Research Report for ERI Visit
2019/02/25 to 2019/03/01
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The purpose of this visit was to initiate a collaboration to study earthquake complexity arising from fault geometric complexity. Specifically, we developed a method to simulate earthquake sequences on fractally rough faults. Previous studies had examined single dynamic rupture events on rough faults (e.g., Dunham et al., 2011; Fang and Dunham, 2013; Shi and Day, 2013; Bruhat et al., 2016; Duru and Dunham, 2016). Those studies demonstrated how geometric complexities can either inhibit or facilitate rupture propagation, leading to fluctuations in rupture velocity, slip, and radiation of incoherent high frequency seismic waves. Inspired by the static solutions for slip on a rough fault and analyses by Dieterich and Smith (2009), Fang and Dunham (2013) developed a second-order boundary perturbation to the problem of slip on a rough fault. They quantified an additional resistance to slip, present even without friction, that arises from elastic straining of the off-fault material adjacent to roughness features. This resistance, termed roughness drag (or backstress), requires rough faults to be prestressed to higher levels than flat faults in order to host self-sustaining ruptures. More recently, Tal et al. (2018) and Ozawa et al. (2019) performed simulations of earthquake nucleation on rough faults. For this problem, roughness was demonstrated to increase nucleation length or, in some cases, even suppress nucleation entirely.

However, both the single event dynamic rupture simulations and the nucleation studies were limited by an assumed spatially uniform prestress in the medium. This uniform prestress is in striking contrast to the highly heterogeneous stress field that is left after the rough fault slips. It is therefore necessary to perform simulations that capture multiple events on a rough fault that arise spontaneously in response to gradual tectonic loading. This is a very challenging problem because most simulation techniques for earthquake sequences are based on boundary element solvers for linear elasticity, like the one used by Ozawa et al. (2019), and in an elastic medium, stresses build up indefinitely and lead to fault opening on rough faults. In reality, the off-fault material within fault damage zones yields and stresses are bounded to realistic levels. This yield is captured with continuum Drucker-Prager plasticity in the single-event dynamic rupture simulations by Dunham's groups. However, the code used in singe-event simulations is based on a formulation of elasticity that is not suitable for the quasi-static problem.

The project initiated during this research visit to ERI was to develop a novel simulation methodology, using Dunham's dynamic rupture code with plasticity for the coseismic phase and Ozawa's quasi-dynamic code for the postseismic, interseismic, and early nucleation phases. Switching between the codes is based on a nondimensionalized slip velocity threshold. The general strategy for code coupling was developed during the research visit to ERI. So Ozawa, a MS student with host Takahiro Hatano and PhD student with collaborator Ryosuke Ando, returned with Dunham to Stanford University and over the past month has implemented the method developed during the ERI visit. Some preliminary results are shown below.

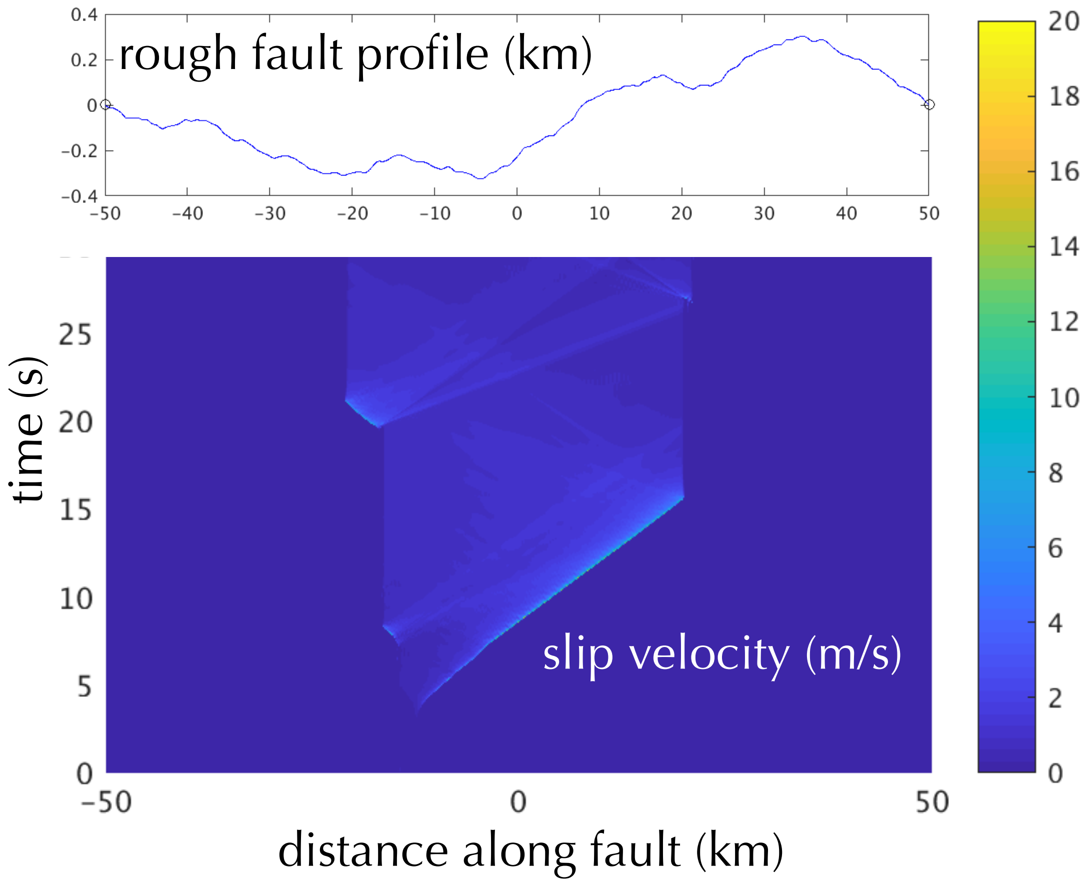

Figure 1. Space-time plot of slip velocity from a dynamic rupture on a rough fault that has spontaneously nucleated in response to gradual tectonic loading. Previous rupture events led to a highly heterogeneous initial stress field that, together with the fault geometry, determines how this rupture propagates.

References:

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