1 Project background

An Enhanced Geothermal System (EGS) is an engineered reservoir, in which hot dry rock with intrinsically insufficient natural permeability is stimulated hydraulically. Enhancing permeability in a safe way is challenging (Zang et al., 2013). One option to do so is a stepwise treatment enhancing permeability while induced seismity is kept below a safe threshold. This is demonstrated at Pohang EGS site, South Korea (Fig. 1, Hofmann et al., 2019).

In this study, we investigate the hydraulic stimulations conducted at Pohang site using the 3D finite-element code FracMan (Golder Associates 2019). We focus on studying coupled processes using the database of stimulation reported in Hofmann et al., 2019 after 2017 in well PX-1 (Fig. 2). This enables characterizing the fractured crystalline reservoir.

2 Hydraulic Stimulations

Five stimulations were conducted in granite rock to improve the hydraulic performance of the system (Fig. 3). Based on hydraulic and seismic analyses of the stimulations and earthquakes, two large fault structures are inferred, planes P1 and P2 (Fig. 4, Bethmann et al., 2019).

3 Numerical Method and Setup

The numerical method and model of hydro-mechanical coupling for simulating fluid injection is illustrated in Fig. 5 and Fig. 6 using the equations (1)-(4).

Eq. (1) \[ \frac{dP}{dt} = \frac{Q}{A} \]

Eq. (2) \[ \frac{d\sigma}{dt} = \frac{1}{E} \left( \frac{dP}{dt} - \dot{\varepsilon} \right) \]

Eq. (3) \[ \frac{d\varepsilon}{dt} = \frac{1}{E} \left( \frac{dP}{dt} - \sigma \right) \]

Eq. (4) \[ \frac{d\sigma}{dt} = \frac{1}{E} \left( \frac{dP}{dt} - \dot{\varepsilon} \right) \]

4 Results and Discussion

A. History matching of PX-1 2nd stimulation in August 2017

The model calibration is made by matching the simulated wellhead pressure history against field observations. The procedure requires adjusting the input parameters governing the hydro-mechanical coupling sequentially. These are referred to as split-points dividing the simulation into sequences (Fig. 7).

At the time of change in parameters, the pressure output of the last time step is taken as an input for the subsequent phase of the simulation. Consequently, all parameters remain valid for a period until the next split-point is defined.

The constant parameters used in the simulation are summarized in Table 1. Those that are adjusted are shown in Table 2. Based on the achieved history match, we characterize the resulting wellbore and hydraulic-mechanical parameters.

B. Hydraulic aperture and transmissivity evolution

The change in the stress-aperture relationship due to UCS adjustment results in shift of the stress-aperture relationship. The increase in UCS shifts the curve upwards, decreasing in that has opposite effect (Fig. 8).

The evolution of aperture at the borehole shows non-linear behavior and reversibility with pressure change, typical for hydraulic jacking. On the other hand, wellbore analyses of hydraulic stimulations in well PX-1 revealed hydro-shearing (Hofmann et al., 2019; Lee et al., 2019).

Hydraulic aperture at injection point is converted to transmissivity as follows:

\[ T = \frac{K}{h} \]

The transmissivity shows an increase in the order of one magnitude approx. from \( 10^{-3} \) to \( 10^{-2} \) m²/s (Fig. 9). This generally agrees with that reported by Hofmann et al. 2019 at different periods of the hydraulic stimulation.

C. Extent of pressurized area

The extent of overpressure area (Lee et al., 2019) with radius of 150 m for 0.01 MPa overpressure level implies that the hydraulic-diffusion is limited relatively close to borehole area (Fig. 10).

The simulated injection point location is approx. 350 m as shortest distance from plane P2, the modelling results reveal that the pore pressure, and thus, the effective stresses at fault P2 are probably not affected by PX-1 SE stimulation.

5 Conclusions

Reasonable history matching of pressure curves could only be achieved by partitioning the treatment into separate periods. This enables capturing change in hydraulic aperture and wellbore transmissivity.

- The hydraulic aperture evolution is typical of hydraulic jacking. However, the fault is favorably oriented for hydro-shearing. This implies that the stimulation mechanism could be a combination of hydraulic jacking and shearing.
- The extent of pore pressure difference for inducing potential seismic events, is approx. 150 m in the short term, which is equivalent to the shortest possible distance to the plane P2 based on the numerical simulations. Thus, the effective stresses at fault P2, which is located approx. 350 m are probably not affected within the model limitations.