Qualitative Evaluation of Undisturbed GP Samples Extracted from Alluvial Sandy Soil Deposits Based on Dynamic Shear Modulus Measurements

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ABSTRACT: A site investigation program was undertaken in Chiba (Japan) to evaluate the undrained cyclic strength properties of two sandy soils (Holocene and landfill deposits), which is believed to have experienced liquefaction during the 2011 Off the Pacific Coast of Tohoku Earthquake. In this regards, the application of advanced sampling technology was crucial for obtaining high quality undisturbed samples, as soil fabric and ageing effects would be significant. This paper examines the quality of undisturbed samples which were taken by “Gel-push” (GP) sampling using comparisons between dynamic shear moduli directly evaluated in-situ (downhole) and those measured in the laboratory on undisturbed triaxial samples extracted by both GP and conventional triple-tube sampling (TB) techniques. Preliminary results are presented endorsing the ability of the GP sampler to achieve higher quality samples suitable for liquefaction strength testing compared to the TB sampler.

1 INTRODUCTION

The 2011 Off the Pacific Coast of Tohoku Earthquake (M_W=9) caused devastating soil liquefaction over a wide region of Eastern Japan, particularly affecting landfill and deposits of fine sands and silty sands of recent fluvial origin (Holocene) Since May 2014 a site investigation program has been undertaken by the Authors in Mihama, Chiba City, located about 50 km east of Tokyo (Fig. 1), to evaluate the undrained cyclic strength properties of two sandy soils (Holocene and landfill deposits), which is understood to have experienced severe liquefaction during such severe earthquake (Nakai and Sekiguchi, 2011).

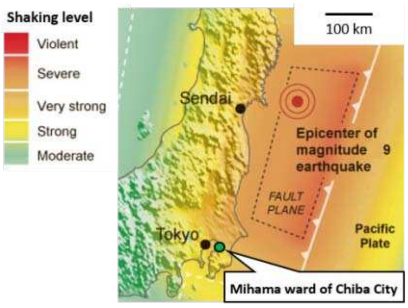

Fig. 1 Shaking level across Eastern Japan during the 2011 off the Pacific Coast of Tohoku Earthquake (adapted from http://earthquake.usgs.gov/)

In order to properly investigate liquefaction properties of sandy soils, laboratory tests on undisturbed samples are essential, as soil fabric (particle arrangement) and ageing effects are significant (Ishihara 1993). However, this is not an easy task, because sandy samples can be disturbed easily during the sampling procedure. Reflecting such a situation, a new technique for obtaining high quality undisturbed samples using a "Gel-push” (GP) sampler was developed over the last decade and successfully employed in New Zealand (Taylor et al., 2012), Taiwan and Japan (Chen et al., 2014).

Yet, a comprehensive discussion on the qualitative assessment of GP samples for liquefiable soils has not yet been made. Therefore, an attempt is made in this paper, where the GP sample quality is evaluated by comparisons between dynamic shear moduli directly estimated in-situ (downhole) and those measured in the laboratory on undisturbed triaxial samples extracted by GP and triple-tube (TB) sampling techniques. Based on the analysis of the dynamic shear modulus measurement, a classification of sample quality for undisturbed GP and TB samples as well as the effects of sample quality on the liquefaction properties of soils in the laboratory tests are provided.

2 GEL-PUSH SAMPLING TECHNIQUE

Sandy samples can be greatly disturbed during sampling procedure. For instance, using conventional TB and Shelby tube sampling techniques, the excessive friction generated during penetration tends to cause serious disturbance to the specimens, resulting in partial soil sampling and poor quality. Alternatively, the ground freezing method, used for preserving sampled soil quality, frequently cause drifting of fines content and disturbance on sensitive micro-structure during freezing and defrosting processes (Chen et al., 2014).

As a result, over the last decade, a new technique using a GP sampler was introduced by Kiso-Jiban Consultants Co. Ltd. for obtaining high quality undisturbed samples. As described in detail by Chen et al. (2014), the GP sampling technique was first developed in Japan to retrieve gravel material as an alternative to ground freezing methods. Then, in an attempt to obtain undisturbed high fines content silty sand, the GP sampler was modified to accommodate the thin wall tube inside the sampler to become a triple-tube system. The GP sampler was aimed to allow a polymer lubricant to seep into the tube wall while penetrating the tube into the soil by hydraulic pressure. Moreover, the sampler was equipped with a cutter attached to the guiding tube to allow smooth penetration, and a catcher fixed at the bottom of the thin wall tube to prevent the soil sample from falling out during uplifting. As a very small amount of polymer gel is employed, it contaminates only a limited superficial portion of the sample. As a result, the GP sampler can effectively reduce the wall friction, so that a good quality sensitive silty sand specimen can be recovered. The GP sampler employed in this study is shown in Fig. 2a.

