A generic formulation for microtremor exploration methods using three-component records from a circular array

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SUMMARY
We present a generic formulation for analysis methods that estimate phase velocities of Rayleigh and Love waves, by way of intermediary quantities called ‘spectral ratios’, using three-component records of microtremors from a circular array of sensors. At each time instant, the set of records are expanded in a Fourier series with respect to azimuth, so that we obtain a set of Fourier coefficients that are represented in the form of complex time histories. We then estimate power- and cross-spectral densities of those Fourier coefficients. The spectral densities, thus obtained, generally contain information on the phase velocities, powers and arrival directions of individual modes of Rayleigh and Love waves. By taking the quotient of two different sorts of such spectral densities, we can cancel out information on their powers and arrival directions, and extract information on their phase velocities alone. The spectral ratios have to be estimated, in practice, on the basis of records from a finite number of seismic sensors that are either evenly or unevenly spaced around a circumference. We describe a general procedure for their estimation, and discuss the effects of directional aliasing that the finite number of sensors and their configuration have on the estimates of spectral ratios. We also discuss biases in the estimates of spectral ratios caused by the presence of incoherent noise. By using our method, it is also possible to estimate the central arrival direction of the microtremors, the ellipticity of the Rayleigh waves, and whether the Rayleigh waves are prograde or retrograde.

Key words: exploration seismology, Love waves, microtremors, Rayleigh waves, seismic array, surface waves.

1 INTRODUCTION

The phase velocity dispersion curve of surface waves constituting microtremors (ambient vibrations) gives useful constraints on the estimation of subsurface velocity structures (e.g. Liaw & McEvilly 1979; Asten & Henstridge 1984; Horike 1985). Among the most popularly used tools for the estimation of phase velocities of surface waves is the frequency–wavenumber spectral method (Capon et al. 1967; Capon 1969) that decomposes a given wavefield in the frequency–wavenumber domain and identifies the powers of individual wave components. When using the frequency–wavenumber spectral method, we have to take notice of different constraints on the seismic array design to improve the spatial resolution. Asten & Henstridge (1984) stated, for example, that the array diameter should be as large as the longest wavelength of interest to give adequate resolution in long wavelength ranges.

Aki (1957) proposed a completely different approach to estimate phase velocities of surface waves. In his approach, the whole information on the wavefield in question is integrated into a single quantity, which is called the azimuthal average of the spatial autocorrelation function. This quantity contains information on the phase velocities of the waves alone; information on other attributes of the waves, such as their powers and arrival directions, is canceled out in the process of its derivation. The array design is subject to no constraint relevant to the resolving power, because this algorithm contains no procedure to resolve individual plane wave components. Cho et al. (2004). However, Aki (1957) presented his theory in two separate formulations, one relevant to the vertical motion alone and the other relevant to the horizontal motion alone, and he did not presuppose cases where both components are present. His formulation for the horizontal motion is again presented in separate ways for waves of Rayleigh-like polarization and for waves of Love-like polarization, and thus is not applicable to cases where both types of waves are present.