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Experimental monitoring of the hydro-mechanical state of a discontinuity using controlled source seismic method

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Great earthquakes often occur in crystalline rocks, and basement rocks can host geothermal and hydrocarbon resources. In such rocks, the fluid storage and transfer properties depend mainly on the natural fault and fracture networks. Therefore, it is of primary importance to characterise the physical properties of the fault zones in order to better understand the seismogenic processes and how the resources can be exploited. Seismic waves are known to be sensitive to many parameters which evolve depending on the fault response to stresses and fluid type. Therefore seismic methods show a great potential to monitor the hydro-mechanical state of structures remotely, with no need for drilling through the structures.

We developed a basic experimental approach at sample scale to monitor the mechanical coupling through a discontinuity between a granite sample in contact with a piece of steel, when the effective pressure (Peff) and the nature of the filling fluid vary. Piezoceramics utilised both as sources and sensors are located on the steel (in which the attenuation is assumed to be zero) and both generate and record the P and S wave fields reflected off the discontinuity at normal incidence. This permits the normal (Bn) and tangential (Bt) fracture compliances to be calculated after Schoenberg's linear slip theory from the measurement of P-P and S-S reflection coefficients. The roughness of the sample surface, as well as the effect of fluid type (air or water) and Peff were studied.

Under dry conditions, it is observed that the poorer the contact area, the higher Bn and Bt, meaning that the seismic energy of P and S waves is less transmitted. Increasing the effective pressure decreases the compliances, which is interpreted as the effect of the closure of the voids at the interface; this permits more seismic energy to be transmitted through the interface. It is also observed that Bn is significantly higher than Bt at low Peff (<60 MPa). Under water saturated conditions, and at low Peff, Bn is significantly lower than in dry conditions. The presence of water therefore helps transmitting the seismic energy of compressional waves through the interface. However, the magnitude of Bt is not as dramatically altered, which is related to the inability to transmit S waves in water.

This experimental approach therefore shows that the assumption Bn = Bt commonly found in theoretical approaches does not always stand. The ratio Bn/Bt actually reflects the type of saturating fluids and the effective pressure, which opens promising field applications: measuring remotely the ratio Bn/Bt from reflected waves should indeed provide valuable information about the hydro-mechanical state of fault zones, in particular to monitor rupture or healing processes, as well as fluid migration.