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The eXtended Finite Element Method applied to porous saturated media

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In the following, we introduce a new finite element to model the coupled effects of groundwater flow and fracture evolution in a fractured porous medium submitted to local or regional stress-state variations. An enriched finite element formulation is preferred to a standard formulation in order to overcome the difficulties brought by the presence of arbitrary discontinuities. The internal interfaces are then taken into account by additional degrees-of-freedom so that the finite element mesh does not need to conform to the fracture geometry. The discontinuous shape functions associated to these additional degrees-of-freedom simulate the presence of fractures in the medium. Therefore the XFEM method [1], based on the partition of unity [2], is employed to discretize the variational formulation of the fully-coupled Hydro-Mechanical (HM) problem.

The partially saturated porous-mechanical model developed by Khoei & al. [3] provided us a basis for the establishment of our model. It includes both discontinuous displacement and pore pressure fields across the fracture. We complete this work with the introduction of two additional fields:

- the fluid pressure field generated by the flow through and inside the fracture,
- a Lagrange multiplier field resulting from the dualisation of the pressure continuity condition (at the fracture wall) between the pore pressure and the fluid pressure inside the fracture allowing us to model permeable fractures as well as non-permeable fractures.

Under the assumption of small perturbations, the fracture aperture is driven by the fluid flow which itself depends on fracture aperture due to the Cubic law. A regularized cohesive law is adopted to handle the fracture evolution. A comparison with Griffith's criterion is also proposed.

The model is implemented in EDF's software Code_Aster. In order to ensure numerical stability of the model, cautions must be taken. In particular the numerical LBB condition has to be satisfied. To fulfill this requirement close to the fracture:

- quadratic shape functions are used to for the interpolation of the displacement field close to the fracture and linear shape functions for the pore pressure, the fluid pressure and the Lagrange multiplier fields,
- the computational approach proposed in Moës & al. [4] is implemented to prevent these last two fields from oscillating.

A first comparison with analytical solutions in the case of a zero pore pressure in the bulk material and no fluid inside the fracture has shown that the proposed numerical scheme gives good results. Impact of coupling with fluid flow inside the fracture and simulation of the fracture propagation by means of the cohesive constitutive law will be presented and discussed. Finally, simplified examples of hydraulic fracturing applications will illustrate the capability of this model.

REFERENCES

[1] J. Dolbow, N. Moës, T. Belytschko, *Discontinuous enrichment in finite elements with a partition of unity method,* Finite Elements in Analysis and Design. 36 (2000) 235-260.

[2] J.M. Melenek, I. Babushka, *The partition of unity finite element method : Basic theory and applications,* Computer Methods in Applied Mechanics and Engineering. 139 (1996) 289-314.

[3] A.R. Khoei, S. Moallemi, E. Haghighat, *Extended finite element modeling of deformable porous media with arbitrary interfaces,* Applied Mathematical Modeling. 35 (2011) 5426-5441.

[4] N. Moës, E. Bechet, M. Tourbier, *Imposing Dirichlet boundary conditions in the extended finite element method,* International Journal for Numerical Methods in Engineering. 67 (2006) 1641-1669