Simulation of Complex Recurrence Behavior of Earthquakes with an Interacting Fault System Model

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Abstract

Activity of large earthquakes in and around the Japanese Islands is simulated with a model that incorporates mechanical interactions between faults, including both interplate and intraplate faults. In this simulation, each fault element is assumed to accumulate stress with a constant slip deficit rate and redistribute its accumulated stress to surrounding faults by making a forward (coseismic) slip when the cumulative stress reaches an assumed threshold. The results from the inversion of geodetic data by Hashimoto and Jackson (1993) were used to specify slip deficit rates for these faults. Each fault in this model is divided into nine equal-sized elements, three in the length direction and three in the width direction, so that this model can simulate events as small as M6. The rate of stress accumulation is not necessarily constant for all faults, which may be attributed to the interaction between faults. It is interesting that fluctuations in the amplitude of stress changes with periods of about 2,000 years or longer are seen for some inland faults. Smaller events in which only one element on a fault ruptures frequently occur, but large events with three or more rupturing elements are rarely seen.

Introduction

Recent studies on seismic triggering suggest that fault system interacts mechanically by transferring accumulated stresses when earthquakes occur. Therefore it is important to incorporate interacting fault system for the purpose of precise forecast of earthquake occurrence. In this paper, activity of large earthquakes in and around the Japanese Islands is simulated with a fault system model incorporating mechanical interactions between faults.

Method

In this simulation each fault segment is assumed to accumulate stress with constant slip deficit rate and distribute their accumulate stress to the surrounding faults by making a forward slip when cumulative stress reaches assumed thresholds. This simulation uses a time-marching scheme. First initial state of faults is given by perturbing stresses randomly within the interval of 0 and threshold for rupture. Beginning form this initial state, stresses of all faults change according to their movements. Movements of faults are divided into two categories: slip deficit and forward slip. Slip deficit represents the accumulation process of stress (Savage, 1982[1]; Matsu'ura et al., 1986[2]). On the other hand, forward slip is an earthquake. When accumulated stress for a fault exceeds rupture thresholds, forward slip occurs and stress is redistributed referring to the relationship between unit slip of the fault and stress changes raised on the other faults and the amount of slip. In this study, we assume forward slip releases all the accumulated stress for the rupturing segment. Slip is calculated by dividing accumulated stress by stiffness of the fault. This assumption implies that the slip is constant, without interaction. Otherwise, stress of a segment accumulates at a rate of the sum of contribution from the movements of all the segments. This judgment is done at every time step. If there is a rupturing segment, accumulated stress is redistributed and added to the other segments. After the adding stress changes to other segments, the judgment of rupture is made again for all segments till no rupturing segments are found. If there are no rupturing segments, calculation goes to the next time step. In this paper, we use 1 year as the time interval. We calculate stress history for 10,000 years in order to see many events at all faults enough to discuss recurrence behavior.

Mechanical interaction between faults are represented by changes in Coulomb Failure Function (hereafter ΔCFF) for preferred slip of each fault induced by slip events of other faults. ΔCFF is defined as

$$\Delta CFF = \Delta\tau - \mu(\Delta\sigma_n - \Delta P) = \Delta\tau - \mu'\Delta\sigma_n \qquad (1),$$

where $\Delta\tau$ and $\Delta\sigma_n$ are changes in shear stress parallel to the direction of preferred slip and normal stress (compression is positive), respectively. ΔP, μ and μ' are change in pore pressure, coefficient of internal friction, and reduced coefficient of internal friction, respectively. Here we use 0.4 for reduced coefficient of internal friction, since the effect of pore pressure change is hard to estimate. ΔCFF is estimated at the center of each segment on modeled faults. We assume perfectly elastic half space with rigidity of 40GPa and Poisson's ratio of 0.25 in the calculation of stress using Okada's (1992)[3] formula. Preferred slip of each fault is referred to the results of inversion of geodetic data (Hashimoto and Jackson, 1993[4]), and is assumed the same for all segments on a fault. The first step of simulation is to calculate ΔCFF of each segment on all faults due to unit slip of all segments and store them as a matrix.

Rupture threshold is one of the key parameters, which control the timing of rupture and magnitude of slip. After Hashimoto (1998)[5], we assume 0.5 and 2.0 MPa for interplate and inland faults, respectively, which are roughly equivalent to forward slip of 4-6m for interplate boundaries such as the Nankai and Suruga troughs and 2m for inland faults, respectively, when entire fault breaks.

