New methods of microtremor exploration using circular seismic arrays: Implementation to records from miniature arrays

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The spatial autocorrelation (SPAC) method is a technique of geophysical exploration that is popularly used to infer phase velocities of Rayleigh waves on the basis of records of microtremors from a circular array of seismic sensors deployed on the ground surface. Recently, Cho et al. (2006a), in the wake of Henstridge's (1979) theory, reinterpreted the basic rationale of the SPAC method, and demonstrated that a variety of other circular-array methods were conceivable within the same theoretical framework. Among all conceivable alternatives, the "centerless circular array (CCA) method," which allows to infer phase velocities of Rayleigh waves, has been discussed in depth by Cho et al. (2006b). The present study illustrates the performance of numerous other circular-array techniques of microtremor exploration, in addition to the CCA method, in their implementation to field data.

Apart from the (1) CCA method, we deal, in the present study, with three more methods to infer phase velocities of Rayleigh waves which we tentatively call the (2) H0, (3) H1 and (4) V methods; their variants called the (1b) noise-compensated CCA and (4b) noise-compensated V methods, both with enhanced resolution in long-wavelength ranges; and two methods to infer principal arrival directions of Rayleigh waves which we call (5) Henstridge's circle phase method and the (6) CCA circle phase method.

Preliminary examinations have revealed that some out of the six new methods of phase velocity identification may possibly retain high resolution up to far longer wavelengths than the traditional SPAC method. If this holds true for very small seismic arrays with radii on the order of just one meter or so, it logically follows that measurements with such "miniature arrays" may suffice to infer subsurface soil structures up to several ten to several hundred meters in depth, which could prompt a radical progress in microtremor exploration researches in general.

In October 2006, we deployed, in Kasukabe, miniature circular arrays with radii ranging between 0.3 and 2.5 meters, and analyzed the seismograms with the SPAC and the six new methods of microtremor exploration to infer phase velocities of Rayleigh waves. The estimates were then checked against theoretical dispersion curves calculated on the basis of existing PS-logging data. With the SPAC and the (2) H0 methods, reasonable estimates of phase velocities were obtained only up to wavelengths 30-50 times as long as the array radius, and they sometimes failed to be obtained with enough stability. With the (1) CCA and the (4) V methods, in contrast, reasonable estimates were obtained stably in all cases examined, and they continued to persist up to wavelengths as long as 40-220 times the array radius. The maximum resolvable wavelengths of the (1b) noise-compensated CCA and the (4b) noise-compensated V methods amounted to 60-270 times the array radius, well above the resolution limits for their non-compensated counterparts. The (3) H1 method tends to be relatively weak in short-wavelength ranges, but in the cases we have examined, it proved about as competent, in long-wavelength ranges, as the (1) CCA and the (4) V methods.

We focussed special attention on the (1) CCA and the (1b) noise-compensated CCA methods, and applied them to microtremor seismograms from miniature circular arrays of radii 0.3-2.5 meters, which we deployed at two sites in the Tokyo metropolitan district in 2006. The two methods did produce reasonable estimates of phase velocities of Rayleigh waves up to very long wavelengths, amounting to 110-200 times and 110-290 times the array radius, respectively.

At different measurement sites, (5) Henstridge's and the (6) CCA circle phase methods produced estimates for the principal arrival directions of Rayleigh waves which were mostly compatible with the azimuths of major traffic vibration sources located in the neighborhood.