Modelling hydraulic-fracturing in 2D*

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Abstract

Hydraulic fracturing is an important process for fluid flow in the subsurface. It appears in a variety of natural systems such as: a fluid release mechanism from reservoirs during pressure build-up over geological time, primary migration of hydrocarbons, melt migration in the crust, melt intrusions as sills and dykes, mud volcanoes and hydrothermal plumes. In reservoir engineering, it is an important mean to increase the reservoir productivity or injectivity of wells.

Introduction

We have developed a finite element procedure for the modelling of hydraulic fracturing. The procedure is so far in 2D and it has been tested with fluid injection and pressure build-up from a well (Figure 1). The model is based on the Biot equations for coupled fluid flow and deformations in the rock. Fractures are represented on the same grid as the rock. Two important properties of the fracture are its volume and its ability to conduct fluid, which are represented by means of “fracture porosity” and “fracture permeability”, respectively. These properties are represented on the original grid, and it is therefore possible to make a uniform finite element formulation for both the rock and the fracture on the same grid.

Discussion

Fracture propagation takes place as discrete events when the fracture extends into one or more elements. The element size is therefore the smallest step a fracture can advance during propagation. The fracture volume, represented by equivalent fracture porosity, is important because it controls the pressure drop that follows an event. A fracture event is assumed to take place instantaneously. The volume of fluid in the fracture is then the same right after an event as it was right before the event. A fracture becomes extended after an event, and a lower pressure is normally needed to keep a “long” fracture open than a “short” fracture. Furthermore, a reduced fracture width is needed after the event for the fracture to have the same volume.

The current implementation of hydraulic-fracturing is tested by fluid injected from a well. We model the pressure build-up between the fracture events and the pressure drop that follows an event. The modelling shows that the well pressure during hydraulic fracturing fluctuates around a plateau value (Figure 2).

The rock strength is assigned to the element sides in the current 2D implementation. An element side is called a bond and it has a bond-strength. When a bond is stretched beyond the strength-limit, defined in terms of strain, it breaks. The use of bond-strength is a concept taken from other 2D models of hydraulic-fracturing, like the spring-model and the beam-model. When a bond at the fracture surface breaks it implies that the element on the outside changes properties from rock to fracture. A fracture element has zero (or almost zero) Young's modulus, and it gets fracture porosity and fracture permeability. A limitation of the use of bond-strength is that it currently allows for only Mode I fractures.

The bond-strengths depend on the grid size. It is shown numerically that the bond-strength scales as the square root of the number of nodes in a spatial direction. This result is shown to follow from the linear elastic stress singularity at a fracture tip.

A constant bond-strength models a homogeneous rock. Assigning random strength to the bonds makes the rock heterogeneous. We have tested both cases on a reservoir scale. The homogeneous case shows an initial increase in the fluid pressure until the first bonds breaks. Then follows a train of fracture events where one bond is broken at a time, with a slight pressure increase in between. A linear fracture develops symmetrically around the injection well.

The heterogeneous case is different in several respects. After the initial pressure build-up, which breaks the first bond, follows intermittent fracturing. It is a non-even period between the fracture events and several bonds may break in each fracture event. The fracture that develops shows branches.

Summary

There are no size restrictions in the model. It can equally well be applied on a reservoir scale as on a core scale. Although we have only tested the model with fluid injection we think that it has the potential to model hydraulic fracturing in other processes like for instance primary migration and fracturing of seals from overpressure build-up in reservoirs.

