Underlying Physics of Rate- and State-Dependent Friction Law

SHINGO YOSHIDA[1], MASAO NAKATANI[1], KOHEI NAGATA[1]

[1] *Earthquake Research Institute, Univ. of Tokyo*

Recently the underlying physics of rate- and state-dependent friction (RSF) law has been understood [e.g., Nakatani, 2001]. The conventional form of the first equation of the RSF law is tau/sigma = tau*/sigma + theta + a ln(V/V*) (1), where tau and sigma are shear and normal stresses, respectively, tau* is the steady state friction at a reference velocity V*, theta is a state variable, and a is a friction law parameter. Eq. (1) can be rewritten as V=V* exp((tau - Phi)/(a sigma)) (2), where Phi=tau*+theta sigma, which is defined as a shear stress required to cause slip at velocity V*. This expression says that slip velocity V is determined by the applied stress for a given interface state. By noticing that if Phi is higher we need higher applied stress to obtain V*, it is natural to regard Phi as interface strength. This presentation allows us to grasp the RSF law more intuitively. Next, we consider microscopic mechanism of the RSF law. Rough surfaces under normal load are in contact only at junctions at the tips of contacting asperities. The shear deformation rate of the junctions should be governed by the shear stress tauc acting on them, which is much higher than the applied nominal shear stress. Considering that the shear deformation is thermally activation process, we may write the rate of deformation as r = C exp (-(E - Omega tauc)/kT) - C exp (-(E + Omega tauc) /kT) (3), where E is energy barrier (or activation energy) in a potential field, Omega is an activation volume, T is temperature, and k is the Boltzman constant. When shear stress is applied, the effective energy barrier to be jumped over in the direction of the applied stress is reduced by Omega tauc. The first term is the rate at which a molecule (or atom) moves to the location of the neighboring molecule beyond the energy barrier in the direction of the applied stress, and the second term is the rate in the opposite direction. When the second term is negligible, Eq. (3) corresponds to the RSF law (2), and we can represent RSF law parameters a, b, in terms of the microscopic material property. It is often pointed out that the RSF law may include physically unrealistic description because Eq. (1) cannot express the situation around V=0. However, Eq. (3) without neglecting the second term says that when the applied stress is zero, the slip velocity also becomes zero. As Eq. (2) predicts, slip velocity under a constant shear stress below the sliding level gradually decreases when the interface strength Phi increases due to time-dependent healing. We paid attention to this behavior, and proposed a method to estimate a value of b/a from measurement of slip displacement at a constant shear stress, assuming that healing occurs logarithmically with time (proportional to b logt). Combining it with a-b determined from the difference between shear stresses during steady-state slip at different velocities, we obtained values of a and b. The estimated values were larger than those previously obtained from velocity step tests. Estimation from velocity step tests depends on evolution laws, which may not correctly express transitional change. On the other hand, logarithmically time-dependent healing is believed to be established description.