Reflection, radiation and attenuation of Stoneley guided waves (SGW) in fluid-filled finite cracks*

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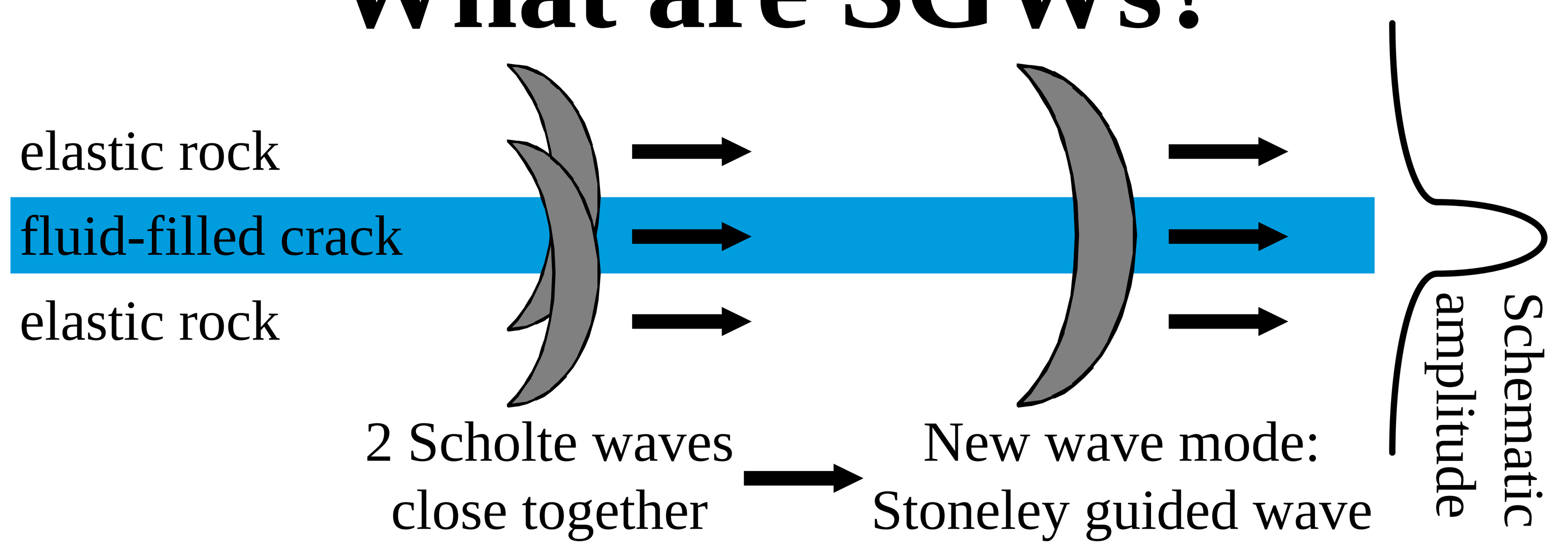
Summary

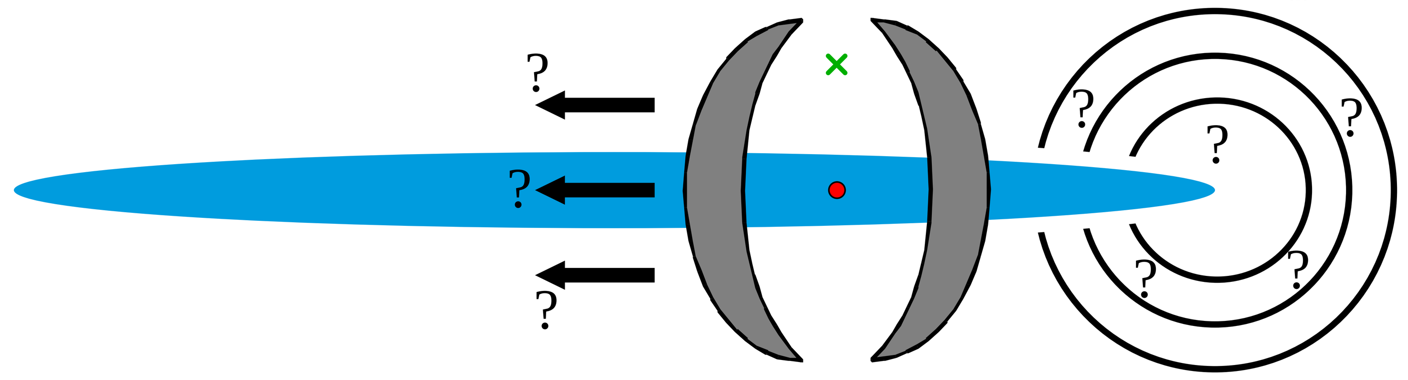
The reflection and scattering of Stoneley guided waves at the tip of a crack filled with a viscous fluid is studied numerically in two dimensions using the finite element method. The rock surrounding the crack is fully elastic and the fluid filling the crack is elastic in its bulk deformation behavior and viscous in its shear deformation behavior. The crack geometry, especially the crack tip, is resolved in detail by the unstructured finite element mesh. At the tip of the crack the Stoneley guided wave is reflected. The reflection coefficient is calculated from numerical simulations and depends on the type of fluid filling the crack and on the crack geometry. The part of the Stoneley guided wave that is not reflected is scattered at the crack tip and radiated into the surrounding elastic rock as body waves. For fully saturated cracks the radiation pattern of these elastic body waves points in all directions from the crack tip. The exponential amplitude decay of Stoneley guided waves away from the crack makes them difficult to detect at relatively short distances away from the crack. However, the radiated body waves may allow detecting Stoneley guided wave-related signals at greater distances away from the crack.

