Faculty of Mathematics, Physics and Informatics Comenius University, Bratislava

and

Geophysical Institute Slovak Academy of Sciences, Bratislava

Workshop on

Numerical Modeling of Earthquake Source Dynamics

2007 NMESD

Proceedings of the Workshop - Abstract Book

September 2 - 6, 2007

Smolenice Castle
(near Bratislava)
Slovak Republic

Workshop on

Numerical Modeling

of Earthquake Source Dynamics

NMESD 2007

September 2-6, 2007

Smolenice Castle, Slovak Republic

PROCEEDINGS OF THE WORKSHOP

-

ABSTRACT BOOK

http://www.nuquake.eu/NMESD2007/

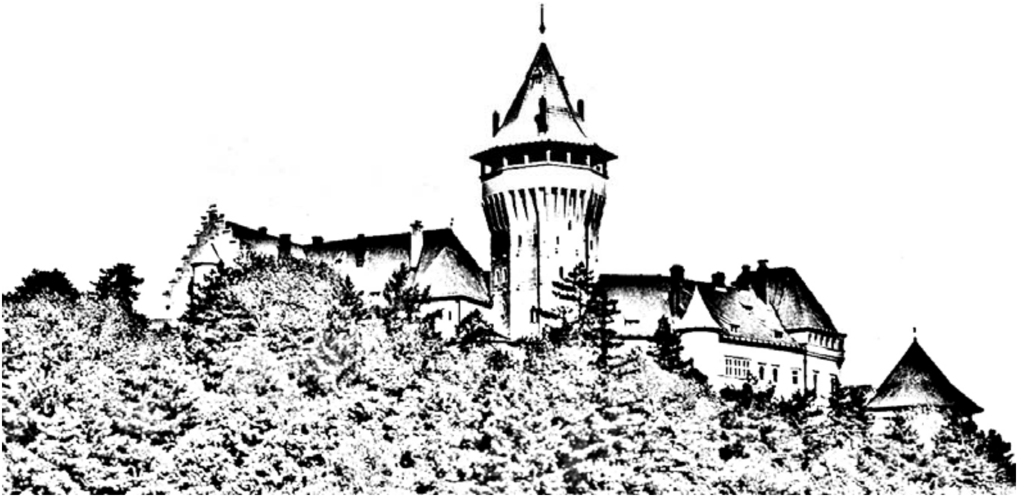
Editors: Ralph J. Archuleta, Peter Moczo, Peter Labák
Technical preparation: Andrej Cipciar, Peter Pažák

Published by Comenius University in Bratislava, Slovak Republic

ISBN: 978-80-223-2373-4

CONTENTS

A B S T R A C T S



CONSTRAINING FAULT CONSTITUTIVE BEHAVIOR WITH SLIP AND STRESS HETEROGENEITY

Brad T. Aagaard [1], baagaard@usgs.gov
Thomas H. Heaton [2], heatont@caltech.edu

[1] Earthquake Hazards Team, U. S. Geological Survey, Menlo Park, CA, USA
[2] Department of Geologic and Planetary Sciences,
California Institute of Technology,Pasadena, CA, USA

We explore features of rupture dynamics that (1) lead to slip heterogeneity in earthquake ruptures and (2) maintain these conditions following rupture, so that the stress field is compatible with the generation of aftershocks and facilitates heterogeneous slip in subsequent events. Our 3-D finite-element simulations of magnitude 7 events on a vertical, planar strike-slip fault show that the conditions that lead to slip heterogeneity remain in place after large events when the initial shear stress and sliding stress are spatially heterogeneous. Simulations that also include spatially heterogeneous fracture energy tend to produce narrower slip pulses independent of a slip rate dependence in the fault constitutive model. An alternative mechanism for generating these confined slip pulses might be fault constitutive models that have a stronger rate dependence, which make them difficult to implement in numerical models. We conjecture that very narrow slip pulses and a fractal stress field might explain seismologic observations of slip heterogeneity and increasing fracture energies with earthquake size, and geologic observations of millimeter-wide primary slip surfaces and fracture energies estimates on the order of 10 kJ/m^2.

DYNAMIC RUPTURE ON VELOCITY-WEAKENING BIMATERIAL FAULTS WITH OFF-FAULT PLASTICITY AND DAMAGE

Jean-Paul Ampuero, ampuero@erdw.ethz.ch

Institute of Geophysics, ETH Zurich, Zurich, Switzerland

In the prevailing paradigm for modeling dynamic earthquake rupture, non-linearities are confined to a fault plane governed by friction laws, for which the constitutive parameters (e.g. fracture energy) are understood as material properties. However, a dynamic rupture may excite non-linear behavior in the vicinity of the main fault plane, for instance through secondary micro-fracture. These off-fault processes can in turn have a dynamic feedback on the main rupture and be a key to understand the earthquake energy budget and the physical bounds on extreme ground motion. These effects are of special importance in the case of ruptures running along faults that separate rocks of different elastic properties, because they can generate asymmetric patterns of material degradation out of the fault plane that might be observable in the field.

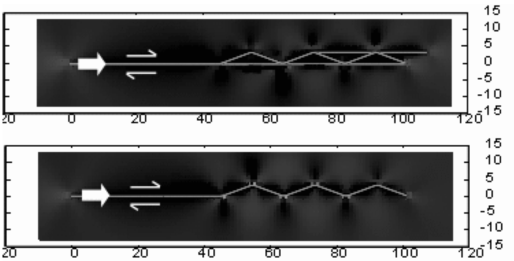
We explore the dynamics of earthquake ruptures on bimaterial fault interfaces governed by velocity-weakening friction and including inelastic dissipative processes on the surrounding rock. Two rheologies are studied and compared: strain softening visco-plasticity and a damage law developed by V. Lyakhovsky, Y. Ben-Zion and coworkers. We will present the results of numerical simulations of this combination of challenging problems based on the Spectral Element Method (SEM) and will discuss their relevance for natural earthquake faulting.

RUPTURE DYNAMICS, SEISMIC CYCLES AND GEOMETRICAL EVOLUTION OF WAVY FAULTS

Ryosuke Ando [1], ando@bosai.go.jp
Christopher H. Scholz [2], scholz@ldeo.columbia.edu

[1] Department of Seismological Research, National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Japan
[2] Lamont-Doherty Earth Observatory, Columbia University, New York, USA

It has been known that the kinked parts of faults suppress slip and control the propagation of ruptures beyond these points. Since the kinks in wavy faults cause the intensified concentration of stresses around them, the nucleations of secondary faults or branches are expected from the kinks. In order to analyze this problems we use a newly developed boundary integral equation method (BIEM) [Ando et al., 2007, EPS], which are capable of the of full dynamic modeling of rupture on non-planar faults as well as quasi-static modeling during a seismic cycle. By the simulations, we confirm that off-fault stresses can be accumulated around the kinks associated with recurrent slip events on the faults, and then the concentrated stress eventually triggers the formation of new branch faults as shown in fig.1. In fig.1, resulting fault geometry (green lines) and shear stress fields (color contour) after 1st (bottom) and 2nd (top) rupture events. The rupture propagates along preexisting wavy faults and the stress increases around kinks. The new faults emerge from kinks due to the dynamic rupture. These branches are shown to dynamically propagate cutting through preexisting wavy geometry. Since pinning of slip at kinks is avoided by this event, the released moment become much larger than those of previous events propagating on preexisting wavy fault. This result suggests that non-planar fault geometry is essential for the segmentation and interaction of earthquake rupture, which depends on the history of geometrical evolution of faults. In addition our study explains interesting co-seismic and tectonic phenomena such as off-fault aftershocks, flattening of fault plane with increasing slip, and variation in directivity and paths of ruptures from one event to the next.



PREDICTABILITY OF GROUND MOTION: SIMULATIONS FOR THE 2003 TOKACHI-OKI-LIKE EARTHQUAKE

Ryosuke Ando [1,3], ando@bosai.go.jp
Eiichi Fukuyama [1,3], fuku@bosai.go.jp
Shin Aoi [1,3], aoi@bosai.go.jp
Chihiro Hashimoto [2,3], hashi@eps.s.u-tokyo.ac.jp
Mitsuhiro Matsuura [2,3], matsuura@eps.s.u-tokyo.ac.jp

[1] Earthquake Research Department, National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Japan
[2] Department of Earth Science, University of Tokyo, Tokyo, Japan
[3] CREST, Japan Science and Technology Agency, Tokyo, Japan

We have conducted a joint simulation from the plate subduction to the generation of seismic waves through the earthquake dynamic process (also refer Fukuyama et al. in this abstract volume). To make a practical estimation of seismic hazard, it is important to evaluate source effects on ground motions based on several earthquake rupture scenarios because the source processes such as rupture directivity and asperity locations leave huge uncertainties comparing to the crustal structures. In this presentation, we focus on the ground motion simulation using the finite difference method with a 3-D crustal structure [Aoi and Fujiwara, 1999] for the 2003 Tokachi-oki earthquake, which occurred in a subduction zone off Hokkaido, Japan. We examined three rupture scenarios to evaluate the rupture directivity effect under a set of dynamic parameters which is given to reproduce the 2003 event. Rupture models are computed by the integral equation method where initial stress and constitutive relation are given by the simulation of plate subduction [Fukuyama et al., this abstract book]. The rupture nucleations are assumed, respectively, at a hypocenter of this earthquake in model S, at the shallowest point on the fault area in model A, and at its deepest point in model B. In all models, seismic moments are the same, which is constrained by the amount of stress drop allowed in the dynamic models. Generally, we observe a clear correlation between amplification of ground motions and the basin structure. In model S, the synthetic seismograms appear to reasonably reproduce the observations. We could observe some differences between the models, which is caused by the different rupture scenarios. These variations should be important for the seismic hazard estimation.

BROADBAND SOURCE INVERSION FOR ESTIMATING HETEROGENEOUS SLIP AND SLIP-VELOCITY DISTRIBUTIONS USING EMPIRICAL GREEN'S FUNCTION AND CRACK SOURCE MODEL

Kimiyuki Asano, k-asano@egmdpri01.dpri.kyoto-u.ac.jp
Tomotaka Iwata, iwata@egmdpri01.dpri.kyoto-u.ac.jp

Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan

It is quite important to estimate quantitatively slip velocity during faulting for investigating strong motion generation process including high-frequency seismic waves. A new source inversion method is developed to obtain slip, peak slip velocity, and rupture time distributions on the fault in the broadband frequency range, and applied it to the strong motion data set of the 2003 off Miyagi intraslab earthquake (M_W=7.0), which occurred at a depth of 72 km within the Pacific slab.

