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The deformation field in a rock mass during an in-situ hydraulic stimulation experiment

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In the framework of the In-situ Stimulation and Circulation (ISC) experiment we carried out six decameter-scale in-situ hydraulic shearing (HS) experiments in February 2017 at the Grimsel Test Site, Switzerland. Inside the test volume we mapped various fractures and five major shear zones, that can be subdivided into two sets, with respect to orientation. During the experiments, pre-existing shear zones and fractures were hydraulically reactivated in 0.7 m long borehole intervals. The spatial mechanical response of the rock mass was monitored using 60 Fibre-Bragg Grating (FBG) strain sensors and 3 tiltmeters. The FBG sensors had a baselength of 1 m and were equally distributed in three differently orientated boreholes, covering shear zones, fractures and intact rock. They monitored strain signals with a sampling rate of 1000 Hz, a resolution of 0.1 microstrains and an accuracy of 1 microstrain. The 3 tiltmeters were positioned west of the experimental volume on the tunnel floor, measuring the deviation from horizontal in two axes (i.e. tunnel-parallel and -perpendicular axis) with a sensitivity of 0.1 microradians and a sample rate of 100 Hz.

The observed strain signals exhibit a strong dependency of their magnitude on the distance to the injection point. The peak strains have been were observed closest to the injection point (around 4 m) with a magnitude between 400 to 500 microstrains. In addition to the distance to the injection point, the magnitudes were influenced by the number of fractures across the sensor baselength. To quantify the 3D deformation field, we analyzed the maximum (compressive or tensional) and permanent strains, as well as the ratio between both quantities. This ratio was used to qualitatively infer importance of normal opening or slip along monitored fractures. These qualitative observations were correlated with the calculated slip tendencies (based on in-situ stress measurements). Besides the magnitude, we analyzed the delay in observed strain signal with respect to increased injection pressure increment.

The tiltmeters indicate significantly different behavior with respect to the two shear zone directions. Using the signals of the tunnel-perpendicular tilt component, we observe an expansion of the test volume (i.e. tiltmeters north and south of stimulated shear zone tilted towards west) for one shear zone orientation and shear displacement along the shear zone (i.e. tiltmeters north and south of stimulated shear zone tilted in opposite directions) for the other. The signals for the tunnel-parallel tilt component also indicate two distinct different behaviors for the two different shear zone directions. These variations in tilt responses are related to different reactivation mechanisms of the two shear zones, due to their different orientation within the in-situ stress field. Using these characteristics of the tunnel-parallel axes, we were able to constrain simple numerical models to infer the orientation of the stimulated shear zone.

A correlation of the mechanical response with the observed pressure propagation during the experiments is work in progress.