Modified stress~strain state parameters for representing small strain deformation characteristics of granular materials under different testing conditions

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Introduction: In modeling of stress~strain characteristics of granular materials under various stress conditions, a particular set of stress and strain parameters do not always give unique relationships because of several influential factors such as initial void ratio, stress path, stress history, material properties etc. In order to make the modeling approach more relevant to general conditions, selection of a suitable set of stress and strain parameters which overcome such possible differences in practice is needed [1], and such an attempt is presented in this paper referring to the plastic deformation characteristics of some gravels and sands subjected to drained triaxial compression or plane strain compression under constant cell pressure.

Testing Procedure: Some results from drained triaxial compression (TC) tests performed on rectangular prismatic specimens (57cm x 23cm x 23cm) of Chiba gravel, undisturbed Tokushima gravel (D=30cm, H=60cm), air pluviated Toyoura sand (D=5cm, H=10 cm), Hostun sand (D=7.5cm, H=15 cm)[2] along with plane strain compression (PSC) tests performed on Toyoura sand (20cm x 16cm x 8cm)[3] [4] are presented in this paper. Deformations were measured locally. The specimens were initially consolidated isotropically and then sheared with keeping the cell pressure constant. Though, the specimens were also subjected to large unloading and reloading cycles in some cases, only the monotonic virgin loading parts are considered in this study.

Test results and discussion: The irreversible plastic strains were estimated from the measured total strain and using the quasi-elastic model as reported before[1]. Considering relative symmetry in stress~strain relationship during TC and TE, $\sin(\phi)_{mob}$ [$=(\sigma_v-\sigma_h)/(\sigma_v+\sigma_h)$] and plastic shear strain γ^P [$=\gamma^{total} - \gamma^{elastic}$; $\gamma=\varepsilon_v-\varepsilon_h$] were used as the stress and strain parameters respectively. A comparison among the above mentioned stress~strain characteristics of Toyoura sand under various testing condition is presented in Fig. 1.

It could be seen that there is a significant difference between the curves which make it impossible to fix a unique relationship independent of testing condition, stress path, initial void ratio etc. As an attempt to make the parameters more relevant to take into account the effects of initial void ratio and different stress paths [5], and hence to reduce the differences among the curves, the stress parameters were normalized by $\sin(\phi)_{peak}$ depending on the corresponding stress path and/or the failure envelop, whereas the strain values were normalized by a reference strain γ_r [$=\tau_{peak}/G_O$], where τ_{peak} is the peak shear stress and G_O is the quasi-elastic shear modulus[1]. Note that, G_O is not a constant, but influenced by the current stress state and the damage due to the previous strain history. In the present study, with neglecting the effects of damage to soil structure, G_O values were obtained as $G_O = E_v / 2(1+\nu_{vh})$; where E_v is the vertical quasi-elastic Young's modulus [$=f(\sigma_v)$] and ν_{vh} is the quasi-elastic Poisson's ratio [$=g(\sigma_v/\sigma_h)$]. It is also assumed that τ_{peak} is not a constant throughout the loading, but is a function of current σ_m [$=(\sigma_v+\sigma_h)/2$]. Failure envelopes are obtained based on relevant test results with empirical extrapolation. For unsaturated gravels which posses a cohesion, assumption of a parabolic failure line gave better results, whereas for dry/saturated sands without cohesion, the failure line was assumed as a straight line.

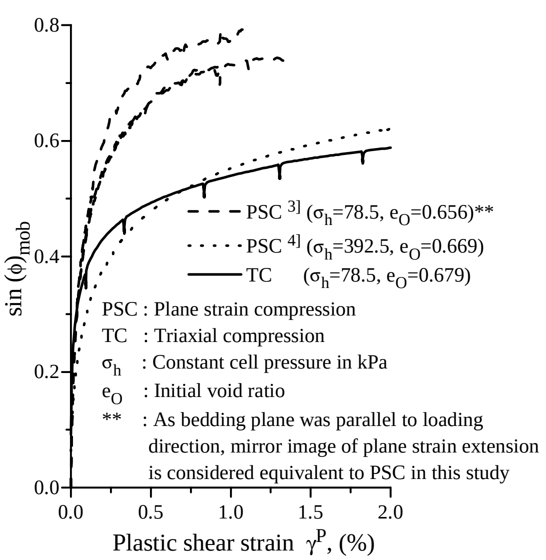

Fig. 1: Plastic deformation characteristics of Toyoura sand during shearing under different testing conditions.

