Modeling of wave propagation in 4m biaxial rock friction apparatus for Green's functions of AE events on the fault

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Many efforts have been made to narrow down the mechanism of growth of the dynamic earthquake ruptures. Observations, laboratory experiments and numerical modeling show the potential mechanisms can be either pre-slip model, where the rupture is nucleated following aseismic slip around the hypocenter, or cascade model, where the failure of a patch sequentially trigger the rupture on a larger patch [e.g. Ellsworth and Beroza, 1995]. The characteristics of seismic events associated with the dynamic ruptures during stick-slip experiments are thus of great interest to investigate the hypothetical rupture nucleation processes.

As the meter-scale experiments help bridge the scale gap to natural earthquakes, National Research Institute for Earth Science and Disaster Resilience (NIED) installed the biaxial friction apparatus, which comprises a pair of metagabbro rock specimens, whose simulated fault area is 4.0m x 0.1m. Our aim is to improve the spatiotemporal resolution of monitoring the nucleation phase and rupture propagation on the simulated fault.

The source parameters such as seismic moment and stress drop associated with acoustic emissions (AEs) during stick-slip experiments are inferred from the spectrum of AEs [McLaskey et al., 2015; Marty, 2020, PhD thesis] or the fitting of synthetic seismograms [McLaskey et al., 2014]. As the numerical model of wave propagation using the rock specimens accounts for all phases of direct, reflected and refracted waves with radiation patterns, which could improve the estimation of source parameters, we perform the 3D numerical modeling of wave propagation towards computing the synthetic Green’s functions used to investigate the source parameters of AEs and rupture dynamics.

In this study, we show the modeling of wave propagation for the case of ball-drop test to calibrate our numerical setup on the friction apparatus. We use a steel ball with a diameter of 3 mm as a source. The ball is dropped onto the simulated fault surface of the bottom block from the height of 500mm to cause the wave radiation with the predetermined source locations. The source characteristics are described based on Hertzian theory, which provides an analytical form of source time function associated with the impact of ball-drop on the surface. Thus, the waveforms recorded at the broadband AE sensors (Olympus V103-RM) attached on the side surfaces of the bottom block orthogonal to the simulated fault plane can be synthesized using the analytical source time function and elastic properties of the medium inferred from the independent measurements [Fukuyama et al., 2016]. We use FDM-based software OpenSWPC [Maeda et al., 2017] to compute the wave propagation through the rock block.

The synthetic waveforms and the recorded waves with band-pass filtering between 10kHz and 400kHz are in good agreement of the polarities in early part of signals and are consistent with phase arrivals of Rayleigh waves. The AE sensors whose distance from the ball-drop source within ~400 mm show higher correlations between the synthetic and observed waveforms, which has a potential to determine the source characteristics, while the rest of sensors shows discrepancy due to insufficient S/N ratio of the observed waveforms. We also perform the simulations with random medium to evaluate the effect of velocity fluctuation of rock block on the recoded waveforms.

This work contributes to calibrate the numerical setup for the modeling of wave propagation through the rock blocks. Further work includes the calculation of Green’s function feasible to estimate the source time function associated with AEs, which is used to investigate the nucleation mechanisms and the energy budget accounting for the radiated and dissipated energies of the events on the simulated fault.

Keywords: friction experiments, large-scale laboratory experiments, simulation of wave propagation