Influence of fault surface condition on slip stability in large-scale biaxial friction experiment

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Slow slips and/or foreshocks preceding large earthquakes were often observed (e.g. Bouchon *et al.*, 2011; Kato *et al.*, 2012). To reproduce and investigate those activities in laboratory, we have conducted stick-slip experiments using large-scale biaxial friction apparatus at NIED (Fukuyama *et al.*, 2014). We used two rectangular metagabbro blocks as experimental specimen. The nominal contacting area was 1.5 m long and 0.1 m wide and the contacting surfaces were polished so that the undulation was less than 10 μm before the first experiment. We repeatedly conducted the experiments with the same pair of specimens, which means the fault surface continuously evolved with the frictional slip. The stick-slip experiments were conducted under the condition of constant normal stress of 6.7 MPa and loading rate of 0.01 mm/s. To monitor various phenomena on the fault, we installed dense arrays of strain gauges and PZT seismic sensors along the fault. In the first experiment, very few foreshocks were observed over the entire history of the experiment while precursory slow slips were observed before each main stick-slip event. We also found that both the occurrence location of slow slip and its occurrence time relative to the main rupture followed a mono-modal distribution at this initial stage. In later experiments, however, a variety of occurrence times and locations of slow slips was observed. The number of foreshocks also increased with the evolution of the fault surface, and the estimated hypocenters were located around the area where many gouge particles were generated during those experiments. To further investigate the relationship between foreshock activities and the existence of gouge, we focused on two experiments at the similar evolution stage but with different initial gouge conditions; one experiment was started with all previous gouge removed while the other was started with gouge from the previous experiment remained. Note that distribution of the gouge is not homogeneous but heterogeneous, because we did not give any operations to make the gouge layer uniform. First of all, both the number and magnitude of foreshocks were larger in the experiment with pre-existing gouge (denoted by PEG hereafter). In particular, relatively large number of big foreshocks were observed, which was revealed by a lower *b* value relative to the other. We also found that the maximum magnitudes of the foreshocks increased with the slip distance during the experiment without PEG, whereas they are almost constant in the experiment with PEG. The increase in the foreshock magnitude should be caused by an increase in the amount of newly generated gouge with slip. Therefore, these observations suggest that the upper limit of the foreshock magnitude is controlled by the gouge layer thickness. The gouge condition also affects how main event occurs. In the experiment without PEG, precursory slow slips were observed before every main event but foreshocks occurred only at the end of the nucleation process. The strain data suggested that foreshock occurrence in this condition requires relatively large stress concentration and subsequent stress release induced by the slow slip. In the experiment with PEG, on the contrary, no clear precursory slow slips were observed by the strain measurement. Instead, the number and magnitude of foreshocks increased towards the main event at an accelerated rate, which were confirmed by a decreasing *b* value. Spatiotemporal distribution of foreshock hypocenters suggests that foreshocks migrate and cascade up to the main event. We infer that heterogeneous gouge distribution caused stress-concentrated and destructive patches, which impeded slow and stable slip and activated foreshocks on the fault. These results confirm that fault surface condition affects the slip stability on it even under the same loading condition. They also suggest that *b* value is a key parameter to explore the condition.

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