What are SGWs?

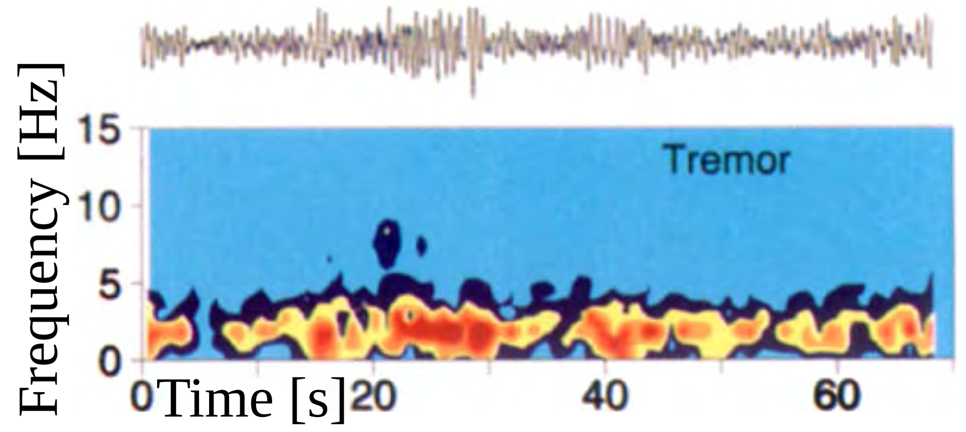


- Scholte wave: Interface wave between solid and fluid
- Interference between two Scholte waves propagating very close together leads to a new wave mode: The Stoneley guided wave
- Properties: Strongly dispersive ($V_{SGW} = 0$ for f = 0)
  Not attenuating for inviscid fluids
- Ferrazzini and Aki, JGR (1987); Korneev, Geophysics (2008)

Why are SGWs interesting?



- SGWs can exhibit a resonance frequency when propagating back and forth along a finite crack.
- Used for explaining low-frequency volcanic tremor (e.g. Chouet, Nature 1996)
- This study focusses on the reflection process.

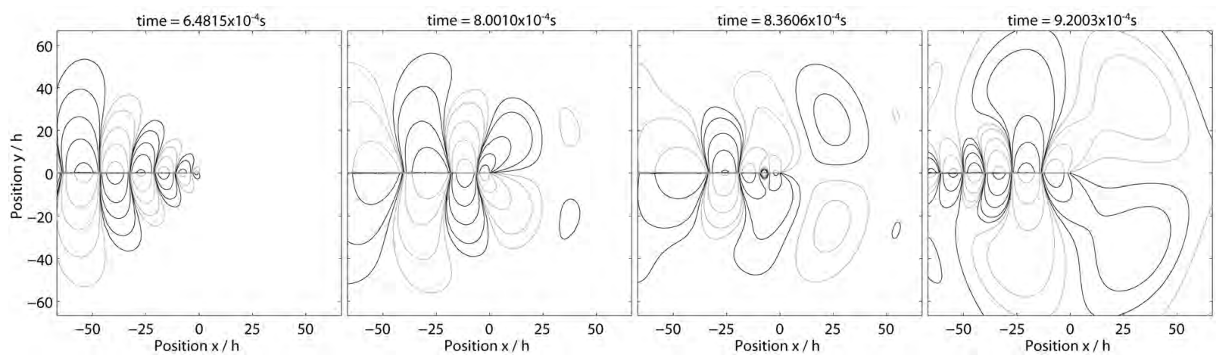


Chouet, Nature (1996)
Volcanic tremor,
Mt. Redoubt, Alaska
Continuous narrow-band seismic signal

