System stiffness and unstable slip in the lab and in nature

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Unconventional fossil fuel resources such as shale gas and oil have been produced by cracking deep underground rocks with hydraulic fracturing. During this process, induced and triggered earthquakes may occur by injecting fluid into bedrocks. Two M5.5 disastrous earthquakes occurred in Korea, one of which was close to the enhanced geothermal system (EGS) (Grigoli et al., 2018). Induced/triggered earthquakes are caused by the decrease in effective normal stress on the pre-existing fault due to the increase in pore fluid pressure. However, it is very difficult to directly monitor the effective stress change in bedrocks at depth.

In this study, we investigate the relation between system stiffness and fault friction for large scale friction experiments and for natural earthquakes. The purpose of the study is to consider the conditions for safe hydraulic fracturing without causing induced earthquakes at the site. We use the data obtained by the large scale friction experiments at the National Research Institute for Earth Science and Disaster Resilience (NIED). In the experiment, the top metagabbro specimen (1.5 m long, 0.5 m wide and 0.5 m high),was stacked on the bottom metagabbro one (2.0 m long, 0.1 m wide and 0.5 m high), where the nominal contacting area was 1.5 m long and 0.1 m wide. 6.7 MPa normal stress were applied to the stacked rocks, and the shear stress were applied by moving the shaking table horizontally. Macroscopic ratio of the shear stress to the normal stress on the fault was estimated from those measured by the loadcells. The stiffness of the system can be estimated by dividing the amount of stress change before and after the stick slip by the amount of relative displacement during that period (e.g. Shimamoto et al.,1980).In this study, we used four experiments data whose loading velocity was 0.01 mm/s.

The stiffenss values were estimated as 1.88 GPa/m and 1.81 GPa/m based on the data before and after stick slip events, respectively. We confirmed that the stiffness values were approximately the same before and after the stick slip events.

McLaskey & Kilgore(2013) defined the critical stiffness (K_{crit}) based on the the rate- and state- dependent friction law (slip law). We estimated the friction parameters a, b, and Lc from the experiment data using the Runge-Kutta method (Urata et al., 2015). The critical stiffness was estimated as 83.4 GPa/m . This K_{crit} was larger than the estimated stiffness K. Thus we confirmed that unstable slip occurred in the experiments.

We shall infer the condition of the induced earthquake that occurred in October 2017 at EGS in Korea from the critical stiffness. From the seismic moment, stress drop, the width and length of the fault estimated by Grigoli et al., (2018),stiffness can be evaluated. The stiffness becomes 29.4 MPa/m. On the other hand, the critical stiffness is 1.08 GPa/m if we apply the friction parameters for saturated granite in Marone et al. (1990). Because of $K_{crit} > K$ in the induced earthquake in Korea, unstable slip occurs when induced earthquakes occur regardless of the amount of injected fracturing fluid.

Keywords: induced and triggered earthquakes, stiffness, stick slip

