Can a bi-lateral stress jump really arrest the height growth of a hydraulic fracture?

C. Peruzzo[1*], B. Fryer[2], B. Lecampion[1]

[1] Gaznat chair on Geo-Energy, Institute of Civil Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 18, 1015 Lausanne, Switzerland, carlo.peruzzo@epfl.ch, brice.lecampion@epfl.ch
[2] Laboratory of Experimental Rock Mechanics, Institute of Civil Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 18, 1015 Lausanne, Switzerland, barnaby.fryer@epfl.ch

In certain industrial applications, vertical growth of hydraulic fractures beyond a targeted formation of interest can cause economic loss and pose a risk to environmentally sensitive layers [1]. In addition, when micro hydraulic fracturing is used to measure the minimum in-situ principal stress in the subsurface, the vertical fracture growth can lead to packer bypass, compromising the measurement [2].

In sedimentary formations, the presence of layers of high confining stress above and below the formation of interest is a well-known mechanism for the containment of a hydraulic fracture [3]. As the hydraulic fracture penetrates the region of higher confining stress, the stress intensity factor decreases thus limiting the (fracture)-height growth and promoting the propagation parallel to the layers direction. However, a simple 2D plane strain argument shows that there is a limiting penetration above which the vertical growth can no longer be arrested [4]. This raises the question of whether the vertical growth of an initially radial hydraulic fracture can really be arrested when penetrating the higher stress layers.

We consider the symmetrical scenario of an injection point located at the center of a target formation bounded by two layers with similar properties. We assume that the confining stress in the central layer is lower than in the bounding layers, while the other properties are assumed to be uniform for clarity. Using 3D planar simulations and scaling arguments, we determine under what conditions and for how long a hydraulic fracture driven by a constant injection rate can remain confined between two high-stress boundary layers. We find that true, albeit transient, confinement exists and under two conditions. The first is that the radial fracture must be toughness dominated when reaching the interfaces while the second is that the dimensionless confining stress must be above a given threshold. When these two conditions are fulfilled the radial fracture transitions to a toughness dominated PKN-like fracture (see ref. in [4-5]) for which we develop a new analytical solution following the one derived in [5]. In all other cases, the propagation velocity in the vertical direction is only temporarily reduced, so that the fracture regains its radial footprint at a late stage. We show that no hydraulic fracture can be contained indefinitely by a stress jump. Finally, for the case where the true containment exists, we estimate, both analytically and numerically, how long the fracture remains vertically contained.

References

[1] A. P. Bunger, B. Lecampion, Four critical issues for successful hydraulic fracturing applications, Rock Mech. and Eng. (2017) Jul 20:551-93.

[2] M. Thiercelin and J. Desroches, Improving the performance of open hole stress tools, Int. J. of Rock Mech. and Min. Sci. and Geomech. Abstr., United Kingdom, 1249-1252, (1993).

[3] E. R. Simonson, A. S. Abou-Sayed, and R. J. Clifton, Containment of massive hydraulic fractures, Soc. of Petr. Eng. J. 18, no. 01 (1978): 27-32.

[4] J. I. Adachi, E. Detournay, and A. P. Peirce. Analysis of the classical pseudo-3D model for hydraulic fracture with equilibrium height growth across stress barriers, Int. J. of Rock Mec. and Min. Sci. 47, no. 4 (2010): 625-639.

[5] E. Sarvaramini, and D. I. Garagash, Breakdown of a pressurized fingerlike crack in a permeable solid, J. of App. Mech. 82, no. 6 (2015).