AN ALTERNATIVE REPRESENTATION OF THE SOIL PROFILE FOR MASW ANALYSIS

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Abstract

A conventional 1-D representation of the soil profile employed in Multi-channel Analysis of Surface Waves (MASW) consists of a fixed grid of layers. Each layer is assumed elastic with material properties of S-wave velocity, P-wave velocity, and mass density. Of these three, the S-wave velocity dominates. Phase velocity dispersion of the Rayleigh wave fundamental mode is often inverted with the S-wave velocity in each fixed layer being the primary object of investigation. This paper presents an alternative representation of the soil profile. In this alternative, control points are the target of investigation. These control points are free to move both in the S-velocity and depth directions. Between the control points, the elastic moduli are interpolated into fine layers which are able to represent gradational variation. In this way, the number of unknowns is kept small compared to the large number of layers. Gradational trends in phase velocity dispersion have been represented well with this approach. The method is illustrated with synthetic data. References to field data papers are also provided. The inversion method employed is Singular Value Decomposition (SVD).

Introduction

Multi-channel Analysis of Surface Waves (MASW) requires an inversion of a measured dispersion curve into a dynamic soil profile. Rayleigh waves are a mix of P- and SV-wave motion dependent on the soil's mass density, P-wave velocity, and S-wave velocity. However, the primary object of investigation is the S-wave velocity. A common approach is to functionally relate P-velocity and density to either S-velocity or to fix these less sensitive parameters while inverting for S-wave velocity with depth. For example, Park *et al.* (1999) required estimates of Poisson's ratio and density and kept the layer thicknesses unchanged during the inversion. It is common to employ a fixed grid or stack of constant velocity layers to represent the soil profile. One solves for velocity in each layer while setting the other dynamic properties by a chosen relationship to S-velocity or some other strategy. The stack of layers can be thick and of constant thickness (Hutchinson *et al.*, 2008; Coe *et al.*, 2016). The layers can also be variable coarse in thicknesses (Park, 2013; Miller *et al.*, 1999). One challenge in composing the layer grid is for the investigator to capture the soil profile as it exists in nature. An investigation into low and high velocity layers have been performed to address what might be resolved (Shen *et al.*, 2013). Placing a layer at the correct depth is not easy. Once one has laid out a grid, that choice will inevitably regularize the problem in a way that may not capture the boundaries present in nature.

Alternatives in Soil Profile Representation

It is possible to repose the problem in terms of fixed velocity steps. One would then solve for the layering that best fits the dispersion curve with predefined velocities being fixed. This approach would be difficult to implement since it requires deciding on the velocities, fixing those values, and then inverting for the layer thicknesses. A fixed grid of velocity steps solving for layer thicknesses is in some ways similar to a fixed grid of layers solving for velocities. In either case, one is predisposing a texture to the problem's solution.

This author has begun to employ an alternative approach which makes both the velocity and layer details the objects of investigation. The parameters are control points free to move in velocity and depth. Elastic moduli are linearly interpolated (not velocity) between control points. The layer thickness can be set thin. The result is capable of representing fine gradations or coarse steps with a single mechanism.

Synthetic Example

The example chosen is similar to what one would expect for a granular soil on bedrock. The granular soil shear velocity would increase with increasing depth of burial due to increased effective stress which increases the shear modulus. The simulation is shown in Figure 1. The source wavelet was minimum phase (0.1 to 80 Hz).

