Application of Genetic Algorithm to the Analysis of Surface-wave Data Including Higher Modes

Koichi Hayashi

Geometrics

Analysis of surface wave data generally assumes that a dispersion curve mainly consists of a fundamental mode. Higher modes may dominate in several types of velocity structures, such as a model in which a high-velocity layer overlays on a low-velocity layer or a model in which a high-velocity layer is embedded in low-velocity layers. In these types of complex velocity structures, higher modes may dominate in particular frequency range and observed dispersion curves look very complex. It is generally difficult to separate fundamental and higher modes correctly and traditional inversion methods cannot be applied. In order to overcome these difficulties, we have developed a new inversion method using a genetic algorithm (GA). In this new method, phase velocities and relative amplitude for the fundamental and higher modes are calculated. For each frequency, residual between observed and theoretical phase velocities is defined as the difference of an observed phase velocity and a synthetic phase velocity that has maximum relative amplitude in all modes.

Fig.1 shows an example of waveforms and its phase velocity image in the frequency domain. The waveforms were recorded at an alluvium plain where a high-velocity thin layer overlays a low-velocity peat layer. In the phase-velocity image (Fig.1b), above 5 Hz, phase velocity increases as frequency increases. Phase velocities are discontinuous at frequencies above 10Hz. This type of dispersion curve cannot be explained by a fundamental mode of Rayleigh waves. Fig.2 shows an S-wave velocity

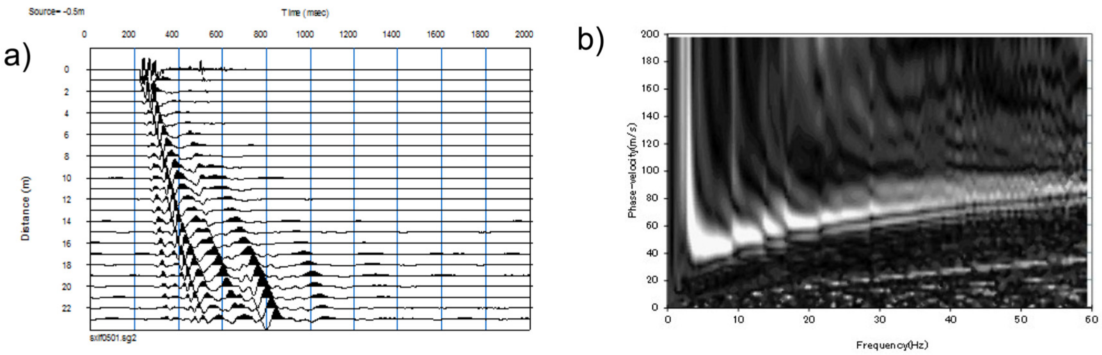

Fig.1. Observed waveform (a) and its phase velocity image (b).

(Vs) model that generate similar phase velocity image shown in Fig.1. Fig.3a shows theoretical waveforms for the model calculated by the discrete wave number method (DWM). Fig.3b shows a phase velocity image for these theoretical waveforms calculated by the multi-channel analysis of surface waves (MASW) method. DWM can calculate the full waveform including body waves using the same source-receiver configuration and we can consider these waveforms as exact replicates of observed data in terms of phase velocity and amplitude. We can see that the theoretical phase velocity image (Fig.3b) looks similar to the observed phase velocity image shown in Fig.1b.

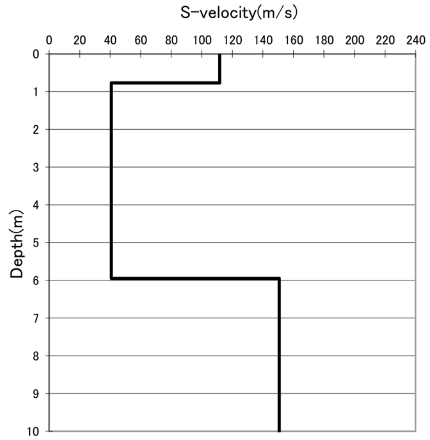

Fig.2. Velocity model estimated by try and error.

