Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SSS025-01 Room:302 Time:May 27 14:15-14:30

A model of seismogenic layer inferred from the number-magnitude distribution of earthquakes

harumi aoki[1*]

[1]TRIES

The number-magnitude distribution of earthquakes suggests an irregular structure of the crust. The model presented here supposes a layer made up of broken blocks in the crust, where size of earthquake depends on block size. In order to simulate such a structure, the original layer is divided into two blocks with arbitrary ratio. Next, each block is similarly divided into two. The k-th division makes 2**k blocks. We call it k-th division of basic process. The number-size distribution of basic process is obtained with the use of random function. At a point in time, however, the order of division is different from place to place. Such a block distribution is interpreted as a weighted sum of basic processes. It is found that the equal weight gives rise to a b value close to 1 and lower weight in higher order of division, less than 1, respectively. The constancy of b value is held for a wide range of magnitude.

Keywords: b value, magnitude, simulation, fault, seismogenic layer

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SSS025-02 Room:302 Time:May 27 14:30-14:45

Early aftershocks following the 2007 Noto Hanto, Japan, earthquake

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A shallow Mw = 6.7 inland earthquake occurred on the west coast of the Noto Peninsula in Japan on March 25, 2007. A fine local tomography and a magnetotelluric (MT) survey conducted after the mainshock [Kato et al., 2008; Yoshimura et al., 2008] found out a low-Vp and high-conductivity anomaly beneath the mainshock hypocenter. In addition, an anomalous depth dependency of the stress field associated with the mainshock was revealed [Kato et al., 2011]. These results suggest a potential involvement of a deep fluid reservoir with the earthquake generation. To access the dynamic interaction of fluids with the aftershock generation, I focus on the early aftershocks just following the mainshock. Recovery of the missing early aftershocks is quite important to state aftershock activity induced by fluid migrations. Thus, I used the waveforms of aftershocks as templates to detect the missing events within one-day after the mainshock, applying the matched filter technique [Shelly et al., 2007, Peng and Zhao, 2009]. We have a total of several hundreds of thousands positive detections.

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SSS025-03 Room:302 Time:May 27 14:45-15:00

Medium-scale characteristic earthquakes around Japan

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Medium-scale characteristic earthquakes around Japan have been detected on the basis of regularity, geographical proximity, magnitude, correlation coefficient and coherence. Among 30 detected groups, 16 groups had digital wave data of 87-type strong motion seismometer and 95-type seismic intensity meter of JMA. Among them, 11 groups showed high correlation coefficients and coherences. They are Off Akkeshi M4.8, Off Hidaka M4.8, Off Urakawa M5.4, Off Taneichi M5.9, Off Kamaishi M4.7, Off Iwaki M5.6, Hitachi M5.2, Tsukuba M5.3, Off Choshi M5.0, Group A of West of the Okinoerabu Island M5.1 and South of the Miyakojima Island M6.5.

Keywords: Characteristic earthquake, Recurrent earthquake, Correlation coefficient, Coherence, Off Hidaka, Hitachi

Japan Geoscience Union Meeting 2011
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SSS025-04 Room:302 Time:May 27 15:00-15:15

Detection of M5 level recurrent earthquakes associated with the Boso slow slip events

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M5 level recurrent earthquakes on the plate boundary between the North American plate and the Phillipine Sea plate around the Boso peninsula have been detected by waveform correlation. The similarity of the waveforms among six M5 level earthquakes on October 20, 1955, 2 events on July 14, 1966, December 30, 1990 and 2 events on August 18, 2007 at Tokyo station has been confirmed by relatively high correlation coefficient. In particular, three of them which occurred on December 30, 1990 and August 18, 2007 have had similar waveforms at Yokohama station and Tateyama station. The epicenters of three recent M5 level earthquakes on December 30, 1990 and August 18, 2007 have been located within a radius of 2.5 km and the depth range is 20 - 37 km. This means that these M5 level earthquakes are recurrent earthquakes which result from repeated slip of the same asperity patch on the plate boundary. In addition, it has become clear that the waveforms of these M5 level earthquakes and M4.5 earthquake on May 22, 1983 look similar. Taking this and two cases of two repeating earthquakes occurred on same day into account, this asperity patch may be ruptured at once or at least twice which are divided into main-event and sub-event. Main-events have about 17-year recurrence time, and this suggests that the stick ratio of this asperity is estimated about 90%. Four recent recurrent earthquakes had occurred in the earthquake swarm activities with the Boso slow slip event(SSE). This means that the earthquake swarm activities with the Boso SSE might also occur in October, 1955 and July, 1966. Main-events of M5 level recurrent earthquakes may occur in every third the earthquake swarm activities with the Boso SSE. The event probability of the next main-event of M5 level recurrent earthquake within 20 years is estimated to be 73 - 77% by small sampling theory and the renewal model with lognormal distribution.

Keywords: Boso slow slip event, Earthquake swarm, Recurrent earthquake, Waveform correlation, Asperity, Probabilistic prediction

Japan Geoscience Union Meeting 2011
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SSS025-05 Room:302 Time:May 27 15:15-15:30

Stress drops of interplate earthquakes along the Japan trench by coda spectrum ratio analysis

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The use of S-wave coda spectrum-ratio in estimating corner frequencies is thought to have advantages that it can reduce the effect of site, path and radiation pattern differences significantly (e.g., Mayeda et al., 2007; Somei, 2010; Wada et al. 2010; Moyer et al., 2010). First of all in this study, we applied the method to the off-Kamaishi M˜4.9 repeating earthquake sequence (Matsuzawa et al., 2001) to check its validity for relatively separated event pairs. The results show that the corner frequencies are estimated precisely even for earthquake pairs with hypocentral separations of 40-50km. Here, we used multiple time windows of 5 s by repeatedly shifting by 1 s in the time range of 20-50s after the S wave arrival. Next we applied this method to three categories of interplate earthquakes along the Japan trench: 1) small repeating earthquakes (M3.0-4.4, Uchida et al. 2006, 2009), 2) moderate sized repeating earthquakes (M4.5-5.9, Uchida et al., 2010), 3) low-angle thrust type earthquakes (M3.6-5.9, NIED, 2011). For these offshore earthquakes, the hypocenter errors sometimes exceed 20km and it is difficult to select closely located earthquakes. Thus, the coda spectrum ratio can contribute to the precise estimation of corner frequencies and stress drops for these earthquakes. The estimation show that the stress drops for the earthquakes in these three categories increase with their depths. This probably reflects the increase of confining stress with depth.