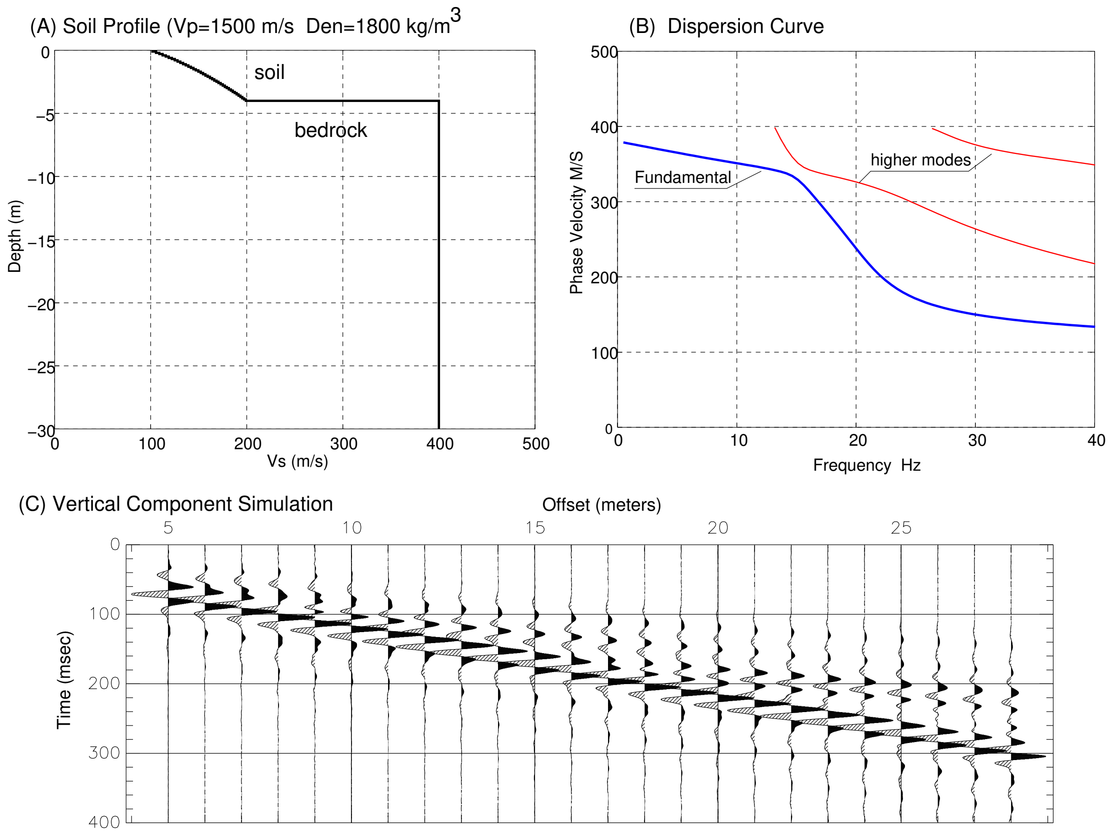

Figure 1: (A) Shear velocity profile, (B) Computed phase velocity dispersion, (C) Synthetic seismic record.

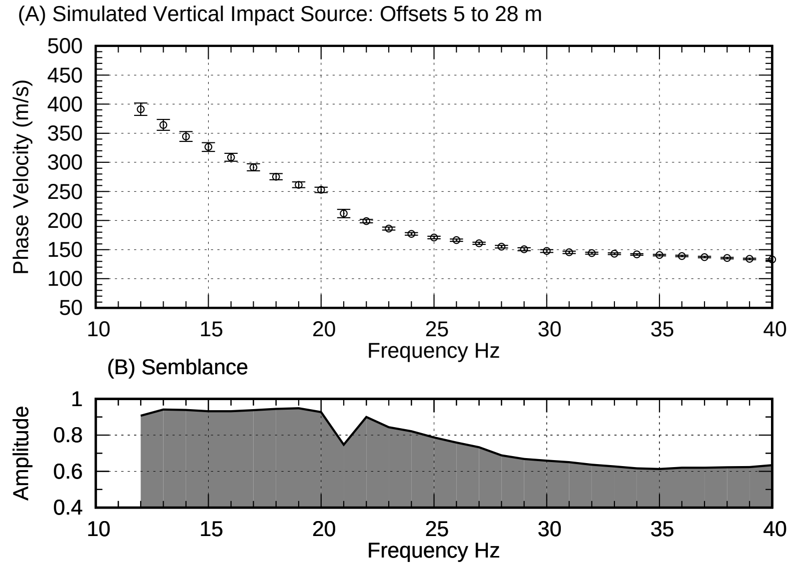

Figure 2: (A) Extracted phase velocity dispersion, 95% confidence. (B) Semblance.

