Numerical modeling and simulation of the interaction between hydraulic and natural fractures using high aspect ratio interface elements

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Hydraulic fracturing is a reservoir stimulation technique widely used in the oil industry mainly to induce hydraulic fractures in low permeability reservoirs through the injection of a fluid highly pressurized. Thus, the hydraulic fracture (HF) facilitates the fluid flow in the reservoir. In the cases where the reservoirs have natural fractures (NF), the interaction between the HF and NF can occur in different ways, such as (i) HF directly crossing the NF; (ii) NF blocking the HF propagation; and (iii) NF changing the direction of HF propagation [1].

This is a complex multiphysics problem that involves the coupling of at least three process [2]: (i) the fluid pressure inducing mechanical deformation; (ii) the flow of fluid within the fracture; and (iii) the fracture propagation. In order to overcome this challenging task, this work proposes the use of high aspect ratio interface elements (HAR-IEs) to model the HF formation and propagation as well as its interaction with the NF. The HAR-IEs mechanical behavior is described via an appropriate scalar damage model and the fluid flow behavior is expressed by the classical cubic law [3]. Moreover, these elements are positioned in the finite element mesh according to the Mesh Fragmentation Technique, which allows the HF propagates freely in the domain [4]. The proposed methodology present some advantages to deal with discontinuities in porous media: (i) it is relatively simple to implement HAR-IEs in already existing finite element codes, since they are based on standard elements; (ii) no special integration rules to obtain the internal forces are required; (iii) the analyses are conducted in a completely continuum framework; (iv) tracking algorithms to control the fracture propagation through the domain are not necessary.

The numerical simulations performed in this work studied the scenarios resulting from HF-NF interaction under: (i) different NF apertures; (ii) different approach angles between HF-NF; and (iii) different *in-situ* stress states. Smaller apertures do not influence significantly the HF propagation, since the fluid penetration in the NF is negligible, and in this case, the HF directly crosses the NF. On the other hand, higher apertures affect the HF propagation by changing its preferential direction. The approach angles can affect the HF propagation mainly when they are smaller because the NF represents a path easier to follow than the rock mass. Confinement stresses play another important role in the HF-NF interaction, which enforces HF propagates through the NF (i.e., crossing it). Moreover, the numerical technique proposed in this work proved to be robust, stable, and efficient, since the simulations did not present non-convergence issues and the results agree well with works available in the literature.

References

[1] X. Wang, Modeling of complex hydraulic fractures in naturally fractured formation, Journal of Unconventional Oil and Gas Resources 9 (2015) 114–135.

[2] J. Adachi, E. Siebrits, A. Peirce, J. Desroches, Computer simulation of hydraulic fractures, International Journal of Rock Mechanics and Mining Sciences 44 (2007) 739–757.

[3] O. L. Manzoli, P. R. Cleto, M. Sánchez, L. J. N. Guimarães, M. A. Maedo, On the use of high aspect ratio finite elements to model hydraulic fracturing in deformable porous media, Computer Methods in Applied Mechanics and Engineering 350 (2019) 57–80.

[4] P. R. Cleto, O. L. Manzoli, M. Sánchez, M. A. Maedo, L. B. Beserra, L. J. Guimarães, Hydromechanical coupled modeling of hydraulic fracturing using the mesh fragmentation technique, Computers and Geotechnics 124 (2020) 103591.