SAMPLE RECOVERY RATIOS AND SAMPLER PENETRATION RESISTANCE IN TUBE SAMPLING FOR NIIGATA SAND

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ABSTRACT

In this paper, sample recovery ratios, fluid pressure and sampler penetration resistance in tube sampling are discussed. The samplers were taken by two types of hydraulic piston samplers, one a two-chambered sampler with inner diameters of 45 mm and 50 mm, and the second a one-chambered sampler having a 70 mm diameter. The second type is the one commonly used in Japan and which was also used at the Meike Elementary School, the JGS-1989 investigation site. These samplers are here after referred to as the 45D, 50D and 70S samplers. The mean value of the sample recovery ratios from the 45D and 50D samplers was 93% greater than that of the 70S sampler. This value remained independent of the sands having $N=3 \sim 54$ from the standard penetration test. Guidelines for estimating the pump fluid pressure for tube sampling of sand, sampler and drilling equipment penetration resistance forces and the relationship between the sample recovery ratios and the drilling mud densities, etc., were established for Niigata sand. The end results contribute to a safer and more reliable sampling method.

Key words: CPT, mud density, penetration pressure, sample recovery ratio, sand, small diameter sampler, SPT, undisturbed tube sampling (IGC: C5/C6)

INTRODUCTION

The soil sampling committee of the Japanese Society for Soil Mechanics and Geotechnical Engineering conducted systematic sampling in Niigata city (JGS-1989 investigation) in order to establish a tube sampling method for natural sand deposits and an evaluation technique for the sample quality obtained (Japanese Geotechnical Society, 1989). In this sampling, 33% of the samples were 0% of the sample recovery ratios (R_r), which is defined in an equation as the ratio of the length of the sample before withdrawal over the penetration depth during sampling. It was thought that the reason for the low R_r values was medium sand, in which 50% of the grain size is about 0.3 mm, the percentage of grain size smaller than 0.075 mm is small and the uniformity coefficient of the sand is about 2 (Japanese Geotechnical Society, 1989).

The undisturbed samples for these sands are usually obtained by an in-situ freezing method, since tube sampling is very difficult. However, if in-situ dynamic strength properties can be estimated from laboratory tests for undisturbed samples using a tube sampler, the geotechnical investigation and design accuracy can be improved, therefore greatly reducing costs. For sand sampling using a tube sampler, lack of penetration resistance to the sampler affects the R_r and sample quality. The penetration force of the sampler depends upon the soil strength. However, there have been no guidelines estab-

lished for the fluid pressure and penetration resistance forces. If this information can be obtained from the N -value of the Standard Penetration Test (SPT), and/or the cone index (q_c) of the Cone Penetration Test (CPT) before sampling, then estimating the resistance forces for sampler and drilling equipment penetration can be done, resulting in a safer, more reliable sampling method.

Shogaki (1997) developed a new sampler called a 45D sampler, which has a 45 mm inner diameter and a two-chambered hydraulic piston and its applicability was tested through unconfined compression tests for six different sites in Japan (Shogaki and Tokuda, 2001). It was confirmed from Shogaki and Tokuda (2001) that for Japanese clay deposits having unconfined compressive strength (q_u) ranging from 23 kPa to 604 kPa, the q_u and the secant of modulus (E_{50}) for samples obtained from this sampler were between (20~70)% and (30~90)% greater than those of the 75 mm samplers normally used in Japan, one of which is a non-rotary, thin-walled, single tube type with a fixed piston and the other a rotary, double-tube sampler.

In this study, the applicability of the 45D sampler for Niigata sand, and guidelines for measuring pump fluid pressure and sampler penetration resistance in tube sampling of sand deposits are discussed. The samples were taken by a 45D sampler, a 50D sampler and a 70 mm sampler (70S sampler).

The R_r values from the 45D and 50D samplers were

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Fig. 1. Layout of the geotechnical investigation sites

greater than those of the 70S sampler and independent of the sands having $N=3 \sim 54$ from the SPT. Valuable information, such as the relationships between the N -values and the penetration pressure of the sampling tube, the R_r and the drilling mud density, etc., can be obtained by the method used in this study.

