

POSSIBILITY OF USING SHEAR WAVE OSCILLATION DIRECTION TO PREDICT SOIL INNER FABRIC

The University of Tokyo	Student member	○Junming LIU
The University of Tokyo	Regular member	Masahide OTSUBO
The University of Tokyo	Fellow member	Reiko KUWANO

1. INTRODUCTION

Shear wave (S-wave), whose oscillation direction is perpendicular to its propagation direction, is widely used in the laboratory and in the field to evaluate the small-strain stiffness of soils. Previous research has confirmed that S-wave propagation directions are sensitive to anisotropy of soil fabric, e.g., more elliptical S-wave velocity (V_s) surface (polar plots of V_s in arbitrary propagation directions) corresponds to larger soil anisotropy (Bellotti, et al., 1996; Fioravante, 2000). However, due to the technical limitations of bender elements, it is difficult to control the direction of S-wave oscillation; thus, research on the correlation between S-wave oscillation directions and soil's initial inner fabric are quite limited.

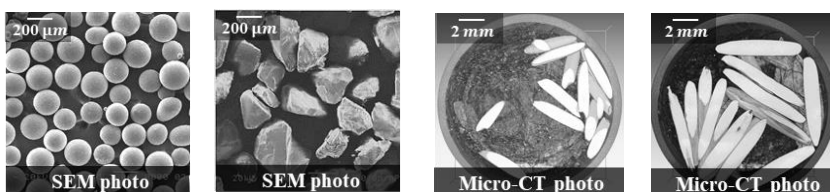
Recently, the disk-shaped shear plates were developed to conduct S-wave measurements in the laboratory, and its circular shape makes it possible to rotate S-wave oscillation to arbitrary directions while keeping the same propagation direction. Benefiting from the aforementioned advantage, this study can focus on the sensitivity of S-wave oscillation directions to anisotropic soil fabric with the help of disk-shaped shear plates.

2. LABORATORY EXPERIMENTAL PROCEDURE

2.1 Tested Materials and Specimen Preparation

Four granular materials, glass beads (GB), Toyoura sand (TS), basmati rice (BR) and wild rice (WR) (Fig. 1), were used in this study. Due to their different shapes, the four materials were assumed to display various degree of fabric anisotropy with same preparation method and confining pressure. Details of these four materials can be found in Liu, et al. (2022).

Each of the tested materials was enclosed in the special customized octagonal prism shape membrane cell as shown in Fig. 2. The distance between each pair of opposite faces of the specimen was approximately 125 mm except in the vertical direction, where the distance between the top and bottom faces was approximately 165 mm. During the specimen preparation, each material was air-pluviated into the membrane cell and compacted by a wooden rammer layer by layer for ten layers to achieve a dense packing. Isotropic confinement of 50 kPa was applied to each specimen by vacuum after specimen preparation. The relative densities of GB, TS, BR and WR were 69%, 75%, 64% and 75%, respectively, which all exceeded 60% and can be regarded as dense states. Prior to the specimen preparation, a 20 mm-in-diameter circular opening was cut at the center of each membrane face, then a 0.2 mm thick acrylic sheet was pasted behind the opening, so that disk-shaped shear plates with a 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 and rotated after each measurement.



(a) glass beads (b) Toyoura sand (c) basmati rice (d) wild rice

Fig. 1. Images of tested materials

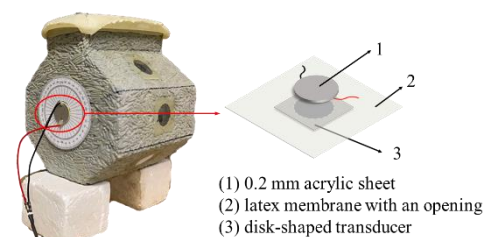


Fig. 2. Octagonal prism shape specimen

2.2 Dynamic Wave Propagation Tests

Referring to the schematic in Fig. 3(a), at each pair of opposite faces of the specimen, both transmitter and receiver shear plates were rotated from 0° (oscillates horizontally) to 90° (oscillates vertically) simultaneously and the corresponding V_s was measured every 10° , where S-wave propagation direction was fixed with various oscillation directions. 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 10 kHz for GB and TS, and 5kHz for BR and WR. The time difference between the first major peaks of input and output signals is adopted as the travel time of S-wave.

Keywords: shear wave velocity, shear wave oscillation direction, soil fabric, soil anisotropy

Contact address: Institute of Industrial Science, 4-6-1, Komaba, Meguro, Tokyo 153-8505, Japan, Tel: 03-5452-6843

3. RESULTS AND DISCUSSIONS

For GB and TS, whose initial fabric anisotropy is relatively smaller compared to BR and WR specimens prepared by air-pluviation and tamping (Liu, et al., 2022). The arrival of S-waves, i.e., the first peaks of received signals, changed smoothly when S-wave oscillation was rotated from horizontal to vertical directions. Fig. 3(a) shows an example of S-wave signals of GB specimen when keeping S-wave propagating along X direction and oscillating in different directions. Similar waveform tendencies can also be found in other S-wave propagation directions.

For BR and WR, the arrival of S-waves seemed to suddenly move backward during the change of oscillation direction from 50° to 70°, corresponding to the sudden drop of V_s in all the S-wave propagation directions except in the vertical direction. The typical S-wave signals of BR in the X propagation direction can be found in Fig. 3(b). Liu, et al. (2022) revealed that S-wave travels faster when its oscillation direction coincides with the orientation of particle major axis. Thus, the discontinuity of S-wave arrival change in BR and WR may be attributed to the orientation of rice particles, as major axes of most rice particles are assumed to lie within or at a small angle to the horizontal plane after tamping. In other words, there are few particles at an angle larger than 50° from the horizontal plane.

