ENAC / PROJET DE MASTER 2020-2021
SECTION DE GÉNIE CIVIL

Revisiting the Pohang induced earthquake

Auteur : Tristan Liardon

Encadrement : Prof. Brice Lecampion / Alexis Sáez

Introduction

Enhanced geothermal systems use of hydraulic stimulations to increase the permeability of the formation. These are known to induce seismicity that can be felt and even destructive (Basel, Soultz-sous-Forêts). Involved processes and their significance are not well understood, as in the case of the Mw 5.5 earthquake of Pohang, South Korea, in 2017, which is the focus of this master thesis. At Pohang, prior to this event, five hydraulic stimulations took place in two wells that happened to be on both sides of a large fault, at a 4200 m depth, in which the Mw 5.5 earthquake nucleated.

Pressure diffusion is the main driver of the fault destabilization. However, the poroelastic response of the medium and the stress redistribution linked to the foreshocks are believed to be important contributors (Chang et al. 2020, Yeo et al. 2020). How all these mechanisms were involved is not clear and requires further analysis. Similarly, discussions on the actual properties of the basement and of the fault are still ongoing.

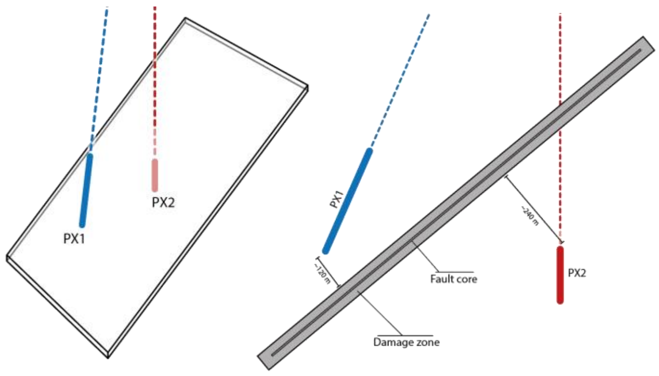

Fig. 1 : Schematic view of the fault and the two wells, which open-hole section correspond to the thick line. The fault is composed of a soft and impermeable core surrounded by a conductive damage zone

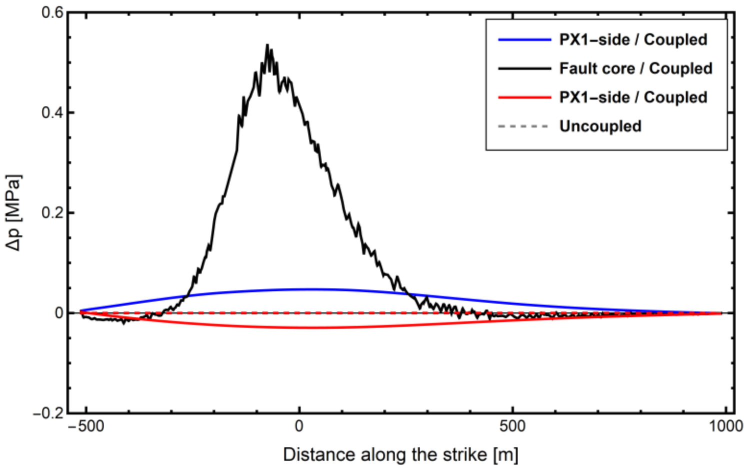

Fig. 2 : Pressure after 335 days since the first stimulations, at the end of the second. The black lines correspond to the middle of the fault core, while the colored one are at the limit of with the damage zone, on both sides. The low permeability basement leads to the high pressure in the core, that is not visible in the damage zone, as the pressure front is still too far. Without coupling, no effect is visible (dashed lines).

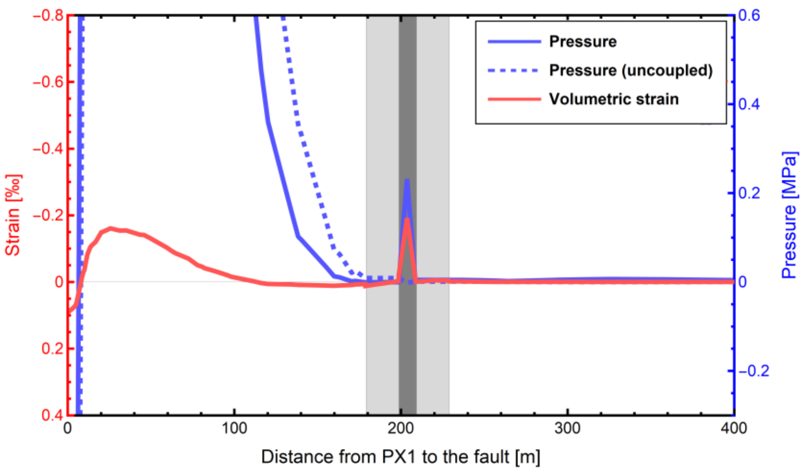

Fig. 3 : Pressure and volumetric strain after 423 days, at the beginning of the third stimulations. The start of the horizontal axis is at the bottom of the PX1 well, and goes towards the fault, with the damage zone in light gray and the fault core in dark gray. The pressure front is still slightly away from the damage zone, therefore not overpressurizing the fault. The peak of volumetric strain and corollary pressure in the fault core is due to the poroelastic coupling. The uncoupled case (dashed line) shows little perturbation of the fault.

Objective and method

The project aimed at evaluating and describing the effect of the hydraulic stimulations using the poroelastic response of the fault. Numerical simulations using the Finite Element Method were conducted on Mathematica. Four cases were simulated by using either coupled poroelasticity or pressure diffusion, both with a high or a low permeability basement (diffusivity of 10^-2 and 10^-4 [m^2/s]). The stimulations were modeled as a source term, in which the injected volume was applied.

Results

The permeability of the basement greatly controls the overpressure in the fault. Without coupling and with a low permeability, the fault experiences almost no change of pressure during the stimulations, failing to explain the seismicity that occured during the injections. At the contrary with the high permeability basement, the pressure front reaches the fault quickly.

The poroelastic effect on the fault core consists in a change of normal and shear stresses, and a “squeezing” effect, where the soft fault core is compressed by the basement on both side. This increase of volumetric strain leads in a very low permeability medium leads to a supplementary increase of pressure in the fault core, as predicted by the poroelastic coupling. This effect is stronger with a less permeable basement.

When accounting for poroelasticity, a low permeability basement still allows the stimulations to destabilize the fault and create seismicity.

Discussion

The results of the numerical simulations lead to the conclusion that the poroelastic coupling effect was non-neglectable in the triggering of the Pohang Mw 5.5 earthquake. The mechanisms at play in this case are likely to be encountered in others EGS sites. The results also give arguments for the case of a low permeability basement.

Although the general patterns from the numerical simulations are clear, detailed analysis were not possible due to the low quality of the results, which are related to the low element order used in the model. Further modeling is necessary to better understand the importance of the fault “squeezing” effect. The influence of the thickness of the fault and the contrast of stiffness with the basement on the destabilization could be important and must be better understood. The time and distance scales at which this phenomenon appears are of interest as well.

References

- Chang, K.W., Yoon, H., Kim, Y. *et al*. Operational and geological controls of coupled poroelastic stressing and pore-pressure accumulation along faults: Induced earthquakes in Pohang, South Korea. *Sci Rep* 10, 2073 (2020)
- Yeo, I.W., Brown, M.R.M., Ge, S. *et al*. Causal mechanism of injection-induced earthquakes through the Mw 5.5 Pohang earthquake case study. *Nat Commun* 11, 2614 (2020)