THE INFLUENCE OF PARTICLE ORIENTATION ON THE ANISOTROPY OF SHEAR WAVE VELOCITY OBSERVED IN ELONGATED PARTICLES

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1. INTRODUCTION

The orientation of particles is an important feature that can induce the fabric anisotropy of a soil specimen and control the elastic constitutive behavior of the soil at a small-strain range (Anandarajah and Kuganenthira, 1995). However, due to the difficulties of measuring the particle orientation and the multi-directional stiffness in a specimen of soil, the underlying mechanisms of such fabric-induced anisotropy has not been fully revealed by past studies (Otsubo et al. 2019).

This research focuses on the anisotropy resulting from the orientation of particles and tries to find the relationship between the particle orientation and the anisotropy of shear (S-) wave velocity as well as the small-strain shear modulus G_0 with the help of shear wave measurements.

2. LABORATORY EXPERIMENTAL PROCEDURE

2.1 Tested Material and Specimen Preparation

The wild rice was adopted in this study due to its elongated shape of particles (Fig. 1) whose major axes can be artificially aligned in one direction during sample preparation. The specific gravity (G_s), maximum (e_{max}) and minimum (e_{min}) void ratio of wild rice are 1.47, 0.97 and 0.66, respectively.

Two cubical specimens with random and uniform particle orientation were prepared. The wild rice was contained within two latex membrane cells and shaped into cubical specimens with the aid of a cubical frame, and each specimen was isotropically compressed to 50 kPa by vacuum pressure as shown in Fig. 2. The dimensions of both two specimens were approximately 125 mm × 125 mm × 125 mm and the dry densities of specimens of random and uniform particle orientation were 0.85 g/cm^3 and 0.91 g/cm^3, respectively. For the specimen of random particle orientation (Fig. 3a), wild rice was air-pluviated into the membrane cell and compacted by a wooden rammer layer by layer for ten layers to achieve a dense condition. For the specimen of uniform particle orientation, the major axes of rice particles were manually aligned in the Y-axis direction within the horizontal plane during the specimen preparation as shown in Fig. 3b. Before the specimen preparation, a circular opening with a diameter of 20 mm was cut at the center of each membrane face, and a 0.2 mm thick acrylic sheet was pasted behind the opening, so that disk-shaped shear plates with diameter of 20 mm and thickness of 2mm can be attached to the sheet by double-sided tape (Fig. 2) and can be easily removed after one measurement.

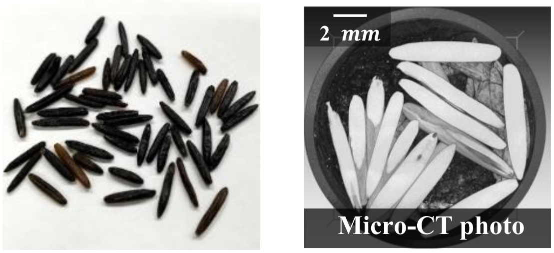

Fig. 1. Images of wild rice

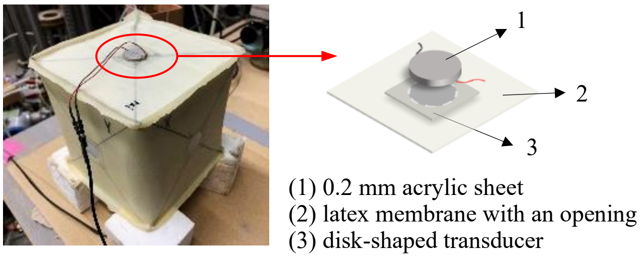

Fig. 2. Cubical specimen of wild rice

(a) (b)

Fig. 3. Particle orientation of cubical specimens
(a) random; (b) Y-axis

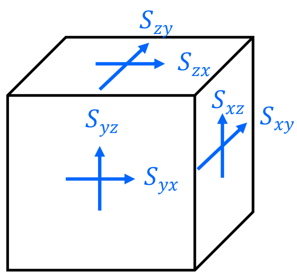

Fig. 4. The six components of S-waves in the principal directions

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2.2 Dynamic Wave Propagation Tests

All the six principal components of S-waves as illustrated in Fig. 4 were measured in this study. A single period of sinusoidal pulse was used to generate S-waves at the transmitter transducer. The double amplitude of input excitation voltage was 140 V and the input frequency was 5 kHz. The peak-to-peak method was used in the current research (recommended by Yamashita et al., 2009), where the time difference between the first major peaks of input and output signal is the travel time.

