A study on the radiation pattern for resonating fluid-filled crack

*Mare Yamamoto[1]

1. Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University

Volcanic earthquakes observed around active volcanoes often exhibit harmonic characteristics having multiple spectral peaks, and thus the oscillation of fluid inclusions beneath volcanoes have been considered as one of the most plausible source models of these signals. As examples of such resonator model, the resonance of fluid inclusions whose shapes are sphere, cylinder, and crack have been proposed and successfully applied to the analyses of observed signals to explain the spectral characteristics of volcanic earthquakes. In recent years, it becomes more common that we have dense seismic observation close to the source of volcanic earthquakes, and we often observe varieties of spectral shapes showing different amplitude pattern between spectral peaks and between stations. To utilize the amplitude information of observed spectral peaks, in this study, I model the radiation pattern for a resonating fluid-filled crack, and discuss about the possibility to estimate the orientation and size of the fluid-filled crack.

In this study, the radiation of elastic waves from a resonating thin fluid-filled crack in 3-D infinite medium is considered. First, I compute the oscillation of fluid-filled crack, and compute the wave radiation from the crack by numerically integrating the elastic waves generated by the tensile dislocation on the crack surface. By computing the energy at each direction, the radiation pattern is then obtained as a function of distance from the crack. Because Yamamoto and Kawakatsu (2008) showed that the distribution of the tensile dislocation on the crack surface can be described by small numbers of Chebyshev polynomials as far as we consider the low-frequency oscillation of the crack, for the sake of comparison, I also calculate the wave propagation using this analytical expression. If we consider only far-field compressional wave, the model setting is same as that discussed in Chouet (1986). In contrast, in this study, I use analytical Green’s function including both near- and far-field terms for P and S waves to study the radiation pattern for the resonating fluid-filled crack.

In the case of the crack containing hydrothermal fluids, which have rather large acoustic velocity contrast between inside and outside of the crack, the radiation pattern of each resonant mode becomes almost comparable to that obtained only with far-field compressional term at distance larger than about 50 times of the crack size. On the other hand, the radiation pattern in short distance range is severely distorted due to the contribution of near-field term and the interference of waves emitted from different point of the crack. In addition, there exists the difference between even- and odd-modes of the resonant mode. These results can be explained by considering the following mainly two points: the wavelength of radiated elastic waves is same order of the crack size, and thus the distant range in which the contribution of near-field term dominates is proportional to the wavelength of each resonant mode; the distribution of tensile dislocation have different symmetry for odd/even modes, and thus the effect of the interference of waves emitted from different point of crack surface depends on the direction, as already pointed out by Kumagai et al. (2002). It also becomes clear that there exists the distant dependency of amplitude ratio between resonant modes.

These results indicate the possibility to estimate the orientation and size of fluid-filled crack beneath volcanoes by observing amplitude ratio between stations and between spectral peaks. Because the spectral amplitude ignoring phase information is less affected by the wave scattering caused by small-scale heterogeneity in shallow volcanic edifice compared to the waveform itself, the methodology has an advantage in practical data analyses. These results also suggest the importance of near-field dense observation to understand the detailed source mechanism and source process of volcanic earthquakes.

Keywords: Volcanic earthquakes, Fluid-filled crack, Source mechanism