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Sophistication of microtremor methods to survey shallow structures, PartI: Development of automatic reading algorithms

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We have been seeking an efficient way to maximize the potential of the microtremor methods for shallow surveys. It is considered that a practical approach has been gained in the observation by the development of portable seismometers (Senna, 2006, 2012) and by the finding of the full usability of the data obtained by a miniature array (radius $<$1 m), optionally together with a small irregular-shaped array (radius less than 10 m) consisting of three seismometers (Cho et al., 2013a).

As an efficient way to infer an S-wave velocity structure, we consider that a classical, simple profiling method (SPM), where a dispersion curve is directly converted into an S-wave velocity structure (e.g., Heukelom and Foster, 1960), is a good scheme from a view point of simplicity, thus, the balance between the efforts and the information to be extracted. It is true, however, that we frequently like to increase to resolution. Facing this dilemma, we suggested a simple tool "H/V depth conversion" (Cho et al., 2013). We found that the use of an H/V depth conversion followed by a simplified inversion method (SIM) of Pelekis and Athanasopoulos (2011) can in fact increase the resolutions (e.g., Senna et al., 2013; Yoshida et al., 2013).

The current problem is to further promote the efficiency in the data processing procedure. A visual reading of analysis results, which we take at the current time, is time consuming to deal with a vast mount of microtremor data, now obtainable by a streamlined observational procedure. The reproducibility and biases constitute other kinds of problem of visual reading.

To address this problem, we invented the following automatic-reading algorithms. We applied them to observed data consisting of multiple arrays along a measurement line. As the results, natural images of two-dimensional S-wave velocity sections were obtained, not considerably different from the one obtained by visual readings (Senna et al., 2014).

Automatic readings of phase velocities

Let us suppose that multiple dispersion curves have been obtained by either multiple arrays or multiple analysis methods (i.e., nc-CCA, CCA, and SPAC methods) at a single observation point. In the first step, apply the following procedure to each dispersion curve. (i) Divide the frequency range used for analyses into equally-spaced intervals (bins) in a logarithmic scale. Take an average of phase-velocity data in each bin. (ii) Exclude the results from the analyses either when the wavelengths relative to an array radius lie out of the range defined a-priori for each method or when they exceeds the analysis limits having been evaluated by the use of an array with a sensor at the center point. Also, exclude the results when they seem to align in a line passing through the origin.

An automatic reading is obtained for each bin by averaging all values left after the procedure (ii). Readings are deleted, however, when they seem to align in a line passing through the origin.

Automatic readings of peak and troughs of an H/V spectrum

First, an H/V spectrum obtained at a single observation point, or an average spectrum if there are multiple spectra as a representative value, is smoothed using a spectral windows having a frequency-dependent window width. Peaks and troughs of the spectrum are searched from the lower side of the frequency range by using the derivatives. We search pairs of a peak and a trough to stabilize the analysis result: A pair is excluded from the reading results when the difference in either frequency or H/V ratio between a peak and trough is smaller than a threshold. Also, a pair is excluded when a peak (trough) value is smaller than that of an anterior peak (trough). The peak and trough of each pair, thus obtained, are used for the depth conversion, and the resulting depths are averaged to be the representative depth obtained by an automatic reading.

Keywords: Microtremor, velocity structure, surface waves, phase velocity, expolation method, array

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