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EFFECT OF SAMPLING METHODS ON LIQUEFACTION RESISTANCE OF LOOSE SAND

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SUMMARY

Recently, in-situ freezing has been studied as the sampling method to obtain good-quality undisturbed samples of sand, whereas dense clean sand was the object in conventional studies.

This study sampled loose sand containing fine particles in both the conventional tube sampling method (by triple tube sampler) and the in-situ freezing to investigate the effect of the difference in sampling method on the liquefaction resistance of sand.

To investigate the effect of freezing on liquefaction resistance of sand containing fine particles, the sample was subjected to the freeze-thaw process in a triaxial condition to examine the effect of the process on liquefaction resistance of sand. From results of these tests, effectiveness of in-situ freezing for loose sand with fine particle (under 74μm) content of about 6% was confirmed. At the same time, it was found that the tube sampling could cause an estimation of an excessively large liquefaction resistance.

INTRODUCTION

Accurate estimation of dynamic properties of soil is important for the appropriate evaluation of soil structure stability during an earthquake. Recently, in-situ freezing is studied as the sampling method of obtain high-quality undisturbed sand samples. This method has been studied by Yoshimi et al.[1)] mainly for dense "clean sand"

In this study, undisturbed samples were taken from the body of a small earth dam damaged by liquefaction due to the 1983 Mid Japan Sea earthquake through methods of the tube sampling and the in-situ freezing. These undisturbed samples were subjected to cyclic triaxial tests to determine the effect of the difference in sampling method on the liquefaction resistance of sand. Further, to determine the effect of the freeze-thaw process, liquefaction resistance values were compared between samples subjected and not subjected to the process in the triaxial chamber.

Damage of KANSUKE dam and soil properties

As many as about 230 small earth dams for irrigation were damaged by the

1983 Mid Japan-Sea earthquake in both Aomori and Akita prefectures. Some of the dams were thought to be damaged by liquefaction of dam body or foundation ground. The KANSUKE dam located in Kizukuri-machi, Aomori pref. (height 5.4 meters, crest length 202 meters) is the typical dam that was damaged by liquefaction[2]. After the earthquake, boring survey and cyclic triaxial test were conducted with undisturbed samples obtained by the conventional tube sampler method and the in-situ freezing method.

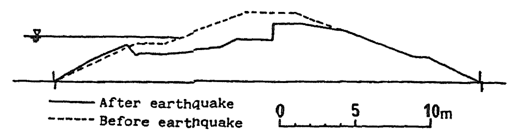

Fig.1 Cross section of 'KANSUKE' dam

The KANSUKE dam largely settled by the earthquake as shown in Fig. 1. The maximum recorded settlement was about 1.8 meters without failure. The result of the boring made after the earthquake is as shown in Fig. 2.

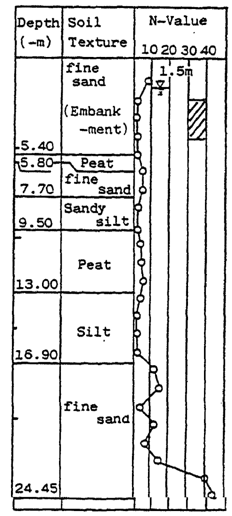

Fig.2 Results of soil investigation

The dam body and its foundation ground of -5.4∿-7.7 meters from G.L. consist of very loose fine sand whose N value is smaller than 5. The further depth consists of alternate layers of peat, sand and silt. Its N value is less than 10 down to a depth of 16 meters. The average particle size of the body is shown in Fig. 3. The soil is classified as SM according to the unified soil classification system. Though fine soil is locally present since the dam is an artificial soil structure, the fine particle content is below 6%.

Undisturbed sampling

a. Sampling by in-situ freezing

Sampling by in-situ freezing was made near the center of the dam body. The in-situ freezing was conducted in conformity with the procedure developed by Yoshimi et al.[1] The outline of the freezing sampling is as shown in Fig. 4. Freezing was made in the range of G.L. -2.0∿-4.1 meters with ethanol as the coolant, and the ethanol in the freezing tube was circulated at -50°C with dry ice. The freezing was continued for 24 hours. The frozen soil column of 2.0 meters in length and 37 cm in diameter was drawn out after removing the unfrozen sand. The frozen column was disassembled into blocks with blowing N_2 gas so that the column may not be melted, and transported with a refrigerator car.

