# Stoneley guided wave reflection and scattering at the tips of fluid-filled finite fractures

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Understanding seismic wave propagation in fractured fluid-rock systems is important for estimating, for example, fluid properties or fracture densities from geophysical measurements such as ground motion. Stoneley guided waves have been used, for example, to explain long-period volcanic tremor signals or to propose potential methods for estimating the fluid properties in fractured rocks. In this study, the finite element method (FEM) is used to model two-dimensional wave propagation in an elastic rock with a finite crack filled with a viscous fluid. The surrounding rock is fully elastic with non-dispersive P- and S-waves able to propagate without attenuation. The fluid filling the crack is elastic in its bulk deformation behavior but viscous in its shear deformation behavior. Therefore, only P-waves are able to propagate in the crack, which are dispersive and attenuated. The crack geometry, especially the crack tip, is resolved in detail by the applied unstructured finite element mesh using 7-node triangles. A Stoneley guided wave is a special wave mode that is bound to and propagates along the crack with a much smaller velocity than all other waves in the system. In this study, the wave length of the Stoneley guided wave is around two orders of magnitude larger than the thickness of the crack. Its amplitude decreases exponentially away from the crack, which makes the Stoneley guided wave difficult to detect at relatively short distances away from the crack. At the tip of the crack the Stoneley guided wave is reflected. The reflection coefficient is calculated from numerical simulations and depends on the geometry of the crack and on the type of fluid filling the crack. For an elliptically shaped crack (aspect ratio of ellipse = 333) the reflection coefficient varies between 75% for oil and water and almost 100% for gas. Although the crack thickness is around two orders of magnitude smaller than the wave length of the Stoneley guided wave, the shape of the crack tip influences the reflection coefficient significantly. The reflection coefficient of a Stoneley guided wave at the tip of a straight water-filled crack with a flat crack tip is around 43%. The part of the Stoneley guided wave that is not reflected is scattered at the crack tip and emitted into the surrounding elastic rock as P- and S-waves. For fully saturated cracks the radiation of these elastic body waves points in all directions from the crack tip. In the presence of a small gas-cap at the tip of a fluid-filed crack the radiation of the elastic body waves is strongly forward directed. The relatively high reflection coefficient at the crack tip enables the Stoneley guided wave to travel several times back and forth along a finite crack before it lost too much of its initial energy. This leads to a periodic radiation of body waves at the crack tip. The corresponding frequency can be low in relatively small cracks due to the small velocity of Stoneley guided waves. The emitted elastic body waves may allow detecting Stoneley guided wave-related signals at distances away from the crack where the amplitude of the Stoneley guided wave itself is too small to be detected. Such low frequency signals may explain low frequency volcanic tremor, long-period volcanic earthquakes or low frequency tremor related to fractured hydrocarbon reservoirs.