Evaluating deformation and liquefaction properties of sandy ground from in-situ and laboratory tests

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ABSTRACT

Obtaining good samples from loose sand layers within bay areas are necessary to evaluate their deformation and liquefaction properties. Until now, high-quality sampling in the loose sandy ground are achieved by applying an expensive in-situ freezing technique. In order to find an alternative and cost-effective sampling method applicable to these loose alluvial deposits, sand samples were collected in this study from Kobe Bay area by using two different types of sampler and were comparatively examined by evaluating their physical properties, deformation characteristics and liquefaction strength. A close match of relative density, deformation properties and that of liquefaction strength properties to that of the field was shown by the samples collected by GS sampler than the Triple-tube types. This suggests a possibility of using a relatively less expensive GS sampler to collect high-quality samples from a loose sandy ground that is now primarily being applied for waste collection.

Keywords: alluvial sand, liquefaction, cyclic deformation properties, sampling technique

1 INTRODUCTION

Reassessment of the earthquake and tsunami hazard around Japan is being done after the occurrence of Tohoku Earthquake in 2011. Nankai trough earthquake is one of the very large earthquakes that seismologists are expecting to occur in the near future. An enormous damage is expected in the Hyogo Prefecture as a whole due to the combined effect of liquefaction, tsunami and steep slope failure at various regions from this earthquake’s expected scale. In order to understand the deformation amount and damages on various facilities due to the aforesaid earthquake, Kobe City has currently started a movement to prepare a database of fundamental properties for sandy soils in the Bay area by accurately evaluating their deformation and liquefaction strength properties. In order to evaluate them, it is necessary to carry out in-situ as well as various laboratory tests, such as cyclic triaxial tests and undrained cyclic triaxial test, by collecting a high-quality undisturbed samples from the site. The current practice of extracting undisturbed samples from the sandy or silty soil layer is by using an in-situ freezing technique (Yoshimi et al., 1989). High quality samples can be collected by this method but are very costly to recommend for general investigations.

In this study, a fixed piston double tube sampler (known as GS sampler) has been considered as a method for collecting high quality samples that could be less expensive as well. This sampler (JGS, 2013) is currently being used in collecting waste materials comprising of conventional gravelly soil or dust. The cost of sampling is relatively cheaper than that of in-situ freezing technique. In this sampler, the samples are prevented from falling out of the tube with their in-built fixed piston and double tube structure. However, having only a few application case examples in sandy soils, there are not much researches about evaluation of deformation and liquefaction strength of collected samples. As a comparative study, undisturbed sand samples were also collected by using rotary type “Triple–tube sampler” from the same depth. Soil properties were evaluated by performing laboratory experiments on the samples extruded by above two different samplers and compared with the in-situ properties as well.
Sandy soil samples collected at Kobe Bay area are used in the test. The target ground in this study (depth 7.0~8.0 m) consisted of fine to medium loose alluvial sand deposit. Two types of sampler, GS sampler and rotary type Triple tube sampler, were applied to collect undisturbed samples from the site in order to use them in the laboratory tests. Fig. 1 shows a schematic diagram of these samplers. Grain-size distribution curve for the soil extracted from both type of samplers are shown in Fig. 2. A high possibility for liquefaction is envisaged for this ground on observing the particle size range of 0.1~1.0 mm. In order to minimize the disturbance, samples collected from both methods were frozen by using dry ice and then transported to the laboratory.

Physical properties of samples collected by using the above two sampling techniques are shown in Table 1. Although there is no significant difference in the value of the maximum and minimum density as well as soil specific gravity, wet density of the samples taken by GS sampler was found to be comparatively smaller ($\rho_s = 1.65 ~ 1.75 \text{ g/cm}^3$) than those of Triple tube type ($\rho_s = 1.80 ~ 1.90 \text{ g/cm}^3$). The relative density, $Dr$, calculated for the former type of samples were smaller ($Dr = 62~71\%$) than those of latter Triple-tube samples ($Dr = 84~102\%$) although the SPT N values obtained from the field tests performed at respective sites fell in a narrow range of 14-16. This well infers that the sampling techniques applied to get the samples have significant effect on the quality of samples. These data are plotted in Fig. 3 along with the relationship between SPT N values and relative density for in-situ frozen samples from Yoshimi (1994). The relative density for N value of 15, as shown by the solid line, is about 60% and it can be seen that sandy soil samples collected by GS sampler have quite closer values. Thus, there is sufficient reason to emphasize that GS sampler can be used to collect high quality samples in the sandy ground.
On the other hand, it is more likely that the relative density of sandy samples collected in Triple-tube sampler tends to become higher than the in-situ state during sampling.

