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SHEAR WAVE VELOCITIES IN DILUVIAL GRAVEL SAMPLES DURING TRIAXIAL COMPRESSION TESTS

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SUMMARY

Change in shear wave velocities which occurred during triaxial compression tests were measured on undisturbed samples obtained from a diluvial gravel deposit by an in-situ freezing method. Measurements on the reconstituted gravel samples were also conducted to compare the characteristics of shear wave velocities. The results of these measurements indicated that the change in shear wave velocities corresponded well with the expansive volumetric strain which occurred in compression tests. Moreover, it was verified that the reduction of shear wave velocities in undisturbed samples was more significant than that in reconstituted samples during compression tests.

INTRODUCTION

Diluvial gravel deposits have been widely recognized to possess large mechanical strength, and many structures have been constructed on this type of ground. However, the need for an evaluation of the dynamic strength of these deposits has recently become more urgent since this type of ground is often considered for the construction of highly important structures such as nuclear power plants, which must be designed to resist extremely strong earthquakes.

The dynamic properties of diluvial gravel deposits have not been fully clarified because of the lack of a sampling method which can be used to obtain undisturbed samples. By utilizing the in-situ freezing method, the authors have succeeded in obtaining undisturbed samples (300mm in diameter, 600mm in height) from a diluvial gravel deposit (Ref. 1) and have conducted a series of triaxial tests (Ref. 2). The object of this study is to examine the features of diluvial gravel by means of the shear wave velocities in undisturbed samples during triaxial compression tests.

SOIL TESTED

The soil used in this study was an undisturbed sample obtained from a type of diluvial gravel deposit called Mandano gravel, in Chiba Prefecture, Japan. Fig. 1 shows the soil profile at the sampling site. The diluvial gravel deposit was located 5.5m below the ground surface and the ground water level was found to be in this deposit. The in-situ shear wave velocities investigated by the down hole method were above 300m/sec. The sampling depth was from 6m to 9m below the ground surface. The samples, 300mm in diameter and 600mm in height, were obtained by the in-situ freezing method. Detailed sampling procedures are described elsewhere (Ref. 1). These samples were transported to the laboratory, and stored in the refrigerator kept at -20°C.

The grain size distribution of the gravel samples is shown in Fig. 2, and the typical physical properties are summarized in Table 1. The chief mineral present in the gravel composition is chert, with a content of 43 percent. The shape of the gravel grain is flat and rounded. The gravel samples used in this study were those obtained at sampling depths of 8-9m.

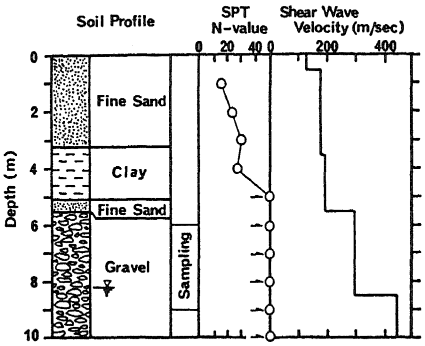

Fig. 1 Soil Profile at Sampling Site

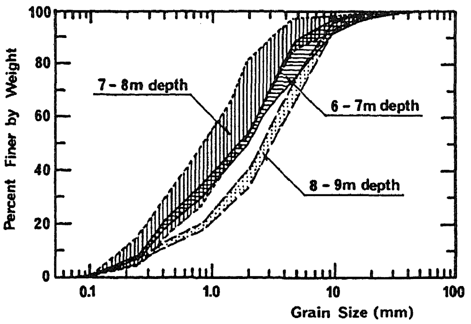

Fig. 2 Grain Size Distribution of Diluvial Gravel

Table 1. Physical properties of gravel samples tested

Properties	Sample Sampling depth		
	6 - 7m	7 - 8m	8 - 9m
Specific gravity	2.66	2.67	2.66
Void ratio	0.35-0.37	0.40-0.50	0.36-0.38
Maximum grain size (mm)	76	94	55
Mean grain size (mm)*	1.8	1.2	2.8
Uniformity coefficient*	8.6	5.7	10.3
Finer than 74 μm (%)*	0.43	0.56	0.33
Maximum dry density (Mg/m^3)	2.027	1.953	1.974
Minimum dry density (Mg/m^3)	1.641	1.586	1.630
Relative density (%)	80-88	56-89	87-95

* : Average value of 6 samples

EXPERIMENTS

Measurement of Shear Wave Velocity A large scale cyclic triaxial test apparatus (dimensions of specimen: 300mm in diameter, 600mm in height) was employed in this study. The shear wave is generated by tapping the top cap of the specimen. Fig. 3 shows the structure of a lateral piston designed for this operation. A lateral piston is set against the side wall of the triaxial cell, enabling the top cap to be tapped horizontally from outside the triaxial cell. The axial rod of this piston can be moved freely by applying cell pressure to the pressure chamber partitioned by bellofram. This method does not require an electric pulse or complicated equipment such as ultrasonic pulse devices, so only a slight modification of the standard triaxial apparatus is necessary.

