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Extensions to the Pseudo-Dynamic Source Characterization: PD-Source 2.0

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Summary

This report summarizes briefly our activities in the SCEC-funded project 'Extensions to the pseudo-dynamic source characterization', a research project carried out by PhD-student B. Mena-Cabrera, supervised by P.M. Mai, at ETH Zurich. The goal is to update and improve the initial pseudo-dynamic source model, developed by Mai (2001) and Guatteri et al (2003, 2004), to facilitate ground-motion simulations based on dynamically consistent source-rupture parameterizations. Our work is embedded in several SCEC activities related to dynamic rupture modeling and broadband ground-motion simulations, in that we profit from recent research findings on scaling of dynamic source parameters (e.g. Rice et al, 2005; Abercrombie and Rice 2006; Tinti et al, 2005, Mai et al. 2006), but will then apply and test our technology in the framework of broadband ground-motion calculations from realistic source models.

Due to the student's heavy involvement in the broadband validation exercises (lead by R. Graves, P. Somerville and others, with contributions from URS, UCSB, and SDSU-ETH) which demanded code developments, implementation and testing for very specific deadlines, we focused our attention to the BB-simulation work. The work on the pseudo-dynamic source characterization has therefore progressed slowly, but a few tests and new results are presented below. We will continue working on the pseudo-dynamic codes, now that the BB-simulation project has moved rapidly forward and requires less time from our side. It is planned that the updated pseudo-dynamic source representation, once tested in detail and applied to a number of target events, will be added to the broadband simulation modules.

A pseudo-dynamic source model for the 1984 Morgan Hill earthquake

As a first step to further improve the pseudo-dynamic source model we apply its current implementation to the 1984 Morgan Hill earthquake. Using slip inversion results from Beroza and Spudich (1988) and Hartzell and Heaton (1986), we compute the corresponding static stress change (Ripperger and Mai, 2004), and estimate a realization of fracture energy from the fracture-energy scaling of Guatteri et al. (2004). Using these estimates of stress-drop and fracture energy we then compute the temporal rupture evolution based on Andrews (1976); a distribution of rise-times is simulated using again relations developed by Guatteri et al (2004). We apply this work-flow to the slip distributions of Beroza & Spudich (1988) and Hartzell & Heaton (1986), and then compute ground-motions at a number of near-source sites that recorded the earthquake. This general setup allows us to test and validate the pseudo-dynamic source model against past earthquakes in order to examine its strength and weaknesses. This is necessary since the original development of the pseudo-dynamic model was based on dynamic simulations of M 7.0 strike slip earthquakes, i.e. events of significantly larger magnitude, and it is not clear if these scaling relations are applicable to smaller events as well.

Figure 1 displays the final slip distribution for the 1984 Morgan Hill earthquake (Beroza & Spudich, 1988), the corresponding pseudo-dynamic source model parameters, and the source-site geometry used for computing near-source seismograms. For this purpose we used the COMPSYN package (Spudich and Xu, 2003), and calculated full-wavefield synthetics at 6 sites for a maximum resolving frequency 2.5 Hz, using a Kostrov-type slip velocity function. In Figure 2 we show seismograms and response spectra at three sites, indicating that the fault-normal component of motion is well reproduced (compared with the actual data) at these three sites for both rupture-model realizations, but that the fault-parallel component does not match well for the Hartzell-Heaten source model. We are currently investigating potential explanations for this discrepancies and will seek appropriate modeling modifications.

