THE COMPARISON OF DIRECT AND INDIRECT LOCAL DEFORMATIONS OF SILICA SAND BY IMAGE ANALYSIS IN TRIAXIAL LIQUEFACTION TESTS

The University of Tokyo, Student Member ○Chuang ZHAO
The University of Tokyo, Member Yukika Miyashita
The University of Tokyo, Fellow Member Junichi Koseki

1. INTRODUCTION

Soil failure is frequently accompanied with strain localization, resulting in the formation of shear band in drained tests. If the strain got localized during loading, then global strain measured at the boundaries of specimen may not be a valid parameter to represent the behavior of soils. Large number of researches have already been conducted on shear band analysis, especially strain localization in zones of shearing. One of the technologies named DIC (Digital Image Correlation) is widely considered as a useful tool for the strain localizations. Yoshida et al. (1997) tried to use printed pictures taken during tests and got the coordinates of nodes of grids on each pictures automatically in plane strain compression tests. Similarly, void ratio evolution inside shear bands in triaxial tests was studied by computed tomography (Desrues et al., 1996). However, almost all of these tests are focused on shear bands in drained tests and little attention has been paid on undrained tests especially liquefaction tests. Recently, Hoshino et al. (2015) have made efforts on liquefaction tests by image analysis. The aim of this paper is to study local deformations of sand specimen during liquefaction by using image analysis technique through a transparent membrane.

2. TEST MATERIALS

The materials employed in this study were colored silica sand with white and black colors. The grain size distribution curve of white silica No.5 is shown in Fig. 1 with a mean particle size of 0.52mm, a uniformity coefficient of 2.0, a gradation coefficient of 0.92 and a specific gravity of 2.65. Its maximum and minimum void ratios were 1.085 and 0.659 respectively. The black colored sand has same properties as white colored sand.

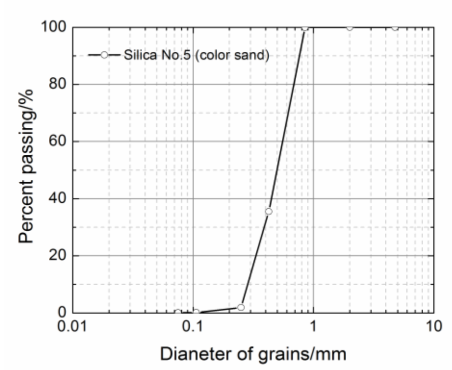


Fig.1 Grain size distribution of test materials

3. APPARATUS AND TEST PROCEDURE

A triaxial apparatus presented in Fig. 2 was used in this study. After mixing black-colored sand with white-colored sand at a mass ratio of 1 to 10, all the specimens were prepared by moist tamping method with ten layers. The weight of sand at each layer was controlled, which could be adjusted for achieving target density (Tatsuoka et.al, 1986). In these tests, relative densities were arranged from 50% to 75%. Cylindrical specimens with 150 mm in height and 75 mm in diameter were prepared. The specimen was put in a fridge for 24 hours freezing. After thawing, it was saturated by double vacuuming method (Ampadu and Tatsuka, 1993) to achieve a high B value which was more than 0.96. After the saturation process, the specimen was consolidated isotropically at an effective confining stress of 100 kPa. Undrained cyclic axial loading with a constant single amplitude deviator stress was applied. The single amplitude of deviator stresses were set as 60, 80 and 90 kPa to get the cyclic stress ratios of 0.3, 0.4 and 0.45 respectively. In each tests, the axial loading rate was controlled to be 0.1%/min.

During the cyclic loading stage, image analysis was applied in these tests for capturing the local strains. A transparent membrane made of silicone rubber was used in these tests. For tracing the movements of membrane and sand particles inside, black-colored latex dots were pasted on the membrane by a constant interval of 5 mm and black-colored sand particles were mixed in specimens to increase contrast to white-colored sand particles. Digital images were taken by the commercial camera and lens, Nikon D810 and Nikkor 24 mm f/1.4G ED, respectively. A commercial software named Move-tr 2D was used to obtain the displacements of dots on membrane and patterns of sand particles. Finally, local strains in four grid nodes were analyzed by using MATLAB.

