Stage MASTER 2

Academic Year: 2021-2022

Supervisors

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Location of internship
GeM, IUT de Saint-Nazaire

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

Description of the subject:

SOCIETAL CONTEXT: 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.

OBJECTIVES: During this internship, several numerical specimens will be modeled thanks to the Discrete Element Method, in order to better understand the physical links between pore space characteristics (Reboul et al., 2010; 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. Two types of GSDs will be studied: gap graded and upwardly concave GSDs since they are known to be susceptible to suffusion.

DEM: The method based on the Delaunay triangulation proposed by Nguyen et al. (2021) will be used to subdivide the pore space into pores and constrictions. A constriction is defined as the narrowest section of the channel between two neighboring pores. This method was found to be capable of giving accurate information on the pore size distribution (PSD) and the constriction size distribution (CSD) for materials under consideration. In addition, the controlling constriction size D_c^* (also called opening size) of the pore space can be determined by taking the largest mode of the CSD (Seblany et al., 2021).

HOM NUM: The full field homogenization technique (NUM HOM) presented by Bignonnet (2020) allows the permeability k_F to be precisely determined. The NUM HOM solves the steady-state Stokes flow of the fluid past the solid grains at the pore scale on the numerical specimen. The microstructure is discretized on a regular grid, like a 3D picture with either solid, fluid or interfacial voxels (3D pixels). For an imposed overall pressure gradient on the specimen, the flow problem is reformulated as an integro-differential equation whose primary unknowns are only the drag forces in voxels at the solid-fluid interface which are required to meet the no-slip boundary condition. The discretization of the integro-differential equation on a regular grid results in a linear system of equations which is efficiently solved by resorting to fast Fourier transforms and an iterative solver. The direct outputs of the simulation are the local drag forces acting on the grain surface as well as the homogenized permeability k_F. Importantly, these drag forces will be directly used in the DEM to update the grains' position.

COUPLAGE DEM-HOM NUM: The coupling of these two numerical methods can be performed in an incremental manner as presented in Figure 1. (i) For each increment, the DEM gives the radii and the positions of all solid grains at instant t and the CSD of the specimen is determined. (ii) A computation is performed with the NUM HOM to determine the permeability and drag forces exerted by the fluid flow on the grains. (iii) Next, these drag forces are inserted in the DEM and the positions of the grains are integrated up to instant t + dt. Finally, the microstructure of the specimen is updated and the next increment is handled. By doing so, the microstructure and the permeability evolve during the suffusion process.

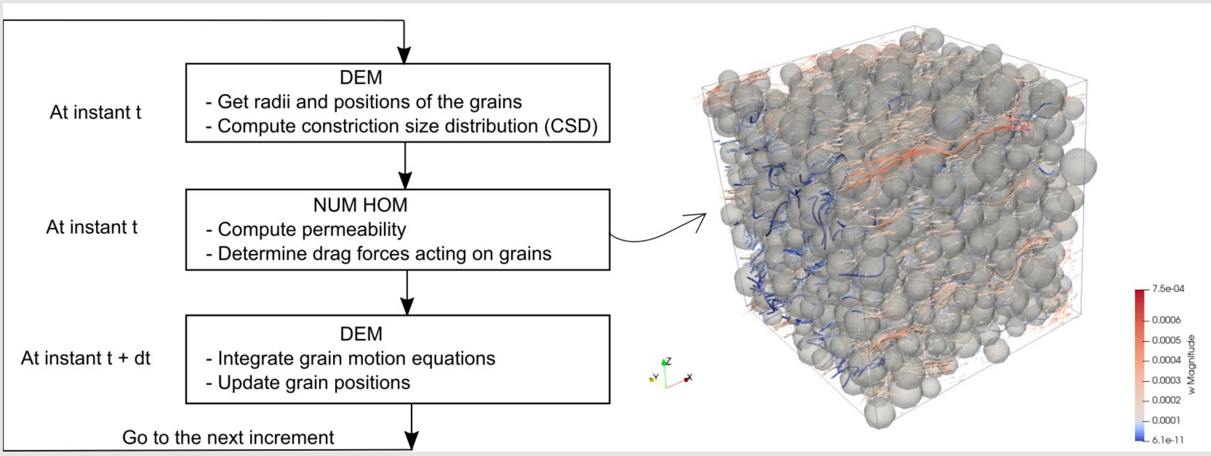

Figure 1: Coupled DEM and NUM HOM methods to study the link between the evolution of the permeability and the evolution of the micro-structure.

FINANCIAL CONTEXT: This internship is part of a broader ANR project (February 2022 to January 2026) organized in 4 work packages and involving five numerical methods along with experimental tests. To fulfil this project, one Master student, one PhD student (starting October 2022) and one post-doctorate fellow will be recruited (Starting January 2024).

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.

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.

Key words

Permeability, discrete element method, homogenization, internal erosion, suffusion

Required skills

- Highly motivated by scientific research, serious, curious
- Continuum mechanics, Homogenization, Numerical modeling, Constitutive laws

Additional information

Duration of the internship: 6 months
Internship scholarship: Yes
Amount: In accordance with the French legislation
PhD opportunity after this internship: YES (ANR project)
Other useful information (housing, ...)?
Possibility to provide a financial help regarding travelling costs