INVERSION OF PHASE VELOCITIES OF SURFACE WAVES WITH HIGH MODES

Jianghai Xia, Richard D. Miller, and Choon B. Park
Kansas Geological Survey, Lawrence, Kansas, USA

Elastic properties of near-surface materials and their effects on seismic wave propagation are of fundamental interest in groundwater, engineering, and environmental studies. As an example, Imai and Tonouchi (1982) studied compressional (P) and shear (S) wave velocities in an embankment, and also in alluvial, diluvial, and Tertiary layers, showing that S-wave velocities (V_s) in such deposits correspond to the N-value ($V_s = 97.0 \times N^{0.314}$), an index value of formation hardness used in soil mechanics and foundation engineering. S-wave velocity is also used to determine "stiffness," one of the key earth properties in construction engineering. The S-wave velocity profile, a function of depth, can be derived from inverting the phase velocity of the surface (Rayleigh and/or Love) wave. The Rayleigh-wave phase velocity of a layered earth model is a function of frequency and four groups of earth parameters: P-wave velocity, S-wave velocity, density, and thickness of layers. Estimations of S-wave velocity from ground roll, a particular type of Rayleigh wave, have for the most part focused almost exclusively on the fundamental mode of Rayleigh waves. The technique developed to determine the shear wave velocity from the fundamental mode using multichannel recording consists of: 1) acquisition of wide band ground roll using a multichannel recording system; 2) creation of efficient and accurate algorithms to extract Rayleigh-wave dispersion curves from ground roll using a basic, robust, and pseudo-automated processing sequence (Park et al., 1999); and 3) development of stable and efficient inversion algorithms to obtain S-wave velocity profiles (Xia et al., 1999). This technique has also been successfully applied to map a bed rock interface and voids based on S-wave velocity anomalies (Miller et al., 1999). Empirically it has been shown that higher mode energy tends to become more dominant as the source-offset distance becomes larger. In some cases, the shorter wavelength components of the fundamental mode Rayleigh waves are obscured by more dominant higher modes of Rayleigh waves in a higher frequency range, making analysis of higher mode data essential.

Analysis of the Jacobian matrix for high frequencies (5-40 Hz) provides a measure of higher-mode dispersion curve sensitivity to earth model parameters. S-wave velocity is the dominant influence of the four earth model parameters in higher-mode dispersion curves. Modeling results demonstrate at least two unique and useful properties of higher modes. First, we know that the penetrating depth of surface waves is limited by a wavelength of a surface-wave component. For fundamental and higher mode Rayleigh wave data with the same wavelength, higher modes penetrate deeper (longer than the wavelength) than the fundamental mode (normally shorter than the wavelength). For the layer model (Xia et al., 1999), in order to "see" a depth of 17 m, a wavelength of 12.3 m is required for fundamental mode data. For the second-mode data, however, a component with a wavelength of 10.9 m can penetrate a depth of 17 m. For the third-mode data, a component with a wavelength of only 6 m can "see" a depth of 17 m. We concluded that high-mode Rayleigh-wave data can "see" deeper in comparison to the same wavelength components of the fundamental mode Rayleigh-wave data.

Second, an inversion with higher mode data increases the resolution of the inverted S-wave velocities. Figure 1 shows the difference in phase velocities calculated from two S-wave velocity models. Although one model contains more than 100% relative error at 6 m and 7 m, the standard deviation between the fundamental mode phase velocities from these two models is only 4.6 m/s. Thus, the inversion process will not guarantee to choose the true model at a 4.6 m/s error level. However, because the standard deviations are 33.5 m/s for the second mode (solid squares with a solid line in Figure 1) and 27.3 m/s for the third mode (solid triangles with a dashed line), an inversion with high-mode data will only be allowed to choose the true model so that a stabilized inversion is achieved and resolution is improved. The larger difference in higher modes suggests that higher modes are more sensitive to the changes in S-wave velocities than is the fundamental mode. Inverted S-wave velocity profiles of real world examples are comparable to direct borehole measurements showing improved resolution and accuracy of inverted S-wave velocity profiles using high-mode data.

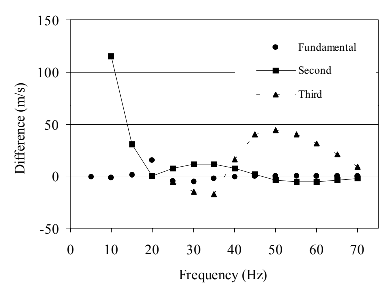

Figure 1. Differences in phase velocities calculated from two S-wave velocity models.

References:

Imai, T., and Tonouchi, K., (1982), Correlation of N-value with S-wave velocity, Proc. of 2nd Europ. Sym. on Penetration Testing, 67-72.

Miller, R.D., Xia, J., Park, C.B., and Ivanov, J., (1999), Multichannel analysis of surface waves to map bedrock, *The Leading Edge*, 18(12), 1392-1396.

Park, C.B., Miller, R.D., and Xia, J., (1999), Multi-channel analysis of surface waves, *Geophysics*, 64(3), 800-808.

Xia, J., Miller, R.D., and Park, C.B., (1999), Estimation of near-surface shear-wave velocity by inversion of Rayleigh waves, *Geophysics*, 64(3), 691-700.