2003 Annual Report

A Dynamical Damage Model for the Formation of Fault Gouge and the Associated Generation of High-Frequency Seismic Radiation

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The primary objective of this research was to combine our recent model for the stress field in the vicinity of a dynamic slip pulse (Rice et al., 2003) with the micromechanical damage mechanics formulated by Ashby and Sammis (1990) to estimate the extent of breccia formation during an earthquake, and to calculate the orientations of optimal Coulomb slip surfaces with that breccia. Having achieved that, we also proposed to explore its dependence on depth, preexisting damage in the source rock, and characteristics of the rupture such as its velocity and breakdown displacement. As a final objective, we proposed to extend the model developed by Johnson and Sammis (2001) to estimate the high frequency seismic energy generated by the damage process.

The analytical slip pulse model is shown in Fig. 1 below. Slip is restricted to a finite length *L* and slip weakening occurs over a distance *R*.

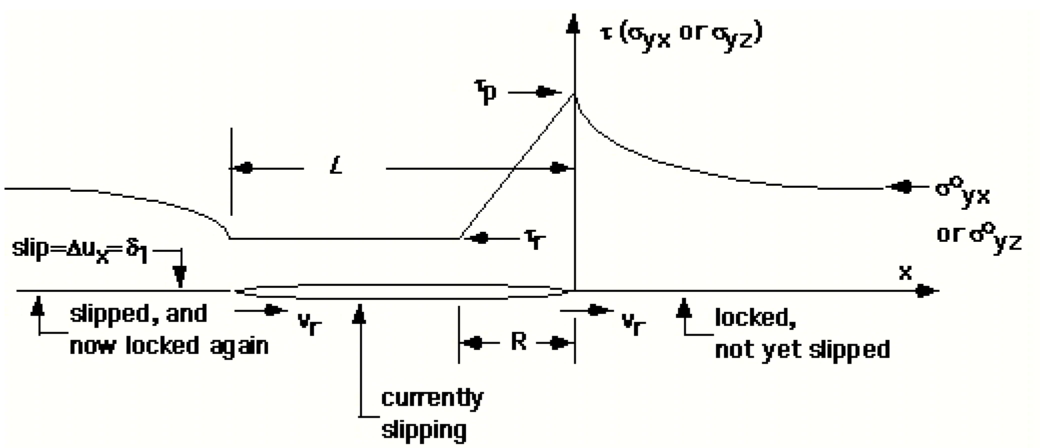

Figure 1. Slip pulse of length *L* propagating with velocity v_x .

The ratio of *L* to *R* is determined by the dynamic stress drop scaled by the strength drop $\left(\sigma^o_{yx} - \tau_r\right)/\left(\tau_p - \tau_r\right)$. Predicted off-fault damage is controlled by that scaled stress drop, static and dynamic friction coefficients, rupture velocity, principal pre-stress orientation, and the poroelastic Skempton coefficient. All lengths can be scaled by R_o^*, the value of *R* in the low rupture velocity, low stress drop, limit, which is proportional to $G/(\tau_p - \tau_r)^2$, where G is the fracture energy. The region which supports Coulomb failure reaches a maximum size of order R_o^* when mode II rupture speed approaches the limiting Rayleigh speed. Analysis of slip pulses documented by Heaton (1990) leads to estimates of the fracture energy, each with a factor-of-two model uncertainty from 0.1 to 9 MJ/m2 (including the factor), averaging 2-4 MJ/m2. In most cases, secondary faulting should extend, at high rupture speeds, to distances from the principal fault surface of order 1 to 2 $R_o^* \approx 1 - 80$ m for a 100 MPA strength drop; that distance should vary with depth, being larger near the surface.

The main product from last year's research was a publication submitted to the B.S.S.A.:

> Rice, J.R., C.G. Sammis, and R. Parsons, Off-fault Secondary Failure Induced by a Dynamic Slip Pulse, Bull. Seism. Soc. Am., submitted, 2003.

Beyond the results in that paper, we have initiated a formal damage mechanics analysis, using the formulation by Ashby and Sammis (1990), to map the boundaries of fragmentation and increased damage. A typical result of these calculations is shown in Figure 2.

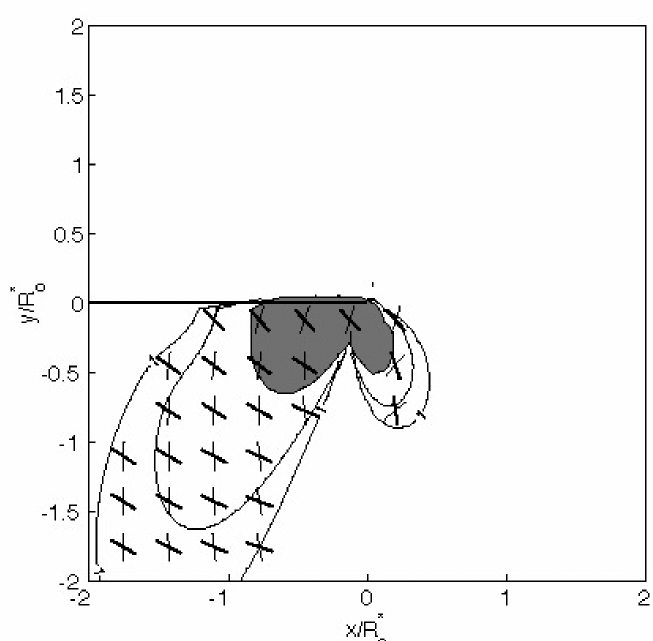

Figure 2. Damage generated in the vicinity of the slip pulse in Fig. 1. For this choice of parameters, brecciation extends to a scaled distance of about $0.5R_o^*$ from the fault plane (within the darkest shading). Damage extends to about $1.5R_o^*$ and Couloumb slip to $y > 2R_o^*$. The lines indicate the orientation of optimal slip surfaces.

Fragmentation is favored by a preexisting maximum compression direction at a high angle Ψ to the fault plane, and a high value of the rupture velocity v_r. The extent to which the fragmentation zone becomes narrower with depth depends on the depth dependence of $\delta_1 / \left(\tau_p - \tau_r\right)$. If $\left(\tau_p - \tau_r\right)$ depends on the effective normal stress through a coefficient of friction, then the zone width should decrease linearly with depth. Work on the secondary radiation is still in progress, and is a top priority in this years proposal.

As part of this year's effort, we also used a stereo-pair of digital cameras and imaging software developed by the Computer Science department at USC to generate a 3-dimensonal map slip surfaces and associated slip vectors in fault breccia from the Sierra Madre fault exposed near the Jet Propulsion Laboratory in Pasadena. We are currently analyzing the stress orientations implied by this data. The results will be presented by Ory Dor, the graduate student on this project, at the Fall AGU meeting in San Francisco.

References

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