Dynamic formation process of fault zone: Macroscopic fault branches and mesoscopic fault branches

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Recent theoretical, experimental and observational developments of earthquake source study allow us to investigate the entire dynamic process of earthquake rupture from its nucleation to arresting. In such study, fault constitutive laws are, in general, empirically formulated based only on laboratory experiments and seismological data analyses. These two will be two end-members of earthquake rupture phenomena; the former and latter are regarded as microscopic- and macroscopic-scale earthquake ruptures. Such formulation poses a critical problem because scaling relationship between microscopic and macroscopic rupture phenomena is not considered appropriately.

To overcome this problem, we introduce a new concept termed Multi-Scale Earthquake Rupture Model (MSERM) in the formulation of macroscopic fault constitutive law, and in the investigation of fault geometry. A key element in this modeling is the consideration of fault zone, which plays a role of mesoscopic structure existing between microscopic and macroscopic ones. Our model has a significant feature of multi-level hierarchy structure consisting of microscopic-, mesoscopic- and macroscopic-scale structures; physical process on a lower scale is mapped onto one on an upper scale using an average procedure.

We investigate the formation process of fault zone structure using MSERM and the above newly developed numerical method. Step-over, bending and branching of a fault, which are regarded as mesoscopic fault structures in our modeling, are quite commonly observed. The fault branching occurs as results of secondary ruptures; we find in our simulations that the lengths of such branches are proportional to the length of the main-fault. We call those branches as mesoscopic branches. We, however, find that if the main-fault exceeds a critical length, such a simple proportionality is violated, and some branches begin to extend unstably and emerge as macroscopic-scale ruptures. We call those branches extending unstably are macroscopic branches. Understanding such different formation processes of fault branches is typically important to understand scale dependence and physical entities of macroscopic fracture energy observed in natural earthquakes.