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SSS025-06 Room:302 Time:May 27 15:30-15:45

Complex seismic source inversion method with the data covariance matrix: Application to the 2010 Haiti earthquake

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In general, it is difficult to approximate seismic source fault zone by a simple fault plane because of its complex geometry. Most of pervious study, however, applied the planar fault approximation for estimating the seismic source process of large earthquakes. Since the planar fault approximation should lead to a biased result in the seismic waveform analysis, it is important to formulate observed equation so as to mitigate modeling errors originated from complexity of fault geometry. Modeling errors of fault geometry can be divided into two parts: error of strike and dip of the fault, and error of location of the seismic source. Modeling error originated from a restriction on focal mechanism especially in strike and dip may be predominant in the analysis of teleseismic body wave, considering that travel time is insensitive to relative location of the seismic source. This modeling error can be mitigated by increasing freedom of mechanism solutions in assumed seismic source area.

We developed a waveform inversion method to estimate a spatio-temporal moment tensor distribution from teleseismic body wave (P-wave), which is able to describe a complex seismic source model that reflects complexity of geometry of real seismic source fault. We constructed mathematical formulation expanded from Yagi and Fukahata (2010), which considers data covariance components of observation and Green's function error, to stably obtain a solution through the model with high degree of freedom.

We applied the present method to the 2010 Haiti earthquake, whose seismic source process should be complex. P-axes distribution consistent with stress field of the region was obtained only with smoothness constraint in space and time. Moment tensor distribution suggests three faulting zones having different mechanism solution: near hypocenter, east and west of the hypocenter, were activated in the 2010 Haiti earthquake. Estimated Strikes for east-westward nodal planes of each faulting zone are consistent with hinge line of eastward displacement distribution obtained from InSAR data by Hayes et al. (2010). This consistency suggests that the 2010 Haiti earthquake occurred on unmapped fault whose strike is oblique to surface trace of the Enriquillo fault.

Focusing on the time variation, we found that the rupture propagation through shallow part of crust, which is weaker than deeper part and east fault zone were ruptured earlier than west one. Similarity of fault geometry between east and hypocenter are higher than that of west and hypocenter. Our result shows that the complex fault geometries controls rupture propagation manner. Aftershocks, whose mechanism solutions were different from that of the west fault, were triggered at west of the west fault. Westward rupture seems terminated at the focal mechanism transition zone.

Keywords: teleseismic body wave, the 2010 Haiti earthquake, complex fault geometry, seismic source inversion

Japan Geoscience Union Meeting 2011
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SSS025-07 Room:302 Time:May 27 15:45-16:00

Anomalies of rupture velocity in deep earthquakes

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Explaining rupture mechanics and seismicity of deep earthquake is a long-standing challenge in earth science. Previous researchers had estimated seismic rupture process of deep earthquake on the basis of the seismic wavefrom modeling. From previous source studies, however, it had been difficult to find clear characteristic in rupture process of deep earthquake, since seismic source models for same deep earthquake are often quite different from one another. To estimate stable and detailed rupture model of deep large earthquakes, we applied the back projection method to tele-seismic body waveforms (P-wave) recorded Global Seismograph Network (GSN) and Federation of Digital Broad-Band Seismograph (FDSN). Using this method, we can obtain an image of the seismic source process from the observed data without a priori constraints or discarding parameters. We further applied 4th-root stacking technique which significantly improved resolution of rupture image compared to standard linear stacking. By imaging the seismic rupture process for a set of recent deep earthquakes using the back projection of teleseismic P-waves, we found that the rupture velocities are less than 60% of the shear wave velocity except in the depth range of 530 to 610 km. In this exceptional depth range, about eighty percent of earthquakes have fast rupture velocity ($Vr > 0.6Vs$) and seismicity reaches local maximum. We propose that large fracture surface energy (Gc) values for deep earthquakes generally prevent the acceleration of dynamic rupture propagation and generation of earthquakes between 300 and 700 km depth, whereas small Gc value in the exceptional depth range promote dynamic rupture propagation and explain the seismicity peak near 600 km.

Keywords: deep earthquake, back projection method, rupture process, rupture velocity

Japan Geoscience Union Meeting 2011
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SSS025-08 Room:302 Time:May 27 16:00-16:15

Scaling Model of Intraslab Earthquakes

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Intraslab earthquakes are particularly interested on their mechanism generating short-period seismic waves not only in the seismological field but also in the earthquake engineering aspect. We have studied the relation between short-period acceleration level A and seismic moment M_0 by large intraslab earthquakes evaluated independently. The relation has been tested against the theory of complex faulting process by Koyama(1997) and the standard omega-square model. The observation favors the former predicted by a relation of M_0 proportional to A-square. The physical background of this result will be presented.

Keywords: Intraslab earthquakes, scaling law

Japan Geoscience Union Meeting 2011
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SSS025-09 Room:302 Time:May 27 16:30-16:45

Dynamic Fault Rupture Propagation in Agarose-gel

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We report on the experimental observation of mode-II crack propagation along a weak plane in agarose-gel. Agarose gels of three different concentration(1, 2,and 3 wt%) are prepared and their rheological properties are measured. In the experiment, transparent agarose-gel which contains straight weak plane is applied constant load. The position of crack tip is tracked by means of photoelastic visualization. We observed evolution of rupture front from slow nucleation to fast, unstable propagation. Observed terminal velocity of rupture propagation for 1wt%-gel is typically about 4m/s, which is corresponding to shear wave velocity of the gel. Terminal velocity and critical crack size are compared with theoretical expectations.

We also discuss the capability of the experiment to investigate the earthquake rupture process.

Keywords: fracture experiment, fault dynamics, fault nucleation, laboratory experiment, photoelasticity, gel

Japan Geoscience Union Meeting 2011
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SSS025-10 Room:302 Time:May 27 16:45-17:00

Understanding of diversity of the secondary fracture based on energy change due to damage evolution

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We consider damage effect to investigate how the secondary fracture evolves with dynamic crack extension. The secondary fracture, defined as the fracture created near and around the main fault plane by the fault motion, shows many aspects. Some experimental studies show many microcracks distributed in a medium around the fault plane after the main fault slip. In addition, the region where the rocks are pulverized sometimes appears around the fault plane. For example, Dor et al. (2006) investigated San Andreas Fault zone and found homogeneous pulverization and selective pulverization zones. The former is defined as the zone where the crystals yield a rock-flour texture, while the latter is defined as the zone where only some of the crystals yield powdery texture. Though these various behaviors about the secondary fracture are known to exist, the unified model explaining all of them has not been established. We will construct the model based on the framework of Murakami and Kamiya (1997). We assume damage tensor D and energy release tensor Y here. The damage tensor describes the damage state of the medium and the energy release tensor denotes the strain energy released by unit damage evolution.

