic shear stress of 10 kPa is applied to the specimen under constant volume condition. In this study, the liquefaction was defined as the state whenever the double amplitude of shear strain reached 2.0%. The liquefaction stage was completed by applying another half cycle of shear loading to the origin (γ=0). The next liquefaction stage continued by following the same procedure as the one described in the first liquefaction stage.

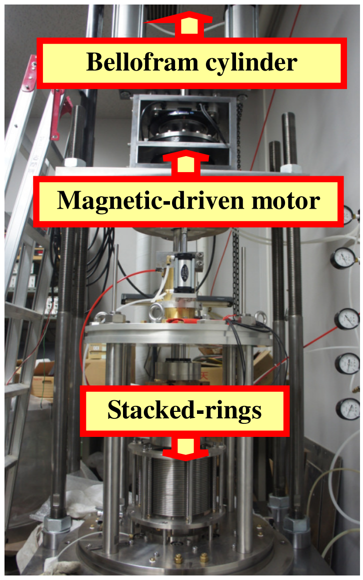

Fig. 1: Stacked-rings shear apparatus

3. TEST RESULTS AND DISCUSSION

To impart the pre-shearing history into the specimens, each of them was sheared with a pre-fixed maximum shear strain double amplitude ($\gamma_{DA(Max.)}$). Figure 2 shows one of the examples of typical result on re-liquefied sand sheared with 2% maximum shear strain double amplitude ($\gamma_{DA(Max.\ 2.0\%)}$). On each liquefaction stage, the numbers of loading cycle until the liquefaction and the changes in specimen's density due to re-consolidation process in post liquefaction were evaluated.

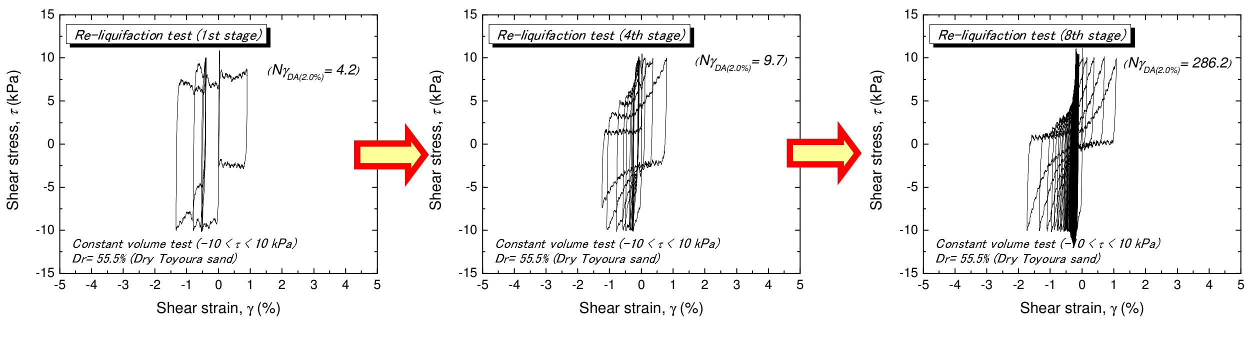

Fig. 2: Typical results of a re-liquefaction test at stages 1, 4 and 8 (Stages 2, 3, 5, 6, and 7 are skipped)

Figure 3(a) shows the change of number of cycle to liquefy with the liquefaction stage while Fig. 3(b) shows the corresponding change in the specimen's density. The latter figure shows that the specimen's density increased almost linearly in all tests. This figure indicates that the larger the shear strain applied, the larger the increase of the specimen's density. The relationship between re-liquefaction resistance and the change in specimen's density is plotted in Fig. 4(a). This figure shows that the increase of the specimen's density did not directly translate to the increase of liquefaction resistance at least during early stages. However, the liquefaction resistance increased exponentially at one point when the liquefaction stage continues further. It can be noticed that, the larger the shear strain history applied, the weaker the soil resistance against re-liquefaction. Figure 4(a) also shows the comparison between the liquefaction resistance of re-liquefied soils and a reference soil that liquefied for the first time. In the latter stages, the resistance of the re-liquefied soil was stronger than the reference soils in all tests. This may suggest that pre-shearing history also contributes to the increase of re-liquefaction resistance of sand as compared with the reference soil. The detail behavior on the re-liquefaction resistance during early stages can be seen in Fig. 4(b). This figure shows no clear correlation between the re-liquefaction resistance of soil and the increase of soil density. The possible reason was the changes of soil structure induced by the pre-shearing history during previous liquefaction became more predominant factor than the increase of soil density. The larger the soil deformed, the greater the changes in soil structure. From this figure, it can be noticed that the 2nd stage is the weakest stage against re-liquefaction in all tests, except the test on the specimen sheared with 4.0 shear strain double amplitude. However, it is expected when the specimens become denser and denser in the further stages, the soil resistance against re-liquefaction will become stronger.

