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EFFECT OF ANISOTROPY ON DRAINED AND UNDRAINED SHEAR BEHAVIOR OF IN-SITU SANDY SOILS

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ABSTRACT

Two different types of undisturbed cylindrical specimen (V-specimen : the axis is parallel to the direction of sedimentation, and H-specimen : the axis is perpendicular to the direction of sedimentation), were prepared from high quality undisturbed sand column obtained by in-situ freezing technique. A series of drained compression and extension tests (CD_C test, CD_E test) and cyclic undrained triaxial tests (liquefaction test) on these samples were performed in order to investigate the effect of the anisotropy on the drained and undrained shear behavior. Following were concluded. 1) The effect of anisotropy on both internal friction angle and liquefaction strength is negligible. 2) The difference in deformation characteristics between V and H-specimens for Holocene soil layer appeared in both CD and liquefaction tests implies that in-situ soil is easier to compress in horizontal direction than in vertical direction. 3) The effect of anisotropy on deformation characteristic of Pleistocene sand samples is not so remarkable as that of Holocene sand.

INTRODUCTION

As widely known, the inherent anisotropy of in-situ soils has some effects on their mechanical properties. Based on a series of liquefaction tests on undisturbed (obtained by block sampling) and reconstituted samples, Miura and Toki pointed out that the anisotropy of both samples has significant effects on their liquefaction strength. However, the data on the anisotropy of in-situ sandy soils is quite limited and no systematic research on high-quality undisturbed sand samples has been done.

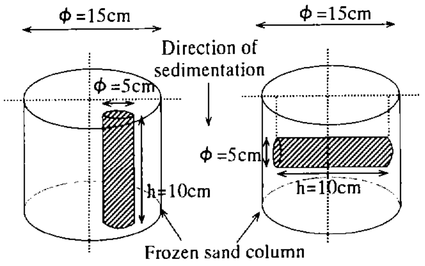
The objective of the present paper is to investigate the effect of the anisotropy of undisturbed sand samples recovered by in-situ freezing technique on their drained and undrained cyclic shear behavior by performing a series of CD and liquefaction tests. Two different types of undisturbed cylindrical specimen, V and H-specimen, were used in this study.

SAMPLE PREPARATION AND PHYSICAL PROPERTIES TESTED

Two different types of cylindrical shape test samples, 5 cm in diameter and 10 cm in height, were prepared from a frozen sand column obtained by the in-situ freezing technique. Hatanaka et al. described the detail of the in-situ freezing method. The sample whose axis is parallel to the direction of sedimentation is designated as V-specimen, while the sample whose axis is perpendicular to the direction of sedimentation is called H-specimen as illustrated in Fig.1.

The physical properties of samples used in CD and liquefaction tests are indicated in Table 1 and 2, respectively.

Sand A and sand B samples were recovered from Holocene soil layers, while sand C was obtained from Pleistocene soil layer. In Table 2, the physical properties show the average values of three test specimens of each depth. The SPT N-value normalized by the effective overburden stress using Eq.1, N_1-value, was introduced for discussion.



(a) V-specimen (b) H- specimen

Fig.1 Preparation method of V and H-specimens

$$N_1=N/(\sigma_v'/98)^{0.5} \qquad (1)$$

σ_v': effective overburden stress at the depth of SPT (kPa)

As shown in Table 2, it can be seen a slight difference of physical properties between V and H-specimens for sand A. However, there is no significant difference for sand B and sand C.

TEST METHOD

The prepared frozen samples were set in the triaxial cell and were allowed to thaw for about two hours under a confining pressure of 19.6 kPa. After that, by supplying CO_2 gas and circulating the de-aired water with the aid of a backpressure of 196 kPa, samples were saturated. The pore pressure coefficient B-value was maintained to be equal or larger than 0.95. After saturation, the samples were isotropically consolidated under a confining stress equal to the in-situ overburden stress in liquefaction tests, while larger confining stresses than the in-situ overburden stress were used in CD test.

After consolidation, both triaxial extension and compression tests were performed under drained condition (the axial strain rate is about 0.1 %/min). In liquefaction test, the sinusoidal cyclic stress of 0.1 Hz was uniformly applied to the specimen for cyclic undrained shear (0.5 Hz was used in V-specimen of B sand).