We consider a 2-D crack embedded in a medium causing damage. The fracture criterion is introduced for the energy release tensor as follows. First, the tensors Y and D are rotated with the principal axes for Y, which makes Y diagonal. If 1-1 (2-2) component of the diagonalized Y exceeds the criterion Yc, the 1-1 (2-2) component of the rotated D is set to be unity artificially. If all the eigenvalues of the tensor D become unity, we can regard the region as homogeneously pulverized. On the other hand, if not all of the eigenvalues become unity, the region is regarded as selectively pulverized. We have here Yc and other two parameters, eta2 and eta4, and diversity observed for the secondary fracture can be understood in terms of those parameters. The homogeneous pulverization is represented by the situation where eta2 has a finite value, eta4 equals to zero and Yc is sufficiently so small that the fracture criterion is satisfied. The tensors D and Y are proportional to the unit tensor in this case and pulverization occurs in an isotropic way. On the other hand, the selective pulverization is represented by the condition where eta4 has a finite value and Yc is sufficiently small. The nondiagonal components of D and Y appear in this case and they generate the anisotropic pulverization. If Yc is sufficiently high, pulverization does not occur and microcracks distribute around the fault plane. Both the open and shear microcracks can be understood in our framework because we can consider both maximum extension direction and normal directions of microcracks in the medium. Their parallel components describe the open mode, while perpendicular components stand for the shear mode. The results obtained here suggest that the damage effect should be treated by the tensor, not by scalar parameters.

Keywords: damage tensor, energy release tensor, secondary fracture, microcrack, pulverization

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SSS025-11 Room:302 Time:May 27 17:00-17:15

2-D simulation of shear faulting: the slip- and time-dependent fault constitutive law and a diversity of slip behaviour

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The occurrence of interplate earthquakes can be regarded as the process of tectonic stress accumulation and release in source regions, driven by relative plate motion. Stress accumulation between earthquakes results from slip deficit relative to steady plate motion. Recently, on the basis of detailed analysis of geodetic and seismic data, it have been revealed that many slow earthquakes that have extraordinary low slip-velocity occur at plate interfaces. This indicates a diversity of slip behaviour to release the accumulated stress at plate interfaces. The mode of fault slip is prescribed by constitutive properties there. Thus, to understand the process of tectonic stress accumulation and release in plate subduction zones, it is crucial to make clear the dependence of slip behaviour on the constitutive properties.

In the present study, we developed a simple two-dimensional simulation model of shear faulting to examine in detail the dependence of slip behaviour on fault constitutive properties through the entire process of earthquake generation cycles. The coupled non-linear system prescribing the process of stress accumulation and release in a strength asperity consists of the equation of equilibrium for two-dimensional shear faulting, fault constitutive relation, and steady slip motion as a driving force. First, we used a simple slip-weakening fault constitutive law. In this system, slip behaviour in the strength asperity is controlled by a single non-dimensional parameter defined by (rigidity∗critical weakening displacement)/(peak strength∗characteristic length indicating the size of the strength asperity). In the case that the non-dimensional parameter is small, accumulated stress is released by unstable slip, while in the case that the non-dimensional parameter is very large, accumulated stress is released by stable slip. Only in the case that the non-dimensional parameter is moderately large, a slow slip event can be realized. Second, we used the slip- and time-dependent constitutive law by Aochi & Matsu'ura (2002), which has been derived from theoretical consideration on the fault-surface abrasion with slip and adhesion with contact. Through numerical simulation, we reproduced recurrent stable/unstable fault slip in the strength asperity. In this case, the dependence of slip behaviour on the constitutive parameters is not so simple. The essential parameters controlling the slip-and time-dependent fault constitutive law are the abrasion rate and the adhesion rate. Given the values of the abrasion rate and the adhesion rate, and the past history of the fault slip, the values of fault constitutive parameters, the breakdown strength drop and the critical weakening displacement, can be defined at each moment. Such a process dependence of the fault constitutive parameters causes complicated fault slip behaviour.

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SSS025-12 Room:302 Time:May 27 17:15-17:30

Dependence of earthquake stress drop on critical slip-weakening distance

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Earthquake stress drop is one of the most fundamental parameters that characterize earthquake sources. It is known that there is a large variation of estimated stress drop, and its origin is unknown. Numerical simulations are carried out in order to examine factors that control stress drop of earthquakes. A straight fault, on which friction obeys a rate- and state-dependent friction law, is embedded in a 2D uniform elastic medium, and the fault is shear loaded at a constant rate. Velocity-weakening friction is assumed on the central part of the fault, which is sandwiched between regions of velocity-strengthening friction. Stable sliding at the velocity-strengthening regions generates stress concentration at the edges of the velocity-weakening region, which results in earthquake occurrence. Stress drop is measured by the ratio of average slip on the fault to the fault rupture length, using a plane-strain shear crack model. Many simulations are done for various values of applied normal stress to the fault and characteristic slip distance L. Simulation results indicate that the average stress drop increases with the normal stress and L. By definition, the stress drop is proportional to the average seismic slip at the velocity-weakening region of the model fault, and therefore to accumulated slip deficit during an interseismic period approximately. Rupture occurs when the stress concentration at an edge of the locked zone becomes large enough to overcome fracture energy Gc, which is approximately proportional to the normal stress and L. Critical slip-weakening distance Dc and Gc are estimated from relations between shear stress and slip obtained for simulated data, and it is found that stress drop increases with Gc and Dc. Stress drop does not linearly increase with normal stress, which may be related to relatively small depth dependence of observed stress drop. Note that the above results hold when seismic coupling is high and rupture starts near an edge of the locked region of the fault. When seismic coupling is low because of low normal stress or large L, stress drop is simply proportional to the normal stress and is not dependent on L or Dc. It is known that stress drop is little dependent on L and is proportional to normal stress for a single-degree-of-freedom spring-block model. This is because stress concentration at an edge of a locked zone cannot be realized in the spring-block model.

Keywords: earthquake mechanics, earthquake parameters, friction, numerical simulation

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SSS025-13 Room:302 Time:May 27 17:30-17:45

Shear fracture strength of faults (V): The orientation of in-situ stress and the direction of GPS velocity

Kiyohiko Yamamoto[1*], Yasuo Yabe[2], Namiko Sato[3]

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1. Introduction: The in-situ stress measurements by DRA have revealed as follows; 1) The smallest horizontal stress in the Kitakami Mountains lies almost parallel to the GPS velocity. 2) The direction of the smallest horizontal stress in ODP Hole 794C is close to that of the largest P-wave velocity of the upper mantle beneath the Sea of Japan. 3) The largest horizontal stress is almost perpendicular to the fault strike in the vicinity of the Nojima fault. The results (1) and (2) suggest that the crust is driven by the motion of the upper mantle and the result (3) suggests that the strength of the fault is small or the fault is weak.

