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3D coupled HM-XFEM modeling with cohesive zone model and applications to non planar hydraulic fracture propagation and multiple hydraulic fractures interference

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Abstract

A 3D fully coupled hydromechanical model for the simulation of fluid-driven fracture propagation through poroelastic saturated media is presented and compared to several analytical or numerical benchmarks. The hydromechanical coupling in the porous matrix is derived within the framework of the generalized Biot theory and the fluid flow in the fractures satisfies the lubrication equation. The presence and propagation of fluid-driven fractures is handled with the extended finite element method and the propagation of the fluid-driven fractures is governed by a mixed linear cohesive law relying on a stable mortar formalism. A comparison between numerical results and a semi-analytical solution for plane fluid-driven fractures in porous media assess the validity of the proposed model. Then, a procedure for the propagation of fluid-driven fractures on non predefined paths is detailed. In particular, the fracture reorientation angle is computed exclusively from cohesive quantities. Various numerical experiments are performed to study the interferences between neighboring fluid-driven fractures as well as the reorientation of fluid-driven fractures under complex stress conditions. Finally, the model is extended to discontinuity junctions and an application to arrays of vertical fractures initiated from horizontal wells is presented.

Keywords: X-FEM, hydro-mechanical coupling, fluid-driven fracture, cohesive zone model, fracture spacing, fracture interference, complex fracture

1. Introduction

Predicting occurrence of hydraulically induced damage in geological systems constitutes a major challenge in subsurface engineering. Geo-resource completion (geothermal, oil and gas resources), underground storage management (confinement of hazardous wastes, CO_2 storage) or building and maintenance of constructions (tunnels, dams, mines) can be affected by the progressive development of cracks due to stress relaxation and fluid flow circulation inside the host formation. Hydro-mechanical (HM) processes may be caused by natural or anthropic forcing that need to be understood and modeled for a variety of problems. Large injections of gas (CO_2, H_2) in underground reservoir storages can result in significant pressure build-up which can affect the stress field and induce large deformations or initiate induced seismicity [1]. These HM processes can eventually damage the cap rock and open up new flow paths which, ultimately, could ruin the efforts made for keeping the gas stored underground. There is, therefore, a critical need to build capable numerical models (fully coupled, multi-scale, etc) to gain better insights into these complex phenomena and thus to improve their predictive capabilities.

During the last decades, the problem of fluid-driven fracture propagation has been tackled analytically ([2], [3], [4]) and more recently by different numerical approaches ([5], [6]). The analytical effort on this subject aimed at solving

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