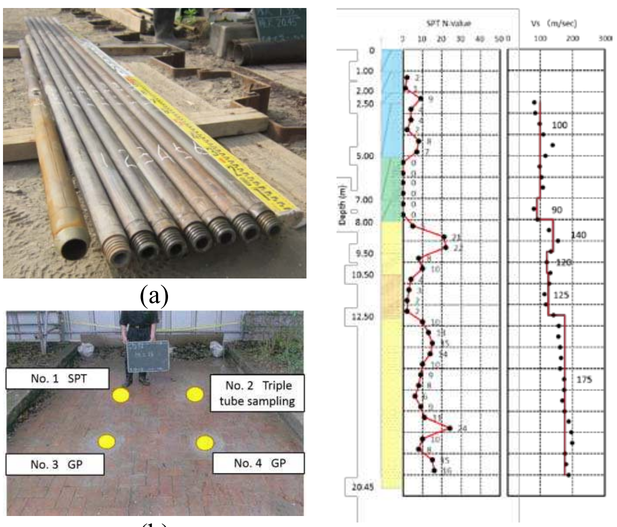

Fig. 2 (a) GP sampler; (b) boreholes configuration; and (c) soil profile with corresponding field measurements

3 SITE CONDITIONS

At the investigation site in Mihama, four boreholes were performed up to a depth of 20 m below the ground surface (Fig. 2b) to evaluate SPT *N*-values and field S-wave measurements (No. 1), and to collect undisturbed samples by using conventional Shelby TB sampling (No. 2) as well by the new GP sampling (No. 3 and No. 4).

As shown in Fig. 2c, the soil profile consists of two distinct soil deposits: (i) a fill deposit made of silty sand (Fsc) and clayey sand (Fc2) layers, which were created by hydraulic deposition of dredged soils taken from Tokyo Bay; and (ii) an alluvial deposit (Holocene) made of alternate sandy soil (As1, As2) and clayey soil (Ac2) layers.

4 IN-SITU DYNAMIC MEASUREMENTS

In-situ determination of shear wave velocities (V_s) was done by means of downhole test with P-S logging. As displayed in Fig. 2c, measurements were taken at 0.5-meter depth intervals. The values of V_s were then used to calculate dynamic shear modulus (G_d) as follows:

$$G_d = \rho_{sat} V_s^2 \quad (1)$$

where ρ_{sat} is the saturated soil density.

Fig. 3 shows typical correlations between adjusted SPT N-value (N_a) and V_s or G_d obtained by P-S logging for both fill and alluvial deposits of tested Chiba sands. N_a was originally introduced by Tokimatsu and Yoshimi (1983) to adjust N from the effects of effective overburden stress (σ_0') and fines content (F_c). Accordingly, Eqn. (2) is valid for $F_c \geq 10\%$:

$$N_a = \frac{1.7}{\sigma_0'/98 + 0.7} N + (0.1F_c + 4) \quad (2)$$

From Figs. 3 and 4, it is clear that for a given value of N_a, the V_s and G_d values are very different between the two soil deposits, being much higher for the natural soil. This can be attributed to different fabric and stiffness of sands, reflecting different deposition processes and ageing effects. This may also imply that liquefaction resistance of these two sands may be very different although N_a is the same. Based on these field findings, hereafter, V_s and G_d will be used as useful parameters for better assessing the ability of the GP sampler to achieve higher quality samples suitable for liquefaction strength testing.

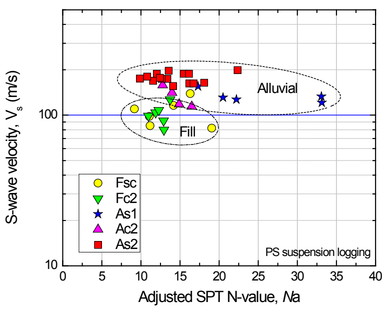

Fig. 3 V_s-N_a relationships for tested Chiba sands samples retrieved from alluvial and fill deposits

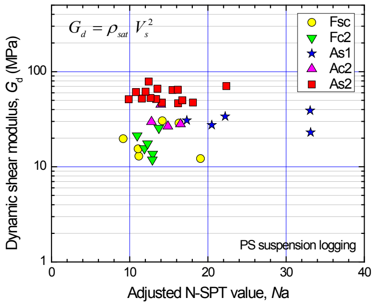

Fig. 4 G_d-N_a relationships for tested Chiba sands samples retrieved from alluvial and fill deposits

