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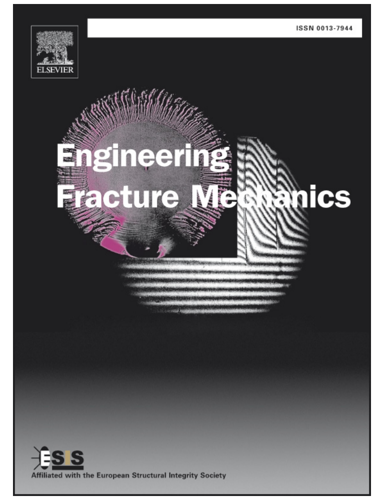

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An enhanced pseudo-3D model for hydraulic fracturing accounting for viscous height growth, non-local elasticity, and lateral toughness

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Abstract

The goal of this paper is to develop a more accurate pseudo-3D model for hydraulic fracturing. The primary weaknesses of the classical pseudo-3D model are: 1) its inability to capture viscous height growth, and 2) its failure to include lateral fracture toughness. These flaws are addressed respectively by: 1) introducing an apparent fracture toughness in the vertical direction, and 2) using an approximate non-local elasticity operator. To evaluate the accuracy and the level of improvement of the model we have developed, the results are compared to the predictions calculated using a recently developed fully planar hydraulic fracturing simulator.

Keywords: Hydraulic fracturing, pseudo-3D model, non-local elasticity.

1. Introduction

Hydraulic fracturing (HF) is a process in which a pressurized fluid is injected into rock to cause fracture initiation and propagation. Industrial applications of HF include accelerating the waste remediation process [1], waste disposal [2], preconditioning in rock mining [3], and oil and gas reservoir stimulation [4], where the latter stands out as one of the most common applications.

To successfully apply HF, the treatment should be designed using an appropriate HF model or numerical simulator. The earliest models started with the simplest one-dimensional Khristianovich-Zheltov-Geertsma-De Klerk (KGD) model [5], in which the fracture propagates under plane strain conditions and the coupling between viscous fluid flow and elasticity is included. Later, the Perkins-Kern-Nordgren (PKN) model [6, 7] was developed to simulate fracture propagation in a horizontally layered medium. The PKN model assumes that the fracture propagates in the horizontal direction (i.e. along the reservoir layer) and has a constant height that is equal to the thickness of the reservoir layer. Each vertical cross-section is assumed to be elliptic with a uniform fluid pressure, where the latter is calculated assuming that a state of plane strain prevails in each vertical plane. The primary advantage of the PKN model lies in its computational efficiency, since averaging over the vertical direction reduces the calculations to solving a one-dimensional problem.

To allow for height growth, the pseudo-3D (P3D) model has been developed [8, 9, 10] as an extension of the PKN model. There have been multiple variations of the P3D model. In particular, the geometry of the fracture was either approximated by ellipses or the fracture's lateral dimension was divided into elements, where each element had a specific height. The first case corresponds to the so-called lumped P3D model [11, 12], while the second variation is called a cell-based P3D model [9, 10]. In addition, two types of height growth mechanisms were used: i) equilibrium height growth [9], and ii) dynamic height growth [10]. In the first case it is assumed that the pressure is uniform and a toughness propagation criterion is used to calculate the fracture height. In the second case the height is calculated from the solution of a KGD problem (or its approximation) for each vertical cross-section.

With the advent of more computational power, scientific effort has shifted towards developing more accurate planar 3D models (PL3D) [13, 14, 15]. In such models, the fracture footprint is assumed to be planar and is discretized using a two-dimensional mesh. Two-dimensional fluid flow and elastic interactions between all elements are then considered. These modifications significantly increase the accuracy of HF