Table 1 Physical properties of samples used in CD tests

Sand name	Specimen	Sample depth (m)	SPT N-value	No	Confining stress σ_c' (kPa)	Test type	Fines content F_c (%)	Relative density D_r (%)	Void ratio e	50% diameter D_{50} (mm)	Uniformity coefficient U_c
A	V	9.70-10.15	17	1	108	Compression	2.1	62	0.99	0.38	2.15
				2	216		3.2	59	1.04	0.4	2.27
				3	323		4.6	49	1.06	0.4	2.46
				4	108	Extension	0.1	58	0.91	0.22	2.08
	H	9.65-10.35		1	108	Compression	0.7	65	0.98	0.24	2.64
				2	216		1.3	56	0.96	0.23	2.17
				3	323		2.2	59	1.08	0.24	2.25
				4	108	Extension	0.1	57	0.98	0.27	2.31

Table 2 Physical properties of samples used in liquefaction tests

Sand name	Specimen	Geological age	Sample depth (m)	Effective overburden pressure σ_v' (kPa)	SPT N-value	Normalized N-value N_1	Fines content F_c (%)	Relative density D_r (%)	Void ratio e	50% diameter D_{50} (mm)	Uniformity coefficient U_c
A	V	Holocene	9.30-10.00	98	17	17	2.8	72	0.91	0.25	2.0
	H						0.2	59	1.04	0.32	2.2
B	V	Holocene	11.55-11.90	107.8	37	35	0.5	87	0.83	0.15	1.5
	H						0.4	75	0.90	0.16	1.5
C	V	Pleistocene	11.40-12.60	117.6	22	20	3.7	70	0.84	0.48	3.8
	H						3.2	70	0.87	0.50	4.3

TEST RESULTS AND DISCUSSION

CD test results

CD test was conducted for sand A obtained from Holocene layer. Figs. 2(a) and (b) show the typical stress-strain (deviator stress-axial strain) relationships obtained in CD_C tests. Figure 3 indicates similar results obtained in CD_E tests. The correlation between volumetric strain and axial strain were also shown in Figs.2 and 3. As it is shown in Fig.2, the maximum deviator stress of H-specimen is about 5 to 15 % smaller than that of V-specimen in compression tests. However, the maximum deviator stress of H-specimen is about 15 % larger than that of V-specimen in extension tests (See Fig.3). The volumetric strains between V and H-specimens have similar differences to the maximum deviator stresses in both compression and extension tests. As indicated in Table 1, the physical properties of V-specimen and H-specimen tested are almost the same, the differences in the maximum deviator stresses and the volumetric strains between these specimens are considered to be due to the effect of the anisotropy.

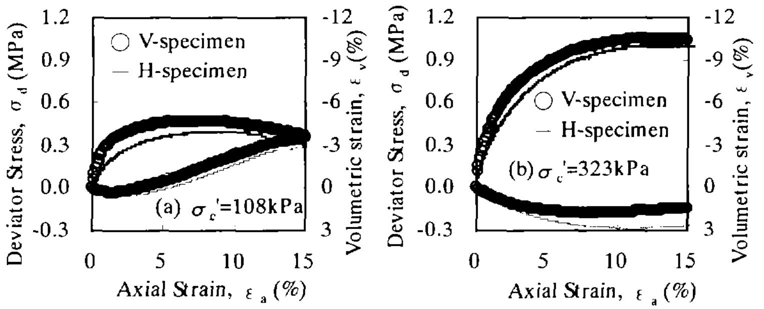
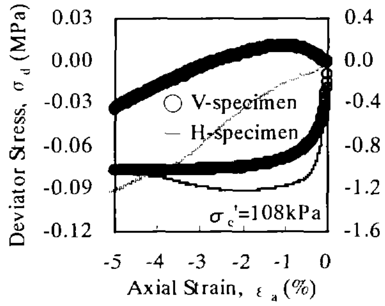


Fig.2 Deviator stress-axial strain curves (CDc test)



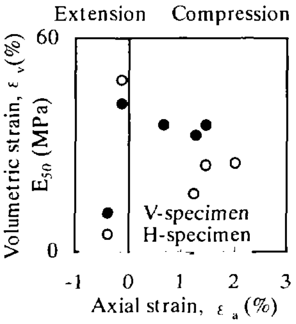


Fig.3 Deviator stress-axial strain curves (CD_E test)

Fig.4 Correlation between secant modulus (E50) at half of the maximum deviator stress

The internal friction angles of V and H-specimens obtained from the CD test are 35.1 and 35.7, respectively. As a result, the effect of the anisotropy on the internal friction angle is not so large for sand A.