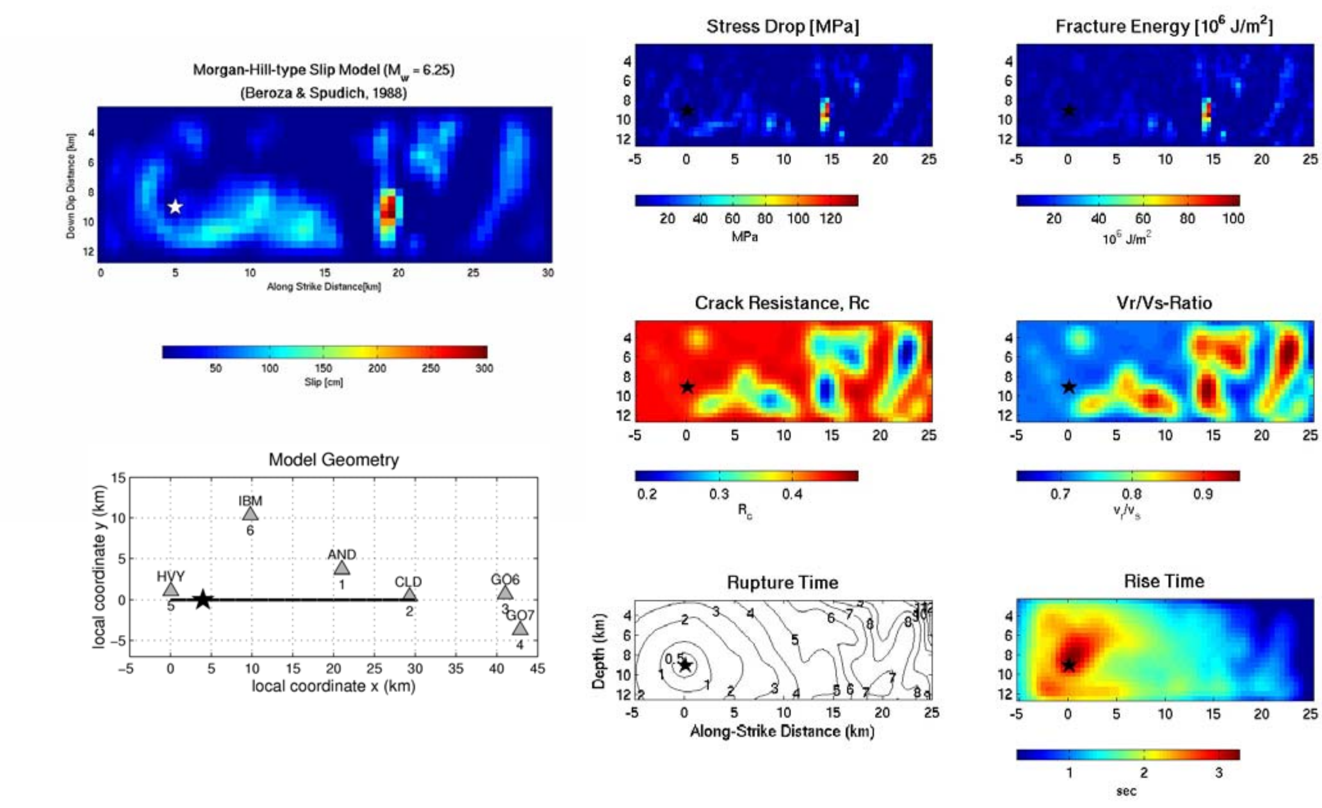

Figure 1 Pseudo-dynamic source model for the 1984 Morgan Hill earthquake, based on the slip inversion of Beroza and Spudich (1988), shown in the top-left. The lower-left panel displays the source-station geometry for computing synthetic seismograms. The source parameters of the pseudo-dynamic source characterization are shown in the six panels to the left: stress-drop (top-left), fracture energy (top-right); two intermediate quantities in the center (crack resistance and ratio of rupture to shear-wave velocity); and finally the resulting rupture onset times (bottom left) and rise times (bottom right).