The source model is estimated by jointly inverting the velocity waveforms in the low-frequency range (0.2-1 Hz) and acceleration envelopes in the high-frequency range (1-10 Hz). The forward formulation of the waveform inversion is based on the empirical Green's function method by Irikura (1986) and Irikura et al. (1997). The method is extended to introduce spatial heterogeneities of slip velocity intensity, duration of the filtering function, and rupture time. The unknown parameters for the inversion are those three parameters at each subfault. The source parameters of the small event or the EGF event are estimated by waveform modeling with a quasi-dynamic circular crack source model. Using these parameters, the absolute values of final slip and peak slip velocity for the large event can be obtained.

The obtained slip distribution showed two asperities or large slip areas. The first asperity including the hypocenter has large peak slip velocity near the hypocenter. The second asperity at the deep portion shows relatively large peak slip velocity close to the north edge of the asperity. The maximum value of the peak slip velocity is 10 m/s, which is somewhat large compared to that of shallow inland crustal earthquakes. It is related to the high stress drop of intraslab earthquakes.

WHAT CONTROLS RUPTURE VELOCITY DURING EARTHQUAKES ?

Michel Bouchon [1], michel.bouchon@ujf-grenoble.fr
Hayrullah Karabulut [2], kara@boun.edu.tr

[1] LGIT, University of Grenoble, Grenoble, France
[2] Kandilli Observatory, Bogazici University, Istanbul, Turkey

We try to investigate the factors which control the speed at which a fault breaks during an earthquake. To this aim we review the recent observations of rupture velocities during strike-slip earthquakes and we try to find what fault characteristics are commonly encountered for events with fast or slow rupture velocities. All the reported episodes of fast rupture occurred on fault segments with extremely simple fault geometry/morphology. This suggests that rupture velocity is controled in part by the geometry/morphology of the fault.

DYNAMIC RUPTURE ALONG BIMATERIAL INTERFACES IN 3D

Gilbert B. Brietzke [1], brietzke@geophysik.uni-muenchen.de
Alain Cochard [2], Alain.Cochard@eost.u-strasbg.fr
Heiner Igel [1], igel@geophysik.uni-muenchen.de

[1] Earth and Environmental Sciences, Ludwig-Maximilians-Universität München, Munich, Germany
[2] Ecole et Observatoire des Sciences de la Terre, Université Louis Pasteur, Strasbourg, France

Large faults with a long slip history often separate rocks of different elastic properties. Such bimaterial interfaces have been reported to accommodate remarkable dynamic properties in the 2D in-plane case that may be relevant to many issues of basic and applied science (Ben-Zion, 2001). Slip along a bimaterial interface generates dynamic changes of normal stress, modifying the local fault strength which, in principle, can generate a unilateral wrinkle-like pulse. This mechanism is neither present in the homogeneous case nor the 2D anti-plane case. Recently it has been shown that some of these properties stay valid also in the 3D case where there is a mixing of the in-plane and anti-plane case (e.g., Brietzke et al. 2007). However, the relevance of this mechanism for natural faulting is a subject of ongoing debate (e.g. Andrews and Harris, 2005). Independently there are good examples for which the bimaterial mechanism seems to be necessary to properly interpret the observations: Rubin and Ampuero (2007) observed asymmetric alongstrike distribution of aftershocks on the San Andreas fault and Dor et al. (2006) observed asymmetric rock damage across faults of the San Andreas system. The uncertainty in the physical concepts and the constraints of their parameter ranges makes it difficult to come to definite conclusions. Here we present results of an ongoing numerical investigation of bimaterial ruptures in 3D extending the parameter range and resolution of previous studies.

EARTHQUAKE SCALING AND GENERIC PROPERTIES OF SLIP PROFILES

Michel Campillo, michel.campillo@obs.ujf-grenoble.fr
Isabelle Manighetti, isabelle.manighetti@obs.ujf-grenoble.fr
Sébastien Hok, sebastien.hok@obs.ujf-grenoble.fr

LGIT, Universite Joseph Fourier and CNRS, Grenoble, France

Slip and length measurements on earthquakes suggest large stress drop variability when analyzed on the basis of the crack model. For large earthquakes, the scaling relation includes the width of the seismogenic zone as a characteristic length. Based on the analysis of an extended set of slip-length surface measurements for large earthquakes (M>6), we propose that the apparent variability actually arises from earthquakes breaking a variable number of major fault segments. Each broken segment roughly scales as a crack, while the total multi-segment rupture does not. Stress drop on individual segments is roughly constant, only varying between 3.5 to 9 MPa. We present dynamic simulations illustrating the implications of segmentation for earthquake scaling relations.

The analysis of the available earthquake slip distributions suggests the existence of generic features beyond individual heterogeneities, namely a roughly triangular shape both along strike and dip, and asymmetric in most cases. Long linear tapers are found both in coseismic and in long-term, cumulative slip profiles. For earthquakes, the overall triangular shape is observed independently of the size of the event. This suggests that the linear tapers are not associated with the constitutive friction properties for those are not expected to change with the size of the earthquake. Similar observations have been made for cumulative slip profiles. Explanations have been proposed that involve secondary faulting or off fault damage. We have analyzed the quasi-static behaviour of antiplane noncoplanar fault systems subject to a slip-dependent friction. Some of the resulting slip profiles show long, linear sections. A plastic behaviour in the bulk around the fault plane is considered in a companion presentation.

RUPTURE DYNAMICS OF EARTHQUAKE FAULT IN 3D HALF-SPACE AND OCCURRENCE OF SUPERSHEAR TRANSITION

Xiaofei Chen [1,2], xfchen@pku.edu.cn
Haiming Zhang [1], zhanghm@pku.edu.cn

[1] School of Earth and Space Science, Peking University, Beijing, China
[2] School of Earth and Space Science, University of Science and Technology of China, Hefei, China

Recently, we successfully extended the BIEM to include the effect of free surface by incorporating Green's function for half-space (Chen and Zhang, 2004, 2006a,b,c). The extended BIEM was applied to investigate the influences of geometrical and physical parameters, such as the dip angle (δ) and depth (h) of the fault, radius of the nucleation region (R_{asp}), slip-weakening distance (D_c), and stress inside (T_i) and outside (T_e) the nucleation region, on the dynamic rupture processes on the fault embedded in a 3-D half space. Numerical results show that (1) overall pattern of the rupture depends on whether the fault runs up to the free surface or not, especially for strike slip, (2) although final slip distribution is influenced by the dip angle of the fault, the dip angle plays a less important role in the major feature of the rupture progress, (3) different value of h, δ, R_{asp}, T_e, T_i and D_c may influence the balance of energy and thus the acceleration time of the rupture, but the final rupture speed is not controlled by these parameters. An interesting feature of the dynamic process on a fault embedded in a 3-D half space is the appearance of a secondary rupture front propagating at a supershear speed for a strike slip. Numerical simulations indicate that for a fault intersecting the ground surface, all strike-slip faults can evolve with supershear rupture. However, a dip-slip rupture propagates always with subshear speed. These features may attribute to the disturbance of shear stress ahead of the rupture front in the in-plane direction, which is greatly enhanced by the interaction between the dynamic rupture itself and the ground surface.

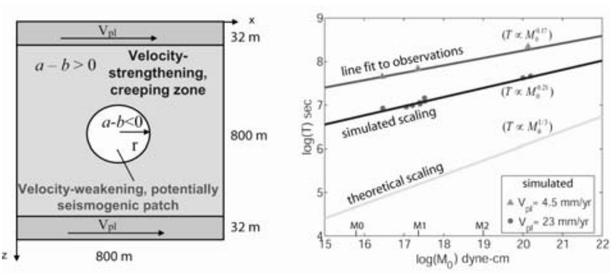
SIMULATIONS OF SMALL REPEATING EARTHQUAKES THAT REPRODUCE THE OBSERVED SCALING OF SEISMIC MOMENT WITH RECURRENCE TIME

Ting Chen [1], tchen@gps.caltech.edu
Nadia Lapusta [2], lapusta@caltech.edu

[1] Division of Geological & Planetary Sciences, California Institute of Technology, Pasadena, USA
[2] Division of Geological & Planetary Sciences and Division of Engineering & Applied Science, California Institute of Technology, Pasadena, USA

Observations show that the recurrence time *T* and seismic moment M_0 of small repeating earthquakes in Parkfield scale as $T\infty M_0^{0.17}$ (Nadeau and Johnson, 1998). This is different from the typical scaling $T\infty M_0^{1/3}$ which can be explained by a simple model of circular ruptures with stress drop independent of M_0 and slip proportional to *T*. Several explanations for this discrepancy have been proposed, including high stress drop (Nadeau and Johnson, 1998), shading asperity (Sammis and Rice, 2001) and aseismic slip due to strain hardening (Beeler et al., 2001). These events are the targets of the San Andreas Fault Observatory at Depth (SAFOD) drilling project.

We use the methodology of Liu and Lapusta to simulate repeating events in a 3D model of a strike-slip fault embedded into an elastic space and governed by rate and state friction laws. On the fault, a small circular patch with steady-state velocity-weakening properties is embedded into a larger region governed by velocity strengthening. The model incorporates tectonic-like loading and all dynamic effects during unstable sliding. In our simulations, preseismic slip and afterslip constitute a progressively larger part of the total slip for smaller earthquakes, resulting in the scaling $T\infty M_0^{0.21}$, very similar to the one observed. Hence we provide a laboratory-based foundation to the idea of Beeler at el. (2001) that much of the overall slip at the places of small repeating earthquakes is accumulated aseismically. Stress drops of the simulated events are within the typical range. Our current and future goals are to explore the parameter space of the model and to compare the simulated behavior with detailed SAFOD observations.



DYNAMICAL PROPERTIES OF THE ASPERITIES OF THE STILFONTEIN EARTHQUAKE, ML 5.3

Artur Cichowicz, artur@geoscience.org.za

Seismology, Council for Geoscience, Pretoria, South Africa

The largest recorded earthquake associated with deep gold mining ocurred near the town of Stilfontein, South Africa. The earthquake was located at a depth of 2.1 km on an ancient normal fault. Underground investigation revealed a strong fragmentation of the fault. Waveform inversion was performed at regional distances for a point source model.

