Numerical study on the onset of explosion earthquakes

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Vulcanian eruption is characterized by sudden ejection of volcanic fragments, excitation of shock wave, and explosion earthquake. Analysis of explosion earthquakes provides us important features to understand the source dynamics of Vulcanian eruptions. A number of previous studies reported that the polarity of the onset of explosion earthquakes is compressional at all stations (e.g., Minakami, 1960). The focal depth of explosion earthquakes is usually estimated at several km beneath the active vent (e.g., Imai, 1980). Observed waveforms of explosion earthquakes are explained by volume change (e.g., Tameguri et al., 2002) or vertical single force (e.g., Ohminato et al., 2006). However, the source mechanism obtained from inverse analysis of observed waveforms represents macroscopic force system at the source region. It is still challenging to infer the dynamics in the volcanic conduit from seismic analysis.

Magma fragmentation and ejection of volcanic material accompanying Vulcanian eruptions are often modeled by the shock tube theory (e.g., Woods , 1998). To obtain fundamental characteristics of explosion earthquakes, we examine displacement field induced by the shock tube problem in a vertical elastic pipe. We adopt OpenFOAM to calculate fluid-solid interaction (FSI). Since the original version of FSI solver in OpenFOAM(foam-extend 3.0) can handle incompressible flow only, we modify the solver to calculate the interaction between compressible flow and elastic media. For simplicity, the fluid in the elastic pipe is assumed as ideal gas. The elastic pipe has 20 m radius and 4 km length. The elastic media surrounding the pipe is set for 4 km from the pipe. The depth of a diaphragm of shock tube is assumed at the focal depth of explosion earthquakes at some volcanoes. We set the pressure difference at the diaphragm in the pipe referring estimated overpressure of Vulcanian eruptions by previous studies. In the pipe, high pressure region is assumed beneath the low pressure region as the initial condition.

The result of our numerical simulation shows that compressional displacement field is induced in the elastic media at the depth where the pressure in the pipe has increased. Contrary, dilatational displacement field is seen at the depth where the pressure in the pipe has decreased. The elastic wave propagates from fluid-solid boundary at the depth of the diaphragm. The polarity of the onset of elastic wave has a nodal plane about 30° upward from the horizontal plane. The elastic wave propagating above the nodal plane show the compressional polarity. Therefore, the displacement waveforms at the surface of elastic media near the pipe show the compressional onset. On the other hand, since the nodal plane across the ground surface, displacement waveforms at far side from the pipe have the dilatational onset. The pressure change in the pipe below the diaphragm (pressure decreasing) is almost twice of that above the diaphragm (pressure increasing). Therefore, the angle of the nodal plane of the polarity may reflect the pressure change in the pipe.

We compare the result of numerical simulation and features of explosion earthquakes at Lokon-Empung volcano (Yamada et al., 2016). Yamada et al. (2016) reported that the focal depth of explosion earthquakes is about 1 km beneath the active vent. The polarity of the onset of explosion earthquakes are compressional at all stations, ranging 1.7-6.9 km from the active vent. Our numerical simulation shows that the compressional onset is seen at the region near the pipe (< 1.5 km), assuming the diaphragm as 1 km beneath the surface. Contrary, the compressional onset cannot be seen at far side region (> 1.5 km) from the pipe. Therefore, it is suggested that additional source process has to be considered to reproduce the initial compressional wave at all stations. The ejection of volcanic fragments accompanying Vulcanian eruptions lasts only about several tens of seconds, Therefore, it is regarded that the fragmentation process of Vulcanian eruptions also has the same range of duration. Since the fluid in the pipe is assumed as ideal gas, the process that terminates the eruption is not considered in our numerical simulation. Taking into account this process will be valuable to examine the entire characteristics of observed waveforms.

Keywords: Vulcanian eruption, shock tube, OpenFOAM