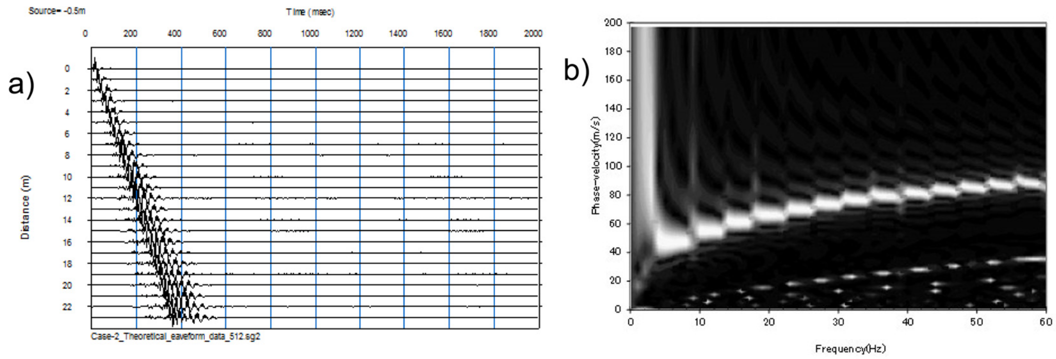

Fig.3. Theoretical waveform data (a) and its phase velocity image (b).

Complex dispersion curves as shown in Fig.1b cannot be explained by a fundamental mode of Rayleigh waves. We investigate these complex dispersion curves further in terms of a Normal Mode Solution (NMS), including higher modes, by solving a characteristic equation of Rayleigh waves. Both phase velocity and relative amplitude are calculated for each mode of Rayleigh waves by NMS. The NMS only takes into account surface waves and a source at infinity is assumed. Fig.4 shows fundamental and higher mode dispersion curves and their relative amplitude for the velocity models shown in Fig.2 with a phase velocity image for theoretical waveforms calculated by DWM. In Fig.4, solid lines and broken lines indicate dispersion curves and relative amplitudes respectively. White circles indicate phase velocities whose amplitude is maximum at each frequency. We see from this figure that observed dispersion curves can be explained as phase velocities whose amplitude is maximum at each frequency and discontinuity of dispersion curves is associated with transition from one mode to another mode.

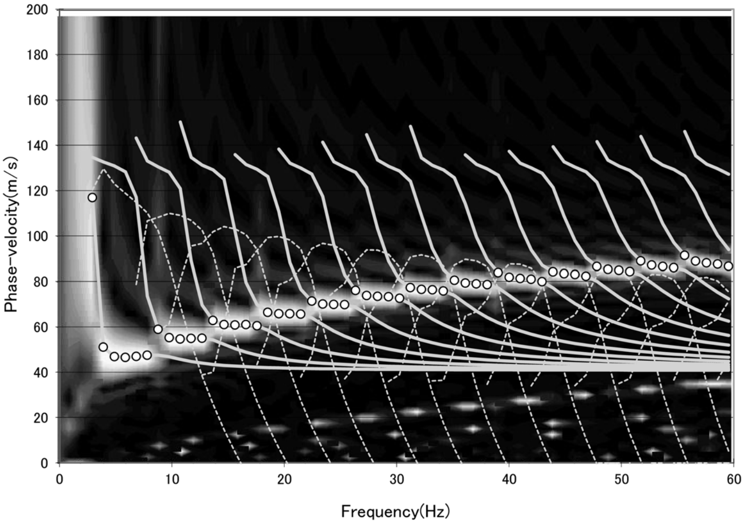

Fig.4. Fundamental and higher mode dispersion curves (solid lines) and their relative amplitude (broken lines) with a phase-velocity image of theoretical waveform calculated by the DWM.

In these complex velocity models, an observed dispersion curve can be considered as a series of phase velocities whose amplitude is maximum at each frequency and a conventional inversion based on the fundamental mode simply cannot be applied. We propose an alternative inversion that uses phase velocities with maximum amplitude at each frequency. In this method, maximum amplitude phase velocities are compared with observed phase velocities obtained through MASW. In our proposed method, observed data is defined as maximum amplitude phase velocity in each frequency of phase velocity image calculated by MASW. Observed phase velocities are compared with theoretical phase velocities defined as the maximum amplitude mode at each frequency calculated by NMS. A maximum

