Hydraulic fracture modelling with double node zero-thickness interface elements.

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In recent years, numerical modelling of hydraulic fracture has become a hot topic in Petroleum Engineering. The main difficulty is related to the numerical treatment of discontinuities in a geological medium. Several approaches can be found in the literature (Boone and Ingraffea, 1990; Adachi *et al*., 2007); however, some of them resort to simplifications that make them inapplicable in complex cases such as non-uniform initial stress states or boreholes with axis skew to the principal stress directions.

In this work, the approach described is based on the FEM with zero-thickness interface elements of the Goodman type. If formulated appropriately in the context of classical "u-p" coupled geotechnical analysis (Zienkiewicz *et al*., 1977), the approach developed seems capable of representing realistically the opening of cracks or fractures induced by fluid pressure (Segura and Carol, 2008).

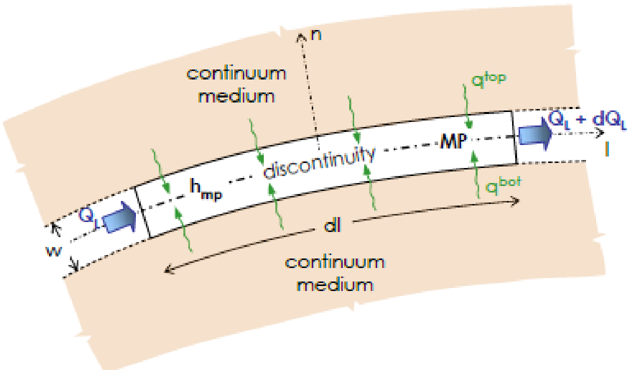

Figure 1) Flow through the differential joint element (Segura, 2007).

One of the key aspects to realistically represent hydraulic fracture, is the mechanical constitutive law used for the interface. In this case, an elastoplastic law which incorporates concepts of fracture mechanics, previously developed for pure mechanical analysis of concrete and geomaterials (Carol *et al*., 1997), has been used. The model incorporates a history variable controlling the behaviour of the interface, with the meaning of the energy dissipated in fracture processes. This assumption makes it possible to introduce in a natural, simple way, the fracture energy parameters associated to mode I and mode IIa (G_F^I and G_F^{IIa}), as the basic parameters of the hardening/softening law. Concerning the fluid flow problem, the zero-thickness interface element formulation decomposes the flow in two components, one along and the other across the discontinuity (Fig.1), with the corresponding longitudinal and transversal conductivity parameters which in turn may be affected significantly by the fracture opening (cubic law).

The applications described in this paper are extensions of the previous work presented by the authors on the propagation of a single fracture in 2D (Garolera *et al*., 2014). In the current paper, the analysis is focused on the 3D extension of the analysis of a single fracture. The calculations performed include two cases which are compared with previous analytical and numerical solutions (Boone and Ingraffea, 1990). The first example consists of a horizontal layer of 1m thickness, with a vertical line-like distributed flow injection. This setup is chosen to numerically reproduce as close as possible the conditions assumed for the standard GDK formula (Yew, 1997).

The second example of application consists of a cubic block of 80x80x80m which includes a thin horizontal layer of 1m thickness, and three sets of zero-thickness interfaces: one over the vertical mid-plane of the volume, and two sets located at each contact between the horizontal layers. The results of this case are compared with the classical PKN solution (Yew, 1997).

The results obtained in both cases show a good agreement with the formula predictions and with other existing numerical solutions (Figures 2 and 3).

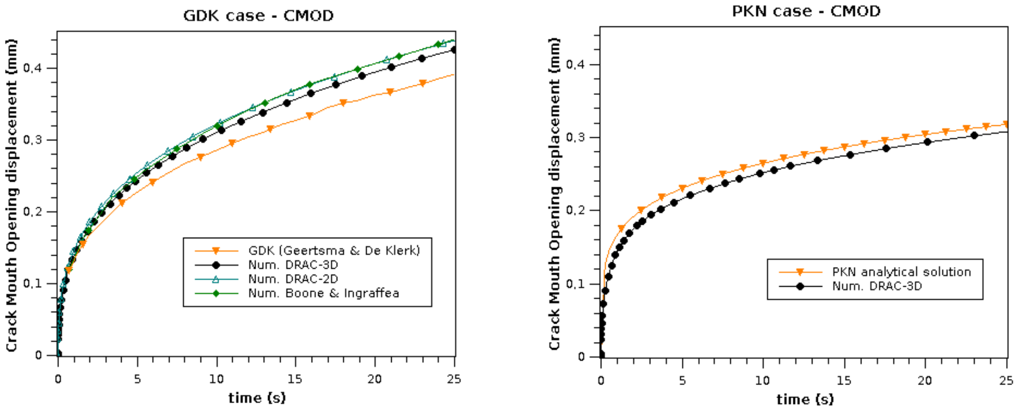

Figure 2) Curves of Crack Mouth Opening Displacement (CMOD) evolution with time, for the two-dimensional GDK formula problem (left), and for the 3D GDK formula problem(right). The numerical results are all obtained in 3D.

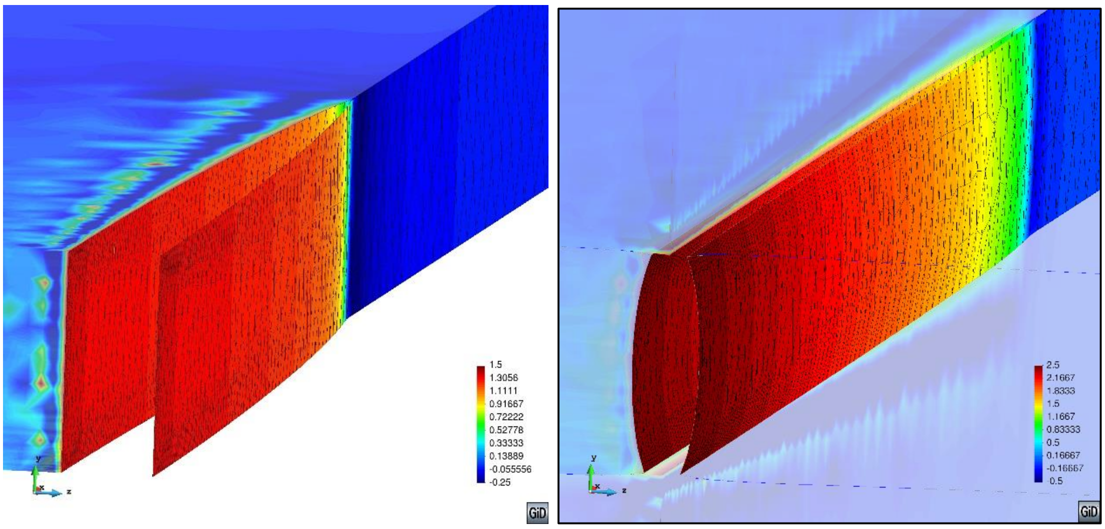

Figure 3) Fluid pressure distribution after stopping injection (25 seconds): 3D numerical results obtained for the 2D GDK formula (left), and 3D PKN formula (right). Colors represent pressure intensities depicted over deformed mesh (with x1000 magnification factor).

Acknowledgements

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