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Three-dimensional hydraulic fracturing modelling using Lattice Element Method

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Hydraulic fracturing has wide engineering applications including exploration of unconventional resources, Enhanced Geothermal System, storage of radioactive waste and mining. It is a multi-physics and multi-scale problem which makes it difficult to be evaluated numerically. The multi-physics nature is arisen from coupling of at least three physical processes – deformation of rock under applied stress, fracture propagation and fluid flow along fracture while the multi-scales nature comes from the presence of discontinuities in different scales in rock mass. Also, fracture growth is highly sensitive to existing discontinuities which either enhance or suppress the growth. In this paper, a simple discontinuum numerical method – Lattice Element Method (LEM) is proposed to simulate hydraulic fracturing in large scale three-dimensional model. Rock is modelled as lattice network composed of 1D Hookean's springs. Fracturing is modelled by removing lattice exceeding a threshold as determined by critical energy release rate of rock. By introducing disorder in the model, the heterogeneity of rock is modelled and mesh dependency in fracture growth is removed. Disordered network is generated by Delaunay triangulation of randomly generated nodes and geometries of Voronoi cells are used for scaling of lattice stiffness and breaking threshold to match macroscopic parameters. Complicated fracture evolution like fracture branching and fracture coalescence can be modelled by LEM. Fluid flow along fractures is simplified as pipe network and cubic law model is used to relate the dependency between fluid transmissivity and aperture of fracture. An in-house C++ code using parallel conjugate solver is developed which is capable to handle large scale three-dimensional models composed of millions of degree of freedom running thousands of steps. LEM simulations of hydraulic fracturing under different pre-existing fractures and different in-situ stress are presented to demonstrate the feasibility and potential of LEM to model field scale problem in three dimensions with consideration of heterogeneity of rock and influence of fracture networks.