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Spatial heterogeneity effects on K_0 loading

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ABSTRACT: Spatial heterogeneity prevails in soils, even in remolded specimens formed in the laboratory under carefully controlled conditions. Spatial variability prompts the emergence of mechanical phenomena that are not encountered in homogeneous media. The purpose of this study is to explore phenomena associated to spatial variability in soils, taking into consideration their particulate nature. We focus on the effect of variability in soil stiffness on the load-deformation response under zero-lateral strain conditions, using complementary finite element simulations (correlated random media) and experiments (rubber-sand mixtures). Results show the development of non-homogeneous stress and strain fields, intricate load transfer and stress concentration along percolating stiff zones, the reduction in K_0 values, more complex interpretation of wave propagation traces for the characterization of small strain stiffness, and suggest judicious use of mixture formulas.

1. INTRODUCTION

Spatial heterogeneity is an inherent characteristic in natural soils. The spatial variability of geotechnical engineering properties can be captured using statistical data such as the mean trend μ, the coefficient of variation COV, and spatial correlation (Vanmarke 1977; DeGroot and Baecher 1993; Lacasse and Nadim 1996; Phoon and Kulhawy 1999).

2. NUMERICAL SIMULATION

The local and global mechanical response of heterogeneous soils subjected to K_0 loading is explored first using finite element simulations.

2.1 Procedure

The horizontally constrained square medium is discretized into 100x100 four-node plane strain elements, and the soil is modeled using the modified Duncan-Chang material model (Code: ABAQUS 2007).

Figure 1 shows the K_0 load-deformation response in each case. Higher compressibility is observed for higher variance in stiffness distribution, in agreement with the earlier studies with linear elastic material models (Baecher and Ingra, 1981; Zeitoun and Baker, 1992; Paice et al., 1996).

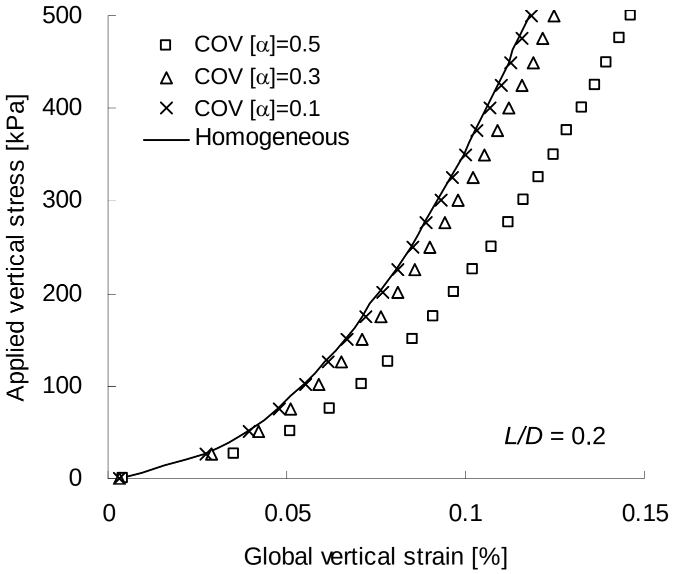

Figure 1. Increased compressibility with higher variance

3. EXPERIMENTAL STUDY

The behavior of a soil mass with large soft inclusions is experimentally studied next using a mixture of sand and large rubber chips (much larger than the sand grains). Material properties are summarized in the Table 1.

Table 1. Properties of materials

	D_{50} (mm)	G_s	E (kPa)
Ottawa 50/70 sand	0.35	2.65	5.9×10^{7}
Rubber chips	3.5	1.14	1.0×10^{3}

3.1 *Zero-lateral strain compressibility*

The K_0 load-deformation response is determined in a modified oedometer cell that includes bender elements on the top cap and bottom plate to measure a small strain elastic wave velocity.

Equation (1) reflects that the small strain stiffness $E_{\tan}$ of a granular material depends on the flatness of contacts, as captured in Hertz theory for a system of two spheres.

$$\frac{E_{\tan}}{E_g} = \frac{1}{2\left(1-\nu_g^2\right)}\frac{r_c}{R} \tag{1}$$

where E_g and ν_g are young's modulus and Poisson ratio for the mineral that makes the grain, and R and r_c are the particle radius and the radius of the contact area.

4. CONCLUSIONS

Internal stiffness heterogeneity in particulate materials promotes intricate local mechanisms and the emergence of new global behavior in zero-lateral strain loading, including stress induced homogenization, stress focusing, and reduction in K_0 coefficient.

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REFERENCES

Beacher, G.B. and Ingra, T.S. (1981). "Stochastic FEM in settlement predictions," J. Soil Mech. Fdns. Div., ASCE, 107(4), 449-463

Popescu, R., Prevost, J.H. and Deodatis, G. (1996). "Influence of spatial variability of soil properties on seismically induced soil liquefaction," Proc., Uncertainty in the Geologic Environment: from Theory to Practice, Shackelford, C.D., Nelson, P.P., and Roth, M.J.S., eds., ASCE, Madison, WI, 1098-1112

Santamarina, J.C., Klein, K.A., and Fam, M.A. (2001). Soils and waves, John Wiley and Sons Ltd. New York, 103-113

Kim, H.-K. (2005). Spatial variability in soils: Stiffness and strength, Ph.D. thesis, Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, U.S.A., 56-70