PhD position at Univ Gustave Eiffel/ANDRA

Modeling and Simulation of Hydrogen Transport and Damage in Clay Rocks

Context

In the context of radioactive waste disposal, the excavation of underground galleries induces a redistribution of stresses and pore pressure, which may lead to the formation of cracks and fractures in the immediate vicinity of the cavities, particularly in clay rocks. This phenomenon results in the development of an Excavation Damaged Zone (EDZ), characterized by significant changes in the hydromechanical properties of the rock. In addition, deep clay formations exhibit time-dependent behavior, mainly governed by creep.

Alongside the presence of groundwater, after repository closure, an increase in gas pressure—predominantly hydrogen produced by anoxic corrosion of metals (waste, containment materials, steel reinforcements)—is observed, potentially reaching several MPa. The formation of the damaged zone around underground structures and its evolution over time, particularly during gas pressurization, are processes that must be accurately modeled to demonstrate repository integrity over timescales of several thousand years.

Objectives

The objective of this PhD thesis is to model the formation and evolution of fractures around radioactive waste disposal galleries, from the excavation phase through to the post-closure phase. A numerical modeling and simulation approach based on the nonlinear poromechanical (hydromechanical) behavior of fractured two-phase media will be adopted. This approach will account for damage (via the phase-field method), plasticity, and permeability evolution as a function of damage. The evolution of the deformation state of the rock surrounding the disposal galleries during the different phases—excavation, operation, and post-closure—will be simulated. Immediately after repository closure, ventilation will stop and resaturation of the EDZ will occur. The combination of resaturation and mechanical consolidation of the EDZ by the lining/support induces a fracture self-sealing phenomenon. This phenomenon will be included in the simulations to accurately assess the behavior of the fractured zone under hydrogen generation.

Expected Work and Outcomes

The MSME laboratory (https://msme.univ-gustave-eiffel.fr/) has been recognized for many years in the field of modeling and numerical simulation of material behavior. Advanced computational tools and codes for fracture simulation, based on the Finite Element Method (FEM) and the Fast Fourier Transform (FFT), have been developed there. Within this PhD project, the following work is planned:

- Development of a fracture model coupling poroelasticity, plasticity, viscoplasticity and possibly shear friction. Implementation in in-house numerical simulation codes; benchmarking and comparison of different methods.

- Excavation and operational phases: construction of a gallery–rock model and simulation of elastoviscoplastic damageable behavior (phase-field model) and two-phase transport (water and hydrogen). Quantitative study of the evolution of crack networks in the rock and of permeability.
- Post-closure phase: simulation of hydro-mechanical–gas coupling, in particular the effect of hydrogen transport in the fractured medium on the evolution of the EDZ.

Candidate Profile

The candidate should hold a research Master's degree (or equivalent) at the start date of the PhD. Strong knowledge in solid mechanics is required, as well as numerical simulation skills with programming experience. Background in damage modeling, fracture mechanics, or transport in porous media will be appreciated.

Funding: The PhD candidate will be employed by ANDRA (French National Radioactive Waste Management Agency).

PhD location

The PhD will be carried out at the MSME laboratory, Université Gustave Eiffel, Marne-la-Vallée campus, 5 Bd Descartes, 77454 Marne-la-Vallée Cedex 2, France. Occasional visits will be organized to ANDRA, 1 Rue Jean Monnet, 92290 Châtenay-Malabry (headquarters), and to the Underground Research Laboratory, Bure, 55290 (RD960), France.

Planned start date: October 2026.

Supervision

Quy-Dong To, Associate Professor (HDR), Université Gustave Eiffel, MSME
Julien Yvonnet, Full Professor, Université Gustave Eiffel, MSME
Vu Minh Ngoc, ANDRA
Jean Talendier, ANDRA

Application documents to be provided

- A recent CV
- The most recent academic transcripts (M1/M2 or equivalent)
- A letter of recommendation, preferably from the M2 internship/final project supervisor or from a program director
- Send all documents as a single file to quy-dong.to@univ-eiffel.fr