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学 位 論 文 要 旨
Dissertation Summary

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論　文　名: Effects of small pre-shaking history on liquefaction resistance and deformation characteristics of sand
(Dissertation Title)

Soil liquefaction during an earthquake can result in severe damage to engineering structures. Prediction of liquefaction triggering is still a significant challenge because of the complicated nature of soil resistance to liquefaction. Stress and strain histories in processes that soils have been gone through since deposition are known to have a significant influence on liquefaction strength of sandy soils. For instance, repeated small shaking events due to earthquakes significantly enhance liquefaction resistance of soils. Careful analyses on liquefaction case histories revealed that soils in a region where a number of small earthquakes have hit exhibit higher resistance to liquefaction. A number of laboratory test and large-scale testing have been done to investigate the effects of small shakings, herein called pre-shaking, on liquefaction resistance, but none could uniquely quantify the effect of pre-shaking on liquefaction resistance. In this study, a series of cyclic triaxial testing and centrifuge testing have been conducted to quantify the effect of pre-shaking on liquefaction resistance using a single index parameter, volumetric strain due to pre-shaking.

Series of stress-controlled undrained cyclic triaxial test with pre-shaking histories were conducted on medium dense Toyoura sand. Three target volumetric strains during pre-shaking were set, 0.1, 0.3 and 0.8%. Several parameters were systematically varied by test, including cyclic stress ratio, number of cycles, and shear strain amplitude. It was confirmed that in a range of shear strain amplitude (γ_{DA}<0.35%), pre-shearing enhanced the liquefaction strength of the specimens. Samples subjected to a different combination of cyclic stress ratio and number samples during pre-shearing with the same target volumetric strain exhibited the same liquefaction resistance. The fundamental mechanism is that the volumetric contraction during pre-shearing exhausts the ability of the samples

to further contract its volume in the subsequent shearing event. Figure 1 shows the relationship between liquefaction resistance and shear strain amplitude during pre-shaking. Liquefaction resistance is uniquely correlated with volumetric strain due to pre-shearing. A slight volumetric strain of about 0.8% almost doubles the liquefaction resistance. On the other hand, for pre-shearing with shear strain amplitude larger than 0.6%, liquefaction resistance decreases with increasing shear strain amplitude even though volumetric strain also increases accordingly. Degradation of liquefaction resistance with increasing shear strain amplitude during pre-shearing from a threshold value (γ_{DA} =0.5%) was first reported by Finn et al (1975).

The degradation of the liquefaction resistance is attributed to a large reduction of mean effective stress on the first cycles that is characteristic of sand subjected to large shear strain. The effects of large strains on the volumetric contraction characteristics of the sand can be explained by the effect of induced anisotropy due to the large strain pre-shearing. It was also found that the effect of large shear strain pre-shearing was easily erased by several cycles of small strain amplitude shearing.

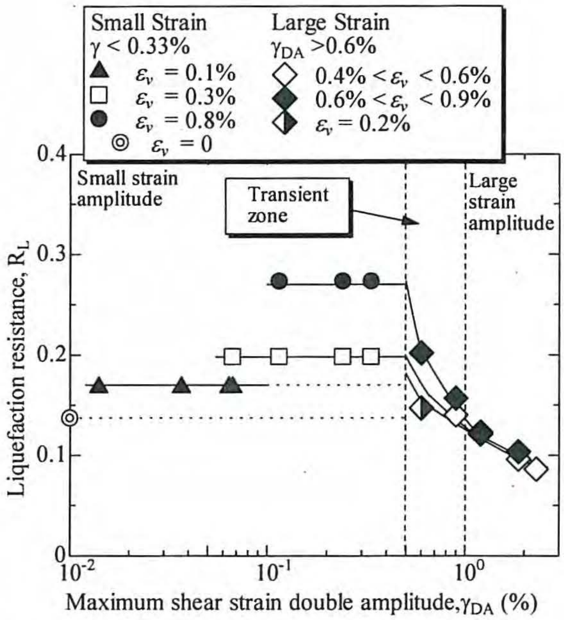

Figure 1. The relationship between liquefaction resistance and shear strain amplitude.

