<u>Two-year</u> post-doctoral position

Constitutive laws for partially saturated granular materials via thermodynamics-based artificial neural networks trained on GPU DEM-LBM simulations

The LaSIE lab from La Rochelle university in collaboration with INRAE and ENSTA, member of the Institut Polytechnique de Paris, are pleased to invite applications for a postdoc position on the development of innovative constitutive models for partially saturated granular materials.

This postdoc proposal is part of the project SolMar supported by the French Region Nouvelle Aquitaine and the R&D program of the French bureau for natural hazards prevention (DGPR) related to the safety of dikes and dams. In a context of global change, the project targets a better understanding of the behavior of maritime dikes subjected to more intense wetting-drying cycles.

Within this project, the postdoc will aim at:

i) using the GPU accelerated DEM-LBM code developed in LaSIE (Younes et al. 2022 and 2023; Bouchard et al. 2024) to construct extensive databases of the material behavior

ii) developing and extending the currently existing Thermodynamics-based Articificial Neural Networks (TANN) framework to transfer transfer the microscale physics captured from DEM-LBM simulations to constitutive modelling at the engineering scale.

Context and objectives

Granular soils display intricate behavior due to their discrete composition, rendering their mechanical properties inherently complex. Under partially saturated conditions, this complexity is further amplified by the existence of capillary effects, challenging the effectiveness of traditional constitutive models usually developed for dry or fully saturated conditions. However, for a wide class of situations, accounting for varying degree of saturation is essential to accurately analyze and predict the mechanical behavior and stability of granular soils. In particular, for the design of maritime dikes, it is crucial for engineers to develop accessible and practical constitutive models to account for wetting and drying cycles at the structural scale.

Recent work from the supervision team has demonstrated the potential of the multiphase Lattice Boltzmann method (LBM) coupled to the Discrete Element Method (DEM), to capture the increase and loss of cohesion in granular soils when water content increases from dry to fully saturated conditions. The multiphase LBM-DEM coupling code developed in the project StabDigue leaded by Olivier Millet enables to capture regime transitions in partially saturated porous media from pendular to capillary regimes (Younes et al. 2022 and 2023; Bouchard et al. 2024). However, numerical calculations remain intensive (even with the use of GPU), which prevents simulating the mechanical strength and associated stability of a partially saturated granular soil at the engineering scale.

The optimized coupled LBM-DEM code should enable to construct a large database for the behavior of granular materials of varying water content for different grain size distributions and contact law properties (objective i). Such database will be constructed either directly at the representative elementary volume scale with several thousands of grains or (most likely) for collections of representative mesostructures of a few grains. Several mechanical and hydraulic loading paths will be considered through directional analyses.

The above-mentioned database will then be utilized to derive the constitutive behavior of partially saturated heterogeneous granular soils undergoing wetting and drying cycles using Machine Learning (ML). Different from phenomenological models, we will derive the constitutive behavior of the material using thermodynamics-based artificial neural networks - TANN (objective ii). TANN, trained on the previously established database, can play a central role in this scale-shifting process and identify the fundamental state variables of the system. This important part of the work will benefit from the expertise of Ioannis Stefanou regarding TANN and ML and the ongoing MiMoDiM project leaded by Antoine Wautier developing new classes of multi-scale models that can be adapted to partially saturated materials.

As a perspective, the proposed models may be implemented in continuum scale methods such as the material point method (MPM) or the finite element method (FEM) to address engineering scale problems.

Postdoctoral Supervisors

- **Olivier Millet**, University of La Rochelle (France)
- **Antoine Wautier,** INRAE Aix-en-Provence (France)
- **Ioannis Stefanou**, ENSTA Paris (France)

Student Requirements

Applicants should hold a PhD degree in engineering or applied mathematics, with a strong background in

- Continuum mechanics
- Applied and computational mechanics
- Programming in Python and/or C++

while skills in Machine Learning will be highly appreciated.

