Abstract

The goal of this research is to explore the influence of fines content and stress induced anisotropy on the small and intermediate strain properties ($G_{\text{max}}$, $G(\gamma)$ and $\eta(\gamma)$) of granular materials from microscopic to macroscopic level. Accordingly, the work is divided into two parts: in the first part the influence of fines content is examined and in the second part the influence of stress-induced anisotropy is assessed.

(1) The resonant column tests were conducted on clean Hostun Sand to detect the influence of mean effective stress, $p'$, and void ratio, $e$, on $G_{\text{max}}$, $G(\gamma)$ and $\eta(\gamma)$. Then, the effect of fines on the maximum shear modulus, $G_{\text{max}}$, $G(\gamma)$ and damping ratio, $\eta(\gamma)$, was investigated with a systematic increase in fines content, $f_c$, up to 40%. The experimental results revealed that $G_{\text{max}}$ decreased with an increase in $e$ and $f_c$. Furthermore, the experimental results showed that damping ratio increased with an increase in $f_c$ up to $f_c$ of 20% and it then decreased with further increase in fines content.

Micro CT scans demonstrated that sand with fines develops two different micro-structures: “fines-in-sand” and “sand-in-fines”. For “fines-in-sand”, fine particles are partially active in the sand force structure and for “sand-in-fines”, sand particles float in fine particles. The void ratio, $e$, does not capture the force structure or fabric of the sample and only represents the density of the sample. The equivalent granular void ratio, $e^*$, is a parameter for the density and fabric of the sample in transition soils. Analyses conducted in this study revealed that $e^*$ in comparison with $e$ provides a unique relationship between $G_{\text{max}}$, $f(p')$ and $f(e^*)$ in space, where the fitting parameters of Hardin´s relationship are the same as clean sand. This unique relationship can be used to predict the small and intermediate strain properties of granular materials containing fines based on test results for the clean host material.

(2) The resonant column device was modified for applying the additional vertical stress inside the samples for the anisotropic stress state tests. Simulation using FEM and piezoelectric elements were employed for the calibration and validation of the modified device. Then a series of stress induced anisotropic tests were conducted on Hostun Sand specimens for various stress paths (sp): isotropic loading, sp I ($\sigma_3 = \text{constant}$), sp II ($p' = \text{constant}$), sp III ($K = \text{constant}$), where $\sigma_1$ and $\sigma_3$ are the principal stresses, $p' = (\sigma_1 + 2\sigma_3)/3$ and $K = \sigma_3/\sigma_1$. Experimental results revealed that the impact of stress induced anisotropy on the small and intermediate strain properties of dry Hostun Sand depends on the adopted stress path. In sp I, the effect of the stress ratio on $G_{\text{max}}$ was significant but the influ-
ence of the stress ratio on $G(\gamma)/G_{max}$ and $\eta(\gamma)$ was not significant. The experimental results reveal a significant influence of stress induced anisotropy on $G_{max}$, $G(\gamma)/G_{max}$ and $\eta(\gamma)$ for sp II and III. The empirical relationships were written as a function of stress components to predict the small and intermediate strain properties of granular material subjected to stress induced anisotropy for different stress paths.

DEM analyses were also conducted on a granular packing to determine the effect of stress induced anisotropy on the contact properties for various stress paths from the microscopic point of view. The micro-mechanical observations showed that the variations in normal contact force in the grain-to-grain contacts and coordination numbers were the main micro-mechanical properties which had a significant effect on the values of $G_{max}$ and $G/G_{max}$ for different stress paths.