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The SPAC+L method: Direct estimation of Love-wave phase velocities using circular-array records of horizontal-motion microtremors

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We have derived a new technique of geophysical exploration that allows one to directly infer phase velocities of Love waves (c^L) using two-component, horizontal-motion, circular-array records of microtremors (also known as ambient vibrations, ambient noise, or seismic noise). We refer to our new technique as the SPAC+L method, because its basic formula was derived as an extension of the SPAC method (Aki, 1957), a popular technique of microtremor exploration using circular arrays (the symbol +L is short for Love waves).

Most commonly, the SPAC method is used to infer phase velocities of Rayleigh waves (c^R) on the basis of vertical-motion data alone. When three-component records are available, it also provides the possibility to infer c^L, a useful, additional constraint on the subsurface soil structure (e.g. Okada and Matsushima, 1989; Ferrazzini et al., 1991). In the three-component SPAC method, however, the c^L values have to be inferred as part of the solution of a nonlinear system of equations, in which the unknowns to be solved for also include c^R and the Rayleigh-to-Love (R/L) power partition ratios.

In the SPAC+L method, by contrast, c^L is the only unknown to appear in the basic equation. All we need as the input is the two-component, horizontal-motion records of microtremors around a circle of radius r and at its center.

The formula of the SPAC+L method states:

G_{R1T0}(r,r;omega) / G_{R1T0}(0,r;omega) = (J_0+J_2)(r omega/c^L(omega)).

The quantity on the left-hand side is called the spectral ratio, and is defined as the quotient of two different sorts of cross-spectral densities, both of which are calculable from the radial (R)- and tangential (T)-component records of the circular array (the notations follow that of Cho et al., 2006). On the right-hand side, J_0 and J_2 are the zeroth- and second-order Bessel functions of the first kind. Omega denotes the frequency. Once the spectral ratio on the left-hand side is known from field measurement records, it is quite straightforward to infer c^L by simple inversion.

We have tested the practical utility of the SPAC+L method by applying it to field data from two sites in the broader Tokyo region. The method produced reasonable estimates of c^L in a wide range of wavelengths, the lower limits lying in the area of 2-5 times the array radius r and the upper limits in the area of 10-25 times r.

Extension of the SPAC method's theory also produces two analogous methods of direct c^L estimation, which we have named the SPAC-L and CCA-L methods, respectively. Application to the field data suggest that they have slightly narrower wavelength ranges of validity than the SPAC+L method.

Similar circular-array microtremor methods, which allows direct estimation of c^L, were conceived by other authors and by ourselves in the recent past. However, the SPAC+L method is superior to the double-circle methods of Tada et al. [2006] and Garcia-Jerez et al. [2008a] because of its lower logistical costs (fewer numbers of seismic stations needed), and is also mathematically much simpler than the 'SCAM' technique of Garcia-Jerez et al. [2008b].

Using further theoretical ramifications of the SPAC+L method, we have also derived formulae that allow one to directly infer c^R and the R/L power partition ratios using two-component, horizontal-motion, circular-array records of microtremors.