Summary of Session 4:

Simulation of earthquake rupture, wave propagation and standard models for different tectonic settings

Kim Olsen [(1)], Heiner Igel[(2)] and Takashi Furumura[(3)]

(1) Institute for Crustal Studies, University of California, Santa Barbara, USA (e-mail: kbolsen@crustal.ucsb.edu; phone: +1 805 893 7394; fax: +1 805 893 8649). (2) Institute of Geophysics, Ludwig-Maximilians University, Munich, Germany (e-mail: igel@geophysik.uni-muenchen.de; phone +49 89 23944204; fax: +49 89 23944205. (3). (1)Earthquake Research Institute, University ofTokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-0032 Japan (e-mail: furumura@eri.u-tokyo.ac.jp, inquiry@taro.eri.u-tokyo.ac.jp)

Presentations

The topics discussed in this session include general dynamics on dipping/curved/segmented faults and friction, dynamic rupture scenarios (e.g., Chi-Chi, Kocaeli), dynamic radiation, fault-trapped waves,seismic hazards, hybrid methods, and broadband time histories.

Dalguer and Irikura simulated 2D dynamic rupture propagation for two strike-slip sections of the 1999 Chi-Chi, Taiwan, earthquake. They used models with asperities of different size to explain that the peak ground motions for > 1 Hz and < 1 Hz are larger near the southern and northern parts of the fault, respectively. The simulations showed the importance of including the dynamic source mechanism in ground motion prediction.

Madariaga argued from simple 2D in-plane studies that the effects of the free surface depend on the dip of the fault. However, he found that the free surface effects on dynamic rupture propagation, which several authors have discussed in the literature, are extremely complicated and not yet clearly explained.

Aochi and Fukuyama discussed 3D dynamic models for the 1992 Landers earthquake using the BIEM with non-planar geometries. While their model explained stress transfer between segments as well as the total seismic moment their synthetics underestimated the strong motion records and surface slip. A likely reason for the discrepancy is lack of lateral heterogeneity in stress and frictional parameters.

Olsen, Fukuyama, Aochi and Madariaga presented a hybrid method to compute dynamic rupture propagation on non-planar fault geometries in a 3D heterogeneous medium. They used BIEM for the dynamics and FD for the radiation and demonstrated the method using a simple curved fault geometry. The method has potential of becoming an important tool for large-scale dynamic modeling of the statistics of recurrent ruptures on multiple, arbitrarily-shaped fault systems in complex earth models.

Igel, Jahnke, Kaser and Ben-Zion explained a sophisticated technique for wave propagation simulation on unstructured grids, which is suitable for evaluating topographic effects on the wave propagation. They evaluated the accuracy and computational efficiency of this new technique by comparing with traditional finite-difference methods. They also presented studies on fault-trapped waves using a 3-D finite-difference method to understand the detailed structure of the fault.

Kennett and Furumura stated the importance of 3-D crust and upper-mantle structure on strong motion. They presented a number of observations and simulations on this topic. They also showed results of 3-D simulation of the 2000 Tottori-ken Seibu earthquake, Japan, and showed that the generation of Lg and Rg wave in western Japan enhanced the seismic intensities considerably.

Furumura, Wen and Koketsu conducted numerical 3-D simulation of the 1999 Chi-Chi, Taiwan earthquake using the parallel PSM/FDM hybrid method. They evaluated the effect of source, path and site effects on the generation of strong ground motion at regional distances. They concluded that the shallow slip at the fault contribute to the generation of surface waves at the coast and that the deeper slip is responsible for the amplification of ground motion at longer distances.

Pulido and Kubo presented a hybrid method which uses the discrete-wavenumber technique for calculation of the low-frequency wavefield (f<1Hz) and the stochastic Green's function method for evaluating high-frequencies. They applied this technique to the simulation of the 1999 Kocaeli earthquake to show the efficiency of this approach for broad-band simulation of strong ground motion.

