AE events observed during loading velocity step change in large-scale gouge friction experiments

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In recent years, hydraulic fracturing has been carried out to artificially crack the bedrock for oil and shale gas oil mining. Injection of fracturing fluids into the bedrock can increase the pore pressure, decrease the effective normal stress, and therefore decrease the fault strength, which may induce earthquakes. In this study, we conducted large-scale gouge friction experiments, in which the loading velocity was changed stepwise. We analyzed AE (Acoustic Emission) events that occurred during the experiments to investigate the effect of the loading velocity on the AE event occurrence (timing and location).
The experiment was carried out using a large biaxial rock friction apparatus at the National Research Institute for Earth Science and Disaster Resilience (NIED). Metagabbro was used as host blocks whose dimensions were L1.5 m x W0.5 m x H0.5 m for the top block and L2.0 m x W0.1 m x H0.5 m for the bottom block. These two blocks were stacked vertically, and the normal load was applied onto the top face of the top block. The shear load was applied onto the side face of the top block. Before each experiment, simulated gouge was distributed between the host blocks, so that the thickness of gouge layer was 3 mm (Fig.a). The gouge was made of the same metagabbro pieces by crushing them, so that the average particle size is 10 μm and the maximum particle size is 200 μm. All gouge used in an experiment was removed and new gouge was distributed before the next experiment. In the present study, we focus on four experiments (LB21-003 and LB21-004 with 3.3MPa normal stress and LB21-007 and LB21-008 with 6.5 MPa normal stress). The loading velocity was changed stepwise among 0.01 mm/s, 0.1 mm/s, and 1 mm/s (Fig.b). 16 AE sensors were installed on both side surfaces of the top block 70 mm away from the sliding surface with 180 mm intervals. We first picked up the time window when the AE events were detected by using InSite software (made by Applied Seismology Consulting Ltd), and then manually picked the P wave arrival times of all events. Their locations were estimated using the data of the four sensors with the earliest P wave arrival. The grid search method was used for the estimation of the hypocenter (x, y) and the origin time (t) that minimized $G = \Sigma|g_i|$, where $g_i = \{(x-x_i)^2 + (y-y_i)^2 + z_i^2\}^{1/2} / Vp-(t_i - t)$, x_i, y_i, and z_i are the location of the i-th sensor, and ti is the P wave arrival time at the i-th sensor. In this estimation, we assumed that the AE events occurred on the sliding surface and the P wave velocity Vp = 6919 (m/s), which was estimated from the physical properties of the host rock. The grid interval was 0.5 mm in the x and y directions and 0.1 μs in time. Furthermore, cross-correlation analysis was performed for events whose epicenter was not well determined. By utilizing the time difference with respect to those of well-located events, we could further reduce the error function G. The cross-correlation analysis should be effective for locating event whose P wave arrival is unclear.
Figure c shows the spatial distribution of AE events observed during the LB21-007 experiment. The AE events were clustered at four locations. It should be noted that the locations of the AE clusters were quite similar to each other in four all experiments . Because such a clustering was not observed in the rock-on-rock experiments without the gouge layer, the spatially-concentrated occurrences of the AE events should be relevant to the presence of the gouge layer. Figure b shows the temporal change in the number of the AE event, which suggests that most events occurred immediately after the loading velocity was increased to 1 mm/s. Statistical characteristic of the AE event clearly shows a positive correlation of the occurrence number with the loading velocity: averaged numbers of the AE events per unit displacement in LB21-007 were 0.17, 0.28, and 0.91 under the loading velocities of 0.01, 0.1, and 1 mm/s, respectively.

Keywords: rock friction experiment, acoustic emission, epicenter determination