Normalized liquefaction resistance, which quantifies the improvement ratio on liquefaction resistance due to pre-shaking of Toyoura sand obtained from the small strain triaxial test and centrifuge test is plotted against volumetric strain as shown in Figure 2. The test results obtained by Goto and Towhata (2015) in a similar test as the triaxial test conducted in this study is also plotted. For the triaxial testing, liquefaction resistance ratio increases uniquely with volumetric strain due to pre-shaking for Toyoura sand regardless of relative density, a number of cycles and initial induced fabric (different preparation methods - alluviation, and wet tamping). The results obtained by the centrifuge modeling and triaxial testing agree quite well, suggesting that volumetric strain due to pre-shearing is the dominant factor. Additionally, triaxial test data retrieved from the literature (Okamura and Soga, 2006, Tokimatsu and Nakamura, 1986) to compare the effects of volumetric strain due to different phenomenon of imperfect saturation and partially drainage due to membrane penetration on liquefaction resistance. These test results shows a good agreement to that obtained in this study (Figure 3). It was concluded that, whenever volumetric strain occurs, either during undrained shearing or before the shearing, liquefaction resistance ratio is dependant sololy on volumetric strain..

A series of dynamic centrifuge testing was conducted to assess the effect of pre-shaking on liquefaction resistance under level ground condition. Models simulating a 3m deep medium-dense, fully saturated sand deposits were subjected to several small horizontal pre-shaking until the target volumetric strain was attained and then a strong shaking, surfficiently strong to liquefy the model was imparted to the model. During pre-sharing index parameters, including, relative density, shear wave velocity and coefficient of earth pressure were closely monitored. Liquefaction resistance of the models subjected to pre-shearing was significantly enhanced. As an example, the model with pre-shaking events to a target volumetric strain of 0.8% demanded an input base acceleration 2.2 times bigger than the model without pre-shaking. I was found that shear wave velocity increased only several percents with the pre-shaking events, which cannot explaine the significant increase in liquefaction strength of the models. A similar result was also found on the triaxial testing regarding the shear wave velocity. This substantial increment in liquefaction resistance cannot also be an account on the change of coefficient of horizontal earth pressure, which increased from about 0.45 to 0.57, that translates in an 18% change in mean effective stress. Another series of dynamic centrifuge test on thin saturated sand layers were also performed to assess the effect of volumetric strain due to partially drained condition on liquefaction resistance. The test results showed that liquefaction resistance ratio increase in the quite similar trend with volumetric strain due to pre-shaking and partially drained condition.

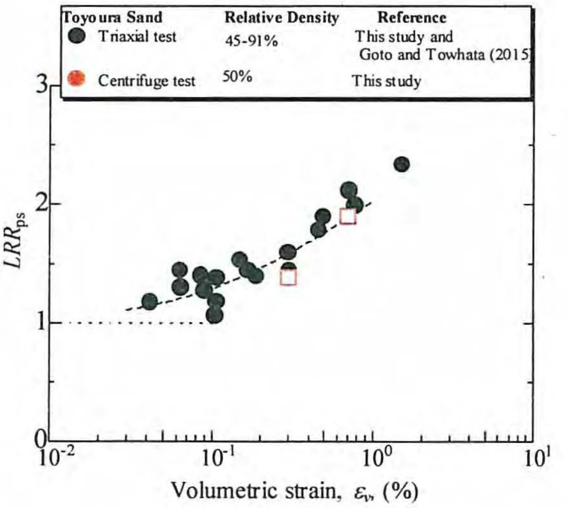

Figure 2. Effect of volumetric strain due to pre-shaking on liquefaction resistance

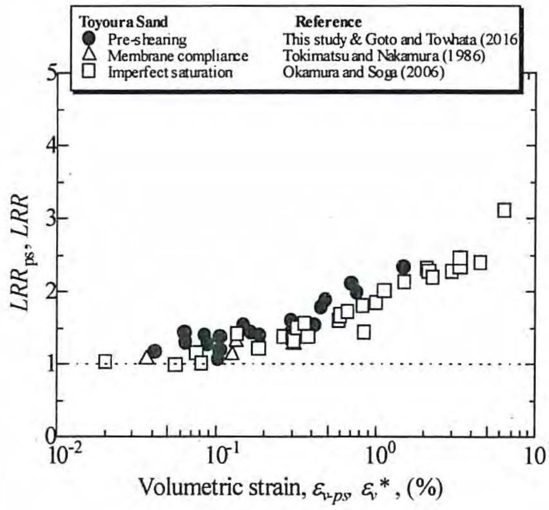

Figure 3. Effect of volumetric on liquefaction resistance

In addition to the liquefaction strength, effects of pre-shearing on the deformation characteristics of sandy soils was investigated in this study. Pre-shaking increased the stiffness of the sand by about 30%. It was also observed that small strain pre-shearing cycles extended the elastic strain region of the shear modulus.