EFFECT OF MEDIAN PARTICLE SIZE ON S-WAVE VELOCITY AND FREQUENCY DOMAIN RESPONSES OF GRANULAR MATERIALS

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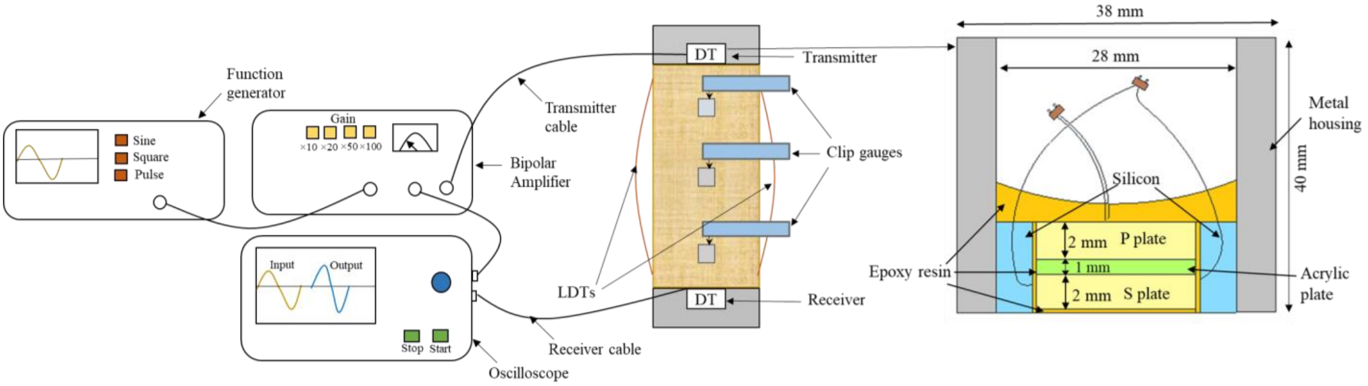
1. INTRODUCTION

The influence of void ratio and confining pressure on the elastic wave velocity and hence, the small-strain stiffness of granular materials has been ascertained by numerous previous researchers. However, there has been no unanimity achieved on the effect of median particle size (D_{50}) on the shear wave velocity (V_s) and small strain shear modulus (G_o). Iwasaki & Tatsuoka (1977) stated that the effect of D_{50} on G_o is limited. Sharifipour et al. (2004) observed an increase in V_s of glass beads with increasing D_{50}, whereas Patel et al. (2008) reported contradictory findings. Performing experiments on glass beads of different D_{50}, Yang & Gu (2013) detected a slight reduction in V_s as D_{50} increases, however, admitting experimental uncertainties, suggested that the influence of D_{50} on V_s is negligible. In the present research, disk transducers were employed to measure shear wave signals on glass beads and natural silica sands to discuss the influence of D_{50} on the shear wave velocities and their frequency responses.

2. MATERIALS AND TESTING ASSEMBLY

Samples of ballotini glass beads with four different D_{50} values were investigated (D_{50} = 0.2, 0.5, 1, 1.8 mm), having specific gravity (G_s), particle Young's modulus, and Poisson's ratio values of 2.5, 71.6 GPa, and 0.23, respectively. Four different sizes of silica sands were also tested with comparable D_{50} values of 0.3, 0.5, 1, 1.8 mm having G_s of 2.63, 2.64, 2.64, 2.64 respectively. All the materials were uniformly graded having a coefficient of uniformity (U_c) of about 1.2.

The overall test setup used for performing the wave measurements is illustrated in Fig. 1. Wave measurements were conducted at an isotropic stress (p') of 100 kPa. The excitation wave signals were produced using a digital function generator which was then amplified by a bipolar amplifier (±70V). The amplified input signal was sent to the transmitter element of the disk transducer. Disk transducers, comprising of both P- and S-type elements were developed based on Suwal & Kuwano (2013) (Fig. 1(b)). Each element is 20 mm in diameter and 2 mm thick. The elements were reinforced using silicon and epoxy resin and were placed inside the top cap and bottom pedestal of the triaxial apparatus. The S-type elements were kept closer to the specimen. The present contribution reports S-wave signals measured using the S-type elements.