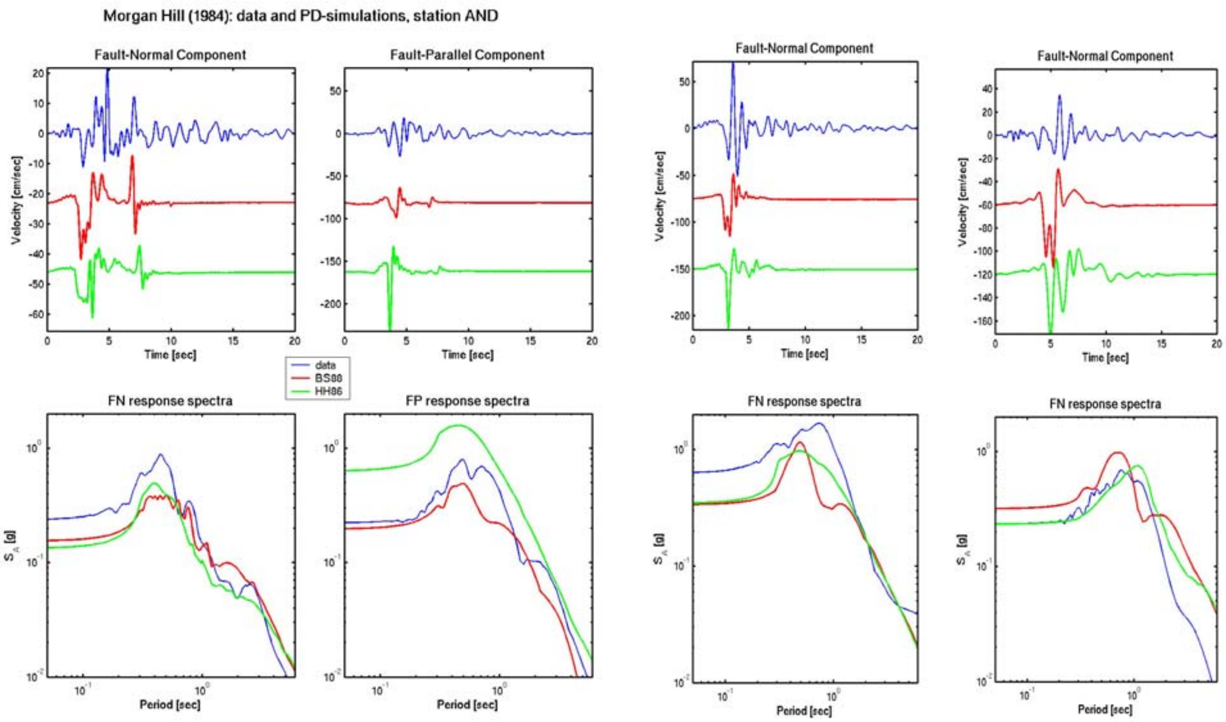

Figure 2 Ground motions at three sites for the 1984 Morgan Hill earthquake, computed for a pseudo-dynamic model based on the slip inversion by Beroza & Spudich (1988) (red lines), the inversion by Hartzell & Heaton (1986) (green lines), compared against the actual recordings (blue lines). The left two panel show seismograms (top) and response spectra (bottom) at station AND (fault-normal and fault-parallel component), the two figures to the right show the fault-normal motions for station CLD and G06, respectively.

A pseudo-dynamic source model for a hypothetical M 9.2 subduction event

Within a collaborative project with K.B. Olsen (San Diego State University) we generated a number of pseudo-dynamic source models for hypothesized mega-event (M 9.2) on the Cascadia subduction zone. In this case, the slip distributions were simulated using the method of Mai and Beroza (2002) for rupture plane dimensions specified by the subduction geometry. This project aimed at long-period ground-motion simulations, but also allowed us test the pseudo-dynamic source-modeling technique way outside the original range of the parameter space in which the scaling relations were developed.

Figure 3 shows one case study for such a mega-thrust subduction earthquake rupture realization. Maximum displacements reach over 40 m within distributed large asperities that occupy the 900 km long and 150 km wide rupture plane. Rupture spreads from the hypocenter, chosen according to Mai et al (2005) in the vicinity of a large-slip patch, with moderate rupture-speed variations. Rise times are long around the hypocenter, typical for a crack-like rupture propagation, but for the resulting ground-motions, the variable distribution of pulse width is more important. Peak-slip velocities reach up to 4 m/s; these needed to be capped since the current pseudo-dynamic model would have produced peak-slip velocities over 10 m/s over a relative large fault area (far away from the hypocenter) which is unrealistic.

To generate this realization of a pseudo-dynamic model for a huge scenario earthquake required a rather coarse grid for computational reasons (a relatively large sub-fault size of 1 x 1 km^2 was needed) and took 6-7 minutes on a 2 GB Ram, 1.8 GHz dual core PC, pointing out that code-optimizations (speed up and memory management) are needed. We also needed to limit the peak-slip velocities manually, which otherwise would have reached unrealistically high values. The crack-like rupture process with large rise times at the hypocenter, decaying sort of in concentric circles, is perhaps also unrealistic for these types of events, suggesting that further improvements in the pseudo-dynamic modeling approach should allow for local healing and hence stronger local variations in the rise time distribution.

