S157-007 Room: 303 Time: May 18 10:45-11:00

Synthesis of vector-wave envelopes for a non-spherical radiation source in a 3-D random medium

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High frequency seismic waves (over 1Hz) are strongly scattered in the inhomogeneous lithosphere. It is appropriate to neglect their phases and to use their envelopes for analyses. The Markov approximation is very effective to synthesize envelopes near the direct arrival, which is applicable to strong motion study and to the estimation of inhomogeneity of the earth. Synthesis of vector-wave envelopes based on the Markov approximation has been studied for an isotropic source. However, those for a non-spherical radiation source have been studied only by Sato and Korn (2005), who simulated 2-D spherical waves in random media by a Monte-Carlo method. In this study, we propose a method to synthesize the Markov approximation-based vector-wave envelopes for a non-spherical radiation source in a 3-D random medium using the stochastic ray path method (Williamson, 1972).

In the case that wavelength is much shorter than the correlation distance of an inhomogeneous medium, backward scattering and PS, SP conversions become negligible. Under such a condition, the ensemble average of the cross correlation function of the wavefield CCF at two locations on the transverse plain obeys a parabolic equation. In the wavenumber domain, the Fourier transform of CCF is called the angular spectral function ASF, which represents the distribution of ray angles for spherical waves. To consider evolution of the ASF with a hypocentral distance, we divide the medium around a point source into many spherical layers with a thickness dr. ASF at a distance r+dr is calculated by a convolution of the scattering angle distribution function Phi and ASF at a distance r. Here, Phi depends on the power spectral density function (PSDF) of the random medium and forward scattering is predominant in it. Therefore, we can calculate ASF at any distances by applying convolution on each layer boundary step by step. In this study, we shot energy particles from the source with the weight of the radiation pattern. The particles propagate through the medium with the mean velocity; V_P or V_S. At each layer boundary, we give a scattering angle following Phi by a Monte-Carlo method, where the propagation direction of energy particles is stochastically determined. At the outermost layer at which the receiver is located, we project the oscillation direction of the particle into three unit vectors. Calculating the travel time of each particle from the source to the outermost layer and make a histogram of travel times, we obtain the 3-component MS envelope.

We use a von-Karman type PSDF for an ensemble of random inhomogeneous media. We choose parameters characterizing the PSDF as follows: an rms amplitude of 0.05, a correlation distance of 5 km, and a role-off parameter of 0.5 at large wavenumbers. We carry out the simulation for a double-coupled source with the hypocentral distance of 100km and the central frequency of 10Hz. As the result, the radiation pattern is clearly visible near the direct arrival, however, it diminishes at 1.2 times of the S-wave travel time. The maximum amplitude of the RMS envelopes varies by azimuth by the factor of 2.4. The radiation pattern diminishes as the hypocentral distance increases, especially for high frequency envelopes. These characteristics of synthesized envelopes are consistent with those of observed seismograms of small earthquakes in short periods.