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

SCG061-P01 Room:Convention Hall Time:May 25 14:00-16:30

Improvement of stress tensor inversion by the revision of computational grid

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We improved a stress inversion method using a spherical code, which was a set of 60,000 points distributed with more or less uniform intervals on a unit sphere in 5-dimensional Euclidean space. The distribution was determined numerically by minimizing the total Coulombic potential of 60,000 charged particles constrained on the sphere. This optimization ran on a personal computer for 3 months.

The points represent 60,000 different stress states with 'uniform' intervals, which can be used as the computational grids in stress inversion methods.

We tested the multiple inverse method using the conventional and the new grid points. For this purpose, artificial data were generated with assumed stresses. The result of the method was significantly improved by the spherical code.

Keywords: stress tensor inversion, tectonics, spherical code, focal mechanism, fault

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Simultaneous determination of tectonic stress field and individual focal mechanisms from seismic amplitude data

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The stress tensor inversion method solves for the orientation of the three principal stress axes and the relative magnitude of the principal stresses using suites of fault slip data. In seismology, focal mechanisms are generally used as the basis for searching the best fit stress model (e.g., Gephart and Forsyth, 1984; Michael, 1984). In the 90s, a sophisticated approach by inverting directly from polarity data of P-wave to a stress tensor was proposed (e.g, Horiuchi et al., 1995; Loohuis and van Eck, 1996; Abers and Gephart, 2001). In this study, we try to extend the approach by using seismic amplitude data, together with P-wave polarity.

The inversion procedure consists of two nested grid searches. The outer search is conduced over a range of the stress tensor, where the principal stress axes and stress ratio are gridded with an appropriate step size. The inner search is conducted to identify a focal mechanism for each earthquake that best fit the observations by testing stress-consistent focal mechanisms (SFM). Here SFM is the suite of focal mechanisms whose fault plane can have any orientations, but the slip direction must be aligned with the shear stress direction predicted by the stress tensor of the outer search. By summing the residual of each earthquake, we determine the misfit of the stress model (S). As a result of the two nested grid searches, we obtain the best stress tensor that minimizes the misfit S and individual focal mechanisms. In this study, we call the present method ”ASTI (Amplitude-based Stress Tensor Inversion)” and the original method using polarity alone ”POSTI (Polarity-based Stress Tensor Inversion)”, respectively.

In order to investigate the performance of ASTI and POSTI, we conducted numerical tests using synthetic data set. We generated 20 earthquakes whose fault planes were oriented in random directions. The slip direction of each fault plane was calculated so that it aligns with the shear stress direction predicted by the assumed stress tensor. Random angle values with the standard deviation of 10 degrees were added to the slip directions. For each earthquake, 20 observations (P-wave polarity and amplitude) were calculated. The result of the numerical test indicates that a correct solution of the stress tensor was determined by both methods, though some fault planes were incorrectly determined in the case of POSTI. When we decreased the observations for each earthquake down to 10, the ASTI method still succeeded in estimating the true stress tensor, while the POSTI method failed.

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Keywords: stress field, focal mechanism, seismic amplutude data, stress tensor inversion

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Importance of stress distance in stress inversion analysis and its physical meaning

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Stress inversion methods are widely used to infer crustal stress states from fault-silp data. For the purpose of detecting different stresses separately from a heterogeneous fault-slip data set, we need to measure the difference between stress tensors. A statistical assessment of optimal stress solution or a comparison of solutions obtained through several methods also requires a measure of difference. However, it is not easy to define the difference of tensors. The unknown of stress inversion analysis is called reduced stress tensor, which carries the orientations of three pricipal stress axes and a stress ratio, the shape factor of stress ellipsoid. The problem is how to synthesize the differences in orientations and stress ratios.

Orife and Lisle (2003) proposed a solution to this problem. They calculated so-called ”stress difference” between various stress tensors, which is defined as square root of second basic invariant of the difference tensor of two tensors, and showed its convenience. For example, given a nearly axial compressional stress with magnitude of sigma3 comparable to sigma2, a rotation around sigma1-axis yields small value of stress difference, while a rotation of sigma1-axis is evaluated as large difference. Although the stress difference was useful, its characteristics were clarified only empirically and its physical meaning remained unclear.

