An approach to track crack connectivity for hydraulic fracturing using graph and disjoint-set data structures

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Abstract

Hydraulic fracturing is widely employed to stimulate oil and gas reservoirs to increase their productivity. Various numerical techniques exist to examine hydraulic fracture propagation. However, in most these methods, there are a few non-interacting cracks that propagate or the interaction between the hydraulically loaded crack and the other cracks is not incorporated.

Motivated by this observation, we present an approach that implements complex data structures within a finite element method scheme to dynamically track crack connectivity and hydraulic load propagation. Fracture solutions are determined by a spacetime discontinuous Galerkin finite element analysis scheme which offers greater accuracy, efficiency than conventional (continuous) finite elements methods and enables direct tracking of arbitrary crack propagation patterns. As cracks propagate, their patterns can be modeled analogous to a simplicial complex and geometrical information can be managed with a graph theory approach. In conjunction with graph theory algorithms, a disjoint-set data structure is used to monitor load propagation and transfers between independent sets of fracture inclusions. This not only results in correct modeling of interaction between different cracks, but also allows imposing independent loading conditions for arbitrary sets of fracture sets.

Numerical results from various crack configurations and loading conditions will be presented. The simplest case that will be considered is the interaction of a hydraulically loaded and horizontally oriented crack with an arbitrarily oriented unloaded natural fracture. This has applications in the stability analysis of natural faults close to hydraulic fracturing wells. Using the graph and disjoint-set data structures, the loaded crack will propagate subsequently intersecting the natural fracture allowing the load information to transfer. We will also present more complex examples where the hydraulic load is transferred to already existing natural fissures in rocks and results in the extension of these fissures due to the transferred load.

KEY WORKS: hydraulic fracture, graph theory, disjoint-sets, simplicial complex, spacetime discontinuous Galerkin