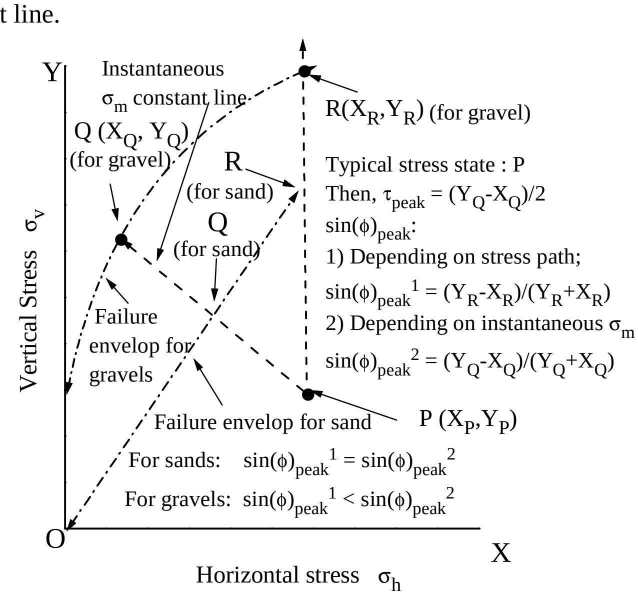

Fig. 2: Sketch to demonstrate evaluation of modifying parameters from an instantaneous stress state.

Key words: Stress-strain relation, Elasto-plasticity, Triaxial test, Plane strain test
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The instantaneous τ_{peak} values were obtained by drawing "σ_m constant" lines up to the failure envelops, while $\sin(\phi)_{peak}$ values were evaluated by extending the corresponding stress path lines to the failure envelops in two different ways, as typically demonstrated in Fig. 2. After these modifications, the stress and strain parameters are newly defined as $\sin(\phi)_{mob}/\sin(\phi)_{peak}$ and $\int(d\gamma^P/\gamma_r)$, respectively. Considering the degree of differences among various curves, a convergence towards a unique curve could be observed when both parameters were modified as shown in Fig. 3. Similar comparison can be made in Figs. 4 & 5 on different materials under TC condition. It is clear from the results that the influence of several factors still exists. The b-value $[=(\sigma'_2-\sigma'_3)/(\sigma'_1-\sigma'_3)]$ effect could be seen comparing TC and PSC test results of Toyoura sand under same σ_h of 78.5 kPa (Figs. 1 & 3). In the case of Chiba gravel (Figs. 4 & 5) the effect of initial density and confining stress could be reduced considerably by selecting different failure envelops depending on density. The effect of fines content, indicated as *F* in the figures, also seems to play a roll showing softer response with higher amount of fines. In Fig. 6, the $\sin(\phi)_{peak}$ values for gravels defined in a different manner from those in the previous figures are employed for comparison. Though the previous method gave better results in some cases, the later one can be used to make the approach more relevant to a general stress condition.

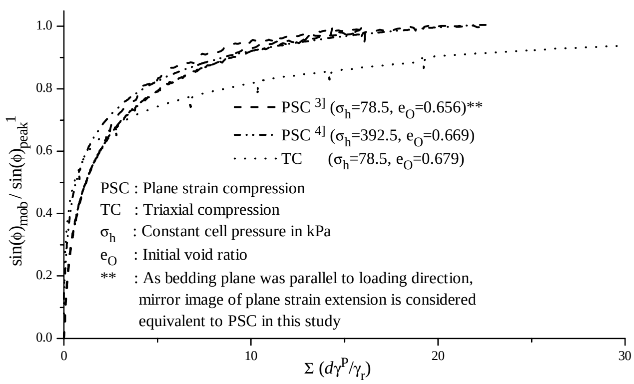

Fig. 3: Modified deformation characteristics of Toyoura sand during shearing under different testing conditions.

