The Effect of Lateral Variation and Model Parameterization on Surface Wave Dispersion Inversion

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Abstract

The traditional inversion of the surface wave dispersion curve is usually carried out with the linearized techniques to obtain S wave velocities in layers with fixed thicknesses. Nonlinear inversion methods, which can simultaneously invert for both thicknesses and S wave velocities, are becoming more popular. Since layer thicknesses are expected to vary along the propagation path, several synthetic tests were performed with a 1D model inversion using the average dispersion curve of an inhomogeneous propagation path. In the inversions, we used an improved genetic algorithm and several different model parameterizations (e.g., fixed or variable thickness, smoothing constraints, etc.). For approximately homogenous structure (i.e., little lateral variation), the main features of the average synthetic model can be retrieved for different model parameterizations. For strong lateral variations, however, the average dispersion curve can produce very different 1D inverted models depending on the parameterization. Artifacts, such as strong low velocity zones can be produced. Also, the 1D inverted models may differ significantly from the average properties of the inhomogeneous path, and wrong depths to interfaces may be inferred.

Introduction

Surface wave dispersion is extensively used to get the S-wave velocity structure in many different depth scales. In seismology, long-period surface waves (up to 200s) are used to study the upper mantle structure down to about 300 km depth. Short-period surface waves (~0.5 to 2s) can give information on the shallow crustal layers, such as sediments, down to a few kilometers (e.g., Kocaoglu and Long, 1993; Chourak et al., 2001). In seismic exploration, high frequency Rayleigh waves can be used in geotechnical studies of soil down to tens or hundreds of meters as if it were an in-situ method to determine shear wave velocity profile (Stokoe et al, 1989; Stokoe and Nazarian, 1983).

Inversion of surface wave dispersion is usually done with horizontally homogeneous model. In real observations, the path always crosses different geological provinces, and the resulting 1-D model is taken to represent an average of the structure along the path. But how similar to the "average" structure is the inverted model? This is an important question in interpretating the inverted models. Here synthetic tests were used to study the effect of lateral variations on the inverted 1-D model to help the interpretation of real data. In the inversion, we fixed P- to S-velocity ratio at 1.732 and calculated the density from the P-wave velocity. The improved genetic algorithm (An and Assumpção, 2001) was used. The forward model was computed with the code *surfmo* (Lomax and Sneider, 1995).

The synthetic data were calculated for a sedimentary basin with several layers on a basement with constant velocity. The inversion was done in two modes of model parameterizations:

Mode 1: S-wave velocity and thickness of a small number of layers. We invert for both S-wave and thickness of three layers. The search ranges (thickness, S-velocity) used are respectively: (0.1 ~ 1.5km, 1.0 ~ 3.5km/s); (0.1 ~ 3.0km; 1.0 ~ 3.5km/s); (0.1 ~ 4.0km; 1.5 ~ 4.0km/s).

Mode 2: Multi-layer, with fixed thicknesses. Only S-waves of five layers are inverted and the search range was set to 1.5 to 4.0 km/s for all layers.

Synthetic tests for lateral variation

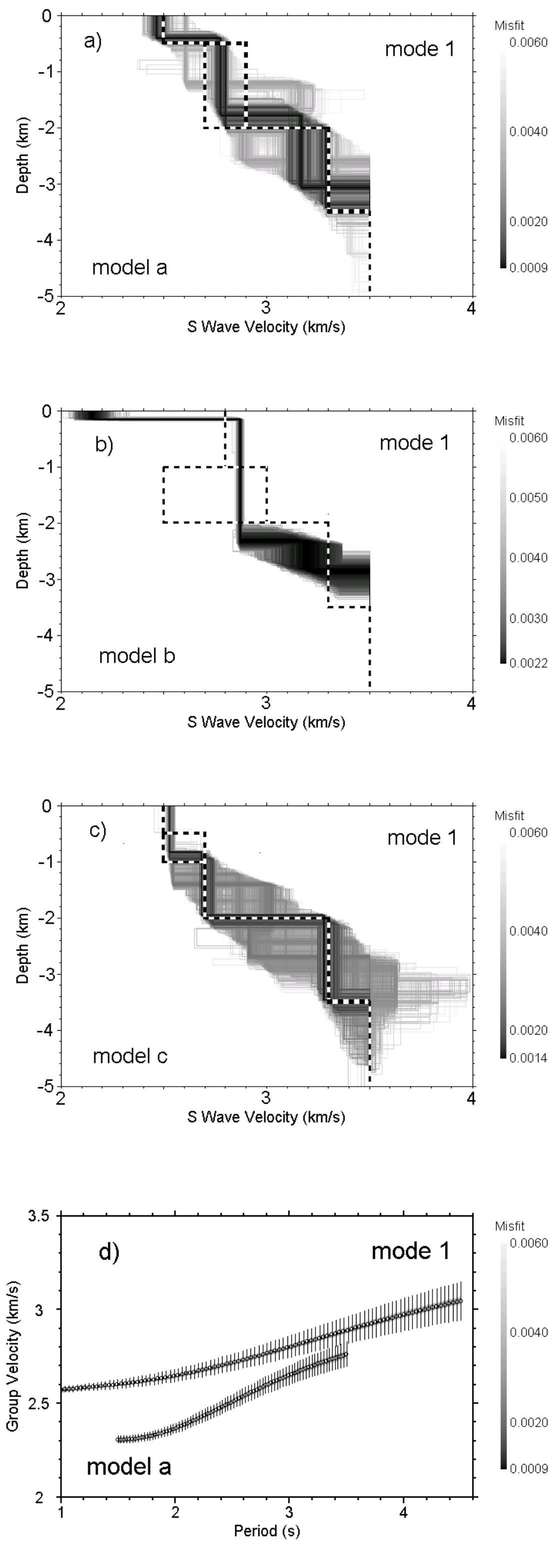
Mode 1

We designed two groups of the homogeneous section pairs: (1) the two synthetic sections in each pair differ only in the S velocity of the second layer; (2) the difference only in the thickness of the first and second layers.

