Post-doctoral position

Topic: Permeability evolution of granular soils in an internal erosion context

Secured financial support: ANR PERSÉE project carried by the GeM Institut (UMR CNRS 6183)
Starting period: January to March 2023
Funding length: 1 year

Scientific supervisors: Rachel GELET, Didier MAROT

Localization: GeM Institute (UMR CNRS 6183, https://gem.ec-nantes.fr/ieg-2/), Nantes Université, 58 rue Michel Ange, 44600 Saint-Nazaire

Description of the PERSÉE project

France relies on a significant stock of hydraulic structures with more than 9 000 km of protection against flooding, 8 000 km of dikes for navigation canals and 1 000 km of hydroelectric canals. The number of small embankment dams is around several tens of thousands, while the number of large dams approaches 600. An important aspect of this French hydraulic asset is its age: while most dams are older than half a century, most dikes are more than 100 years old. Hence, the maintenance of such a wide and old patrimony requires a costly upkeep and calls for scientific progress on the mechanisms which induce instabilities on these earth-structures. In addition, the probable consequences of climate change on the sea level and continental hydrology will lead to increasing solicitations on coastal and fluvial structures, which will reinforce the need for their surveillance and maintenance.

Hydraulic earth structures can suffer from instabilities induced by internal erosion processes, which are responsible for 46% of all disorders. The risk management related to volumetric erosion, named suffusion, calls for the numerical modelling of these structures. Such modelling requires the development of a new relationship that can describe the evolution of the permeability during the suffusion process, i.e. including the evolutions of the grain size distribution (GSD) and the constriction size distribution that both describe the soil's microstructure.

Overall, five numerical methods and several experimental tests will be used to adapt the concept of "controlling constriction size" to soils susceptible to suffusion. Our project is organized in four steps:

(i) First, numerical specimens will be studied to better understand the physical links between pore space characteristics extracted from granular specimens simulated with the discrete element method (Nguyen et al., 2021) and the permeability that can be computed thanks to a numerical full field homogenization technique (Bignonnet, 2020). The idea is to work on numerical specimens constituted of spherical grains and simplified GSDs, with respect to that of in-situ soils.

(ii) Second, a physically-based relationship relating the key microstructure characteristics, identified previously, to the permeability will be sought with a semi-analytical homogenization method. This method provides an estimate of the permeability from a simplified and implicit representation of the microstructure, such as spherical grains, cylindrical pores, etc. This first relationship will be validated against the numerical simulations realised in step (i), by focusing on simplified GSDs and spherical grains. Next, this relationship will be extended to in-situ soil GSDs by using a probabilistic approach to obtain the key microstructure characteristics (Reboul et al., 2010; Seblany et al., 2021). Throughout steps (i) and (ii), the obtained results will be challenged for intact specimens and for suffusion-induced heterogeneous ones.

(iii) The validation of this extended physically-based relationship will be realised against several permeation and suffusion tests. In addition, multiple grain size distributions (initial, post-suffusion, eroded grains) will be realised to further validate the numerical approaches developed in step (ii) and (iv).

(iv) Finally, the extended physically-based relationship and the probabilistic approach will be implemented in our domestic finite element code which features a hydro-mechanical continuous model extended to suffusion (Gelet et al., 2021; Gelet et al. 2022). The numerical predictions of the permeability will be validated against the suffusion tests, performed in step (iii), and subsequently on a reduced physical model of dike.

The final product of this project, in addition to the deliverables of each step, will be a poro-mechanical simulation code that accounts for suffusion-induced fine grain loss and permeability changes. The model implemented inside this code will have been carefully validated against experimental data to allow its practical use by dam and dike stakeholders.

Description of the post-doc
This post-doctoral position is devoted to step (iii), i.e. the experimental validation of the numerical models developed in steps (i) and (ii). To do so, we wish to work on specimens constituted of either glass beads or sand-gravel mixtures with different densities and different grain size distributions (GSD). Two types of GSDs will be studied: gap graded and upwardly concave GSDs as illustrated in Figure 1 (left, dotted line #4) since they are known to be susceptible to suffusion.

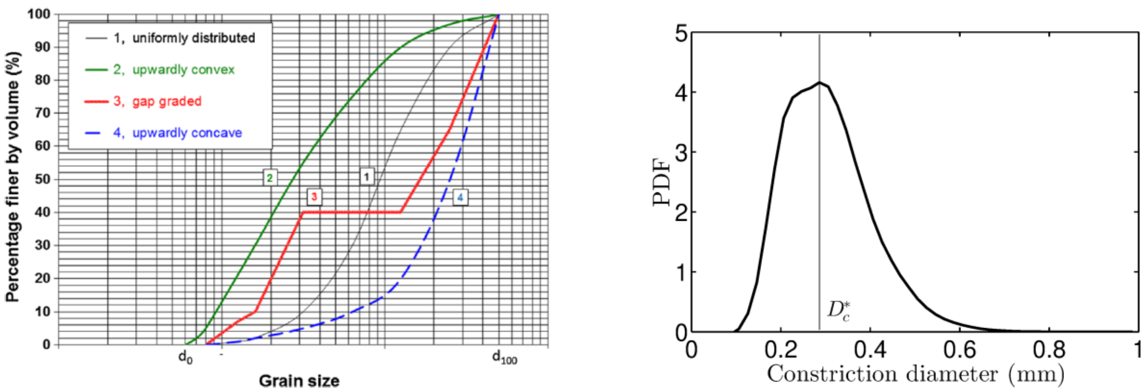

Figure 1: (left) Different GSDs of granular soils and (right) CSD in terms of the probability density function versus the constriction diameter for a gap graded numerical specimen

