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Micromechanical Modelling of Elastic Wave Velocity Variations for Intact Brittle Rocks

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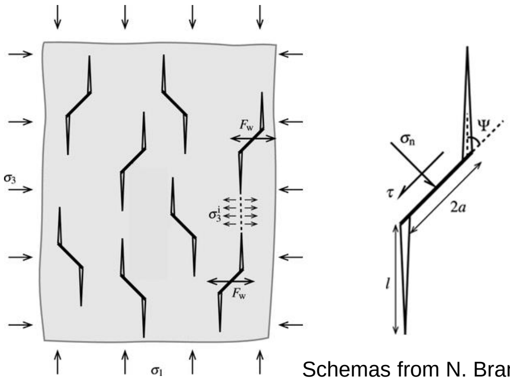
Introduction

In the brittle field, the growth and coalescence of microcracks lead to the formation of faults that play a critical role in lithosphere deformations, affecting seismology and reservoir engineering.

Cracks affect elastic parameters, anisotropy and reduce elastic wave velocities. Sayers & M. Kachanov [1] presented how elastic wave velocities are directly linked with an estimation of damage (crack density).

The wing crack model of Ashby & Sammis [2] is a simple micromechanical model that provides an estimation of the strength according to linear elastic fracture mechanics. The simplified geometry of cracks is presented on the right. The model also predicts the crack geometry, so it could be coupled with the Kachanov's theory.

If this coupling is proven effective by laboratory experiments, the model could be used to estimate in-situ stresses with elastic wave velocities as this process is shown reversible Passelègue *et al.* [3].

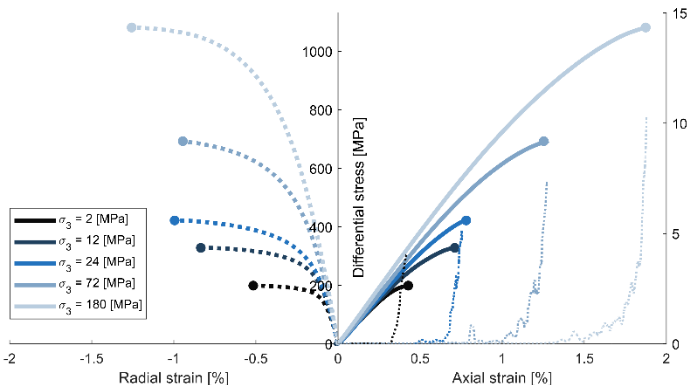


Schemas from N. Brantut

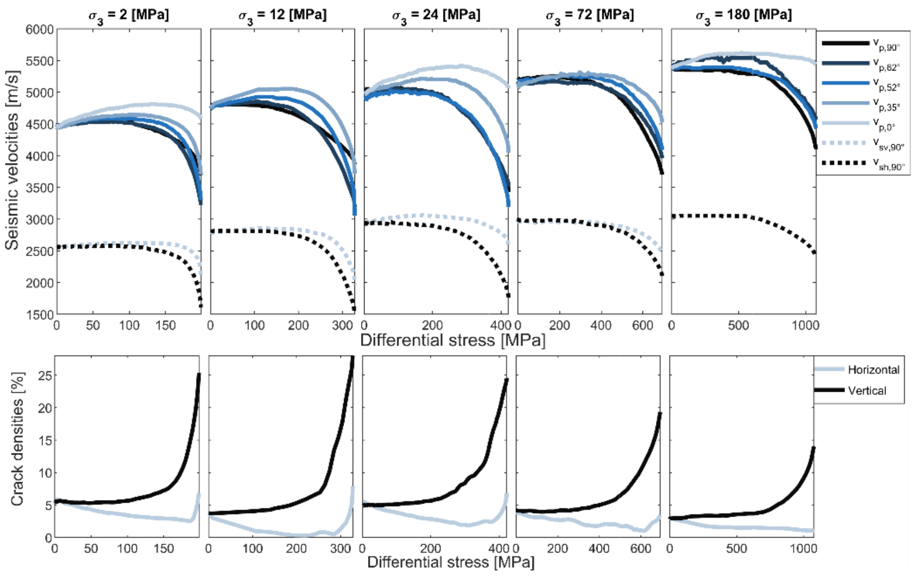
Method

Triaxial experiments were realized on Westerly Granite at various confining pressures while measuring stress, strains, accoustic emissions (AE) and the evolution of seismic velocities with various orientations for P and S-waves. The crack densities are directly inverted.