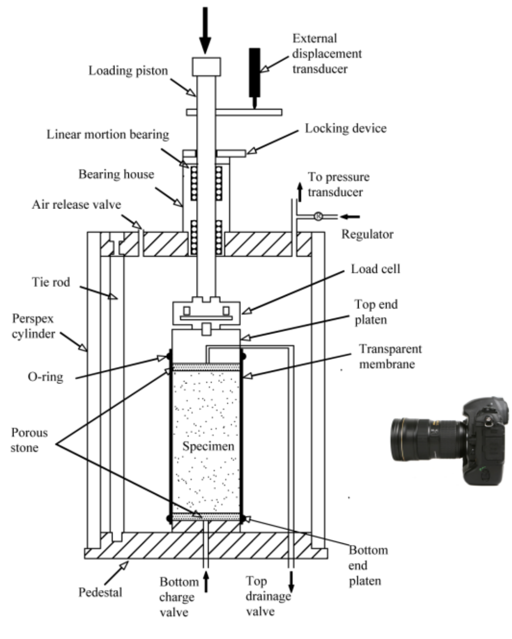
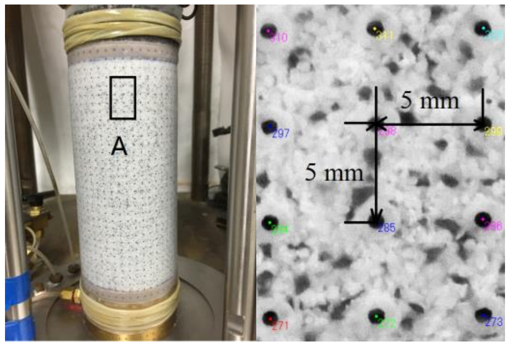


Fig.2 Schematic diagram of triaxial apparatus

4. TEST RESULTS

Keywords: liquefaction, moist tamping, silica sand, image analysis, Local deformations and triaxial tests
Contact address: Geo-lab, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan, Tel: +81- 3-5841-6123

The specimen at a relative density of 51.4% is shown in Fig. 3(a) and Fig. 3(b) shows a magnified area of A defined in Fig. 3(a). The interval of each two dots is 5mm in both vertical and horizontal directions. During the analysis, the displacements of dots on membrane and patterns of black-colored sand particles were obtained and analyzed. The movements of black dots pasted on membrane could represent results from indirect evaluation, while movements of sand particles represent those from direct evaluation. The resolution of image at central bottom position was 0.025 mm/pixel. In order to compare the results between direct and indirect evaluations in a simplified manner, no geometric corrections in terms of the distortion of image caused by cylindrical shape of specimen as well as the lens effect were made in this study. For example, Fig. 4 gives local strains calculated by sand particles and dots on membrane at a bottom part of specimen which are compared with global axial strain with elapsed time. In this figure, local strains exhibited similar trends with global axial strain. However, due to the effect of measured position and sand flowing around the bottom porous stone, these curves had some differences between each other.



(a) Global view (b) Local part
Fig.3 Specimen prepared by color sand with dots on membrane