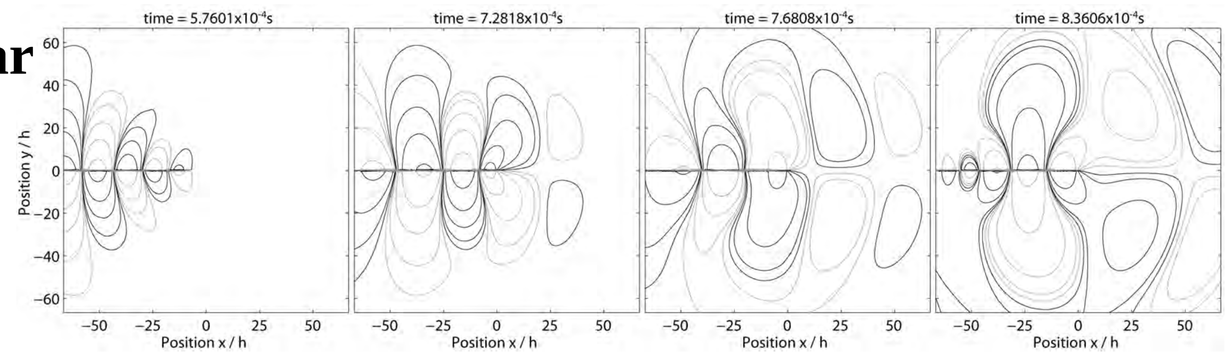
Radiation pattern

2D Finite element simulations of SGWs reflecting at the tip of water-filled cracks, vertical displacement is displayed as logarithmic contour lines (distance between 2 contour lines = $^1/_2$ order of magnitude), crack thickness : wave length ≈ 1 : 100

