# Anisotropy of Shear Wave Velocity
# - Role of Grain Orientation -

## 弾性波伝播速度に現れる粒状体の異方性と粒子配列の関係


Anisotropic soil does not have the same physical properties such as soil stiffness when the direction of measurement is changed. Until now, fundamentals of soil stiffness anisotropy has not been understood comprehensively. In this study, a special elongated granular materials: wild rice was used to figure out the influence of particle orientation on the anisotropy of multi-directional shear wave velocities with the help of a cubical soil box equipped with multi-directional shear plates by which both compression and shear waves can be generated.

弾性波速度測定を用いて地盤材料の微小ひずみ剛性の異方性を把握する試みは、ベンダーエレメントを供試体の水平方向に導入するなどして検討されてきた。しかしながら、弾性波速度測定から得られる微小ひずみ剛性と微小繰返し載荷試験から得られる微小ひずみ剛性に差異があったり、対称性の成立が実験で確認できないなど、未だ不明な点を残している。本研究では、鉛直・水平方向の境界条件が同等な立方体の土槽に、P波・S波の同時測定が可能なディスクトランスデューサーを装着し、ワイルド米を用いて弾性波速度の異方性と粒子配列の関係を調べた。


### (1) Introduction

Most soils display stiffness anisotropy, as the stiffness of soil assemblies depends on the direction. stiffness of a body is defined as the resistance of that body to deformation under applied force. And the stiffness properties, i.e. shear moduli G, can help to evaluate the degree of deformation. Stiffness anisotropy can be classified into stress-induced anisotropy due to anisotropic stress states, and fabric-induced anisotropy caused by the geometry of the soil particles and soil packing. However, there is limited research available on the influence of particle shape and packing characteristics, i.e. particle orientation, on the fabric-induced stiffness anisotropy of granular materials such as gravel and sand.

In evaluating fabric-induced anisotropy, three shear moduli, $G_{hh}$, $G_{hv}$, and $G_{vh}$ (where the subscripts v and h refer to the vertical and horizontal directions), are usually evaluated by shear wave (S-wave) measurement methods.

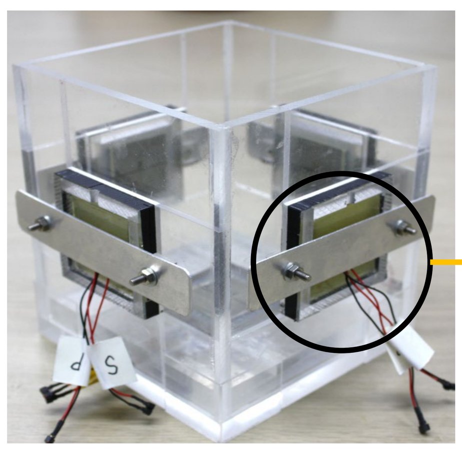
### (2) Methodology and Apparatus

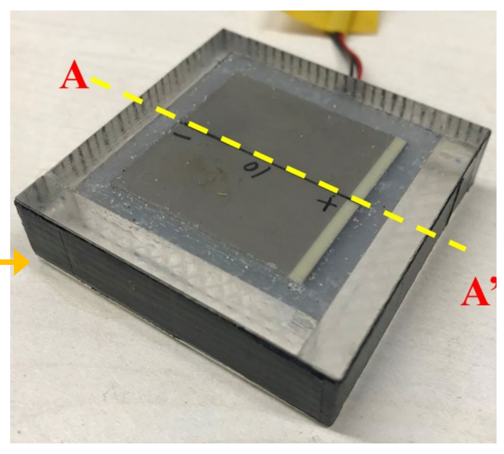
This research adopted shear wave measurement methods and three shear moduli $G_{hh}$, $G_{hv}$, and $G_{vh}$ were calculated from the equation

$$G = \rho v_s^2$$

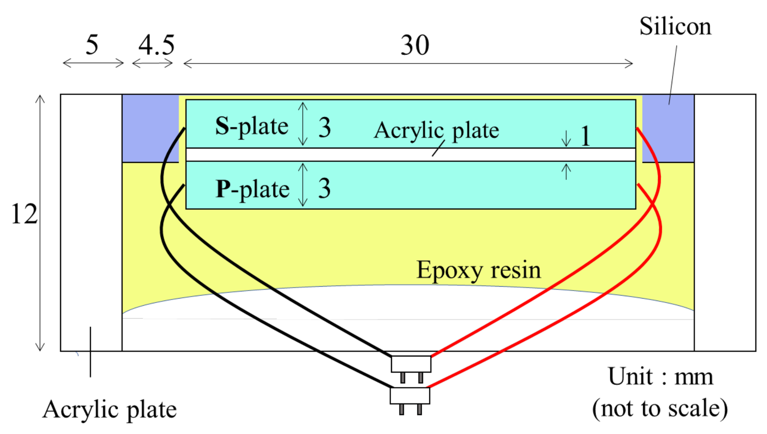
where $\rho$ is soil density; $v_s$ is shear wave velocity measured by an acrylic cubical soil box.