Figure 4 shows the correlation between the axial strain (ε a) and the secant modulus (E50) obtained from the stress-strain curves of both triaxial compression and extension tests. E50 was defined as the ratio between the half of the maximum deviator stress in compression or extension side and the strain corresponding to each stress. It can be seen in Fig.4 that V-specimen shows larger E50 than H-specimen in compression tests, while it indicates lower E50 than H-specimen in extension tests.

These results imply the effect of the anisotropy, and are also explained in Fig.5. Namely, in most cases, in-situ soils are easy to compress in horizontal direction and to extend in vertical direction. These characteristics are also coincident with to the manner of the strain generation found in liquefaction tests, which will be discussed later.

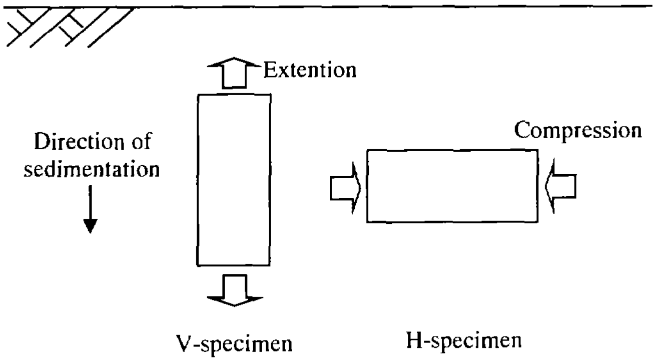
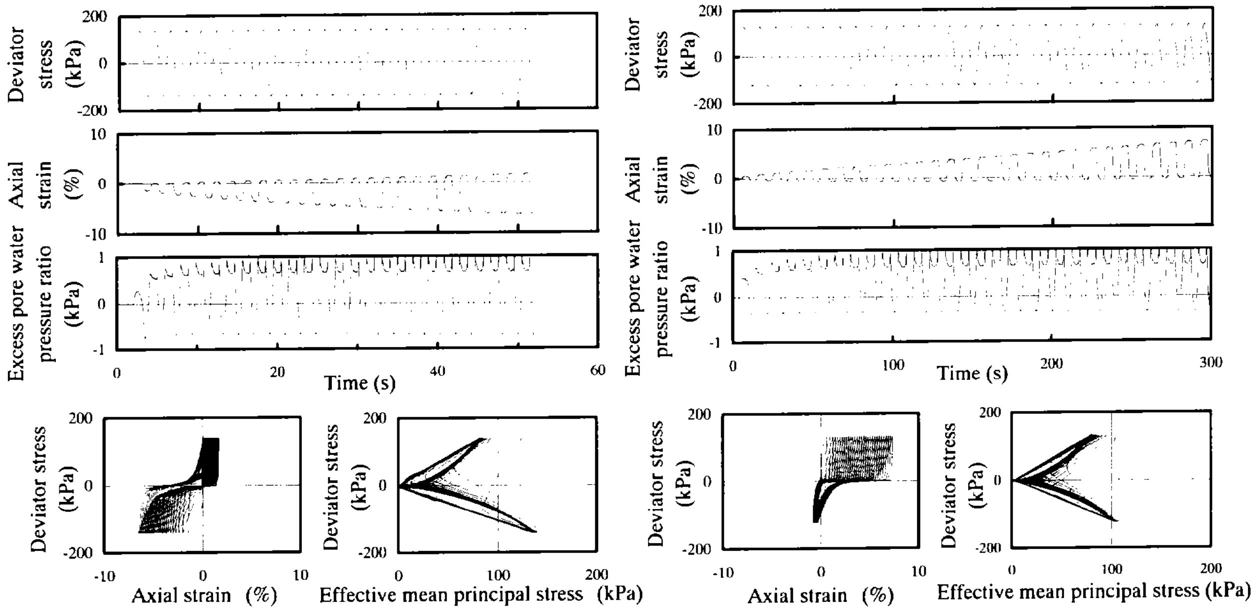


