Laboratory evidence for Krauklis wave resonance in fractures

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Krauklis waves are of major interest since they can lead to resonance effects in fluid-filled fractured rocks. This resonant behavior should lead to strong frequency dependence for seismic body waves, enabling the identification of Krauklis wave-related signals in the coda of recorded seismograms (Korneev, 2008). Aki et al. (1977) and Chouet (1996) used this resonance effect to show the potential of volcanic eruption forecasting by recording long-period volcanic tremor signals, which provide information of the state of fluid in the subsurface. Tary et al. (2014) identified and interpreted the observed resonances during hydraulic fracturing activities. The frequency content of the recorded seismic signals contains useful information for understanding the reservoir formation. The characteristics of Krauklis waves might be one of the keys to reveal properties of fluid-bearing fractured rocks.

Frehner (2014) demonstrates that body waves are capable of initiating Krauklis waves and that the initiation strongly depends on the incident wave mode (P- or S-wave) and fracture orientation. This study also shows that incident S-waves may carry more information about fractures. Here we combine numerical modeling results with laboratory experiments to study and visualize fracture-related effects on seismic wave propagation. We present a laboratory study that mimics similar conditions as in the numerical experiments (Frehner, 2014) of a homogenous medium containing a single well-defined fracture. We record the signals obtained from propagating ultrasonic waves along a sample without a fracture and samples with a fracture with different inclination angles of 30°, 45°, and 60°.

Figure 1 presents the spectrograms of the receiver data. The presence of the fracture induces elevated amplitudes at low frequencies in the coda after the first arrival (150 µs onwards, Figure 1b, c, and d). The spectrogram for the case of 45° fracture inclination exhibits relatively larger amplitude around 0.1 MHz (200 µs, Figure 1c) as compared to the cases of 30° and 60°. This fracture-related effect is very narrow-banded exhibiting a signature frequency around 0.1 MHz and decays relatively slowly over time. The observed signature frequency is independent of the fracture orientation and lower than the used source frequency (i.e., 1 MHz). We interpret this effect as a resonance in the fracture. The resonance frequency is an intrinsic property of the fracture size and elastic properties. In addition, we plan to employ an analytical solution (Lipovsky and Dunham, 2015) to verify our laboratory results by investigating the relationship between the fracture width, fracture length, resonance frequency, and quality factor. The ultimate goal is to identify relationships between the recorded seismic signal and the fracture properties (e.g., geometry and orientation).

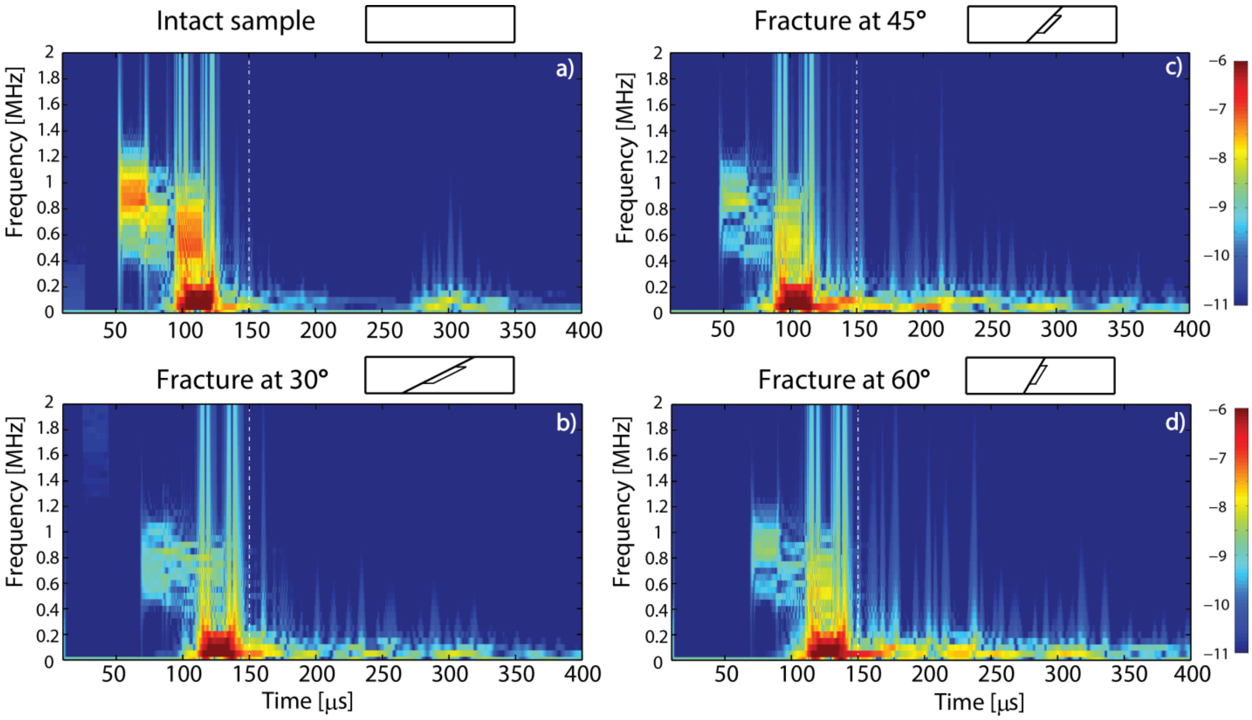

Figure 1. Spectrograms of receiver time signals generated by an S-wave with a dominant source frequency of 1 MHz propagating through the intact sample (a) ,and through fractured samples with a fracture inclination angle of 30° (b), 45° (c), and 60° (d), respectively.

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