Terms and contract

The successful postdoctoral candidate will be employed by La Rochelle university. They will benefit from a 12-month renewable contract, scheduled to start between October 2025 and December 2025. A renewal for additional 12 months is possible, leading to a total of 2 years. The gross salary is expected to be around 2800€ depending on previous experience.

Working environment

The Postdoc candidate will benefit from the very active International Research Network (IRN GeoMech), focused on Multi-Physics and Multi-scale Couplings in Geo-environmental Mechanics, leaded by Olivier

Millet (LaSIE-CNRS). The collaborative framework, between La Rochelle University, INRAE Aix-en-Provence and ENSTA Paris, ensures a robust academic foundation and the partners of SolMar will root the scientific work into important societal issues related to maritime dike stability and durability.

Application

Applicants should submit a CV and a cover letter (in English or French) describing interests and qualifications related to the position and the contact details of two people who can provide references. Inquiries and applications should be sent by email to:

- **Olivier Millet**: olivier.millet@univ-lr.fr
- **Antoine Wautier**: antoine.wautier@inrae.fr
- **Ioannis Stefanou** : ioannis.stefanou@ensta.fr

Selected references related to the postdoc subject

N. Younes, Z. Benseghier, O. Millet, A. Wautier, F. Nicot, R. Wan: Phase-field Lattice Boltzmann model for liquid bridges and coalescence, Powder Technology, Volume 411, 2022.

N. Younes, A. Wautier, R. Wan, O. Millet, F. Nicot, and R. Bouchard. "DEM-LBM coupling for partially saturated granular assemblies." Computers and Geotechnics 162 (2023): 105677.

R. Bouchard, N. Younes, O. Millet, A. Wautier (2024): Parameter optimization of phase-field-based LBM model for calculating capillary forces, Computers and Geotechnics, Volume 172, August 2024, 106391

M. Miot (2021) Multi-scale modelling of the mechanical behaviour of unsaturated soils. PhD thesis, Ecole Doctorale 353 – Sciences pour l'ingénieur : mécanique, physique, micro et nanoélectronique.

N. Younes (2023) Etude micromécanique de la transition des régimes hydriques dans les sols granulaires partiellement saturés. PhD thesis, Ecole Doctorale EUCLIDE 618.

Piunno, G., Stefanou, I. & Jommi, C. (2024), A POD-TANN approach for the multiscale modeling of materials and macroelement derivation in geomechanics, accepted, Numerical and Analytical Methods in Geomechanics, https://doi.org/10.1002/nag.3891

Masi, F. and Stefanou, I. (2023), Evolution TANN and the discovery of the internal variables and evolution equations in solid mechanics, Journal of the Mechanics and Physics of Solids, 174, https://doi.org/10.1016/j.jmps.2023.105245

F. Masi, I. Stefanou, I. (2022). Multiscale modeling of inelastic materials with Thermodynamics-based Artificial Neural Networks (TANN). Computer Methods in Applied Mechanics and Engineering, 398, 115190.

F. Masi, I. Stefanou, P. Vannucci, V. Maffi-Berthier (2021). Thermodynamics-based artificial neural networks for constitutive modeling. Journal of the Mechanics and Physics of Solids, 147, 104277.

H. Xiong, Z.-Y. Yin, F. Nicot, A. Wautier, M. Marie, F. Darve, G. Veylon, and Pierre Philippe. A novel multi-scale large deformation approach for modelling of granular collapse. Acta Geotechnica, 16:2371–2388, 2021.

A. Wautier, A. Li, W. Qu, M. Pouragha, F. Nicot. Multiscale modeling of granular materials using mesoscale dem and machine learning approaches. In IOP Conference Series: Earth and Environmental Science, volume 1480, page 012048. IOP Publishing, 2025.

M. Miot, G. Veylon, A. Wautier, F. Nicot, P. Philippe. Calculation of capillary forces in a mesoscale assembly of grains. In 24ème Congrès Français de Mécanique.

Deadline for Application : 15 September 2025