Summary of Session 2.2: Simulation of earthquake rupture, seismic wave propagation and strong motion

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There is a clear consensus between the participants that the modeling of single earthquake ruptures is reaching the stage where we will be able to invert for the rupture process directly from near field seismic observations. The experience obtained by different groups in the study of several well recorded earthquakes is impressive. We now have accurate estimates of Fracture energy release of the order of $1 - 10 MJ/m^2$ that match very well the values proposed by K. Aki many years ago on the basis of the energy required to stop the propagation of rupture for large earthquakes.

The kinematic inversions have been used by several authors including Ide and Takeo, Day and colleagues and Bouchon and colleagues in order to invert the slip weakening law from seismic observations. These inversions are limited to the frequency band in which accelerograms can currently be modeled. This band extends down to about 0.5 Hz, or wavelengths of 5 km for S-waves. For those wavelengths the slip resolution is of the order of a few 10s of cm. For large shallow strike-slip earthquakes this means that we can now resolve more than 10 wavelengths along the fault and between 4 or 6 in the depth direction (the free surface boundary condition doubles the resolution). Recent work on the Kobe earthquake by Spudich and others has shown that it is even possible to resolve variations in the direction of slip as a function of position on the fault.

It is important to remark that at these wavelengths and slip resolution most faults appear relatively simple with a few fault strands at most. The gouge zones on them order of 300 m are well bellow the current resolution. A problem that appears clearly is what is the friction law that we have to use to simulate rupture at these scales. Is it the laboratory friction law obtained between relatively two rough surfaces, or is it a much coarser grain friction law that represents the slip between the country rock surrounding the weak fault zone. This is closely related to the presentations by Aki concerning gouge zone waves and Knopoff as relates to aftershock generation in the vicinity of faults. Thanks to the new resolution of seismic observations these and other questions can now be posed. These observations are giving new impetus to the modeling of seismic ruptures under increasingly realistic conditions. Friction laws can only be resolved in their coarsest scales, but slip distributions can be inverted and matched against geodetic observations and rupture along the surface. One of the most promising sources of information is the inversion of SAR images combined with GPS and seismic observations.

Most of the presentations in this session were related directly or indirectly with the development of numerical techniques for the accurate modeling of rupture propagation by either finite differences, finite elements or boundary integral equations. Although no explicit comparison of these techniques was presented during the lectures, all of them give quantitatively similar results in spite of their different domains of validity. We can thus roughly say that it is nowadays possible to model a rupture in numerical fault model discretised with 1000x300 grids. This number has to be divided by 8 or 10 in order to include appropriate slip weakening in order to regularise friction on the fault. We have then a useful resolution of about 250x40. This is about 10 points per wavelength for the frequencies currently resolved in kinematic inversions. This is clearly largely sufficient to capture all the details of rupture that are resolved in these inversions. We can expect thus very interesting results from dynamic inversion. One of the most important issues nowadays is what can really be resolved from accelerogram inversion? Can we resolve rupture propagation without kinematic rupture constraints?, for instance. Most kinematic inversions impose a rough rupture model and explore variations about this model. This imposes for instance that a single rupture wave crosses the fault during the earthquake.

In the talks, Dr. Fukuyama presented his numerical modeling of fracture initiation from a set of interacting asperities or initial patches as they are now called. He showed that the initial signal emitted by earthquakes should contain information about the interaction. An interesting question that can be studied with his method is the nature of the initial or break out phases from large earthquakes, what are the similarities of these phases from event to event.

Dr. Nielsen's talk was presented by K.B. Olsen. These authors are exploring the conditions for the spontaneous appearance of complexity in 3D ruptures. They clearly show that complexity develops spontaneously on a uniform fault only if there are at least two very different lengths scales. For instance in long rectangular faults complexity appears when the ratio W/L is about 2. In roughly circular or square faults complexity appears only if the friction law contains additional length scales like a short slip weakening distance and a distance associated with velocity weakening.

Aochi and colleagues discussed a promising new boundary equation model for the study of curved faults. This is an interesting problem that poses a number of questions because it is clear that a curved fault can not conserve its form for finite slip, questions were then risen about the limits of the discrete approximation in the case of infinitesimal slip.

Olsen then discussed his own work on the dynamic inversion of accelerograms. As he pointed out propagation of signals all the way from the fault to the observation points is extremely expensive. In order to save computer costs and efforts, he proposed to compute synthetic seismograms from the kinematic inversions and to use these synthetic records in the inversion invert. In this way the main questions raised earlier about rupture front geometries, duration, etc can be addressed without the extra load of computing seismograms far away from the fault.

Prof. Miyatake presented simulations of earthquake ruptures in order to study realistic seismic wave generation. As he pointed out most current methods for generating synthetics for applications in earthquake engineering use kinematic models that are not necessarily physically sound. He proposed to include dynamic rupture modeling in the modeling of acceleration spectra, etc.

Dr. Cai presented a Lagrangian Displacement Discontinuity algorithm for the simulation of earthquakes that includes displacement discontinuities, relatively rigid blocks. He presented an application to the computation of displacements on a model of a fault embedded in a heterogeneous medium.

Finally, Ralph Archuleta presented some of his recent work on the non linear inversion of accelerograms using not the full wave signals but the envelope of the accelerograms. The inverse problem in the envelopes is fully non-linear, but he and Peng Chu have obtained very promising results with this novel techniques that eliminates the variability of seismic signals at high frequency, but conserves the basic features of energy flow.