Numerical modeling of injection induced shear failure in fractured reservoirs using extended finite volume method

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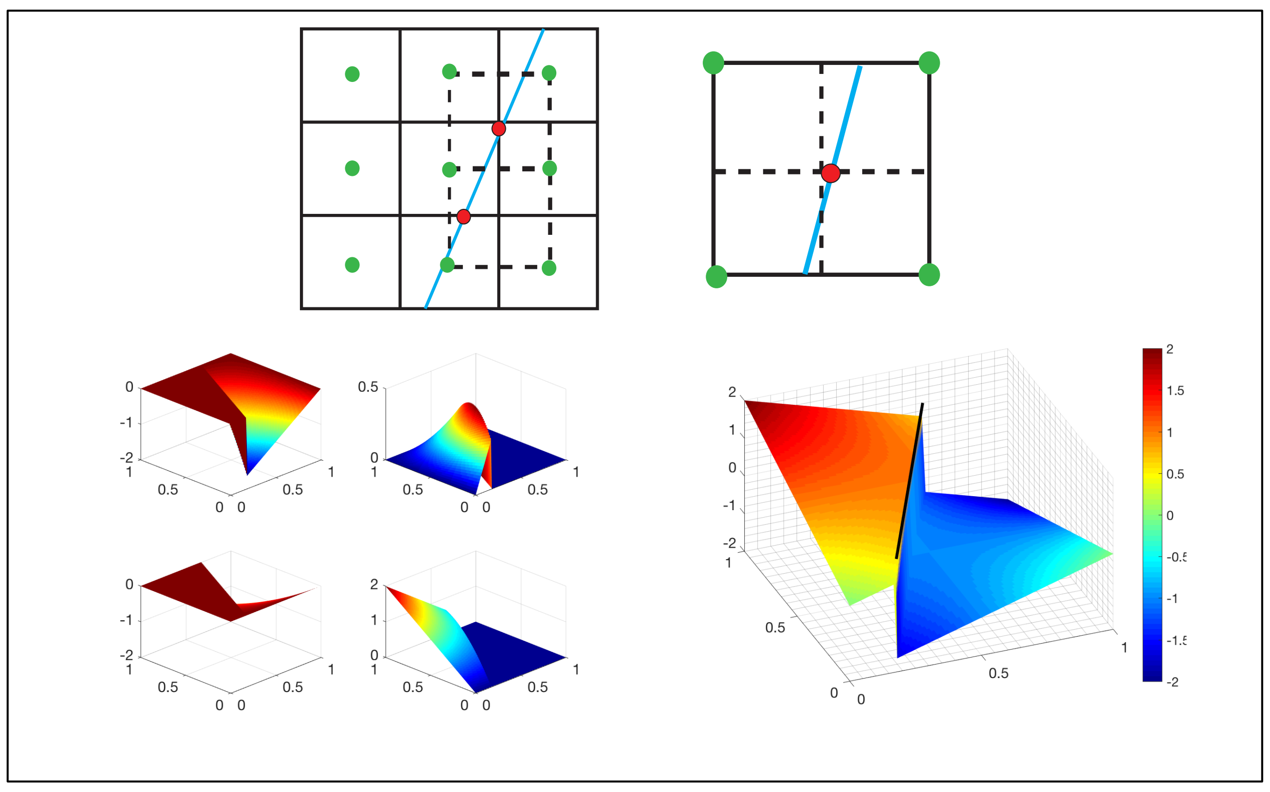
Abstract

A numerical modeling framework to simulate shear failure in fractured reservoirs has been developed using a finite volume method. The Coulomb friction law is applied to describe the failure criterion. In order to obtain the fluid injection induced shear failure in a grid and time step size independent manner, it is shown that a time step size which scales with the square of fracture segment size is necessary. Alternatively, the Prakash and Cliffton law provides grid and time step size convergent slip solutions using a numerical time step size, which resolves the shear relaxation timescale.

Slip Elements



In the HFR framework, fractures are represented as low dimensional manifolds in a higher dimensional matrix domain. The displacement solution is given by

$$\mathbf{u} = \sum_{i=1}^{N_e} \mathbf{u_i} N_i(\mathbf{x}) + \sum_{j=1}^{N_s} \mathbf{s_j} \left(\sum_{p=1}^{4} N_p(\mathbf{x}) H_p(f(\mathbf{x})) \right) \quad (1)$$

$$H_p(f(\mathbf{x})) = H(f(\mathbf{x})) - H(f(\mathbf{x_p})) \quad (2)$$

Further, an extended finite volume method (XFVM) is used along with frictional constraint relations on the fracture segments [1].