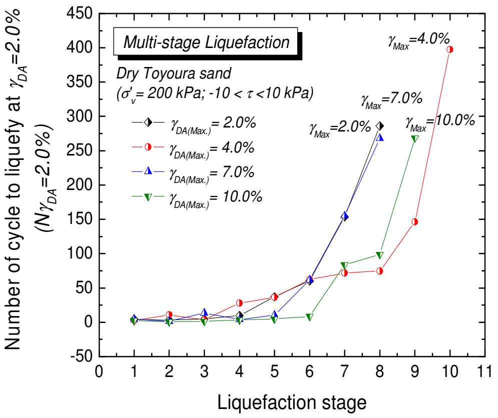

Fig. 3(a): Liq. resistance & liq. stage

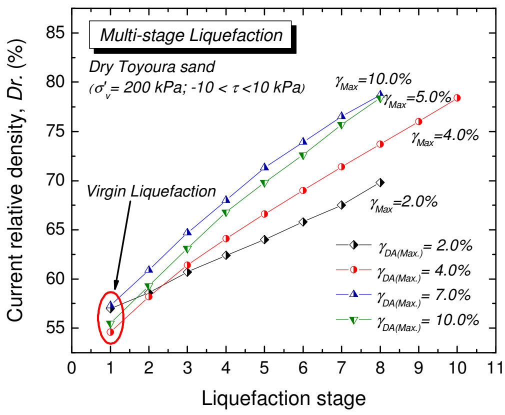

Fig. 3(b): Change density & liq. stage

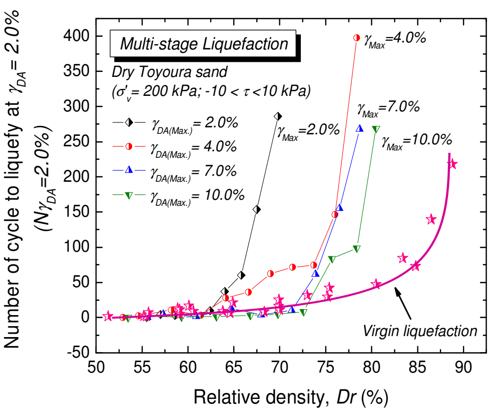

Fig. 4(a): Liq. resistance & density relationship

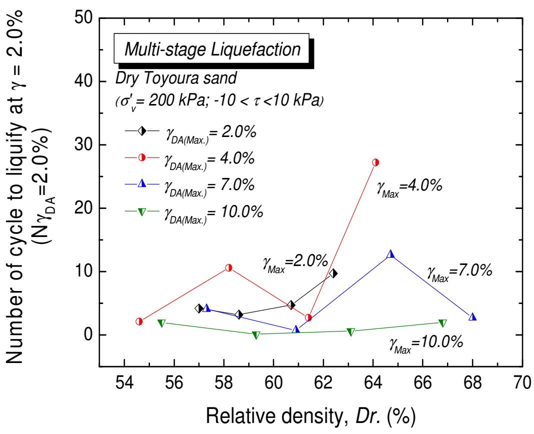

Fig. 4(b):Liq. resistance & density in early stage

4. CONCLUSIONS

The investigation on the effects of pre-shearing history in the re-liquefaction behavior of sand revealed several observations, which are: 1.) The re-liquefaction resistance of sand is significantly affected by the pre-shearing history of soil, in which the larger the deformation of soil during the previous liquefaction, the weaker the soil resistance against re-liquefaction; 2.) The behavior of re-liquefied soils in the early stages may imply that changes in soil structure could play more important role than the increase of soil density in determining their resistance; 3.) However, it is expected as liquefaction stage goes further, the resistance of soil against re-liquefaction will increase exponentially.

5. REFERENCE

Wakamatsu, K.: Recurrent liquefaction induced by the 2011 Great East Japan Earthquake compared with the 1987 earthquake. *Proc. of Intl. Symp. On Eng. Lessons Learned from 2011 Great East Japan Earthquake*, 2012, pp. 675-686.