The Hydro-Mechanical Response of Pre-Structured Reservoirs Subjected to Hydraulic Fracture

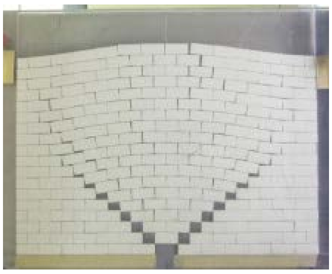
Shahrzad Roshankhah[1 *], Lucio Gerardo Cruz[2], Hosung Shin[3], Arcesio Lizcano[4], Juan Carlos Santamarina[5]

[1] California Institute of Technology, Pasadena, USA
[2] University of the Cauca, Popayan, Colombia
[3] University of Ulsan, Ulsan, South Korea
[4] SRK consulting, Vancouver, Canada
[5] King Abdullah University of Science & Technology, Thuwal, Kingdom of Saudi Arabia
* shroshan@caltech.edu

Kinematic Dilation of Blocky Media

A single planar fracture geometry dominates the process of hydraulic fracturing in homogeneous and isotropic intact rocks and sediments (e.g., Hubbert and Willis, 1957). However, this fracture geometry cannot explain the high recovery efficiency observed in shale gas and enhanced geothermal energy. Local mechanisms such as shear-induced dilation of critically-stressed joints have been recognized in the past (e.g., Rutqvist and Stephansson, 2003; Damjanac and Cundall, 2016). Experimental and numerical studies reported here demonstrate that pre-structured reservoirs experience extensive, global geometric distortion and dilation around the generated main opening-mode discontinuity. The discrete openings remain open all over the medium even after the stimulation cause ceases (Figure 1).

a)



b)

c)

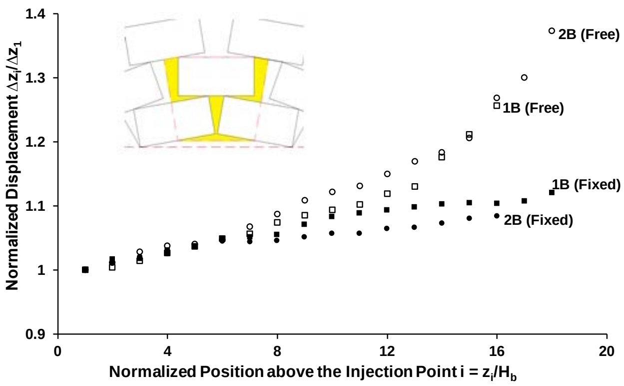


Fig. 1: a) Kinematic dilation of a laterally confined blocky medium with 50% inter-block overlap (brick-wall fabric) upon stimulation by imposing displacement on one block. b) Irreversible inter-block openings when the stimulation ceases. c) 5% to 35% dilation measured upon stimulation of the brick-wall fabric blocky medium

We constructed blocky samples with various internal fabrics and boundary conditions and subjected them to hydraulic and mechanical stimulations with different characteristic length and time scales (i.e., length of imposed main opening, fluid injection rate, and fluid viscosity). Parameters such as the dominant joint set orientation, block size and slenderness, and blocks' overlap length characterize a pre-structured medium and determine its deformation pattern and hydro-mechanical behavior (e.g., Barton and Bandis, 1982; Barton et al., 1985; Goodman and Shi, 1985). A completely different displacement field emerges when the inter-block overlap increases (Figure 2).

a) b)

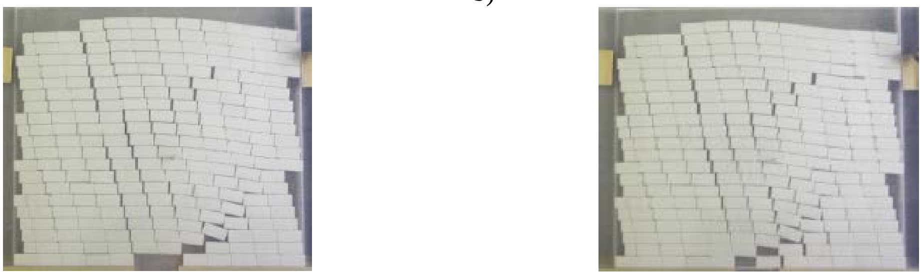


Fig. 2: a) Kinematic dilation of a laterally confined blocky medium with 90% inter-block overlap upon stimulation by imposing displacement on two blocks. b) Irreversible inter-block openings when the stimulation ceases

Kinematically-controlled dilational distortion greatly improves fluid conductivity in the pre-structured medium and remains productive after depressurization. A six-power relationship is anticipated between the enhanced hydraulic conductivity and the roundness of the main opening.

$$K_{hyd} = \frac{\gamma L_b^2}{48\eta}\left(\frac{O_F}{L_F}\right)^6$$

Structure interlocking and injection conditions determine the orientation and slenderness of the main opening (rounder for high injection rates and fluid viscosity, higher O_F/L_F), the formation of wing openings, the extent of self-propped openings, and the seismic expression of the reservoir during stimulation.

Limitations at In-Situ Conditions

This kinematic dilation may decrease at high confining stresses because blocks deform and split, and edges crush. Figure 3 shows that blocks around the main opening bend, which can suppress the effect of global kinematic dilation.

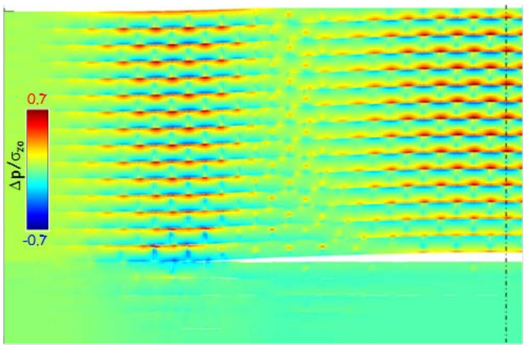


Fig. 3: Dilational distortion in numerical simulations: induced bending of blocks (Red: compression. Blue: tension)

This study highlights that the orientation and path of hydraulic fracture in pre-fractured media is not exclusively controlled by the orientation of principal in-situ stresses but the media's internal structure plays a critical role under various boundary conditions. These observations inform the interpretation of in-situ seismic events.

References

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