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EGS Injection and Seismicity Modeling with Rate/State Friction

Mark McClure and Roland Horne
Stanford University, Stanford, California

Hydraulic stimulation in Enhanced Geothermal Systems typically occurs when increased fluid pressure caused by injection induces slip on preexisting fractures. The slip enhances the fracture permeability permanently. An undesirable side effect of induced slip is the generation of microseismicity. The largest microseismic events during EGS stimulations have been significant enough to be felt at the surface. These relatively large events caused very little or no damage but inspired questions over whether there is a possibility of triggering a more significant event. It has become an important research concern to quantify and understand what risk may exist.

We carried out a numerical investigation of the effect of various physical parameters on induced seismicity during fluid injection into fractures. By varying different factors, such as *in situ* stress, frictional properties, injection rate, and the permeability/slip coupling function, we investigated the relationship between measurable physical properties, controllable injection strategies, and induced seismicity. We found that under certain circumstances, it could be possible to trigger a significant seismic event. Along with geological and geophysical data, modeling could be used to determine whether risk of a major event exists in a given location prior to performing stimulation. Modeling could also be used to optimize injection strategy in order to minimize seismicity while maximizing economic parameters such as flow rate.

A key aspect of our study was to model the process of fracture slip directly using a rate/state friction law. The rate/state friction law was developed to describe laboratory observations of rock friction in fractures (Dietrich, 1979 and 1981 and Ruina 1983). This approach has since been used to model earthquakes in a variety of applications. A modern example is Noda, Dunham and Rice (2009). A good overview can be found in Segall (2010), and a more detailed treatment is in LaPusta (2001). The rate/state law relates the frictional coefficient to sliding velocity and a "state" variable that is a function of past sliding history.

We compared calculations using rate/state friction to results using static/dynamic friction, a constant coefficient of friction, and with and without stress perturbation caused by slip. We also investigated methods of solving the rate/state equations with respect to accuracy and efficiency.

The rate/state slip simulator was coupled with a discrete fracture flow simulator. The coupling allowed direct investigation of the interrelated process of fluid flow and seismicity during injection. The flow and slip simulations were carried out on a discrete fracture network in which fractures were discretized directly without upscaling to rectangular grid blocks. We modeled injection into both a single, isolated fracture and a network of fractures generated stochastically. The advantage of discrete fracture modeling is that it can capture the heterogeneous flow that occurs in fractured reservoirs and directly model the nucleation and advance of seismic slip on a fracture or network of fractures. The slip simulator included a radiation damping term to account for inertial effects. Dynamic stress transfer was neglected. The model was two-dimensional. No new fractures were created because it was assumed that the primary mechanism of stimulation is slip of preexisting fractures.

An example of the coupled fluid flow and rate/state simulation is shown in Figure 1. The plots show the slip velocity, state, shear stress, fluid pressure, and cumulative displacement along the fault during injection as well as a plot of injection rate and event magnitude versus time.

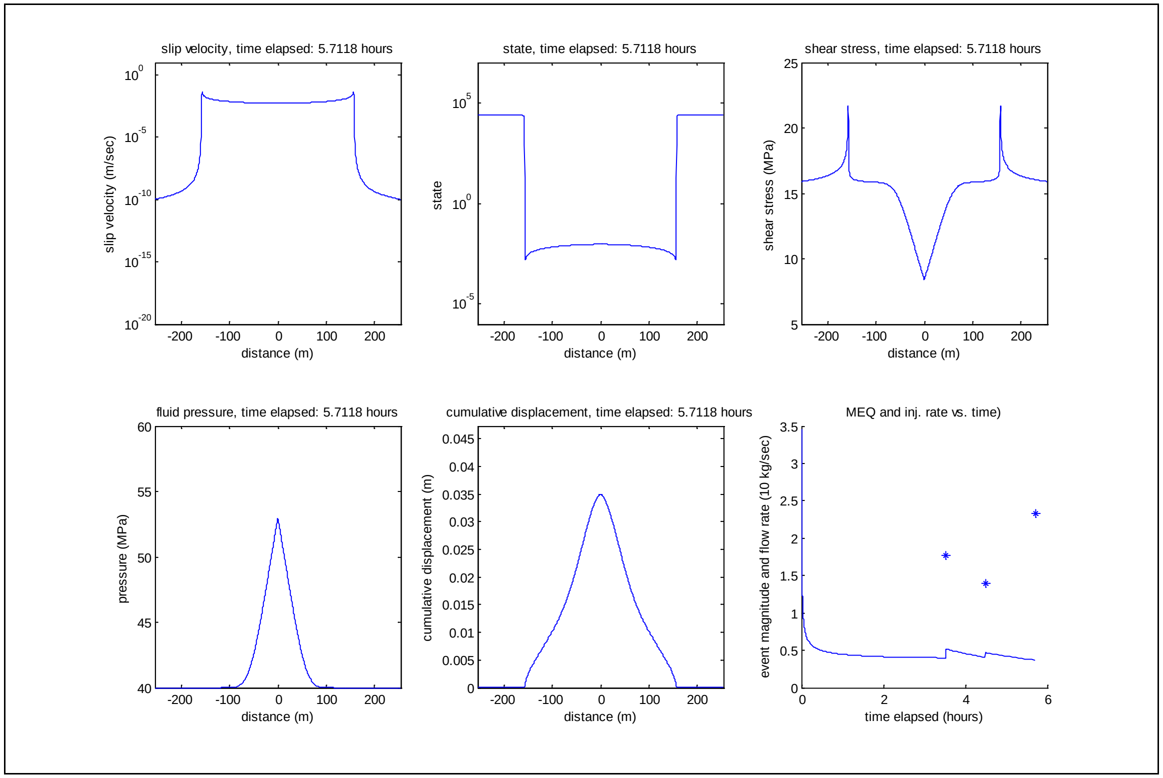

Figure 1: Injection into a single, isolated fracture. Slip velocity, state, shear stress, fluid pressure and cumulative displacement plotted along the length of the fracture. In the bottom right plot, flow rate and magnitude are plotted versus time.

Works Cited:

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