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Technical Note

Effects of grading and particle characteristics on small strain properties of granular materials

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Abstract

A series of drained triaxial compression tests was conducted in order to evaluate the effects of grading and particle characteristics on the small strain stiffness of a wide variety of granular materials. To evaluate the quasi-elastic deformation property at small strain levels around 0.001% by static measurement, many small vertical cycles were applied at two isotropic stress states. The effects of maximum and mean particle diameters, fines content, coefficient of uniformity, and degree of particle angularity on the quasi-elastic vertical Young's moduli, E_{vs}, by the static measurement were investigated. Within the limited range of grading and particle characteristics tested in the present study, the results showed that: (1) the E_{vs} values were generally independent of maximum and mean particle diameters; (2) the E_{vs} values seemed to decrease with increasing coefficient of uniformity; (3) the effects of fines content and particle angularity on the E_{vs} values were not clear; and (4) the effects of the effective confining pressure on the above-mentioned three trends were insignificant.

Keywords: Small strain stiffness; Static measurement; Triaxial compression; Granular material; Grading and particle characteristics

1. Introduction

Deformation properties of geomaterials at small as well as relatively large strain levels play an important role in predicting the short- and long-term residual deformation of the ground and structural displacement. These properties are affected by many factors which include grading and particle characteristics of geomaterials.

The methods to evaluate small strain properties experimentally can be divided into static and dynamic ones. To evaluate those properties dynamically in the laboratory, the bender element method has been widely used (e.g., Dyvik and Madshus, 1985). A technique using accelerometers and wave sources was recently developed by AnhDan et al. (2002) for dynamic measurement. On the other hand, the soil behavior observed by applying many small unload/reload cycles of axial stress statically in the laboratory tests is essentially linear and nearly recoverable within a very small strain range lesser than about 0.001% (e.g., Tatsuoka and Shibuya, 1992; Enomoto et al., 2013). For taking these static measurements, the experimental device has to be extremely precise with a high degree of accuracy.

Some studies have been conducted to experimentally investigate the effects of grading and particle characteristics on the small strain properties. Among them, Iwasaki and Tatsuoka (1977) conducted resonant-column tests on a wide variety of sands and reported that the shear modulus measured dynamically decreased with increasing coefficient of uniformity, U_c, or fines content, F_c, and was not related to the mean particle diameter, D_{50}. Wichtmann and Triantafyllidis (2009) also performed resonant-column tests on sands and concluded that the shear modulus did not depend on D_{50} while it decreased with increasing U_c. On the other hand, Kokusho

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and Yoshida (1997) showed the opposite effect of U_c on the shear wave velocity of gravels. Yang and Gu (2013) revealed that, in bender element tests, the improper interpretation of wave signals led to contrastive trends with the shear modulus either increasing or decreasing with increasing D_{50} for a given excitation frequency. Shin and Santamarina (2013) reported the effects of particle angularity on the shear modulus measured with bender elements. Enomoto et al. (2013) investigated the effects of maximum particle diameter, D_{max}, D_{50} and U_c on the difference between the shear moduli based on the static and dynamic measurements by conducting drained triaxial compression tests on undisturbed gravelly soils, although their data were relatively scattered due to heterogeneity of the tested materials. Despite these investigations on the small strain properties of geomaterials, the effects of grading and particle characteristics on those properties, in particular based on the static measurement, are not well known.

In view of the above, a series of drained triaxial compression tests on mainly a wide variety of sands was conducted in the present study in order to clarify the effects of grading and particle characteristics on the small strain properties based on the static measurement.

