PhD position 2020 – 2023

Numerical modeling of fracturing of a clay-rich rock under gas overpressure

Host laboratory: LISN CEA Paris-Saclay and LMT ENS Paris-Saclay

Advisor: François Hild (LMT), co-advisor: Darius Seyedi (CEA/LISN)

1. Context:

The Cigeo project is the French plan for a deep disposal center for radioactive waste. The excavation operations induce a network of fractures around the repository structures, which are to be built in the framework of the Cigeo project within the Callovo-Oxfordian claystone (COx) considered as a potential host geological formation. The geometry and extent of these fracture networks have been widely studied by Andra around the structures of the Underground Research Laboratory in Meuse/Haute-Marne (Armand et al., 2014).

Corrosion of metallic materials used for the disposal and radiolysis of water by organic materials produce gases, mainly hydrogen. The accumulation of gas and its pressurization may affect the hydromechanical behavior of the fractured zone around the structures. Andra has been conducting research since 2003 to study the effects of gas pressure increase. In this context, some gas fracturing tests were carried out in a vertical borehole, drilled from the surface, and in boreholes drilled in the URL.

The main goal of the present research work is to develop models and numerical tools capable of modeling the fracturing of claystone due to gas overpressure. Particular attention will be paid to the influence of the anisotropy of the claystone on the initiation and propagation of fractures.

2. Research program

The proposed research program concerns two main tasks; experimental and numerical.

Experimental investigations

The main objective is to study the influence of the anisotropy of COx on the initiation and propagation of fractures. The proposed project also intends to benefit from numerous experimental campaigns already carried out by Andra. The main tasks are:

- Synthesis of available experimental data on failure parameters
    - Fracture toughness, tensile strength
- Performing new tests
    - Investigation of the anisotropy of toughness
    - Experimental study of crack propagation in different directions

The toughness of a material represents its ability to resist against the propagation of cracks. It is proposed to identify the toughness of COx using three-point bend tests on pre-cracked beams taken in different directions. To our knowledge, this type of test has never been carried out on COx specimens. Pre-cracking a brittle material requires special attention. It will be carried out using a specific experimental configuration known as sandwich-beam set-up (Fig. 1). Digital image correlation will be used for the detection of the crack and for the follow-up of its propagation.

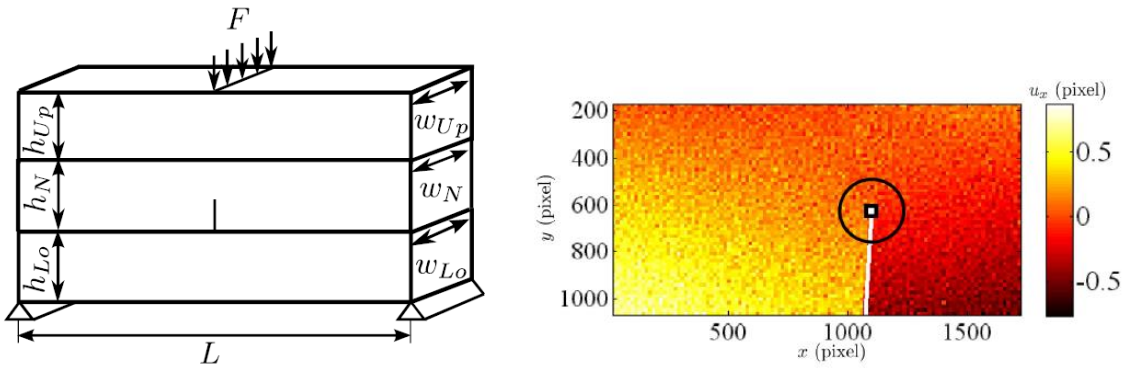

Figure 1. Sandwich-Beam test in which the rock sample is loaded with two aluminum alloy beams (left). Measured horizontal displacement field (expressed in pixels) when rigid body translations have been removed (right), after Guy et al. (2018)

Development of an anisotropic fracturing model

A probabilistic model has already been developed to take into account the effect of the heterogeneity of the material on its damage and cracking (Guy et al., 2012). Two different thresholds, both based on a regularized stress, have been used for the initiation and propagation of cracks. The developed stress regularization operator not only makes it possible to obtain mesh-objective results but also to calculate directly the value of the stress intensity factor without any mesh refinement. The model also allows the opening of each crack to be calculated. The permeability of a fractured element can thus be assessed based on crack openings. This model was then extended to take into account hydromechanical couplings through the concept of effective stress (Seyedi et al., 2013).

This model will be extended to anisotropic media. First, the effect of elastic anisotropy on initiation and especially propagation of cracks will be taken into account. It can be shown that elastic anisotropy can introduce propagation in mixed mode even when the crack is loaded in pure mode I. One can expect this effect to influence the direction of crack propagation. A hydromechanical coupling scheme in which the hydraulic and mechanical equations are solved separately will then be used. The coupling is ensured through the influence of each phenomenon on the control parameters of the other. Such a scheme allows (i) complex models to be considered for each phenomenon; (ii) the necessary numerical implementations to be optimized.

The developed model will be used to simulate existing in situ tests and to study different conditions for initiation and propagation of gas fracturing.

3. Funding

A funding request will be submitted within the call for applications launched by the French National Agency for Radioactive Waste Management (Andra).

4. Application

The applicant must hold a Master degree or equivalent in the field of solid mechanics or civil engineering. Interested applicants are invited to send a CV, a cover letter and their transcripts to François Hild (francois.hild@ens-paris-saclay.fr) and Darius Seyedi (darius.seyedi@cea.fr) by 27 March 2020.

5. References

Armand, G., Leveau, F., Nussbaum, C., de La Vaissiere, R., Noiret, A., Jaeggi, D., Landrein, P. Righini, C. (2014). Geometry and properties of the excavation induced fractures at the Meuse/Haute-Marne URL drifts. *Rock Mech. Rock Eng*., 47, 21-41. DOI:10.1007/s00603-012-0339-6.

Guy N, Seyedi D.M., Hild F, (2018) "Characterizing fracturing of clay-rich Lower Watrous rock: From laboratory experiments to nonlocal damage-based simulations", *Rock Mechanics and Rock Engineering.* DOI : 10.1007/s00603-018-1432-2.

Guy N., Seyedi D.M., Hild F. (2012) "A probabilistic nonlocal model for crack initiation and propagation in heterogeneous brittle materials", *International Journal of Numerical Methods in Engineering*, **90**, pp 1053-1072. DOI: 10.1002/nme.3362.

Seyedi D.M., Guy N., Sy S., Granet S., Hild F. (2013) "A non-local damage model for heterogeneous rocks – application to rock fracturing evaluation under gas injection conditions", In *Geomechanics in CO_2 Storage Facilities*, Pijaudier-Cabot G., Pereira J.M., Eds., p. 59-73, John Wiley & Sons, Inc., Hoboken, NJ USA. DOI: 10.1002/9781118577424.ch4.