3. RESULTS AND DISCUSSION

For the specimen with random particle orientation, the order of the magnitude of S-wave velocities is: $V_{s,xy} \approx V_{s,yx} > V_{s,xz} \approx V_{s,zx} \approx V_{s,yz} \approx V_{s,zy}$, revealing that most of the major axes of rice particles were deposited within the horizontal plane (for larger S-wave velocities of $V_{s,xy}$ and $V_{s,yx}$), and the specimen was subjected to the assumption that granular materials are cross-anisotropic ($V_{s,xy} \approx V_{s,yx}$, $V_{s,xz} \approx V_{s,zx} \approx V_{s,yz} \approx V_{s,zy}$).

For the specimen with most of longer axes of rice particles aligning in the Y-axis direction (the particle orientation direction), $V_{s,yx} > V_{s,yz} \approx V_{s,xy} > V_{s,zy} > V_{s,xz} \approx V_{s,zx}$. It is conspicuous that S-waves propagated along the particle orientation (Y-axis direction), i.e., $V_{s,yx}$ and $V_{s,yz}$ were overall faster than those oscillated along the particle orientation but propagated along other directions, i.e., $V_{s,xy}$ and $V_{s,zy}$. S-waves neither propagated nor oscillated along the particle orientation were the slowest i.e., $V_{s,xz}$ and $V_{s,zx}$. The maximum discrepancy between G_{hv} and G_{vh} calculated from $V_{s,yz}$ and $V_{s,zy}$ by the equation of $G_0 = \rho V_s^2$ is 10%. The value is larger than discrepancies measured from specimens with random particle orientation (around 5%), which may result from the strong directivity of rice particles.

Three orthogonal directions: particle orientation *O*, particle deposition direction *D*, and the direction perpendicular to the particle orientation and within the depositional plane *P* are defined to generalize the influence of particle orientation on S-wave velocities. According to the results above, the relative magnitude of S-wave velocities can be assumed as (the example of Y-axis particle orientation under isotropic confinement is shown in Fig. 5):

$$V_{s,OP} > V_{s,OD} > V_{s,PO} > V_{s,DO} > V_{s,PD} > V_{s,DP}$$

The first and second subscripts indicate the direction of the S-wave propagation and oscillation, respectively, e.g., $V_{s,OP}$ represents the S-wave that propagates along the particle orientation and oscillate along the direction perpendicular to the particle orientation and within the depositional plane.

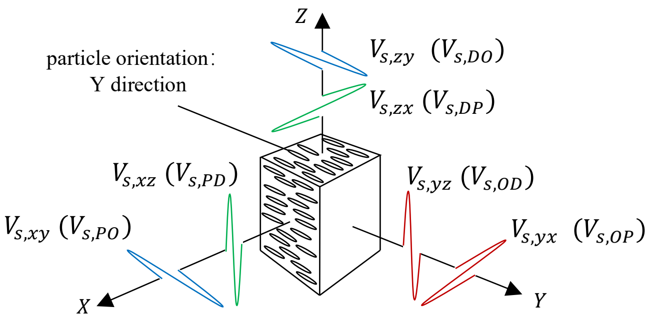

Fig. 5. Relative magnitude of shear wave velocities under the influence of particle orientation (in the Y-axis)

4. CONCLUSIONS

This study discussed the effect of particle orientation on the anisotropy of S-waves, as well as small-strain shear modulus of wild rice specimens. Results confirmed that particle orientation is one of the parameters contributing to anisotropic behaviors of granular materials. Furthermore, the relations among particle orientation, direction of S-wave propagation and oscillation were observed in this study. Generally, S-wave travels faster when the direction of wave propagation is parallel to the particle orientation, as compared to velocities of S-waves oscillating along the particle orientation. Among all the six principal components of S-waves, those neither propagating nor oscillating along the particle orientation are the slowest.

References:

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