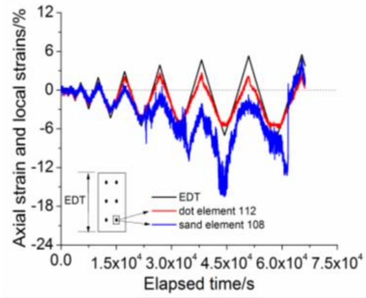


Fig.4 Comparsion of axial strain and local strains at bottom part

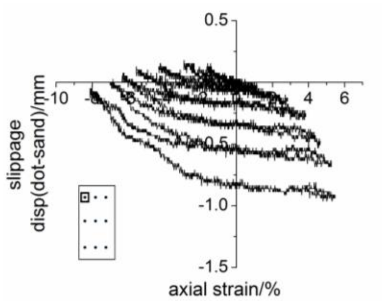


Fig.5 Typical result of slippage at top left part with axial strain

Fig. 5 shows a typical result of slippage with axial strain. Slippage in Fig. 5 is defined as the difference in the displacements of dot and sand. During cyclic loading, slippage did not remain constant but changed with axial strain. This means dots and sand particles have relative movements to each other. For each half cycle, double amplitude of strain will increase with cycle number and the variation of absolute slippage also increases with double amplitude. In addition, accumulated slippage had a downward trend when axial strain reached zero. Similar trends can be seen in Fig. 6, where accumulated slippage decreased especially after several cyclic loading. This phenomenon could be affected by the increase of duration when there was no effective stress at each half cycle. In Fig. 7, the relationship between accumulated slippage and maximum excess pore water pressure ratios at each half cycle are presented. Based on this figure, slippage occurred easily when excess pore water pressure ratio almost reached unit at each half cycle.

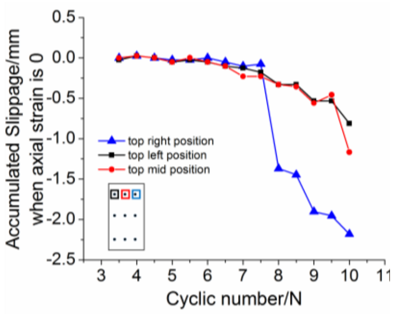


Fig.6 Typical result of accumulated slippage with cycle

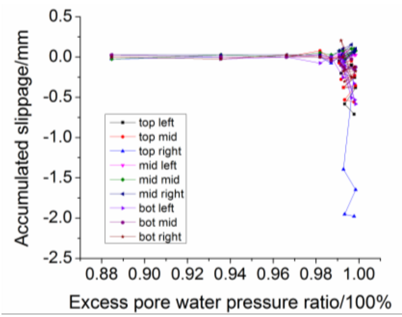


Fig.7 Typical result of accumulated slippage with excess pore water pressure ratio

5. CONCLUSIONS

Being different from traditional measurement by external displacement transducer, image analysis could be used for measuring direct and indirect local strains with high accuracy. The relative displacements between dots on membrane and sand particles named slippage will not be zero and could not remain constant along cyclic loading. The absolute slippage at each half cycle will increase as double amplitude of axial strain increases. When global axial strain returns back to zero, accumulate slippage always have a gradual decline with cyclic number. Finally, current study indicates that slippage has a significant leap when excess pore water pressure ratio reaches around 1 at each time, which means sand particles sink during liquefaction stage.

REFERENCES

Yoshida, T. and Tatsuoka, F.: deformation property of shear band in sand subjected to plane strain compression and its relation to particle characteristics, Proc. Of 14th Intl. Conf. on Soil Mech. And Found. Engrg., 1, 1997, pp. 237-340.
Desrues, J., Chambon, R., Mokni, M. and Mozerolle, F.: void ratio evolution inside shear bands in triaxial sand specimens studied by computed tomography, Geotechnique, London(3), 1996, pp. 539-516.
Hoshino, R., Miyashita, Y., Sato, T. and Koseki, J.: local deformation properties of sand specimens in triaxial liquefaction tests evaluated by direct and indirect observations, Bulletin of ERS, No. 48, 2015, pp. 63-71.
Tatsuoka, F., Ochi, K., Fujii, S., and Okamoto, M.: Cyclic undrained triaxial and torsional shear strength of sands for different sample preparation methods, Soils and Foundations, 26(3), 1986, pp. 23-41.
Ampadu S.K. and Tatstuoka, F.: Effects of setting method on the behavior of clays in triaxial compression from saturation to undraineded shear, Soils and Foundations, 33 (2), 1993, pp. 14–34.