(a) (b)

Fig. 1 (a) Schematic assembly to perform wave measurements (b) Schematic of disk transducer

3. RESULTS AND DISCUSSIONS

For the glass bead specimens prepared at a similar void ratio (e_o = 0.616–0.617), the travel time (T_{travel}) for the different D_{50} values are similar despite selecting different input frequencies (Fig. 2(a)). Referring to Fig. 2(b) for the silica sand, the sample with D_{50} = 1.8 mm which had a marginally larger e_o exhibits a longer T_{travel} (i.e. lower V_s) when compared to other smaller D_{50} samples (D_{50} = 0.3 mm & 0.5 mm), while T_{travel} for the finer sands are similar. The higher sphericity for the 1.8 mm silica sand grains obtained from QICPIC apparatus may explain the lower V_s values observed; more angular particles display higher V_s values under equivalent conditions (Liu & Yang, 2018). Hence, the influence of D_{50} on V_s is found to be negligible. The $V_s/f(e)$ lie within 5% and 9% of $[V_s/f(e)]_{\mathrm{avg}}$ for glass beads and silica sand respectively.

Figures 3(a) & 3(b) describe the variation in gain factor (ratio of the fast Fourier transforms of received (FFT_{out}) to the fast Fourier transform of transmitted signals (FFT_{in})) with frequency (f) for glass beads and silica sand respectively. The gain factor observed at a given frequency reduces with increasing D_{50}, consistent with the higher amplitude of received signals observed in the smaller D_{50} samples (Figs. 2(a) to 2(b)).

Keywords: Disk transducers, Shear wave velocity, Frequency response, Lowpass frequency
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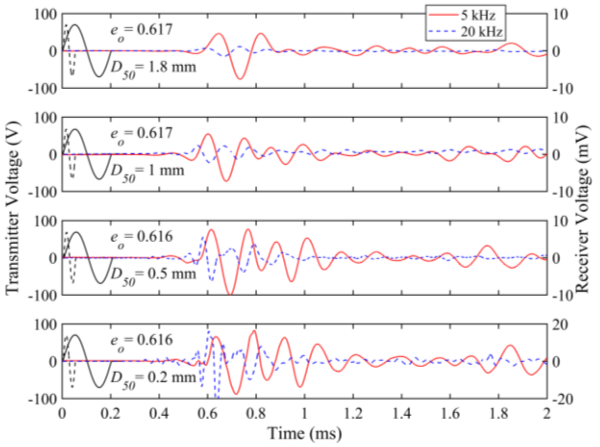

Fig. 2(a) S-wave responses of glass beads (p'= 100 kPa)

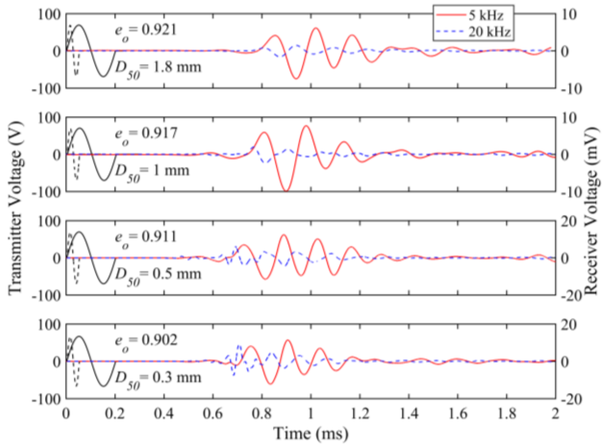

Fig. 2(b) S-wave responses of silica sand (p'= 100 kPa)

The lowpass frequency (f_{lp}) is the maximum signal frequency that can be transferred by the granular packing. Low amplitude high-frequency signals (noise) invariably appear during the wave measurement, and so f_{lp} was determined by considering a threshold gain factor value of 5×10^{-6} as indicated in Fig. 3. For both glass beads and silica sands, f_{lp} values increase linearly with increasing $1/D_{50}$ (Fig. 4). From the dispersion theory, the following relationship between V_s and f_{lp} can be derived for a regular array of mono-sized spheres (Otsubo et al., 2017b):

$$V_s \propto L f_{lp} \tag{1}$$

where L = equivalent distance between particles which is related to D_{50}.