The wave generated at the cap propagates downward in the specimen and is detected by accelerometers attached to the side surface of the specimen. The accelerometer employed is a piezoelectric type with a built-in pre-amplifier. The accelerometer has a sensitivity of 10mV/G, a range of responsive frequency(3dB) of 3 to 12000Hz, and a resonant frequency of 25kHz. It is 14mm in diameter, 28mm in length, and it weighs 210mN. The arrangement of the accelerometers is shown in Fig. 4. Accelerometers are attached to the rubber membrane by rubber bands (10mm in width, 2mm in thickness) and are arranged in a vertical line positioned on the cylinder surface 90° removed from the tapping point on the top cap. The shear wave velocity was determined by calculations based on the distances between the accelerometers, and the time delays in the arrival of the shear waves as detected by the accelerometers. Detailed measurement methods are described elsewhere (Ref. 3). By this method, the change in shear wave velocities during triaxial compression tests could be investigated.

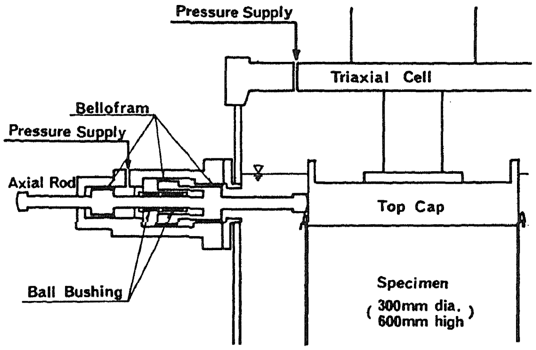

Fig. 3 Structure of Lateral Piston

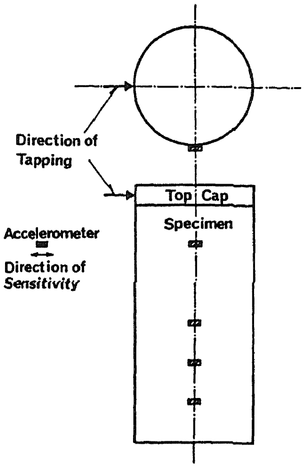

Fig. 4 Arrangement of Accelerometers

<u>Test Procedure</u> The frozen gravel sample was set up in the triaxial cell, and was allowed to thaw by circulating warm water at a temperature of 60°C through the cell water under a cell pressure of 35kPa. Subsequently, carbon dioxide was percolated through the specimen for about 16 hours, and de-aired water was permeated into the voids at a differential head of about 20kPa. Then, back pressure was applied and increased until Skempton's B-value was confirmed to be above 0.95. The cell pressure was increased in steps to the value which produces an isotropic stress condition. At each step, the specimen was consolidated for about two hours. Triaxial compression tests were conducted under drained conditions at a constant cell pressure. The rate of axial strain was 0.1% per minute.

Reconstituted samples which have the same grain size distributionas the undisturbed samples, as represented by the average values shown in Fig. 2, were also tested to compare the mechanical properties. They were prepared by vibrating oven-dried gravel in a forming mold. The density of each specimen was controlled by varying the vibrating time. This method was adopted to avoid particle breakage as much as possible. The testing procedures for the reconstituted samples were the same as mentioned above, except for the thawing stage.

These test results were arranged by the following stress and strain parameters. The mean principal stress, p', is defined by $(\sigma'_a + 2\cdot\sigma'_r)/3$, and the deviator stress, q, is given by ($\sigma'_a - \sigma'_r$), where σ'_a and σ'_r are the effective axial and radial stress, respectively. The volumetric strain, v, is defined by ($\varepsilon_a + 2\cdot\varepsilon_r$), where ε_a and ε_r are the axial and radial component of strain developed in the triaxial sample.

TEST RESULTS AND DISCUSSION

Triaxial Compression Tests Figure 5(a) and 5(b) show the change of q and v with ε_a during the triaxial compression tests on the undisturbed samples and the reconstituted samples. The effective mean principal stress at consolidation is represented by p_c' in this figure. Remarkable differences in the deformation-strength characteristics of both samples can be seen for each stress condition. That is, the deformability and volume contractability of the undisturbed samples are more significant than those of the reconstituted samples at the same consolidation pressure. Despite the significant difference in the shear wave velocities of the two samples at consolidation, as mentioned later, the reduction in the shear strengths of the reconstituted samples appear relatively small. On the other hand, in the same type of sample, the deformability and volume contractability are more significant for a higher consolidation pressure.

