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Hydrofracture Formation

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Hydrofracturing is a common and important geological process in a variety of geological settings and at a wide range of scales. Hydrofractures are fractures generated by internal pressure from any kind of crustal fluid such as gas, oil, magma (dykes, sills, and inclined sheets), geothermal water (mineral veins) or groundwater (many joints).

To get a better insight into the basic physics of hydrofracture generation, maintenance and shape of hydrofractures at medium scale (1 m), we present a simple phenomenological numerical description that incorporates both the elastic deformation and fracturing of the solid media, along with hydrodynamic interactions.

The numerical scheme is based on a 2d (two dimensional) Lattice model that utilize the small-scale triangular discrete spring network of the software 'Latte' (part of the modeling environment 'Elle') as representation of a fracturing media, and hybridized it with a large-scale (fixed) square lattice of continuum description given by the compressible Navier-Stokes equation. The coupled model thus in general resides two slightly overlapping areas in the physical space and is efficient as it avoids the large computational cost of solving for detailed hydrodynamic flow fields between grains.

A general form of the macroscopic diffusion equation of pressure is derived by ensuring conservation of mass of the fluid and the particles and local Darcy's Law. The pressure is then discretized by the ADI method on the square lattice of the hydrodynamic part in order to get the hydraulic head for each fluid element. The hydraulic head then contributes to the net force on each particle in the elastic lattice through a smoothing function.

The function of the model is twofold, first it produces an adequate fluid pressure gradient during diffusion that causes forces on the nodes of the spring network which therefore deforms, leading to hydrofractures to occur and second this deformation on the other hand changes the permeability which again changes the evolution of the fluid pressure until a state of equilibrium is reached, thus giving this coupled hydro-mechanical process a dynamic mode.

The manipulation of the model on simple test cases like point sources and sink areas is in agreement with theoretical predictions. The preliminary results demonstrate that a local increase in fluid pressure leads to an increase in pressure gradients and thus high stresses concentrations and the formation of hydrofractures in the granular system. The growth of a hydrofracture depends primarily on the hydraulic and mechanical properties of the granular system. As long as the fluid pressure exceeds the strength of the discrete granular media, hydrofractures will keep propagating and a hydrofracture pattern develops that leads to an increase in permeability and thus a local drop in pressure.