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Nondimensional Controlling Parameter about Inelastic Porosity Evolution Law and its Effect on Dynamic Earthquake Slip

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In a series of our studies, we have studied effects of the interaction among effects of shear heating, fluid pressure and inelastic pore creation on dynamic fault slip and found two nondimensional controlling parameters Su and Su' about the interaction for one-dimensional (1-D) fault model. The parameter Su represents the relative dominance of the effect of inelastic pore creation on the fluid pressure change over that of shear heating, while Su' is associated with the dominance of fluid flow effect over the effect of shear heating. We have succeeded in explaining many aspects of dynamic earthquake slip behavior in a unified way on the basis of the parameters: for example, ordinary earthquakes and slow earthquakes are understood in terms of those parameters.

However, there is a problem in our modeling that we have assumed too simple form of inelastic porosity evolution; inelastic porosity change rate was assumed to be proportional to slip velocity. Porosity in natural faults is suggested to have an upper limit, phi_{inf}, by observational and experimental studies. The framework the authors have employed assumes that porosity change, phi, is negligibly smaller than the upper limit.

We introduce the third nondimensional parameter, Su^{ul}, to describe the effect of the upper limit of inelastic porosity. We neglect here fluid flow; that is, Su'=0. If we assume Su$>$1, fluid pressure decrease due to inelastic pore creation at an initial stage of slip reduces slip velocity. After the initial stage, two qualitatively different behaviors of slip appear. For some parameter ranges of Su and Su^{ul}, slip accelerates and the slip velocity approaches to a positive constant value. This behavior occurs because phi approximately approaches to phi_{inf} and effect reducing the fluid pressure (and the slip velocity) due to pore creation vanishes. In this case, shear stress acting on a fault plane is completely released at the final stage due to thermal pressurization. On the other hand, for the other ranges, slip velocity approximately approaches to zero and the slip ceases spontaneously because phi is so small that the effect of phi_{inf} does not appear. Both high speed slip and spontaneous slip cessation can be understood in a single framework in the present model.

We also found that two important governing porosities, phi_1* and phi_2*, exist in the present model and succeeded in obtaining their analytical forms in terms of Su and Su^{ul}. The value phi_f*, defined as the value of normalized inelastic porosity phi$*$ after an infinitely long time, cannot take values between phi_1* and unity at the stable state (situation where phi$*$ is unity represents phi equals to the upper limit) because if phi$*$ approaches to phi_1*, the slip accelerates and phi_f* takes a value unity. The porosity phi_1* can be regarded as the critical value distinguishing the system behavior, slip acceleration and spontaneous slip cessation. In addition, the value of phi_f* cannot take values smaller than phi_2*, which is related to thermal energy generation. Observed porosity can be an indicator of thermal energy.

Keywords: heat, fluid pressure, inelastic porosity, high speed slip, spontaneous slip cessation