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Physical mechanisms for low-frequency seismic wave attenuation in fractured media

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Abstract

Attenuation and dispersion of seismic waves is an important parameter for analyzing seismic data, because it can provide additional information compared to analysis based only on velocity and density. Understanding the mechanisms causing attenuation is a challenging rock physics task.

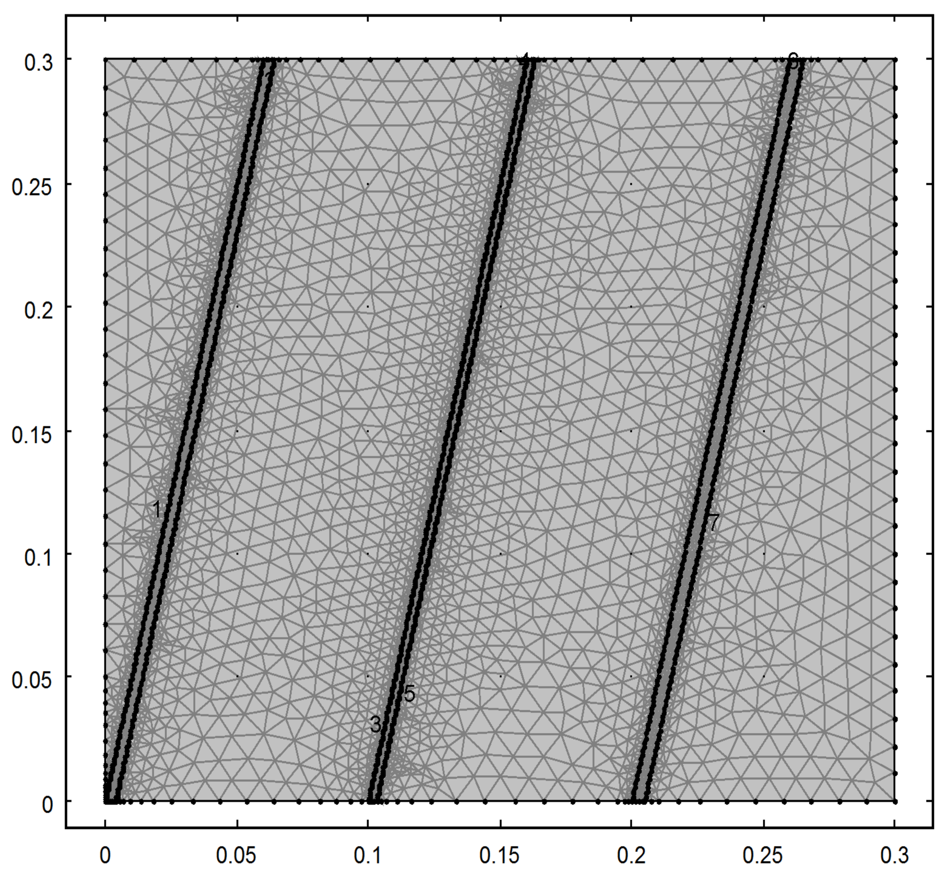
In fractured rocks, special attenuation mechanisms occur. We present two physical mechanisms that can cause attenuation and dispersion of seismic waves in fractured media.

1. Wave-induced fluid flow
2. Krauklis wave initiation

Both mechanisms are studied numerically using the FEM.

Wave-induced fluid flow

We performed 2D numerical simulations of a quasi-static experiment to calculate attenuation ($1/Q$) caused by wave-induced fluid flow in a heterogeneous poro-elastic medium (with patchy saturation and double porosity). The methodology is described in Quintal et al. (2011) and COMSOL Multiphysics was used for these simulations. The finite element method using an unstructured mesh (Figure 1) was applied. The model consists of gas-saturated kerogen-rich shale with open fractures, which are saturated with water (injected during the fracturing). The petrophysical properties for such model is shown below in Table 1. The fractures, shown in Figure 1, are 4, 3, and 5 mm thick, respectively, from left to right. A zoom in the 3-mm fracture is shown in Figure 2. The results of the simulation are shown in Figure 2. The minimum value of Q is 10.2 at 1.6 Hz.