The synthetic seismic record shown in (c) of Figure 1 was then processed to extract a dispersion curve. The computation is done in the time domain with a sequence of narrow band filters and trial velocities, automatically selecting a phase velocity by a golden section search for the maximum semblance. The dispersion is plotted in Figure 2.

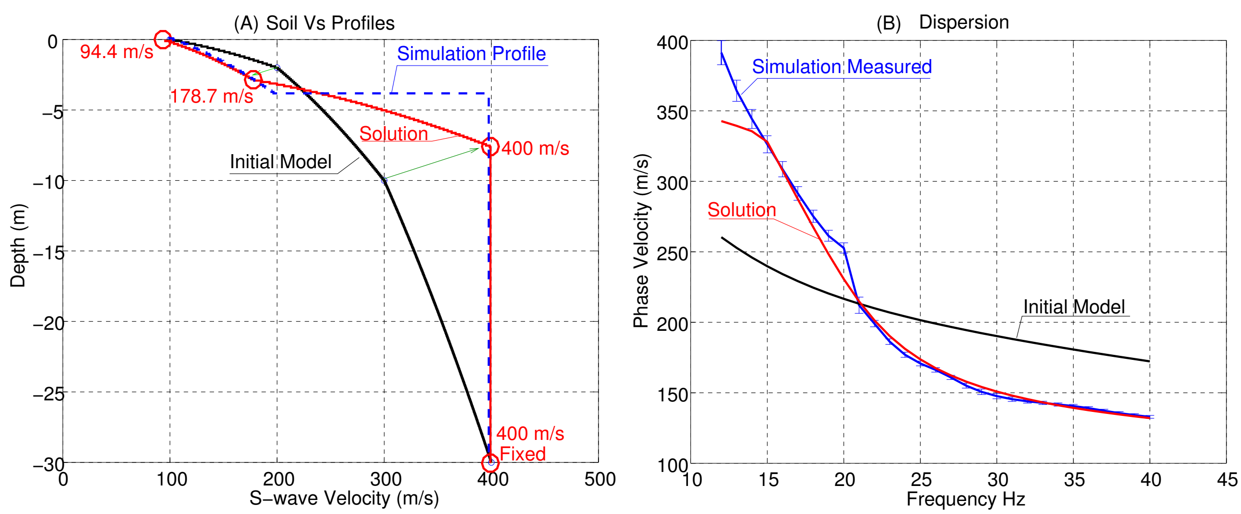

Figure 3: (A) S-wave velocity profiles (B) Dispersion measured and computed.

Inversion of the measured dispersion from the simulation data was conducted using a Singular Value Decomposition (SVD) algorithm, truncating the number of singular values to the largest three values (out of seven total). Figure 3(A) shows the soil profiles for the the simulation, the initial model, and the solution after 20 iterations. Figure 3(B) shows the dispersion for the initial model and the final solution compared to the observed dispersion. The layer thickness is 0.1 meters. The inversion algorithm was set to fix both velocity and depth for the deepest control point. The surface control point was fixed only in depth. The first control point below the surface moved slower and deeper. The control point below that moved faster and more shallow (see green arrows in Figure 3(A)).

Discussion

This alternative representation significantly reduces the imposition of a structure to the MASW inversion solution. Rather than having to choose layer boundaries before beginning the inversion, the investigator may spread just a few control points across the likely depth of investigation. The velocities are spread from the slowest to fastest measured phase velocities. The layer thickness can be set very thin, permitting soil profiles with gradual velocity changes, or abrupt changes as shown in this example at the 400 m/s control point at 7.5 meters depth. In this problem, the $Vs_{30} = 322$ m/s is found by employing the formula 36-1 (UBC-97, 1997). With this representation, there are 300 layers.

$$Vs_{30} = \frac{\sum Z_i}{\sum (Z_i / Vs_i)} \tag{1}$$

Space does not permit here to present field data. For examples of this representation with field data, the reader is referred to Michaels (2011, 2014). The computation of solution confidence intervals is covered in these papers.

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