RELATIONSHIP BETWEEN COMPRESSIONAL AND SHEAR WAVES VELOCITIES IN ISOTROPIC STRESS STATES FOR GRANULAR MATERIALS

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1. INTRODUCTION

Elastic wave velocities directly associate with the material's properties. Compressional and shear waves reflect longitudinal and lateral deformation characteristics of materials. Measurements of both compressional and shear waves are well established in geophysical and seismological sectors, which are quite informative to study of earth's structures and predicting earthquakes. A flat disk shaped peizo-ceramic transducer, "Disk Transducer", has been introduced for measuring both compressional and shear waves in triaxial laboratory specimens in IIS (Institute of Industrial Science), the University of Tokyo. Employing this transducer, both compressional and shear wave velocities are measured on three kinds of granular geomaterials at several isotropic stress states.

2. MATERIALS AND METHODOLOGY

Three sorts of geo-materials ranges from fine sand to coarse sand (fine gravel) were tested in this study. Toyoura sand is fine uniformly graded sand originated from Toyoura beach of Yamaguchi prefecture, Japan. Silica sand is one of the popular varieties of sand in the world. The grain size of Silica sand varies from fine to coarse. In this study, Silica sand having mean diameter, D_{50}, 0.45mm was used. Hime gravel is poorly sorted and angular grain shaped gravel. It was collected from Hime River, Otari, Kitaazumi, Nagano prefecture, Japan. It is derived from sandstone, chert, granite, sill, quartz etc. The gradation curves are shown in Fig. 1. Small size, gear driven and strain controlled triaxial apparatus was used for performing experiments. Specimens of 75 mm in diameter and 150 mm in height were prepared by air pluviation technique. The materials were poured through air keeping constant height of pouring to maintain constant density throughout the specimen. Lower pouring height was adopted for erecting loose specimen and higher for dense specimen. The specimens were erected at an isotropic stress state of 25 kPa, and then the stress level was increased maintaining isotropic stress state of 50, 100, 200 and 400kPa respectively.

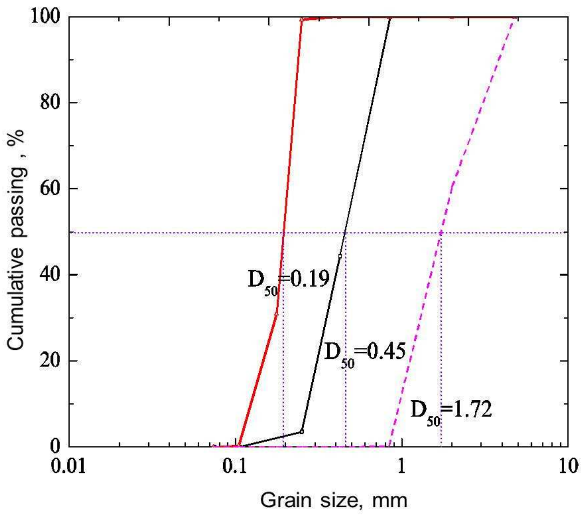

Fig.1 Particle size distribution curve of tested materials

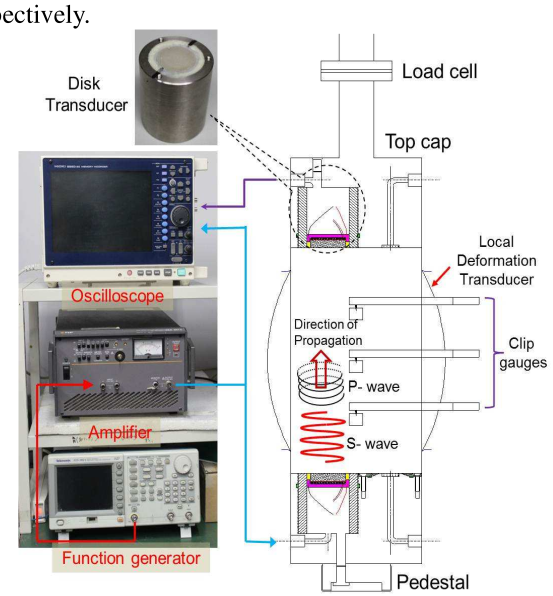

Fig.2 Experimental set up

Elastic waves measurement was conducted at each stress states. Disk transducer method was recently developed in the University of Tokyo (Suwal et al., 2010). Industrially produced flat disk piezo ceramic elements (P and S types) are assembled in metal housing which is placed in the top cap and pedestal. This transducer is called as a Disk Transducer here. By means of this transducer, both compressional and shear waves velocities are evaluated. The experimental set up is shown in Fig. 2. Signal for transmitting wave was generated by a digital automatic function generator. It can produce a maximum peak to peak voltage of 10 V and is capable of producing twelve kinds of different waveforms at frequency ranges of 0.001Hz to 25MHz. An amplifier was used to amplify the input signal generated by the function generator before feeding it into the transducer. The oscilloscope was used to record and display waveforms of the transmitted and received signals.

