Effective average wave-velocity in 2-D anisotropic random media: Formulation using the Rytov method

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The ray theory, which is derived under the high-frequency limit of waves, predicts that travel times are independent of wave frequency. On the other hand, wave theoretical approach predicts that wave scattering in inhomogeneous media changes according to wave frequency; the scattering distorts wavefield including its initial phase. Hence, when we consider an effective average velocity Veff as the ratio of a travel distance to average travel-time of the initial phases in inhomogeneous media, the effective average velocity should depend on the frequency and differ from volume-average velocity Vo. Shapiro et al. [1996] theoretically derived the effective average velocity in the isotropic random media, where velocity is randomly and isotropically distributed in space, by using the Rytov method which assumes dominant forward scattering of waves. They showed that the effective average velocity Veff is faster than the volume-average velocity Vo and increases with increasing frequency and travel distance when wavelength is smaller than a characteristic scale of the inhomogeneity. Since their formulation is limited to the isotropic inhomogeneity, it is not realistic enough to model subsurface inhomogeneity. The present study formulates the effective average velocity in 2-D anisotropic random media by using the Rytov method.

Let us consider scalar plane-wave incidence into 2-D random media where velocity is randomly distributed in space with the volume-average velocity Vo. Stations located at a travel distance, which constitute a line array perpendicular to the global ray direction, observe wave traces. Even though all the stations are located at the same travel distance, the onset of the initial phase is different from station to station due to the inhomogeneous velocity structure. The effective average velocity Veff is defined as the ratio of the travel distance to the average travel-time. We consider anisotropic random media that are parameterized by horizontal- and vertical- correlation distances and the RMS value of the fractional velocity fluctuation. Extending the method of Shapiro et al. [1996], we theoretically derive the effective average wave-velocity in 2-D anisotropic media on the basis of the small-angle (forward) scattering approximation; the small-angle scattering dominates over large-angle (backward) scattering when wavelength is smaller than the correlation distances. The effective average velocity depends on the two correlation distances, the RMS value of the fractional velocity fluctuation, the frequency, the travel distance, and the travel direction. Especially, an analytic solution is derived when random media are characterized by a Gaussian auto-correlation function. The effective average velocity increases with increasing frequency as in the case of isotropic random media. Additionally, wave propagates faster along the direction of long correlation distance than the direction of a short correlation distance in anisotropic random media. To confirm the reliability of the theoretical derivation, we numerically simulate wave propagation with the finite difference method. We can see that waves propagate faster along the direction of long correlation distance, although the values of effective average velocity from the numerical simulations are unstable due to the large fluctuation of the onset.

This study indicates that the anisotropic random inhomogeneity results in both the inverse dispersion of seismic wave and the seismic-velocity anisotropy.