4 CYCLIC TRIAXIAL TESTS WITH DYNAMIC MEASUREMENTS

A total of 18 specimens of sand with no plastic fines (F_c = 10-15%) obtained from the As2 alluvial deposit (depth of 14.5-19 m) were tested in the laboratory. The specimens were carefully extruded from the sample tube and trimmed to accommodate in a triaxial apparatus (i.e. H =10 cm and ϕ = 5 cm), which was equipped with a dynamic measurement device (Fig. 5). To ensure full saturation (i.e. B-value ≥ 0.97) a back pressure of 200 kPa was applied. Undrained cyclic shearing was then conducted at a frequency of 0.1 Hz on specimens isotropically consolidated at different confining pressures (σ_0'=140 -170 kPa) representative of field stress conditions.

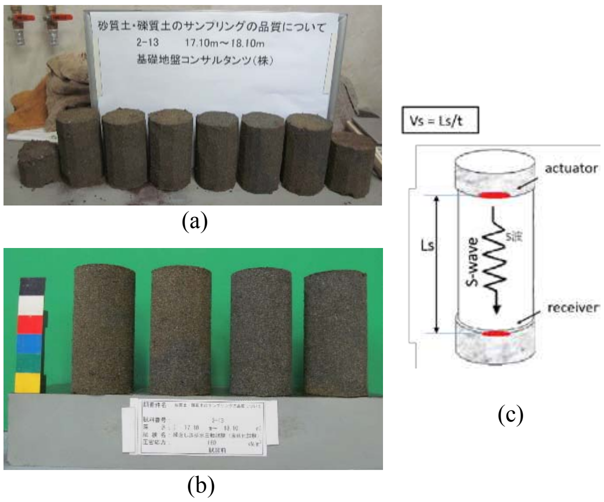

Fig. 5 (a) Extruded samples of As2 Chiba sand; (b) samples after trimming; and (c) sketch of dynamic measurement device employed in this study

Typical cyclic behaviour of a GP sample is reported in Fig. 6a in terms of stress path and stress strain curve. As well, liquefaction curves obtained for the tested As2 soils are shown in Fig. 6b. It is clear that liquefaction resistance (here defined as the number of cycles to cause shear strain double amplitude of 5%) of TB samples is greater than that of GP samples. As discussed later, this can be associated with possible sample disturbance during the sampling process.

Recently, correlations between cyclic resistance and S-wave velocity have been developed based on field performance (e.g. Andrus and Stokoe, 2000). However, an alternative approach to use field data is to use laboratory data. In fact, the cyclic resistance from triaxial tests (CSR_{tx}) can be converted to field values using the following expression proposed by Seed (1979):

$$CSR = 0.9 \times C_r \times CSR_{tx} \tag{3}$$

where C_r $(= 2(1+K_0)/3\sqrt{3}$; Castro, 1975) here is taken as 0.77 (i.e. $K_0 = 0.5$).

Moreover, measured S-wave can be corrected to a reference stress p_a=100 kPa by the following expression by Andrus and Stokoe (2000):

$$V_{s1} = V_s \sqrt[4]{p_a / \sigma_0^{'}} \tag{4}$$

In Fig. 7, the data available from this study are plotted in terms of CSR vs. V_{s1}, together with reference curves indicating whether liquefaction will occur in 15 cycles of loading or not.

In the case of TB samples the data seems to be randomly distributed and, thus, a clear distinction between liquefaction and no-liquefaction zones cannot be made. Alternatively, in the case of GP samples, it appears that the experimental data fit better the CSR-V_{s1} plot. This may be evidence of higher disturbance of TB samples compared to GP samples.

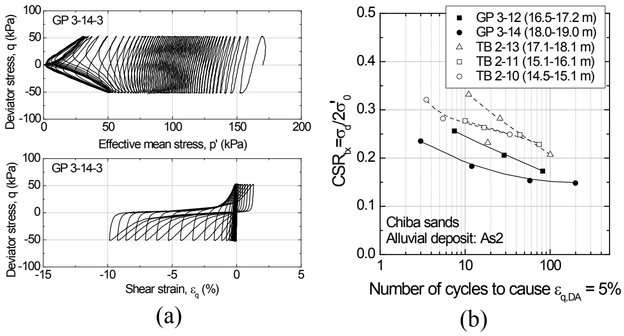

Fig. 6 (a) typical cyclic behaviour of a sample retrieved by GP sampler; and (b) liquefaction curves obtained for As2 Chiba specimens tested in this study