Experimental results



Strains stress plot with AE events above; the evolution of the seismic velocities and crack densities on the right.



Discussion

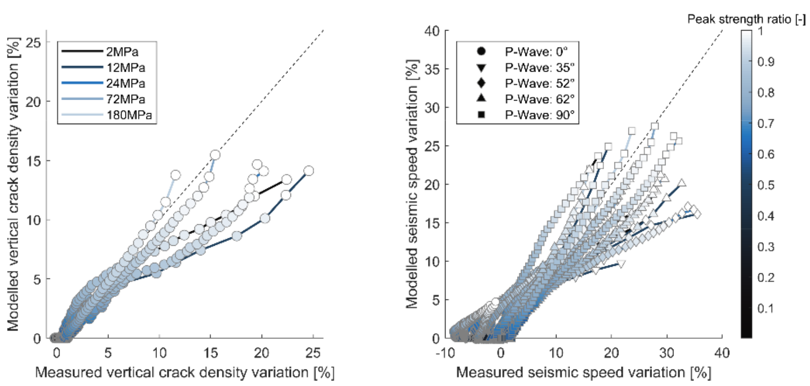
A long elastic phase is succeeded by a weakening caused by the crack propagation that ultimately leads to failure. During loading, velocities initially increase slightly, then decreases exponentially until failure. It is interpreted as an initial horizontal cracks closure, followed by a vertical crack growth (in the direction of the principal stress).

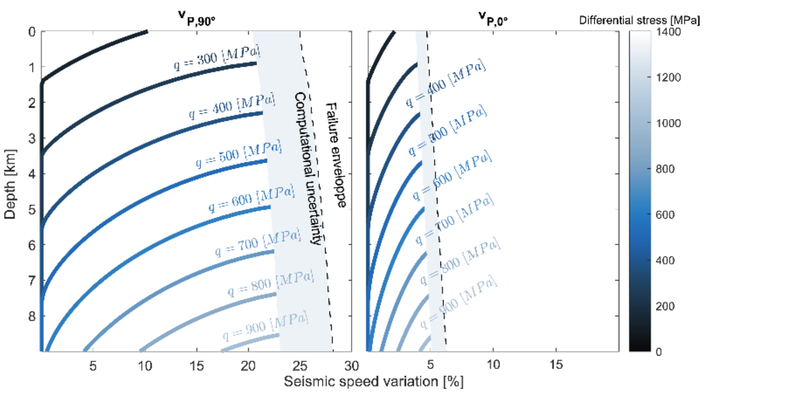
The failure envelope of these experiments fitted the parameters of the wing crack model with mediocre but acceptable accuracy. Then, the coupling with Kachanov's theory is realized from the definition of crack density.

The figure on the left shows the correlation between measured and modelled variations of the vertical crack density and of the velocities. Despite minor misfits (divergence close to failure and only vertical crack growth), the accuracy is excellent.

Hence, the model can be theoretically used to predict the velocity losses for any given loading as the figure on the bottom right shows. Note that:

- A budget of the energy dissipated to open cracks according to the mechanical results and the seismic velocities showed a compatibility with the use of the wing crack model.
- In-situ monitoring of shallow fault zones presented contradicting results Brenguier *et al.* [4]. The strength of fault zones is lower than crack nucleation process, so the model cannot be applied for damaged rocks.
- The model might be used for intact rocks or at depth where cracks are healing.





References

1. Sayers, C. M. & Kachanov, M. Microcrack-induced elastic wave anisotropy of brittle rocks. Journal of Geophysical Research: *Solid Earth* 100, 4149–4156 (1995).
2. Ashby, M. & Sammis, C. The Damage Mechanics of Brittle Solids in Compression. *Pure and Applied Geophysics* 133, 489–521 (1990).
3. Passelègue, F. X. et al. Development and Recovery of Stress-Induced Elastic Anisotropy During Cyclic Loading Experiment on Westerly Granite. *Geophysical Research Letters* 45, 8156–8166 (2018).
4. Brenguier, F. et al. Postseismic Relaxation Along the San Andreas Fault at Parkfield from Continuous Seismological Observations. *Science* 321, 1478–1481. (2008).