Irregular earthquake cycles due to interactions between fault segments: A numerical simulation

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The places where large earthquakes occur are thought to be controlled by the locations of asperities on plate boundaries and fault segments. Concerning the occurrence times of large earthquakes, on the other hand, statistical forecasts have been made on the basis of the average and the scatter of recurrence intervals. However, the statistical characteristics of recurrence intervals are little known because these data are limited. Numerical simulations may be useful to obtain insight into the statistical characteristics of earthquake recurrence. Several origins of the scatter of recurrence intervals have been proposed. In the present study, we investigate the effect of interactions between fault segments on seismic cycles through numerical simulations to discuss what controls the distribution of recurrence intervals of large earthquakes.

We performed a numerical simulation of seismic activity along the Xianshuihe fault, a highly active strike-slip fault 350 km long, located along the eastern margin area of the Tibetan plateau, southwestern China. Historical earthquake data over the last 300 years indicate repeated periods of seismic activity, and migration of large earthquakes along the fault during active seismic periods. We performed a numerical simulation of slip behavior along the fault, assuming that the friction on the model fault obeys a laboratory-derived rate- and state-dependent friction law. Frictional property within fault segments is assumed to be velocity-weakening property, while that within segment boundary regions is velocity strengthening property. We determined appropriate friction parameters so that the simulated earthquake cycles would mimic the characteristics of past large earthquakes along the Xianshuihe fault. For the frictional characteristics at the boundary segment regions, we considered two cases as follows: (1) strong velocity strengthening and relatively a small characteristic slip distance, and (2) weak velocity strengthening and a large characteristic slip distance. In both the cases, aseismic sliding tend to occur due to (1) high frictional resistance at high velocities and (2) slow degradation of resistance with slip, respectively.

We obtained simulation results as follows: (i) Postseismic sliding occurs in the boundary segment regions. Postseismic sliding is well approximated by a logarithmic time function for (1) strong velocity-strengthening region, while it has more rapid increase rates in the initial stages and lower rates in later phases for (2) the regions with large characteristic slip distance. (ii) When an earthquake occurs at a fault segment, earthquakes tend to occur at the neighboring segments with some time delays since stress is propagating due to propagation of postseismic sliding. Because of the difference in time function of postseismic sliding, temporal characteristics of stress transfer is different between cases (1) and (2). There is a wide range in time delay for case (1), while there is a significant peak in time delay in case (2). (iii) The distribution of recurrence intervals of large earthquakes at a segment approximately obeys Brownian passage time (BPT) distribution or lognormal distribution for case (1). On the other hand, there is a significant peak in the distribution of recurrence intervals for case (2). (iv) The scatter in the recurrence intervals of large earthquakes tends to be large for segments where interactions between fault segments are large. (v) The simulated slip time function at a point on a fault does not obey the time-predictable model or the slip-predictable model. (vi) The characteristics of earthquake recurrence randomly changes.

Strong velocity-strengthening frictional property at segment boundary regions seem to explain better the characteristics of earthquake recurrence. The frictional property of faults controls time dependent interaction between fault segments and the statistical characteristics of earthquake recurrence.