Estimating constitutive parameters from velocity step tests with a rotary-shear friction apparatus

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INTRODUCTION

Many experimental studies to investigate the mechanism of earthquakes and faulting behaviors have been performed since 1970's. Dietrich (1979), Ruina (1983), and so forth empirically introduced slip-rate and state-variable dependent constitutive law based on the laboratory friction data from low slip velocity (less than 0.1 mm/s) experiments. Upon an increase in slip velocity, coefficient of friction transiently increases (direct effect, parameter **a**) and then gradually decreases towards the new steady-state value (evolution effect, parameter **b**). The slip required to renew the steady state is called **Dc**. These constitutive parameters are easily estimated from a friction vs slip plot for the velocity step tests. Friction apparatus, in general, however, can't change the loading velocity within infinitesimally small time particularly for higher slip rate tests (the finite acceleration effect) and has finite stiffness (the apparatus stiffness effect), which characteristics rule out the ideal step-change of the slip velocity. In this study, taking these factors into account, we established a method to estimate the constitutive parameters from the velocity pseudo-step tests with the least-square fitting. We estimated the parameters from the low- to intermediate-velocity tests on the initially bare rock surfaces (granite-granite, and gabbro-gabbro) and granular fault gouge materials.

METHOD

Shear deformation experiments were performed with a rotary-shear, intermediate- to high- velocity friction apparatus at Kyoto University. Samples were a pair of 22-25mm diameter cylinders of granite, those of gabbro, and granular fault gouges (hemipelagic mud cored by NanTroSEIZE drilling project, C0006E25X-2-W). The experiments were performed at normal stresses of 5MPa and at the slip velocity from 0.003 to 30 mm/s. To estimate the parameters from the experimental data, we search the parameter value which minimizes root-square-mean error with obtaining theoretical coefficient of friction with solving simultaneous differential equations for each parameter value.

RESULTS

It is revealed that constitutive parameter **a** positively correlates with the slip velocity (before pseudo-step change), and the correlation is approximately expressed with the power function. Parameter **Dc** positively correlates with the slip velocity (after pseudo-step change). For the experiments on gouge, it is found that friction negatively depends on the velocity within the slip velocity from 0.003 to 3 mm/s. When shear displacement becomes large, velocity dependence of friction becomes different for the velocity- increase tests and the velocity-decrease tests. For velocity decreasing steps in the slip velocity from 3 to 0.3 mm/s, friction shows neutral or slight positive dependence on the velocity. On the other hand, for velocity increasing steps in the slip velocity from 0.3 to 3 mm/s, friction shows strong negative dependence on the velocity. In such a situation, coefficient of friction would decrease with the increase in the velocity, while would not change with the decrease in the slip velocity. These results suggest that the sheared gouge behavior could depend on the sign of the acceleration history of a fault during the step.