Modular development of poroelastic XFEM framework for interacting fractures in porous materials

C. Huang[a] and S.L. Chen[a*]

[a] Louisiana State University, Baton Rouge, LA, USA
* corresponding author: shenglichen@lsu.edu

Abstract:

A fully coupled poroelastic framework is developed for the general modeling of interacting fractures in porous materials based on the extended finite element method (XFEM). Fluid dissipation and thus poroelasticity in porous materials often plays a critical role in the time-dependent damage analysis. The XFEM, as a popular numerical method for discontinuity modeling, has gained a lot of attention and evolutions. Nevertheless, most of the advances are limited to one-phase materials. There is a need to develop an extensible fully coupled poroelastic XFEM framework for model prototyping of damage analysis in porous materials. Most importantly, the framework should be capable of modelling an arbitrary number of interacting fractures.

This program is built for modularity and extensibility. It takes advantage of the hierarchical nature of finite element method (FEM) and the modular nature of the object-oriented programming (OOP) paradigm. Interfaces are designed at different levels and model variations can be readily programmed. For example, the geometry of discontinuity can be explicitly modeled by standard method or the level set function method. The enrichment functions are not tied with the enrich items so that both strong and weak discontinuities can be flexibly included. The integration scheme for the enriched element also supports both conforming triangles and non-conforming quadrilaterals, even when multiple cracks are involved in the element. When it comes to the cohesive zone model, different traction separation laws have been made available. In addition to the extensibility, robustness is also considered when developing the coupled poroelastic framework. The finite element code implements the fully coupled poroelastic formulation. The Newton-Raphson iterator is implemented so that nonlinear analysis can be handled, and the step size can be automatically adjusted. Implicit time stepping scheme is adopted so that the time step size is not constrained due to the CFL (Courant Friedrichs Lewy) condition.

This numerical framework has been successfully applied to several benchmark problems such as a porous column under pure tension. Especially, a modified cohesive traction-separation law has been devised and incorporated into the framework in an attempt to consider the composite-like organic-rich shales. With the fully coupled poroelastic formulation and the capability for multiple interacting fractures, the impacts of the ductility of organic-rich shales on hydraulic fracturing are investigated. It is found that an increased ductility in shales leads to less extended fracture network and higher leak-off volume.