

Funded PhD project proposal

Multi-scale Investigation of Degradation Processes in Cemented Granular Materials

X-ray and Neutron Tomography; double-scale FEMxDEM coupling

Context: Cemented granular materials, ranging from sandstones to grouted sands, are ubiquitous in natural and engineered environments. The three main micro-mechanical processes governing the degradation of these highly heterogeneous materials are commonly identified as (i) cement damage, (ii) grain crushing and (iii) fragment rearrangement. Recently, micro-inspired constitutive models (e.g. [1,2,3]) aim to acknowledge this connection by including internal variables representing these processes influencing the macroscopic response of the material. Nonetheless, experimental validation by quantitative characterization of cement damage processes and its evolution in time and space cannot be fully captured and quantified by X-ray tomography (CT), currently the most used non-destructive technique in laboratory geomechanics. While X-ray CT provides useful information on the degradation process, a clear distinction of cement and grain damage requires the acquisition of complimentary 3D image modalities.

Project Proposal: A novel approach to this problem consists in complementing the use of X-ray imaging with Neutron tomography. Neutron flux attenuation is sensitive to different chemical species inside a material and can therefore reveal highly complementary and rich information about the degradation at the cement bridge sites. The candidate will focus on the design, performance, and analysis of experimental campaigns where triaxial loading of an artificial sandstone is performed while acquiring X-ray and neutron CT simultaneously. The rich dataset will enable a comparison of different types of cement, grain surface bonding effect and grain properties. The candidate will study the relationship between damage distribution and its evolution on the material response, by using advanced segmentation, correlation and image analysis tools. (Fig.1)

Complementarily to the experimental work, the candidate will be conducting a multi-scale numerical study on the degradation process of cemented granular materials. This numerical part will be performed within the framework of a multi-scale approach, combining the discrete element method (DEM), considering the granular microstructure, and the finite element method (FEM) representing the macro (sample or structural) scale. In this spirit, a double-scale framework is operational and continuously developed at the 3SR laboratory [4]. The candidate is expected to learn about the approach and take part in developments pertaining to the current project. Advances will be made on the following topics: creation of tomography based numerical periodic microstructures, integration of particle fragmentation, enrichment of contact laws to consider realistic bond damage, spatial analysis of microstructure evolution. (Fig.2)

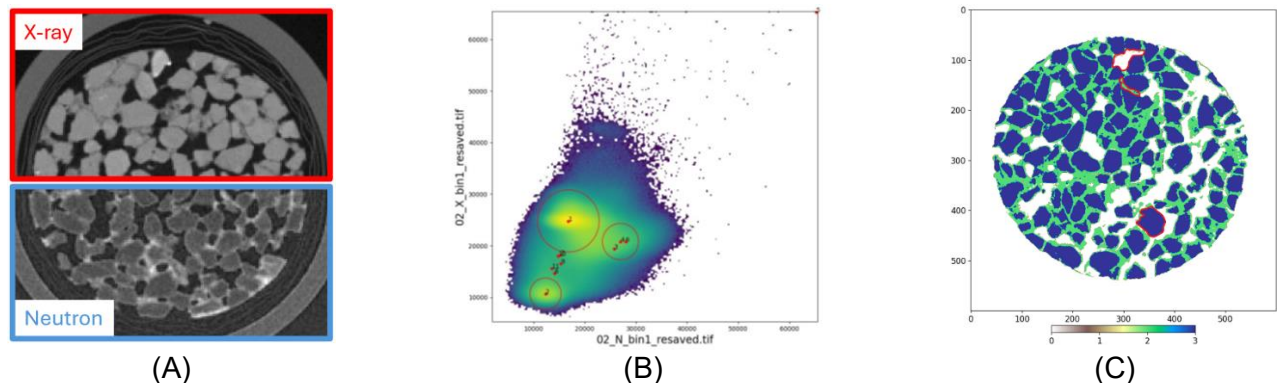


Fig.1 Complementarity of X-ray and Neutron imaging modalities: 3D reconstructed image (A), jointed histogram for multi-modal registration and phase identification (B), segmented grains and cement phases (C).

