DEVELOPMENT OF STACKED-RING SHEAR APPARATUS IN THE INVESTIGATION ON CHARACTERISTICS OF RE-LIQUEFIED SAND

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

1. INTRODUCTION

Recently, the re-liquefaction phenomenon has been re-emerged to be one of the major issues in geotechnical engineering field. It was reported that liquefaction had re-occurred at least 60 sites in 2011 during Great East Japan Earthquake Disaster alone. These evidences raised concern among researchers about the potential danger of re-liquefaction that might occur in the future large earthquake.

Wahyudi and Koseki (2013) had investigated the characteristics of re-liquefied soil using so called stacked-ring shear apparatus. In this early study, a couple of important observations have been found in the characteristics of re-liquefied soil. However, large friction was generated due to the nature of the apparatus itself and the size of the specimen in the original setting of the testing apparatus. Therefore, this paper aims to report the latest development on the stacked-ring shear apparatus for the investigation of re-liquefaction behavior of sand.

2. TEST PROCEDURES

The newly developed stacked-ring shear apparatus is shown in Fig. 1. The axial load and torque have the capacity of 30 kN and 1500 N.m, respectively. Two load cells were installed in this apparatus to measure the axial load and the torque at both top and bottom of the specimen. The differences of the measured stresses in both load cells will be used later to observe the reduction of vertical stress (σ_v) due to friction between soil particles and metal rings mobilized during the test.

An annular specimen is placed in between inner and outer parts of the stacked rings. Each ring has the thickness of 5 mm and is able to move independently in the circumferential direction while constrained in the vertical direction. The inner and outer diameters of the specimen are 90 mm and 150 mm, respectively, and the height of the specimen is 55 mm (=11 pieces of stacked rings).

Toyoura sand was used as the test material. Four specimens were prepared by air pluviation method having the initial relative density (Dr_0) in the range of 53% - 56%. Each specimen was sheared cyclically while keeping the specimen volume constant until the shear strain double amplitudes ($\gamma_{DA.Max}$) exceeded 2.0%, 5.0%, 7.0% and 10.0%, respectively.

To conduct a multiple-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 25.0 kPa was applied to the specimen under constant volume condition. In this study, liquefaction is 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-ring shear apparatus

3. TEST RESULTS AND DISCUSSIONS

In the stacked-ring shear apparatus, the use of rigid boundaries naturally induces friction between metal ring and soil particles. This friction consequently reduces the vertical stress (σ_v) applied to the specimen. Therefore, the vertical stress measured at the bottom load cell is always lesser than the one applied at the top one. In the early studies, Wahyudi and Koseki (2013) had conducted multiple-liquefaction tests using 31 pieces (155 mm high) of non-coated stacked rings. However, this setting generated excessive friction as will be discussed later. Current study was executed by using 11 pieces (55 mm high) of coated stacked rings. The new rings were coated with so-called DLC material (Diamond-Like Coating) having frictional coefficient of 1 (μ =1) while the original non-coated ring has frictional coefficient of 4 (μ =4). The combination on the reduction of specimen height as well as the reduction of frictional coefficient were expected to be able to reduce the excessive friction of the

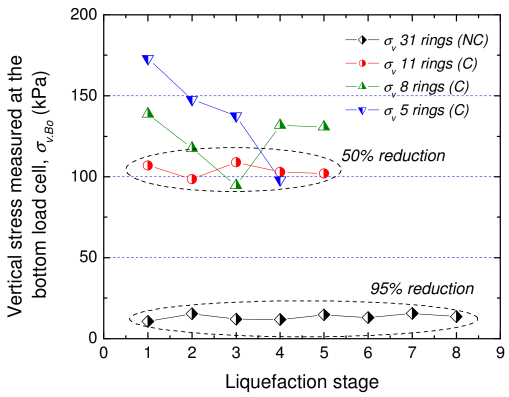

Fig. 2: Vertical stress at the bottom of specimen

latest stacked-ring shear apparatus. Figure 2 shows the comparison of vertical stress measured at the bottom of specimen of 5, 8, 11 rings of coated types and 31 rings of non-coated type after re-consolidation of the specimen before each liquefaction stage. About 95% of the vertical stress was lost due to friction with the 31 rings of non-coated type, while about 50% of vertical stress was lost with the 11 rings of coated type. The 50% reduction of applied vertical stress with the 11 rings is still considerably large, however, this was considered as the optimum choice in the latest development of the testing apparatus. On the rest of 5 and 8 coated ring types, the lost of vertical stress were less than 11 rings type, however, its reduction were not constant on each liquefaction stages.