Elliptical crack: Low-amplitude radiation

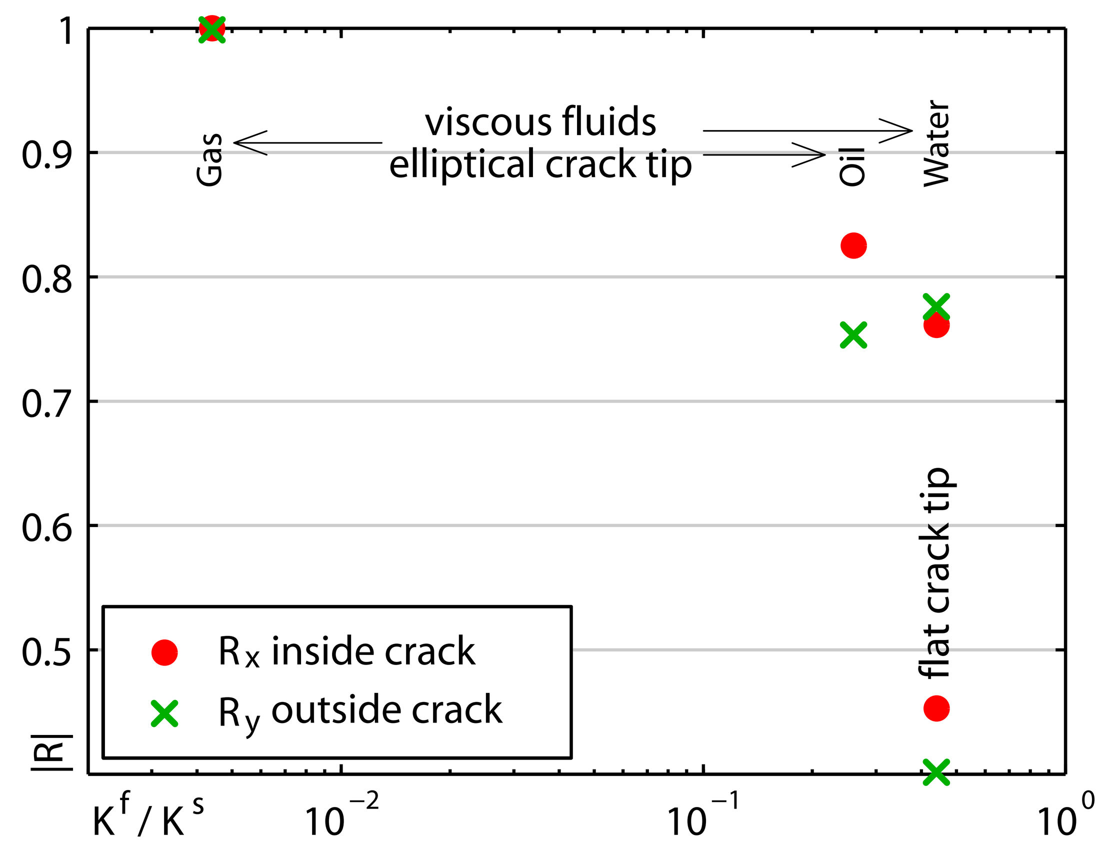


Rectangular crack: High-amplitude radiation

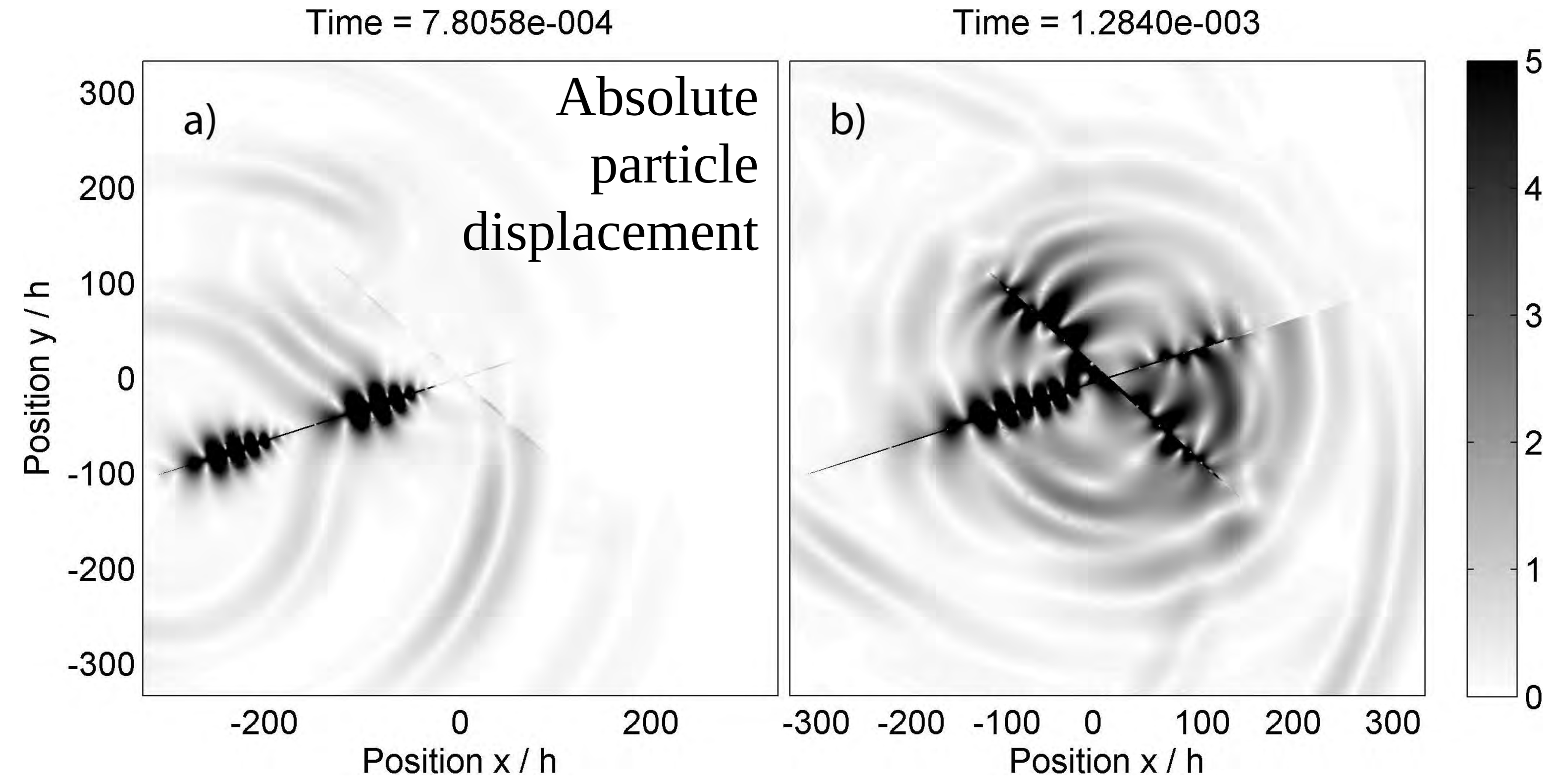


Reflection coefficient

During numerical simulations incident and reflected SGW amplitudes are measured at indicated virtual receivers. Reflection coefficient |R| is calculated from aplitude difference.



Intersecting cracks



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References

Chouet, B.A., 1996: Long-period volcano seismicity: Its source and use in eruption forecasting, Nature 380, 309-316
Ferrazzini, V. and Aki, K., 1987: Slow waves trapped in a fluid-filled infinite crack: Implications for volcanic tremor, Journal of Geophysical Research 92, 9215-9223
Korneev, V., 2008: Slow waves in fractures filled with viscous fluid, Geophysics 73, N1-N7, doi: 10.1190/1.2802174