# PhD thesis proposal

# Study of the interactions between initial and acquired heterogeneities of geomaterials in a strain localisation context

## General informations:

**Research Unit:** 3SR Lab. (UGA, CNRS and Grenoble INP joint unit), Grenoble, France.

**Research group:** Geomechanics (webpage)

**Thesis supervisors**: Pierre Bésuelle (senior research prof., CNRS) & Quentin Rousseau (associate prof., Grenoble-INP)

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**Keywords**: Strain localisation, Acquired heterogeneities, Natural heterogeneities, Spatial variability, Enriched models, Rocks

**Starting date**: October 1st, 2023 | **Deadline for application:** april 30th, 2023

## Summary of the PhD project:

To mitigate the climate change requires the activation of several levers. One of the most important is the use of low carbon energies, as for instance hydropower and nuclear energies. However, to ensure the sustainability of the hydraulic structures that produces this energy, or even that of the underground nuclear wastes storage facilities (which is one of the major potential wastes storage solutions), engineers need to design the structures by accounting for a detailed knowledge of the hydro-mechanical behaviour of the natural materials in the direct neighbourhood of the structures. The storage of renewable energies is as well an important challenge. The deep underground storage of dihydrogen, produced by water electrolyse, appears to be a promising technique, but requires to guarantee the perennity of the storage welbore as well as the ability of the reservoir caprock to maintain a low permeability even after being subjected to high pressure levels. This PhD proposal aims to enhance the understanding of the hydro-mechanical behaviour of the abovementioned natural materials, with a particular focus of the effects of initial heterogeneities on the global response of a geostructure, particularly in terms of strain localisation.

The post-failure behaviour of the geomaterials is characterised by the emergence of kinematics heterogeneities acquired in the form of specific deformation patterns called shear bands. Although it is now well known, especially through numerical modelling of boundary value problems, that initial heterogeneites (in the form of non-homogeneous mechanical properties) can play a major role on the strain localisation pattern, the quantitative assessment of this influence still suffers lacks. The research works proposed in this project address the issue of the interplay between initial heterogeneities and the localised mechanical response of a natural material.

First, aiming at characterizing the non-uniformity of different rocks, the analysis and modelling of the spatial variability of laboratory samples captured *via* microscopic and tomographic techniques, will be carried out using geostatistical methods. In addition with the information collection on the spatial correlation of the microstructure properties of the targeted materials (the Vosges sandstone, the Callovo-Oxfordian Clayrock and the Tournemire clay), we will be able to reconstruct fields with heterogeneities equivalent to those of the natural materials by Random Field simulation or kriging. For the Vosges sandstone, the interest will be focused on porosity. For the clayrocks, we will focus on the mineralogy as well as the geometrical description of the mineral inclusions imbedded in the clay matrix.

Then, the aquired heterogeneities due to strain localisation will be analysed in the light of geostatistics. This will allow to enlight non-conventional localisation precursors, based on the precise quantification of the loss of uniformity of the mechanical response and on the spatial correlation of the kinematical fluctuations of the medium. Moreover, using multivariate geostatistics, we will conduct a robust quantitative analysis of the correlations between initial and acquired heterogeneities.

For the mechanical simulations, the heterogeneities will be described using the kriging method and incorporated to the boundary value problem *via* the constitutive laws parameters. First, for the Vosges sandstone, the heterogeneities of the pore space will be taken into account by a phenomenological poro-elasto-plastic constitutive model. For the clayrocks, the microstructure heterogeneities will be taken into account explicitly by using a double scale model in the context of a computational homogenisation scheme ($FE^2$). This will allow to model the initiation of strain localisation, possibly reproducing the recently observed experimentally early diffuse localisation phenomenon, and the modelling of the post localisation response of the material. By isolating the key parameters of the spatial variability model (*e.g.* fluctuation scale), a parametric study will be carried out and will exposes the implication of the spatial variability on the bifurcation mode and the eventual competition between the fluctuation scales and the geometric characteristic quantities such as thickness and orientation of the shear bands. These investigations will be conducted on boundary value problems with initial homogeneous stress conditions (*e.g.* reproducing laboratory test) or problems with initially heterogeneous stress distributions, inducing stress concentration regions with various symmetries. The non-uniqueness of the solutions then determined will be studied.

Finally, the project will switch to the engineering scale, this time simulating the response of a massive geological structure to the excavation of a gallery. Comparisons with simulation results obtained on homogeneous and heterogeneous geological structures will allow the contribution of the initial large-scale heterogeneities on the determination of the localisation pattern in the Excavation Damage Zone (EDZ) to be quantified. Special investigations on the competition between characteristic scales (*e.g.* internal length of an enriched medium), the fluctuation scale and the non-uniformities of the stress field will be addressed.

## Additional informations:

**Profile**:

The candidate must have a master degree or equivalent, related to one (or more) of the following fields: mechanics, computational mechanics, geomechanics, civil engineering. The candidate should show a proper knowledge of the classical continuum mechanics (kinematics, dynamics and boundary value problems) and the constitutive modelling (elasto-plasticity for instance). Abilities to use the finite element method to solve an elementary boundary value problem are required. Programming skills (Python and/or Fortran) will be appreciated, as well as the ease at using Linux systems.

**Documents required for application**:

Curriculum vitae, cover letter, master degree transcript. Recommendations letters will be appreciated.

**Gross salary**: 1.975€/month