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Modeling Reservoir-Induced Seismicity using Rate-and-State Friction law

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Triggering of earthquakes due to the filling of dam reservoir is attributed to mechanical disequilibria, build-up by pore pressure diffusion driven differences in deformation and stresses in the subsurface rocks, ultimately compensated by the reactivation of faults. This kind of earthquake, also known as Reservoir induced seismicity (RIS) has the characteristics of small magnitude, high intensity, shallow source and long period. In some cases, seismic activities have lasted for several decades after the initial impoundment (e.g. in Koyna-Warna, India). Various approaches have been made by researchers to comprehend the role of water reservoirs in triggering such unique events. Modeling fluid-induced earthquakes requires coupling geomechanics, flow through porous media, and fault friction. A 2D poroelastic finite element model has been employed, incorporating coupled pore fluid diffusion and stress analysis along with contact interaction coupled to rate-and-state friction law, to simulate the stress change, deformation in rocks and fault slip due to reservoir impounding. Rate-and-state friction has been used with an aim to develop a modelling framework that can capture multiple earthquake sequences in order to understand the protracted RIS phenomenon. A fault is embedded in a 2D subsurface domain as contacting surfaces, the frictional behaviour along the fault surfaces is prescribed using a user subroutine FRIC in ABAQUS/Standard. The rate-and-state law has been defined in the subroutine. The ability of the subroutine to simulate multiple events of stick-slip motion has been checked using a simple spring-block slider analogy. The fault model is first initialised by simulating the in-situ field conditions, geostatic stresses are defined in the domain, frictional contact at the fault is established and zero pore pressure conditions are defined. After which, reservoir loading is applied on the top surface of the domain over a transient consolidation step and the pore pressure evolution down at the fault is studied. The decrease in fault strength is a result of increase in pore pressure that reduces the effective normal compressive stresses. The stress path, accumulated slip and friction coefficient at the midpoint of the fault is observed. The fault remains locked at the beginning, while the effective normal stress continues to decrease, at a point the fault strength drops and it starts to slip. Friction coefficient increases at the onset of slip, which is known as the direct effect, then decreases as the slip accelerates. Later, the fault rupture is arrested and the friction coefficient goes back to a higher value gradually. While simulating rupture in the fault, the contact interaction undergoes chattering when the fault slips abruptly, causing simulation to fail. In a non-dynamic analysis, instabilities will occur as the strain energy released due to fault slip cannot be dissipated. Contact damping has to be specified to dissipate the released energy. In the present study, only one event of fault slip has occurred. Increase in the pore pressure near the fault due to reservoir loading is not high enough for a second slip event.

Keywords: Reservoir Induced Seismicity, Poroelasticity, Rate and State Friction, Fault Slip