In addition, uniquely, the earthquake was well recorded by the underground mining seismological networks equipped with more than hundred high-frequency sensors. Four individual pulses were resolved within the S-wave train. All pulses are assumed to be associated with the failure of patches of the source region. The onset points of the patches were independently located on the fault plane, leading to calculation of the delay time between the beginnings of asperities and the rupture velocity without any additional assumptions. To estimate the size of the corresponding asperity the rise time or duration of the pulses is used. The dynamical properties such as the static stress drop, the seismic energy, the apparent stress drop and the fracture energy for each asperity were calculated. The fracture energy for the sequence of the asperity was calculated using the Abercrombie and Rice (2005) method. Temporary and space variation of the dynamical properties rupture was analyzed. This study is unusual as mining geology had provided information on the strong fragmentation of the fault, allowing for detailed comparison of the features of asperities with the unbreakable barriers created by fault heterogeneity. Those measurements lead to the construction of a model of the seismic source as a composition of the asperities, with additional displacement outside the area of those asperities.

USING GEOPHYSICAL DATA INVERSION TO CONSTRAIN EARTHQUAKE DYNAMICS: A STUDY ON DYNAMICALLY CONSISTENT SOURCE TIME FUNCTIONS

Antonella Cirella, cirella@ingv.it
Elisa Tinti, tinti@ingv.it
Alessio Piatanesi, piatanesi@ingv.it
Massimo Cocco, cocco@ingv.it

Istituto Nazionale di Geofisica e Vulcanologia,
Department of Seismology and Tectonophysics, Rome, Italy

Earthquake kinematic models are often used to retrieve the main parameters of the causative dynamic rupture process. These models are usually obtained through the inversion of seismograms and geodetic data and they can be used as boundary conditions in dynamic modeling to calculate the traction evolution on the fault. Once traction and slip time histories are inferred at each point on the fault plane, it is feasible to estimate the dynamic and breakdown stress drop, the strength excess and the slip weakening distance (D_c). However the measure of these quantities can be biased by the adopted parameterization of kinematic source models. Here we focus our attention on the importance of adopting source time functions (STFs) compatible with earthquake dynamics to image the kinematic rupture history on a finite fault. We first compute synthetic waveforms, through a forward modeling, to evaluate the effects of STFs on the ground motion and on the radiated energy. Therefore, adopting different STFs, we perform kinematic inversion of strong motion and GPS data, using a new non linear two-stages search algorithm (Piatanesi et al., 2006). We have quantitatively verified that the choice of STF affects ground motion time histories within the frequency band commonly used in kinematic inversion and that the inferred peak slip velocity and rise time strongly change among the inverted models. These differences has a dramatic impact when kinematic models are used to infer dynamic traction evolution. The shape of the slip weakening curve, the ratio between D_c and the final slip and the dynamic stress drop distribution are remarkably affected by the adopted STFs. We recommend the adoption in kinematic inversions of source time functions that are compatible with earthquake dynamics.

SCALE DEPENDENCE IN THE DYNAMICS OF EARTHQUAKE RUPTURE PROPAGATION: EVIDENCE FROM GEOLOGICAL AND SEISMOLOGICAL OBSERVATIONS

Massimo Cocco, cocco@ingv.it
Elisa Tinti, tinti@ingv.it

Istituto Nazionale di Geofisica e Vulcanologia,
Department of Seismology and Tectonophysics, Rome, Italy

Geological observations reveal that natural fault zones are characterized by slip localization and complex structures; slip occurs on principal slipping zones located in fault cores surrounded by fractured damage zones and faults have a finite thickness. Earthquake ruptures occur on interfaces of finite thickness and involve various non-linear dissipation processes coupled over a wide range of spatial and temporal scales. Therefore, earthquakes associated with natural faults have to be scale-dependent (implying a departure from self-similarity). Most of our understanding of dynamic earthquake ruptures relies on frequency-dependent seismological observations, raising the question of scale dependence and scale separation during earthquakes. No theoretical solutions are available today for a physically consistent renormalization of earthquake rupture dynamics based on an accurate physical representation of dissipation processes occurring at different scales. This is due to the poor knowledge of the constitutive laws governing each process occurring within the fault zone and controlling strain localization, fault weakening and stress evolution. In the absence of such a detailed physical description of a scale dependent process, we are forced to use classical continuum mechanics and a phenomenological approach to describe dynamic fault weakening and rupture propagation on a virtual mathematical plane of zero thickness. This implies that shear stress, slip and slip velocity should be considered as macroscopic parameters. Fault friction should be also considered as a phenomenological macroscopic parameter. In this context fracture energy and slip-weakening distance (D_c) are scale dependent parameters not directly associated with the processes occurring at smaller scales.

EFFECTS OF 3D ON THE RUPTURE DIRECTIONALITY OF RUPTURE PROPAGATION AT BIMATERIAL INTERFACE

Luis A. Dalguer, ldalguer@moho.sdsu.edu
Steven M. Day, day@moho.sdsu.edu

Department of Geological Sciences, San Diego State University, San Diego, CA, USA

Normal stress perturbations near the tip of a propagating mode II rupture along a bimaterial interface can introduce asymmetries in the rupture velocity and eventually excite unilateral rupture. We explore this problem in 3D, using the simple slip weakening friction model, to study rupture directionality in strike-slip faulting. Our study has revealed a mechanism for exciting the preferred-direction unilateral rupture on a bimaterial interface. This mechanism, observed in 3D only, initially develops as a crack-like asymmetric rupture, and subsequently, due to the reflecting S waves coming from the top and bottom of the fault (stopping phases) the rupture separates into two separate slip pulses traveling in opposite directions. The slip pulse in the preferred direction propagates indefinitely, while the one in the non-preferred direction dies out. This mechanism for a bilateral-to-unilateral transition only takes place over a small range of prestress and for high values of the quotient $(1+\Phi_s)/(1-\Phi_d)$, where Φ_s and Φ_d are, respectively, the static and dynamic friction coefficients. The distance of the rupture in the non-preferred direction reduces for high values of this quotient, and increases or becomes bilateral rupture for law values. The free-surface also takes an important role on the directionality of the rupture. The unilateral rupture, for a fault that reaches the free-surface, occurs when the width of the fault is half of the width of an equivalent embedded fault, and the distance of the rupture in the non-preferred direction also increases due to the free-surface effects.

EFFECTIVE NORMAL STRESS CHANGES IN RUPTURE DYNAMICS

Eric M. Dunham [1], edunham@fas.harvard.edu
David Belanger [2], belang@fas.harvard.edu
James R. Rice [3], rice@esag.deas.harvard.edu

[1] Department of Earth and Planetary Sciences, Harvard University,Cambridge, Massachusetts, USA
[2] Department of Mathematics,Harvard University, Cambridge, Massachusetts, USA
[3] School of Engineering and Applied Science and Department of Earth and Planetary Sciences, Harvard University, Cambridge, Massachusetts, USA

A mismatch of elastic properties across a fault induces normal stress changes during spatially nonuniform in-plane slip. Recently, Rudnicki and Rice [2006] showed that similar effects follow from a mismatch of poroelastic properties within fluid-saturated damage fringes along the fault walls; in this case, it is pore pressure on the slip plane and hence effective normal stress that is altered during slip. The sign of both changes can be either positive or negative, and they need not agree. Both signs reverse when the rupture propagates in the opposite direction, introducing asymmetry into the rupture process. We model a poroelastic fault zone cut by a planar fault separating different poroelastic media. Slip compresses one side of the fault and dilates the opposite side. The resulting undrained pore pressure change is of opposite sign across the fault, and pore fluid diffuses to ensure continuity of pore pressure and fluid flux across the fault. Pore pressure on the fault decreases if the compressive side is less permeable (all other quantities being equal) and vice-versa. When both elastic and poroelastic properties are discontinuous across the fault, steady sliding is unstable for all friction coefficients if the elastic mismatch permits the existence of a generalized Rayleigh wave.

Even in the absence of material contrasts, fault roughness alters normal stress. We use a coordinate transformation to map our physical domain with irregular boundaries to a rectangular computational domain. The coordinate transformation alters the governing equations, but permits us to solve these equations on a uniform mesh in the computational domain. By coupling these equations with a rate-and-state friction law on the fault, we model dynamic ruptures on rough faults.

FEM - FDM COUPLING STRATEGIES FOR WAVE PROPAGATION. APPLICATION TO SEISMIC RUPTURE MODELING

Pascal Favreau [1], pfavre@ipgp.jussieu.fr
Sylvie Wolf [2], sylvie.wolf@ecp.fr
Ioan R. Ionescu [3], ionescu@univ-savoie.fr

[1] Laboratoire de Sismologie, Institut de Physique du Globe de Paris, Paris, France
[2] Laboratoire de Mathématiques Appliquées aux Systemes, Ecole Centrale de Paris, Châtenay-Malabry, France
[3] Laboratoire de Mathématiques, Université de Savoie, Chambéry, France

On one hand, the classical finite element (FE) method on triangular unstructured mesh provides a robust and highly adaptive geometrical description of fault interfaces, but implies the resolution of a costly non-linear system of equations at each time step. On the other hand, the finite difference (FD) method is a low-cost and accurate method for wave propagation but cannot handle complex fault geometries. To cumulate both methods advantages, FE and FD are coupled as follows. The FE domain, which includes faults, is embedded in a surrounding velocity-stress FD domain. In the FE domain, an iterative domain decomposition technique is used to solve the non-linear problem. Both 2D SH and PSV configurations are considered. In SH, various coupling strategies are compared: coupling by the velocity field, by the stress field or both; with fully staggered FD grid or rotated staggered FD grid; with FD of order 2 or 4; with or without interpolation of the coupled field. Results are very comparable but it turns out that the simplest method is the coupling by velocity. In PSV, it comes out that the rotated staggered grid is the best option. To conclude, some simulations of rupture propagation on discontinuous faults are presented.

