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Multiscale Extended Finite Element Method for the Simulation of Fractured Geological Formations

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In the prevailing context of the 21st century, characterized by a predominant reliance on oil and gas, or in the promising future where green energy shapes a human society committed to net-zero emissions, the role of underground fractured formations in energy production (geothermal) and storage remains pivotal and irreplaceable. In the past decade, hazardous consequences of failing to predict the geomechanics behaviors of fractured formations has led to a pronounced focus on developing simulation strategies that are both accurate and efficient for subsurface fractured formations.
As a widely used simulation method in fracture mechanics, the extended finite element method (XFEM) provides a precise approach to simulate deformation and fractures propagation within highly fractured media. It is also a convenient strategy as it allows for the use of structured grids. However, the expensive computational cost of using classical XFEM in the simulation of fracture networks makes this method not immediately suitable in the geoscientific community.
To resolve this challenge, a multiscale extended finite element method (MS-XFEM) is proposed to provide a novel approach to simulate the highly fractured subsurface formations accurately and efficiently. The deformation and fractures propagation are both simulated by interpolating the solutions from a larger yet sparser coarse grid to the original fine-scale grid. This interpolation process requires the construction of the basis functions matrix. The novelty of this work is to involve the fractures into basis functions only, thus the coarse scale system is constructed based on a standard finite element method. More importantly, this construction of basis functions is fully algebraic and can be updated locally and adaptively for the simulation of propagating fractures. This method has been implemented and tested to prove its efficiency and accuracy. All test results prove the good qualities of solutions computed from MS-XFEM when compared to fine scale XFEM solutions. Basis functions are constructed successfully with the algebraic method since they capture all different types of discontinuities. These tests reveal the potential of MS-XFEM in simulating real-world subsurface fractured formations.

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Primary author: XU, Fanxiang

Co-authors: Prof. SLUYS, Bert (Delft University of Technology); Prof. HAJIBEYGI, Hadi (Delft University of Technology)

Presenter: XU, Fanxiang

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