SOIL PROFILE OF SAMPLING SITE

Figure 1 shows the layout of the geotechnical investigation site, including the JGS-1989 investigation area. This paper's authors did the tube sampling, SPT and CPT in a $5 \text{ m} \times 2 \text{ m}$ area on the eastern side of the JGS-1989 investigation area. The N and q_c values, including those of the JGS-1989 investigation, are plotted against the depth (z) in Fig. 2. The CPT were performed in accordance with the Japanese Geotechnical Standard for electric cone penetration test (JGS 1435-1995). Based on the N and the q_c values, it was determined that the layer at a depth of $2 \sim 7 \text{ m}$ was a sand hill and the lower sand layer at a depth greater than 7 m had been deposited by river water. The N and q_c values increase with depth and the scatter of these values at the same depth in an area about $35 \text{ m} \times 22 \text{ m}$ are $N=10 \sim 15$ and $q_c=(3 \sim 12) \text{ MPa}$. Therefore, it can be judged that the geotechnical properties at equal depths throughout this area are almost similar. Figure 3 shows the relationship between the N and q_c values. The q_c values are obtained from one of the mean depths of the measured N -value and compared with the closest borehole. The straight line, $q_c=0.613N$ (in MPa) as shown in

Fig. 3, is a regression line obtained from the least square method. The correlation coefficient (r) of the regression equation is 0.916 and it is a high value.

SAMPLERS USED AND THE BORER SET-UP

A sketch of the samplers used in this study is shown in Fig. 4 and their specifications are summarized in Table 1. The 45D and 50D samplers can be used in the same borehole with SPT, since the greatest outside diameter of these samplers is 60 mm, as shown in Table 1. The penetration forces of the 45D and 50D samplers are about twice as powerful as that of the single-chambered hydraulic piston sampler of the same diameter. Trimming-down of the specimen is not necessary in the 45D and 50D samplers if the 50 mm diameter specimen commonly used in Japan is used for the strength test. On the other hand, a 110 mm borehole diameter is required for the 70S sampler.

Both depth and time of penetration were determined by measuring both the wire movement and the air volume increase in the air cylinder from start to finish time of penetration for the 45D, 50D and 70S samplers respectively, as shown in Fig. 4. Figure 5 shows a sketch of the borer set-up. To determine the penetration resistance and safety factors for sand sampling of $N \approx 50$ at $z = -12 \text{ m}$, eight concrete blocks 1 m in height, 1 m in width and 0.5 m in length were placed underneath the frame of the drilling machine and fixed to it with two H-shaped steel supports, wires and chain blocks. In this borer set-up, the

Fig. 2. Test results of SPT and CPT against the depths

Fig. 3. Relationship between N and q_c values

maximum displacement of the central part of the H-shaped steel is calculated as 1.5 cm for a load of 98 kN using 21×10^5 MPa of the secant of modulus for H-shaped steel.

SAND SAMPLING

The sand sampling using 45D, 50D and 70S samplers and SPT were done by the same engineer using the same

Table 1. Specifications of samplers used

	45D	50D	70S
Length of sampler (mm)	1340	1680	1165
Weight of sampler (kg)	10.6	12.8	21.4
Greatest outside diameter of sampler (mm)	60	60	90
Length of tube (mm)	600	800	950
Greatest outside diameter of tube, D_2 (mm)	52	56	76
Inside diameter of tube, D_1 (mm)	48	50	70
Thickness of tube (mm)	2	3	3
Edge taper angle ($^\circ$)	5.4	6.6	31.0
Thickness of edge (mm)	0.2	0.2	0.2
Inside clearance (mm)	0	0	0
Area ratio, C_a (%)	17	25	18
Maximum sample length (mm)	535	735	796

$$C_a = \frac{D_2^2 - D_1^2}{D_1^2} \times 100 (\%)$$

drilling machine, pump, etc., in order to reduce the possibility of human error. The number of samples were 9, 5 and 11 for 45D, 50D and 70S respectively and the relationship between the borehole number and depths is shown in Fig. 6 as plots including R , and depths. The casing point was kept at the bottom of the borehole during

each sampling.

There were misgivings that the sample inside the tube might collapse during the raising of the sampling tube after penetration, since the percentage of grain size smaller than 0.075 mm is about 1% and the uniformity coefficient is about 2 for Niigata sand. In fact, sand sample collapse had been reported in the JGS-1989 investigation. Therefore, a sump for mud was put around the casing tube as a counter measure and the sample was backed with porous stone in the sump, as shown in Fig. 7. The cutting edges

of the sampling tubes did not suffer any damage during all sampling.