Grid Convergence

The pure mechanics problem is grid convergent. However, pressure induced shear failure simulations have an additional restriction on the time step size to obtain a grid converged failure propagation in the context of the Coulomb friction law:-

$$\tau = S_0 + \mu(\sigma_c - p^f) \quad (3)$$

$$\Delta t_{flow} < (\Delta x^2 / (b^f k^f)) \frac{\partial E^f}{\partial p^f} \quad (4)$$

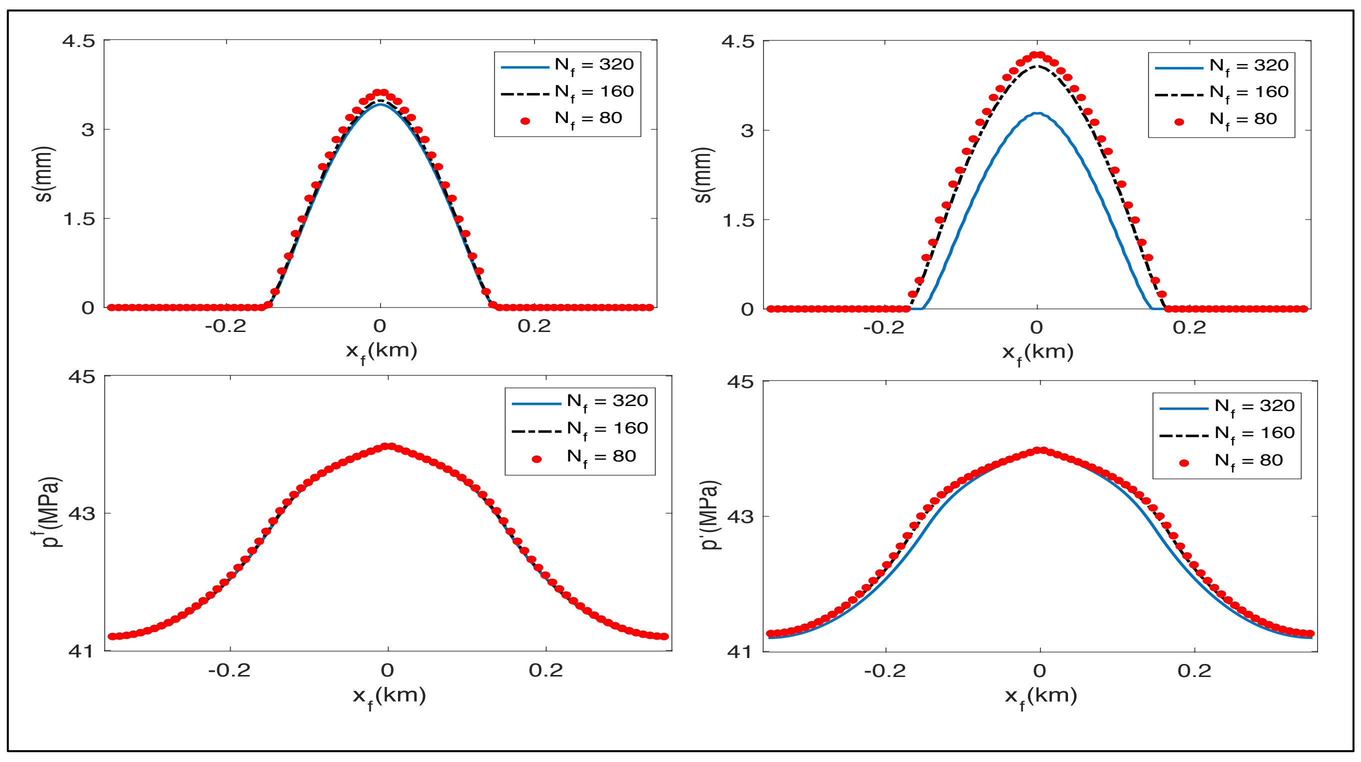
An alternative is to use the Prakash and Cliffton law, where maximum shear strength on a fracture segment relaxes over a timescale to the Coulomb friction value as given below :-

$$\tau = \tau_{max} \quad (5)$$

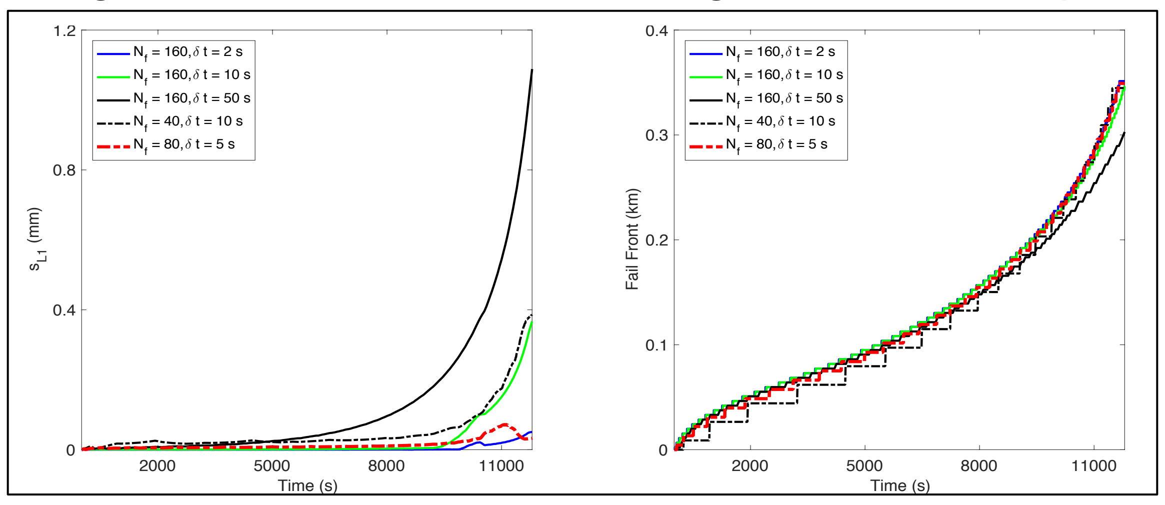
$$\frac{d\tau_{max}}{dt} = -(1/\tau_f)(\tau_{max} - \mu(\sigma_c - p^f)) \quad (6)$$

