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Laboratory measurements of fluid pressure diffusion in a fractured carbonate sample

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Better understanding the complex poromechanics of fluid-saturated fractured rock is important to numerous areas in the exploitation of subsurface resources. Fluid pressure diffusion (FPD) between fractures and the embedding porous matrix and/or between interconnected fractures can be a significant source of intrinsic seismic wave attenuation and dispersion, as indicated by theoretical studies (e.g. Brajanovski et al., 2005, Rubino et al., 2013, Quintal et al., 2019). Experiments investigating fractured rocks are scarce and only recently has FPD from a saw cut fracture into the porous matrix been demonstrated during hydrostatic oscillations of the confining pressure (Gallagher et al., 2022).

We extend the investigation of Gallagher et al. (2022) to a more realistic scenario by using a carbonate sample with naturally occurring fractures that were delineated with micro-X-ray computed tomography (CT). In a novel setup, two pressure transducers were implemented to probe the pore fluid pressure response in the main fracture and in the porous background. Strain gauges mounted on the surface of the sample measured the radial and axial strains of the porous sample. Ultrasonic P- and S-wave travel times were measured along the axis of the cylindrical sample and perpendicular to the interface of the main fracture. Hydrostatic confining pressure oscillations were performed on the glycerin saturated sample to investigate the bulk modulus dispersion and attenuation. By adjusting the temperature of the experiment (19 to 45 ℃), an apparent frequency range as broad as 4×10-3 to 7 Hz could be investigated by scaling the measured frequency with the change in glycerin viscosity. The sample, fracture, sensor configuration, the locally measured attenuation and bulk modulus dispersion, as well as the pore pressure are shown in the supplementary figure.

The dry sample had significantly higher P-wave velocities in the axial direction compared to that in the transverse direction. Increasing the confining pressure up to 17 MPa increased the P-wave velocities, but it did not impact the anisotropy. This observation suggests that small cracks in porous matrix were closed, while the main fracture remained partially open. In the glycerin saturated sample, we observed negative bulk modulus dispersion and attenuation, which is a consequence of measuring the strain locally on the sample surface with strain gauges, as numerically demonstrated by Chapman and Quintal (2018). At low frequencies the pore pressure is equilibrated between the fracture and porous matrix, but with increasing frequency we observed a higher pore pressure response in the matrix than in the fracture. A larger pore pressure response in the fracture was expected, due to its presumably larger compliance than that of the porous matrix. This unusual observation may be attributed to the large aperture of the main fracture in certain places where it potentially acts as a dead volume into which fluid can be drained from the other portions of the sample. The results highlight the complexity of the poromechanics of highly heterogenous and fractured rocks.

Participation

In-Person

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Primary authors: Dr CHAPMAN, Samuel (Ecole Normale Supérieure / CNRS UMR 8538); Dr LISSA, Simon (Universidad Nacional de la Plata); Dr FORTIN, Jerome (Ecole Normale Supérieure / CNRS UMR 8538); Dr QUINTAL, Beatriz (University of Lausanne)

Presenter: Dr CHAPMAN, Samuel (Ecole Normale Supérieure / CNRS UMR 8538)

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