Modelling of the propagation of hydraulic fracture using cohesive zone models

Dong Liu, Brice Lecampion & Lorenzo Benedetti

Geo-Energy Lab EPFL-ENAC-JGEL St.8a 18 CH-1015, Switzerland

I. Introduction

Hydraulic fracturing (HF) is widely used in the oil and gas industry to enhance production from tight reservoirs. The process involves the injection of fluid at a given flow rate into a wellbore in order to propagate a fracture in rocks and thus increase their permeability.

Linear hydraulic fracture mechanics (LHFM) theories have been developed to predict the fracture propagation, assuming a linear elastic solid and the lubrication fluid flow in the fracture. However, some studies (Chudnovsky et al. 2008, Papamantou 1999) have shown deviations from LHFM predictions which indicate the existence of solid non-linearity and a deviation of the Poisson law.

We revisit the problem of a plane-strain hydraulic fracture driven by the injection of a Newtonian fluid in a tight rock. By modelling the quasi-brittle nature of the rock with different cohesive zone models, we study the effect of solid non-linearity on toughness and viscosity-dominated HF regimes.

II. Problem formulation

We revisit the problem of a plane-strain hydraulic fracture driven by the injection of a Newtonian fluid in a tight rock. By modelling the quasi-brittle nature of the rock with different cohesive zone models, we study the effect of solid non-linearity on toughness and viscosity-dominated HF regimes.

1. The numerical algorithm reproduces the same results as LHFM solutions at early time, where the cohesive zone is large compared with the fracture length. At large time, different cohesive models all tend to the same LHFM solutions. This indicates that the fracture energy dominates the fracture propagation regardless of the cohesive zone models. However, numerical oscillations are found during the application of Dugdale-Barenblatt model, which are not observed in the analytical solutions using Dugdale-Barenblatt model. These oscillations are not real and are related to the discretization of the mesh, the injection volume and the sudden drop of cohesive forces in the model.

Influence of the mesh size

The numerical accuracy relies on the mesh size, especially for the problem related to cohesive zone, where the cohesive length is small compared with the whole fracture length, but characterizes the most important critical fracture energy during the propagation. We calculate the relative error of the dimensionless net pressure and fracture length, see Figure 3. One finds that all of these models get decreasing errors while increasing the element number, from which we can control the relative errors by playing the relation between the critical opening and the mesh size.

Figure 3 also shows the relative errors of the fracture length. Knowing that the cohesive length determines the relative error, it’s more reasonable to compare the fracture length with the LHFM solutions after taking off the cohesive length (the length whose corresponding opening is below the critical opening \( w^* \)). However, this method is only correct for the linear softening model, where the cohesive length zone covers all the fracture energy. This explains the increasing relative error for the exponential linear model which has a more important part of fracture energy outside the calculated cohesive zone.

IV. Results and analysis

IV.1. Scaling parameters

The numerical results obtained with a cohesive zone model deviates from the LHFM solution at early time, where the cohesive zone is large compared with the fracture length. At large time, different cohesive models all tend to the same LHFM solutions. This indicates that the fracture energy dominates the fracture propagation regardless of the cohesive zone models. However, numerical oscillations are found during the application of Dugdale-Barenblatt model, which are not observed in the analytical solutions using Dugdale-Barenblatt model. These oscillations are not real and are related to the discretization of the mesh, the injection volume and the sudden drop of cohesive forces in the model.

Effect of cohesive zone models

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V. Conclusions

1. The numerical algorithm reproduces the same results as LHFM solutions at large time when the cohesive zone is small compared to the fracture length. The shape of the material softening law or cohesive zone model does not influence the results.

2. The accuracy of this method depends on the mesh refinement in the cohesive zone model. Further work would be done in studying the deviation of Poiseuille law coupled with the solid non-linearity. A spectral approach would be used to improve the numerical precision limited by the numerical cost of the method mentioned in this work. Moreover, a mesh-adaptive method would also be studied.

VI. Future work

Further work would be done in studying the deviation of Poiseuille law coupled with the solid non-linearity. A spectral approach would be used to improve the numerical precision limited by the numerical cost of the method mentioned in this work. Moreover, a mesh-adaptive method would also be studied.

VII. References


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