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AN EXTENDED FINITE ELEMENT METHOD FOR HYDRAULIC FRACTURING OF FULLY SATURATED POROUS MEDIA

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We present an extended finite element method (XFEM) for modelling 3D hydraulic fracturing of fully saturated, permeable and porous media subjected to a compressive state of stress. Standard 3D isoparametric elements are equipped with mixed displacement/pressure degrees of freedom attached to their corner nodes to interpolate the porous medium deformations and the fluid pressure in the pore system. The phantom node approach [1] and the level set method [2] are employed to represent the displacement and pore pressure discontinuities across the propagating fracture and to track the configuration of the fracture surface and fracture tip. In addition, we attach to all element edges a new phantom node equipped with a single degree of freedom to interpolate the fracturing fluid pressure within the fracture. The degrees of freedom associated to both the corner and edge phantom nodes are activated upon fracture initiation, whereby we model a) the de-cohesion of the fracture process zone using an effective traction-separation law with progressive damage, b) the progressive filtration of fracturing fluid tangential to the cohesive element, c) the progressive application of fracturing fluid pressure normal to the fracture surfaces, and d) the progressive leakage of fracturing fluid into the pores adjacent to the fracture surfaces. The XFEM formulation presented in this work has been implemented within the context of the commercial FEA software package SIMULIA® Abaqus as an integrated component of its general purpose, non-linear porous media analysis solver. The resulting solution procedure, which shares some features with the cohesive element formulation described in [3], accounts for the non-linear coupling between a) the deformation of the fully saturated porous medium, modelled with Biot's theory of poroelasticity, b) the flow of pore fluid through the deformable pore volume, assumed to obey Darcy's law, c) the flow of fracturing fluid within the narrow opening between the moving fracture surfaces, governed by Reynolds lubrication theory, and d) the porous medium fracture, assumed to extend across a cohesive process zone with separation resisted by cohesive effective tractions. The proposed formulation and solution procedure are validated by simulating the propagation of a vertical, planar fracture of uniform width within a prismatic-shaped reservoir (KGDK model) and the propagation of horizontal, circle-shaped fracture within a cylindrical reservoir ("Penny-shaped" model), driven in both cases by a fracturing fluid injected at a constant rate. The numerical solution obtained for each model is compared with asymptotic analytical solutions for the toughness dominated and viscosity dominated propagation regimes [4,5], with and without leak-off and with no fluid lag. The solution is found to reproduce accurately the analytical solutions in all propagation regimes and to converge monotonically as the mesh is refined. This validation exercise provides confidence in the ability and readiness of this XFEM formulation to simulate fluid driven fracturing applications for the oil and gas industry including drilling, stimulation and injection operations

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