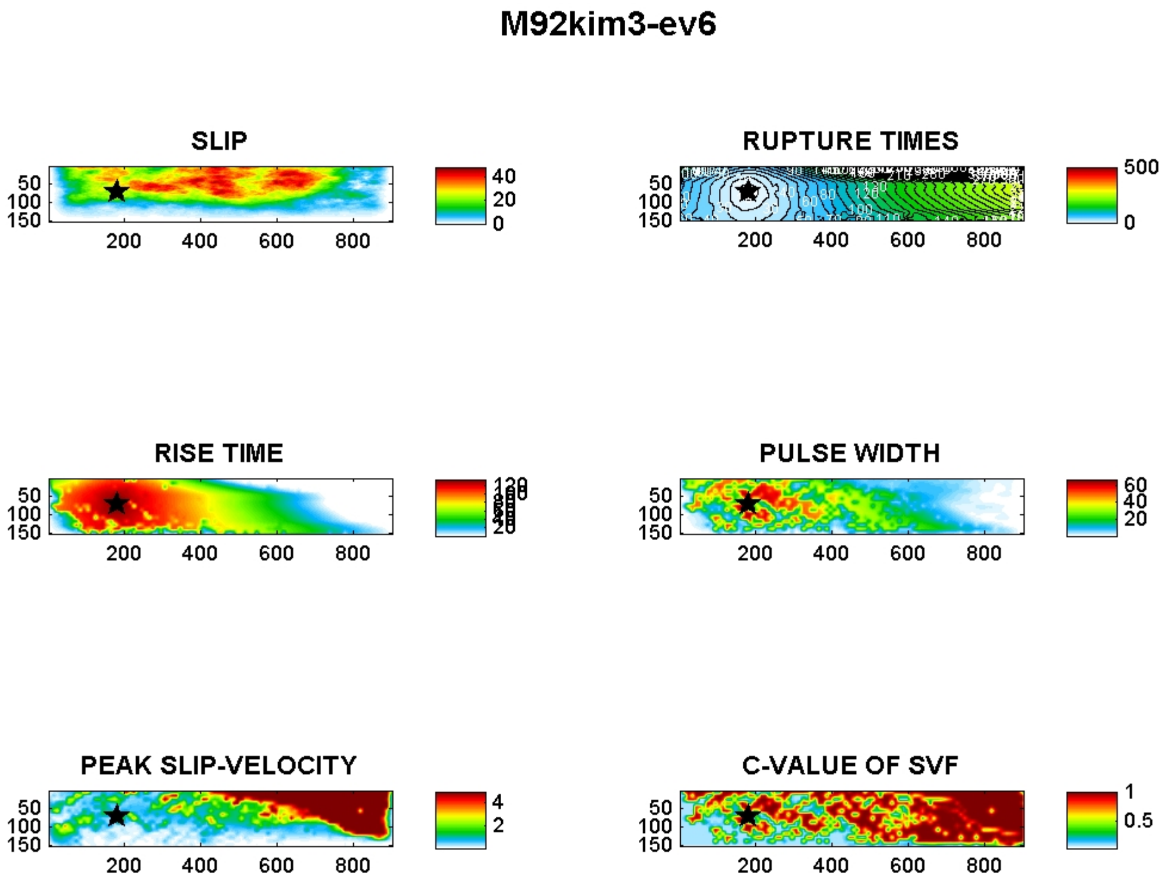

Figure 3 Pseudo-dynamic rupture model for scenario earthquake of a M 9.2 mega-thrust earthquake on the Cascadia subduction zone. See text for details on the generation and properties of this rupture model.

Implementation of the Yoffe-function for the pseudo-dynamic source model

The pseudo-dynamic source model uses a simple slip-velocity function, parameterized in terms of two overlapping triangles whose lengths and peak-values (i.e. peak-slip values) were derived from scaling relations (Gautteri et al, 2004). While those functions serve their purpose for ground-motion simulations, a more physical approach is desirable. We therefore tested the potential use of the recently proposed ‘regularized Yoffe’ function (Tinti et al, 2005) as more physical alternative. Figure 4 shows an example of this regularized Yoffe function, computed for an initial acceleration time $T_{acc} = 0.3\ s$ and a rise time $\tau_r = 4$ sec. Obviously, this functional form resembles a Kostrov-like slip-velocity function or typical slip-functions seen in dynamic rupture models much more than a combination of two triangles. We thus will add this option for a slip-velocity function parameterization to the pseudo-dynamic source characterization.

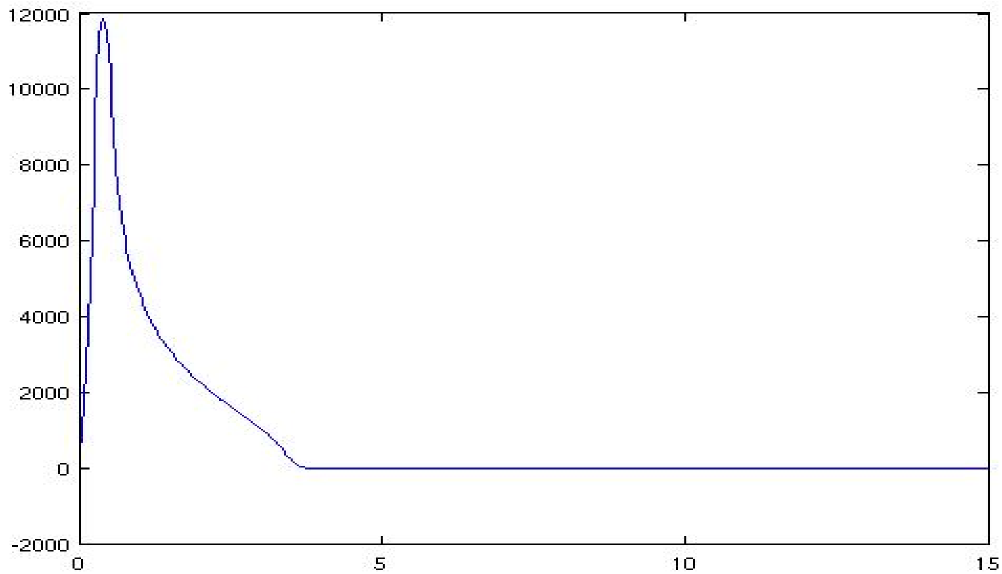

Figure 4 Example for the implementation of the regularized Yoffe function proposed by Tinti et al. (2005).

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