A Numerical Rocks Physics Approach to Model Wave Propagation in Hydrocarbon Reservoirs

2017 PIMS WORKSHOP on Imaging and Inversion, Calgary University, Calgary, Alberta, May 23-26, 2017

Juan E. Santos,

Department of Mathematics, Purdue University, West Lafayette, Indiana, USA, Instituto del Gas y del Petróleo (IGPUBA), Universidad de Buenos Aires, Argentina, and Universidad Nacional de La Plata, Argentina.
In collaboration with P. M. Gauzellino, Ariel Sanchez Camus and Robiel Martinez Corredor, Universidad Nacional de La Plata, Argentina.

March 9, 2017

Fractured media. I

- Fractures are common in the earth's crust due to different factors, for instance, tectonic stresses and natural or artificial hydraulic fracturing caused by a pressurized fluid.
- Seismic wave propagation through fractures and cracks is an important subject in exploration and production geophysics, earthquake seismology and mining.
- Fractures constitute the sources of earthquakes, and hydrocarbon and geothermal reservoirs are mainly composed of fractured rocks.

Fractured media. II

- Modeling fractures requires a suitable interface model. Schoenberg (JASA (1980), GP (1983)) proposed the so-called linear-slip boundary condition model (LSBC), based on the discontinuity of the displacement across the fractures. (Schoenberg's model).
- A generalization of the (LSBC) (Carcione, JGR (1996)) states that across a fracture stress components are proportional to the displacement and velocity discontinuities through the specific stiffnesses and specific (viscosities), respectively.

Fractured media. III

- Displacement discontinuities conserve energy, while velocity discontinuities generate energy loss at the fractures. The specific viscosity accounts for the presence of a liquid under saturated conditions, introducing a viscous coupling between both sides of a fracture.
- Schoemberg's theory predicts that a dense set of parallel plane fractures behaves as a Transversely Isotropic Viscoelastic (TIV) medium if the dominant wavelength of the traveling waves is much larger than the distance between the fractures.

Fractured media. IV

- Schoenberg's model has never been simulated with a numerical method.
- To test the theory, in the context of Numerical rock physics we developped a novel numerical solver that can be used in more general situations.
- Numerical rock physics offer an alternative to laboratory measurements.
- Numerical experiments are inexpensive, repeatable, essentially free from experimental errors and can easily be run using alternative models of the materials being analized.

Fractured media. V

- To determine the complex stiffness coefficients of the equivalent TIV medium, we solve a set of boundary value problems (BVP's) for the wave equation of motion in the frequency-domain using the finite-element method (FEM).
- The BVP's represent harmonic tests at a finite number of frequencies on a sample having a dense set of fractures, modeled using the LSBC.

The equivalent TIV medium. I

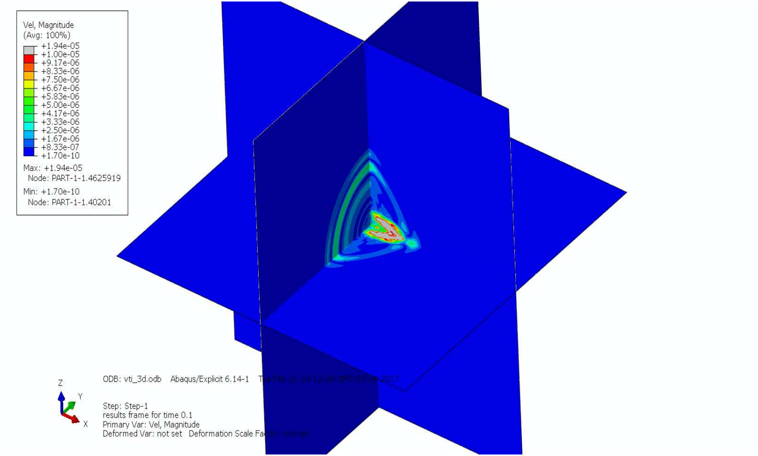
Consider a viscoelastic isotropic background medium having a set of parallel (horizontal) fractures and its description in the space-frequency domain.
$\mathbf{u}$, $e_{ij}(\mathbf{u}), \sigma_{ij}(\mathbf{u})$: frequency domain displacement vector, strain components and stress components of the background medium.
The stress-strain relations and equations of motion:

$$\sigma_{jk}(\mathbf{u}) = \lambda \delta_{jk} \nabla \cdot \mathbf{u} + 2\mu e_{jk}(\mathbf{u})$$

$$\rho \omega^2 \mathbf{u}(x,z,\omega) + \nabla \dot{U} \cdot \boldsymbol{\sigma}[\mathbf{u}(x,z,\omega)] = 0$$

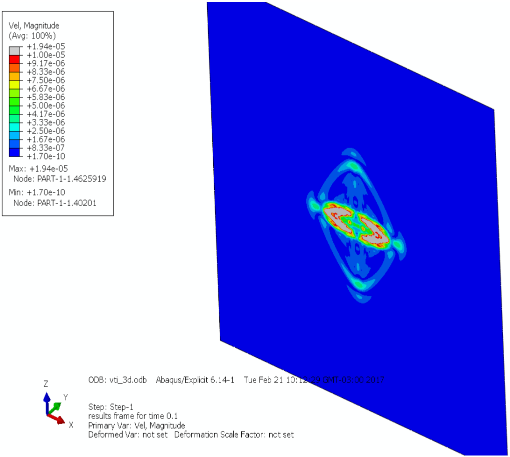
δ_{jk}: Kroenecker delta λ, μ: complex Lamé constants ρ: mass density.