The physical meaning was given by Yamaji and Sato (2006). The stress difference approximately has one-to-one correspondence to the expected angular difference in shear stress directions on a randomly-oriented fault surface exerted by two stresses in comparison. In other words, the difference in stress tensor can be measured by that in fault-slip direction according to the Wallace-Bott hypothesis, which states a fault slips in the direction of shear stress. This fact means that the stress difference is suitable for solutions of stress inversion analyses based on the hypothesis.

The author recently found that the above-mentioned physical meaning was not exact. The stress difference turned out to be analytically equivalent to the expected difference in shear stress vectors on a randomly-oriented fault surface. The differences not only in directions, but also in magnitudes of shear stresses are involved in a value of stress difference. This discovery is inconvenient for the usage of stress difference in inversion analyses in which the magnitudes of stress are normalized. We need to pay attention to the fact that the way of normalization inevitably affects the values of stress differences.

References

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Keywords: stress tensor inversion, stress difference, angular stress distance, fault-slip data, deviatoric stress space

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Method and significance to determine stresses from heterogeneous fault-slip data obtained in different depths

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We will present the significance to determine stresses from heterogeneous fault-slip data obtained in different depths and the result of applying the multiple inverse method (Yamaji, 2000; Otsubo and Yamaji, 2006) the data. We can obtain the data from outcrops, borehole cores and focal mechanisms. A heterogeneous data set comes also from a rock mass in which the state of stress changes spatially and/or temporarily.

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Otsubo, M. and Yamaji, A. (2006) Improved resolution of the multiple inverse method by eliminating erroneous solutions. Computers & Geosciences, 32, 1221-1227.

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Keywords: Stress, Fault-slip data, Multiple inverse method, Tectonics, Crust, Earthquake

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Incremental fold test for stress tensor inversion based on fitness evaluation to fault-slip data

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We present a method of incremental fold test for the paleostress inversion of fault-slip data obtained from folded sedimentary rock, which provides not only the orientations of the three principal stress axes and the stress ratio, but also the relative timing of folding and faulting. The method is based on the stepwise backtilting of strata that was tilted before, during, or after fault activity. At each step, the rotated fault-slip data are analyzed by a stress inversion technique, based on the Hough transform. The inversion technique calculates the degree of fitness of all possible stresses to the fault data and detects the optimal fitness. The peak values of fitness are compared among the various backtilting steps to find the maximum value. The stress and the backtilting step that yield the maximum fitness are selected as the optimal solution. To assess the validity of the method, we applied it to artificial fault-slip datasets generated with hypothetical histories of folding and faulting and with known paleostresses. The proposed method succeeded in determining the supposed stresses and the relative ages of folding and faulting.

Keywords: minor fault, stress inversion, fold test

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Relation between formation of echelon faults and stress fields in rock mass-Simulation using MPS method-

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Echelon faults are a group of cracks and faults which have a certain angle to the main shear faults caused by earthquakes and crustal deformation. In Japan, they can be observed off the coast of Izu Peninsula. The mechanism and formation of the echelon faults are not well investigated, and there still remains an important geophysical subject to look into. In this study, we try to simulate the formation of echelon faults to investigate the nucleation conditions by the MPS (Moving Particle Semi-implicit) method which is a particle method developed for incompressible flow analysis. Particle interaction models for differential operators are prepared in this method. The government equations of elastic structures are interpreted into interactions between particles. In the finite difference and the finite element method, the failure at faults or cracks would not be well simulated when the displacement becomes large or the grid-based structure is broken. Particle methods are free from this difficulty. We simulate uniaxial and triaxial compression of 2D rectangle elastic structure. In the triaxial compression, we change the cohesion and the confining pressure to investigate the relation to the form of echelon faults. Our results show that the conjugate faults or cracks are generated with higher density as the cohesion and the confining pressure becomes higher. This suggests that we could estimate the magnitude and the direction of stress in rocks from the distribution of echelon faults.

Keywords: echelon, particle method, MPS method, compression test