SIMULATION OF EARTHQUAKE DYNAMIC RUPTURE AND GROUND MOTIONS FOR THE 2003 TOKACHI-OKI EARTHQUAKE

Eiichi Fukuyama [1,3], fuku@bosai.go.jp
Shin Aoi [1,3], aoi@bosai.go.jp
Chihiro Hashimoto [2,3], hashi@eps.s.u-tokyo.ac.jp
Ryosuke Ando [1,3], ando@bosai.go.jp
Mitsuhiro Matsuura [2,3], matsuura@eps.s.u-tokyo.ac.jp

[1] Earthquake Research Department, National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Japan
[2] Department of Earth and Planetary Sciences, University Tokyo, Tokyo, Japan
[3] CREST, Japan Science and Technology Agency, Tokyo, Japan

We conducted a joint simulation from the plate subduction to the generation of seismic waves through the earthquake dynamic rupture process. In the simulation of dynamic rupture, we employed shear stress distribution and slip-weakening constitutive relation computed by the quasi-static simulation of earthquake cycles due to the plate subduction [Hashimoto et al., 2004] based on slip- and time- dependent constitutive relation [Aochi and Matsuura, 2002]. The plate boundary model is based on the ISC hypocenter catalog, and was qualified by examining the strain distribution caused by the subduction of plates [Hashimoto et al., 2004]. In the dynamic rupture simulation, the boundary integral equation method is used that allows us to model non-planar fault geometry [Tada et al., 2000; Tada, 2006]. Using the obtained slip function on the fault, we computed seismic wave propagation using the finite difference method assuming a 3-D heterogeneous velocity structure in this region [Aoi and Fujiwara, 1999]. Here, we focus on the 2003 Tokachi-oki earthquake (M=8.3). We used a shear stress distribution and slip-weakening constitutive law for the Tokachi-oki-like earthquake obtained by the simulation of plate subduction with non-uniform strength distribution along the plate boundary. After this computation, we obtain the spatio-temporal distribution of slip on the fault, which becomes the input for the simulation of seismic wave propagation. In the computation, we employed realistic 3-D velocity structure model in this area to take into account the propagation path and local site effects as mush as possible. Finally, we obtained the distribution of ground motions caused by the Tokachi-oki like earthquake.

PROPERTIES OF HIGH-FREQUENCY SEISMIC RADIATION AND INTRINSIC FAULT STRUCTURE RELEVANT TO REALISTIC SOURCE PROCESS SIMULATION

Alexander A. Gusev, gusev@emsd.iks.ru

Institute of Volcanology and Seismology, Russian Academy of Science,
Petropavlovsk-Kamchatsky, Russia

In efforts to simulate earthquake source more realistically, it is of use to take into account specific properties of high-frequency (HF) seismic radiation known mostly from accelerograms. These properties include: (1) Random-like appearance of HF records; this may indicate randomness of: slip in space, local slip velocity in time, and rupture front propagation history. (2) “Spikiness” of HF records: non-Gaussian, heavy-tailed statistics of HF amplitudes; this may reflect “spiky” local stress drop, or constructive interference from arcuate segments of rupture isochrone, or, rather, both. (3) Significantly deteriorated directivity as compared to low-frequency band; this may indicate true incoherence of radiation, with no deterministic rupture front. (4) Specific spectral shapes, mostly with flat acceleration source spectra over 0.5-10 Hz band but with important deviations outside it. Another important point is the relationship between local slip rate and HF radiation capability over the fault surface. For some earthquakes, close correlation was found between these; other data indicate limited or poor correlation. Most simulation techniques assume close correlation; this is probably not the general case. Complexity of ruptures seem to be related to non-flat, random fault geometry. Sliding of rough fault walls combined with confining pressure may cause normal stress singularities; but these may be less important if fault walls assumed non-monolithic and separated into blocks by secondary faults. Still, significant normal stress concentrations arise also in this case, leading to intermittent strength distribution (barriers and asperities) and eventually to HF radiation in a broad frequency range when a rupture propagates through such a strength field.

THE SCEC/USGS EARTHQUAKE RUPTURE DYNAMICS CODE VALIDATION EXERCISE

Ruth A. Harris [1], harris@usgs.gov
Michael Barall [1], mbinv@invisiblesoft.com
Ralph J. Archuleta [2], ralph@crustal.ucsb.edu
Brad Aagaard [1], baagaard@usgs.gov
Jean-Paul Ampuero [3], ampuero@erdw.ethz.ch
Harsha Bhat [4], bhat@esag.harvard.edu
Luis Dalguer [5], ldalguer@moho.sdsu.edu
Steven M. Day [5], day@moho.sdsu.edu
Benchun Duan [5], bduan@rohan.sdsu.edu
Eric Dunham [4], edunham@fas.harvard.edu
Geoff Ely [6], gely@ucsd.edu
Yuko Kase [7], kasep@ni.aist.go.jp
Nadia Lapusta [8], lapusta@caltech.edu
Yi Liu [8], yil@caltech.edu
Shuo Ma [9], shuoma@pangea.stanford.edu
David Oglesby [10], david.oglesby@ucr.edu
Kim Olsen [5], kbolsen@sciences.sdsu.edu
Arben Pitarka [11], arben_pitarka@urscorp.com
Elizabeth Templeton [4], templet@esag.harvard.edu

[1] Earthquake Hazards Team, U. S. Geological Survey, Menlo Park, USA
[2] Department of Earth Science, University of California, Santa Barbara, USA
[3] Institute of Geophysics, ETH, Zurich, Switzerland
[4] Division of EAS, Harvard University, Cambridge, USA
[5] Department of Geological Sciences, San Diego State University, San Diego, USA
[6] IGPP, University of California, San Diego, La Jolla, USA
[7] Geological Survey of Japan , AIST, Tsukuba, Ibaraki, Japan
[8] Divisions of EAS and GPS, California Institute of Technology, Pasadena, USA
[9] Geophysics Department, Stanford University, Stanford, USA
[10] Department of Earth Sciences, University of California, Riverside, USA
[11] Principal Seismologist, URS Corporation, Pasadena, USA

Computer simulations of spontaneously propagating earthquake ruptures started more than 30 years ago, but until a decade ago only a few researchers were able to numerically simulate 3D rupture propagation. Currently, numerous earthquake rupture computer codes are being developed and used by researchers worldwide, and the simulation results are starting to be incorporated in earthquake hazard assessment, for both seismological and engineering applications. Since most of the problems simulated using this numerical approach have no analytical solutions, it is imperative to compare and validate the various implementations of this research tool. To this end, a collaborative project of the Southern California Earthquake Center is underway. Our objective is to understand the simulation methods and their ability to faithfully replicate earthquake rupture physics and the resulting ground motion. We started with the problem of earthquake nucleation and rupture propagation in a simple geologic setting. Each subsequent simulation exercise involves increased complexity. An initial challenge for the exercise was to provide benchmark descriptions with sufficient detail that all participants could interpret the benchmarks similarly, but inperson workshops have helped. To date the comparisons have identified problems with certain codes and verified fixes. The exercise has encouraged cooperation towards improving modeling techniques among the participants, senior and junior scientists, postdocs, and students, from government, academia, and the private sector. All participants have contributed to the newfound knowledge that can only come from this type of collaborative effort, and we are encouraged by the fact that many of our codes are now producing similar results.

2D AND 3D RUPTURE DYNAMICS WITH NON-ELASTIC BEHAVIOUR IN THE BULK

Sébastien Hok [1], sebastien.hok@obs.ujf-grenoble.fr
Michel Campillo [1], campillo@obs.ujf-grenoble.fr
Ioan Ionescu [2], ionescu@univ-savoie.fr
Fabrice Cotton [1], fcotton@obs.ujf-grenoble.fr

[1] LGIT, Université Joseph Fourier, Grenoble, France
[2] LAMA, Université de Savoie, Le Bourget du Lac, France

We include a plastic yielding criterion in the bulk surrounding the fault in order to account for damaging around the fault plane. The previous studies showed that plasticity, by limiting the shear stresses in the medium, has an effect on 2D in-plane rupture dynamics calculations. We extend this work to 2D anti-plane and 3D geometries. Using a finite difference scheme with a slip weakening friction law, i.e a code which is different from the ones of previous studies, we are able to reproduce exactly the features observed for the 2D in-plane calculation. The 2D anti-plane and 3D cases lead to the same general characteristics, compared to elastic case:

- the slip velocity is strongly limited,
- the rupture speed is slightly decreased,
- the overall slip shape shows little differences (maximum and mean slip are increased, with higher slip gradient next to barriers).

We found also that the energy balance is highly modified, in such a way that the rupture cannot break barriers as easily as a purely elastic crack does. We think that, in this case where the fracture energy is prescribed to be constant on the fault plane by the slip weakening law, the strain energy cannot grow as a linear function of crack length. It stays constant beyond a certain point, stabilizing the rupture instability. According to these results, damage could be a critical phenomenon to take in account for a better understanding of earthquakes propagation and arrest.

SPECTRAL ELEMENT MODELING OF DYNAMIC RUPTURE AND LONG-TERM SLIP ON RATE AND STATE FAULTS

Yoshihiro Kaneko [1], ykaneko@gps.caltech.edu
Nadia Lapusta [1,2], lapusta@caltech.edu
Jean-Paul Ampuero [3], ampuero@erdw.ethz.ch

[1] Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, USA
[2] Division of Engineering and Applied Science, California Institute of Technology, Pasadena, USA
[3] Institute of Geophysics, ETH, Zurich, Switzerland

In this work, the spectral element method (SEM) is used to model earthquake rupture and longer-term slip on a vertical strike-slip fault governed by rate and state friction. Previous studies of long-term slip behavior on rate and state faults mostly used boundary integral methods (BIM) which cannot include, at least in their current implementation, complex crustal structures such as variable bulk properties, fault damage zones, and non-planar fault geometries. SEM approach will allow to include those factors into models that simulate long histories of seismic and aseismic slip.

We have extended SEM to dynamic rupture simulations on rate and state faults and validated it by comparison with BIM solutions for a 2D test problem. We use the 3D dynamic SEM formulation to study several problems, including the effect of a shallow steady-state velocity-strengthening fault region (or layer) on a single simulated earthquake. In the absence of the layer, the rupture speed becomes supershear near the free surface due to a phase conversion, as also observed on linear slip-weakening faults. In contrast, when a velocity-strengthening layer exits, the supershear pulse is suppressed, which could explain the lack of universally observed supershear rupture near the free surface.

We are also advancing towards a SEM formulation for modeling long-term slip histories, by combining the dynamic SEM with a quasi-static SEM formulation that we developed for simulations of aseismic slip. We have used the combined formulation to simulate slow nucleation, dynamic rupture, and postseismic response in a 2D test model, and find that the results are in agreement with those of BIM. We will report our current effort to extend the combined SEM formulation to 3D.

SLIP-LENGTH SCALING IN MULTI-SEGMENT RUPTURE: DEPENDENCE ON MAXIMUM SHEAR STRESS DIRECTION

Yuko Kase, kasep@ni.aist.go.jp

Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

We investigate slip-length scaling, simulating dynamic rupture a multi-segmented fault system under depth-dependent (horizontally homogeneous) stress conditions. Slip gently increases with fault length on a multi-segmented fault. In a dip-slip fault, a rupture can jump across a longer jog than a strike-slip fault, and the increase rate of slip is larger.

We put a multi-segmented fault in a 3-D, semi-infinite, homogeneous, isotropic, and linear elastic medium. Both length and width of the segments are 15 km. Each fault model has 1-7 segments. We also assume two maximum shear stress conditions: a strike-slip and a dip-slip cases. We calculate spontaneous rupture processes in each combination of fault models and stress conditions, and investigate the surface slip-length scaling.

