Harmonic
experiments to
model fracture
induced
anisotropy

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- **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**.

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- 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.

- 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.

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- Schoenberg's model has never been simulated with a numerical method.

- To test the theory, in the context of Numerical rock physics we developed 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.

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- 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.

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:

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

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

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