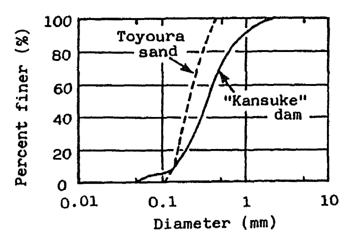

Fig.3 Grain size distribution

To determine the density distribution of the frozen soil, the dry density ρ d of the soil was measured in lateral and depth directions by the mercury substitution method. Fig. 5 shows the result of dry density measurement made in the lateral direction within the range of G.L. -2.5∿-3.0 meters. Almost the same density is exhibited at the distance of 6∿15 cm from the freezing tube for each depth, while a disturbance is judged to be present near and outside the freezing tube. Fig. 6 shows the density distribution in the depth direction. Density fluctuates in the region of G.L. -2.0∿-2.8 meters, but it is nearly constant in other regions.

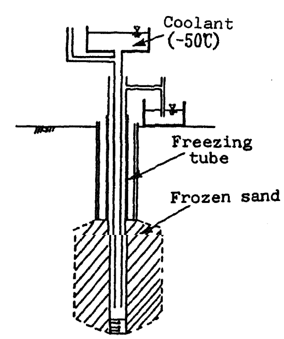

Fig.4 Freezing method

Tests were made with specimens cut from undisturbed portion of the sample.

b. Sampling by the tube sampler

Undisturbed samples were taken near the place where the in-situ freezing was made from regions G.L. -2.5∿3.5 meters and -4.4∿5.0 meters. These samples may be regarded as equivalent samples viewing from their densities and particle size distribution. After sampling completion, the tube was drained and frozen for transportation.

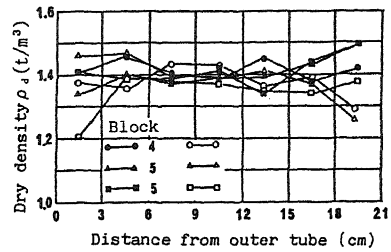

Fig.5 Dry density of frozen sand

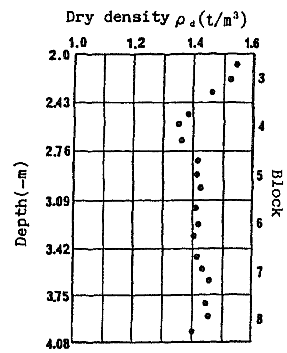

Fig.6 Dry density of frozen sand

Soil properties and testing method

Physical properties of the sample prepared by the in-situ freezing are as listed in Table 1. These are averages of data obtained from physical tests for each specimen after used in the experiment. The average contents of fine particles that affect the disturbance due to freezing was 5.4%. Those samples obtained by means of the triple tube sampler exhibited almost similar physical properties.

From several studies in the past[1)3)], it can be judged that little effect of freezing is exerted on liquefaction resistance if only the confining pressure exceeds 49 Kpa. The portion of G.L -2.8∿-3.1 meters was used as the frozen sample.

Samples of 5 cm diameter and 10 cm height cut from the frozen block and the sampler were set in the triaxial chamber and thawed for 12 hours under a confining pressure. After thawed, the samples were exposed to CO_2 gas and sufficiently to degassed water for complete saturation. Only those samples that satisfy the requirement of B>0.95 were subjected to the cyclic triaxial test with a confining pressure of σ_c'=49 Kpa taking into account the soil coverage pressure at the site, a back pressure of 198∿294 Kpa, and a sin wave frequency of 1 Hz using the testing apparatus shown in Fig. 7.

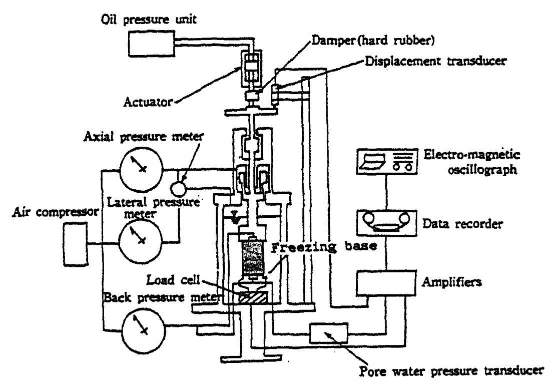

Fig.7 Cyclic triaxial test apparatus

Effect of freezing-thaw on liquefaction resistance

The following experiment was conducted with the sample of KANSUKE dam that contains fine particles to check if the freezing-thaw process affects the liquefaction resistance.