In a dip-slip fault, slip is larger than a strike-slip fault with the same stress drop, and a rupture can jump across a longer jog. The slip hardly increases with the number of segments in a fault model with three or more segments. Slip on the six-segmented 90 km-length fault is about twice as much as on the 15 km-length fault. These are the same features as in a strike-slip fault. In a continuous fault model, however, slip-length scaling of dip-slip is different from one of strike-slip. Slip hardly increases with fault length when it is more than four times as long as the width, while slip increases in a strike-slip fault when the length is less than six times the width. We have reported that slip-length scaling depends on dip angle. It is suggested that slip-length scaling could become various by combination of dip angle and maximum shear stress condition.

INSIGHTS FROM MODELING LONG-TERM SLIP HISTORIES OF FAULTS GOVERNED BY LABORATORY-DERIVED FRICTION LAWS

Nadia Lapusta, lapusta@caltech.edu

Division of Geological & Planetary Sciences and Division of Engineering & Applied Science, California Institute of Technology, Pasadena, USA

We have been developing a methodology that allows us to simulate long histories of seismic and aseismic fault slip while accounting for slow tectonic loading and all inertial effects, using both boundary integral (Lapusta et al., 2000; Liu and Lapusta, NMESD2007) and spectral element (Kaneko, Lapusta, and Ampuero, NMESD2007) approaches. Our simulations incorporate laboratory-derived rate and state friction laws and, in 2D models, additional dynamic weakening mechanisms due to shear heating.

In 2D models that incorporate high fault strength for slow slips, low strength for fast slips, and defect regions to nucleate ruptures, we find that the fault operates under low average shear stress and low heat production, while producing earthquakes that have typical stress drops and pulse-like mode of rupture propagation (Lapusta and Rice, 2007). Hence the models reconcile several laboratory and observational constraints. Decreasing the degree of dynamic weakening causes the fault to operate at progressively higher average levels of shear stress and results in systematic change of rupture mode from pulse-like to crack-like. Such change of dynamic rupture mode with fault prestress has been recently documented in laboratory experiments (Lu, Lapusta, and Rosakis, 2007).

Our 3D models have incorporated only rate and state friction so far. We have used them, in part, to reproduce abnormal scaling of moment and recurrence time for small repeating earthquakes at Parkfield (Chen and Lapusta, NMESD2007) and to study interactions of rupture with fault heterogeneities over many earthquake cycles. We will report on our current efforts to extend our 3D models to more realistic geometries and dynamic weakening mechanisms.

TRANSITION OF MODE II CRACKS FROM SUB-RAYLEIGH TO SUPERSHEAR SPEEDS IN THE PRESENCE OF FAVORABLE HETEROGENEITY

Yi Liu [1], yil@caltech.edu
Nadia Lapusta [2], lapusta@caltech.edu

[1] Division of Engineering and Applied Science, California Institute of Technology, Pasadena, USA
[2] Division of Geological and Planetary Science and Division of Engineering and Applied Science, California Institute of Technology, Pasadena, USA

Understanding sub-Rayleigh-to-supershear transition of mode II (shear) cracks has important practical implications for earthquake dynamics and seismic radiation. In the Burridge-Andrews mechanism (BAM) of transition, a supershear daughter crack nucleates, for sufficiently high prestress, at the shear stress peak traveling in front of the main crack. We find that transition and sustained supershear propagation occurs in a number of models that subject developing cracks to supershear loading fields. We consider a spontaneously expanding sub-Rayleigh crack (or main crack) which advances, along a planar interface with linear slip-weakening friction, towards a place of favorable heterogeneity, such as a preexisting subcritical crack, a small patch of higher prestress, or a patch of lower static strength. For a range of model parameters, a secondary crack nucleates at the heterogeneity and acquires supershear speeds due to the supershear stress field propagating in front of the main crack. Transition to supershear speeds often occurs directly at the tip of the secondary crack, with the tip accelerating rapidly to values numerically equal to the Rayleigh wave speed and then abruptly jumping to a supershear speed. This is different from BAM, in which the daughter crack is born supershear. Models with favorable heterogeneity achieve supershear transition and propagation for much lower prestress levels than the ones implied by the Burridge-Andrews mechanism. These models have transition distances that depend on the position of heterogeneity, unlike BAM in which the transition distance depends on the prestress level and critical crack length. We will discuss the dependence of supershear transition on model parameters and implications for earthquake dynamics.

INTERACTION OF DYNAMIC RUPTURE WITH FAULT HETEROGENEITY OVER SEVERAL EARTHQUAKE CYCLES IN 3D SIMULATIONS OF SEISMIC AND ASEISMIC FAULT SLIP

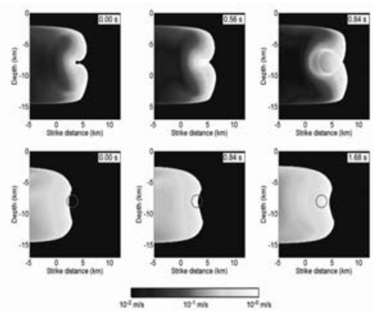
Yi Liu [1], yil@caltech.edu
Nadia Lapusta [2], lapusta@caltech.edu

[1] Division of Engineering and Applied Science, California Institute of Technology, Pasadena, USA
[2] Division of Geological and Planetary Science and Division of Engineering and Applied Science, California Institute of Technology, Pasadena, USA

Dynamic rupture propagation strongly depends on prestress and other initial conditions, which in turn depend on the history of prior slip. Hence it is important to consider dynamic events as a part of long-term simulations of slip accumulation. Based on previous 2D studies, we have developed a 3D methodology for simulating spontaneous seismic and aseismic slip of a planar vertical strike-slip fault embedded into a uniform elastic medium. The methodology uses a boundary-integral approach and incorporates slow tectonic loading as well as inertial effects during occasional seismic events. The fault is governed by rate and state friction.

We apply the methodology to a fault with a 12 km by 30 km steady-state velocity-weakening region, surrounded by velocity-strengthening regions and embedded into an elastic half-space. The loading is provided by slow slip on the deeper extension of the fault. Simulations produce realistic earthquakes and complex aseismic slip patterns. After each earthquake, accelerated postseismic creep occurs in the surrounding velocity-strengthening regions. During interseismic periods, the fault exhibits aseismic slip which travels along the interface.

The methodology can be used, in part, to consider interaction of dynamic rupture with fault heterogeneities over several earthquake cycles. We find that the first simulated earthquake can be affected by heterogeneity in ways which are not repeated in the following slip history of the fault. As an example, a small (stronger) patch of 20% higher effective normal stress causes a supershear rupture burst during the first simulated earthquake but not for subsequent events, due to stress redistribution by prior slip history. We will discuss these results and their implications.



Snapshots of slip velocity during the first (top panels) and second (bottom panels) dynamic events on the fault with a patch 20% larger normal stress. Numbers in the upper-right corners indicate the time elapsed since the time of the left-most snapshot. In the first event, the rupture front is delayed by the heterogeneity and then exhibits a supershear burst. In the second event, no supershear propagation occurs and the rupture does not feel the heterogeneity (indicated by the red circle) due to redistribution of shear stress by prior slip.

QUANTIFYING PROPERTIES OF LARGE-SLIP "ASPERITIES" IN EARTHQUAKE SOURCE MODELS

Martin P. Mai, mai@sed.ethz.ch

Institute of Geophysics, ETH Zurich, Zurich, Switzerland

The generation of near-source strong ground motion strongly depends on the details of the earthquake rupture process. Recent work in numerical ground-motion prediction has focused on including all aspects of earthquake dynamics (or some flavour of pseudo-dynamic) into the source-modelling approach, instead of using only simple kinematic rupture models. Moreover, finite-source inversions for a large number of earthquakes show that fault slip is heterogeneous at all scales. Several models have been proposed to characterize this spatial variability of earthquake slip, either in a deterministic manner [Somerville, et al., 1999] by counting asperities (regions of large slip on the fault plane) or using a random-field model to quantify the statistical nature of the slip maps [Lavallee and Archuleta, 2003; Lavallee, et al., 2005; Mai and Beroza, 2002]. Little attention, however, has been given to further investigate, quantify, and statistically analyze the properties of asperities that affect the seismic radiation emitted from these high slip patches.

In this study I examine in detail some of the properties of large-slip asperities and how those contribute to near-source radiation. In particular, I analyze the slip-contrasts between asperities and low-slip areas, asperity stress-drop, rise-time on the asperity, local rupture velocity over the asperity (the last two points can only be addressed for a limited number of models), size and number of asperities. It is also important to relate these asperity properties to their position with respect to the hypocenter and known/mapped fault-segmentation. For a few earthquakes, dynamic rupture models exist which are used to relate asperity properties to rupture-dynamic quantities like dynamic stress drop and fracture energy.

Studying slip asperity properties helps to address the general topic of "strength" of asperities in terms of seismic radiation, whereby only for a limited set of events (for which dynamic models are available), we can refer to "strength" in more physical sense (although not in absolute strength levels with respect to the strengths of rocks). It is also necessary to distinguish between single-segment and multi-segment source models to investigate if asperities on single-segment faults show different properties than those in multi-segment ruptures, bearing in mind that earthquakes on young, immature faults may show different characteristics and rupture behaviour than earthquakes on old, mature and rather straight faults.

THE STAGGERED-GRID FD AND RESTORING-FORCE FE IMPLEMENTATIONS OF THE TSN METHOD

Peter Moczo [1], moczo@fmph.uniba.sk
Martin Gális [1], martin.galis@fmph.uniba.sk
Jozef Kristek [1], kristek@fmph.uniba.sk
Miriam Kristeková [2], kristekova@savba.sk

[1] Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava, Slovakia
[2] Geophysical Institute, Slovak Academy of Sciences, Bratislava, Slovakia

The Traction-at-Split-Node (TSN) method for simulation of dynamic rupture propagation has been independently developed by Andrews (1973, 1999) and Day (1977, 1982). Day et al. (2005) showed very good level of agreement of the method with the boundary integral method. Dalguer & Day (2006) demonstrated its superior accuracy relative to the thick-fault method (Madariaga et al. 1998) and stress-glut method (Andrews 1999). We developed four implementations of the TSN method (Moczo et al. 2007):

- the 2nd-order restoring-force e-invariants finite-element (FE) – FE-2;
- velocity-stress (VS) staggered-grid (SG) finite-difference (FD) scheme, 2nd-order at grid points close to and grid points on the fault plane, 4th-order elsewhere – SG-FD-2;
- VS SG FD scheme, 2nd-order at grid points close to the fault plane, 4th-order elsewhere (including grid points on the fault plane) – SG-FD-24;
- VS SG FD scheme, 4th-order at all grid points – SG-FD-4.

