Applicability of a two-chamber hydraulic piston sampler for hard soil deposits

Yoshihito Nakano i) and Takaharu Shogaki ii)

i) Department of Engineering, Kowa Co. Ltd, 4-7-22 Toyano, Niigata, 950-0951, Japan
ii) Department of Civil Engineering, National Defense Academy, 1-10-20 Hashirimizu, Yokosuka, 239-8686, Japan

ABSTRACT

The applicability of the 45-mm and 50-mm samplers is examined for highly organic, clayey and sandy samples obtained from Holocene and Pleistocene tertiary clays and Holocene sand deposits at 41 sites including some abroad. It is confirmed that the 45-mm sampler can take high-quality samples just as well as rotary double-tube (JGS 1222-2012) and rotary triple-tube (JGS 1223-2012) samplers for soils having an unconfined compressive strength of $q_u=8$~$1415$ kN/m$^2$ and SPT $N$-values of 3~54. Therefore, the 45-mm sampler can be applied as a sampler of JGS 1221, JGS 1222 and JGS 1223 to recover undisturbed soil samples suitable for laboratory tests.

Keywords: clay, consolidation yield stress, sample quality, sample disturbance, strength, tube sampling

1. INTRODUCTION

Small-diameter samplers, with a two-chamber hydraulic piston (45-mm and 50-mm samplers), have been developed by Shogaki (1997), and their applicability to Holocene and Pleistocene clays (Shogaki and Sakamoto, 2004) and Niigata sand (Shogaki et al., 2006) deposits has been examined. From these achievements, the 45-mm and 50-mm samplers have been adopted in the Japanese Geotechnical Standard (JGS 1221-2012) as samplers satisfying the standard for thin-walled tube samplers with a fixed piston. By using the 45-mm sampler, high-quality samples can be taken from the same borehole in Standard Penetration Tests (SPTs). In this paper, the applicability of the 45-mm sampler is examined for highly organic, clayey and sandy samples obtained from Holocene and Pleistocene clays, Tertiary clay and Holocene sand deposits at 41 sites including some abroad.

It has been confirmed that the 45-mm and 50-mm samplers can take high-quality samples just as well as rotary double-tube (JGS 1222-2012) and rotary triple-tube (JGS 1223-2012) samplers for soils having an unconfined compressive strength ($q_u$) of $8$~$1415$ kN/m$^2$ and SPT $N$-values of 3~54. Therefore, the 45-mm and 50-mm samplers can be applied as samplers of JGS 1221, JGS 1222 and JGS 1223 to recover undisturbed soil samples suitable for laboratory tests.

2. SAMPLING SITES AND SOIL PROPERTIES

Figure 1 and Tables 1 and 2 summarize the sampling sites and the soil properties of the soil samples, respectively, taken with the 45-mm and 50-mm samplers. The plasticity index ($I_p$), $q_u$ and consolidation yield stress ($\sigma'_c$) are in the range of 7 to 370, 8 to 1415 kN/m$^2$ and 21 to 2118 kN/m$^2$, respectively, for the highly organic and clayey samples. The $N$ values obtained from Standard Penetration Tests (SPTs) are in the range of 3 to 54 for the sandy samples. These samples were taken from Holocene, Pleistocene and Tertiary deposits at 41 sampling sites including some in Italy and Korea. The 41 samples, including 22 new ones without references and 19 with references, as shown in Tables 1 and 2, are examined in this paper.

3. RELATIONSHIP BETWEEN SHEAR STRENGTH AND LENGTH OF RECOVERED SAMPLES

The lengths ($l$) of the recovered samples, obtained with the 45-mm and 50-mm samplers, are plotted against $q_u$ in Figure 2 for highly organic and clayey soils. Figure 3 shows a similar relationship between the $l$ and $N$ for sandy soils. The sample diameters are 45 mm and 50 mm for the 45-mm and 50-mm samplers, respectively. The maximum lengths ($l_{\text{max}}$) of the recovered samples are 500 mm and 735 mm for the 45-mm and 50-mm samplers, respectively. For clayey soils, the soil is sampled by the weight of about 3 tons with a drilling machine and a temporary scaffold, etc. The samples with almost $l_{\text{max}}$ are under conditions of $q_u\leq 510$ kN/m$^2$ for the 45-mm sampler and $q_u\leq 519$ kN/m$^2$ for the 50-mm sampler, as shown in Figure 2. Also, the samples of 60% and 75% of $l_{\text{max}}$ for the 45-mm and 50-mm samplers are under conditions of $q_u=1415$ kN/m$^2$ and $q_u=907$ kN/m$^2$, respectively. For
Resistance force ≈ 3~10 ton

Mean values of unconfined compressive strength, $q_u$ (kN/m²)