Fig.5 Schematic diagram showing the generation of axial stain

Liquefaction test results

Comparison of time history between V and H-specimen

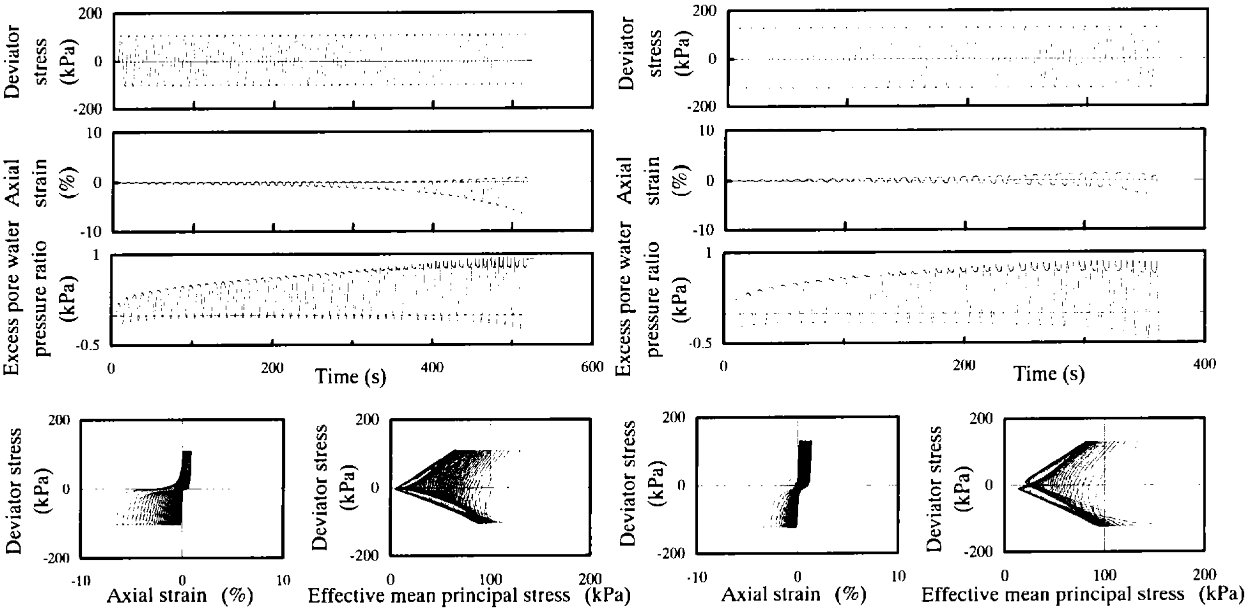
Liquefaction test was carried out for sand A, B and C. Figures 6 and 7 show typical test results of V and H-specimen for sand B and C, respectively. The deviator stress applied to the V-specimen was almost the same as that to the H-specimen in Figs. 6 and 7. There is a significant difference in the way of the strain generating during undrained cyclic shear for sand B obtained from Holocene layer. Namely, in case for V-specimen, the double amplitude axial strain (DA) is increasing toward to the extension side (See Fig.6 (a)). On the other hand, the double amplitude axial strain of H-specimen is increasing toward to the compression side (See Fig.6 (b)).



(a) V-specimen

(b) H-specimen

Fig.6 Liquefaction test results for sand B



(a) V-specimen

(b) H-specimen

Fig.7 Liquefaction test results for sand C

While the maximum excess pore water pressure ratio of V and H-specimen reached 1.0 at almost the same number of cycles, the excess pore water pressure ratio of V-specimen in negative side was larger than that of H-specimen. The difference in the direction of the axial strain generation appeared in V and H-specimens of sand B must be caused by their inherent anisotropy. This means that the B-sand dose not has an isotropic fabric, it is easier to compress in horizontal direction than in vertical direction. This trend is basically corresponding to the strain behavior observed in CD test.

On the contrary, sand C indicates the different tendencies with sand B in axial strain generating during undrained cyclic shear. As shown in Fig.7, V-specimen of sand C shows the same manner of axial strain generation as that of sand B. However, the axial strain of H-specimen is almost generating symmetrically to the zero axis of strain in the early to middle stage of shear. And after that, the axial strain moves to the extension side and failed locally before the double amplitude of axial strain reached about 5 %.

It also can be pointed out that, though the maximum excess pore water pressure ratio of V-specimen for all sands reached to 1.0, that of H-specimen for sand C is only about 0.9. The local failure observed in the axial strain generation of H-specimen may affect the behavior of the excess pore water pressure.