A fault zone model has been proposed to explain the weak faults by Yamamoto (in preparation). The result (1) suggests that the direction of GPS velocity can be employed in place of the principal direction of in-situ stress. In order to show that the model is universal for every fault, Yamamoto and Yabe (2007) have investigated the relationship of the direction of a fault strike to that of GPS velocity for the recent large earthquakes. They have found that the directions are parallel or perpendicular to each other within an error less than about 15 degree. In-situ stress data by DRA are newly obtained for 6 sites in the Tohoku district (Yabe, 2005). The relationship between the in-situ stress and the GPS velocity will be reexamined in this study.

2. Results: The in-situ stress measured by DRA is thought to be the average in-situ stress, to which a rock has been subjected at a depth for a time longer than a few years at least (Yamamoto, 2009). Therefore, the GPS velocities to be used for the comparison should be their averages over a time longer than a few years. In this study, the GPS velocity means the shift rate of the coordinate of a GPS station from 1997/4 to 2007/5. The direction of the largest or the smallest horizontal stress is compared with the directions of GPS velocity at the stations located at a distance within 20 km from the site of stress measurement. When a site (GNB) in the back born mountain range is neglected, the average difference in the direction between the largest or the smallest stress and the GPS velocity is about 10 degree. The largest is about 23 degree at a site FDI on the northern coast of the Pacific Ocean. It has been already shown that the largest horizontal stresses in the vicinity of the Nojima Fault lie nearly parallel to the GPS velocity.

The precision of the direction determined by DRA is about 5 degree. Referring to the data at the sites near the Nojima Fault by Sato et al. (2003), the direction of the largest horizontal stress varies by 25 degree at largest with depth in a hole. This suggests that the direction of the principal direction of stress has an ambiguity of about +/-13 degree at largest. The direction of GPS velocity shows the changes due to an earthquake occurrence. We divide the period from ’97 to ’07 into two periods, ’97 to ’02 and ’02 to ’07, to know the fluctuation of the direction with the period. The large difference between the two periods is seen for the stations around ENS and SND in the southeastern part of the Tohoku district. The difference amounts to +/- 25 degree. This may be caused mainly by the earthquakes that have occurred in and around the district during the period after 2003.

3. Conclusion: Although the direction of GPS velocity changes with an earthquake near a region, it is confirmed that the direction of GPS velocity in a long term approximates the principal direction of stress with an error smaller than about 10 degree. Yamamoto and Yabe (2007) have shown that the fault strikes are perpendicular or parallel to the GPS velocity with an error smaller than about 15 degree for the relatively large earthquakes that have recently occurred. The present results support thus that the fault surface is nearly equal to one of the principal plane of stress, or, the faults are weak.

Keywords: weak faults, GPS velocity, in-situ stress, deformation rate analysis (DRA), strike of a fault, ODP Hole 794C

Japan Geoscience Union Meeting 2011
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SSS025-14 Room:302 Time:May 27 17:45-18:00

A primary model of earthquake cycle almost controlled by pore pressure evolution

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In a recent Ph.D thesis by the first author (and related papers), certain effects of pore pressure evolution are introduced to simple numerical models for earthquake cycles. One is the pore pressure increase by shear heating, and the others are the pore pressure alteration by porosity changes. Since evolution of pore pressure within fault zones directly affect friction as well as frictional coefficient, earth cycles in fluid-saturated fault zones are related to pore pressure evolution by necessity. This introduction of the pore pressure evolution was an essential step toward constructing realistic mechanical models for natural faults.

On that basis, here, we make a model of earthquake cycle, almost controlled by continuous evolution of pore pressure. It would be an alternative model to that just controlled by evolution of frictional coefficient. By unifying our previous models of one-degree-of-freedom (*Mitsui and Hirahara* [2009, JGR], *Mitsui and Hirahara* [2009, GRL], *Mitsui and Cocco* [2010, GRL]), we can implement the continuous effects of pore pressure evolution by shear heating (including heat diffusion), porosity changes (pore dilatancy and compaction) and fluid diffusion in a traditional model for earthquake cycles only controlled by a rate- and state-dependent friction law.

Since the shear heating and porosity changes are assumed to occur homogeneously within a certain thickness in our simplified model, the fault behavior strongly depends on the value of the fault thickness. This fault thickness almost represents the thickness of fault gouge. We show examples that the fault behavior changes from stick-slip behavior, recurrence of moderate (slow) slip and completely aseismic slip, depending on the thickness value. Although the assumptions in our present model are too rough to represent the structures of natural faults, this is another fundamental step for realistic fault models.

Keywords: Earthquake cycle, pore pressure fluctuation, thermal pressurization, porosity change, fluid diffusion, fault thickness

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SSS025-15 Room:302 Time:May 27 18:00-18:15

Heterogeneous pre-stress field in source region

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In the previous SSJ fall meeting, we found that the heterogeneous 3D structure model of the 2004 Chuetsu earthquake generate the stress field which could cause a high stress drop in asperity of the event and also minimum strength excess around the hypocenter. In order to interpret the above, we study the relationship between the heterogeneity of the crustal structure and the resultant stress field by using simple crustal model.

Keywords: Earthquake source process, stress field

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SSS025-16 Room:302 Time:May 27 18:15-18:30

Precise estimation of AE behavior prior to rock failure with continuous broadband recording

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A laboratory rock fracture experiment enables us to observe elastic waves radiated from micro fractures (Acoustic Emission; AE) at the proximity to the rupture plane. Previous experiments indicated that AEs are activated and concentrate on and around a future rupture plane prior to the rock failure (e.g., Yanagidani et al., 1985; Lockner et al., 1991). However, waves arrive within a mask time of the last trigger were missed in a trigger mode recording. Furthermore, they used narrowband recordings, so that information about source process could not be obtained. To apply the knowledge obtained from AE analysis, it is necessary that AE source parameters are estimated in a similar manner as natural earthquake parameters. Broadband records enable us to precisely estimate source parameters, such as rupture duration, seismic moment, and seismic energy. In this study, we conducted continuous and broadband recording through a uni-axial rock fracture experiment under a dry condition at an ambient temperature.

First, as a preliminary experiment, we prepared a cylindrical Oshima granite sample, 110 mm in height and 45 mm in diameter. A P wave type broadband transducer and a PZT (narrowband transducer) were attached on the both side surfaces of the sample. Recording was continued with 33MS/s even after the sample fractured.

Spectrum of waveforms showed clear variability of corner frequency, corresponding to their amplitude level. We will conduct further experiments with several broadband sensors, and discuss source characteristics of AEs, from the determination of source parameters of them.

