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Two-dimensional simulation of shear faulting with the slip-dependent constitutive law: a study of slow slip events

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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 (slip that is insufficient to fully accommodate plate movement). Recently, on the basis of detailed analysis of geodetic and seismic data, it have been revealed that many slow earthquakes that have extraordinary small slip-velocity occur at plate interfaces, for example, in deeper narrow zones along the Eurasian-Philippine Sea plate interface in southwest Japan. This indicates a variety 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 simulation model of shear faulting with a slip-dependent constitutive law.

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-dimentional anti-plane shear faulting, slip-dependent fault constitutive relation, and steady slip motion at the outside of the modelled region as a driving force. 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). Through numerical simulation, we obtained the following results. Stress accumulation due to slip deficit proceeds in the strength asperity, while a stable fault slip proceeds in the surrounding region. When the system reaches a critical state, accumulated stress in the strength asperity is released by unstable/stable fault slip. In the case that the non-dimensional parameter is small, accumulated stress is released by unstable slip. On the other hand, 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, which is stable but has a distinct peak in the slip velocity, can be realized. Given proper values of the rigidity, the peak strength, and the characteristic length, we can find that the result shows a dependence of slip behaviour on the critical weakening displacement. This means that a slow slip event necessarily can occur in the narrow transition zone of the critical weakening displacement, such as, at a depth corresponding to the brittle-ductile transition zone, where the critical weakening displacement has a significant temperature dependence.

Keywords: slow slip, shear faulting, constitutive relation, critical weakening displacement, brittle-ductile transition