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Coupled THM-statistical modeling of induced seismicity during deep geothermal exploitation

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During deep geothermal exploitation, seismicity is unavoidably induced, posing potential hazard for structures and concerns to the local community. Thus, understanding how to avoid triggering of large earthquakes plays a crucial role in the success of underground anthropogenic activities.

Recent works, combining physical consideration with stochastic elements, showed the importance of developing tools for hazard and risk assessment that can operate in real-time during reservoir stimulation, and which depend on the ability to efficiently model induced seismicity.

Understanding the triggering mechanism is a fundamental step towards controlling the seismicity generated by deep underground exploitation. Although seismicity is generally controlled by fluid injection, it is not possible to rule out some other mechanisms such as static stress transfers between neighbor asperities, or creep-mediated stress interactions along the fault zone. In these conditions, the relationship between fluid pressure and induced seismicity is much more complex. Moreover, while current modeling approaches focus mostly on the active injection phase, the static stress transfer may become import at later stage during the post-injection phase.

In order to address these effects, we here propose a novel modeling approach based on coupling a Thermo-Hydro-Mechanical (THM) simulator with a statistical model. The THM simulator provides the fluid flow and the poro-elastic deformation, and the permeability may be enhanced by stress/strain changes. The transient pressure field is then used to trigger events at so-called ‘seed points’ that are randomly distributed in space and represent potential earthquake hypocenters. Assuming a fault orientation with respect to the stress field and a Mohr–Coulomb failure criterion, we evaluate at each time step, if a seed point is triggered by the pressure/stress change at the seed location. In case of a triggered event, the magnitude of such event is randomly assigned from a power-law distribution with a b value corresponding to the differential stress at the triggered seed point. After reactivation, we calculate a stress drop and a further permeability enhancement that are then fed back to the THM simulator. At the same time step, the reactivation of seed point may also occur by static stress transfer.

This strategy of modeling flow and seismicity in a decoupled manner has been shown to ensure efficiency and flexibility of the model, and accounting for more detailed description of stress and strain changes within the engineered reservoir provides a more comprehensive representation of the triggering mechanics.