Keywords: AE (Acoustic Emission), laboratory experiment, broadband, continuous recording, source process

Japan Geoscience Union Meeting 2011
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SSS025-P01 Room:Convention Hall Time:May 27 10:30-13:00

Detection and analysis of early afterslip following the 2008 Iwate-Miyagi Nairiku, Japan, earthquake

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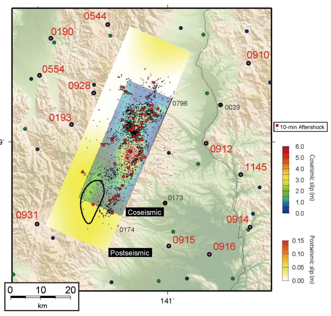
[Introduction] Afterslip is one of the slow earthquakes which have the long time period. Because of difficulty to observe and analyze the early afterslip phase, it's not clear how the early afterslip phase progresses. We first calculated time series of correlation coefficient between the 1-Hz GPS (Global Positioning System) waveform data and trends preliminary projected by afterslip near the mainshock and checked the afterslip signals. Because this data involved not only the afterslip signals but also the coseismic signals, we next enhanced the 1-Hz GPS waveform inversion to investigate simultaneously coseismic slip and early afterslip. Finally we investigated early (10-minutes) afterslip following the 2008 Iwate-Miyagi Nairiku, Japan, earthquake using this method.

[Detection] Static and dynamic ground displacements for this earthquake were observed at one-second intervals by a dense GPS network, called GEONET, operated by the Geographical Survey Institute of Japan (GSI) by processing GPS phase data using the method described by *Larson et al.* [2003]. This data was applied to infer the source process of this earthquake [*Yokota et al.*, 2009]. In this study, we first calculated time series of correlation coefficients between the 1-Hz GPS waveform data and trends preliminary projected by afterslip near the mainshock. The time series during about 2-hours before and after the mainshock showed the characteristic trends only during about 10 minutes after the mainshock.

[Inversion] In order to investigate simultaneously coseismic slip and early afterslip using this data, we next enhanced the 1-Hz GPS waveform inversion of *Yoshida et al.* [1996]. We adopted the 72 km x 24 km afterslip fault model with (strike, dip) = (203^o, 37^o), which was constructed by early aftershock distribution [*Enescu et al.*, 2010] and coseismic fault model used by *Yokota et al.* [2009]. We used the 1-Hz GPS data of 12 stations, which were selected from stations within approximately 50 km of the hypocenter so as to cover all directions. The GPS waveform data were windowed for 10 minutes. We calculated the dynamic Green's function for coseismic slip using FK method [*Zhu and Rivera*, 2002]. The slip rate function for afterslip was represented by B-spline function with knot interval of 60 seconds using the static Green's function calculated using FK method.

[Result] Figure shows the resultant slip distribution. This result suggests the total seismic moment of 3.0 x 10^{17} Nm (*Mw* ~ 5.5) and maximum slip of about 5 cm. Early afterslip distribution is compared with the coseismic slip distribution for the *Mw* ~ 6.9 mainshock and the 29-days afterslip distributions [*Iinuma et al.*, 2009]. The resultant early afterslip phases are inferred at the southwestern adjacent region of the main asperity, which are possibly triggered by the southern large asperity. The 29-day northern and eastern afterslips subsequently occurred. The resultant afterslip distribution and early (10-min) aftershock distributions determined by *Enescu et al.* [2010] are also partitioning in a complementary fashion. This result also shows that the afterslip does not evolve along the slow slip scaling [*Ide et al.*, 2007].

Acknowledgment. The GPS data were recorded by GEONET of the Geospatial Information Authority of Japan (GSI). We would like to thank them.



Keywords: early afterslip, high-rate GPS, the 2008 Iwate-Miyagi Nairiku, Japan, earthquake

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Slow rupture velocity of two Indonesia earthquakes

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The 17 July 2006 Mw 7.8 Java earthquake and the 25 October Mw 7.8 Sumatra earthquake are the two typical tsunami earthquakes. We used modified back projection method to trace the rupture velocities of the two earthquakes. Weighting based on smoothed envelopes of a small earthquake recordings, is introduced when the waveforms are summated. The used small earthquakes have the same locations and focal mechanisms with the two tsunami earthquakes.

The result shows a clear and unusual slow rupture velocity (1-1.5 km/s) for these two earthquakes. The reason for this extraordinary slow rupture velocity is not well known now. But the two earthquakes occurred at the shallow portions of the subduction zone, somehow suggesting a very close relation with the unique hydrologic properties.

Keywords: rupture velocity, back projection, tsunami earthquake

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Source Characteristics of Outer Rise Earthquakes

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An outer rise earthquake occurs in an oceanic plate beyond a trench axis. Due to the bending stress of the oceanic plate and the seismic stress transfer from a continental plate, normal and reverse faulting events are often observed (Lay et al., 1987). The focal depths of outer rise events are generally shallower than 30 km, therefore it well generates tsunami as seen during the 2009 Samoa earthquake (Mw 8.1). Around the Japan Islands, the 1933 Sanriku earthquake (Mj 8.1) is one of disastrous and significant examples, where the maximum tsunami height was 28.7 m and 3,064 people were dead or missing. The most recent outer rise earthquake is the 2010 off Chichijima earthquake (Mj 7.4), and tsunami 0.5 m high was observed after this event.

We performed source inversions of teleseismic body-wave data for outer rise earthquakes (Mw > 7.0) around the Japan Islands in 1990 or later, then investigated rupture areas and average slips derived from the results of the source inversions and compared them with those of other kinds of earthquakes. Since outer rise earthquakes occur offshore, it is hard to obtain records observed in a near-source region, and therefore it is effective to analyze global data. We chose seven outer rise earthquakes. Those in the Pacific plate are the 2005 off Sanriku (Mw 7.0, 18.0 km deep, normal faulting), 2007 eastern Kuril Islands (Mw 8.1, 12.0 km deep, normal faulting), and 2009 eastern Kuril Islands (Mw 7.4, 45.2 km deep, reverse faulting), and 2010 off Chichijima (Mw 7.4, depth 18.6 km, normal faulting) earthquakes. The 1998 south off Ishigakijima (Mw 7.4, 22.9 km deep, strike-slip faulting), 2004 off Kii peninsula (Mw 7.2, 16.0 km deep, reverse faulting), and 2004 off Tokaido (Mw 7.4, 12.0 km deep, reverse faulting) earthquakes occurred in the Philippine Sea plate (The magnitudes and depths are reported by the Global CMT Project).

We used teleseismic data obtained from global observation networks through IRIS DMC. The velocity structure used is based on the Jeffreys-Bullen model, and we replaced a part of the top layer with the water layer of CRUST 2.0 in the source region. We first performed point source analyses, and then inversions for slip distributions on the finite faults determined from the results using the method of Kikuchi et al. (2003). Due to the low accuracy of the aftershock distribution, we used the residuals of an inversion for choosing the actual source fault out of two conjugate fault planes. The slip distributions of most outer rise earthquakes provided large slips above the hypocenters, and no systematic difference in source characteristics is found according to focal mechanisms and plates.