EFFECTS OF SEVERAL FACTORS ON SAMPLE RECOVERY RATIOS

The results of grain size distribution tests are summarized in Table 2. Figure 6 also shows the R_r and the grain properties obtained from the SPT sample for borehole No. 3. The Niigata sands tested were medium sand, in which 50% of the grain size is about 0.25 mm, the percentage of grain size smaller than 0.075 mm is about 1%, excluding (4~7)% of $z = -(8 \sim 10)$ m, and the uniformity coefficient and coefficient of curvature are about 2 and 1, respectively. Figure 8 shows the relationship between the penetration depth and required penetration time (t_p) for the 45D, 50D and 70S samplers. The penetration depth and the t_p depend on the samplers used and the rate of penetration was not uniform for items 1 and 2.

The amounts of pressurized water required (p_w) for penetration of the sampling tube are shown in Fig. 9 for the 45D, 50D and 70S samplers. This data is shown in sampling depth order. The dashed lines shown for each sampler are the mean values of the p_w . The p_w of items 3 and 4 shown for the 45D and 50D samplers in Fig. 9 are about twice those of other data. The items 1 and 2 shown at the R_r plots in Fig. 6 represent a sampling in which the sump was dry and the penetration speed was not uniform as described in Fig. 8. The items 3 and 4 shown at the R_r plots in Fig. 6 represent the partial collapse of samples which is thought to have been caused by a decrease in the mud density when water leaked out during tube penetration. It can be judged that the grain properties do not

Fig. 4. A sketch of the samplers used and the measuring method for the penetration depths

Fig. 5. A sketch of the borer set-up

Fig. 6. Sample recovery ratio and the grain properties (No.3 SPT sample)

Fig. 7. A sump for mud to avoid sand sample collapse

Fig. 8. Relationship between penetration depth and required penetration time

affect the R_r value since the Niigata sands in this site have almost similar grain properties at varying depths.

Figures 10 and 11 show the relationships between the R_r and N , q_c values, respectively. The R_r values for the plots of 1 through 4 described above are as small as 53% to 74%, compared to other plots. The R_r values of the 45D and 50D samplers, excluding these plots, are in the range of 85% to 97% and the mean value is 93%. The values of the 70S sampler are (81 ~ 97)% and 89% respectively, and have small values compared with those of the 45D and 50D samplers. These tendencies are independent of $N=3 \sim 54$ and $q_c=2 \sim 26$ MPa.

The effect of the mud densities on the R_r values is shown in Fig. 12. When the sampling tube penetrates below the bottom of the borehole, the drilling mud is replaced by new mud having a higher density in order to decrease sample collapse. The mud densities in Fig. 12 are the new densities and were obtained immediately after sampling. The R_r values of the 45D and 50D samplers, excluding the plots of 1 through 4 as shown in Fig. 12, are greater than 85% and independent of the mud densities having 1.02 g/cm³ to 1.05 g/cm³. The straight line in Fig. 12 is a regression line for the plots of the 70S sam-

Table 2. Results of grain size distribution tests

Depth (m)	Gravel (%)	Sand (%)	Clay and silt (%)	$D_{\max}$ (mm)	D_{60} (mm)	D_{50} (mm)	D_{30} (mm)	D_{10} (mm)	U_C	U_C'
2.3	0.0	98.9	1.1	0.85	0.270	0.250	0.206	0.150	1.8	1.0
3.3	0.0	99.1	0.9	0.85	0.263	0.241	0.195	0.138	1.9	1.0
4.3	0.0	98.9	1.1	0.85	0.257	0.238	0.195	0.139	1.8	1.1
5.3	0.0	98.8	1.2	0.85	0.263	0.243	0.198	0.139	1.9	1.1
6.3	0.0	98.9	1.1	0.85	0.259	0.241	0.202	0.147	1.8	1.1
7.3	0.0	98.7	1.3	0.85	0.276	0.258	0.220	0.162	1.7	1.1
8.3	0.0	93.2	6.8	0.85	0.283	0.261	0.211	0.127	2.2	1.2
9.3	0.0	94.9	5.1	0.85	0.300	0.279	0.237	0.173	1.7	1.1
10.3	0.3	95.2	4.5	4.75	0.301	0.281	0.240	0.180	1.7	1.1
11.3	0.1	99.0	0.9	4.75	0.290	0.275	0.244	0.192	1.5	1.1
12.3	0.4	99.0	0.6	4.75	0.373	0.344	0.292	0.231	1.6	1.0

