Inversion of peak delay time of high frequency S-wave envelope to estimate medium inhomogeneity beneath the eastern Honshu, Japan

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High-frequency seismic waves impulsively radiated from a microearthquake are broadened as travel distance increases. This phenomenon is called as envelope broadening, and is known to be caused by multiple forward scattering and diffraction process due to medium inhomogeneities. A peak delay time of direct wave being measured from its onset is a good parameter reflecting such scattering effect since this measurement is unsusceptible to intrinsic attenuation. Recently, we found that peak delay times are relatively long for the ray paths propagating beneath Quaternary volcanoes in northeastern Honshu, Japan, which indicates an existence of strong inhomogeneities. In present study, we present an inversion of peak delay time of high frequency S-wave to characterize medium inhomogeneities.

According to the Markov approximation theory for envelope broadening, the peak delay time (tp) is a function of the power of travel distance (R) in uniformly inhomogeneous media, that is expressed by tp = B * R ^{A}. Coefficient B and exponent A are related to the parameters of inhomogeneities, such as fractional velocity fluctuation, correlation distance and spectral decay of velocity fluctuation. We use A and B as unknown parameters in our inversion. To formulate the inverse problem, we construct a method to evaluate peak delay time in non-uniformly inhomogeneous media as follows. When a seismic ray propagates through a medium having different inhomogeneities (named as medium-2) after traveling a certain distance in a medium (medium-1), we replace the travel distance in medium-1 to an equivalent travel distance which results in the same peak delay time in medium-2. By using the sum of this equivalent travel distance and a travel distance in medium-2, we calculate the peak delay time with the medium inhomogeneities of medium-2. This approach, in other words, replaces the ray propagation in medium-1 and -2 to that in medium-2. By using this procedure like a phase screen approach, we can evaluate the peak delay time at a receiver for any non-uniform inhomogeneous media. The validity of this approach is confirmed by Monte Carlo numerical simulations based on the Markov approximation.

We apply this approach to estimate the medium inhomogeneities beneath the eastern Honshu, Japan, by using genetic algorism in which the L2-norm of logarithmic peak delay time residuals is minimized. We analyze peak delay times in 2~4Hz, 4~8Hz, 8~16Hz and 16~32Hz frequency bands from S-wave envelopes. The number of peak delay time measurements for 4-frequency bands is 27,336. In this inversion analysis, we take into account the frequency dependence of peak delay time assuming spherically radiated waves in von Karman type random media. We divide the whole space into small blocks having a size of 0.2 degree x 0.2 degree in horizontal direction and 20km in depth. The number of unknown parameters is 5,606. To secure the stability of the inversion, we constraint the parameters in the fore-arc side based on those estimated by Saito et al. (2004). The results show that the volcanic front in the eastern Japan is imaged as strong heterogeneities as compared with those in the fore- and back-arc side. A volcanic group including Iwate volcano is imaged as relatively strong inhomogeneities than its surrounding area.