Multi-mode phase speed measurements of surface waves with array-based analysis

*Hitoshi Matsuzawa[1], Kazunori Yoshizawa[1,2]

1. Graduate School of Science, Hokkaido University, 2. Faculty of Science, Hokkaido University

Recent deployment of dense broadband seismic networks, such as USArray in the United States, leads to the construction of improved 3-D upper mantle models with unprecedented horizontal resolution using surface waves, although many of such dispersion measurements have been primarily based on the analysis of fundamental mode. Higher-mode information can be of great help in the further improvement of the vertical resolution of 3-D models, but their phase speed analysis is intrinsically difficult, since wave trains of several modes are overlapped each other in an observed seismogram. In case of Love waves, even the fundamental mode tends be overlapped with higher modes, which result in larger uncertainties in the phase speed measurements of the fundamental-mode Love waves than those of Rayleigh waves. Modal separation is not a straightforward issue because several higher-modes share similar group speeds, but it can be done by utilizing a dense seismic array. In this study, we develop an efficient method for measuring the phase speeds of the fundamental- and higher-mode surface waves based on an array-based analysis, and demonstrate its utility through extensive synthetic experiments and its application to USArray.

Our array-based analysis of multi-mode dispersion measurements is modeled on a one-dimensional frequency-wavenumber method originally developed by Nolet (1975, GRL), which can be applied to broadband seismic records observed in a linear array along a great circle path. At first, proper seismic signals are extracted using varying group-speed windows and slant-stacked with a fixed wavenumber to generate a “beam”. Since the spectrum of this beam is a function of frequency *f*, phase speed *c* and group speed *U*, we can construct spectrograms in *c*-*U* domain for each *f*. After the reduction/removal of spurious spectral peaks by applying narrow wavenumber filter to the largest spectral peaks, the spectrograms in *c*-*U* domain are projected in a *c*-*f* domain, which eventually provides us with multi-mode dispersion curves.

Extensive sets of synthetic experiments suggest that the method works well for a long linear array with lateral extension of several thousand kilometers. Estimated dispersion curves in the period range between 20 and 150 seconds using a heterogeneous array (i.e., an irregularly distributed stations) reflect an average velocity structure beneath the centroid of the array. The dispersion curves are matched well with theoretical estimation from the average structure depending on the station configuration, especially in a period range with sufficiently strong excitation of each mode. In practical applications, the reliability and errors of measured phase speeds can be assessed by using the width of spectral peaks in a *c*-*f* plane. This array-based method of multi-mode phase speed measurement can be of help in the reconstruction of 3-D upper mantle structures with enhanced vertical resolution.

Keywords: surface waves, higher mode, seismic array, North America, USArray