The cubical soil box was made of acrylic plates and was assembled in which a soil specimen can be prepared with dimensions of 100×100×100 mm. Each face of the soil box had a square hole and it can facilitate an assembly of planar piezoelectric transducers.


Cubical Soil Box



Shear Plate Transducer



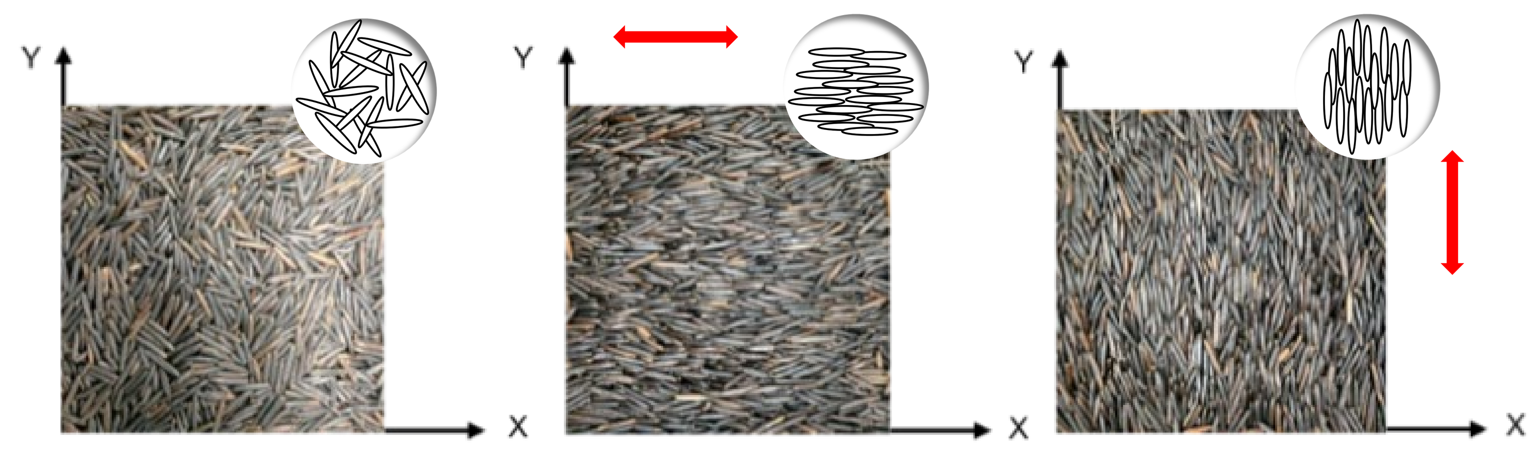
Schematic of design configuration of shear plate

### (3) Sample Preparation

a special elongated granular materials: wild rice was used in this study because its longer axis can be easily placed along a specific direction.

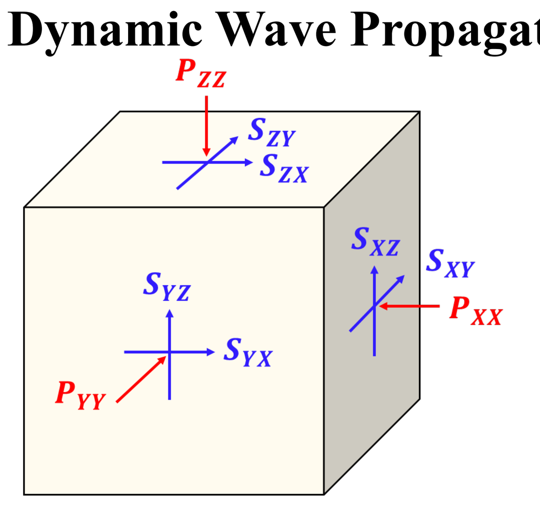
Four specimens with different particle orientation were prepared:

- **Random orientation condition**: wild rice was pluviated into the soil box under dry condition
- **One direction orientation condition**: 3 specimens were prepared under two orientation conditions: one was the X axis orientation specimen and the other two were Y axis orientation specimens

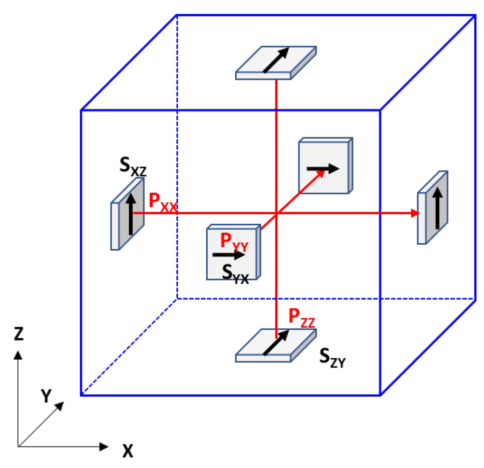


Random orientation　X axis orientation　Y aix orientation

### (4) Dynamic Wave Propagation Tests




- Considering both P- and S-waves, there are nine types of elastic wave components as illustrated the left hand.
- The first subscript indicates the direction of propagation and the second subscript corresponds to the direction of oscillation.