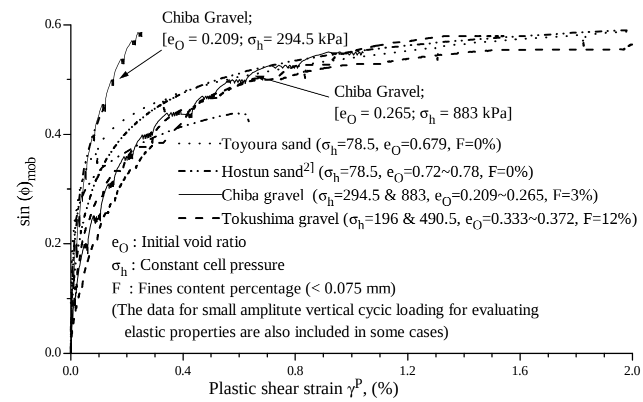

Fig. 4: Plastic deformation characteristics of different granular materials during shearing under TC.

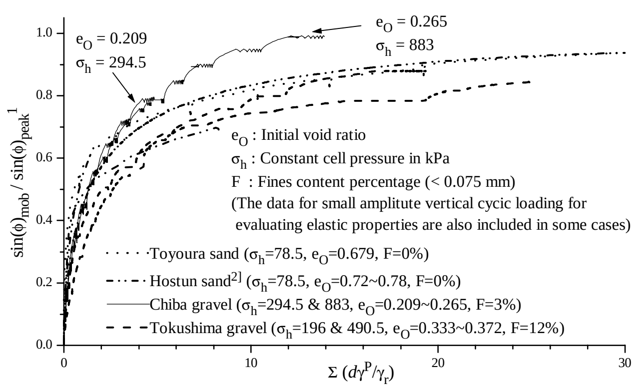

Fig. 5: Modified deformation characteristics of different granular materials during shearing under TC.

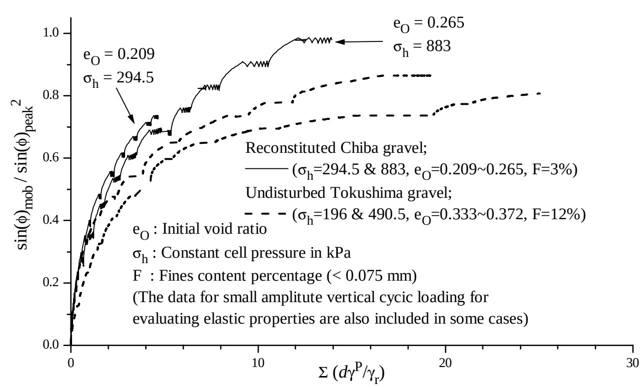

Fig. 6: Modified deformation characteristics of gravels using $\sin(\phi)_{peak}$ depending on instantaneous σ_m.

Conclusion: Modification of the stress and strain parameters made a significant improvement for a unique relationship among the stress~strain characteristics under different initial conditions & stress paths. Several factors such as b-value, fines content, density etc., however, still influenced the modified relationships for general stress & material conditions.

References: 1] Balakrishnaiyer, K. et al.(2000), "Modified stress~strain state parameters for representing small strain deformation characteristics of dense gravel", Proc. of 35th annual meeting of JGS. 2] Hoque, E. (1996),"Elastic deformation of sands in triaxial tests", Doctoral thesis, Univ. of Tokyo. 3] Masuda, T. (1998), "Study on the effects of pre-load on the deformation of excavated ground", Doctoral thesis, Univ. of Tokyo. 4] Yasin, S.J.M. (1998), "Strength and deformation characteristics of sands in plane strain shear tests", Doctoral thesis, Univ. of Tokyo. 5] Tatsuoka,F. et al. (1999), "Stress-Strain Behavior at Small Strains of Unbound Granular Materials and Its Laboratory Tests", Unbound Granular Materials, Balkema, pp. 17-61.