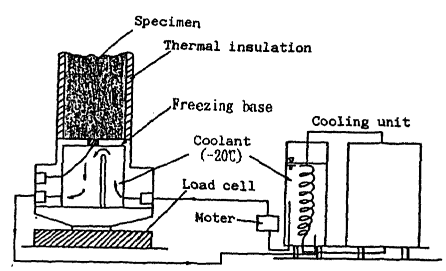

Fig.8 Freezing system

Reconstituted samples were prepared by wet tamping method and rammed to field density. The samples thus prepared were furnished with a stress history to examine the effect of freezing-thaw. One sample was subjected to the cyclic triaxial test only with a stress history, while the other sample was subjected to the same test with a freezing-thaw cycle besides the stress history. The stress history was provided as follows under draining condition. (Stress ratio $\theta=\sigma d/2\sigma'_c=0.090$, 20 times) + ($\theta=0.135$, 90 times) + ($\theta=0.180$, 20 times)

The change in sample density may be negligible since the consolidation due to the stress history is only about 1 cc. The freezing system shown in Fig. 8 was built in the triaxial chamber shown in Fig. 7 for practising the freezing-thaw cycle after providing the stress history to the sample. Freezing was carried out under a confining pressure of $\sigma'_c=49$ Kpa by cooling the bottom of the sample with coolant of -20°C for 24 hours. The sample was wrapped with heat insulation material during the process of freezing and the material was removed after freezing completion. The frozen sample was thawed for 12 hours before subjected to the triaxial test.

Fig. 9 shows the result of cyclic triaxial test for reconstituted samples that bear stress history with and without the freezing-thaw process. Liquefaction resistance increases by providing stress history. No change in liquefaction resistance is caused by adding a freezing-thaw process to the sample with stress history. Thus, it may be said that the sample of the KANSUKE dam is not affected by in-situ freezing when a confining pressure $\sigma_c'=49$ Kpa is present. Consequently, the liquefaction resistance obtained from the in-situ freezing sample may be regarded as the "true liquefaction resistance".

Effect of sampling method on liquefaction resistance

Fig. 10 shows the result of cyclic triaxial test with undisturbed in-situ freezing samples. Fig. 11 shows the result of the same test with undisturbed samples obtained from the tube sampler (triple tube sampler). Density values largely vary within the range from $\rho d=1.42$ t/m^3 to 1.63 t/m^3. Those samples of

Table 1 Soil properties

Depth (m)	G_s	D_{50} (mm)	U_c	F_c (%)	ρ_{dmax} (t/m^3)	ρ_{dmin} (t/m^3)	ρ_d (t/m^3)	D_r (%)
2.76~3.09	2.65	0.33	2.60	5.4 (3.4~7.1)	1.712	1.361	1.483	40.1

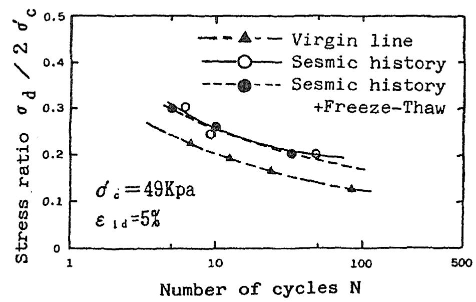

Fig.9 Effect of freeze-thaw on liquefaction resistance (reconstitued samples)

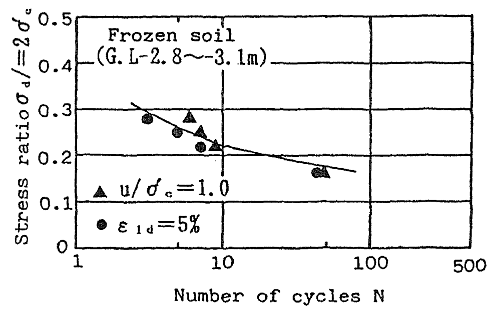

Fig.10 Undrained cyclic strength of undisturbed samples (In-situ freezing)

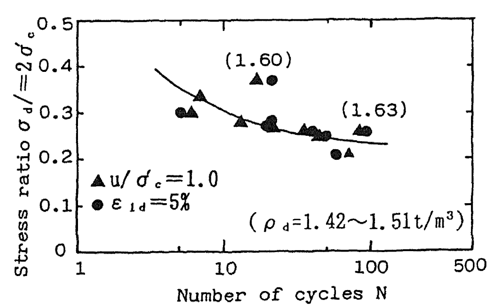

Fig.11 Undrained cyclic strength of undisturbed samples (Tube sampling)

particularly high densities were also obtained from nearly the same depth as the in-situ freezing region. The rise in density may be probably caused when the loose sand is penetrated with the tube. The curves were prepared with too high density data omitted.

