Comprehensive understanding of dynamic earthquake rupture

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Some aspects of earthquake rupture behavior are known to be largely different among earthquakes. For example, very low-frequency earthquakes seem to have stress drops significantly smaller than ordinary earthquakes. There is a tendency that different aspects of earthquake rupture are modeled by particular models. Hence, there exist a number of models that can represent particular aspects of earthquake rupture. However, a unified model is required for the comprehensive understanding of earthquake rupture behavior. Some people may think that one of such candidates is a model based on rate- and state-dependent fault constitutive law. However, such model lacks of the validity as a model for dynamic earthquake rupture.

We now propose a model that will be useful for the comprehensive understanding of dynamic earthquake rupture. We consider frictional heating, inelastic pore creation and fluid flow in the modeling; the fault is assumed to be embedded in a thermo-poroelastic medium saturated with fluid. If the frictional heating is dominant, the slip weakening emerges because of thermal pressurization. On the other hand, if the inelastic pore creation is dominant, the slip strengthening occurs because of the sudden decrease in the pore fluid pressure. We found in our earlier study that the dominance of the effect of inelastic pore creation relative to that of frictional heating is represented by the nondimensional parameter Su. In other words, the slip strengthening emerges if Su is greater than P∗, where P∗is a positive number slightly smaller than unity. We recently found that the relative effect of fluid flow is described by the other nondimensional parameter Su', which is proportional to the fluid permeability. As long as a 1D fault model is concerned, the qualitative nature of system behavior is controlled only by these two parameters. For the quantitative understanding, we also need the information about the initial shear stress acting on the fault.

We found in our recent 2D study that features of slow earthquakes, such as significantly slow extension rate and stress drops, can be simulated successfully if the values of Su and Su' are remarkably larger than those appropriate for ordinary high-speed earthquake ruptures. This occurs because the slow fluid flow onto the fault tends to suppress the slip strengthening slowly and causes the slow fault growth.

In the above studies, we assumed spatially homogeneous distributions for Su and Su'. We now extend our study and take account of spatial heterogeneity in the distribution of Su. If we assume that Su is less than P∗only in a localized zone surrounded by an outer region featured by the relation significantly large Su, we can simulate features of asperities. If a small-size event is nucleated in the outer region and Su' is relatively large there, slow fault slip will be triggered. The development of such slow slip will accumulate stress at the edge of the zone where Su is less than P∗and trigger a significantly large event there. This roughly agrees with a generally accepted view on the asperity. If instead an event is nucleated in the zone where Su is less than P∗, the fault tip extension into the outer region will trigger afterslip.

It can also be shown that the arresting of dynamic fault growth is much easier in our present model than in a classical fault model widely assumed in simulations.

As shown above, our fault model has features that can simulate many apparently different aspects of dynamic earthquake rupture in a unified way, and it will contribute to the comprehensive understanding of dynamic earthquake rupture.