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A study on the oscillation of finite-length fluid-filled cracks

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To explain the observed properties of volcanic seismic signals, various models including resonator models with various geometries and flow induced oscillations have been proposed. Among these, one of the most standard source models of long-period events may be the fluid-filled crack model (e.g., Chouet, 1986). Chouet and his co-workers' studies demonstrated that many of the observed characteristics of long-period events can be well explained by the model. Furthermore, the possibilities to estimate the properties of fluid inside the crack and their temporal change from the observed seismic signals have also been discussed (e.g., Kumagai and Chouet, 2000). However, so far, the oscillation of finite-length fluid-filled cracks has been studied only by numerical methods like the finite-difference method (e.g., Chouet, 1986), the boundary integral method (Yamamoto and Kawakatsu, 2008), and the finite element method (Frechner et al., 2008), while analytical solutions for an infinite-length crack (e.g., Krauklis, 1962, Ferrazzini and Aki, 1987) and a 2-D ellipsoid (Yamamoto, 2007) have been derived. In this study, by feeding back the implications from numerical modeling into analytical consideration, we propose a simple method to obtain an approximate solution for the dynamics of finite-length fluid-filled cracks.

In this study, we consider a thin finite-length crack embedded in a 2-D infinite elastic medium. The crack is filled with an inviscid fluid, and the thickness of the fluid-filled crack is assumed to be much smaller than its length. Under the assumption, the motion of fluid inside the crack can be treated as one-dimensional one, and the distribution of normal dislocation of the crack surface can be well expressed by a series of Chebychev polynomials of the second kind with a weight depending on the position along the crack. Here, it is noted that among the series of polynomials, only the polynomials of low-degree are sufficient to expand the low-order modes of crack oscillation as demonstrated by Yamamoto and Kawakatsu (2008). The fact corresponds to the result of Spence and Turcotte (1985), who showed that the static normal dislocations due to uniform and linearly-varying changes in fluid pressure are expressed by the zeroth- and first-degree Chebychev polynomials, respectively. On the other hand, once we have an expression for distribution of the normal dislocation, we can analytically compute the motion of the fluid. In addition, using the obtained fluid motion in normal and along-crack directions, we can compute the effective bulk modulus of the fluid using the method of Yamamura (1997) and corresponding eigen oscillation of the fluid-filled crack.

For the fundamental mode of the oscillation of a fluid-filled crack, we can evaluate the effective bulk modulus using only the first-degree Chebychev polynomial, because the contribution of the first-degree polynomial to the dislocation distribution is about one order larger than those of higher-degree ones. The resultant effective bulk modulus is about half of that of the fluid, and the result is consistent with an empirical fact that the crack wave velocity corresponding to the fundamental mode is about half of the acoustic velocity of the fluid as pointed by the previous studies. For the higher modes, it is rather difficult to directly apply this method. However, considering that the crack wave velocity approaches to the fluid velocity in the limit of short wavelength, we can make a rough estimate from the result for the fundamental mode.

These results help us in understanding the physical basis of known empirical facts about the characteristics of dynamics of fluid-filled cracks, and at the same time, provide us an alternative efficient method to analyze observed volcanic seismic signals.

Keywords: fluid-filled crack, fluid-solid interaction, long-period event