For all the tested materials, V_s in the vertical direction (Z direction) are relatively stable regardless of change of S-wave oscillation directions, revealing the isotropy in the horizontal plane after air-pluviation and tamping and under isotropic confinement.

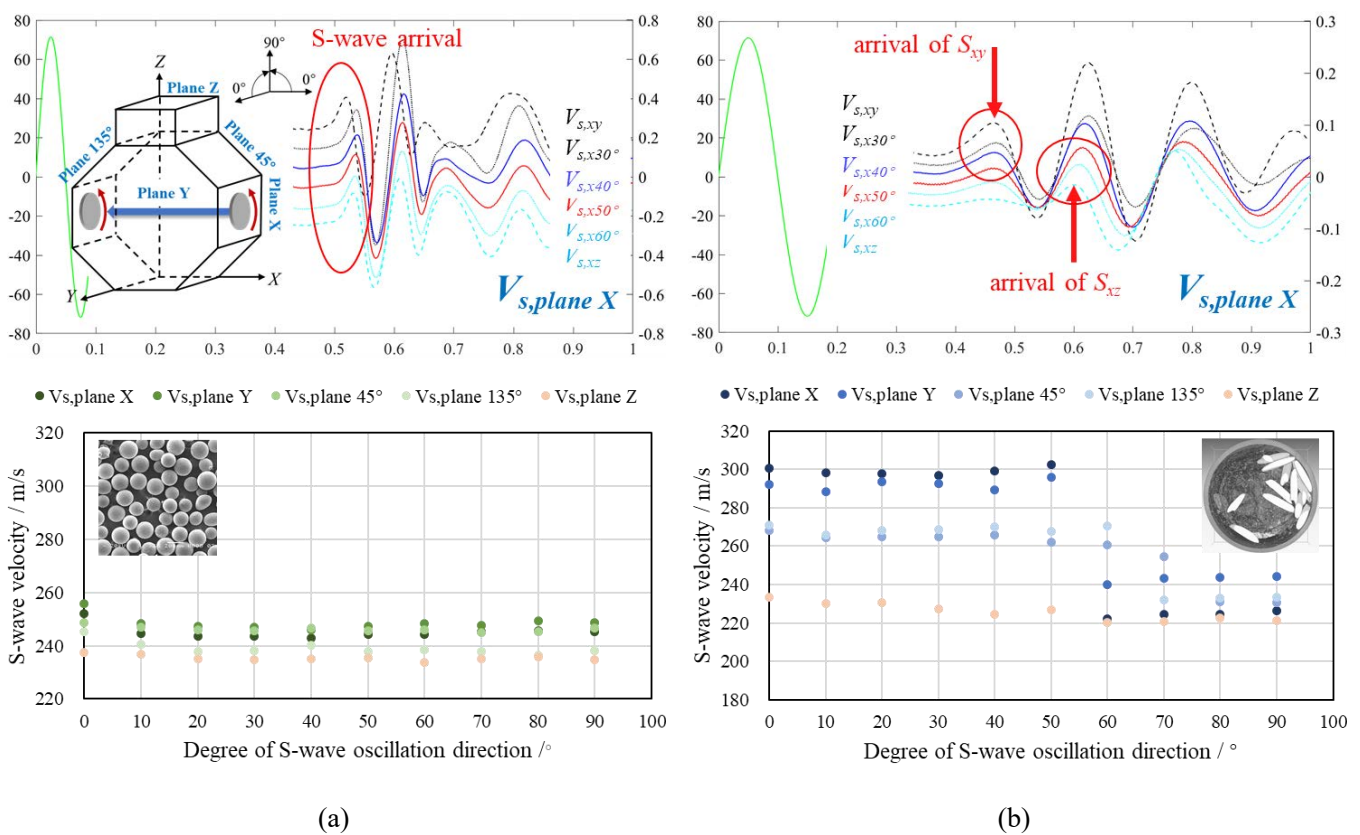


Fig. 3. S-wave velocities (V_s) with various oscillation directions and fixed propagation directions for (a) GB; (b) BR.

4. CONCLUSIONS

This study investigated the correlation between S-wave oscillation directions and inner fabric of soil specimen by developing octagonal prism shape specimens and conducting S-wave propagation tests. The experimental results reveal that S-wave oscillation direction can capture the anisotropy of soil inner fabric. The discontinuous changes of V_s with the same propagation direction but various oscillation directions were found in both BR and WR, which is different from continuous changes of V_s in GB and TS, whose particles are smaller and less anisotropic in shape.

References:

- Bellotti, R., Jamiolkowski, M., Lo Presti, D. C. F. & O'Neill, D. A. (1996). Anisotropy of small strain stiffness in Ticino sand. *Geotechnique* 46(1), 115 – 131.
- Fioravante, V. (2000). Anisotropy of small strain stiffness of Ticino and Kenya sands from seismic wave propagation measured in triaxial testing. *Soils and Foundations* 40(4), 129-142.
- Liu, J., Otsubo, M., Kawaguchi, Y., & Kuwano, R. (2022). Anisotropy in small-strain shear modulus of granular materials: Effects of particle properties and experimental conditions. *Soils and Foundations* 62(1), 101105.