Liquefaction strength difference between V and H-specimen

Figure 8 indicates the stress ratio to cause a double amplitude axial strain of 2 (for sand C only) or 5 %. It is because sand C failed before its strain reached 5 %. As clearly shown in Fig.8, there is no significant difference of liquefaction strength between V and H-specimen for every sand. As a result, according to the widely used definition of liquefaction by using double amplitude axial strain, we can reasonably evaluate the liquefaction strength from both V and H-specimens.

The liquefaction strength at DA=2 % in 10 cycles of sand C is 0.55, which is larger than that of sand B (0.4), though sand C has smaller normalized SPT N-value, N_1, compared with sand B. The difference of the liquefaction strength between sand C and sand B is considered due to the aging effect rather than N_1-value or relative density of samples.

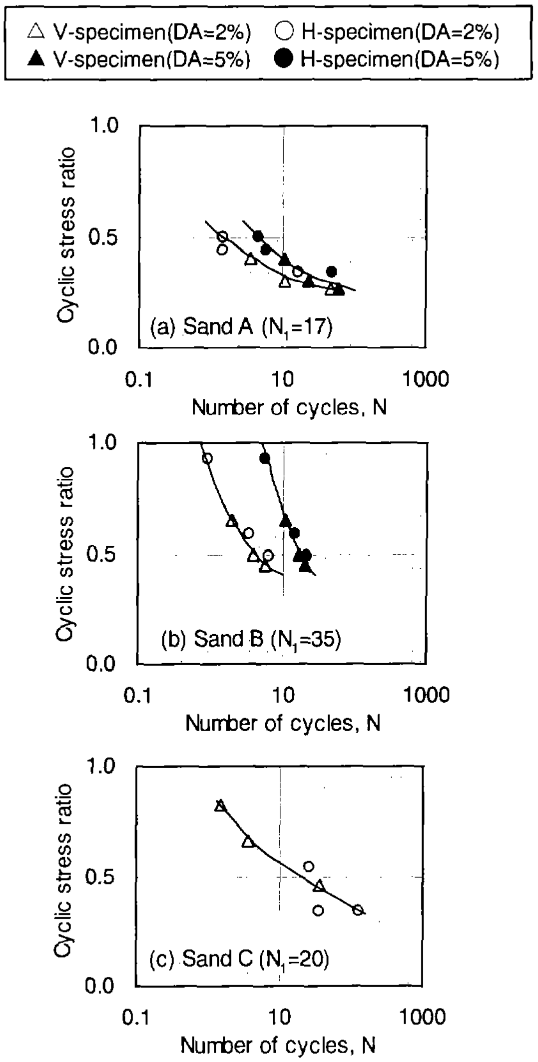


Fig.8 Comparison of liquefaction strength between V and H-specimen

CONCLUSIONS

Two different types of undisturbed sample, V and H-specimen, were prepared from high quality undisturbed sand columns recovered by in-situ freezing technique. Based on the test results obtained from a series of drained and cyclic undrained triaxial tests on these samples, the effect of the anisotropy on their drained and cyclic undrained shear behavior was investigated. They are shown as following.

Effect on the stress strain behavior in drained shear

1) There is a slight difference in the maximum deviator stress and the volumetric strain both on extension and compression sides between V and H-specimen. The difference implies that in-situ soil is easier to compress in horizontal direction than in vertical direction. And this trend is basically corresponding to the strain behavior appeared in liquefaction tests of Holocene samples.

2) The internal friction angle of V and H-specimens obtained from the CD tests are almost the same value. The effect of the anisotropy on the internal friction angle is small.

Effect on the strength and strain behavior in undrained cyclic shear

1) In case for sand B of Holocene soil layer, there was a significant difference in the manner of the axial strain generation between V and H-specimen. The test results indicated that such soil is easier to compress in horizontal direction than in vertical direction.

2) In case for sand C of Pleistocene soil layer, the difference in the manner of the axial strain generation between V and H-specimen is not so large as that of sand B. It means that sand C of Pleistocene soil layer has much more complicated stress histories; as a result, the effect of the anisotropy on deformation characteristics of Pleistocene sand is not so remarkable as that of Holocene sand.

3) There is no significant difference of the liquefaction strength between V and H-specimen for all sand, so long as the double amplitude of axial strain defines the liquefaction strength.

AKNOWLEDGEMENTS

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