Measurements of shear wave velocities were conducted at the marked point on the curves in Fig. 5(a) and 5(b).

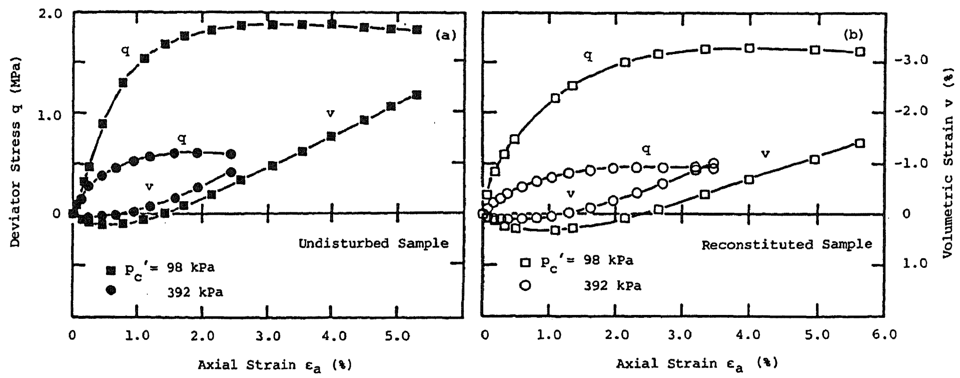

Fig. 5 Stress - Strain Curves during Triaxial Compression Tests
(a) Undisturbed Sample (b) Reconstituted Sample

Shear Wave Velocities during Triaxial Compression Tests Hardin and Richart (Ref. 4) gave the empirical expression for estimating the shear wave velocity, V_s, as follows:

$$V_s = [111 - (51.0)\cdot e]\cdot(p_c')^{0.25}$$
$$: \text{round-grained sands} \quad (0.3 < e < 0.8) \qquad (1)$$

$$V_s = [104 - (34.9)\cdot e]\cdot(p_c')^{0.25}$$
$$: \text{angular-grained sands} \quad (0.6 < e < 1.3) \qquad (2)$$

where p_c' is in kPa. Based on these equations, the effect of p_c' on Vs during consolidation tests was determined as shown in Fig. 6. This figure shows that these relationships could be approximated by a straight line for both of the samples. The test results in Fig. 6 lead to the following relationships for each sample:

$$V_s = 75 \cdot (p_c')^{0.32} \quad : \text{undisturbed sample} \quad (e_0 = 0.38) \tag{3}$$

$$V_s = 62 \cdot (p_c')^{0.29} \quad : \text{reconstituted sample} \quad (e_0 = 0.33) \tag{4}$$

where e_0 is the void ratio before consolidation. It should be noted that the undisturbed samples show considerably higher values of the power of p_c' than those of the Hardin and Richart Equations. From the above equations, the V_s at an in-situ overburden pressure of 154kPa for 8-9m depth was determined to be 380m/sec from Eq.(3) and 270m/sec from Eq.(4). The values of V_s in the reconstituted samples were about 30 percent below those in the undisturbed samples.