We performed a series of numerical simulations of spontaneous rupture propagation on a planar fault in a homogeneous unbounded elastic medium for the SCEC Version 3 model configuration and its modifications. We implemented an alternative configuration of the initialization zone and investigated its effect relative to the SCEC initialization on the rupture propagation for the initial traction parallel and oblique with respect to the coordinate axis. We numerically compared rupture propagation for the linear slip-weakening friction law and Ohnaka-Yamashita's friction law. We also compared convergence rates of all the four implementations. Based on our numerical results we suggested a modified version of the benchmark configuration.

NON-LINEAR SOURCE INVERSION AND BAYESIAN INFERENCE FOR A SYNTHETIC TEST CASE AND THE 2000 WESTERN TOTTORI EARTHQUAKE

Damiano Monelli, monelli@tomo.ig.erdw.ethz.ch
Martin P. Mai, martin.mai@sed.ethz.ch

Institute of Geophysics, ETH Zurich, Zurich, Switzerland

Independent earthquake source inversions often result in kinematic rupture models that show significant differences for the same event, yet providing acceptable fit to the data. This multiplicity of solutions is due to certain choices in the inversion concerning the forward modeling, the model parameterization, the inversion methodology, the type of data and data processing. However, independent of the particular inversion approach, intrinsic reasons common to each inversion render the problem of inferring earthquake rupture parameters fundamentally unstable: uncertainties in data and in forward modeling, and general lack of resolution. To deal with this intrinsic non-uniqueness we adopt a Bayesian approach to invert strong motion data and to investigate their resolution power in retrieving kinematic earthquake rupture parameters. Within this approach, the solution to an inverse problem - the posterior state of information - is given by the conjunction of "states of information", expressed in terms of probability densities, which reflect our a priori knowledge about model parameters, data, and their correlation. For the earthquake-source imaging problem we estimate this posterior probability density in two steps. First, we explore the model space using an Evolutionary Algorithm, whose intrinsic parallel nature allows for a straightforward parallelization, rendering the exploration of large model spaces an easier task when time consuming forward modeling is required. Secondly, using a Neighborhood Algorithm and considering the entire ensemble of models found during the search stage, a geometric approximation of the true posterior is calculated from which Bayesian inference is performed. Uncertainties on inverted parameters are stated in terms of marginal probability densities. We first apply this methodology to a synthetic test, to avoid uncertainties in forward modeling and to focus on data uncertainties and model parameterization. We invert strong motion data generated by a synthetic fault rupture characterized by an inhomogeneous slip-rate pattern evolving in time as a circular pulse with constant rupture velocity and rise time. We show that using a dense observational network, without errors in the forward modeling and small uncertainties in the data, it is possible to infer with a good resolution, the magnitude of the rupture process, its large scale features (location and magnitude of the asperities) and the parameters governing the time evolution of the slip, whereas local properties, like maximum slip-rate values at fault locations, are usually affected by larger uncertainties. We also apply this methodology to the inversion of strong motion data from the 2000 Western Tottori earthquake (M_W = 6.6). In the inversion we allow for heterogeneous distribution of peak slip-velocity, rupture time and rise time. Our inverted models show features similar to what has been found in previous studies, in particular a region of low slip near the hypocenter region and high slip near the surface. Moreover, the rise time distribution shows an intersting pattern with high values near the hypocenter which gradually decrease towards the fault boundaries, suggesting therefore a crack mode type of rupture behaviour.

ISSUES IN INTERACTING STRIKE-SLIP FAULTS

David D. Oglesby, david.oglesby@ucr.edu

Department of Earth Sciences, University of California, Riverside, USA

One of the pressing issues in seismic hazard analysis is the probability of earthquake rupture jumping between fault segments, resulting in a large cascading event. Researchers (e.g., Wesnousky, 2006) have conducted observational surveys to determine the maximum width of stepover that rupture may jump in strike-slip systems, and other researchers (e.g., Harris et al., 1991; Kase and Kuge, 1998; Harris and Day, 1999) have used numerical methods to study the dynamics of such systems. Both methods imply that ruptures have difficulty propagating across stepovers with widths greater than 3-4 km, with possible differences between compressional and dilational stepovers. The present study extends the numerical modeling work above to address some remaining questions, such as 1) How does the method of rupture termination on the primary segment affect the ability of rupture to jump to the secondary segment? and 2) How do assumptions about the normal stress dependence of friction affect the dynamics of such systems? I find that if the stress field on the edge of the primary (nucleating) fault tapers to zero gradually, the ability of rupture to propagate a fault stepover is greatly reduced compared to the case in which stress drops to zero abruptly. In addition, I find that decreases in the time-dependent normal stress field radiated by the primary fault facilitate jumping rupture in both dilational and compressional stepovers. Removing normal stress dependence from the friction law reduces the ability of rupture to jump in both dilational and compressional cases. The results may have implications for seismic hazard in near multi-segment strike-slip systems.

THE SPICE CODE VALIDATION

Peter Pažák [1], pazak@fmph.uniba.sk
Peter Franek [2], geofpefr@savba.sk
Peter Moczo [1], moczo@fmph.uniba.sk
Jozef Kristek [1], kristek@fmph.uniba.sk
Martin Gális [1], martin.galis@fmph.uniba.sk
Miriam Kristeková [2], kristekova@savba.sk

[1] Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava, Slovakia
[2] Geophysical Institute, Slovak Academy of Sciences, Bratislava, Slovakia

Development of the earthquake motion numerical simulation methods is one of the primary goals of the SPICE project that involves fourteen European institutions. This is why the SPICE project provides a reasonable platform for a code validation effort in Europe. The main intention of the SPICE Code Validation is to create a long-term basis for possible tests/comparisons/validation of numerical methods and codes for the seismic wave propagation and earthquake motion simulation. Wave propagation models will include simplest canonical models for testing accuracy of methods with respect to individual factors/features of the models, models combining two or more basic structural features, and realistic models. The source dynamics models will be organized in a similar way. Time-frequency misfit criteria are used to evaluate solutions. The validation is facilitated using the interactive web interface (http://www.nuquake.eu/SPICECVal). The interface has been developed by the SPICE team at the Comenius University in Bratislava. The web-interactive procedure includes the following steps: 1. Registration of a participant and a method. 2. Selection of a model and download of the model description. 3. Conversion of the solution into the upload format. 4. Upload of the solution. 5. Comparison of the uploaded solution to selected solution(s).

Each participant can, in principle, use several computational methods/codes and upload several solutions for each model.

We present a basic problem configuration for numerical modeling of dynamic rupture propagation. The configuration is a modification of the original SCEC TPV3 configuration. The modification relates to the rupture initialization and test evaluation.

SOURCE RUPTURE PROCESS OF THE 2005 TARAPACA INTERMEDIATE DEPTH EARTHQUAKE

Sophie Peyrat, peyrat@ipgp.jussieu.fr
Pascal Favreau, pfavre@ipgp.jussieu.fr

Laboratoire de Sismologie, Institut de Physique du Globe, Paris, France

Large intraplate earthquakes in subduction zone are quite common although very few have been studied in detail. Consequently, the determination of source rupture for intermediate intraslab events is important to understand the rupture process of these earthquakes. We investigate the details of the rupture process of the large (M_W=7.7) intermediate-depth earthquake that occurred on 13 June 2005 in the Tarapaca region of the Northern Chile seismic gap. This earthquake was a slab-pull event with down dip extensional source mechanism. The aftershock distribution, determined from a post-seismic temporary array, indicates a sub-horizontal fault plane lying between the upper and lower planes of the double seismic zone. This earthquake was recorded by a permanent digital strong-motion network operated by the University of Chile. These records have absolute time and high dynamic range so that they contain direct information about the rupture process. We used a systematic, fully nonlinear inversion method based on the neighbourhood algorithm to invert for the kinematic slip distribution using the accelerometric data set. This low frequency inversion provides a relatively smooth image of the rupture history. Based on the kinematic inversion results, we propose a dynamic rupture model in order to quantify the dynamic rupture process. We simulate the dynamic rupture process and the strong ground motion using a 3D finite-difference method. In our simulation, dynamic rupture grows under the simultaneous control of initial stress and rupture resistance by friction. We constrain dynamic rupture parameters of the Tarapaca earthquake by simple trial and error. The results of our analysis provide constraints on the physical mechanism by which intermediate depth occur.

BROADBAND STRONG GROUND MOTION SIMULATION BASED ON A DYNAMIC FAULT RUPTURE MODEL: APPLICATION TO THE 2000 TOTTORI, JAPAN EARTHQUAKE

Nelson Pulido [1], nelson2bosai.go.jp
Luis A. Dalguer [2], ldalguer@moho.sdsu.edu

[1] National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Ibaraki, Japan
[2] Department of Geological Sciences, San Diego State University, San Diego, CA, USA

In the present study we apply a full spontaneous rupture dynamics approach to investigate the high frequency (HF) radiation mechanism of the 2000 Tottori earthquake, Japan, and extend the procedure for the simulation of broadband strong ground motion. We generalize the model of HF radiation model of a suddenly stopping crack, to the heterogeneous rupture of a finite fault. In our model, HF is radiated during local changes of rupture velocity across the fault plane. We first calculate local rupture velocity vectors by evaluating the gradient of rupture times from the spontaneous dynamic model. Then rupture velocity changes are obtained by calculating the divergence of local rupture velocity vectors. Finally the HF distribution across the fault plane is investigated by calculating the far field radiation from every grid within the fault plane, as the product of local rupture velocity changes and local stress drops. In order to calculate the HF ground motion from the finite fault we assume the fault plane is composed of many elementary cracks, and add their far-field radiation.

The spontaneous dynamic process of the Tottori earthquake is calculated by using the Staggered-grid Split Node model (SGSN). The low frequency waveforms are calculated by propagating the dynamic rupture model through the FDM grid by directly using the SGSN method. The broadband motion is calculated in low and high frequency bands separately and then added in time domain.

Our results suggest that HF is mostly radiated from regions where a strong dynamic stress drop is overlapped with large local variations in rupture velocity. We obtained a good agreement between observed and simulated broadband near-source ground motions, by introducing a physically based fault rupture process.