- The present test setup provides three types of P-waves, i.e. $P_{XX}$, $P_{YY}$ and $P_{ZZ}$, and three types of S-waves, i.e. $S_{YX}$, $S_{XZ}$ and $S_{ZY}$
- Assuming homogeneous distribution of particle orientation in the horizontal plane, X and Y components can be treated equally, thus expressed as H, while Z component is treated as V in this study. Therefore, the three S-wave components are expressed as $S_{HH}$, $S_{HV}$ and $S_{VH}$.

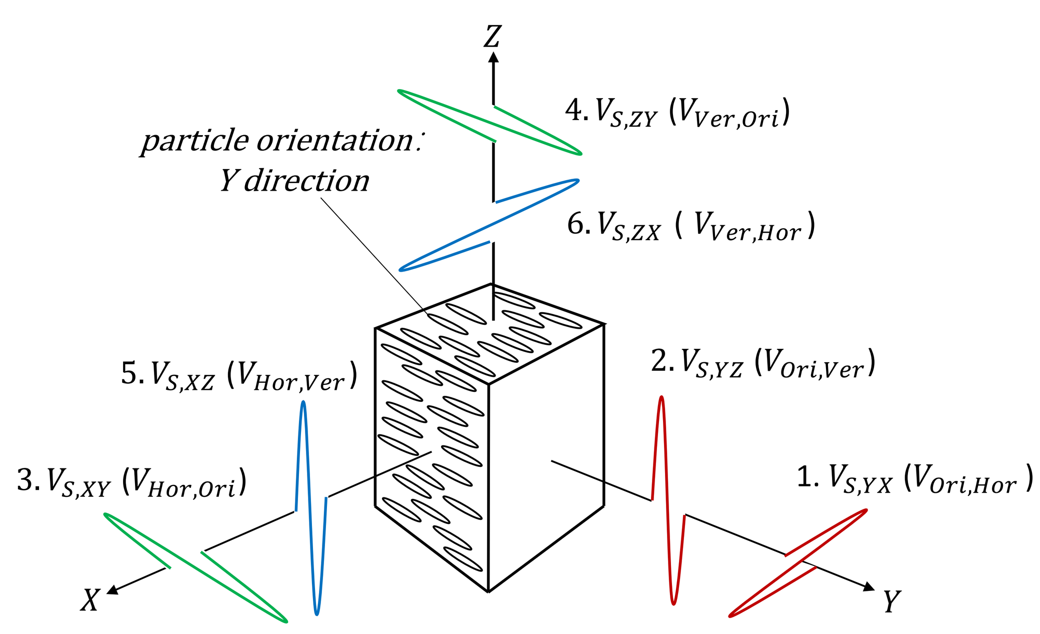
### (5) Experimental Results

Three notations of Ori, Hor and Ver are used to represent the particle orientation, the direction perpendicular to particle orientation within horizontal plane and the vertical direction, respectively. According to the results above, the relative magnitude of shear wave velocities can be described as:

$$v_{Ori,Hor} > v_{Ori,Ver} > v_{Hor,Ori} > v_{Ver,Ori} > v_{Hor,Ver} > v_{Ver,Hor}$$

The first and second subscripts indicate the direction of the S-wave propagation and oscillation, respectively, i.e., $v_{Ori,Hor}$ represents the shear waves that propagate along particle orientation and oscillate within the horizontal plane; $v_{Hor,Ver}$ means the shear waves that propagate perpendicularly to the particle orientation within the horizontal plane and oscillate along the vertical direction.

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.




### (6) Features and Uniqueness of the Research

- **Adoption of planar piezoelectric transducer developed at U-Tokyo**: compared with bender element, which is widely used in previous studies, planer transducer has several advantages: soil specimen is not disturbed during sample preparation, coarse grains can be tested, and more planar P- and S-waves can be generated to make accurate measurement of multi-directional stiffness
- **Consideration of the influence of particle orientation: t**hanks to the elongated wild rice, it is possible to dispose particles at specific directions. This makes the research unique, as it systematically discussed the effect of particle orientation ignored by previous studies.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