

Modeling Hydraulic Fracture Entering Stress Barrier: Theory and Practical Recommendations

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Abstract

Numerical modeling of hydraulic fracturing is complicated when a fracture reaches a stress barrier. For high barriers, it may require changing of a computational scheme. Despite there are examples of modeling propagation through barriers, there is no general theory clarifying when and why conventional schemes may become inefficient, and how to overcome computational difficulties. The paper presents the theory and practical recommendations following from it.

We start from the definition of the barrier intensity, which exposes that the barrier strength may change from zero for contrast-free propagation to infinity for channelized propagation. The analysis reveals two types of computational difficulties caused by *spatial discretization*: (i) *general* arising for fine grids and aggravated by a barrier; and (ii) *specific*, caused entirely by a strong barrier.

The *asymptotic approach* which avoids spatial discretization is suggested. It is illustrated by solving *bench-mark* problems for barriers of arbitrary intensity. The analysis distinguishes three typical stages of the fracture penetration into a barrier, and provides theoretical values of the Nolte-Smith slope parameter and arrest time as functions of the barrier intensity.

Special analysis establishes the accuracy and bounds of the asymptotic approach. It appears that the approach provides physically significant and accurate results for fracture penetration into high, intermediate and even weak stress barriers.

On this basis, simple practical recommendations are given for modeling hydraulic fractures in rocks with stress barriers. The recommendations may be promptly implemented in any program using spatial discretization to model fracture propagation.

Keywords Hydraulic fracture; Stress barrier; Barrier intensity; Numerical modeling

1 Introduction

Since early studies of hydraulic fracturing (HF) (e.g., Perkins and Kern 1961; Nordgren 1972), the impact of stress inhomogeneity on the fracture propagation has been taken into account. Specifically, channelized propagation along a pay-layer between impenetrable neighbors was simulated by the classical Perkins-Kern-Nordgren (PKN) model. However, with increasing pumping pressure, a fracture extends also into neighbor layers, what affects final footprints and openings, and so, the efficiency of a HF treatment. This stimulated effort to account for the fracture growth beyond a pay-layer, which resulted in successive development of pseudo-three dimensional (P3D) models (Settari and Cleary 1982, 1986; Palmer and Carroll 1982, 1983; Palmer and Craig 1984; Meyer 1986; Morales 1989; Warpinski and Smith 1989; Mack and Warpinski 2000; Adachi et al. 2007; Rahman and Rahman 2010; Dontsov and Peirce 2015; Linkov and Markov 2020). They complemented the PKN model by equations for out-of-layer growth.

All these models presume that the variation of in-situ stresses, caused by the difference in elastic modules of rock layers, impacts the fracture growth much more significantly than the difference in the modules itself. Then rock mass may be assumed homogeneous, while the assigned initial stresses change. Numerical results, obtained by solving problems for a crack, intersecting layers with different elastic modules and different assigned stresses (Erdogan and Biricikoglu 1973; Peirce and Siebrits 2001a), support the suggestion on the predominant impact of stress-contrasts. Other solutions for 3D layered structures with

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Practical Guide To Hydraulic Fracture

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