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

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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. We present two physical mechanisms that can cause attenuation and dispersion of seismic waves.

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

Both mechanisms are studied numerically using the finite-element method.

1. Wave-induced fluid flow

We performed 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 fractures, also shown in Figure 1, are 4, 3, and 5 mm thick, respectively, from left to right. The medium is considered to be a repetition of the Representative Elementary Volume (REV) shown in Figure 1.

The results of the simulation are shown in Figure 2. The minimum value of Q is 10.2 at 1.6 Hz. H is the P-wave modulus, such that $V_P = \sqrt{H/\rho}$. From the simulation with closed calcite fractures, Q = infinite (and constant), and $\mathrm{Re}(H)$ = 2.5 GPa (constant).

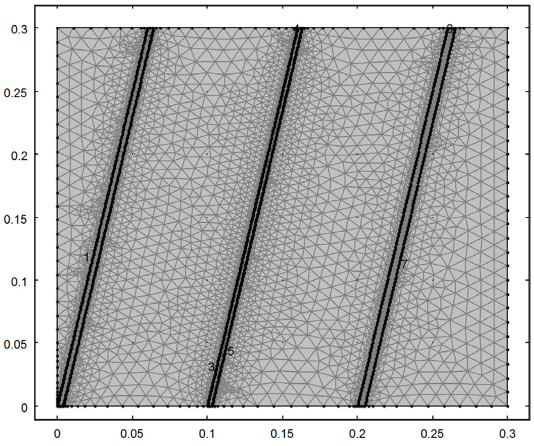

Figure 1: Model (0.3 x 0.3 m) and the unstructured triangular finite-element mesh of the fractured medium.

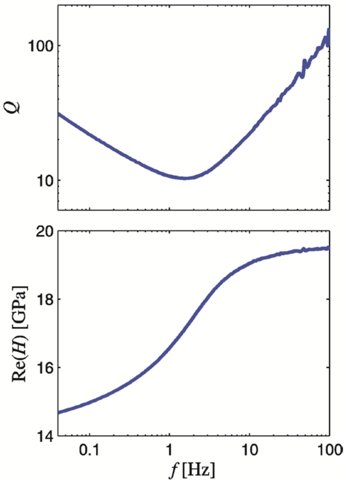

Figure 2: Results for the quality factor (Q) and the real part of the P-wave modulus (H).

2. Krauklis wave initiation

The Krauklis wave is a special wave mode that is bound to and propagates along fluid-filled fractures and can also influence seismic body waves. Krauklis waves can propagate back and forth along a fracture and emit a periodic signal (Frehner and Schmalholz, 2010). Seismic data can contain this characteristic frequency and eventually reveal fracture-related petrophysical parameters of the reservoir. Krauklis waves are well described mathematically for some theoretical cases. However, one key question that is still unclear is how Krauklis waves are initiated by a body wave passing a fluid-filled crack. Figure 3 shows a finite-element study for the case of a plane P-wave passing an elliptical water-filled crack with 45° inclination. The P-wave is scattered and diffracted at the crack and two Krauklis waves are initiated, one at each crack tip (i.e., diffraction points). For more realistic crack geometries and/or intersecting cracks, more diffraction-points will lead to a higher probability to initiate Krauklis waves.

The initiation of Krauklis waves by a passing body wave represents an energy transfer from the body wave to the fracture, and therefore 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. The efficiency of these processes remain to be studied in the future.

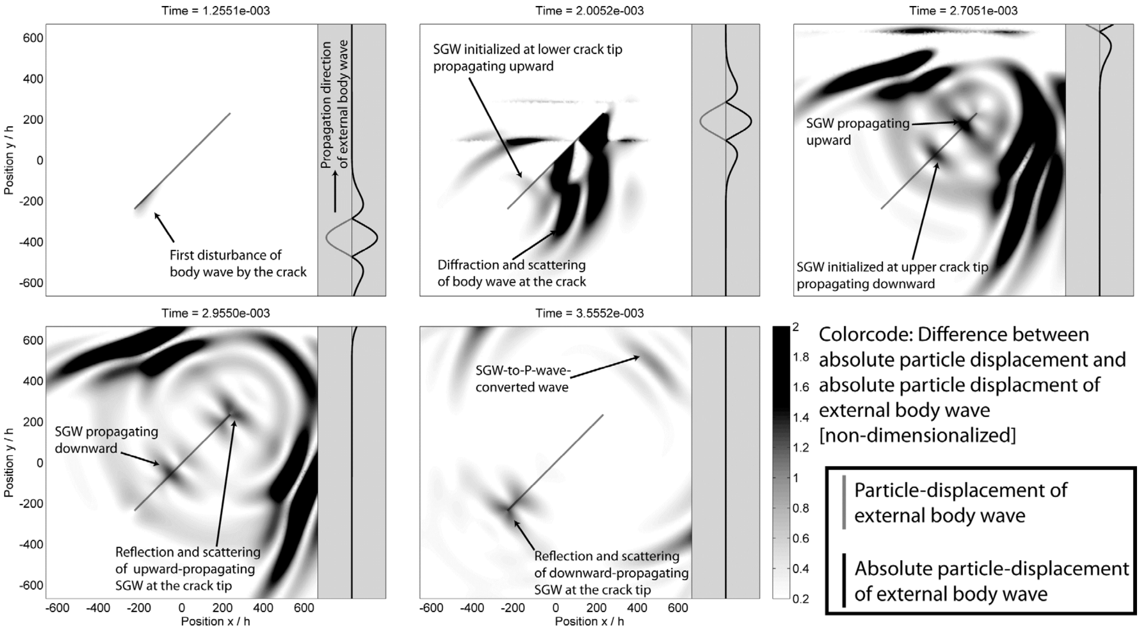

Figure 3: Snapshots of Krauklis waves being initiated by a passing plane P-wave. The single wavelet P-wave propagates from bottom to top and its profile is shown in the gray sidebars. The signal of the passing P-wave is subtracted from the total absolute particle displacement for better visibility.

REFERENCES

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