3. TEST RESULTS AND DISCUSSIONS

Several tests of each type of materials were performed as prior explained. The velocities of the propagated waves are

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calculated as: $Vp = \frac{H}{Tp}$, $Vp = \frac{H}{Ts}$ (1)

Where, Vp and Vs are compression and shear wave velocities, H is the height of specimen and Tp and Ts are the respective time required propagating within specimen during compression and shear wave excitation (Tp for compressional wave and Ts for shear wave, shown in Fig. 3). Input voltage, working frequencies and interpretation techniques are important factors in elastic wave measurement method. The input voltage ranges of 50-100 volts were employed. Previous researcher suggested for using a sinusoidal wave to reduce the uncertainties in the interpretation of the wave. The same shape signals on input and output signal could be achieved using a single sine wave as the input signal (Jovicic et al.,1996). Jovicic proposed the use of a sinusoidal wave and adoption of the point of the first inversion as the arrival of shear wave and suggest employing the high frequency signals for reducing the near field effects. Following the previous researchers, sinusoidal waves are employed in this study. The typical compressional and shear waveforms obtained on Toyoura sand specimen are shown in Fig. 3. This plot was achieved at isotropic stress state of 50 kPa during excitation of sinusoidal signal of 30 kHz frequency. The input voltage is plotted in volt and outputs are expressed in millivolts. As shown in this figure (Fig.3), the travel times for both compressional and shear waves are found and the respective velocities are derived employing eq.1. The obtained compressional wave velocities in m/sec are plotted against the shear wave velocities in m/sec in Fig.4. The results obtained on all those materials are included in this plot. The square symbols are representing the wave velocities obtained on Toyoura sand specimens. Similarly, circles and triangles are associated with the results obtained on Silica sand and Hime gravel. The linear relationships between the compressional and shear wave velocities are established based on the achieved results. The fitted linear lines are drawn in solid lines. The unique relationship between the compressional and shear wave velocities, applicable for those granular materials is proposed in this study and is shown in dotted lines in Fig.4. The proposed equation showed a good agreement with the obtained results. In this equation, the constant parameters, A and B are derived in terms of mean diameter of materials and stress dependency coefficient (m_v). Previous researchers have already concluded that the young's modulus for major elastic principal strain increments in a certain direction be a unique function of the normal stress in that direction as $E = Cons\tan t * \sigma^{m_v}$, where σ is stress state and m_v is stress dependency coefficient (Hoque et al.,1998). The same coefficient is used in this study. 0.48, 0.49 and 0.46 are adopted as a value of m_v for Toyoura sand, Silica sand and Hime gravel respectively. Those values were already determined in previous studies.

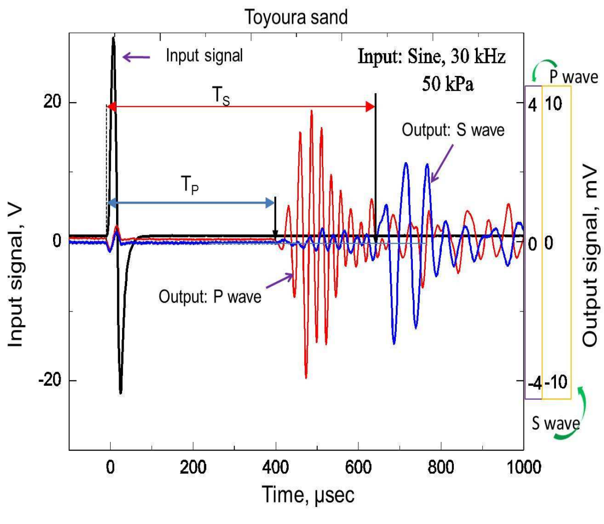

Fig.3 Typical P and S waveforms obtained on Toyoura sand

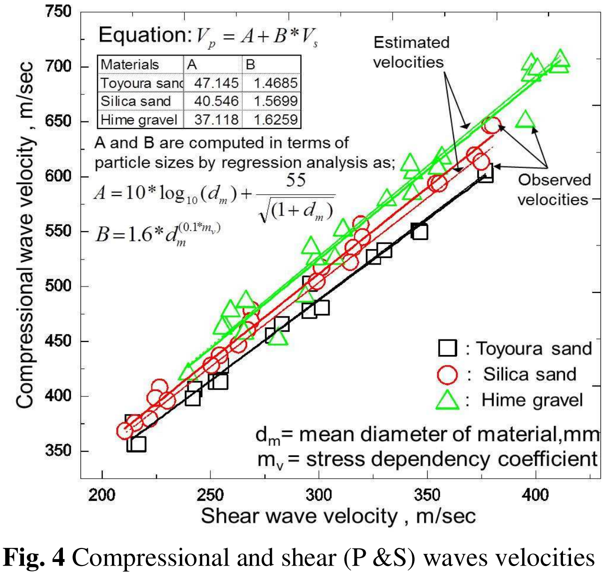

Fig. 4 Compressional and shear (P &S) waves velocities

4. CONCLUSIONS

The linear relationship between compressional and shear wave velocities on three granular materials at isotropic stress states are evaluated and the unique linear relationship is proposed. Good agreements between obtained and estimated results are shown on those three sorts of geomaterials Toyoura sand, Silica sand and Hime gravel.

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