Figure 1. Sampling sites by two-chamber hydraulic piston sampler

Figure 2. Relationship between $l$ and $q_u$ (Soil deposits)

Figure 3. Relationship between $l$ and $N$ (Sand deposits)
### Table 1. Soil properties of clayey samples by two-chamber hydraulic piston sampler

| No. | Sampling site | Soil type | N-value | N_s value | w_s (%) | w_l (%) | U_p (%) | U_f (%) | D_50 (mm) | U_f (%) | D_10 (%) | R_I (%) | OCR σ'v0 (kN/m²) | Sampler | References |
|-----|---------------|-----------|---------|-----------|---------|---------|---------|---------|------------|---------|-----------|---------|----------------|----------|------------|
| 1   | Akita         | Holocene | 20~30   | 30~60     | 20~26   | 17.4    | 455     | 0.12    | 0.26       | 125     | 7~125    | 1.72~1.87 | 588~1172 | 623~1174 | 1093~1322 | 1.3~2.1 | 45-mm | Shogaki and Sakamoto, 2004 |
| 2   | Chiba         | Holocene | 1.72~1.87 | 588~1172 | 623~1174 | 1093~1322 | 1.3~2.1 | 45-mm | Shogaki and Sakamoto, 2004 |
| 3   | Aichi         | Pleistocene | 8~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |
| 4   | Osaka         | Holocene | 7~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |
| 5   | Shizuoka      | Holocene | 7~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |

### Table 2. Soil properties of sandy samples by two-chamber hydraulic piston sampler

| No. | Sampling site | Soil type | N-value | N_s value | w_s (%) | w_l (%) | U_p (%) | U_f (%) | D_50 (mm) | U_f (%) | D_10 (%) | R_I (%) | OCR σ'v0 (kN/m²) | Sampler | References |
|-----|---------------|-----------|---------|-----------|---------|---------|---------|---------|------------|---------|-----------|---------|----------------|----------|------------|
| 1   | Osaka         | Holocene | 8~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |
| 2   | Chiba         | Holocene | 7~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |
| 3   | Aichi         | Holocene | 7~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |
| 4   | Osaka         | Holocene | 7~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |
| 5   | Shizuoka      | Holocene | 7~17 | 48~60 | 71~85 | 39~46 | 2.0~2.1 | 1.9~2.0 | 35~40 | 25~30 | 34~52 | 1.4~1.5 | 84~110 | 1.24~1.31 | 38~46 | 50~62 | 34~52 | 0.7~1.0 | 50-mm | Shogaki and Sakamoto, 2004 |

© Two-chamber hydraulic piston cone sampler/ Shogaki and Nakano, 2010.
sandy soils, the required weight for the soil sampling can be estimated from the relationship between \( N \) and the tube penetration force (Shogaki et al., 2002), and the 45-mm and 50-mm samplers can obtain samples of nearly \( l_{\text{max}} \) for soils with \( N \leq 3 \) to 54.

**4. STRENGTH AND CONSOLIDATION PROPERTIES AND SAMPLE QUALITY**

The representative stress-strain curves of the Unconfined Compression Tests (UCTs) for the Pleistocene and Tertiary clays are shown in Figures 4(a) and (b), respectively. There is a variation in \( q_u \) since the curves include the test results from 3 to 5 deposit sites. The stress-strain curves shown with broken lines express that \( q_u \) became small for the sandy soil and that the sample was \( l/l_{\text{max}} < 60\% \). The sample of \( l/l_{\text{max}} < 60\% \) was disturbed by the lack of resistance force for the sampling. However, the strain values at failure (\( \varepsilon_l \)), shown by the solid lines, are almost less than 3%.

Therefore, it can be judged that the quality of the samples shown by the solid lines is higher.

The \( q_u \) and the deviator stress obtained from the triaxial compression tests under unconsolidated-undrained conditions are plotted against the \( N \) in Figure 5. The plots marked “a” represent sandy soil or soil disturbed by the lack of resistance force for the sampling. The straight line in this figure is the regression line obtained from the least squares method by all plots, except “a”, and \( r \) is the correlation coefficient. The relationships determined to be \( q_u = (0.025 \sim 0.05)N \) for the Holocene and Pleistocene clays obtained from Japanese coastal and inland areas are shown as a shaded area (JGS, 2013), and the regression line is located in the lower part of this area.

It can be judged that the plots (●, ▲) for \( N = 5 \sim 10 \), located outside of the shaded area, represent high-quality samples.