We extracted rupture areas and average slips from the resultant slip distributions using the method of Somerville et al. (1999). The results were compared to the scalings of crustal earthquakes (Somerville et al., 1999), plate-boundary earthquakes (Murotani et al., 2008), and intraslab earthquakes (Iwata and Asano, 2011). The rupture areas of outer rise earthquakes are similar to those of crustal and intraslab earthquakes, and the average slip of outer rise earthquakes are similar to those of crustal earthquakes. Therefore, the source characteristics of outer rise earthquakes are different not only from those of plate-boundary earthquakes (Ammon et al., 2008) but also those of intraslab earthquakes, though both outer rise and intraslab earthquakes belong to a category of intraplate earthquakes. In addition, shallow outer rise earthquakes such as the 2007 eastern Kuril Islands earthquake have obviously different source characteristics from those of intraslab earthquakes. Further investigation is necessary for outer rise earthquakes with smaller magnitudes.

Keywords: outer rise earthquakes, source characteristics, source inversion, slip distributions

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The Source Process of the 2010 Canterbury, New Zealand, Earthquake

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In the Canterbury region of New Zealand's South Island, a moment magnitude (Mw) 7.1 earthquake occurred at 4:35 a.m. local time (16:35 p.m. on November 5 UT) on November 6th, 2010. The hypocenter located by GNS was at (43.55S, 172.18E) and a depth of 10 km. Although the Mw is quite large and the epicenter is only about 40 kilometers west of Christchurch whose population is about 400,000, no deaths were reported according to CNN. In the south of the hypocenter, fault traces were found on the ground surface, and the rupture offset locally reached more than 4m [Quigley, 2010].

We first performed point source inversions of W-phase and P-wave waveforms using the methods developed by Kanamori and Rivera [2008] and Kikuchi and Kanamori [1991], respectively, to derive the focal mechanism of the earthquake. The strike, dip, and rake angles obtained from the W-phase and the P-wave waveforms are (85, 68, 169) and (268, 70, -175) in degree, respectively. Both of the derived solutions suggest focal mechanisms of right-lateral strike slip on an almost vertical fault planes. However, they have different dip directions, and we cannot determine which fault plane is collect from the waveform data. This confusion is also seen from source fault models derived by various institutes. To identify the actual fault plane, we plotted aftershocks occurring in the first 24 hours, but no significant plane was defined. We then took an advantage of the surface fault traces considering their relative location to the surface extensions of the fault planes. In the result, the fault plane derived by the P-wave waveforms is selected.

Interferometric synthetic aperture radar (InSAR) data from both Japanese and European satellites provided high quality maps of surface displacements by this earthquake. According to these results, there observed very large right lateral displacements in the south of the hypocenter followed by a 3km^2-area of little displacement at the western edge. And a northwest-southeast displacement in relatively large area was located in the 10km west of the hypocenter, implying a reverse fault.

Based on the aftershock distribution, surface fault traces and the InSAR image, we set two faults. One includes the hypocenter (fault1), and the other in the western area with NW-SE displacements (fault2). For the fault parameters of each fault, we used the ones from the P-wave focal mechanism and the aftershock distribution in the first 1-week. We next performed a finite source inversion of teleseismic waveform data and strong motion data using this source fault model and the method of Yoshida et al. [1996]. We adopted the CRUST 2.0 model for the crustal structure and used the rigidity based on this model. For the smoothness constraint of the slip distribution and the weight of the constraint, we used a discrete Laplacian in space and Akaike's Baysian Information Criterion (ABIC)[Akaike, 1980], respectively.

The resultant slip distribution is in good agreement with surface fault traces and the InSAR observation. The slip distribution close to the surface fault traces showed large eastward slips. In addition, there derived NW-SE slips in the west and southeast of faults 1 and 2, which are also consistent with the InSAR observation.

In summary, we first derived the focal mechanisms by the waveform inversions. Additionally to the focal mechanisms, we then used the observed data by InSAR and surface fault traces to determine the appropriate fault plane. The obtained slip distribution is in good agreement with the surface fault traces, and the displacements derived from the InSAR image. This study indicates the usefulness of the field fault observation and the InSAR data when it is difficult to identify the appropriate fault parameters only by waveform inversion.

Keywords: source process, inversion, InSAR, focal mechanism, slip distribution, surface fault traces

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Effect of various factors on the estimation of source process by the waveform inversion of teleseismic body waves

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In this study, we perform a test for investigating effect of various factors on the estimation of source process by the waveform inversion of teleseismic body waves. The test is constructed from four steps. First, we assume a slip distribution model. Second, synthetic waveforms at assumed stations are calculated based on the assumed model. Third, using the calculated waveforms as observed waveforms, we conduct waveform inversions in various analysis conditions. Fourth, we compare the obtained slip distribution with the assumed model in each condition.

We assume 24 stations with an equal azimuth interval of 15 deg and a common epicentral distance of 90 deg. P-wave part with a time length of 85s of the up-down component at each station is used for the waveform inversion.

Assuming a down-dip extension type earthquake in the upper plane of the double seismic zone in the Pacific slab beneath Northeastern Japan, we adopt two types of the fault planes: low-angle thrust fault plane and high-angle thrust fault plane. Mechanism of the former is (strike, dip, rake) = (0deg, 20deg, 90deg) and that of the latter is (strike, dip, rake) = (180deg, 70deg, 90deg). The hypocenter depth is assumed to be 70km.

The assumed fault plane is 36km x 24km, divided into 4km x 4km subfaults. The assumed slip distribution is composed of two large-slip areas. One large-slip area has a slip amount of 2.5m over an area of 12km x 8km near the hypocenter. Another has a slip amount of 2.5m over an area of 12km x 12km at about 20km southwest of the hypocenter. A Slip amount in the back ground area is assumed to be zero.

The waveform inversion is done using multiple time window analysis. By using a nonnegative constraint, the rake angle of the slip vector of each subfault is allowed to vary within the central angle +/- 45 deg. A spatial and temporal smoothing constraint is used. The value of smoothing strength parameter is fixed in all the inversions. The values of other source parameters (e.g. first time window velocity) are also fixed.

First, effect of using depth phase is checked by comparing the two cases; one case where only direct waves are used for the inversion, and the other where both of direct waves and depth phases are used.

The assumed model is recovered fairly well in the latter case. In contrast, it is not recovered well in the former case. This result is seen for both of the two types of the fault plane. Since travel times of depth phases are sensitive to source depth, use of depth phases is interpreted to improve the resolution in depth direction. Additionally, recovery of the slip distribution in the case of the high-angle fault plane is better than in the case of the low-angle fault plane. Since the depth difference between adjacent subfaults along a dip direction in the case of the low-angle fault plane is smaller than in the case of the high-angle fault plane, it becomes difficult to distinguish depth phases from adjacent subfaults on the time axis in the case of the low-angle fault plane.