$D_{\max}$: Maximum grain size, D_{60} : 60% diameter of grain size, U_C : Uniformity coefficient, U_C' : Coefficient of curvature

Fig. 9. Relationship between amount of pressurized water required and sampler

Fig. 11. Relationship between R_r and q_c values

Fig. 10. Relationship between R_r and N values

Fig. 12. Relationship between R_r and the mud densities

Table 3. Sampling methods and samplers as shown in Fig. 13

Investigation	Sampling methods and samplers		Inside diameter of tube (mm)
JGS-1989	A	Rotary triple-tube sampler	125
	B	Static penetration-tube sampler	50
	C		70
	D	Pressure balanced rotary triple-tube sampler	82
	E	Rotary triple-tube sampler	83
	F	In-situ freezing method	—
Chugonji (2001)	G	Small diameter sampler with a two-chambered hydraulic piston	50

Fig. 13. Relationship between $G_0/\sqrt{\sigma'_c}$ and N values Fig. 14. Relationship between R_r and the required penetration time

pler. Its tendency is that the R_r values of the 70S sampler decrease with a decrease in the mud density caused by its larger diameter, compared to the 45D and 50D samplers. Primarily, it is thought that the sample in the tube collapses easily during the raising of the sampler where the tube inner diameter is larger, since the effect of friction between the tube wall and sand and the arch action decreases with an increasing inner tube diameter. However, this does not indicate a low quality sample. Figure 13 shows the relationship between $G_0/\sqrt{\sigma'_c}$ and N -values for Niigata sand, where the G_0 is initial shear modulus of rigidity, and σ'_c is effective confining pressure. The test results of the JGS-1989 investigation and the Chugonji site in Niigata city (Nakano et al., 2002) are plotted in Fig. 13. The sands obtained from the Chugonji site are also medium sand, in which 50% of the grain size is about 0.2 mm, the percentage of grain smaller than 0.075 mm is less than 5% and the uniformity coefficient of the sand is 1.6 to 2.0 (Nakano et al., 2002). Both sands have similar grain size distribution and were located on the same sand hill. The sampling methods and samplers as shown in Fig. 13 are listed in Table 3. The $G_0/\sqrt{\sigma'_c}$ values of samples obtained from the in-situ freezing method (■) are larger than those of the tube sampling under the same N -value. However, the $G_0/\sqrt{\sigma'_c}$ values of

samples obtained from the 50D sampler (▲) are almost similar to those of the rotary triple-tube samplers with 125 mm (◆) and 82 mm (+) in inner diameter. The sample quality is independent of the sampler types and the inner diameter of tubes used in this study. However, special attention should be paid concerning the R_r values of the 70S sampler due to changes caused by slight differences in the mud densities.

Figure 14 shows the relationship between the R_r value and the t_p . The t_p values are 15 ~ 32 seconds for the 45D and 50D samplers and 30 ~ 90 seconds for the 70S sampler. The maximum sample lengths are 74 cm and 80 cm for the 50D and 70S samplers, as shown in Table 1, and have similar values. The shorter t_p values of the 50D sampler are caused by the small diameter tube with a two-chambered hydraulic piston. The R_r values are plotted against mean penetration speed (S_p) in Fig. 15, where the S_p value is defined as the ratio of the tube penetration net depth to the time required for penetration. The largest S_p value is about 3 cm/sec. The mean S_p values are 2.1 cm/sec for the 45D and 50D samples, excluding the plots of 1 through 4 and 1.6 cm/sec for the 70S sampler. From the smaller R_r value of the 70S sampler, the mean S_p value of the 70S sampler is about 30% smaller than those of the 45D and 50D samplers.

Fig. 15. Relationship between R_r and the mean penetration speed Fig. 17. Relationship between the mean penetration speed and N -values Fig. 16. Relationship between the required penetration time and N -values Fig. 18. Relationship between the maximum fluid pressure and N -values

The relationship between the t_p values, the S_p and N -values are shown in Figs. 16 and 17. As shown in Fig. 14, there is a difference in the t_p values between the 70S sampler and both two-chambered hydraulic piston samplers. However, the t_p values are almost constant in the range of $N=3 \sim 54$ for both two-chambered hydraulic piston samplers. The S_p values of each sampler are also independent of the N -value.