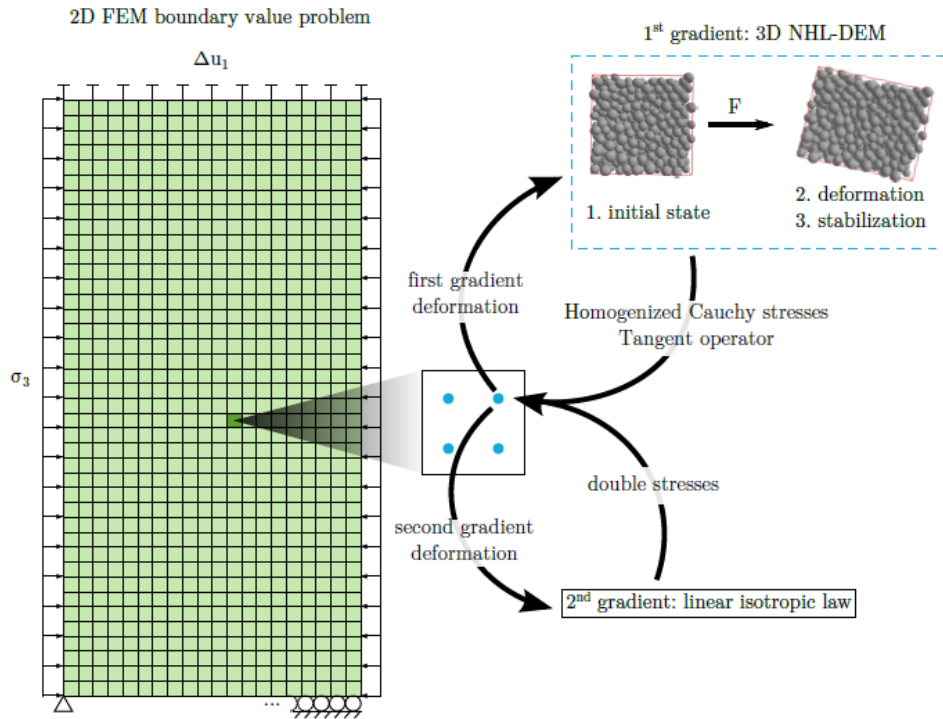


Fig.2 Schematic of the double scale FEMxDEM model in a first and second gradient scheme.

Candidate Skills: The candidate should have a background in civil/mechanical engineering, material science or applied mathematics. The ideal candidate has experience and can be autonomous in generating/analyzing experimental data (imaging methods, instrumentation, sample preparation ...). Good programming skills and familiarity with scientific languages is an asset (C/C++, Matlab, Python, Julia, ...). Additionally, a strong interest and experience in using and developing numerical frameworks and/or constitutive models are highly desirable. Strong oral and written English communication skills are required.

Location: 3SR laboratory, Université Grenoble Alpes (UGA), Grenoble, France.

Start date: December 2025

Application: Open August 26th 2025, until a suitable candidate is selected.

Contact: To apply please send an email to Alessandro Tengattini (alessandro.tengattini@3sr-grenoble.fr), Cyrille Couture (cyrille.couture@3sr-grenoble.fr) and Cino Viggiani (cino.viggiani@3sr-grenoble.fr).

References

- [1] Tengattini, Alessandro, et al. "A thermomechanical constitutive model for cemented granular materials with quantifiable internal variables. Part I—Theory." *Journal of the Mechanics and Physics of Solids* 70 (2014): 281-296.
- [2] Das, Arghya, Alessandro Tengattini, Giang D. Nguyen, Gioacchino Viggiani, Stephen A. Hall, and Itai Einav. "A thermomechanical constitutive model for cemented granular materials with quantifiable internal variables. Part II—validation and localization analysis." *Journal of the Mechanics and Physics of Solids* 70 (2014): 382-405.
- [3] Rossi C., Tengattini A., Viggiani G. (2024) – A constitutive model for lightly cemented granular materials. *Computers and Geotechnics*, Volume 174, October 2024, 106550.
- [4] Desrues, Jacques et al. "From discrete to continuum modelling of boundary value problems in geomechanics: An integrated FEM-DEM approach". *International Journal for Numerical and Analytical Methods in Geomechanics*, 43 (2019) 919–955.