Multiscale Extended Finite Element Method for Simulation of Fractured Geological Formation with Propagating Fractures

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When the equilibrium state of geological fractured formations is violated, fractures can propagate and slide. This change of in-situ stress state can often be activated by an injection or production process. Due to the compressive nature of the stress state in underground formations, mode II mechanical failure, or shearing, is the dominant fracture propagation mechanism while opening fractures can be barely seen. In addition, massive fractures often cross each other in the fractured formations. To avoid the use of excessively high-resolution meshes, while resolving the explicit fractures, the extended finite element method (XFEM) is used [1]. The XFEM introduces jump functions to enrich the FEM continuous space with discontinuities introduced by the fractures. The linear momentum balance equation is then supplemented by the Mohr-Coulomb friction law, which defines the maximum friction that each fractured element can tolerate. Further constraints are applied to ensure that no penetration of elements takes place as a result of significant deformations [2].

For the simulation of highly fractured geological formations, applying XFEM directly is computationally challenging. The large number of extra degrees of freedom (DOFs) due to the highly fractured formations will cause high computational burden. To resolve this challenge, we propose this multiscale extended finite element method (MS-XFEM) to simulate fracture propagation under compressive loading in geological formations. Local XFEM-based basis functions are constructed algebraically to capture the compression and the sliding of fine-scale fractures [3]. In each time step when the fractures propagate, the basis functions are updated adaptively in certain regions where fractures geometries are changed. Using these basis functions, a very efficient FEM-based coarse-scale system is developed since it has no extra DOFs. Once the coarse-scale solution is obtained, it is prolonged to the fine-scale original resolution using the basis functions. This approximate fine-scale solution is then used to estimate the group of growing fracture tips and their growing angles. This allows for exploiting the locality of the propagation process fully while solving a global system. To control the error, an iterative procedure is also developed. MS-XFEM casts a promising method for field-scale applications.

References

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