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A variational hydraulic fracturing model for simulating the hydraulic fracture propagation in fracture-caved porous media

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The fracture-caved porous media contains numerous irregular natural fractures and caves, leading to multi-scale pore structures. The geometry of these pore structures can impact the mechanical characteristics of the porous media, and also significantly affect the hydraulic fracture propagation path. This study presents an innovative hydraulic fracturing model designed to simulate the fracture propagation within fracture-caved poroelastic media, leveraging the capabilities of the phase-field method. Initially, the fracture-cave-reservoir flow governing equations are established through coupling generalized Reynolds flow in the fracture domain, Darcy flow in the reservoir domain and free flow in the cave domain. Biot poroelasticity theory and fracture width serve as the links for hydro-mechanical coupling. To address sharp fractures and cave edges, a smooth phase-field method is introduced. The fully coupled model is solved using a staggered scheme, which independently addresses the pressure and displacement fields in the inner cycle, and then addresses the phase-field in the outer cycle. In contrast to prior research, our model eliminates the need for supplementary enrichment functions to characterize natural fractures and caves. It can naturally detect and simulate the behavior of hydraulic fracture propagation in the presence of natural caves. This alleviates the complex calculations of stress intensity factors as hydraulic fracture nears caves. The efficacy of the proposed model in addressing two-dimensional scenarios is thoroughly demonstrated. Subsequently, the model is expanded to encompass three-dimensional scenarios and multiple cave instances.

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