Derivation of the two nondimensional parameters controlling the dynamic behavior of a 1-D fault

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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, proposed in our previous studies, governs stress-slip constitutive law: if Su is greater or less than the critical value Sc, slip-strengthening or slip-weakening behavior appears, respectively. The parameter Su', associated with fluid flow and derived in the present study, is proportional to permeability, so that larger Su' induces more fluid flow, which occurs much more slowly than shear wave propagation. In addition, the importance of the initial shear stress acting on the fault will be also shown for quantitative investigation of slip behavior. While the other parameters can be fixed easily from laboratory experiments and exhumed fault zone observations, the three parameters mentioned here are hard to estimate. We estimate these values by considering results of seismological observations.

We can summarize the slip behavior in the 1-D fault model as follows: the parameter Su governs the initial slip behavior mainly, while Su' governs the subsequent slip phase. Larger Su suppresses slip velocity more rapidly right after the slip onset owing to slip-strengthening behavior, while larger Su' induces larger slip velocity of subsequent phase because of slow fluid inflow. These features result in that all the slip behaviors in a 1-D fault model consist of initial high-speed slip whose behavior is governed by Su and subsequent low-speed slip decaying with time due to the effect of Su'. What should be noted here is that the orders of high-speed and low-speed are dependent on the initial shear stress; higher shear stress tends to produce higher slip speed. We can suggest values of these qualitative (Su and Su') and quantitative (the initial shear stress) governing parameters by considering seismologically observed earthquake slip behavior.

We compare here the above suggestion with slip behavior of regular shallow earthquakes, which are characterized as almost constant high-speed slip with relatively short duration. These features are more consistent with smaller Su and smaller Su'. In addition to this qualitative suggestion, the initial shear stress can be estimated by the magnitude of seismologically observed slip velocity because the shear stress is roughly proportional to the slip velocity. On the other hand, if we consider slow earthquakes, larger Su and larger Su' with smaller initial shear stress than those of regular earthquakes are appropriate since slow earthquakes have smaller slip velocities and longer slip duration than regular earthquakes. These statements about values of the three parameters are confirmed by numerical calculations with the assumption of the 2-D fault model.