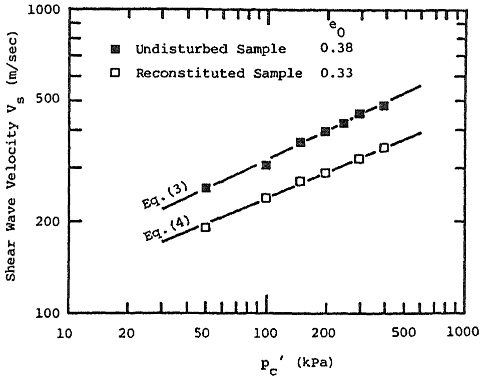

Fig. 6 Change of Shaer Wave Velocities during Consolidation Tests

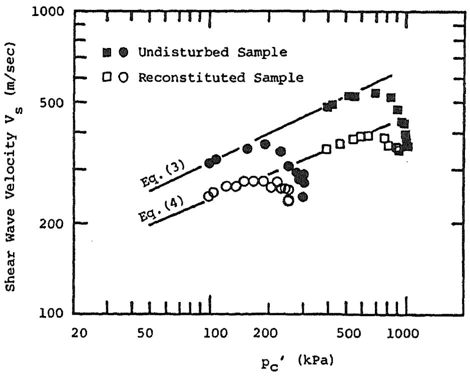

Fig. 7 Change of Shaer Wave Velocities during Triaxial Compression Tests

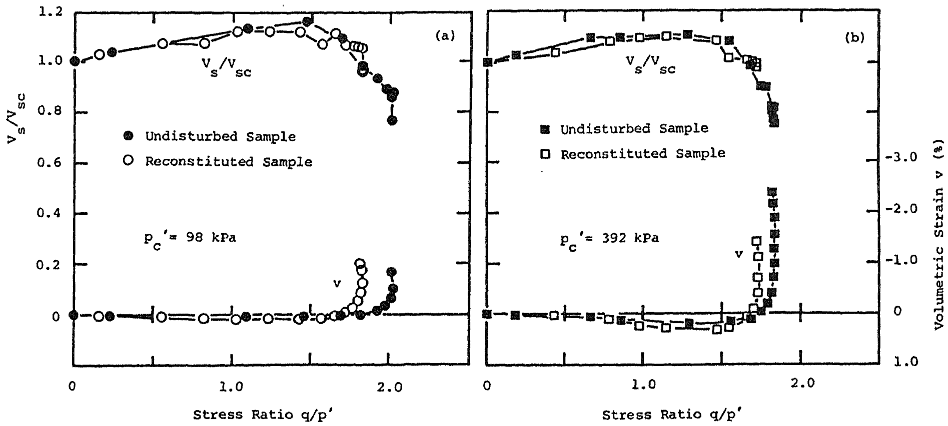

Fig. 8 Volumetric Strain and Shear Wave Velocity during Triaxial Compression Tests
(a) p_c'=98kPa (b) p_c'=392kPa

The change of V_s during triaxial compression tests is shown in Fig. 7. The solid lines in this figure present the relationships represented by Eqs.(3) and (4) obtained from the isotropic consolidation tests. In the early stages of the compression test, V_s increases along the solid line. However, with the progress of the test, V_S decreases gradually separating from the solid lines. Furthermore, at the last stage of the compression test, V_S decreases to almost the same value in both of the samples. This is probably because the difference in inherent fabric between the undisturbed and reconstituted samples almost disappears at failure.

Figure 8(a) and 8(b) show the change in v and the reduction of the shear wave velocity (V_S/V_{SC}) during compression tests at p_c' of 98kPa and 392kPa, where the stress ratio (q/p') is plotted on the horizontal axis. V_{SC} denotes the shear wave velocity at the start of the compression test. It can be seen from this figure that the properties of v and V_S are very similar. That is, the stress ratio at which Vs begins to decrease agrees well with the stress ratio at which expansive volumetric change occurs. Moreover, the reduction of V_S in the undisturbed samples is more significant than that in the reconstituted samples, that is, less than 4% in the reconstituted samples, and about 20% in the undisturbed samples.

CONCLUSIONS

Measurements of the shear wave velocity, V_S, in the undisturbed and reconstituted samples obtained from a diluvial gravel deposit were conducted during triaxial compression tests. General conclusions based on these measurements are:

(1) The values of V_S in the reconstituted samples were about 30 percent below those in the undisturbed samples at the in-situ overburden pressure during isotropic consolidation tests.

(2) In the early stage of the compression test, V_S increased along the $\log(V_S)$ - $\log(p_c')$ lines obtained from isotropic consolidation tests. However, with the progress of the test, V_S decreased gradually separating from the $\log(V_S)$ - $\log(p_c')$ lines. Furthermore, at the last stage of the compression test, V_S decreased to almost the same value in both of the samples.

(3) The change of V_S corresponded well with the expansive volumetric strain which occurred during the compression tests. Moreover, the reduction of V_S in the undisturbed samples is more significant than that in the reconstituted samples during compression tests.

REFERENCES

1. Ohsaki,Y., Goto,S., Akagawa,S., Tamaoki,K., Shamoto,Y. and Nishio,S., "Undisturbed sampling of diluvial gravels by in-situ freezing," Proc., Symp. on Sampling, pp.53-58, (1985) (in Japanese).
2. Shamoto, Y., Nishio, S., Baba, K., Goto, S., Tamaoki, K. and Akagawa, S., "Cyclic Stress Strain Behaviour and Liquefaction Strength of Diluvial Gravels Utilizing Freezing Sampling," Proc., Symp. on Deformation/Strength Characteristics of Coarse Materials and Related Testing Methods, pp.89-94, (1986) (in Japanese).
3. Nishio, S. and Tamaoki, K., "Measurement of Shear Wave Velocities in Diluvial Gravel Samples under Triaxial Conditions," Soils and Foundations, Vol.28, No.2, pp.35-48, (1988).
4. Hardin,B.O. and Richart,F.E.,Jr., "Elastic wave velocities in granular soils," Proc., ASCE, Vol.89, No.SM1, pp.33-65, (1963).