Importance of fault rheology around brittle-plastic transition in long-term behavior of major faults

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Fault behavior such as long-term slip rate, magnitude and recurrence interval of earthquakes, and reaction against stress perturbation depends on the loading condition and mechanical properties of the fault. In considering the latter factor, existence of a ductile shear zone, which underlies a seismogenic part of a major fault, may be of great importance; the brittle-plastic transitional regime has maximum shear resistance in a classical Christmas-tree strength profile, and the slip there directly load the shallower seismogenic part of the fault. In order investigate the long-term, time-averaged fault behavior, numerical simulations of earthquake sequences on a major fault with a ductile shear zone have been conducted in the present study in a simplified geometry.

An elastic crustal plate with a through-going strike-slip fault is assumed, and the fault motion is driven by applying constant far-field shear stress tau_pl. A rate- and state-dependent friction-to-flow fault constitutive law [Shimamoto and Noda, 2014] is used in the present study. In this law, shear resistance is approximately given by a rate- and state-dependent friction law in a shallow brittle part of the fault, and by power-law creep of quartzite (exponent: 4) in a deep, fully plastic part. The rate-dependency of the shear resistance takes the maximum value in a transitional regime between them. Note that the peak in the rate-dependency does not necessarily correspond with peak shear resistance. If we assume excess pore pressure at depth which limits the effective normal stress at a certain value, then a Christmas-tree strength profile does not exist, but a remarkable peak in the rate-dependency still appears in the transitional regime.

In the simulations, the fault hosts repeating earthquakes in the brittle part, and slips by a long-term speed V_pl on average which depends on tau_pl. The relation between tau_pl and V_pl is very well explained by a power law with the exponent about 20. This is similar to what is followed by unstable steady-state solutions with uniform slip rates V_ss. It should be noted that V_pl is larger than V_ss for the same tau_pl approximately by a factor of 2 as long as studied. This is because the brittle part of the fault typically support smaller shear stress than the steady-state level, and thus the ductile shear zone support larger shear stress associated with larger slip rate than the steady state. Since the relation between tau_pl and V_ss is given by spatial average of the rate-dependency, the transitional regime having the prominent peak in the rate-dependency most significantly contributes to the amount of shear stress perturbation required to change the long-term slip rate of the fault. It should be emphasized that the brittle-plastic transitional regime is important not only because of the maximum strength potentially existing there, but also because of the maximum rate-dependency.

Keywords: Brittle-plastic transition, Earthquake sequence, Long-term fault motion