THE ANISOTROPY OF SHEAR WAVE VELOCITY OBSERVED FOR ELONGATED PARTICLES

The University of Tokyo Student member 〇Junming LIU
The University of Tokyo Regular member Masahide OTSUBO
The University of Tokyo Student member Yuichiro KAWAGUCHI
The University of Tokyo Fellow member Reiko KUWANO

1. INTRODUCTION

Natural granular soils comprised of non-cohesive particles display stiffness anisotropy due to fabric-induced anisotropy of soil structure. However, the underlying mechanisms of fabric-induced anisotropy have not been thoroughly discussed in previous studies partially because of the limited technique to measure multi-directional stiffness of a soil specimen accurately in the laboratory (Otsubo et al. 2019).

This study focuses on the fabric-induced anisotropy of non-cohesive particles and discusses the relationship between particle orientation and anisotropy of shear waves by a shear wave velocity measurement method.

2. LABORATORY EXPERIMENTAL PROCEDURE

2.1 Tested Material and Cubical Soil Box

The wild rice which is a non-cohesive granular material with a narrow range of particle size distribution was used in this study. The aspect ratio (AR = shorter axis/longer axis) of the wild rice is 0.158 (around 1/6.3) as illustrated in Fig. 1.

A cubical soil box (Fig. 2) made of acrylic plates was developed in which a soil specimen can be prepared with dimensions of 100×100×100 mm. The top face of the box can be adjusted to the specimen height. Three pairs of transducers and receivers are equipped to the three sets of the opposite faces, and each of the transducer consists of a compression (P-) and a shear (S-) type piezoelectric transducer that can generate P-waves and S-waves respectively.

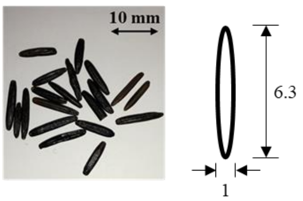

Fig. 1 Tested wild rice

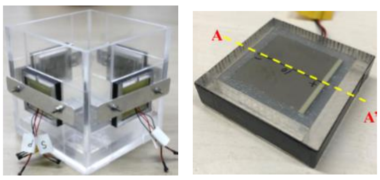

Fig. 2 (a) Cubical soil box (b) shear plate transducer

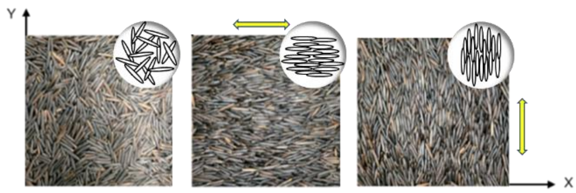

Fig. 3 Sample orientation preparation (top view): (a) random in XY plane (b) X axis (c) Y axis

2.2 Sample Preparation and Dynamic Wave Propagation Tests

Four specimens under three orientation conditions (Fig. 3) were prepared with dimensions of approximately 100×100×100 mm. The dry density of the specimens was slightly different for each test, ranging from 0.873 to 0.897 g/cm^3 (Table 1).

A single period of sinusoidal pulse was used to generate elastic waves at the transmitter transducer. The double amplitude of input excitation voltage was 140 V and the input frequency was varied in order that the transmitter and receiver responses contain similar frequency contents. The input frequency in this study is 3kHz was used, so that shear wave velocity (v_s) based on peak-to-peak method gives a close match with v_s based on start-to-start method of identifying wave arrivals (Yamashita et al. 2009).

Keywords: Granular material, Stiffness anisotropy, Particle orientation, Shear wave measurement
Contact address: The University of Tokyo, Bw304 IIS 4-6-1, Komaba, Meguro, Tokyo 153-8505, Tel: 03-5452-6843

3. RESULTS AND DISCUSSION

For the random orientation case, since rice particles were randomly deposited and compacted in the soil box, it is reasonable to assume the distribution of particle orientation in the horizontal plane is homogenous. Thus, X and Y components can be treated equally as H, while Z component is treated as V under the random orientation condition. The $v_{S,HH}$ component, propagated and oscillated in the H direction, is larger than $v_{S,HV}$ and $v_{S,VH}$ (Table 1), contributing to the ratio of $v_{S,HH}/v_{S,VH} \approx 1.38$, which reveals the anisotropy property of the specimen. Moreover, $v_{S,HV}/v_{S,VH} \approx 1$ verifies the symmetric components of shear waves are equivalent, which agrees with Hooke's law for a transversely isotropic material.

For the X axis orientation case, The sequence of $v_{S,XY} > v_{S,YX} > v_{S,ZY}$ (Table 1) indicates relationships among particle orientation, direction of S-wave propagation and oscillation:

1) S-wave travels the fastest when it propagates and oscillates within the horizontal plane (XY-plane) and propagates along the particle orientation, i.e., $v_{S,XY}$.
2) The velocity of S-wave which propagates and oscillates within the horizontal plane (XY-plane) but oscillates along the particle orientation, i.e., $v_{S,YX}$, becomes slower than that propagates along the particle orientation.
3) S-wave travels the slowest when it propagates vertically (along Z axis), i.e., $v_{S,ZY}$

In general, particle orientation influences both propagation and oscillation components of shear wave.

For the Y axis orientation case, due to the limitation of the cubical soil box used in the present study, two sets of experiments were conducted under the Y axis orientation condition by rotating the transmitter and receiver transducers. The sequence of $v_{S,YX} > v_{S,YZ} > v_{S,XY} > v_{S,ZY} > v_{S,XZ}$ further explains the influences of particle orientation on the propagation and oscillation components of shear wave (Table 1). And the following trends were observed:

1) The Y component dominates the shear wave velocity. When S-waves propagate along the Y direction, their velocities are larger than those oscillate along the Y direction, i.e., $v_{S,YX}$ and $v_{S,YZ}$ are larger than $v_{S,XY}$ and $v_{S,ZY}$.
2) When the position of Y component is given, wave velocities containing the X component are larger than those containing the Z component, i.e., $v_{S,YX} > v_{S,YZ}$ and $v_{S,XY} > v_{S,ZY}$.

Table 1 Laboratory test cases of the influence of particle orientation

Orientation	Dry Density g/cm^3	$v_{S,XY}$ m/s	$v_{S,YX}$ m/s	$v_{S,YZ}$ m/s	$v_{S,ZY}$ m/s	$v_{S,XZ}$ m/s	$v_{S,ZX}$ m/s
Random	0.873	—	119	—	—	86	87
X axis	0.897	126	118	—	80	—	—
Y axis (1)	0.876	—	—	116	110	82	—
Y axis (2)	0.885	113	124	—	101	—	—

4. CONCLUSIONS

Particle orientation has obvious influence on stiffness anisotropy of grain assemblies, which can be captured by shear wave velocities. In other words, shear wave velocities are affected by particle orientation. In general, when the particle orientation is fixed, the direction of S-wave propagation is the most important direction to determine the relative magnitude of shear wave velocities, then the second important one is the direction of S-wave oscillation. The least important one is the vertical direction.

References:

Otsubo M., Liu, J., Dutta TT., Kawaguchi, Y., & Kuwano, R: Anisotropy of Shear Wave Velocity-Role of Grain Shape, Proceedings of the 9th Asian Young Geotechnical Engineers Conference & 15th International Conference on Geotechnical Engineering, 2019, pp. 116-122.

Yamashita, S., Kawaguchi, T., Nakata, Y., Mikami, T., Fujiwara, T. and Shibuya, S: Interpretation of International Parallel Test on the Measurement of Gmax Using Bender Elements, Soils and Foundations, 49(4), 2009, pp. 631-650.