To examine the deformation characteristics and liquefaction strength properties of the collected sandy soil specimens, cyclic triaxial test to determine the deformation properties of geomaterials (JGS 0542-2009) and cyclic undrained triaxial tests (JGS 0541 2009), referred as Type 1 and 2 respectively in the text hereafter, were carried out by using undisturbed samples. For both type of tests, the sample size adopted was 5 cm in diameter and 10 cm in height. Careful attention was paid while shaping the frozen specimen to the required size. Reconstituted samples were also used in Type 2 test, which were prepared filling the required weight of sand in a mold and tamping the mold from outside. The target density was the average of undisturbed samples used, i.e., 1.75 for GS samplers and 1.85 for Triple-tube samplers.

An initial saturation phase and isotropic consolidation phase under the effective overburden stress at the original ground (σ_max=70kPa) was also common for both Type 1 and Type 2 tests. The shearing procedure after consolidation was different for each Test type. For Test type 1, strain level for cyclic loading was varied from 10^{-4} to 10^{-1} and the number of unload-reload cycles adopted was 10. For Test-type 2 conducted to determine the liquefaction strength, the shearing in undrained conditions was done at various stress levels with the loading frequency, f = 0.1 Hz.

3 RESULTS AND DISCUSSION

Fig. 4 shows the relationship between the single-amplitude shear strain, γ_{SA} (= 1.5 (ε_a)_{SA}) and the equivalent shear modulus, G_{eq} (= E_{eq}/3), obtained from the cyclic triaxial test, Type 1. From the figure, it is obvious that G_{eq} for the samples taken by triple tube sampler are very high as compared to those from GS sampler. The possible reason could be density difference between the two showing a densification of Triple-tube samples while sampling. On the other hand, Fig. 5 shows the damping factor, h and γ_{SA} relationship for the same pair of sample. The difference due to sampling disturbance, such as seen in γ_{SA}-G_{eq} relationship, could not be confirmed. In addition, the results obtained this time show the very similar trend as that between the frozen samples and tube samples described in the past researches (Yamashita et al., 1997). This could suggest a likely disturbance of the triple-tube samples during sampling.

Fig. 6 is a relationship between the number of loading cycles, N and cyclic stress ratio, R_c (= \frac{\sigma_d}{2\sigma_v}) of the undisturbed samples obtained by each sampler types. The number of cycles for this plot at various applied stresses was obtained at the double strain amplitude, DA = 5%. In general, N = 20 is taken as the liquefaction strength ratio. Smaller relative density of GS samples also correspond to the smaller, R_c values in the figure. On the other hand, no significant difference in liquefaction strength was noted for the reconstituted samples (dashed line) irrespective of the sampling method.

Fig. 7 shows the normalized in-situ shear modulus, G_{local} obtained by PS logging (open symbols) and shear modulus fitting line estimated by equation, G_{max} =...
5000e^{1.5} \sigma_0^{0.5} \text{ from Shibuya & Tanaka (1996) (filled symbols). Here, void ratio, } e_0 \text{ at various applied stresses, } \sigma_0', \text{ was obtained from additional tests conducted on undisturbed samples from an adjacent depth. In the plot, a void ratio function, } f(e) = (2.17-e)^2/(1 + e), \text{ proposed by Hardin & Richart (1963) has been used for normalization. The normalized plot shows that } G\max/f(e) \text{ of samples taken with GS sampler are higher than those of Triple-tube types. Besides, the } G\max/f(e) \text{ values for GS sampler are also closer to the average } G\max/f(e) \text{ relation shown by dotted lines, suggesting that it is possible to collect the sample in a high quality state by using the GS sampler.}

4 CONCLUSIONS

Following are the summary of results obtained by observing the quality of sandy soil samples collected from the same depth by using two different samplers.

1. The density of samples obtained from GS sampler were lower and also closer to the in-situ values estimated by SPT N values than those from Triple-tube types. On the other hand, the samples from rotary triple-tube sampler were found relatively denser, due possibly to the disturbance.

2. A higher value of } G_{eq} \text{ from Type 1 cyclic triaxial test for Triple-tube sampler than GS sampler was conforming to their higher density state.

3. Although the effect of density on liquefaction strength was not appreciable among the tested reconstituted samples collected by Triple-tube sampler were found to have comparatively higher strength.

4. Sample quality was also examined by preparing a normalized in-situ elastic shear modulus by downhole seismic cone test, } G_{ek} \text{ with a void ratio function } f(e) \text{ against an effective stress and compared with the general relation proposed by Shibuya and Tanaka (1996) for } G_{\max}. \text{ } G_{\max} \text{ obtained from double-tube sampler with fixed piston was closer to the proposed relation than that of Triple-tube sampler.}

The above results suggest a possibility of using a relatively less expensive GS sampler, primarily being applied for waste collection now, to collect high-quality samples from a loose sandy ground.

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