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Diversity in the initial phase of dynamic earthquake rupture in multiscale asperity model

Hiroyuki Noda[1*], Masao Nakatani[2], Takane Hori[1]

[1]IFREE, JAMSTEC, [2]ERI, The Unversity of Tokyo

Seismological observations [e.g., Abercrombie and Rice, 2005] suggest that a larger earthquake has larger fracture energy G_c. One way to realize such scaling is to assume a hierarchical patchy distribution of G_c on a fault; there are patches of different sizes with different G_c so that a larger patch has larger G_c. Ide and Aochi [2005] conducted dynamic rupture simulations with such a distribution of weakening distance D_c in a linear slip-weakening law, initiating ruptures on the smallest patch which sometimes cascades into a larger scale. They suggested that the initial phase of a large earthquake is indistinguishable from that of a small earthquake. Noda et al., [submitted to JGR; 2012 SSJ annual meeting] conducted 3D simulations of sequence of earthquakes in a similar multiscale asperity model with a rate-and-state friction (RSF). Multiscale asperities were represented by a distribution of the state evolution distance in the aging version of RSF evolution law.

A circular rate-weakening patch, Patch L (radius R^L) has been modeled which has a smaller patch, Patch S (radius R^S), in it by the rim. Those patches have their nucleation radii, $R^L{}_c$ and $R^S{}_c$ for Patch L and Patch S respectively, which are determined by the RSF parameters. Here we shall call the ratio of the radii R^L/R^S the scale gap, and the ratio of the patch size to the nucleation size $R^L/R^L{}_c = R^S/R^S{}_c$ the brittleness of the system. Up to $R^L{}_c$ or $R^S{}_c$, compact quasistatic nucleation basically follows $1/t_f$ acceleration where t_f is time to the earthquake, with amplitudes depending on the characteristic slip of state evolution of the patch. If the scale gap dominates, ruptures nucleated in Patch S cannot cascade up into a large earthquake spanning Patch L, and large earthquakes are necessarily preceded by large nucleation inside Patch L but out of Patch S. If the brittleness dominates, the ruptures nucleated in Patch S necessarily cascade up and span Patch L, and large quasistatic nucleation never occurs. If the brittleness and the scale gap are comparable, large earthquakes are initiated in a variety of ways in a single simulation In short, a large nucleation always results in a large earthquake, while a small nucleation occasionally causes a large earthquake through cascade-up. These connections between the size of quasi-static nucleation and the eventual earthquake size were fully reported previously by us.

In the present talk, we focus on so-called 'initial phase', that is, the growth of moment release rate right after it has exceeded a threshold level set to define the onset of dynamic earthquake rupture. In most of our simulations, 'initial phase' correlates with the size of preceding quasi-static nucleation, not caring the eventual earthquake size. Initial phase is strong and short when the preceding quasistatic nucleation is small, while it is gentle and lasting long when preceded by large quasi-static nucleation, as argued previously [e.g., Shizazaki and Matsu'ura, 1998]. However, we also found cases where dynamic rupture of a large earthquake preceded by a large quasistatic nucleation began with a sharp quick initial phase. This happens when the large nucleation interacts with Patch S. The sharp initial phase in this case should be regarded as a frictional noise passive to the ongoing acceleration of large nucleation. This is conceptually distinct from the Patch S event that cascades up, though telling the difference without seeing the spatio-temporal evolution of slip may be difficult.

Keywords: Earthquake cycle, Multiscale asperity, Rate-state friction