STRESS GLUT AND SPLIT NODE METHODS FOR PLANAR AND CURVED FAULTS USING THE FINITE ELEMENT METHOD: SH CASE

Leonardo Ramirez-Guzman, lramirez@andrew.cmu.edu
Jacobo Bielak, jbielak@andrew.cmu.edu

Computational Seismology Laboratory/ Department of Civil & Enviromnetal Enginering,
Carnegie Mellon University, Pittsburgh, PA, USA

We introduce two finite element formulations for simulating the earthquake dynamic rupture process and compare their accuracy and convergence rates. The two schemes represent the fault differently: the Stress Glut Method (SGM), initially proposed by Andrews (1976), approximates the slip conditions using an inelastic zone, while the Split Node (SN) technique, introduced independently in seismology by Andrews (1976) and Day (1978) imposes the discontinuity at the nodal level. We modify slightly the first and propose a new formulation for the second. We study in detail the *h*- and *p*- convergence rates of the SGM and SN methods, using high-order spectral elements for the SH-case with a planar fault. In addition, we examine the computational performance of the two methodologies and take advantage of the flexibility offered by the FEM and extend the SGM for curved faults.

ON THE SPATIAL CORRELATION OF EARTHQUAKE SOURCE PARAMETERS

Jan Schmedes, jasch@crustal.ucsb.edu
Ralph J. Archuleta, ralph@crustal.ucsb.edu
Daniel Lavallee, daniel@crustal.ucsb.edu

Department of Earth Science and Institute for Crustal Studies,
University of California, Santa Barbara, USA

To predict seismic ground motions an accurate method for their computation is needed. The basis of such a method is an understanding of the physical source parameters that control the level of ground-shaking. A correlation between rupture velocity and slip amplitude was observed in different studies. Based on this observations Liu et al. (2006, BSSA, Vol. 96, No 6) developed a kinematic source description based on the spatial correlation of slip amplitude and average rupture velocity, and slip amplitude and rise time on the fault. They chose the values of the correlation for the two pairs of parameters such that the observed records of the 1994 Northridge earthquake were predicted well. In another study, Schmedes et al. (2006, SRL, Vol. 77, No. 2) computed ground motion for different values of the correlation and investigated the influence of such a correlation on the ground motion. To achieve a more physical based understanding of the spatial correlation between earthquake source parameters, dynamic modeling of the earthquake rupture process is necessary. To obtain meaningful statistics, many dynamic models - using random initial stress distributions- have to be computed. In a first step we parallelize the existing open multi processing regular mesh finite element code discussed in Ma and Liu (2006, BSSA, Vol. 96) by using the message passing interface. Speedup and comparisons between the two implementations are performed at the San Diego Supercomputing Center. In the second step we compute a suite of dynamic ruptures for initial stress distributions based on Lavallée et al. (2006, GJI, Vol. 165, No. 2). The computed rupture models are then analyzed to determine the correlations between the source parameters necessary to construct the kinematic source model.

ENERGY PARTITION DURING DYNAMIC RUPTURE PROCESS IN MODELS WITH BIMATERIAL INTERFACE AND SPONTANEOUS GENERATION OF OFF-FAULT PLASTIC STRAIN

Zheqiang Shi [1], zheqians@usc.edu
Yehuda Ben-Zion [1], benzion@usc.edu
Alan Needleman [2], needle@brown.edu

[1] Department of Earth Sciences, University of Southern California, Los Angeles, CA, USA
[2] Division of Engineering, Brown University, Providence, RI, USA

The strain energy in rocks surrounding a fault is partially released during earthquakes, and partitioned into seismic radiation and dissipative components consisting of heat and creation of new surfaces. An improved understanding of the energy partition can have fundamental implications for many issues in earth sciences including the physics of earthquake ruptures. We study properties of dynamic ruptures and the associated energy partition between dissipation and radiation using 2-D in-plane calculations with the FE method. In our recent numerical study (Shi et al., 2007), we used a model consisting of two identical homogeneous isotropic elastic solids separated by a planar interface governed by a general rate- and state-dependent friction. By varying the velocity dependence of the friction, the strength excess parameter and the width of the nucleation zone, we obtained a variety of rupture modes (sub- and supershear cracks, pluses, and trains of pulses) and quantitatively examined the associated energy partition patterns. The calculations were done with model parameters representative of Homalite-100, obtained in Coker et al. (2005) by comparing model calculations to lab results of Rosakis et al. (1999, 2000). Here we discuss results based on rock parameters related to the recent friction experiments of Kilgore et al. (2007) with granite. The current calculations incorporate the generation of plastic strain off the fault. The continuing parameter-space study attempts to clarify the relations between various model results (e.g., rupture properties, energy partition, spatial distribution of off-fault damage and seismic radiation) and model properties (initial stress field, frictional properties of the fault, plastic strain parameters).

RESOLUTION OF NON-DOUBLE-COUPLE MECHANISM: SIMULATION OF SOULTZ INJECTION INDUCED SEISMICITY

Jan Šílený, jsi@ig.cas.cz

Department of Seismology, Institute of Gephysics, Academy of Sciences of Czech Republic, Prague, Czech Republic

In earthquake seismology, traditionally shear-slip is expected in the foci, thus either pure double-couple (DC) or deviatoric part of the moment tensor (MT) are supposed. Injection experiments, in which pressurized fluid opens new cracks, anticipate more general phenomena described by the complete MT. Additional terms to the DC - compensated linear vector-dipole (CLVD) and isotropic component (ISO) - are however difficult to be detected, as they may be false due to noise in the data or unresolved path effects. For the configuration of stations monitoring seismicity invoked by fluid injection into the geothermal borehole in Soultz-sous-Forets, France, we generated synthetic data for both DC and non-DC sources simulating shear-slip and tensile fracture, respectively, and inverted P and S amplitudes for a complete MT. Noise in the data, mislocation of the hypocenter and mismodeling of the Green's functions yield spurious non-DC components which may mask completely source processes departing from the shear-slip. In particular, detection of a tensile fracture from noisy data, inexact location and uncertain crustal model may be obscured.

DIVERSITY OF DYNAMIC EARTHQUAKE SLIP CONTROLLED BY A SINGLE NONDIMENSIONAL PARAMETER

Takehito Suzuki, suzutake@eri.u-tokyo.ac.jp
Teruo Yamashita, tyama@eri.u-tokyo.ac.jp

Earthquake Research Institute, University of Tokyo, Tokyo, Japan

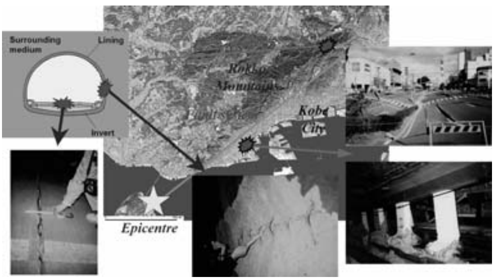
We theoretically study dynamic fault slip taking account of thermoporoelastic effects and inelastic porosity change that is caused by fault slip. First, it is shown in the mathematical analysis of 1D fault model that behavior of dynamic fault slip is controlled by a single non-dimensional parameter Su. While slip-weakening behavior arises because of thermal pressurization for Su<1, slip-strengthening behavior tends to prevail for Su>1; Su is larger if the increase rate of inelastic porosity is larger. Next, we numerically study the dynamic growth of a 2D anti-plane shear fault. Our analysis shows that pulse-like slip velocity is observed for Su>1 because of slip-strengthening. Seismological analyses have revealed that some earthquakes such as the 1992 Landers and 1994 Northridge earthquakes show pulse-like slip velocity. Our study suggests that these earthquakes have Su values greater than unity and that fault slip behavior is controlled by the value of Su. Our model can also solve the paradox that the radiation efficiency sometimes exceeds unity. Our study shows that earthquakes showing pulse-like slip behavior tend to have the radiation efficiency greater than unity. This occurs because the radiation efficiency is defined inappropriately for slip showing slip-strengthening behavior. Venkataraman and Kanamori [2004] actually showed seismologically that the 1992 Landers and 1994 Northridge earthquakes haves the radiation efficiency greater than unity.
In conclusion, our study shows that some diverse behavior of dynamic fault slip is explained in a unified way by the single nondimensional parameter.

SEISMIC WAVES IN THE VERY HIGH FREQUENCY (VHF) RANGE: EXISTENCE CONJECTURED THROUGH DYNAMIC FAILURES OF UNDERGROUND STRUCTURES

Koji Uenishi [1,2], uenishi@kobe-u.ac.jp
Shunsuke Sakurai [2], ssakurai@kensetsuk.or.jp

[1] Research Centre for Urban Safety and Security, Kobe University, Kobe, Japan
[2] Main Office, Construction Engineering Research Institute Foundation, Kobe, Japan

The influence of high-frequency seismic waves on the damage of human and natural structures is still believed to be very small. However, when the epicenter of an earthquake is located very close to an industrially developed urban area, even underground structures, which are considered to be earthquake-resistant, may suffer disastrous damage, because high frequency components of the associated seismic waves may interact with the structures before attenuation: In such circumstances, the dynamic structural behaviour may be different from the one expected from the conventional engineering analyses that mainly take account of the effects of low-frequency horizontal (shear) oscillations. On the occasion of the 1995 Hyogo-ken Nanbu (Kobe) and 2004 Niigata-ken Chuetsu, Japan, earthquakes, unique and previously unrecognised damage to the underground structures was actually found both at depth and near the surface: (1) the collapse of the Daikai Underground Station in the city of Kobe; and (2) the damage to the Bantaki and Uonuma Tunnels in the mountainous regions (see Figure). In both cases, the two-dimensional elastodynamic analysis shows that the observed damage patterns were induced most likely by vertical (longitudinal) oscillations of relatively high frequencies: For (1) about 17 Hz; and for (2) some 100 Hz, implying the necessity of investigating and detecting seismologically such VHF waves and their generation mechanism. This study also suggests that underground structures subjected to dynamic waves vibrate with their surroundings and they are expected to function as sensors that respond only to waves of specific type, frequency and propagation direction.



MODELLING OF THE EARTHQUAKE MAGNITUDE 5.0 THAT OCURRED ON OCTOBER 28TH, 1998 IN CENTRAL MEXICO

Antonio Uribe [1], auribe@cfe.gob.mx
Sixto Fernandez [1], sixto.fernandez@cfe.gob.mx
Carlos Valdez [2], carlosv@ollin.igeofcu.unam.mx

[1] Department of Seismology, Comision Federal de Electricidad, Mexico, Mexico
[2] Instituto de Geofisica, Universidad Nacional Autonoma de Mexico, Mexico, Mexico

The region where the earthquake took place is characterized by rare seismic activity. Intermediate magnitude events could be related to Cuaternary Monogenetic Volcanoes that are present in the area. The ocurrence of the event of October 1998, had some unique features:

A mayor water reservoir was impounded close to the epicenter, No earthquakes were registered since 1987 to 1993 when the filling of the artificuial lake began, up to 1996 thousands of micro earthquakes were registered, only a few of them had CODA magnitude within the range from 2.5 to 4.0. The activity in the neighbourhood of the lake had decreased greately by 1998. The Mc 5.0 event took place just of shore of the tail of the lake, at a shallow water level zone.