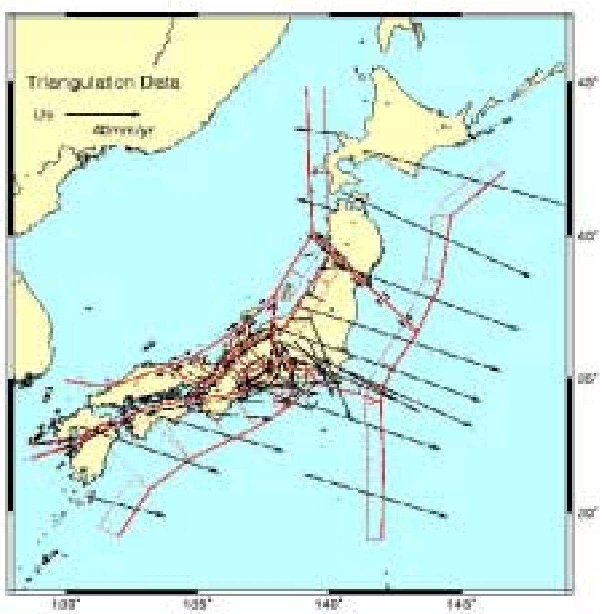

Figure 1. Block and fault model used in this study after Hashimoto and Jackson (1993)[4]

The fault system model and their slip deficit rates are referred to the inversion study of geodetic data by Hashimoto and Jackson (1993)[4] (Figure 1). Each fault is divided into 9 rectangular segments of the same size: 3 by 3 in the length and width directions. This model can simulate as small events as M6. There are 936 segments in total. Rectangles in Figure 1 are projections of dipping fault planes of the original model by Hashimoto and Jackson (1993)[4] to the surface and thick lines show their upper margins. Strike-slip faults are indicated by thick lines with parallel arrows in opposite directions. Arrows show forward slip derived from the inversion.

Results

As a result of 10,000 year run of simulation, complex pattern of seismicity arises. Rate of stress accumulation is not necessarily constant for all faults, which may be attributed to interaction between faults (Figures 2 and 3). It is interesting that fluctuation in amplitude of stress changes with periods of about 2,000 years or longer is seen for several faults (Figure 3). Events of a variety of sizes occur according to number of simultaneously rupturing segments. Smaller events in which only one segment on a fault ruptures frequently occur, but large events with 6 or more rupturing segments are rarely seen (Figures 4 and 5).
Simulations indicate that small error in initial conditions may produce large difference in seismicity after hundred years, though increase of this difference is not monotonous.

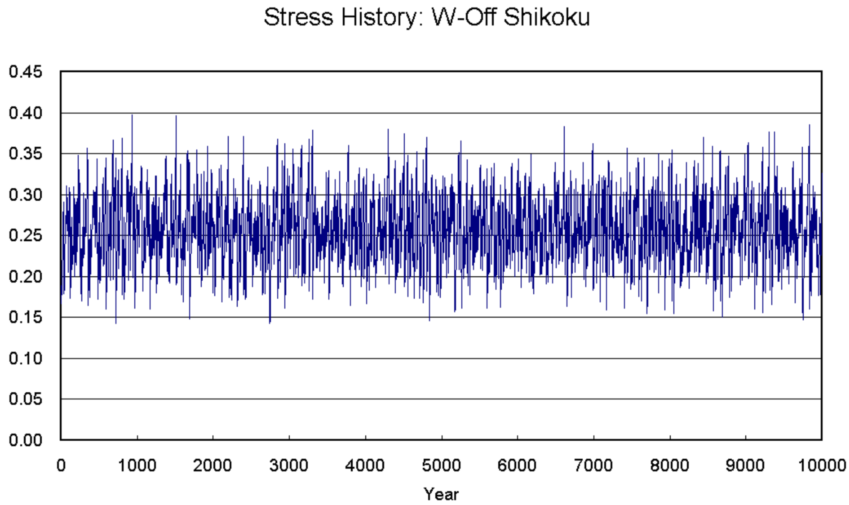

Figure 2: Temporal variation in Coulomb Failure stress on the fault west off Shikoku

