University of Poitiers, IC2MP Laboratory (France)

Call for Applications: 18 month post-doctoral position in Geomechanics

Numerical modelling of hydraulically induced damages and crack propagation under partially-saturated conditions

Context: Although numerous studies have been successful in the modeling of hydro-geomechanical behavior of fractured rock masses, challenges still remain for achieving a precise description of the coupled processes involved as well as for determining the effective hydromechanical (HM) properties of the considered medium. The ANR-funded collaborative project called HydroGeoDam aims at improving our understanding of the HM processes taking place in the subsurface for a better assessment of the associated risks and at proposing non-intrusive methods to help assess these processes. Development of efficient HM numerical models to improve the description of coupled transfer processes in fractured porous environments with the possibility to simulate damage induced phenomena is a part of the objectives.

Because of their consequences on the overall behavior of rock and other brittle materials, numerous models have been proposed to study crack propagation. They are typically classified either as continuum- or discontinuum-based methods. Standard continuum approaches, based on FEM, consider plasticity and damage mechanics and adopt internal variables to capture the influence of history on the evolution of stresses and changes at the micro-structural level **[Hoek et al., 2002]**. However, this kind of approach is usually scale-dependent and some phenomena cannot be explicitly captured. For a low number of discrete fractures, modeling fracture propagation can be successfully conducted using numerical models based on zero-thickness interface elements within the classical FEM (see for example **[Carrier and Granet, 2012]**). Unfortunately, this sort of discretization requires meshes that match the discontinuities and thus imply increased computational cost when fractures propagate in space and time. As an alternative, in the XFEM method, an enriched formulation (with additional degrees-of-freedom at the nodes) is used so that the finite element mesh does not need to conform to the fracture geometry. This method has initially been implemented by **Belytschko et al. [1999]** and has then benefitted from numerous improvements. For instance, XFEM has been employed to model branched and intersected fractures **[Daux et al., 2000]**, fractures with contact **[Nistor et al., 2009; Siavelis et al., 2013]**, fracture growth with cohesive zone model **[Ferté et al., 2016]** and has recently been used in conjunction with HM model to study hydraulically driven fractures **[Réthoré et al., 2007; Mohammadnejad and Khoei, 2013a, b; Faivre et al., 2016]**. From a mathematical point of view, the method allows the local incorporation of enrichment functions. The Heaviside function is usually used to simulate a displacement jump across the fracture in a narrow band of elements. In addition, in the fracture tip area, asymptotic functions are added to represent properly the singularity in this zone **[Zi and Beliytschko, 2003]**. Alternatively, a cohesive zone model **[Barenblatt, 1962]** can be used and the presence of a process zone at the crack tip is considered where crack initiation and propagation occur following a nonlinear mechanical behavior. A level set method is classically associated with XFEM to localize the moving interface. This method is particularly suited to simulate fracture propagation since only two level-set fields per fracture are updated on a fixed mesh at each time step. In other words, the fracture grows independently from the mesh structure. A 3D coupled HM-XFEM based model has been recently developed by our consortium within the open-source software Code_Aster **[Faivre et al., 2014; 2016]**. The formalism takes into account the discontinuity of both the displacement field and the pore pressure field across the fracture surface using a non-regularized cohesive zone model. The Talon-Curnier constitutive law **[Talon and Curnier, 2003]** is considered for the fracture interfaces and its expression has been adapted to the HM coupling taking place during the fracture evolution. Significant extensions of this HM-XFEM model have been recently introduced by **Paul et al [2016]** to include the possibility of having fracture junctions and fracture propagation on non-predefined paths. Note that the extent of the model to anisotropic material is also currently in progress [PhD thesis S. Moosavi 2016-2019] and we will take advantage of this ongoing numerical work for the project.

