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Report on the applicability of the rate and state model

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Deliverable 2.1.1: Report on the applicability of the rate-and-state model

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Introduction

The rate-and-state friction law, introduced by Dieterich [1979] based on laboratory friction experiments, has been frequently used to model both afterslip, slow earthquakes and seismic activity [e.g., Dieterich , 1994]. Depending on the parameters of the rate-and-state friction law, the model is either stable (aseismic slip), or able to produce slip instabilities (earthquakes). In the unstable regime, the rate-and-state friction law provides a relation between stress history and seismicity [Dieterich , 1994]. This relation can be used to predict the seismicity rate triggered by any stress change, such as static or dynamic stress change induced by a mainshock, postseismic slip, or transient deformation associated with intrusions or eruptions, slow earthquakes or tides.

Model

We have studied how a stress perturbation may a□ect a fault obeying the rate-state friction law, using a simple slider-block system. Depending on the model parameters and on the initial stress, the fault exhibits slip singularities ("aftershocks"), a transient slow slip pulse ("slow earthquakes"), or decaying afterslip. We found that the behavior of the rate-state friction law is far more complex than described by the ”steady-state” approximation frequently used to fit afterslip data. We have shown that afterslip and slow earthquakes are not limited to stable faults, but can also occur in seismogenic zones.

Application to model seismic and aseismic deformation

We also fitted the model to the afterslip data measured following the 2000 m=8 Denali earthquake, the 2004 m=6 Parkfield earthquake and the 2005 m=8.7 Nias event. We modeled afterslip measurements for these earthquakes using the complete rate-and-state law, and found a huge variety of model parameters that can fit the data. In particular, it is impossible to distinguish the stable velocity strengthening regime (A>B) from the (potentially) unstable velocity weakening regime (A<B). Therefore, it is not necessary to involve small scale spatial or temporal fluctuations of friction parameters A or B in order to explain the transition between stable sliding and seismic slip. In addition to B/A and stiffness k/k_c, the fault behavior is strongly controlled by stress levels following an event. Stress heterogeneity can thus explain part of the variety of postseismic behaviors observed in nature.

Using the relation between stress and seismicity derived from the rate-and-state friction law, we estimate the aftershock rate triggered by co- and postseismic slip. Aftershock rate does not simply scale with stress rate, but exhibits different characteristic times and sometimes a different power-law exponent. Afterslip is thus a possible candidate to explain observations of aftershock rate decaying as a power-law of time with an Omori exponent that can be either smaller or larger than 1. Progressive unloading due to afterslip can also produce delayed seismic quiescence.

Beeler et al [2003] have performed friction experiments to test the influence of stress pertubations on the dynamics of slip events. The relation between stress changes and the rate of slip events in their expriments is in good agreement with the predictions of the rate -and-state model.

Application to model laboratory experiments

We have compared our model with the slider block experiment built in our laboratory [Voisin et al. 2007]. These experiments display a transition between stick-slip behavior at short times (analog to earthquakes) to slow slip events (analog to slow earthquakes) and stable sliding [Voisin et al, 2007].

Our model can explain qualitatively the transition observed experimentally. For parameters close to the stability transition, the model exhibits oscillations with amplitude and time interval decreasing with time, as observed in the experiments.

Publications:
The analytical and numerical study of the rate and state model has been described in the manuscript:
- Helmstetter, A., and B. E. Shaw, Afterslip and aftershocks in the rate-and-state friction law, submitted to J. Geophys. Res. (2008) (http://aps.arxiv.org/abs/physics/0703249)

The experiment has been described in the paper:
-Voisin, C., F. Renard, and J.-R. Grasso (2007), Long term friction: From stick-slip to stable sliding, Geophys. Res. Lett., 34, L13301, doi:10.1029/2007GL029715

References
- Beeler N. M., D. A. Lockner (2003), Why earthquakes correlate weakly with the solid Earth tides: E□ects of periodic stress on the rate and probability of earthquake occurrence, J. Geophys. Res., 108 (B8), 2391, doi:10.1029/2001JB001518.29(17), 1844, doi 10.1029/2002GL015240.
- Dieterich, J. H. (1979), Modeling of rock friction, 1. Experimental results and constitutive equations. J. Geophys. Res. 84, 2161-2168.
- Dieterich, J. H. (1994), A constitutive law for the rate of earthquake production and its application to earthquake clustering, J. Geophys. Res., 99 , 2601.