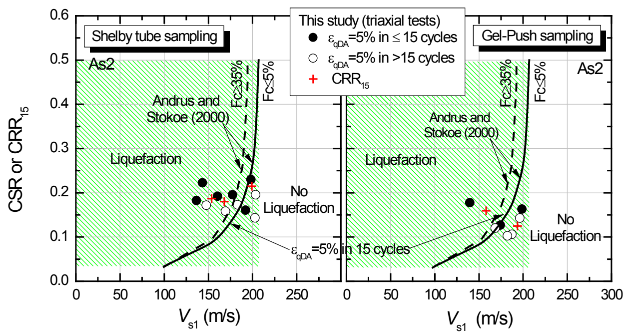

Fig. 7 CSR-V_{s1} correlations for alluvial Chiba sands collected by TB and GP samplers

6 SAMPLE QUALITY ASSESSMENT AND CLASSIFICATION

Taylor et al. (2012) judged the quality of GP samples retrieved in Christchurch (New Zealand) using V_{s1} data obtained from the field and laboratory. They observed that for $V_{S1,Lab}/V_{S1,field} > 1$ loose sample densified, while for $V_{S1,Lab}/V_{S1,field} < 1$ dense sample loosened by the sampling process.

Following a similar approach, hereafter a comparison between laboratory tests performed prior to cyclic loading on GP/TB samples and field (downhole) measurement are presented in Fig. 8 in terms of normalized shear modulus correlations:

$$G_{d1} = \rho_{sat} V_{s1}^2 \qquad (5)$$

Accordingly, in this study, it is assumed that for $G_{d1,Lab}/G_{d1,field} > 1$ a loose sample would densify and for $G_{d1,Lab}/G_{d1,field} < 1$ a dense sample would loosen by the sampling process.

Lunne et at. (1997) proposed a criterion with five quality classes to judge quality of undisturbed clay samples on the basis of change in S-wave velocity and density between laboratory and field measurements. These quality classes are as follows: (i) Excellent: perfect sample; (ii) Very good: undisturbed sample; (iii) Good: fairly undisturbed sample; (iv) Fair: fairly disturbed sample; and (v) Poor: disturbed sample.

While Lunne et al. (1997) practice cannot be readily applied to the tested Chiba sand samples, the use of similar quality zones would help to understand and assess the degree of disturbance of the GP and TB samples examined in this study. Consequently, the five quality classes were conveniently introduced in the plot in Fig. 8. Essentially, it is assumed that for $G_{d1,Lab} = G_{d1,field}$ the sample is intact and in perfect condition. For $G_{d1,Lab} \geq 2G_{d1,field}$, the sample would be fairly disturbed due to excessive densification. Alternatively, for $G_{d1\,field} \geq 2G_{d1,LAb}$ the sample would be fairly disturbed due to excessive loosening during the sampling process. A very good quality undisturbed sample should have a $G_{d1,Lab} \leq 1.33G_{d1,field}$ or $G_{d1\,field} \geq 1.3G_{d1,LAb}$. Consequently, in this study, it was found that all samples loosened during sampling independently from the sampling process adopted. Yet, it seems that overall GP sampling performance was better than TB tube sampling.

7 CONCLUSIONS

In order to properly investigate liquefaction properties of sandy soils, laboratory tests on undisturbed samples are essential, as soil fabric and ageing effects are significant. In this regard, the application of new 'Gel-push' (GP) sampling technology to obtain high quality undisturbed samples was evaluated in this study. To do so, a criterion with different levels of sampling quality was proposed by comparisons between dynamic shear moduli directly evaluated in-situ (downhole) and those measured in the laboratory on undisturbed triaxial samples extracted by both GP and conventional triple-tube sampling (TB) techniques. As a result, the ability of the GP sampler to achieve higher quality samples suitable for liquefaction strength testing compared to the TB sampler was established.

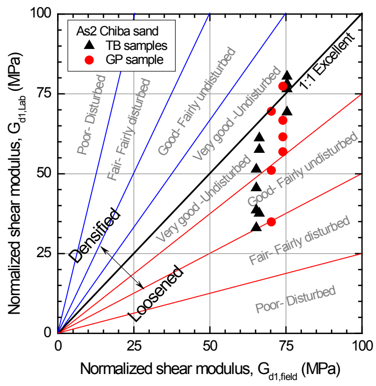

Fig. 8 Proposed quality classification for Chiba sand undisturbed samples retrieved by GP and TB samplers

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