On these two types of GSDs, experimental tests will be carried out: (i) with no induced suffusion (Horikoshi and Takahashi, 2015) and (ii) by inducing suffusion up to the end of the phenomenon (Marot et al., 2016). During these tests, the (i) constant and (ii) evolving permeability will be recorded. In addition, tri-axial boundary conditions will be favored so that a small isostatic confinement can be applied to prevent the development of a preferential flow path between the soil specimen and the wall of the oedometric cell traditionally used. These conditions should limit the development of spatial heterogeneities in the radial direction. At the end of each suffusion test, several post-suffusion GSDs (possibly by layers) will be realized to precisely determine the final microstructural state of each specimen (Figure 2, left).

These GSDs may also be obtained during the development of the suffusion process, which implies in fact several tests since the acquisition of these GSDs is destructive. In addition, the GSDs of the eroded grains collected at the outlet may also be realized (Figure 2, right). In collaboration with step (ii), the probabilistic approach (Reboul et al., 2010; Seblany et al., 2021) will be used to estimate the CSD and its evolution based on the evolutions of the GSD and the relative density for each specimen. The parametrized model linking the CSD key characteristics and the permeability will be validated by comparing the predicted permeability against the measured one.

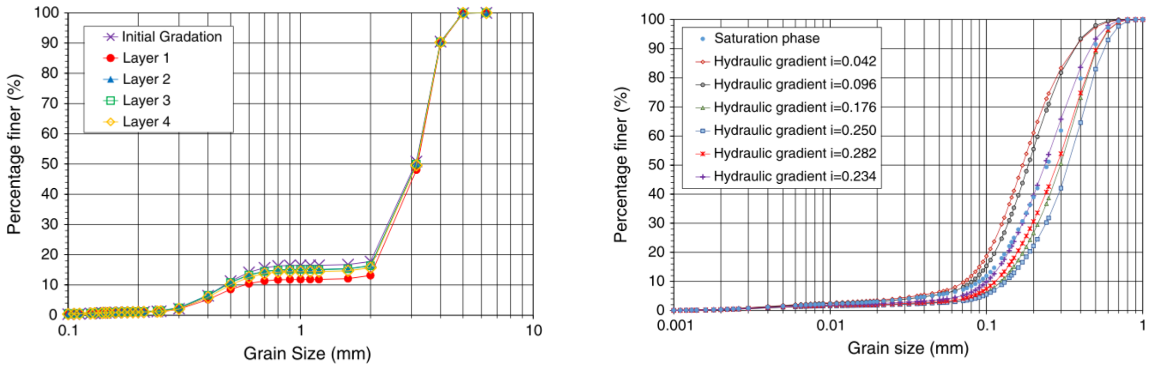

Figure 2: (left) Initial and post-suffusion GSDs by layers and (right) GSDs of eroded grains for the various applied hydraulic gradients, both from Zhong et al. (2018)

A PhD candidate is currently working on steps (i), (ii) and (iv). The post-doctoral fellow is expected to collaborate actively with the PhD candidate to validate the results of steps (i) and (ii) with the experiments realized for step (iii).

References

Bignonnet, F. (2020). Efficient FFT-based upscaling of the permeability of porous media discretized on uniform grids with estimation of RVE size. Computer Methods in Applied Mechanics and Engineering, 369, 113237.

Gelet, R., Kodieh, A., Marot, D., & Nguyen, N. S. (2021). Analysis of volumetric internal erosion in cohesionless soils: Model, experiments and simulations. *International Journal for Numerical and Analytical Methods in Geomechanics*, *45*(18), 2780-2806.

Gelet, R., & Marot, D. (2022). Internal erosion by suffusion on cohesionless gap-graded soils: Model and sensibility analysis. *Geomechanics for Energy and the Environment*, 100313.

Nguyen, N. S., Taha, H., & Marot, D. (2021). A new Delaunay triangulation-based approach to characterize the pore network in granular materials. Acta Geotechnica, 1-19.

Reboul, N., Vincens, E., & Cambou, B. (2010). A computational procedure to assess the distribution of constriction sizes for an assembly of spheres. Computers and Geotechnics, 37(1-2), 195-206.

Seblany, F., Vincens, E., & Picault, C. (2021). Determination of the opening size of granular filters. International Journal for Numerical and Analytical Methods in Geomechanics.

Keywords: Permeability, internal erosion, suffusion, tri-axial permeameter

Required skills

- Highly motivated by scientific research, serious, curious
- Tri-axial and/or permeability tests, internal erosion tests, solid background in soil mechanics
- Very good command in spoken and written English

Application procedure

Fill the application form to https://questionnaires.univ-nantes.fr/index.php/447573?lang=en

- Before proceeding, make sure you have the following files ready to upload in pdf format:
    - resume
    - cover letter
    - record of your academic grades (master)
    - PhD defense report (rapport de soutenance) if available
    - recommendation letter (optional)
- ➢ Please fill the form only once

Application deadline: November 12th, 2023