For a constant V_s, Eq. 2 signifies that f_{lp} is inversely proportional to L; this delivers a fundamental basis for the linear variation between f_{lp} and $1/D_{50}$. Fig. 4 shows that the linearity of Eq. 1 still holds true not only for disordered array of spherical particles but also for natural sands. Considering f_{lp} would lead to a more reliable estimation of T_{travel}.

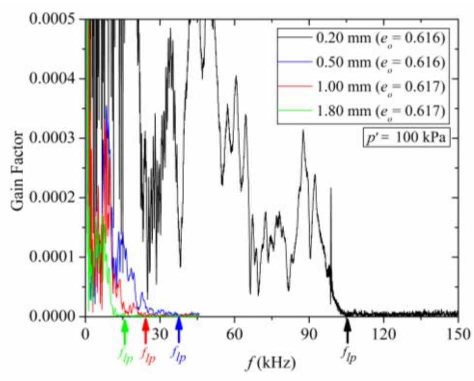

Fig. 3(a) Gain factor vs. f for glass beads

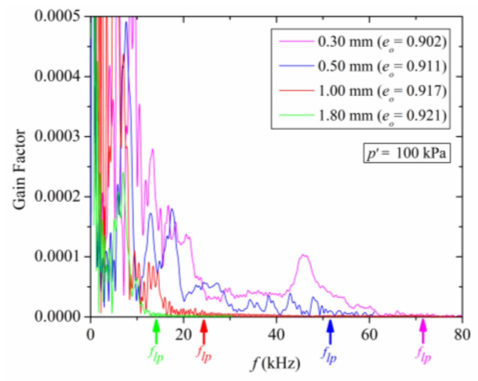

Fig. 3(b) Gain factor vs. f for silica sand

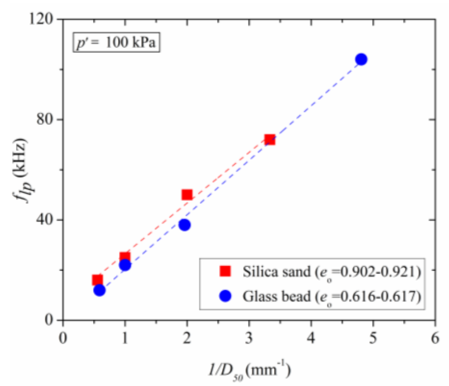

Fig. 4 f_{lp} vs. $1/D_{50}$

4. CONCLUSION

In the current study, disk transducers have been adopted to perform wave measurements to identify the influence of D_{50} on the shear wave velocities and their frequency responses. The S-wave velocity is found to be independent of the median particle size for uniform grain size distribution. However, the range of frequency that can be propagated through the granular packing (f_{lp}) increases with the increase in $1/D_{50}$. The linear relationship between f_{lp} and $1/D_{50}$ for a constant wave velocity, that can be derived from the dispersion theory for a regular packing of mono-sized spheres is found to be valid not only for disordered array of spherical particles but also for natural sands.

REFERENCES

(1) Iwasaki, T, & Tatsuoka, F.: Effect of grain size and grading on dynamic shear moduli of sand. Soils and Foundations, 17-3, 1977, pp. 19–35. (2) Liu, X. and Yang, J. Shear wave velocity in sand: effect of grain shape. Géotechnique, 68-8, 2018, pp. 742-748. (3) Otsubo, M., O'Sullivan, C., Hanley, K. J. and Sim, W.: Influence of packing density and stress on the dynamic response of granular materials. Granular Matter, 19:50, 2017. (4) Patel, A., Bartake, P. P. and Singh, D. N.: An empirical relationship for determining shear wave velocity in granular materials accounting for grain morphology. Geotechnical Testing Journal, 32-1, 2008, pp. 1–10. (5) Sharifipour, M., Dano, C. & Hicher, P. Y.: Wave velocities in assemblies of glass beads using bender-extender elements. In Proceed. of 17th ASCE Engineering Mechanics Conference, Newark, DE, United States, 2004. (6) Suwal, L. P. and Kuwano, R. Disk shaped piezo-ceramic transducer for P and S wave measurement in a laboratory soil specimen. Soils and Foundations, 53-4, 2013, pp. 510–524. (7) Yang, J. and Gu, X. Q.: Shear stiffness of granular material at small strains: does it depend on grain size? Géotechnique, 63-2, 2013, pp. 165–179.