Figure 6 shows the relationship between \( \sigma'_p \) and \( \sigma'_r \). Therefore, it can be judged that the quality of the samples shown by the solid lines is higher.
undrained shear strength $c_u (=q_d/2)$ for the samples used in Figure 4. The straight line and $r$ are obtained in the same manner as for Figure 5. The $\sigma'_u$ increases linearly with the increasing $c_u$; this tendency is unrelated to the soil types. These samples are taken from the Nobi Plain and the regression line is similar to $\sigma'_u = (3 \sim 6)e_u$ (Kubo and Tsubota, 2007).

The relationship between the volumetric strain ($\epsilon_{vo}$) and the overconsolidation ratio (OCR) is shown in Figure 7 together with the Lacasse and Berre (1988) and the 75-mm (Shogaki, 1996) samplers. The 84T (Shogaki and Nakano, 2010), 45-mm and 50-mm (Shogaki, et al. 2005a; Sogaki and Nakano, 2010) and 45-mm and 50-mm samplers are shown in Table 1. The $\epsilon_{vo}$ value is defined by Eq. 1 using $\epsilon_0$ and $\epsilon_1$, where $\epsilon_1$ is the void ratio under the effective overburden pressure ($\sigma'_u$) value and can be used as an index to indicate sample disturbance (Shogaki, 1996).

$$\epsilon_{vo} = \frac{\epsilon_0 - \epsilon_1}{1 + \epsilon_0} \times 100 \, (%) \quad (1)$$

In $in situ$ soil, under a value of $\sigma'_u$, there was no sample disturbance. Therefore, the $\epsilon_{vo}$ value is 0 since the $\epsilon_1$ value is equal to the $\epsilon_0$ value. The $\epsilon_1$ value decreases with sample disturbance, because the $\epsilon$ value decreases with sample disturbance under the same consolidation pressure (Schmertman, 1955; Shogaki and Kaneko, 1994) and the $\epsilon_{vo}$ values become larger. Therefore, the $\epsilon_{vo}$ value can be employed as an index to express the effect of sample disturbance.

The $\epsilon_{vo}$ for plots (▲, ◆, ■) obtained from the 45-mm and 50-mm samplers, shown in Table 1, are similar to the results for the Lacasse and Berre (1988) and the 45-mm and 50-mm samplers (Shogaki, et al., 2005a; Sogaki and Nakano, 2010). Therefore, the 45-mm and 50-mm samplers can take high-quality samples for clayey soils. For sandy soils, it was confirmed that the 50-mm sampler can take high-quality samples just as well as the triple-tube sampler for Niigata East Port (Yoshizu, et al., 2014), Niigata Meike (Shogaki, et al., 2006) and Niigata sand (Nakano, et al., 2002).

It can be confirmed that the two-chamber hydraulic piston (45-mm and 50-mm) samplers can take just as high-quality samples for highly organic, clayey and sandy samples obtained from Holocene, Pleistocene and Tertiary natural deposits with $q_d$=8~1415 kN/m$^2$ and N=3~54, which are very broad. The sample diameters are 45 mm and 50 mm for the 45-mm and 50-mm samplers, respectively. In an engineering sense, there is no difference in either shear strength (Shogaki, 2007) or deformation characteristics (Shogaki, 2006) between the small-size specimens (15 mm in diameter (d) and 35 mm in height (h) for UCT, d30 mm and h10 mm for the Standard Consolidation Tests (SCTs)) and the ordinary-size specimens (d35 mm, h80 mm for UCT, d60 mm and h20 mm for SCT). These small-size specimens are employed as JIS A 1216(2000) and JIS A 1217(2000). Samples obtained with the 50-mm sampler can also be used in cyclic triaxial tests since the 50-mm sampler can take samples 735 mm in length (Shogaki, et al., 2006).

5. CONCLUSIONS

It has been confirmed that the 45-mm and 50-mm samplers can take high-quality samples just as well as rotary double-tube (JGS 1222-2012) and rotary triple-tube (JGS 1223-2012) samplers for soils having $q_d$=8~1415 kN/m$^2$ and SPT N-values of 3~54. Therefore, the 45-mm and 50-mm samplers can be applied as samplers of JGS 1221, JGS 1222 and JGS 1223 to recover undisturbed soil samples suitable for laboratory tests.

The two-chamber hydraulic piston (45-mm and 50-mm) samplers can be used for the technique classified in Category A in Eurocode 7, CEN/TC341.