Objectives and work summary: This post-doctoral work aims at accounting for partial saturation in the modeling of crack propagation in a porous medium subjected to HM couplings. Improvement of the HM behavior in the damage zone with induced permeability changes will also be considered. The work will start from the HM-XFEM model, recently implemented in Code_Aster, in the framework of two PhD theses (Maxime Faivre, Bertrand Paul) through collaboration between GeoRessources, IMSIA and IFPEN. This model with HM coupling was developed in 3D for a fully saturated medium and crack propagation is written through a cohesive zone model. One of the main limitations of this model is that it is constrained to the fully saturated case. Thus, crack propagation due to desaturation in the EDZ or gas transfer into the rock mass cannot be properly modelled. A limited number of authors considered modeling of crack propagation in partially saturated porous medium **[Mohammadnejad and Khoei, 2013a, b; Rethoré et al., 2008; Dastjerdy et al., 2015]**. In essence, their approaches are similar. Multiphase fluid flow in the crack is described by the generalized Darcy law where relative permeabilities and capillary pressure evolve as function of the saturation and interact with the cohesive crack propagation and the porous matrix deformation. But all these models have a limited use since they are restricted to simplified conditions (2D homogeneous medium, single fracture) and to non-miscible phases (no mass transfer between phases). The model developed will be validated and applied to laboratory tests and in situ experimentations carried out in the framework of the ANR HydroGeoDam. In details the work will be divided in three subtasks:

- Theoretical developments: two main questions will have to be addressed in a preliminary step. First, the cohesive zone model used for crack propagation will have to be adapted to partially-saturated porous media. The comparison with the Rice integral formulation should lead to identify the relevant stress intensity factors in the partially saturated case, following an approach similar to the one proposed by [Ferté et al. 2016]. Secondly, the two-phase fluid flow in partially saturated porous media containing cracks will be addressed; including mass transfer between phases (gas and water) and the potential impact on solution accuracy will be investigated.
- Implementation in the Finite Element Code: the model developed will be implemented into Code_Aster (EDF) on the basis of the HM-XFEM model, resulting in an HHM-XFEM model. Such a work has already been initiated and consists, amongst other, in introducing an additional enriched degree of freedom due to gas pressure.

- Model validation on analytical solutions of crack problems in partially saturated medium: this validation could make use of the analytical works of **[Bui 1996]** or **[Tran 2001]**, concerning the deformation of an isolated partially saturated crack in an infinite medium. Numerical benchmarks on crack propagation in a partially saturated medium could also be considered **[Rethoré et al. 2008]**.

Student profile: The candidate must be a highly-motivated and self-directed person with a PhD in computational mechanics, civil engineering, applied mathematics or other relevant fields. A solid background in rock mechanics and a strong interest for computational modelling of hydromechanical couplings are required. An experience in developing numerical methods, particularly finite element and XFEM, and using numerical codes would be a significant asset. The candidate will need to be fluent in English. He/she will have excellent written and oral communication skills. He/she will be willing to create and develop original approaches to tackle open questions.

Location: The position will be held at the IC2MP (Institute of Chemistry of Poitiers: Materials and Natural Resources, UMR 7285) within a pro-active research team in the fields of geomechanics and located in Poitiers, France. The Institute of Chemistry of Poitiers: Materials and Natural Resources (IC2MP, CNRS – Univ. Poitiers) is a multidisciplinary research institute established in 2012, specialized in the study of materials (e.g., clays, catalysts), natural environment (e.g., water, soil), and reactions (natural or caused). All the researchers involved in the HydroGeoDam ANR project are members of the HydrASA group of IC2MP, which is engaged in research in the areas of clays, soils, alterations and their geological and environmental aspects. In order to study all the processes involved in these geological systems, an interdisciplinary strategy is promoted: geologists, mineralogists, hydrogeologists, pedologists, geochemists and geomechanicians of the HydrASA group interact each other in the same interdisciplinary projects. The work will be supervised by **Pr. Richard Giot (**IC2MP**)** in close contact with **Dr. Fabrice Golfier** (GeoRessources) and **Dr. Patrick Massin** (IMSIA).

Funding: This 18 month full-time postdoc position is a part of the recently funded ANR (National French Research Agency) **"HydroGeoDam"** project (2018-2022, reference project ID: ANR-17-CE06-0016). This PhD project is funded for 18 months with salary based on work experience (Net salary, including social security between 1900 and 2200 €/month). The postdoc position should ideally start in the fall 2018 and no later than the end of 2018.

Applications should be sent to **Richard Giot** (richard.giot@univ-poitiers.fr) with copy to **Fabrice Golfier** (Fabrice.Golfier@univ-lorraine.fr) and **Patrick Massin** (patrick.massin@ensta-paristech.fr). They should include a cover letter (including motivation), a short CV (2 – 3 pages, with a publications list), a written sample of academic work (e.g . thesis and/or a recent paper) and contact information for two possible referees (name, institution, email contact).

For further information please contact **Richard Giot** (richard.giot@univ-poitiers.fr)

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