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Stochastic synthesis of vector wave envelopes in layered random media based on the improved Markov approximation

K. Emoto, H. Sato, and T. Nishimura
Tohoku University, Science, Geophysics, Japan (emoto@zisin.gp.tohoku.ac.jp)

Short-period seismograms show complex waveforms due to the scattering and the diffraction by small-scale heterogeneities in the earth medium. In such a case, stochastic methods are more useful rather than deterministic ones. When the wavelength is shorter than the correlation distance of the random medium heterogeneity, the Markov approximation, a stochastic extension of the phase screen method, is a powerful tool to synthesize vector wave envelopes especially around the onset to the peak value in a random medium. We may independently treat P and S wave envelopes disregarding conversion scattering. Solving the development of two-frequency mutual coherence function (TFMCF) of waves propagating in random media, we can calculate mean square (MS) envelopes as its Fourier transform. Though the waves are impulsive at the source radiation, MS envelopes are broadened with travel distance increasing. The envelope broadening is well characterized by the velocity inhomogeneity spectrum.

The angular spectrum, the Fourier transform of TFMCF with respect to transverse coordinates, represents the ray angle distribution of the intensities of scattered waves. We develop the Markov approximation using the angular spectrum in synthesizing the envelopes on the free surface of layered random media having step-like velocity discontinuities. For the vertical incidence of a plane wavelet, multiplying the angular spectrum by the transmission coefficient at each layer boundary, we connect TFMCF below and above the boundary and then solve the development of TFMCF in the above layer.

This method is applicable for a radiation from a point source, too.

We can treat the refraction and amplification at the layer boundary, and synthesize not only the transmitted and reflected wave envelopes but also the converted wave envelopes at the layer boundary.

We confirm the validity of our new method by comparing with finite difference (FD) calculations. We also examine the applicable condition of the Markov approximation in anisotropic random media from a comparison with FD calculations.

For the synthesis of vector wave envelopes, the conventional Markov approximation fails at large reduced times; however, we find that if we consider higher derivative terms of TFMCF, we can calculate accurate envelopes at large reduced times.

This Markov approximation is useful for the interpretation of S and ScS wave envelopes of a deep focus earthquake. The envelope broadening of ScS phase envelopes of M 5.2 earthquake observed by Hi-net in Japan is 2.84 s, which is a little larger than that of S phase envelope at 1 Hz. It means that the small-scale random velocity fluctuation in the lower mantle is much weaker than that in the lithosphere and the upper mantle since the travel distance of ScS phase is very large. Our preliminary result shows that the stochastic parameter of random heterogeneity in the mantle is one order of magnitude smaller than that of previous studies.