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Wide-range frequency analyses of vibration wave radiated from faults during high-speed sliding

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Recent high-velocity rock friction experiments reveal that fault slip at seismic rate generates abundant heat that excites several thermal-activated process such as melting, flash heating and dehydration and these processes cause dynamic and diverse frictional behavior at seismic slip rates. The diversity of the physical process in faulting as well as the fault geometry would be a cause of complexity in dynamic earthquake rupture and the associated seismic waves. In this study, we conducted high-velocity friction experiments on rock samples at seismic slip rates and measured vibrations radiated from the sliding interface of rocks in a wide frequency range from 10 0 Hz to 5 MHz to investigate a generation mechanism of fault vibrations during high speed slipping in relation to the physical process in the fault.
The experiments were preformed at a normal stress of 3 MPa and at a slip rate of 1.5 m/s in room temperature and room humidity condition, using a high-speed rotary-shear apparatus. For each run, we prepared a pair of solid cylindrical specimens of 25 mm in diameter made from India gabbro. We used an amplifier built-in triaxial-accelerometer (Fuji Ceramics Co., Ltd, SA11ZSC-TI) whose amplitude response is flat from 100 Hz to 5 kHz (within 1dB), the sensitivity is 1 mV/m /s^2, and the dynamic range is +/-4000 m/s^2. It was attached to the sample holder of the apparatus with screw clamp. We also used a piezoelectric disc element (produced by Fuji Ceramics Co., Ltd) whose thickness mode resonance frequency is 2MHz, the diameter is 3 mm and the thickness is 2 mm. It was attached to on the bottom surface of the stationary specimen with super glue gel. The accelerometer and piezoelectric transducer were used to measure low (100 to 5kHz) and high (100 k to 2MHz) frequency fault vibration, respectively. The acceleration data were recorded continuously with axial stress, shear stress, axial shortening, and slip velocity using a 24 bit digital recorder with a 20 kHz sampling rate. The piezoelectric transducer data were continuously recorded using a 14 bit A/D recorder with a 20 MHz sampling rate.
From the mechanical data, a rapid decrease of friction coefficient was observed immediately after the start of the experiment. It decreased dynamically from an initial peak value of about 1.0 down to 0.5 within 0.2s. This first weakening is accompanied by the formation of abundant gouge particles. After the first weakening, frictional melting started to occur and the major shear deformation mechanism changes from brittle friction of the gouge particles to viscous shearing of the molten layer. The molten layer thickened as increasing slip and the friction coefficient decreased down to 0.3 (second weakening). Then, the friction coefficient became constant when a steady-state balance was archived in the slipping zone between the production rate and escape rate of molten materials.
In the first weakening stage, strong vibration was observed in all frequency ranges from 100 Hz up to 2 MHz. In the transition of shear deformation mechanism from brittle fracture to viscous shearing, vibration amplitude at higher than 2 kHz decreased by more than one order of magnitude but the low frequency behavior kept the same amplitudes. In the second weakening stage, vibration amplitudes lower than 2 kHz decreased by an order of magnitude. Then, finally, at the steady-state melting, vibration became weak in all frequency ranges. We suggested that brittle friction process is 10 times more effective for the generation of the vibration in all frequency

ranges than that during the frictional melting. Variation in the physical process in faults during an earthquake event would significantly affect seismic wave radiated from the fault.

Keywords: frictional melting, vibration wave, high-velocity friction, brittle friction, viscous shearing