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Synthesis of vector-wave envelopes on the free surface on a random elastic medium: Markov approximation

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The apparent duration of observed seismogram of an earthquake is broadened with travel distance increasing because of scattering due to random velocity inhomogeneities in the solid earth. For the case of P waves, in addition to the broadening of the vertical component envelope, the excitation of transverse component is also found as the result of scattering. It is more appropriate to use stochastic methods for the ensemble of random media than deterministic methods to simulate the scattering contribution of small-scale inhomogeneities. When the wavelength is shorter than the correlation distance of the random media, the Markov approximation is very effective to calculate directly wave envelopes. This is a stochastic extension of the phase screen method focusing on scattering around the forward direction. When infinite random elastic media are characterized by a Gaussian autocorrelation function (ACF), vector-wave envelopes are well synthesized for the incidence of a plane impulsive wavelet (Sato, 2006). But we usually record seismograms on the ground surface. In this study, we propose the synthesis of vector-wave envelopes on the free surface of a random elastic medium based on the Markov approximation.

In the Markov approximation, we define the two-frequency mutual coherence function (TFMCF) on the transverse plane, which is perpendicular to the global ray direction. The Fourier transform of TFMCF with respect to difference angular frequency gives MS envelopes of vector components. The Fourier transform of the TFMCF with respect to transverse coordinates gives the angular spectrum, which shows the distribution of ray directions. Here, we interpret the angular spectrum as the distribution of incident angles to the free surface. In the case of the vertical incidence of a plane impulsive wavelet to infinite elastic media, we can calculate the MS envelopes of vertical and horizontal components by taking the projection of the angular spectrum to each component and transforming to the space domain. To obtain the MS envelopes on the free surface, we multiply the amplification factor corresponding to the incident angle to the angular spectrum obtained for infinite random media and transform it to the space domain, where the excitation of surface waves is neglected.

We first synthesize vector-wave envelopes in infinite 2-D random elastic media characterized by a Gaussian ACF for the incidence of an impulsive plane P and S wavelets at the depth of 100 km, where average P wave velocity 6.0 km/s, S wave velocity 3.46 km/s, MS fractional fluctuation of the velocity 5% and correlation distance 5 km. The time integration of the total MS envelope is normalized to one. We calculate the ratio of maximum peak values on the free surface to those in the infinite media. In the P wave case, the ratio of vertical component is 4.0 and that of horizontal component is 5.1. In the S wave case, the ratio of vertical components is 4.6 and that of horizontal component is 3.9. In the S wave case, the peak delay from the onset of vertical component on the free surface is 0.1s smaller than that in infinite media, but for horizontal and both components in the P wave case, there is little difference of the peak delay. Since the distribution of incident angles varies with time, the contribution of the free surface is not just a multiplication of factor two to the amplitude calculated in infinite media. As a result, the shape of each vector-component envelope is deformed caused by a free surface reflection.