On the other hand, There was no evidence of intermediate magnitude tectonic activity in recent times. The Focal parameters reported by the National Seismological Service of Mexico assigned a depth of more than 100 km, which does not correspond with the low frequency observed in far field strong motion records and with the S-P times from near field readings.

In order to clarify the origin of this earthquake We recalculated the source parameters, and model the accelation far field using stochastic methods.

CRUSTAL ANISOTROPY RETRIEVED FROM NON-DOUBLE-COUPLE MECHANISMS OF MICRO-EARTHQUAKES INDUCED DURING THE 2000 INJECTION EXPERIMENT AT THE KTB SITE, GERMANY

Václav Vavryčuk [1], vv@ig.cas.cz
Marco Bohnhoff [2], bohnhoff@gfz-potsdam.de
Zuzana Jechumtálová [1], zs@ig.cas.cz
Petr Kolář [1], kolar@ig.cas.cz
Jan Šílený [1], jsi@ig.cas.cz

[1] Department of Seismology, Institute of Gephysics, Academy of Sciences of Czech Republic, Prague, Czech Republic
[2] Department of Deformation and Rheology , GeoForschungsZentrum, Potsdam, Germany

A family of 37 most reliable moment tensors of microearthquakes that occurred at a depth level of 5.4 km, having been induced during the 2000 injection experiment at the KTB deep drilling borehole, contain significant non-double-couple (non-DC) components. The DC is on average 60% and the non-DC is 40%. Fault plane solutions computed from the DC part show preferred strike-slip mechanisms with small normal or reverse components. A predominant azimuth of P and T axes is in the range of N 140°-160° E and of N50°-70°E, respectively. The non-DC components contain both the isotropic (ISO) and compensated linear dipole (CLVD) components. The mean value of ISO is 1.5%, the mean value of CLVD is -5.7%. The non-DC components have probably three major origins: random numerical errors produced by the moment tensor inversion due to noise and limitations of input data, systematic errors produced by mismodeling of the medium when calculating the Green functions, and anisotropy in the focal area. Anisotropy is a very likely origin of non-DC components, because a rather strong seismic anisotropy has been observed at the KTB site with strength up to 20% for P waves, and attributed to foliated crystalline rocks composed of gneiss and amphibolite. Adopting four alternative models of anisotropy obtained by other seismic measurements at the KTB, we have employed the non-DC components for estimating an optimum orientation of anisotropy in the focal area. The optimum orientation of the symmetry plane of anisotropy is nearly vertical with a strike of N335°-340°E. This strike coincides well with the strike of 330° typical for many major lithological units and faults and with the orientation of the transversely isotropic model inferred by other authors.

DYNAMIC SIMULATION OF A DIPPING FAULT USING A 3D-FDM WITH NONUNIFORM GRID SPACING

Wenbo Zhang [1], wenbo@gucas.ac.cn
Tomotaka Iwata [2], iwata@egmdpri01.dpri.kyoto-u.ac.jp
Kojiro Irikura [2], irikura@egmdpri01.dpri.kyoto-u.ac.jp

[1] College of Earth Science, Graduate University of Chinese Academy of Sciences, Beijing, China
[2] Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan

We propose a method to analyze dynamic rupture processes of earthquakes with a dipping fault, using a 3D finite-difference (FD) method with nonuniform grid spacing. This approach does not require aligning the fault plane to the FD grid for implementation of the FD method. It can be used to deal with a realistically complex fault geometry model. We validate our method by studying two dynamic source problems that have been analyzed by Madariaga et al. (1998). One is the instantaneous rupture of a circular fault embedded in a homogeneous elastic medium; the other is the spontaneous rupture of a rectangular fault which starts from a local circular asperity on the fault plane. Our numerical results for different dipping faults are similar with those obtained by Madariaga et al. (1998) using a horizontal fault plane model in full space, thus, validating our method for dipping fault models. We apply the proposed approach to analyze the dynamic source process of the 2003 Tokachi-Oki, Japan, earthquake. The fault model of this earthquake is a dipping fault with a dip angle about 18-degree. We rebuild the dynamic rupture process of this event and simulate the near source strong ground motions based on the dynamic source model. Generally, the synthetic waveforms agree well with the observed records. This shows that our dynamic source model reproduces the main features of the long period ground motions of this earthquake.

LIST OF PARTICIPANTS

Dr. Brad **AAGAARD**	baagaard@usgs.gov
Ms. Petra **ADAMOVÁ**	adamova@ig.cas.cz
Dr. Jean-Paul **AMPUERO**	ampuero@erdw.ethz.ch
Dr. Ryosuke **ANDO**	ando@bosai.go.jp
Prof. Ralph J. **ARCHULETA**	ralph@crustal.ucsb.edu
Dr. Kimiyuki **ASANO**	k-asano@egmdpri01.dpri.kyoto-u.ac.jp
Prof. Jacobo **BIELAK**	jbielak@cmu.edu
Dr. Michel **BOUCHON**	Michel.Bouchon@ujf-grenoble.fr
Mr. Gilbert **BRIETZKE**	brietzke@geophysik.uni-muenchen.de
Mr. Jan **BURJÁNEK**	burjanek@karel.troja.mff.cuni.cz
Prof. Michel **CAMPILLO**	Michel.Campillo@ujf-grenoble.fr
Dr. Artur **CICHOWICZ**	artur@geoscience.org.za
Dr. Antonella **CIRELLA**	cirella@ingv.it
Dr. Massimo **COCCO**	cocco@ingv.it
Dr. Luis A. **DALGUER**	ldalguer@moho.sdsu.edu
Mr. Josep **DE LA PUENTE**	jdelapuente@geophysik.uni-muenchen.de
Dr. Eric **DUNHAM**	edunham@fas.harvard.edu
Dr. Pascal **FAVREAU**	pfavre@ipgp.jussieu.fr
Dr. Eiichi **FUKUYAMA**	fuku@bosai.go.jp
Mr. Martin **GÁLIS**	martin.galis@fmph.uniba.sk
Dr. František **GALLOVIČ**	gallovic@karel.troja.mff.cuni.cz
Dr. Alexander **GUSEV**	gusev@emsd.iks.ru
Dr. Ruth A. **HARRIS**	harris@usgs.gov
Ms. Liliana **HROMADOVÁ**	hromadova@fmph.uniba.sk
Mr. Sébastien **HOK**	sebastien.hok@obs.ujf-grenoble.fr
Prof. Xiaofei **CHEN**	xfchen@pku.edu.cn
Ms. Ting **CHEN**	tchen@caltech.edu
Mr. Yoshihiro **KANEKO**	ykaneko@gps.caltech.edu
Dr. Hayrullah **KARABULUT**	kara@boun.edu.tr
Dr. Yuko **KASE**	kasep@ni.aist.go.jp
Dr. Martin **KÄSER**	kaeser@geophysik.uni-muenchen.de
Dr. Jozef **KRISTEK**	kristek@fmph.uniba.sk
Dr. Miriam **KRISTEKOVÁ**	kristekova@savba.sk
Prof. Nadia **LAPUSTA**	lapusta@caltech.edu
Mr. Yi **LIU**	yil@caltech.edu
Dr. Martin P. **MAI**	mai@sed.ethz.ch
Prof. Peter **MOCZO**	moczo@fmph.uniba.sk
Mr. Damiano **MONELLI**	monelli@tomo.ig.erdw.ethz.ch
Prof. David D. **OGLESBY**	david.oglesby@ucr.edu
Mr. Peter **PAŽÁK**	pazak@fmph.uniba.sk
Dr. Sophie **PEYRAT**	peyrat@ipgp.jussieu.fr
Dr. Nelson **PULIDO**	nelson@bosai.go.jp
Mr. Leonardo **RAMIREZ-GUZMAN**	lramirez@andrew.cmu.edu
Dr. Johannes **RIPPERGER**	ripperger@sed.ethz.ch

Mr. Zheqiang **SHI**	zheqians@usc.edu
Mr. Jan **SCHMEDES**	jasch@crustal.ucsb.edu
Dr. Jan **ŠÍLENÝ**	jsi@ig.cas.cz
Dr. Takehito **SUZUKI**	suzutake@eri.u-tokyo.ac.jp
Dr. Elisa **TINTI**	tinti@ingv.it
Dr. Koji **UENISHI**	uenishi@kobe-u.ac.jp
Dr. Antonio **URIBE**	auribe@cfe.gob.mx
Dr. Václav **VAVRYČUK**	vv@ig.cas.cz
Dr. Wenbo **ZHANG**	wenbo@gucas.ac.cn

STEERING COMMITTEE

Prof. Ralph J. **ARCHULETA**	ralph@crustal.ucsb.edu
Dr. Michel **BOUCHON**	Michel.Bouchon@ujf-grenoble.fr
Prof. Michel **CAMPILLO**	Michel.Campillo@ujf-grenoble.fr
Dr. Massimo **COCCO**	cocco@ingv.it
Prof. Steven M. **DAY**	day@moho.sdsu.edu
Dr. Eiichi **FUKUYAMA**	fuku@bosai.go.jp
Prof. Raul I. **MADARIAGA**	madariag@geologie.ens.fr
Prof. Peter **MOCZO**	moczo@fmph.uniba.sk

LOCAL ORGANIZING COMMITTEE

Prof. Peter **MOCZO**	moczo@fmph.uniba.sk
Dr. Jozef **KRISTEK**	kristek@fmph.uniba.sk
Dr. Peter **LABÁK**	geofpela@savba.sk
Mr. Andrej **CIPCIAR**	geofanci@savba.sk
Mr. Peter **FRANEK**	geofpefr@savba.sk
Mr. Martin **GÁLIS**	martin.galis@fmph.uniba.sk
Dr. Miriam **KRISTEKOVÁ**	kristekova@savba.sk
Mr. Peter **PAŽÁK**	pazak@fmph.uniba.sk
Ms. Lucia **FOJTÍKOVÁ**	geoflufo@savba.sk
Dr. Ján **MADARÁS**	geofjama@savba.sk
Mr. Martin **BALAŽOVJECH**	balazovjech@fmph.uniba.sk
Mr. Martin **MINKA**	geofseis@savba.sk

Workshop NMESD 2007 is supported by