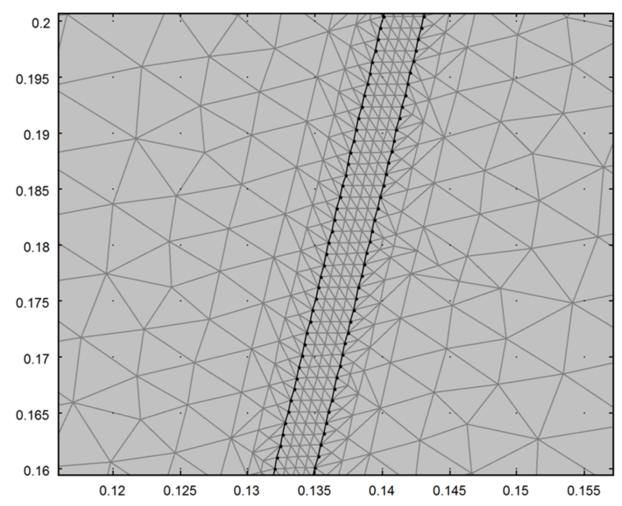


Figure 2: *Zoom in the model shown in Figure 1 for visualization of the elements within the fractures.*

Figure 1: *Model (0.3 x 0.3 meters) and the unstructured triangular finite-element mesh of the fractured medium.*

Physical properties of the fractured medium:

Region	*Host rock*	*Fractures*
Solid frame	*Shale & kerogen*	*Unconsolidated sand*
ρ_s (kg/m³)	2450	2650
K_s (GPa)	34	40
ϕ (%)	0.05	0.50
k (mD)	5×10^{-14}	5000
K (GPa)	12	5
μ (GPa)	8	1
Fluid	*Gas*	*Water*
ρ_f (kg/m³)	140	1000
K_f (GPa)	0.02	2.4
η (Pa·s)	2×10^{-5}	0.003