Next, effect of station distribution related to the directivity on the estimation of the source model is checked. The 24 stations are divided into four groups according to the azimuth; 45deg-135deg (group A), 135deg-225deg (group B), 225deg-315deg (group C) and 315deg-45deg (group D). And we conduct a waveform inversion for each station group. Group B is in the direction of forward directivity and group D is in the direction of backward directivity.

Recovery of slip distribution in the case of using group B is not as good as for the case of using other groups. This result is seen for both of the two types of the fault plane. Since the difference between travel times from adjacent subfaults is small at the stations in the direction of forward directivity, it becomes difficult to distinguish the waves from the adjacent subfaults.

Acknowledgments: We used the program of Kikuchi and Kanamori (1982) for calculating the Green functions of telesesimic body waves.

Keywords: waveform inversion, teleseismic body wave, depth phase, directivity

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Multiple centroid moment tensor analyses using Green's functions computed for a 3-D earth model

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We performed multiple centroid moment tensor (CMT) inversion for 25 large earthquakes that occurred since 1995. Following the algorithm of Hara (2002, A42, 2002 Fall Meeting, SSJ), the inversion was carried out by two steps. In the first step, we performed ordinary CMT inversion. In the second step, we divided an event into two subevents and performed simultaneous inversion for CMTs of two subevents. In each step, we used the iterative linearized inversion technique of Hara (1997, GJI, 130, 251-256). In this technique, Green's functions are calculated using the Direct Solution Method (Hara et al., 1991, GJI, 104, 523-540), in which effects of three dimensional earth structure can be accurately considered. For a three dimensional earth model, we construct our model based on SAW24B16 (Megnin and Romanowicz, 2000, GJI, 143,709-728) in this study. The data for inversion were spectra in the frequency band 2 and 4 mHz, which we calculated from VHZ channel waveform data retrieved from the IRIS DMC. As initial guesses for the first step, we used solutions of the Global CMT catalog (http://www.globalcmt.org/).

For 12 events, CMTs of two subevents were determined stably, and the results are consistent with previous studies in terms of direction of rupture propagation and source duration. This result suggests that it is possible to construct a set of multiple CMT solutions by the data analysis procedure of the present study. We plan to investigate whether modification of the way to set initial guesses for the second step may improve results for the other events.

Keywords: multiple CMT, 3-D earth model

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Numerical experiments of rupture process inversion using the 2.5 dimension finite difference method

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We performed a numerical experiment to investigate accuracy and reliability of rupture process inversion using synthetic seismograms computed for a realistic structure model by the 2.5-D finite difference method (Takenaka and Okamoto, Proc. Int. Workshop on Scientific Use of Submarine Cables, 23-26, 1997; Okamoto and Takenaka, Advances in Geosciences, Vol.13, 215-229, 2009). The target event of this experiment is the 1994 far east off Sanriku earthquake (Mw 7.7 after Global CMT Catalog). Okamoto et al. (2010, P3-29, 2010 Fall Meeting, SSJ) constructed a structure model of crust and mantle surrounding the source region of this event, and showed that the observed waveforms of middle size (Mw 5.9-6.4) events that occurred near the source region were well reproduced by using the model. We constructed an earthquake source process model in this numerical experiment, which we call "input source process model", as follows. We placed three, localized asperities (small areas with large slips) in the shallow, middle and deep parts of the assumed fault plane, respectively. The rupture velocity was set to 2.5 km/s. The rupture starts from the shallowest asperity and propagates toward the deeper part of the fault. For this input source process model, we computed synthetic seismograms for teleseismic P waves using the 2.5-D finite difference method (Takenaka and Okamoto, 1997; Okamoto and Takenaka, 2009). Then, we performed rupture process inversion of these synthetic seismograms using inversion algorithm by Yagi and Fukahata (2008. Geophys. J. Int., 175, 215-221). Green's functions were computed using the method of Kikuchi and Kanamori (1991, BSSA, 81, 2335-2350).

The obtained rupture process model showed three areas with large slips corresponding to three small asperities in the input source process model. This result suggests that it is possible to obtain overall feature of rupture process by applying inversion algorithm of Yagi and Fukahata (2008) to teleseismic P waves. We also note that the areas of asperities in the inversion result are much larger than those in the input source process model. Such "smearing" effect has also been pointed out by Okamoto and Takenaka (EPS, 61, e17-e20, 2009) in the results of the synthetic experiments of the inversion for the slip distribution of tsunami earthquake. Because of the smearing effect, it might be difficult to reveal fine features in the "true" slip distribution.

Keywords: Rupture process inversion, Numerical experiment, 2.5 dimension finite difference method

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Rupture process analysis of the 1994 far east off Sanriku earthquake using the 2.5 dimension finite difference method

Taro Okamoto[1*], Tatsuhiko Hara[2], Hiroshi Takenaka[3]

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The effect of the near-source heterogeneous structure on the teleseismic body waveforms can become large for shallow subduction zone earthquakes: large amplitude later phases are generated as a result of the distortions in the ray paths due to the heterogeneous structure. Such structural effect must be carefully considered in evaluating the results of the source process inversion.

As an example of the source process analysis by considering the effect of the near-source structure, we perform inversion of teleseismic P waveforms for space-time slip distribution of the 1994 far east off Sanriku earthquake (the origin time: 12:19:23.60 UTC, December, 28; location: 40.45 degree N, 143.49 degree E; depth 33.0 km after USGS. Mw: 7.7 after Global CMT Catalog). The broadband waveform data were retrieved from the IRIS DMC. We integrate the velocity records to obtain displacement records, and applied band-pass filter with the pass-band between 0.007 Hz and 0.2 Hz to obtain displacement record for inversion. In order to consider the effects of crust and mantle structure around the source region, we constructed the structure model referring to the studies by Ito et al. (2004, EPSL, 223, 163-175), Ito et al. (2002, Zisin2, 54, 507-520), Amante and Eakins (2009, NOAA Technical Memorandum NESDIS NGDC-24, 19 pp.), Bassin et al. (2000, EOS Trans AGU, 81, F897). We presented the results of comparison between observed waveforms of middle size (Mw: 5.9-6.4) earthquakes that occurred in the source region and synthetic waveforms computed for this model using the 2.5 dimension finite difference method (REF) and showed that this model well explained the observed waveform data (Okamoto et al., 2010, P3-29, 2010 Fall Meeting, SSJ).

Using the Green's functions computed for the model, we invert the data for the slip distribution following the inversion procedure developed by Okamoto and Takenaka (EPS, 61, e17-e20, 2009). The preliminary inversion resulted in a small (weak) moment release near the rupture starting point, and a large (strong) moment release around the middle of the fault after about 30 s from the onset. In the companion paper (Hara et al., this meeting), we will present results of the synthetic experiments of this inversion.