Results

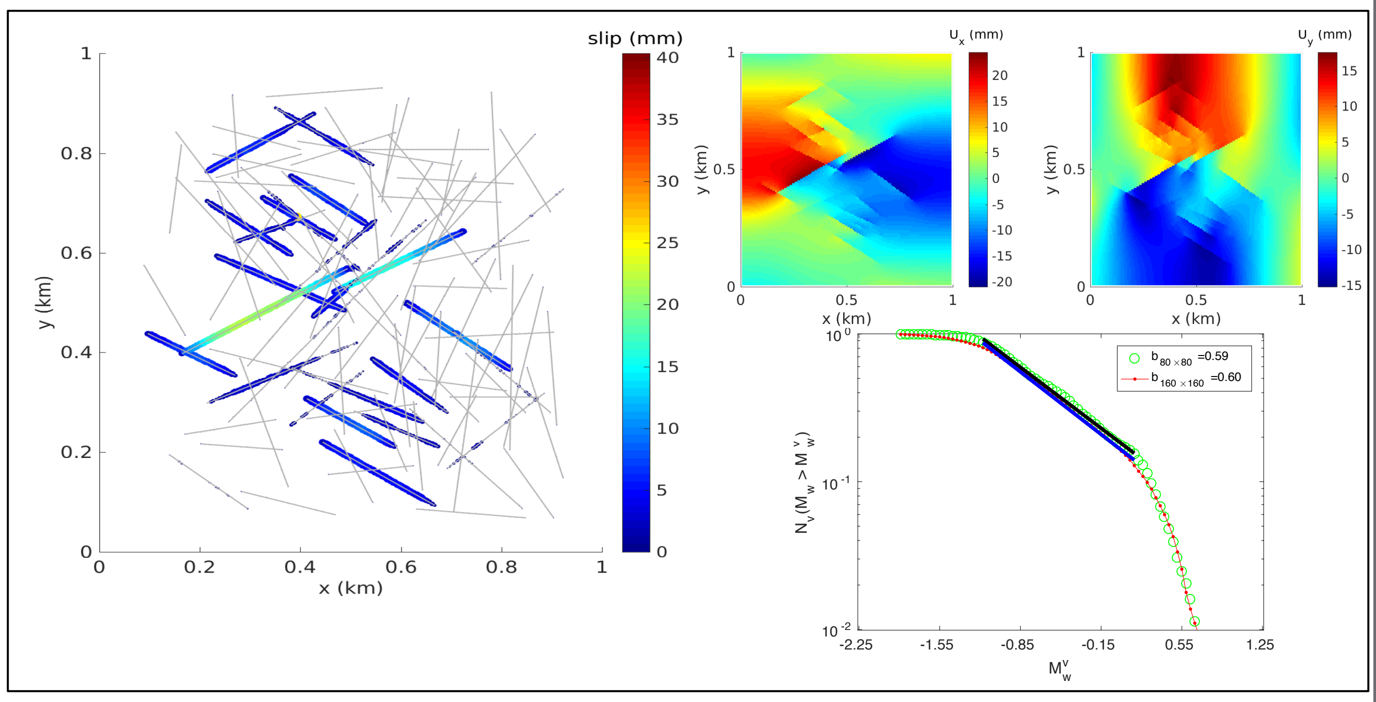
The following figures compare the slip and pressure solutions for different grid resolutions, with and without the shear relaxation for injection at the centre of a single fracture.



Further, the following figures depict how the failure propagation and the L_1-error evolves for slip solutions using different relations between grid and time step size.



XFVM with shear relaxation is now used for a fracture network. The following figures depict the displacement solutions in the matrix domain and the shear slip on the fracture nodes.



The seismic moment magnitude plotted against the frequency of occurrence follows the Gutenberg-Richter law with grid converged b-values.

Conclusion

A XFVM method in the HFR framework is employed and the grid dependent time step size is formulated for injection induced failure in order to obtain grid converged solutions.

Reference:- *R. Deb, P. Jenny* : Modeling of shear failure in fracture reservoir with porous matrix. *ECMOR 2016*