Earthquake dynamics and seismic source inversion

Raul Madariaga, Sergio Ruiz and Maria Lancieri
Laboratoire de Geologie CNRS-Ecole Normale Supérieure, France

The most successful earthquake radiation model, Brune's circular crack, was developed on the basis of a combination of simple geometrical arguments and the amplitude of seismic waves generated by a prescribed instantaneous stress drop. Later this model was shown to model also the radiation from a circular crack running at finite speed and stopping abruptly. Under closer scrutiny, Brune's model actually specifies a particular partition of available strain energy into fracture energy and radiated energy. Seismic efficiency, defined as the ratio between radiated energy and the part of strain energy that can be used for radiation, can be computed for different models of radiation from circular cracks. Efficiency is close to 50 % for Brune's model independently of the size of the earthquake.

In order to study energy balance from near field data, we have developed a non-linear dynamic inversion method for low frequency weak and strong motion records using the Neighbourhood algorithm of Sambridge and colleagues. We look for source models that have a simple geometry (a few ellipses can be used as proposed by Vallée and Bouchon). The forward problem is solved using a finite difference numerical simulation of the seismic rupture process for given distributions of initial stress and fracture resistance (Gc) . We applied the method to a couple of very well recorded earthquakes in Japan and Chile showing that seismic waveforms are dominated by a combination of stress drop, energy release rate and the overall earthquake geometry. Only average values of these parameters can be derived from dynamic inversion as suggested by several previous studies. We demonstrate that many properties of the models retrieved from inversion can be encapsulated by the kappa parameter that controls numerical seismic ruptures. This number derives from the ratio between the strain energy released by the earthquake that is available for radiation and the amount of energy that is required to make the rupture propagate.

For the December 16, 2007 slab push earthquake in Northern Chile we have 9 recordings in the near field. From dynamic inversion we successfully determined all the stress and friction law parameters. Results were verified by a Monte Carlo exploration of model space around the optimum solution. The results are surprisingly simple: a roughly circular fault with a very high initial stress (order of 12 Mpa) and a friction law with Gc of the order of 10^7 MJ/m^2 fits all observed data up to 2 Hz, much higher than in most kinematic inversions. The reason is that in Northern Chile propagation is simple with little attenuation and scattering. In our model the event started near 50 km depth, propagated inside the Nazca plate at relatively low rupture speed, under high stress drop and strong friction, stopping abruptly at a depth of about 60 km. We were surprised that simple models can explain radiation up to 2 Hz. We argue that the reason is that radiation is controlled by stopping phases, so that most of the elastic energy is radiated by localized regions of the fault. A consequence of this observation is that energy release rate grows with earthquake size as suggested by Aki, Ohnaka and others.