Table 1: *Petrophysical model properties.*

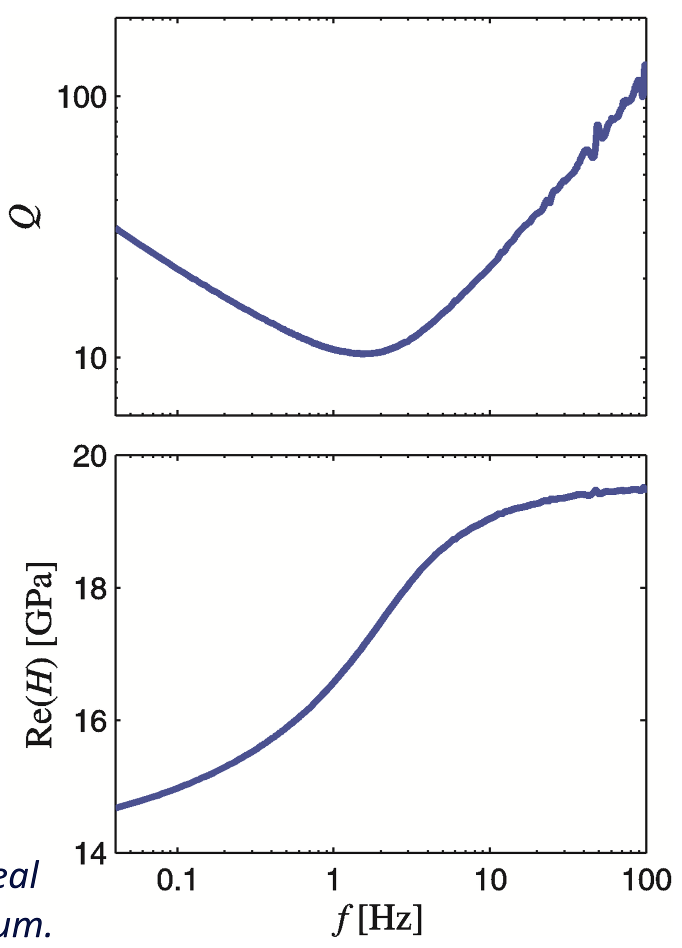
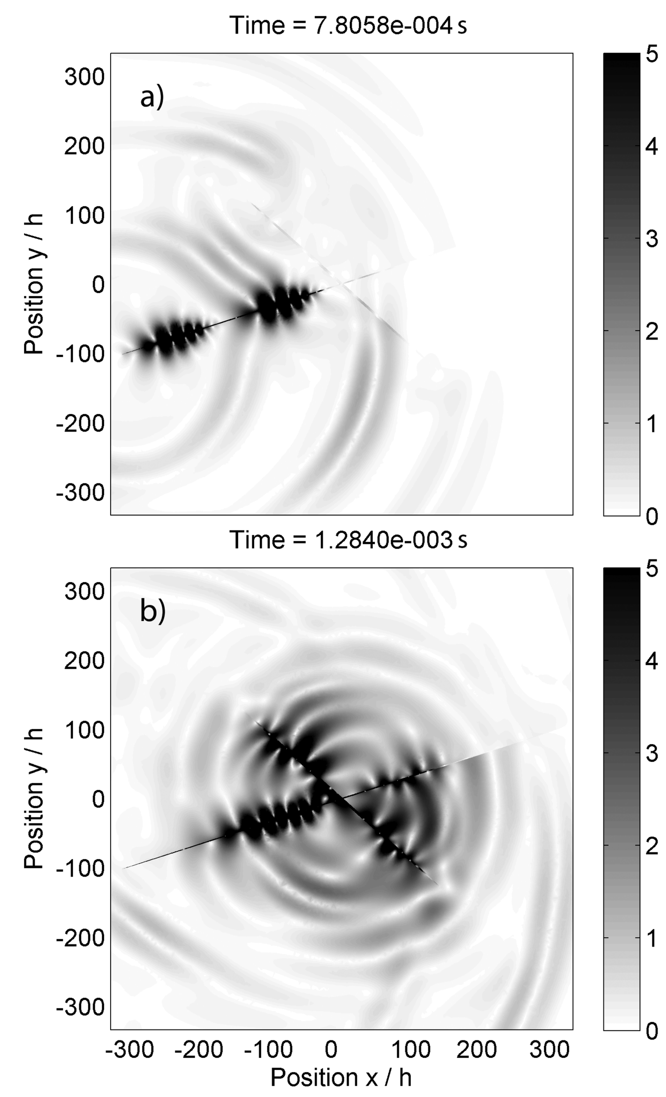


Figure 3: *Results for the quality factor (Q) and the real part of the P-wave modulus (H) in the fractured medium.*

Krauklis wave initiation



The Krauklis wave (Korneev et al., 2012) is a special wave mode that is bound to and propagates along fluid-filled fractures (Figure 3). Krauklis waves can propagate back and forth along a fracture and emit a periodic signal (Frehner and Schmalholz, 2010). Seismic data may contain this characteristic frequency and eventually reveal fracture-related petrophysical parameters of the reservoir.

Figure 3: *Simulation snapshots of a Krauklis wave propagating along a water-filled fracture and being scattered and reflected at an intersecting fracture.*

In existing models Krauklis waves initiate in the fracture (e.g., by hydrofracturing). Figure 4 shows for the first time how Krauklis waves are initated by a body wave. The plane P-wave is scattered and diffracted at the water-filled fracture (45° inclination) and two Krauklis waves are initiated, one at each fracture tip (i.e., diffraction points).

