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# Stable Rupture Propagation in a Heterogeneous Stress Distribution

# Eiichi Fukuyama [1], Raul Madariaga [2]

[1] NIED, [2] ENS Paris, Lab. Geol.

There is a long standing discrepancy between rupture velocities "computed" from the numerical modeling of spontaneous rupture propagation and rupture velocities "estimated" from waveform inversions of real earthquakes. In general, "computed" rupture velocities are much higher. We attribute the origin of this discrepancy to inappropriate assumptions in the numerical computation. Madariaga and Olsen found that critical stress and critical slip displacement must satisfy a certain relationship for ruptures to propagate stably with a subsonic velocity. Here we confirm this using a BIEM computation.

There is a long standing discrepancy between rupture velocities "computed" from the numerical modeling of spontaneous rupture propagation and rupture velocities "estimated" from waveform inversions of real earthquakes. In general, "computed" rupture velocities are much higher than the "estimated" ones; reaching sometimes the terminal velocity (S wave) or even higher transonic velocities as shown, for example, by Day (1982). In this note we attribute the origin of this discrepancy to inappropriate assumptions in the numerical computation. Madariaga and Olsen (1999) found that critical stress level (\tau_b) and critical slip displacement (Dc) must satisfy a certain relationship for ruptures to propagate stably with a subsonic rupture speed. Here we confirm this relation using a BIEM computation (Fukuyama and Madariaga, 1998).

In our simulations we assumed a rectangular fault loaded by a heterogeneous initial stress field oriented longitudinally along the fault (in-plane stress). At one edge of the fault, rupture starts to propagate unilaterally starting from an initial patch where initial stress has been raised to the critical stress level (\tau_b). At time t=0 stress drops abruptly in order to trigger a spontaneous rupture propagation. In the modeling we assume that friction properties are uniform on the fault. We use a simple slip weakening friction law, which is controlled by the two usual parameters, peak stress \tau_b, and critical slip displacement Dc. The initial stress is assumed to have a step-wise stress distribution along the rupture propagation direction.

For the first model we assume a homogeneous stress distribution. We measured the rupture velocity for different stress levels. As pointed out by Madariaga and Olsen (1999), we found a very sharp transition (bifurcation) at 0.412 \tau_b. If the initial stress is lower than this value, rupture stops propagating and the earthquake stops. On the other hand, when the initial stress is greater than 0.45 \tau_b, rupture velocity accelerates and reaches the terminal velocity. Rupture propagates stably only when the stress level in the narrow range between these two values. In the other models, we computed rupture under heterogeneous initial stress conditions along the propagation direction. Stress oscillated between 0.4 \tau_b and 0.5 \tau_b. In this case, rupture propagates very stably and it never reaches terminal velocity. This feature is insensitive to the width of the stress band.

Thus in our numerical computations, in order to model a realistic earthquake, it is necessary to consider heterogeneous stress distributions such that the average stress lays between the two values mentioned above. These results, once confirmed for more general stress distributions and geometries, prove that earthquake ruptures are very similar to critical phenomena, where rupture is stable only for a subtle balance between initial stress and friction resistance. If these conditions are not satisfied ruptures become supersonic and unstable.

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References

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