PhD in numerical modeling of the interplay between fluid flow and faults in deep fractured reservoir: implications for induced seismicity, at ITES/EOST Strasbourg (France)

General information

Workplace : Strasbourg, France – visiting periods at TNO (Utrecht, the Netherlands)
Type of Contract : PhD Student contract / Thesis offer
Contract Period : 36 months
Expected date of employment : 1 September 2024
Proportion of work : Full time
Supervision: J. Schmittbuhl (DR CNRS at Strasbourg University), T. Candela (Senior Scientist at TNO, The Netherlands)
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Missions

The objective of this PhD is to address fluid induced seismicity with a focus on the hydro-mechanical behavior of faults. Faults act indeed as major conduit during injection of fluids in the subsurface but faults also host earthquakes. In the recent years, substantial research progresses have addressed the role of pre-existing faults on the remote triggering of seismicity but little have considered the complexity that lies in the multiscale roughness of faults which controls both fluid flow and slip. This PhD position on induced seismicity aims at jointly assess the hydro and mechanical behavior of a multi-scale deformable rough fault during fluid injection. Foreseen new findings should help to reconciliate our physical models with currently unexplained observations, such as unexpected large, remote or delayed triggered seismicity when reservoirs are initially very close to failure pre-injection. Applications to the case of the deep geothermal sites (Vendenheim, Balmatt, Rittershoffen) will be considered.

Activities

The recruited PhD researcher will:

- Develop numerical (3DEC, ITASCA for Discrete Element approach and MOOSE/GOLEM for Finite Element approach) and analytical hydro and mechanical forward models of a deformable fault with multi-scale asperities in the context of EGS reservoir fluid injection.
- Implement inverse scheme to assimilate real observations and calibrate the forward models.
- Present, publish (ISI peer-review) and communicate research results at scientific meetings and in scholarly journals.

Skills

The recruited PhD researcher must have:

- Strong skills in numerical simulation
- Knowledge of geophysics, seismology, geomechanics or geothermal systems will be considered a strong additional asset
- Proficiency in English level C2 (according to the European Framework for languages)

Work context

Understanding how the injection of fluids in the crust is linked to the occurrence of earthquakes is of primary importance for the assessment of induced seismicity. Faults provide major conduits at all scales through which fluids can flow and impact the mechanical behavior of fractured rock masses. Subsequently, the hydromechanical behavior of faults is of central importance for determining the transport and deformation properties of faulted reservoirs leading to induced seismicity. In this project, the candidate will focus on the hydromechanical behavior of a single fault. More specifically, he/she will study through his/her PhD project, the coupling between pressure and opening during fluid migration along the fault and the conditions for departure from linear pressure diffusion. The project relies on the recent results of two PhD theses recently defended within the ITI GeoT program at Strasbourg University (https://geot.unistra.fr/): a) Qinglin Deng who modeled the fluid pressure propagation in a rigid rough fracture using the finite element code MOOSE (Deng et al, 2021) and the permeability and stiffness evolution of a deformable rough fracture and b) Dariush Javani who modeled with the distinct element code 3DEC (Itasca), the pressure front propagation in a large fracture of the Soultz-sous-Forêts reservoir for different injection rates. The objectives of the project is to link approaches that have been addressed separately up to now: implementation of multiscale fracture roughness geometry in fluid flow modeling; implementation of elastic behavior of the matrix during deformation of the asperities to account for non-linear stiffness effect; implement Darcy (and in a second step, Navier-Stokes) flow in the fracture opening and in the matrix porosity; monitoring of the opening and slip histories along the fault; comparison of finite element (MOOSE) and distinct element (3DEC) methods ; elastic stress redistribution caused by earthquakes or aseismic slip along a rough fault; interpretation in terms of fault permeability evolution and induced seismicity. The core of the work will be to reexplore the fundamental work of Murphy et al, 2004 who proposed semi-analytical solutions for the fluid flow in rock joints with pressure-dependent openings. The present project will aim at extending their formulation for a multiscale fault roughness which was not tackled and will be a significant departure because of the impact of the fault roughness on the fluid channeling and on the stress-dependent behavior of the fault stiffness. The present project is a fundamental research project but is addressing basic physical phenomena that are poorly known and strongly involved in remote triggering of the seismicity like in the case of the remote triggering at Vendenheim site in Nov 2019 where seismicity has been triggered 4-5km to the injection wells without seismicity in between.

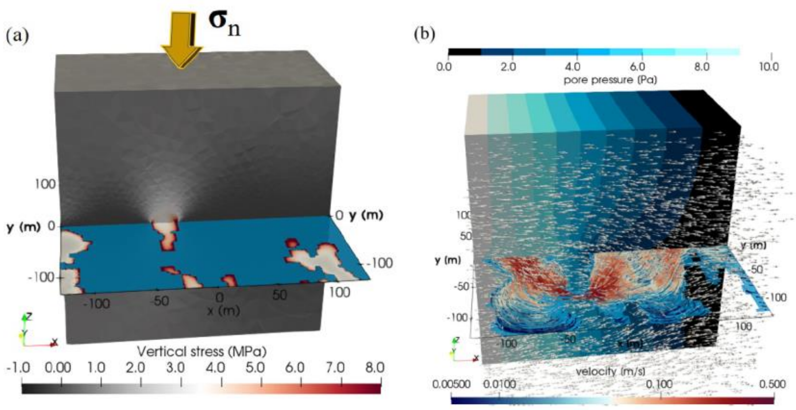

Figure : Sketch of the MOOSE/GOLEM model: a partially open fault (colored horizontal cross-section) is embedded in a 3D block (in dark gray) of size 256 × 256 × 256 m^3 loaded by a normal stress σ_n. (a) The contact areas (in light gray) along the fracture support the applied normal stress with variable local amplification of the stress (reddish zones). The open part of the fracture where fluid circulates is shown in blue. (b) 3D view of the fluid circulation in the fracture (colored horizontal cross-

section) and in the pore space of the matrix (white arrows) when a pressure drop is applied in the x-direction (the vertical thick, blue layers indicate the pressure field in the matrix). The contact areas are transparent here.

The PhD research will be conducted within ITES/EOST Strasbourg (France) and in collaboration with TNO (Utrecht, the Netherlands). It will be part of the ITI GeoT program for the role of deep fluid in the energy transition (https://geot.unistra.fr/).