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# 3D numerical simulation of seismic wavefield in inhomogeneous rock samples

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We focus on expanding the applicability of the transmitted waveforms obtained at laboratory experiments to examine detailed medium structure with the aid of novel numerical simulations. For this purpose, we investigate the feature of elastic waveforms in a centimeter class rock sample based on a 3D finite difference method (FDM) simulation. Previously, there were a few ways to approach the later phase of transmitted waveform in a rock sample because the propagation process of the reflected and converted waves generated in a finite-sized rock sample were not figured out. If analyses with entire waveform including the later phases will be possible, it should bring more detailed information on internal medium structure of rock samples.

First, we obtain transmitted waveforms in laboratory with cylindrical Westerly granite sample which horizontal to vertical ratio is 1 : 2. A source transducer is put on the center of the side surface and step voltage is applied to it. Vibration on sample surface is recorded as velocity waveform by laser Doppler vibrometer.

Next, we prepare the simulation model that covers the size of the rock sample. The volume is discretized into 512 x 512 x 1024 grids with an interval of 100 $\mu$m. Assuming proportional relationship with X-ray absorption coefficient obtained from micro focus X-ray CT images of the rock sample, we set the density (2.5 - 3.1 g/cm$^3$), P wave velocity (5.0 - 6.0 km/s), and S wave velocity (2.8 - 3.5 km/s) on each grid. Then, 3D FDM numerical simulation is performed with a single point force which is the same movement with the source transducer of the experiment. Band pass filter with a cut-off frequency of 50 kHz to 2 MHz is applied to the obtained waveforms.

The wavefield obtained from the simulation show that the reflected (PP, SS, PPP, and SSS) and converted (PS, SP, and PPS) waves are generated at the boundary of the sample. As time progresses, waves reflected at the side boundary return to the source area, and waves reflected at the top of the sample propagate through the sample at same time. Thus, we confirmed that waves trapped in the closed medium generate a very complicated shape of the later part of waveforms. Scattering and conversion at mineral grains are also observed due to the heterogeneity of medium, while they have only a limited effect on the simulated waveform in this case.

Radial component of measured and simulated waveforms recorded in the same horizontal plane at the source position are compared. Each phase shape in entire simulated waveform is matched with measured waveform. Two large amplitude phases observed in the measured waveforms are revealed as direct P wave and reflected SS wave from the simulated waveforms. Complex waveform shapes after the arrival of SS wave are indicated to as multiple reflected and converted S waves at the round boundary of the sample.

Keywords: transmitted wave, reflected wave, rock sample, numerical simulation