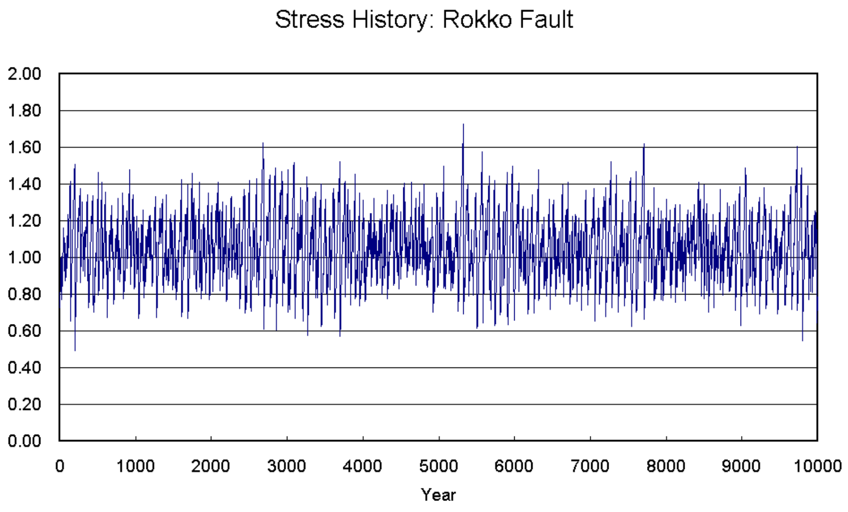

Figure 3: Temporal variation in Coulomb Failure stress on the modeled Rokko fault

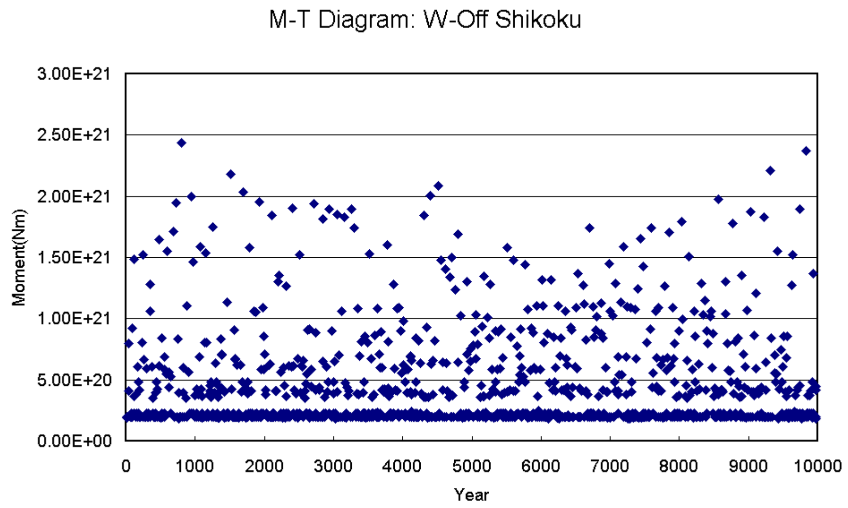

Figure 4: Moment vs Time diagram of events for the fault west off Shikoku

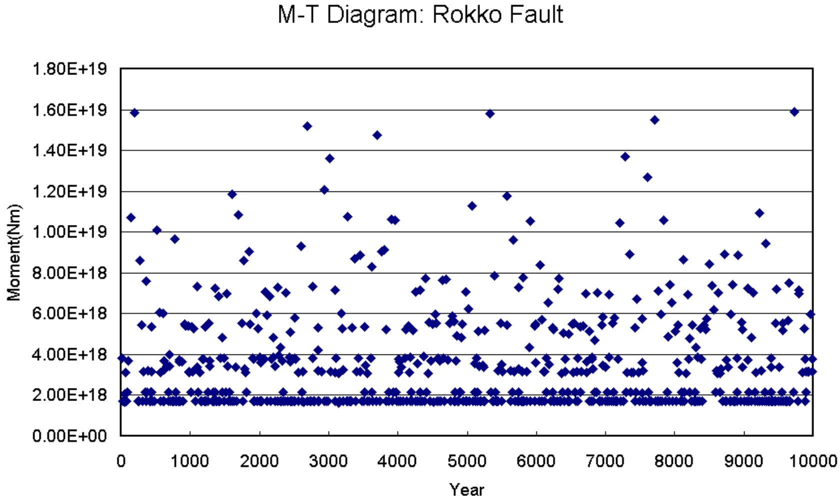

Figure 5: Moment vs Time diagram of events for the modeled Rokko fault

Acknowledgments

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References

[1] Savage, J.C., 1982, *A dislocation model of strain accumulation and release at a subduction zone*, J. Goephys. Res., **88**, 4984-4996.

[2] Matsu'ura, M., and Jackson, D.D., and Cheng, A.B., 1986, *Dislocation model for aseismic crustal deformation at Hollister, California*, J. Geophys. Res., **91**, 12661-12674.

[3] Okada, Y., 1992, *Internal deformation due to shear and tensile faults in a half-space*, Bull. Seismol. Soc. Amer., **82**, 1018-1040.

[4] Hashimoto, M., and Jackson, D.D., 1993, *Plate tectonics and crustal deformation around the Japanese islands,* J. Geophys. Res., **91**, 16149-16166.

[5] Hashimoto, M., 1998, *Simulation of activity of large earthquakes in and around the southwest Japan on the basis of slip deficit model,* Annuals of Disaster Prevention Research Institute, Kyoto Univ., **41**, B-1, 45-59.