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Microphysically derived expressions for rate-and-state friction and fault stability parameters

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Rate-and-state friction (RSF) laws and associated parameters are extensively applied to fault mechanics, mainly on an empirical basis with a limited understanding of the underlying physical mechanisms. We recently established a general microphysical model [*Chen and Spiers*, 2016], for describing both steady-state and transient frictional behavior of any granular fault gouge material undergoing deformation by granular flow plus an arbitrary creep mechanism at grain contacts, such as pressure solution. We further showed that the model is able to reproduce typical experimental frictional results, namely "velocity stepping" and "slide-hold-slide" sequences, in satisfactory agreement with the main features and trends observed.

Here, we extend our model, which we explored only numerically thus far, to obtain analytical solutions for the classical rate and state friction parameters from a purely microphysical modelling basis. By analytically solving the constitutive equations of the model under various boundary conditions, physically meaningful, theoretical expressions for the RSF parameters, i.e. a, b and D_c, are obtained. We also apply linear stability analysis to a spring-slider system, describing interface friction using our model, to yield analytical expressions of the critical stiffness (K_c) and critical recurrence wavelength (W_c) of the system. The values of a , b and D_c, as well as K_c and W_c, predicted by these expressions agree well with the numerical modeling results and acceptably with values obtained from experiments, on calcite for instance. Inserting the parameters obtained into classical RSF laws (slowness and slip laws) and conducting forward modelling gives simulated friction behavior that is fully consistent with the direct predictions of our numerically implemented model. Numerical tests with friction obeying our model show that the slip stability of fault motion exhibits a transition from stable sliding, via self-sustained oscillations, to stick slips with decreasing elastic stiffness, decreasing loading rate, and increasing normal stress, which is fully consistent with our linear stability analysis and also with previous RSF models that employed constant values of the RSF parameters.

Importantly, our analytical expressions for. a, b, D_c, K_c and W_c, are functions of the internal microstructure of the fault (porosity, grain size and shear zone thickness), the material properties of the fault gouge (e.g. creep law parameters like activation energy, stress sensitivity, grain size sensitivity), and the ambient conditions the fault is subjected to (temperature and normal stress). The expressions obtained thus have clear physical meaning allowing a more meaningful extrapolation to natural conditions. On the basis of these physics-based expressions, seismological implications for slip on natural faults (e.g. subduction zone interfaces, faults in carbonate terrains) are discussed.

Reference

Chen, J., and C. J. Spiers (2016), Rate and state frictional and healing behavior of carbonate fault gouge explained using microphysical model, J. Geophys. Res., 121, doi:10.1002/2016JB013470.