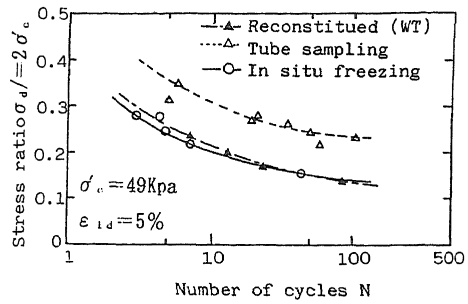

Fig.12 Effect of sampling methods on liquefaction resistance (KANSUKE)

Fig. 12 summarizes the result of cyclic triaxial test with reconstituted samples and two sampling methods. Both reconstituted samples and in-situ freezing samples exhibit almost the same liquefaction resistance, whereas the resistance of tube samples are larger than the above, and this tendency is more obvious at higher stress ratios. The fact that the reconstituted sample and the in-situ freezing sample exhibit nearly equal values of liquefaction resistance may look strange from studies in the past[1)3)], but it can be explained as follows: ① The dam is an artificial soil structure, and its sedimentary structure is similar to that in the "Wet tamping method". ② The high liquefaction resistance of the in-situ freezing sample may be caused by cementation and seismic history of the sand. The KANSUKE dam was subjected to liquefaction due to the 1968 Tokachi offing earthquake and the 1983 Mid Japan Sea earthquake. There is possibility that most of the seismic history were eliminated by the above liquefaction. This allows an estimation of the reason for the liquefaction resistance near those of disturbed samples. The high liquefaction resistance of the tube samples can be explained by the static strain history provided during sampling, according to the study by Suzuki et al.[4)]

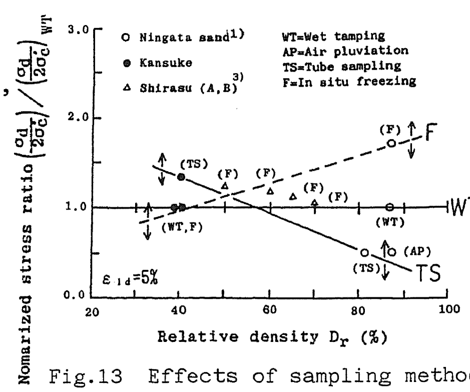

Fig.13 Effects of sampling methods on liquefaction resistance

As for samples not subjected to a large seismic history such as liquefaction, even in the case of an artificial structure, liquefaction resistance values may differ from each other between disturbed and in-situ freezing samples.

Fig. 13 summarizes major in-situ freezing data reported so far to indicate the effect of sampling method on liquefaction resistance with the resistance value obtained from the reconstituted sample as the standard. The result of reference 5) was utilized for preparing the reconstituted sample instead of reference 3) because of the difference in the method of sample preparation, and the liquefaction resistance of samples obtained from the "Wet sampling method" was estimated. The summary may be roughly outlined as follows although enough quantity of data were not available.

Liquefaction resistance values from disturbed and undisturbed samples (in-situ freezing method, the tube sampling method) are related to the relative density of the sample. With loose sand (relative density D_r=40∿60%), the resistance difference is about 40% regardless of the sampling method, whereas with dense sand, the resistance difference can increase to about three times at D_r=90%.

Conclusion

Undisturbed samples of a small earth dam for irrigation were prepared by the in-situ freezing method and the conventional tube sampler (triple tube sampler) to investigate the effect of the difference in sampling methods on the liquefaction resistance of sand. The fact that the freezing does not affect liquefaction resistance of the sand was also confirmed from the result of indoor experiments. From these findings, in the case of loose sand, the in-situ freezing is effective if the fine particle (under 74 μm) content is below 6%. On the other hand, the tube sampling method can cause an excessively large estimation of liquefaction resistance even when the factor of sand density change due to the tube pushing into sand is removed. The above conclusion are obtained from only a few data. Consequently, their validity has to be substantiated in the future.

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