Keywords: Rupture process analysis, 2.5 dimension finite difference method, 1994 far east off Sanriku earthquake

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On the repeatability of the rupturing processes of the moderate-sized repeating earthquakes

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We have investigated rupture processes of moderate-sized repeating earthquakes showing that the processes can be changed from event to event even in the characteristic earthquake sequence off Kamaishi, Iwate Prefecture, Japan (Shimamura et al., 2011). In this study, we investigate rupturing processes of two moderate-sized earthquakes (M5.7 on May 12, 1997 and M5.6 on October 22, 2005) in the repeating earthquake sequence (Hasegawa et al., 2005; Yamada et al., 2009) off Iwaki, Fukushima Prefecture, Japan. Results of preliminary analyses indicate that the rupturing processes of the two events are considerably different: the 1997 event ruptured several small seismic patches while the 2005 event ruptured only one large seismic patch. Amplitude spectra estimated from spectral-ratio technique shows that the two events have almost the same amplitudes and shapes for the frequency range below 1 Hz. However, above 1 Hz higher than corner frequencies of around 0.3Hz, two spectra are very different and the 1997 event has another peak around 3 Hz. This characteristic can be explained by the rupturing of plural small patches investigated in the preliminary analyses of the rupturing processes. This result indicates that an asperity can be occasionally ruptured in different ways than usual suggesting that time variation of the pore pressure may cause the change in the rupturing processes as proposed by Seno (2003).

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Subsidiary multiple crack generation during unstable fast rupture in Agarose-gel fault

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It is well known that earthquake faulting is followed by shear rupture propagation. It is very hard to see dynamic faulting under the ground. In order to observe such a shear rupture many attempts are done in experiments that samples with photo-elasticity are broken under a uni-axial loading and dynamic rupture nucleation is triggered by a explosion. It is, however, far from the actual earthquake nucleation that starts spontaneously. Here we try to nucleate dynamic rupture spontaneously.

We made gel plates (250x400x10mm) including a weak plane, and set it under an uni-axial compression. The gel has two advantages over rock samples. One is that the stress field of sample can be observed by photoelasticity. Another is that dynamic rupture is easy to be observed because of the significant low s-wave velocity, 7m/s. We change strength of the weak-plane so that we can control generation of subsidiary cracking off the main rupture.

We successfully generated subsidiary off-fault cracks when the weak-plane strength is relatively high. We observe significant deceleration of rupture velocity of the main fault during growth of subsidiary cracks. This can be attributed to the energy consumption due to increase of surface energy.

We also discuss geometry of off-fault comparing to theoretical prediction.

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Effects of off-fault damage on the tendency of fault branching

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Fault zones are an elastic medium with distributed damage varying the elastic stiffness of the medium. Considering effects of inelastic behaviors of fault zones is important for understanding physics of macroscopic rupture dynamics. Our main issue is to evaluate these effects on a spontaneously propagating mode II crack on a bimaterial interface (the main fault) and a branching fault.

We develop an explicit finite element code to model dynamic rupture process in a damaged medium. An equation of motion and a kinetic equation for damage evolution introduced by Lyakhovsky et al., 1997 are solved. Slip on the main and branching faults is implemented by split-nodes with a slip-weakening friction law. Outer boundaries are absorbing boundary. We assume homogeneous prestress.

We solve the dynamic rupture problem with the branching fault in homogeneous prestress with various values for the rupture velocity, the branching angle between the main and the branching angle, the material contrast, and the coefficients of damage evolution. We find that the damage is enhanced around crack tip when the rupture velocity is close to the generalized Rayleigh velocity. When the rupture front approaches a branching point, damage evolution at the branching point affects the tendency of fault branching.

Keywords: dynamic rupture propagation, branching fault, off-fault damage

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AE characteristics in a triaxial extension test

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When a high deviatoric stress is applied to a granular rock, there occurs microfractures which accompanied by ultrasonic waves called acoustic emission (AE) are observed. AE is an elastic wave radiated in a deformation process, which is similar to a seismic wave. Some AEs correspond to open crack mode microfractures, and others correspond to shear mode microfractures. AE has been studied to monitor deformation process in a rock sample under a compressive stress state (e.g., Scholz, 1968; Lockner et al., 1992). Although it is expected that AE occurs prior to the main fracture in an unloading process under triaxial extensive stress state, the activity and characteristics of the AE have not been studied.

We carried out continuous AE measurement in a triaxial extension test under a confining pressure of 80 MPa, using a cylindrical Kimachi sandstone sample, 100 mm in height and 50 mm in diameter. The fractured sample showed an extensive fracture plane and a shear fracture plane. Waveforms of the same AE event recorded by different sensors are similar to each other, except for polarities of initial motion. We found AE waveforms with polarity of all dilatational and those with polarity of both dilatational and compressional, which indicates that there occurred both open crack mode microfractures and shear mode microfractures.

Keywords: Triaxial extension test, Kimachi sandstone, Acoustic emission, Focal mechanism

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The simulation of seismic nucleation by modified RSF law added stress dependent term.

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We simulate earthquake nucleation of faults with revised rate- and state- dependent friction law proposed by Nagata (PhD thesis, 2008). The major revisions in the friction law are (1) parameters a and b (direct effect and strength healing rate, respectively) are three times larger than the traditional believed values and (2) the strength evolution law is revised incorporating a newly noticed weakening effect by an increase of shear stress.

We consider a planar fault with a revised friction in an infinite isotropic homogeneous medium. We simulate quasi-static slip evolution process controlled by (a) the revised friction law and by (b) the traditionally believed slowness law. We compare the results so that we can extract the effect of the newly proposed friction law.

We first investigate nucleation process under a high loading rate. In this case the strength healing is negligible and strength weakening is dominant. Simulation results for both friction laws shows a similar tendency: the most rapidly slipping portion of the fault patch constricts to a sub patch with a certain length. This is because the modified law produces significant difference in only the strength evolution compared with the original slowness law, that is, the evolutions of slip-rate and stress are similar to those of the original law.

We second investigate nucleation process under a slow loading rate. In this case the strength healing is comparable to that of weakening. Our preliminary simulation results show significant difference that nucleation length tends to be shorter with the modified law than the original slowness law. This is because larger healing occurs out side the sub patch and it prevents the sub path to grow larger.

Keywords: earthquake, nucleation, RSF

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Elasto-dynamic analysis of non-planar fault based on XFEM

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XFEM (Extended Finite Element Method) is a type of a mesh-free method based on the finite element method (FEM). XFEM has merits in capable of treating arbitrary geometry of cracks. We develop a numerical calculation algorithm based on XFEM for dynamic growth of cracks in an elastic-medium. In this presentation, we will show some preliminary results from the calculations and compare with the results of BIEM analysis.

Keywords: Extended finite element method, XFEM, non-planar fault, elasto-dynamic, fracture, numerical analysis