REFERENCES

1) Hosaka, Y., Ohtsuka, S. and Takahara, T. (2013): Characteristics of the foundation ground at Shimano River Ohkouzu Old Movable Weir, The 68th National Conference on JSCE, CD-R, 313-314 (in Japanese).
2) Japanese Geotechnical Society (2006): Unconfined compression test with suction measurement manual, Proc. of the Miniaturization, Accuracy and Design Reliability for Geotechnical Investigations and Lab Tests, 137-150 (in Japanese).
3) Japanese Geotechnical Society (2013): Method for obtaining soil samples using thin-walled tube sampler with fixed piston (JGS 1221-2012), Japanese Standards and Explanations of Geotechnical and Geoenvironmental Investigation Methods, 226-233 (in Japanese).
4) Japanese Geotechnical Society (2013): Method for obtaining soil samples using rotary double-tube sampler (JGS 1222-2012), Japanese Standards and Explanations of
Geotechnical and Geoenvironmental Investigation Methods, 241-243 (in Japanese).
5) Japanese Geotechnical Society (2013): Method for obtaining soil samples using rotary triple-tube sampler (JGS 1223-2012), Japanese Standards and Explanations of Geotechnical and Geoenvironmental Investigation Methods, 244-246 (in Japanese).
6) Japanese Geotechnical Society (2013): Japanese Standards and Explanations of Geotechnical and Geoenvironmental Investigation Methods, 308-309 (in Japanese).
7) Kubo, Y., Tsubota, K. (2007): About a consolidation characteristics of Ise Bay and Nobi Plain clay deposits, Tsuchi to Iwa, Chubu Geotechnical Consultants Association, 42-44 (in Japanese).
8) Lacasse, S. and Berre, T. (1988): Triaxial testing methods for soils, Advanced triaxial testing of soil and rock, ASTM STP 977, 264-289.
9) Nakano, Y., Shibata, A. and Shogaki, T. (2002): Dynamic Strength and Deformation Properties of Undisturbed Niigata sand using the small diameter sampler with a two-chambered hydraulic piston, The 37th Japan National Conference on Geotechnical Engineering, CD-R , 141-142 (in Japanese).
10) Schmertman, J. H. (1955): The undisturbed consolidation behavior of clay, Transactions ASCE, 120, 1201-1233.
11) Shogaki, T. and Kaneko, M. (1994): Effect of sample disturbance on strength and consolidation parameters of soft clay, Soils and Foundations, 34 (3), 1-10.
12) Shogaki, T. (1996): A method for correcting consolidation parameters for sample disturbance using volumetric strain, Soils and Foundations, 36 (3), 123-131.
13) Shogaki, T. (1997): A small diameter sampler with a two-chambered hydraulic piston and the quality of its samples, Proceedings of the Fourteenth International Conference on Soil Mechanics and Foundation Engineering, 201-204: Hamburg.
14) Shogaki, T., Nakano, Y. and Shibata, A. (2002): Sample recovery ratios and sampler penetration resistance in tube sampling for Niigata sand, Soils and Foundations, 42 (5), 111-120.
15) Shogaki, T. and Sakamoto, R. (2004): The applicability of a small diameter sampler with a two-chambered hydraulic piston for Japanese clay deposits, Soils and Foundations, 44 (1), 113-124.
16) Shogaki, T., Sakamoto, R., Kondo, E. and Tachibana, H. (2004): Small diameter cone sampler and its applicability for Pleistocene Osaka Ma12 clay, Soils and Foundations, 44 (4), 119-126.
17) Shogaki, T., Ebisuzaki, D., Kanno, Y., Nakano, Y. and Kitada, N. (2005a): Geotechnical properties of leaning tower of Pisa clays, Tsuchi to Kiso, 53 (3), 26-28 (in Japanese).
18) Shogaki, T., Nochikawa, Y., Jeong, G. H., Suwa, S. and Kitada, N. (2005b): Strength and consolidation properties of Busan new port clays, Soils and Foundations, 45 (1), 153-169.
19) Shogaki, T. (2006): An improved method for estimating in-situ undrained shear strength of natural deposits, Soils and Foundations, 46 (2), 109-121.
20) Shogaki, T., Sakamoto, R., Nakano, Y. and Shibata, A. (2006): Applicability of the small diameter sampler for Niigata sand deposits, Soils and Foundations, 46 (1), 1-14.
21) Shogaki, T. (2007): Effect of specimen size on unconfined compressive strength properties of natural deposits, Soils and Foundations, 47 (1), 119-129.
22) Shogaki, T., Takahashi, A. and Kumagai, N. (2008): Performance Evaluation Method of an Existing Bank of an Earth Dam, Tsuchi to Kiso, 56 (2), 24-26 (in Japanese).
23) Shogaki, T. and Nakano, Y. (2010): Quality of samples obtained from a two-chambered hydraulic piston cone sampler, Japanese Geotechnical Journal, 5 (2), 363-375 (in Japanese).
24) Yoshizu, T., Shogaki, T., Nakano, Y. and Sugano, T. (2014): Applicability of Improving Estimation of In-situ Dynamic Strength Properties of Niigata east port sand, The 49th Japan National Conference on Geotechnical Engineering, CD-R (in Japanese).