Slip behaviors of the frictionally heterogeneous fault in the pre- and post-seismic period

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The importance of heterogeneity on the fault has been recognized recently. For example, the occurrences of tectonic tremors in subduction zones suggest the slip-weakening or velocity-strengthening frictional property on the plate boundary fault, whereas the sensitivity of tectonic tremors to tiny stress perturbations suggests the velocity-strengthening frictional property (e.g., Miyazaki & Brodsky, 2008; Beeler et al., 2012). Geologic observations on the ancient plate boundary fault also shows that the plate boundary fault is consisted of the mixture of the ductile matrix and the brittle blocks (Fagereng and Sibson, 2010; Fagereng et al., 2014). The pore fluid pressure would also distribute heterogeneously according to the heterogeneous hydraulic properties (Wibberley and Shimamoto, 2003).

This study investigated the slip behaviors of the frictionally heterogeneous fault using numerical simulations. Several studies have already shown that such fault shows the transitions of slip behavior. This study focuses on the pre- and post-seismic behavior in the case where the seismic slip occurs on the entire fault. We consider a finite linear fault in the 2D elastic medium governed by the rate and state dependent friction law, and distribute velocity-weakening zones (VWZs) and velocity-strengthening zones (VSZs) alternatively.

Precursory slip behavior is observed before the mainshock, which ruptures the entire fault, though its activeness significantly varies according to the frictional parameters. Active precursory slip, which include both aseismic slip and seismic foreshocks, occurs around the stability boundary of the fault. When the frictional heterogeneity is small (i.e., $(b-a)\sigma$ of VWZs and $(a-b)\sigma$ of VSZs are small), aseismic slip more dominates in the precursory slip, whereas seismic foreshocks more dominates when the heterogeneity is large. The stacked sequence of foreshocks obeys the inverse-Omori law. This precursory slip behaviors can be considered as the “dynamic” nucleation (Ide & Aochi, 2013) toward the mainshock, which is a preparing process for the mainshock, but is different from the classical concept of the nucleation in that the slip velocity of the nucleation zone is highly perturbed by occurrences of foreshocks.

When the frictional parameter varies significantly along the fault, aftershocks and afterslips are observed both within and outside the mainshock rupture area. Only exception is the center of the fault, where the coseismic slip is at maximum. The largest earthquake in this case cannot rupture the entire fault due to the along-fault variations of frictional properties. Then, the accumulated slip deficit during the inter-seismic period cannot be fully released both within and outside the rupture area during the coseismic period. That remained slip deficit is released as afterslip and aftershocks during the post-seismic period. In the case of weak along-fault variations of frictional properties, the largest earthquake can rupture the entire fault. Aftershocks do not occur in such case because almost all slip deficit is released during the coseismic period.

Those results show that the frictionally heterogeneous fault model can explain not only the slow earthquake (e.g., Ando et al., 2012), but also the seismicity of regular earthquakes. Because even very simple heterogeneity can produce complex seismicity, further research would be required to understand the complex slip behavior on the frictionally heterogeneous fault.

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