DISCUSSION

Contribution of fines to the compressive strength of mixed soils

Q. NI, T. S. TAN, G. R. DASARI and D. W. HIGHT (2004). *Géotechnique* 54, No. 9, 561–569

T. Kanagalingam and S. Thevanayagam, *University at Buffalo*

The authors have presented a very useful experimental evaluation of the concepts of intergranular void ratio proposed by Mitchell (1976) and Kenny (1977) and the equivalent intergranular void ratio proposed by Thevanayagam *et al.* (2002) and their relationship to undrained shear strength at steady state for granular mix soils. It is interesting to find that the authors have found that the factor b is related to $\chi = (d_{10, \text{host-sand}}/d_{50, \text{silt}})$ for non-plastic soil mixes at low silt contents.

The discussers had previously examined the physical meaning of parameter b and its relationship to the characteristics of the host sand grains and silt grains in their original study (Thevanayagam, 2001, 2003; Thevanayagam *et al.*, 2002a, 2003). The factor b represents the degree of participation of fine grains in the internal contact force chain in the soil mix at low fines content. Higher values of b would be expected with increasing space constraint for the fine particles to move within the porous network. It was found that b depends on $R_d (= d_{50, \text{host-sand}}/d_{50, \text{silt}})$ and uniformity coefficients $C_{uc} (= d_{60, \text{host-sand}}/d_{10, \text{sand}})$ and $C_{uf} (= d_{60, \text{silt}}/d_{10, \text{silt}})$. The individual effect of each of these three variables on b , while the other two remain constant, is as follows.

- When R_d decreases, the ratio pore-throat-size_{host-sand}/ $d_{50, \text{silt}}$ decreases, allowing participation by more fine grains in the contact force chain within the soil mix: hence b increases.
- When C_{uc} increases, the ratio pore-throat-size_{host-sand}/ $d_{50, \text{silt}}$ decreases. This allows more participation by the fine grains in the internal force chain in the soil mix, and hence b increases.
- When C_{uf} increases, for the same $d_{50, \text{silt}}$, the fine-grained soil contains a greater number of large size silt particles than the case where C_{uf} is small: hence the contribution of the silt grains to the contact force chain increases, and therefore b increases.

The relationship of b to $(C_{uc}C_{uf}^2/R_d)$ presented in the writers' original study is shown in Fig. 13. Note that

$$\frac{C_{uc}C_{uf}^2}{R_d} = \frac{C_{uf}^2(d_{60, \text{sand}}/d_{50, \text{sand}})}{\chi} \quad (4)$$

which is approximately equal to C_{uf}^2/χ . Also shown in Fig. 13 are the values of b for the soils reported by the authors. The authors' data follow the same trend found before by the discussers. Fig. 14 shows these data in a diagram of b against $d_{50, \text{silt}}/d_{10, \text{host-sand}} (= 1/\chi)$. Figs 13 and 14 are similar, except that Fig. 13 uses C_{uf}^2/χ whereas Fig. 14 uses $1/\chi$ as the x-axis. Fig. 13 is intended to capture the influence of gradation of the silt on b as opposed to its mean size ($d_{50, \text{silt}}$) alone.

A similar relationship was found for the parameter m in the equivalent interfine void ratio

$$(e_f)_{eq} = \frac{e}{f_c + \frac{1-f_c}{(R_d)^m}} \quad (5)$$

Fig. 13. b against $(C_{uc}C_{uf}^2/R_d)$

Fig. 14. b against $(d_{50, \text{silt}}/d_{10, \text{host-sand}})$

where f_c is the silt fraction by dry weight, as shown in Fig. 15. The ratio $(e_f)_{eq}$ was found to correlate well with undrained shear strength at steady state for non-plastic soil mixes containing large fractions of silt. The relationships for limiting silt contents delineating the transition zones where the predominant influence of the sand matrix diminishes and the influence of silt grains begins to dominate are presented in Thevanayagam *et al.* (2002). Further information on the roles of intergranular contacts, fines and friction on the undrained behaviour of granular mix soils can be found in Thevanayagam (2003).

Authors' response

The authors wish to thank Kanagalingam and Thevanayagam for their comments and for bringing to the authors' attention the dependence of the factor b on various parameters as suggested by them, namely R_d , C_{uc} and C_{uf} , which provide more detailed information concerning the space constraints (pore size) relative to the size of the fines. These are useful suggestions to consider when evaluating the value of b . It is clear that, regardless of the choice of parameter to

Fig. 15. m against $(C_{uc} C_{uf}^2 / R_d)$

relate to the factor b , it is a way of expressing the fact that b depends on the degree of freedom for the fines to move within the pore spaces. It is satisfactory that our data are able to fit within the framework of their proposals. The discussion has also shown that there is little difference in the results whether C_{uf}^2 / χ or χ is used. The main reason for the choice of χ in our paper is its simplicity.

From a practical point of view, the true value of the factor, b , is probably if it could be established easily for a particular soil type for a particular site. The choice of a simple parameter such as χ would probably be more helpful in this respect.

REFERENCES

- Thevanayagam, S. (2001). *Role of intergranular contacts on mechanisms causing liquefaction and slope failures in silty sands*, Annual project summary report, USGS Award Number: 01HQGR0032. US Geological Survey, Department of Interior <http://erp-web.er.usgs.gov/reports/annsum/vol43/pt/g0032.pdf>
- Thevanayagam, S. (2003). *Role of intergranular contacts on mechanisms causing liquefaction and slope failures in silty sands*, Final Report, USGS Award No. 01HQGR0032 and 99HQGR0021. US Geological Survey, Department of Interior, USA, <http://erp-web.er.usgs.gov/reports/abstract/2001/pt/01hqgr0032-report.pdf>.
- Thevanayagam, S., Kanagalingam, T. & Shenthnan, T. (2002a). Contact density—confining stress—energy to liquefaction. *Proc. 15th ASCE Eng. Mech Conf.*, Columbia University, Paper No. 428.
- Thevanayagam, S., Kanagalingam, T. & Shenthnan, T. (2003). Inter-grain friction, contact density, and cyclic resistance of sands. *Proc. 2003 Pacific Conf. on Earthquake Engineering*, Christchurch, Paper No. 115.