In group 1, model a (Figure 1a), with a small variation of S velocity in the second layer, produce the best 1-D model looking like the average profile of the two homogeneous synthetic models. In this case, the inverted model shows the approximate average properties of the inhomogeneous profile. For model b (Figure 1b) where the S-wave velocity has a large difference between each homogeneous section, the thicknesses of the two first layers in the inverted model are different than any of the homogeneous section. The inverted models in Figure 1b cannot show the correct boundary between the first two layers; an artificial thin low velocity layer appears in the surface; and the estimated basement depth would be highly underestimated.

For group 2 (Figure 1c), where only the thickness of the first layer is different, the inverted models are similar to the average profile giving an intermediate thickness for the first layer. The estimated basement depth is not much affected by the heterogeneity in the first layer.

These tests show that the inverted 1-D model most differs from the average of the two homogeneous sections, when there is a large lateral variation (model b). If the lateral variation is small (models a, c) the inverted model is close to the average profile of the two homogeneous sections. The thickness of the homogeneous layers seems to be a



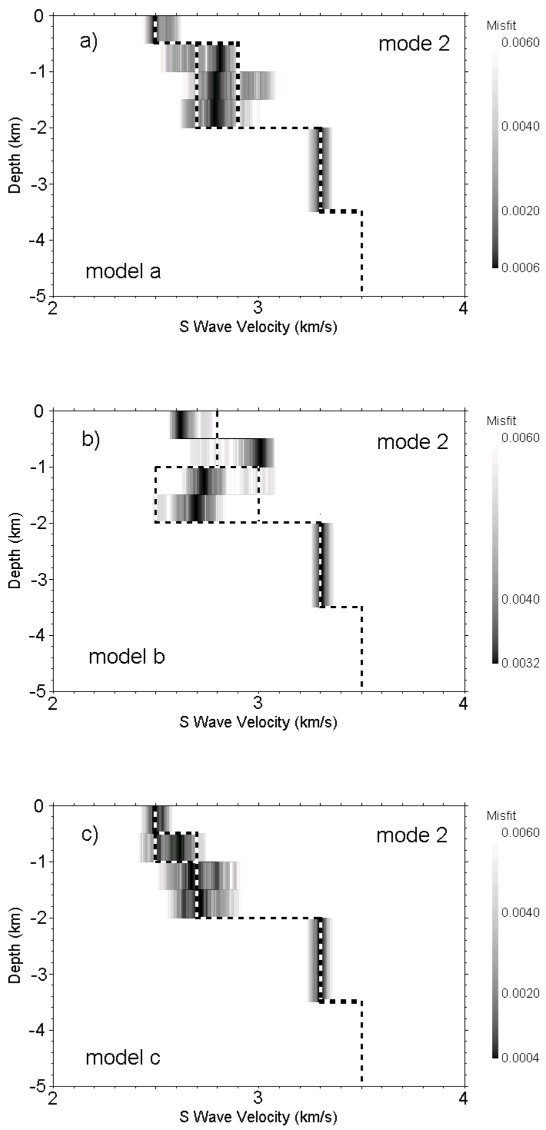


Figure 1 – The good inverted models of mode 1 in the synthetic tests. Two dashed lines are the synthetic profiles. Inverted models are solid lines in gray shades of misfit. d) is the fitness of models in a).

Figure 2 – The good inverted models of mode 2 in the synthetic tests. Two dashed lines are the synthetic profiles. Inverted models are solid lines in gray shades of misfit.

secondary factor to distort the inverted composed model, as seen in model c. Strong variations of velocity are more important.

Mode 2

Using the un-smoothed multi-layer inversion, the composed data from the same inhomogeneous models a-c were inverted. For small differences in the two homogeneous sections, models a, c (Figs. 2a, c), the inverted models give the average velocities of the two sections, as in the previous inversion mode. When lateral variation is stronger (model b in figure 2b), the inverted models show significant differences from the average profiles. In this model, an artificial oscillation in the top two layers is observed, and the best models give the average structure down to 1 km and about the average velocity from 2 to 3 km depth. More importantly, however, is that the resulting inverted models are very different compared with the previous inversion mode 1 (Figure 1b). This implies that the "average" 1-D model, in the presence of strong lateral variations can be highly dependent on the model parameterization, and this must be taken into account when trying to interpret inverted model from observed data.

Discussion and conclusion

In real observations, the propagation path seldom covers a perfectly homogeneous structure, and the surface wave group velocities will be affected by the horizontal heterogeneity. The synthetic tests above showed the inversion of surface wave dispersion can produce different models depending on the chosen parameterization, and analysis of these differences can provide some information on the propagation path. This suggests that one should carry out inversions with different model parameterizations (such as inversion modes 1 and 2) and compare the common features of the resulting models. If the resulting models of different inversions are similar, they can represent an average structure along the propagation path. Otherwise if they are very different and the inverted models include strong oscillations of S-wave velocities between neighboring layers, it is possible that the propagation path has strong lateral variations. In this case, the inverted model may differ significantly from the average structure, and smoothness constraints will be necessary for an estimate of the general S-wave velocity trend.

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