EFFECT OF SOIL STRENGTH INFLUENCING FLUID PRESSURES AND PENETRATION FORCES OF THE SAMPLERS

The relationships between the maximum fluid pressures ($p_{\max}$) for the tube penetration and the N and q_c values are shown in Figs. 18 and 19. The $p_{\max}$ values increase linearly with the increasing N and q_c values and these tendencies are independent of the sampler types. The straight lines in

Figs. 18 and 19 are regression lines obtained from the least square method and the $p_{\max}$ in MPa are determined to be $2.16 + 0.10N$ ($r=0.905$) and the $p_{\max} = 1.48 + 0.22q_c$ ($r=0.864$). The results of Figs. 18 and 19 can be used for estimating the pump fluid pressure for tube sand sampling.

The relationship between the tube penetration forces (F), which is the $p_{\max}$ values times the total area of a two-chambered hydraulic piston, and the N -values is shown in Fig. 20. The F values increase linearly with increasing N -values independent of sampler types. The straight lines in Fig. 20 are regression lines obtained from the least square method for the 70S sampler and the two-chambered hydraulic piston samplers. The F values in kN are given by $6.62 + 0.39N$ ($r=0.903$) for the 45D and 50D samplers and also given by $11.50 + 0.42N$ ($r=0.939$) for the 70S sampler. The F values of the 45D and 50D samplers are (20~40)% smaller than those of the 70S sampler because

Fig. 19. Relationship between the maximum fluid pressure and q_c -values

Fig. 20. Relationship between the tube penetration forces and N -values

of the smaller total area. However, the 45D and 50D samplers can sample sands having an $N=53$ value. The result in Fig. 20 can be used for estimating the resistance forces for sampler and drilling equipment penetration because of the F value equivalent of the resistance force.

The effects of sampler types, R_r , $p_{\max}$ and the tube penetration time influencing sample quality will be quantitatively discussed after completing dynamic tests of the soils.

CONCLUSIONS

The conclusions obtained in this study are summarized as follows:

- 1) The sample recovery ratios (R_r) of the 45D and 50D samplers were in the range of 85% to 97% and the mean value was 93%. The values of the 70S sampler were (81~97)% and 89%, respectively. These tendencies were independent of $N=3 \sim 54$ and $q_c=2 \sim 26$ MPa. However, the R_r values of the 45D and 50D samplers were as small as 53% to 74% in situations where there were either, (i) a dry sump, (ii) lower mud densities, or (iii) the penetration speed was not uniform.
- 2) The R_r values of the 45D and 50D samplers, excluding the above data, were greater than 85% and independent of the mud densities having 1.02 g/cm^3 to 1.05 g/cm^3 . However, the R_r values of the 70S sampler decreased with a decrease in the mud density because of its larger diameter. Special attention should be paid concerning the R_r values of the 70S sampler due to the changes caused by slight differences in the mud densities.
- 3) The maximum fluid pressures ($p_{\max}$) for the tube penetration increased linearly with the increasing N and q_c values and these tendencies are independent of the sampler types. The $p_{\max}$ in MPa can be estimated as $2.16 + 0.10N$ and the $p_{\max} = 1.48 + 0.22q_c$. These

equations can be used for estimating the pump fluid pressure for tube sand sampling since the correlation coefficient (r) of these equations were 0.905 and 0.864 respectively, and are a high value.

- 4) The tube penetration force (F) values increased linearly with increasing N -values independent of sampler types. The F values in kN were given by $6.62 + 0.39N$ ($r=0.903$) for the 45D and 50D samplers and also given by $11.50 + 0.42N$ ($r=0.939$) for the 70S sampler. The F values of the 45D and 50D samplers were (20~40)% smaller than those of the 70S sampler because of the smaller total area. However, the 45D and 50D samplers can sample sands having an $N=53$ value. These equations can be used for estimating the resistance forces for sampler and drilling equipment penetration because of the F value equivalent of the resistance force.

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NOTATIONS

p_w :	amount of pressurized water required
F :	tube penetration force
N :	blow number of the Standard Penetration Test (SPT)
$p_{\max}$:	maximum fluid pressure
q_c :	cone index of the Cone Penetration Test (CPT)
R_r :	sample recovery ratio
r :	correlation coefficient
S_p :	mean penetration speed

t_p : required penetration time

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