Hydro-mechanical modeling of granular soils considering internal erosion

Zhen-Yu Yin, Jie Yang, Farid Laouafa, Pierre-Yves Hicher

Hydro-mechanical modeling of granular soils considering internal erosion

Z.Y. YIN[b,c*], J. YANG[a,b], F. LAOUAFA[a] and P.Y. HICHER[b]

[a]INERIS, Verneuil en Halatte, France
[b]Research Institute of Civil Engineering and Mechanics (GeM), UMR CNRS 6183, Ecole Centrale de Nantes, Nantes, France
[c]Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China

[*] zhenyu.yin@polyu.edu.hk; Zhenyu.yin@gmail.com

Introduction

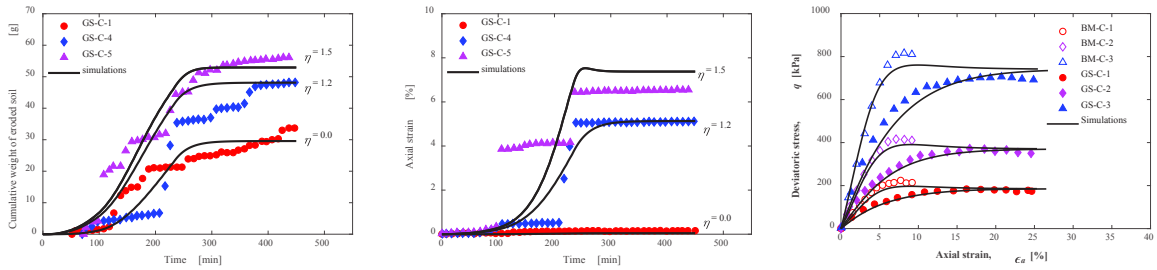
Internal erosion occurs when fine particles are plucked off by hydraulic forces and transported through the coarse matrix. The known causes are either a concentration of leak erosion, backward erosion, soil contact erosion, or suffusion (Bonelli and Marot 2008). This study attempts to formulate a coupled numerical model within the framework of continuum mechanics to investigate the phenomenon of internal erosion and its consequences on the behavior of granular soils. First, a four-constituent model has been developed to describe the detachment and transport of fine particles induced by the fluid flow. This process has been coupled with an enhanced critical state based mechanical model considering the effect of the fines content. Then, the predictive ability of the approach has been examined by simulating internal erosion tests on HK-CDG mixtures. Finally, the influence of the stress state, the initial density, and the initial fines content of the soil have been investigated by the developed numerical model.

Formulation of the time-dependent physical problem

According to Schaufler et al. (2013), it is possible to consider the saturated porous medium as a material system composed of 4 constituents in 2 phases: the stable fabric of the solid skeleton, the erodible fines, the fluidized particles and the pure fluid. The fines can behave either as a fluid-like (described as fluidized particles) or as a solid-like (described as erodible fines) material. Thus, a liquid-solid phase transition process is considered by a mass production term in the corresponding mass balances. The mechanical behaviours of the solid skeleton are reproduced by a non-linear incremental constitutive model including the critical state concept has been adopted (Yin et al. 2018). The model was enhanced by formulating the influence of the fines content on the critical state line in the *e-p'* plane based on experimental results in order to take into account the impact of the amount of eroded fines on soil deformability and strength.

Simulations of laboratory tests on HK-CDG mixture

A series of hydraulic-gradient controlled downward erosion tests on gap-graded HK-CDG mixtures, performed by Chang and Zhang (2011) with a newly developed stress-controlled erosion apparatus, were selected for simulations to investigate the initiation and the development of internal erosion in soils subjected to multi-step fluid flow under complex stress states, as well as the stress-strain behavior of soils subjected to internal erosion.



(a) (b) (c)

Fig. 1. Comparison between experimental results and simulations for HK CDG mixture under different stress states: (a) Cumulative eroded soil mass; (b) axial strain during erosion tests and (c) stress-strain vurves of drained triaxial tests before and after erosion

Fig.1 compared the experimental results and simulations for HK CDG mixture. GS-C-1, GS-C-2, and GS-C-3 were erosion tests under isotropic stress states, GS-C-4 and GS-C-5 were erosion tests under anisotropic stress states, BM-C-1, BM-C-2, and BM-C-3 were conventional drained triaxial tests on isotropically consolidated samples without erosion. The proposed model was able to reproduce the general trend of the cumulative weights of the eroded soil under different stress states. It is also able to reproduce the mechanical behaviors before, during and after erosion. Furthermore, the simulation results confirmed that the deformation is linked to the stress ratio under which the erosion process is active. Interestingly, besides the stress ratio, the amount of loss of fines, which indicates the yielding from a stable to an unstable mechanical response, appeared to be related to the initial density as well as to the initial fines content of the soil mixture.

Conclusion

This study provides a novel contribution to the numerical approach of quantifying the impact of internal erosion on the mechanical behavior of granular soils. A good agreement was obtained between the model predictions and the experimental results on HK-CDG mixtures. The results confirmed that the deformation is linked to the stress ratio under which the erosion process is active, the amount of loss of fines, and the initial fines content of the soil mixture.

Acknowledgements

The financial support provided by both the National Natural Science Foundation of China (51579179) and the National Institute for Industrial Environment and Risks of France (INERIS) is gratefully acknowledged.

References:

Bonelli, S., and Marot, D. On the modelling of internal soil erosion. In The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG). 2008. p. 7.

Chang, D., and Zhang, L. 2011. A stress-controlled erosion apparatus for studying internal erosion in soils. Geotechnical Testing Journal., 34(6): 579-589.

Schaufler, A., Becker, C., and Steeb, H. 2013. Infiltration processes in cohesionless soils. ZAMM-Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik, 93(2-3): 138-146.

Yin, Z.-Y., Wu, Z.-X., and Hicher, P.-Y. 2018. Modeling Monotonic and Cyclic Behavior of Granular Materials by Exponential Constitutive Function. Journal of Engineering Mechanics, 144(4): 04018014.