As mentioned earlier, Wahyudi and Koseki, 2013 had revealed at least two major findings on the characteristics of re-liquefied sand. The summary of these findings can be seen in Fig. 3. First, this figure shows that the density increase in post re-liquefaction has marginal impact on determining the liquefaction resistance of re-liquefied sand. Second, the amplitude of the pre-shearing history on previous liquefaction has significant impact in determining the behavior of future liquefaction. The smaller the amplitude of the pre-shearing history applied, the larger the increase of its re-liquefaction resistances in future liquefaction. In the opposite side, the larger the amplitude of the pre-shearing history applied, the weaker the soil resistance in the future liquefaction.

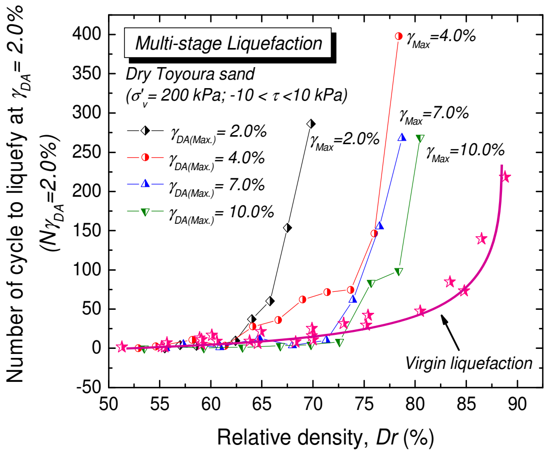

Fig. 3: Re-liquefaction resistance and density relationship with 31 rings of non-coated type

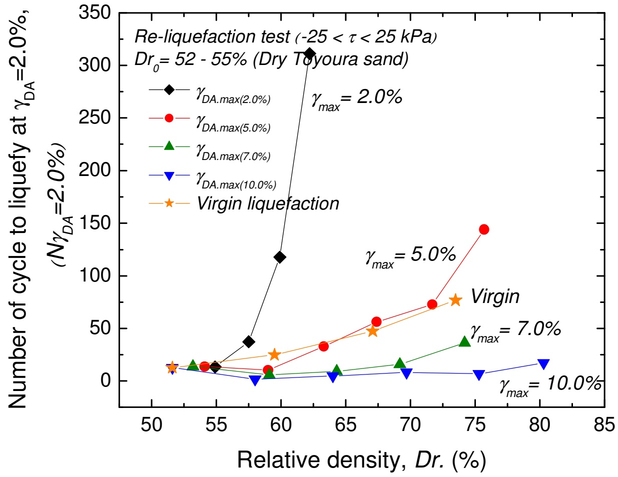

Fig. 4: Re-liquefaction resistance and density relationship with 11 rings of coated type

The latest test results using the current setting of the testing apparatus are shown in Fig. 4. By comparing Fig. 3 and Fig. 4, we can observe that the re-liquefaction tests conducted with 31 rings of non-coated type were different quantitatively from the ones conducted with the 11 rings of coated type. Such differences were expected due to the difference in the amount of mobilized friction between two types of ring. In terms of the re-liquefaction behavior, however, we can conclude that both types show similar trend in a qualitative manner.

With the latest use of 11 rings of coated type, the re-liquefaction resistance of the specimen sheared up to 2.0% shear strain double amplitude increased exponentially in its 2nd, 3rd, 4th re-liquefaction stages. On the other hand, the re-liquefaction resistance of the specimen sheared up to 10.0% shear strain double amplitude was decreased in the 2nd stage, and then gained marginal increase in the following stages. This significant difference shown in both tests is possibly caused by the changes of soil structure. Small shear strain amplitude of pre-shearing history may only cause re-arrangement of soil structure. In this range of strain amplitude, the soil particles experience more contraction than dilation, thus the soil structure becomes stronger in the next liquefaction. In the opposite side, large soil deformation may exceed a kind of virtual limit (threshold) that may alter the entire soil structure and even creates damaging effects to the soil resistance in the future liquefactions. The larger the soil deforms, the greater the changes in soil structure are. Thus, their resistance against re-liquefaction becomes smaller.

4. CONCLUSIONS

Pre-shearing history in the re-liquefaction behavior of sand revealed several observations, which are: 1.) The increase of specimen's density in post liquefaction is less important than the effects of pre-shearing history of soil in determining its re-liquefaction resistance. 2.) The pre-shearing history of soil produces two outcomes. Small amplitude of pre-shearing history causes stronger re-liquefaction resistance while large amplitude causes the opposite result. Small pre-shearing induces the re-arrangement of soil particle, thus soil structure becomes stronger. In the other hand, large deformation at some limit causes large changes in soil structure, thus its resistance against re-liquefaction becomes weaker.

5. REFERENCES

Wahyudi, S. and Koseki, J.: Effects of Pre-shearing History on Re-liquefaction Behavior of Loose Sand Using Stacked-ring Shear Apparatus. *15th JSCE Int'l Summer Symp.*, 2013.