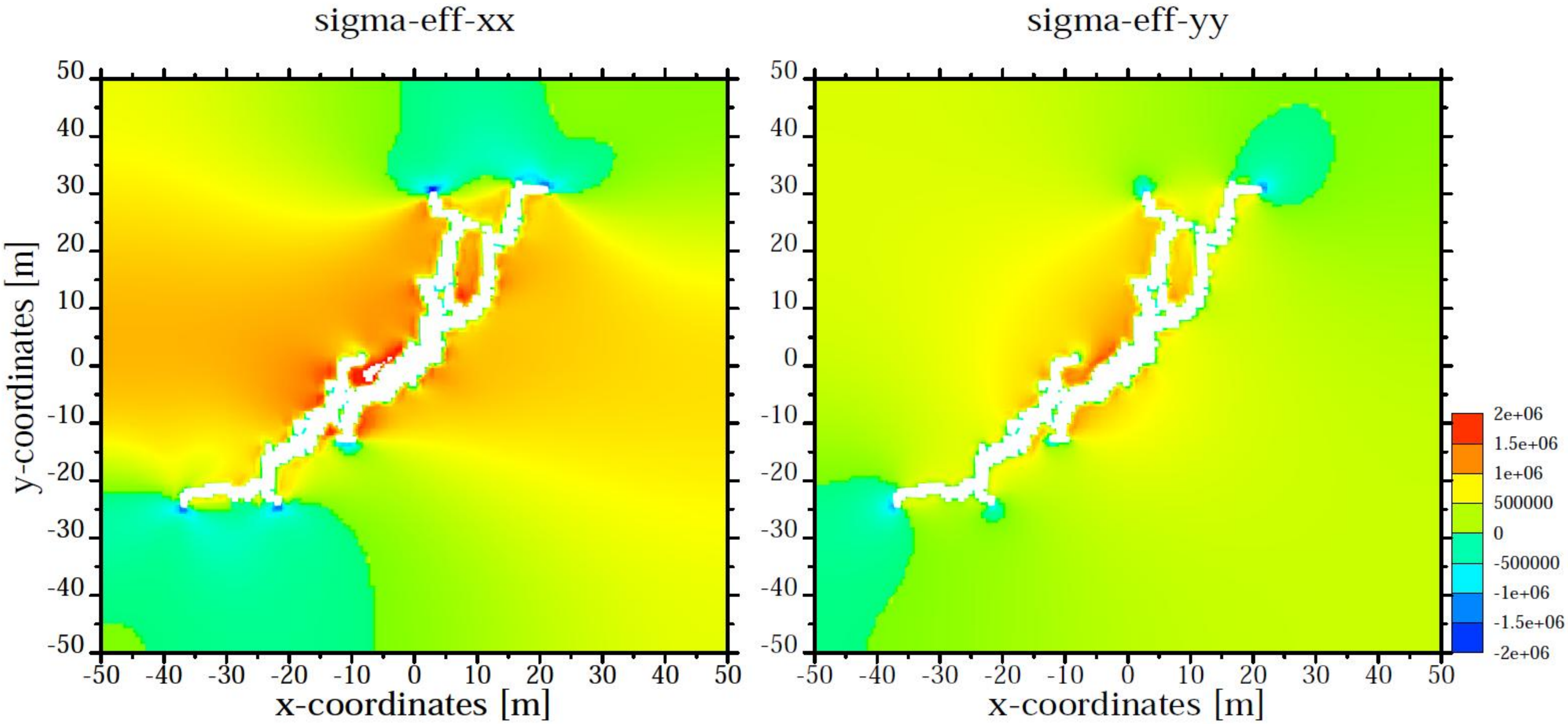

Figure 1. The normal effective stresses in the x- and y-directions. The plot shows the stress concentration at the fracture tips.

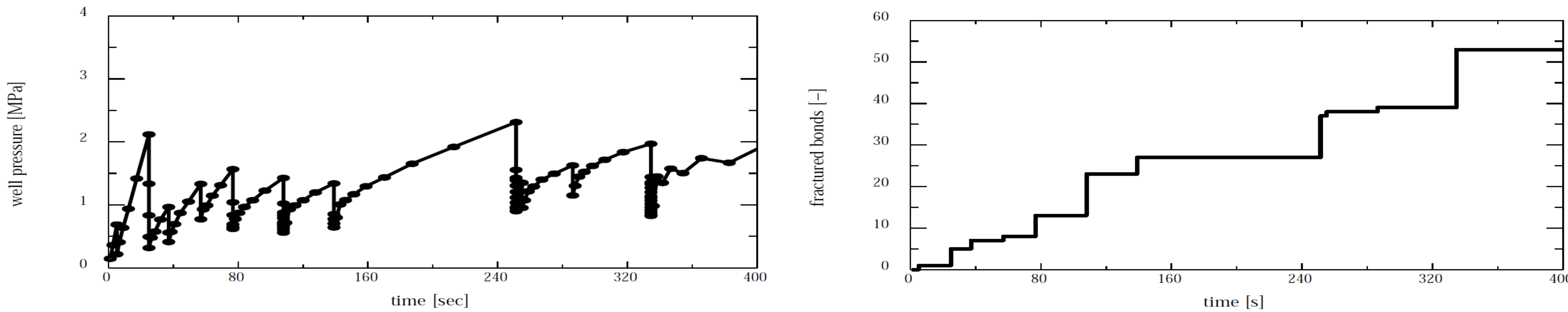

Figure 2. Left: The well pressure as a function of time. The dots on the curve show the time steps. Right: The number of broken bonds as a function of time.