New Circular-Array Microtremor Techniques to Infer Love-Wave Phase Velocities

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Abstract We present simple and novel formulas that help to directly infer phase velocities of Love waves \( c_L \) using two-component, horizontal-motion, circular-array records of microtremors. Our formulas are analogous to those of the spatial autocorrelation (SPAC) method, a technique of microtremor exploration that is popularly used to infer phase velocities of Rayleigh waves \( c_R \). Although the existing theory of the SPAC method does provide the possibility to estimate \( c_L \), this can only be done by solving a nonlinear system of equations, wherein the unknowns to be solved for also include \( c_R \) and the Rayleigh-to-Love power partition ratios. By contrast, \( c_L \) is the only unknown to appear in our formulas.

The field applicability of the \( c_L \) estimation methods based on the proposed formulas—which we name the SPAC + \( L \), SPAC − \( L \), and CCA − \( L \) (where CCA stands for centerless circular array) methods—is demonstrated by analysis results for two test sites. Among the three techniques proposed, the SPAC + \( L \) method distinguished itself as the best-performing. The valid wavelength ranges of the three methods had lower limits in the area of 2–5 times the array radius \( r \) and upper limits in the area of 10–25\( r \).

Similar circular-array microtremor techniques that involve \( c_L \) alone were proposed in recent years, but the methods we present here are either logistically less expensive or mathematically simpler than any of them.

Introduction

In the field of geophysical exploration, extensive use has been made of passive-seismic methods using microtremors (also known as ambient vibrations, ambient noise, or seismic noise), as they provide inexpensive means to infer the properties of surface waves. The single-station method, based on the interpretation of horizontal-to-vertical spectral ratios (Nakamura, 1989), is widely used in site effect studies. When the focus is on elucidating subsurface soil structures, however, it is more common to rely on array methods, such as the frequency–wavenumber (f–k) spectral method (Capon, 1969) and the spatial autocorrelation (SPAC) method (Aki, 1957). Both these methods produce estimates of the phase velocities of surface waves (Rayleigh and Love waves), and their dispersion curve, or the graph showing how they vary with frequency, can be used to invert subsurface structures.

The f–k method allows much liberty in the seismic array design, but the SPAC method is characterized by a fairly rigorous constraint on the array geometry. To be most faithful to the original theory, the SPAC array should consist of seismic sensors, placed equidistantly around a circle, plus another at its center. Meanwhile, the latest years have seen substantial refinement in the SPAC technique, in both theory and practical methodology (e.g., Morikawa et al., 2004; Chávez-García and Luzón, 2005; Chávez-García et al., 2005; Wathelet et al., 2005; Asten, 2006; Cho et al., 2006a,b; Okada, 2006; Chávez-García and Rodríguez, 2007; Tada et al., 2007; Cho et al., 2008a,b; Roberts and Asten, 2008; Yokoi and Margaryan, 2008). Its scope of application has also expanded beyond the traditional limit of circular-array geometry (e.g., Bettig et al., 2001; Ohori et al., 2002; Chávez-García et al., 2006; Maresca et al., 2006; Chávez-García, Domínguez, et al., 2007; Chávez-García, Luzón, et al., 2007; Köhler et al., 2007; Parolai et al., 2007).

Most commonly, the SPAC method is used to infer phase velocities of Rayleigh waves \( c_R \) on the basis of vertical-motion records alone. When horizontal-motion seismograms are available, the SPAC method also provides the possibility to infer phase velocities of Love waves \( c_L \), which should provide useful, additional constraints on the subsurface soil structure. A basic methodology for estimating \( c_L \) is described in the original SPAC theory by Aki (1957). His article, however, treated Love waves separately from the field of Rayleigh waves and did not demonstrate how \( c_L \) could be inferred in the realistic situation in which both types of waves are present.