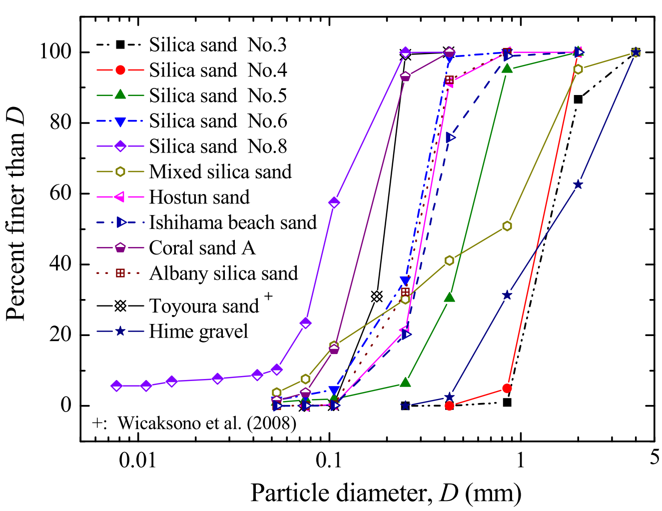

Fig. 1. Grading curves of geomaterials used in the present study.

2. Tested materials

Fig. 1 shows the grading curves of geomaterials used in the present study. Table 1 summarizes the values of specific gravity (G_s), D_{max}, D_{50}, U_c, F_c, and maximum and minimum void ratios, e_{max} and e_{min}. These materials consisted of relatively stiff particles. Mixed silica sand was produced by mixing silica sands Nos. 3, 4, 5, 6 and 8 to have a larger U_c value. Albany silica sand and Hime gravel consisted of relatively round particles while other materials had relatively angular ones. Enomoto et al. (2009) quantitatively determined the particle shapes of the materials shown in Fig. 1 by employing degrees of particle angularity, A^*, which are defined by the following equation (Lees, 1964):

$$A^* = \sum_{i=1}^{n} \left(180^\circ - \alpha_i\right) \cdot \frac{x_i}{r} \quad (1)$$

where α is the angle of a corner; x is the distance from the edge of a corner to the center of the maximum inscribed circle; and r is the radius of the maximum inscribed circle. The values of A^* determined by Enomoto et al. (2009), which are listed in Table 1, were used for analysis in the present study as well. The typical particle pictures of the representative materials tested in the present study are reported in Enomoto et al. (2009).

As reviewed by Janoo (1998), there are several methods to quantify the particle shape. Among them, the concept of the evaluation method using Eq. (1) is simple and reasonable while time-consuming and laborious works are required to calculate the A^* values of a number of geomaterials.

3. Test apparatus and procedure

An automated strain-controlled triaxial apparatus with a high precision gear-type axial loading system (e.g., Santucci de Magistris et al., 1999) was used. The top and bottom ends of specimens were well-lubricated by a 0.3 mm-thick latex rubber smeared with a 0.05 mm-thick silicone grease layer (Tatsuoka et al., 1984). The axial load was measured with a load cell placed inside the triaxial cell to eliminate the effects of piston friction. The vertical deformation was measured with a pair of

Table 1
Properties of geomaterials used in the present study.

Material	G_s	D_{max} (mm)	D_{50} (mm)	U_c	F_c (%)	e_{max}	e_{min}	A^*
Silica sand No.3	2.648	4	1.508	1.69	0	1.040	0.717	1512
Silica sand No.4	2.648	2	1.395	1.66	0	1.008	0.688	1619
Silica sand No.5	2.646	2	0.554	2.24	1.8	2.646	1.079	1600
Silica sand No.6	2.642	0.85	0.290	2.43	3.1	1.174	0.671	1070
Silica sand No.8	2.633	0.425	0.099	2.24	23.4	1.431	0.761	—
Mixed silica sand	2.639	4	0.811	13.08	7.6	0.899	0.473	—
Hostun sand	2.658	2	0.321	2.01	0	1.034	0.621	1435
Ishihama beach sand	2.728	2	0.344	2.12	0.1	0.944	0.593	1705
Coral sand A	2.645	0.425	0.170	2.07	3.7	2.645	0.868	1013
Albany silica sand	2.671	0.85	0.302	2.22	0.1	0.804	0.505	209
Toyoura sand	2.635[a]	0.425[a]	0.196[a]	1.65[a]	0[a]	0.966[a]	0.600[a]	896
Hime gravel	2.682	4	1.537	3.55	0	0.759	0.515	139

[a] Wicaksono et al. (2008).