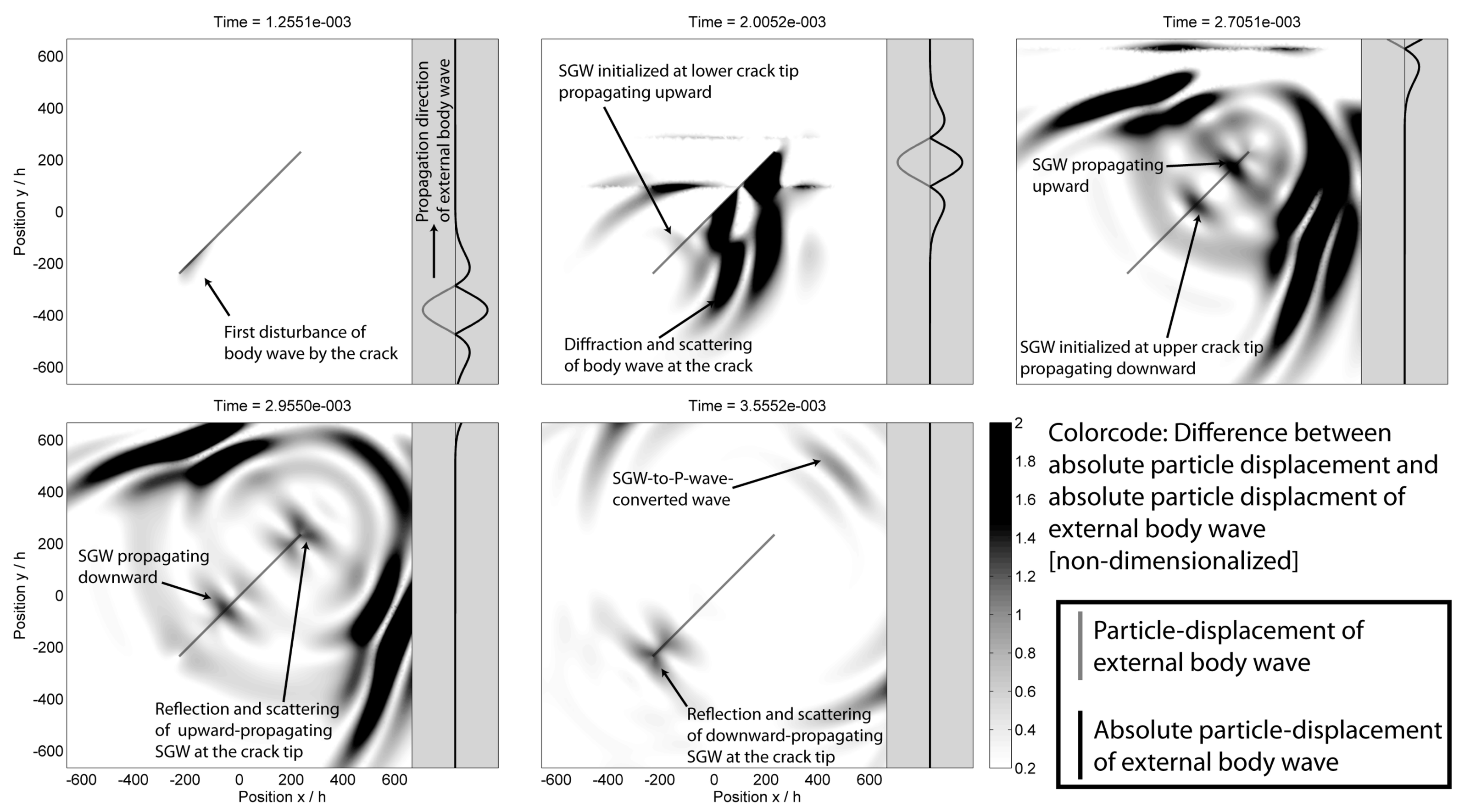


Figure 4: *Snapshots of Krauklis waves being initiated by a passing plane P-wave. The single wavelet propagates from bottom to top. Its profile is shown in gray sidebars. For visibility the particle displacement of the P-wave is substracted from the total particle displacement field.*

Initiating a Krauklis wave requires energy from the body wave, and therefore represents an attenuation mechanism for the body wave. By propagating back and forth the fracture, the Krauklis wave can emit a periodic body wave signal (Frehner and Schmalholz, 2010), which leads to a strong dispersion of the body wave. For more realistic crack geometries and/or intersecting cracks, more diffraction-points will lead to a higher probability to initiate Krauklis waves.

Discussion / Conclusions

Controlling fracture parameters is difficult in the lab and numerical methods are essential. Attenuation can be high due to large compliance contrasts between rock and fractures. Krauklis wave initiation is a potential attenuation mechanism, which needs further research.

References

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