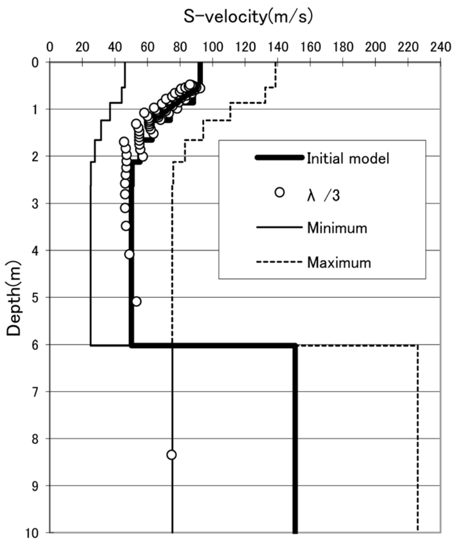

Fig.5. Initial S-wave velocity models and GA search areas.

amplitude mode can easily cross from one mode to another mode and the partial derivative cannot be calculated for theoretical phase velocities. Conventional inversion methods for dispersion curves generally use an iterative non-linear least squares method and calculation of partial derivatives is required. In order to estimate velocity models without the calculation of partial derivatives, we introduce a genetic algorithm (GA).

We combine the NMS with GA and apply them to numerical data. Dispersion curve shown in Fig.3 calculated by DWM are used as observed data. Fig.5 shows initial Vs models created by a simple wavelength transformation in which wavelength is calculated from phase velocity divided by frequency, then divided by three, and plotted at depth. Vs models are represented as 15 thin layers and the Vs of each layer is optimized by GA. The search area of Vs in GA is set to ±50% of the initial Vs. Fig.6a shows the velocity model that have a minimum residual and Fig.6b shows a comparison of observed (calculated by DWM) and theoretical (calculated by NMS) dispersion curves. Although the obtained velocity models are smoother compared with true models, we can see that almost true-velocity models are obtained and the residual between observed and theoretical dispersion curves is much smaller than the initial models.

This paper summarizes the character of Rayleigh wave higher modes and proposes an alternative inversion method for their handling. The result of numerical simulation shows that the proposed inversion enables us to apply surface wave methods to much complex geological situation.

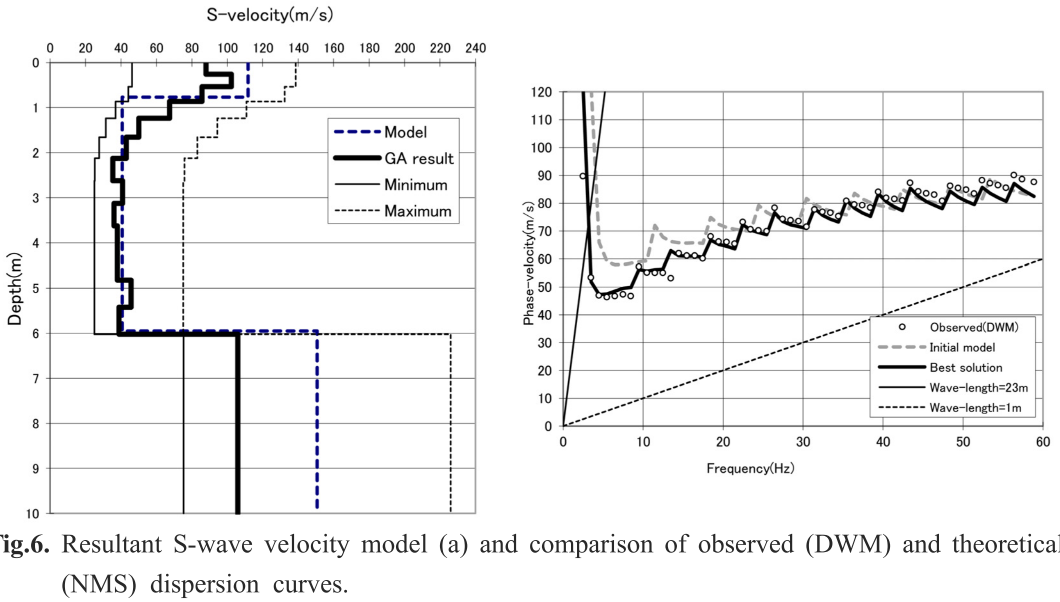

Fig.6. Resultant S-wave velocity model (a) and comparison of observed (DWM) and theoretical (NMS) dispersion curves.