修士論文

Synthesis of seismic-wave envelopes on the free surface of a random medium by using angular spectrum

（角度スペクトルを用いたランダム不均質媒質の自由表面における地震波エンベロープの導出）

東北大学大学院理学研究科
地球物理学専攻
江本　賢太郎
（指導教員　佐藤　春夫　教授）

平成 20 年

要旨

In short-period seismograms of earthquakes, we often observe the broadening of apparent duration of P- and/or S-waves and the excitation of the transverse component especially in P-waves as the travel distance increases. These phenomena are mathematically explained well by scattering caused by random velocity fluctuation in the lithosphere, where the wave propagation is statistically studied by introducing the concept of an ensemble of random media. The Markov approximation for the parabolic wave equation is known as one of the powerful statistical methods for the direct synthesis of vector-wave envelopes in random media when the wavelength is shorter than the correlation distance. Seismograms are usually recorded by seismometers installed on the free surface; however, past studies did not consider the affection of the free surface on seismogram envelopes but synthesized seismogram envelopes only in infinite random media. In the present study, we propose a method to synthesize vector-wave envelopes on the free surface of a random medium.

In the Markov approximation, we define a two frequency mutual coherence function (TFMCF) on the transverse plane as the correlation of wave field. We can solve the parabolic equation for TFMCF by neglecting backscattering. Mean square (MS) envelopes can be described by means of the inverse Fourier transform of TFMCF with respect to angular frequency. Taking the Fourier transform of TFMCF with respect to the transverse coordinates, we obtain the angular spectrum. The angular spectrum shows the distribution of ray angles. In the infinite media, each component of vector-wave MS envelopes is written as the integral of a product of the angular spectrum and a projection factor in the transverse wavenumber space. This angular spectrum has a sharp peak in the global ray direction just after the

direct wave arrival and it is gradually flattened with the increase of the lapse time. In order to obtain the vector-wave MS envelope on the free surface, we replace the projection factor with the amplification factor on the free surface of each component.

We precisely examined vector-wave MS envelopes on the free surface for the vertical incidence of an impulsive plane P-wavelet onto 3-D random media characterized by a Gaussian autocorrelation function (ACF) for the following typical parameters of the lithosphere: correlation distance $a = 5$ km, root mean square fractional velocity fluctuation $\varepsilon = 0.05$, averaged P-wave velocity $\alpha_0 = 6$ km/s, averaged S-wave velocity $\beta_0 = 3.46$ km/s and the propagation distance $Z = 100$ km. The results show that the vertical component MS envelope is amplified by a factor of 4 on the free surface at the peak amplitude and this amplification rate is nearly constant for different reduced times. On the other hand, the amplification rate of the horizontal component MS envelopes depends on the reduced time: 4.8 at the peak and gradually decreases with increase of the reduced time. Due to such time dependence of the amplification rate, the peak delay time of the horizontal component MS envelopes decrease 0.1 s from that in the infinite media.

We also synthesize the vector-wave MS envelopes on the free surface for the vertical incidence of an impulsive plane S-wavelet. The peak delay time slightly increases and the peak amplitude is 3.2 times larger than that in the infinite media for the horizontal component MS envelopes. For the vertical component MS envelope, the peak delay time is decreased 0.2 s and the peak amplitude is amplified by a factor of 4.6.

In order to confirm the validity of our method to synthesize the vector-wave envelopes on the free surface, we conduct finite difference (FD) simulations in 2-D random media for the vertical incidence of a plane P-wavelet. Using the same procedure as used in the 3-D case, we can derive the vector-wave envelopes on the free surface of 2-D random media based on the Markov approximation. From a comparison of the vector-wave MS envelopes derived by the Markov approximation and FD simulations, we find a good coincidence between them.

We first succeeded in the synthesis of vector-wave MS envelopes on the free surface of random elastic media characterized by a Gaussian ACF for the vertical incidence of a plane wavelet. This theory gives a solid mathematical base for the practical analysis of teleseismic waves for the spectral structure study of random velocity inhomogeneities in the lithosphere. Furthermore, we need to study the case of oblique incidence. For more precise estimation of the lithospheric heterogeneity, it is necessary to extend our method for more realistic random media such as von Karman type random media whose power spectral density function obeys a power-law.