Beyond the SPAC Method: Exploiting the Wealth of Circular-Array Methods for Microtremor Exploration

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Abstract  We explore the wealth of alternative methods for inferring phase velocities of Rayleigh waves using vertical-component seismograms of microtremors from a circular array of seismic sensors, which are formulable along the extension of the popularly used spatial autocorrelation (SPAC) method. Four such methods are illustrated here: the centerless circular-array (CCA) method, the Henstridge methods of the zeroth and first orders (the H0 and H1 methods, respectively), and what we tentatively call the fifth (V) method.

Different methods of phase velocity estimation have different wavelength ranges of good resolution. Implementation to field data from two sites reveals that the traditional SPAC method and the H0 method are both capable of producing reasonable estimates of Rayleigh-wave phase velocities within a relatively narrow range on the short-wavelength side, whereas the H1 method is valid in a relatively narrow range on the long-wavelength side. The CCA and V methods both remain valid over a very broad range of wavelengths, the upper limit extending as far up as several 10s of times the array radius. Use of a noise-compensation technique can further prolong the maximum resolvable wavelength of the CCA method.

We also illustrate the field performance of circle phase methods, which give, without recourse to the conventional frequency-wavenumber analysis, estimates for the principal arrival directions of Rayleigh waves on the basis of circular-array seismograms of microtremors.

Introduction

The spatial autocorrelation (SPAC) method, first presented by Aki (1957), is a technique of geophysical exploration that is popularly used to infer phase velocities of surface (Rayleigh and Love) waves using records of microtremors (ambient vibrations) from a circular array of seismic sensors deployed on the ground surface (e.g., Ferrazzini et al., 1991; Métais et al., 1997; Chouet et al., 1998; Saccorotti et al., 2003). Most typically, the SPAC method requires an odd number of seismic sensors, placed at equal azimuthal intervals around a circle, plus another at its center. In recent years, the SPAC method has attracted increasing attention in the research community, as is evident in the growing quantity of literature written on the subject (e.g., Morikawa et al., 2004; Roberts and Asten, 2004; Chávez-García and Luzón, 2005; Chávez-García et al., 2005; Roberts and Asten, 2005; Wathelet et al., 2005; Asten, 2006; Chávez-García et al., 2006; Maresca et al., 2006; Okada, 2006; Shiraishi et al., 2006; Chávez-García, Domínguez, et al., 2007, Chávez-García, Luzón, et al., 2007; Köhler et al., 2007).

Cho et al. (2006a) cast, in the wake of Henstridge (1979), a new light on the theoretical rationale of the SPAC method and developed on its basis a new comprehensive theoretical framework for circular-array methods of microtremor exploration, which is so general in nature that it encompasses both Aki’s (1957) and Henstridge’s (1979) formulations as special cases. They showed that, using their theory, it was possible to devise a number of new circular-array methods to infer surface-wave phase velocities. Their article, however, focused on describing mathematical aspects of the theory, and the scrutiny of more practical aspects, related to the field implementation of those new methods, was postponed to later publications.

The centerless circular-array (CCA) method, thoroughly described and tested by Cho et al. (2006b), is one concrete realization of Cho et al.’s (2006a) general theory that is distinct from the traditional SPAC method. The CCA method uses vertical-motion records of microtremors, obtained at different locations around a single circle (no center station needed), to evaluate phase velocities of Rayleigh waves. Field tests have demonstrated that, even with just three equidistant sensors, the CCA method has the potential to produce accurate estimates of phase velocities up to wavelengths as large as several 10 times the array radius (Cho et al., 2004, 2006b,c). The two-radius circular-array method (Tada...