Fukuyama, Hashimoto, and Matsuura used the BIEM to simulate the transition from quasi-static growth to dynamic rupture propagation for a strike-slip fault. They estimated the initial stress distribution and constitutive relations using quasi-static simulation for a model of two asperities separated by a creep zone. Their results were then used to simulate dynamic rupture propagation. The method shows promise for more realistic simulation of earthquake cycles.

Miyatake used dynamic FD rupture models to study the relationship between rupture propagation and strong ground motion. In particular, he computed dynamic rupture propagation for the 1999, Kocaeli, Turkey, earthquake, using an initial stress distribution computed from kinematic slip inversion. He also discussed the differences between ground motion from strike-slip and dip-slip events, and the effect of near-surface, low-velocity layers.

Kase and Kuge used dynamic 3D FD models to examine rupture propagation between parallel and perpendicular fault segments. They found that the most important factors controlling whether rupture jumps or not include the depth to the top of the segments, the relative location of the segments, and geometry of the segments. Jumps are promoted between parallel segments, in particular near the free surface, compared to perpendicular segments.

Hori and Ichimura developed a new technique ("Macro-Micro analysis") for efficient large-scale simulation of seismic wave propagation. A stochastic model is used to determine the mean response of strong ground motion (macro analysis) and the singular perturbation expansion technique is used to evaluate the displacement field with higher spatial resolution (micro analysis). They demonstrated the efficiency of this technique by simulation of the Chiba earthquake and compared it with actual data at Yokohama-city.

Pavlenko and Irikura estimated nonlinear soil behavior in strong ground motion records during the 1995 Kobe earthquake using the vertical array at Kobe Port-island. They showed different types of time-dependent stress-strain curves at each depth of the borehole record, which is caused by progressive reduction of the shear modulus due to large strain loading during the mainshock of the Kobe earthquake.

Afnimar and Koketsu conducted a joint inversion using seismic refraction and gravity data for the estimation of detailed 3-D basement structure beneath the Osaka basin. The results successfully recovered the buried Kyoto fault and the extension of Ashiya fault very clearly. The results can be applied to revise the 3-D wave propagation simulation of the 1995 Kobe earthquake in the future.

Malytskyy proposed an inverse technique to determine the source and medium parameters, recurrently. The method has potential of becoming an important tool for accurate determination of hypocenters and medium parameters.

Shaw found an increase in average spectral acceleration away from the epicenter for large earthquakes in elastodynamic rupture models, by as much as a factor of 10. The cause of the large increase is still under investigation.

Wu, Gao and Murakami presented finite difference modeling of crustal deformation including discontinuous slipping displacement along a fault plane. Their model includes finite slip-weakening behavior with a simple stress-relative displacement relationship on the fault. Using this technique they succeeded simulating the breakdown process of the fault curvature and folding problem.

Working Group Meeting

The main topic for discussion during the session 4 working group meeting was code validation and definition of standard models for different tectonic settings. We agreed to investigate the possibility of validating numerical codes for the following subgroups: (a) rupture dynamics (Fukuyama), (b) viscoelastic codes inclusive loading (Pollitz), (c) fault-friction algorithms (Tullis), and (d) wave propagation (Olsen). It is the intent that these models allow participants in ACES to compare and validate different numerical and stochastic approaches for simulation of earthquake rupture and wave propagation. Such comparisons are highly desirable to demonstrate the efficiency and applicability to realistic problems, to provide confidence in individual groups results, and to allow more efficient parallel efforts. This may lead to an ``Aces approval stamp'' concept for the use of numerical modeling codes. Olsen and Igel provided overviews of prior validation exercises from southern California (basin simulations within SCEC) and Europe (global models), respectively. It was recommended from the experience gained from those validation exercises to have a systematic progression in problem complexity, or to present an ``entrance ticket'' to participate, in the form of already completed validations for simple (halfspace/layered models). It was noted that there is currently no funding for these exercises. Leaders of the four subgroups (listed in parenthesis after each subgroup) agreed to take charge of the validation, to be directed by Day and Olsen. The group also discussed choices for standard models of three tectonic settings: (1) subduction zone (Japan), (2) interplate (USA), and (c) intraplate (Australia, China). However, simulations relevant for these settings should not start until the validation exercise above has been completed/is well under way.