Progress report for 2008 SCEC Proposal

Title of Project
Developing physical limits to ground motion

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***Proposal Categories*:**
Integration and Theory

Science Objectives:
B2, A7, B5

Special Project: ExGM

Summary

Studies under this project attempt to improve the understanding of physical limits to ground motion generated by earthquakes. Our last year investigations focused on the following two research directions: (1) Understanding how generation of rock damage at the source affects the seismic radiation to the bulk. (2) Calculations of statistical properties of earthquake stress drops in models of long-term evolutionary seismicity on a heterogeneous fault. The studies from the first direction led to one submitted paper and another paper in preparation. The results from the second direction led to a paper in press. Below we summarize the main results from our last year investigations on these problems.

Seismic radiation from regions sustaining material damage

Yehuda Ben-Zion and Jean-Paul Ampuero

(GJI, in review, 2009)

Abstract

We discuss analytical results associated with seismic radiation during rapid episodes of brittle deformation that include, in addition to the standard moment term, contributions stemming from changes of elastic moduli in the source region. The radiation from the damage-related source term is associated with products of the changes of elastic moduli and the total elastic strain components in the source region. Order of magnitude estimates suggest that the damage-related contributions to the motion in the surrounding elastic solid, which are neglected in standard calculations, can have appreciable amplitudes that may in some cases be comparable to or larger than the moment contribution. A decomposition analysis shows that the damage-related source term has an isotropic component that can be larger than its *DC* component.

Interaction Between Dynamic Rupture and Off-fault Brittle Damage

Jean-Paul Ampuero, Yehuda Ben-Zion, Shiqing Xu and Vladimir Lyakhovsky

(in preparation, 2009)

Abstract

The high stress concentration at the front of a dynamic rupture is expected to produce rock damage (reduction of elastic moduli) in the material surrounding the main fault plane. Off-fault yielding and energy absorption in the damage process should reduce the amplitude of the ground motion. However, the reduced elastic moduli in the damaged zone can amplify locally the motion and create a waveguide that may allow the motion to propagate with little geometric attenuation. In addition, the asymmetric damage generated in the in-plane rupture mode may produce bimaterial interfaces that can reduce the frictional dissipation and increase the radiation efficiency. Previous studies incorporated plastic yielding in simulations of dynamic rupture (Andrews, 1975, 2005; Ben-Zion and Shi, 2005; Templeton et al., 2008) while keeping the elastic moduli unchanged. In this work we examine the dynamics of ruptures and generated motion in a model consisting of a frictional fault in a medium governed by a continuum damage rheology that accounts for the evolution of elastic moduli (e.g. Lyakhovsky and Ben-Zion, 2008). We perform numerical simulations based on the Spectral Element Method to study how the

parameters of the friction law, damage rheology and background stress control the rate of growth of the off-fault damage zone, the rupture speed, the energy partition to various components, and the maximum slip rate and ground motion. We compare the peak motion generated with our damage model to results of analogous simulations using Coulomb plastic yielding. Off-fault damage is of special importance for ruptures along faults that separate rocks of different elastic properties, because they can generate asymmetric patterns of material degradation that might be observable in the field. We plan to perform simulations involving velocity-weakening friction and off-fault damage associated with pre-existing bimaterial faults.

Statistics of Earthquake Stress Drops on a Heterogeneous Fault in an Elastic Half-Space

Iain W. Bailey and Yehuda Ben-Zion

(BSSA, in press 2009)

Abstract

We investigate properties of earthquake stress drops in simulations of evolving seismicity and stress field on a heterogeneous fault. The model consists of an inherently discrete strike-slip fault surrounded by a 3D elastic half-space. We consider various spatial distributions of frictional properties and analyze results generated by 150–300 model years. In all cases, the self-organized heterogeneous initial stress distributions at the times of earthquake failure lead to stress drops that are systematically lower than those predicted for a homogeneous process. In particular, the large system-sized events have stress drops that are consistently ~ 25% of predictions based on the average fault strength. The type and amount of assumed spatial heterogeneity on the fault affect the stress-drop statistics of small earthquakes (ML <5) more than those of the larger events. This produces a decrease in the range of stress drops as the earthquake magnitudes increase. The results can resolve the discrepancy between traditional estimates of stress drops and seismological observations. The general tendency for low stress drops of large events provides a rationale for reducing the statistical estimates of potential ground motion associated with large earthquakes.

Publications Supported by this grant

Ampuero, J.-P., Y. Ben-Zion and V. Lyakhovsky, Interaction between dynamic rupture and off-fault damage, *Seism. Res. Lett.*, 79 (2), 295, 2008.

Ampuero, J.-P., Y. Ben-Zion, S. Xu and V. Lyakhovsky, Interaction between dynamic rupture and off-fault brittle damage, ms. in preparation for *Geophys. J. Int*., 2009.

Bailey, I. W. and Y. Ben-Zion, Statistics of earthquake stress drops on a heterogeneous fault in an elastic half-space, *Bull. Seism, Soc. Am.*, 99, doi: 10.1785/0120080254, 2009.

Ben-Zion, Y. and J.-P. Ampuero, Seismic radiation from regions sustaining material damage, *Geophys. J. Int.*, in review, 2009.