3D VTI wave fronts at 100 ms. Brine in background and fractures



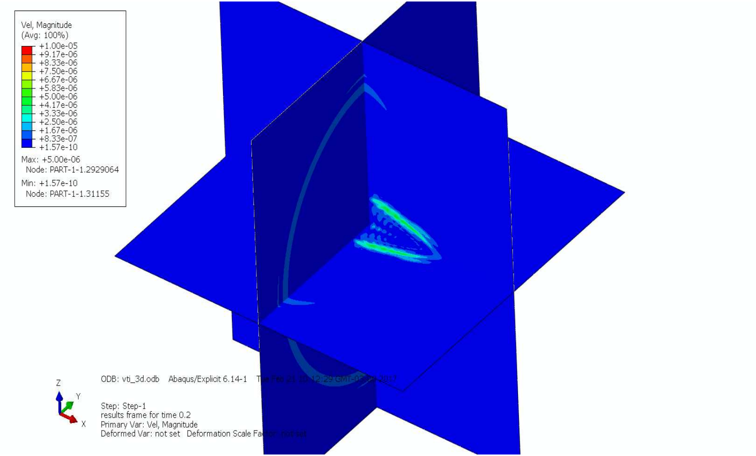
fracture aperture is 1 mm

2D VTI wave fronts at 200 ms, plane (x, z). Brine in background and fractures



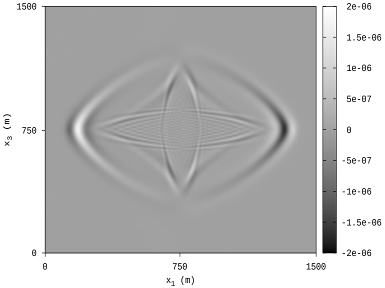
fracture aperture is 1 mm

3D VTI wave fronts at 200 ms. Brine in background and fractures

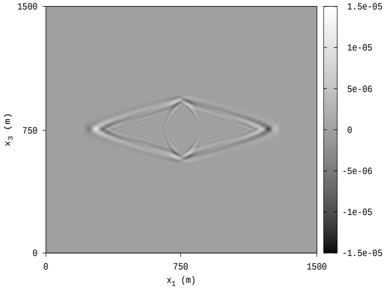


fracture aperture is 1 mm

2D VTI wave fronts at 200 ms, plane (x, z). Full brine versus full gas saturation



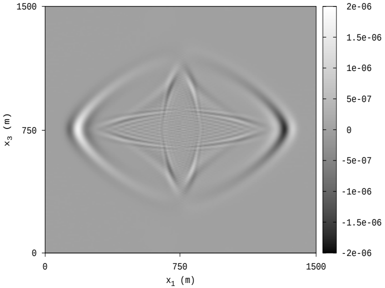
(a)



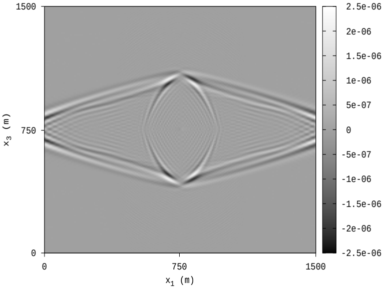
(b)

Fracture aperture is 1 mm. (a) : Full brine saturation, (b) : Full gas saturation.

2D VTI wave fronts at 300 ms, plane (x, z) . Full brine versus full gas saturation



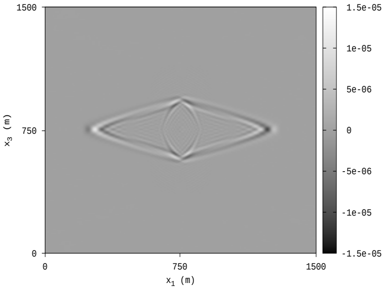
(a)



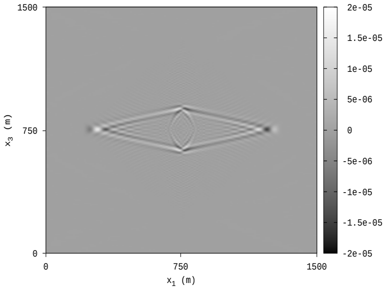
(b)

Fracture aperture is 1 mm. (a) : Full brine saturation, (b) : Full gas saturation.

2D VTI wave fronts at 200 ms, plane (x, z). Full gas versus full gas in background-full brine in fractures



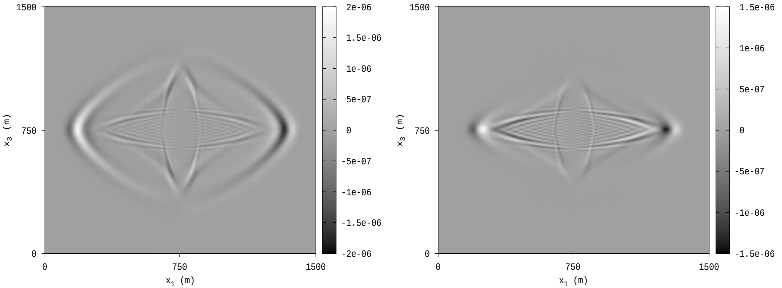
(a)



(b)

Fracture aperture is 1 mm. (a) : Full brine saturation, (b) : Full gas saturation in background- full brine saturation in fractures

2D VTI wave fronts at 200 ms, plane (x, z). Full brine versus patchy gas-brine saturation, 10% gas.



(a) (b)

Fracture aperture is 1 mm. (a) : Full brine saturation, (b) : Patchy gas-brine saturation in background and fractures