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Constructing a dynamic framework of earthquake rupture process in terms of inelastic effect

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We focus here on inelastic effects on dynamic earthquake rupture process. The inelastic processes such as damage and plasticity have been widely known to be important for the rupture process and investigated by a number of researchers. For example, energy loss due to damage evolution is suggested to be a mechanism for reducing rupture velocity; damage consists of sets of microcracks created inelastically in a medium. However, the systematic understanding of the inelastic effect in the rupture process has not been done.

We first clarify the importance of the inelastic effect in the view of the pore creation; the interaction among the inelastic pore creation, heat and fluid pressure is assumed. The thin zone inside which the heat generation and inelastic porosity change occur is assumed. The temporal change rate of the inelastic porosity is assumed to be proportional to the slip velocity based on previous laboratory experiments. We derive the two nondimensional parameters Su and Su' which completely control dynamic fault slip behavior assuming a 1-D fault model. The parameter Su denotes the ratio of the effect of inelastic pore creation to that of heat generation on fluid pressure change. This parameter governs stress-slip constitutive law. If Su is greater than the critical value Sc(~1), the slip-strengthening behavior appears; on the other hand, if Su is less than Sc, the slip-weakening behavior is expected. The parameter Su' is associated with fluid flow and proportional to the permeability, so that larger Su' induces more fluid flow. We succeeded in explaining many aspects of dynamic earthquake slip behavior with those two parameters. For example, the regular earthquakes and slow earthquakes are understood in terms of those parameters as follows. Regular earthquakes are characterized by Su>~1 and small Su' in terms of almost constant high-speed slip with relatively short duration. The balance between the strong slip-strengthening due to fluid pressure reduction (Su much larger than Sc) and the slip-weakening due to fluid inflow (large Su') is found to be critically important to simulate slow earthquakes. Our framework can also simulate slow earthquakes coupled with many tremors.

To extend our formulation, it should be noted that off-fault inelastic effect has not been treated in our framework; as mentioned above, we have considered only the thin zone where inelastic effect appears. The off-fault effect is known to be important for the process in terms of, for example, the energy balance law. A viewpoint of damage is introduced here to extend our framework and to describe the off-fault effect. We also note that damage should be treated by second rank tensor variables since damage effect should describe directions, magnitudes and density of microcracks. The energy balance law is derived analytically with the framework based on Murakami and Kamiya (1997). Assuming a 2-D fault model, the inelastic energy loss is found to be proportional to a square of time based on the derived analytical expression. Combining results about damage theory and the damage tensor with heat and fluid effects will be a future work.

Keywords: inelastic effect, heat, fluid, damage