3-D MASW

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Abstract

Because MASW analysis focuses on the inline propagation of planar surface waves in its data acquisition with linear receiver array and then in the subsequent dispersion imaging process, the useful outcome of 2-D shear-wave velocity (Vs) mapping best represents the cross sectional image of the subsurface below the survey line with minimal influence from the offline features like side scattering. This enables multiple 2-D Vs data sets to be independently used to construct a 3-D cubic data set through a proper interpolation scheme like the tri-linear scheme. This 3-D data set by itself can possess practical value to infer the regional trend of Vs variation without any further and more involved processing such as depth migration in 3-D reflection profiling. A set of 2-D Vs data from three parallel lines at a proposed wind-turbine site is used to illustrate this concept, facilitated by various types of 3-D data presentation skills.

Introduction

3-D characterization of the ground volume is always desirable. The heavy burden of field operation and data processing, however, prohibits it from being routinely used for common geotechnical engineering projects. For example, 3-D subsurface seismic imaging with body (reflection) waves always involves those reflected waves coming off the plane of the survey cross section—also called sideswipe energy (Yilmaz, 2001)—and proper handling of this effect is accomplished only through the heavy cost of 3-D acquisition grids based on the binning concept of body waves, followed by the heavy cost of 3-D migration in data processing. This is the main reason that has prohibited 3-D reflection imaging from being more commonly and routinely used for engineering projects.

Although the MASW method (Park et al., 1999) is still in its infancy with less than ten years of widespread use and its resolution concept has not been clearly understood yet, many practitioners find the method cost-effective and useful for many geotechnical engineering projects none of the other geophysical approaches could deal with as efficiently. In addition, because it is the inline planar surface waves that the MASW method tries to enhance as signal in its principle of data acquisition and subsequent dispersion analysis, influence of those offline (side scattering) waves on the dispersion analysis is usually minimal. This property of MASW may lead to devising a 3-D approach simply by acquiring multiple linear survey lines in parallel, followed by independent processing of each line for a 2-D shear-wave velocity (Vs) map. Then, a 3-D interpolation scheme can be used to construct a 3-D cubic grid that can be displayed in various ways to infer valuable insights to subsurface features.

Although the subsurface resolution limits with MASW should be understood prior to an effective deployment of those constituent linear survey lines, we present an actual attempt with those three survey lines run in parallel east to west at a proposed site for a wind-turbine tower. We emphasize the possible significant gain that can be drawn from the various types of data presentation with extremely simple field and data processing efforts.

Miller et al. (2003) attempted to construct a 3-D Vs grid to be used for a simulation of seismic wave propagation at the Smart Weapon Test Range (SWTR) near Yuma, Arizona, from forty (40) evenly-spaced MASW lines of 300-m long each (Figure 1). Suto (2007) constructed a depth (x-y) slice map at 1-m below ground surface from a series of carefully designed 2-D MASW surveys and compared the result against Dynamic Cone Penetrometer (DCP) test results to show an excellent agreement (Figure 2). We present a simple approach with great potential usefulness to construct a 3-D Vs data set from two or more sets of 2-D data, and then map the constructed 3-D Vs data set with various types of 3-D data presentation skills.

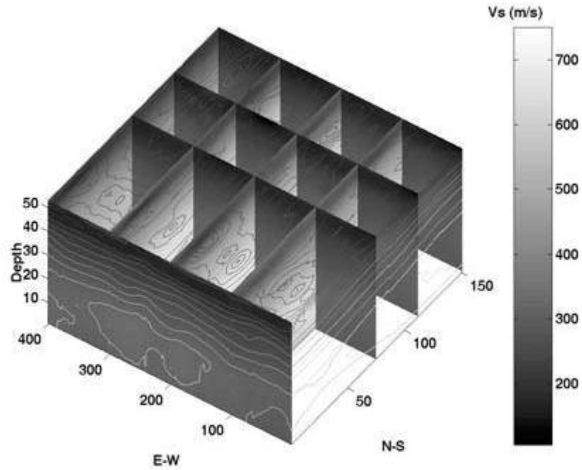

Figure 1. 3-D S-wave velocity used in finite difference calculations (from Miller et al., 2003).

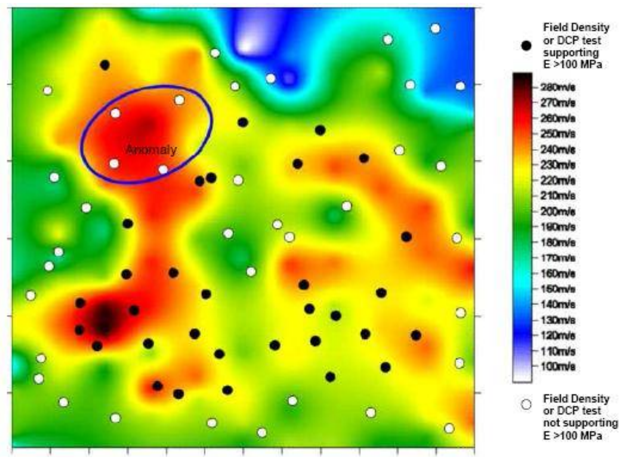

Figure 2. Plan view of competence at the depth of 1m below ground mapped by MASW. The area is approximately 120m by 120m (from Suto, 2007).

Sideswipe Energy in MASW Analysis

In the MASW method, construction of a 2-D Vs map from roll-along data acquisition along a linear survey line is based on an assumption that dispersion of recorded surface waves was shaped by the layered earth (Vs) model right below the receiver spread and nothing else—for example, offline anomalies or scattering objects— can adversely influence the dispersion analysis. Although this assumption is generally accepted as valid, it is further illustrated here through a synthetic experiment in which a side scattering of extraordinary energy is considered (Figure 3). As depicted in the field layout diagram in Figure 3a, the source of the side scattering exists at 5 m offline from the 7th channel location in a 24-channel spread with 1-m spacing and 5 m source offset. Modeled 24-channel records are shown as insets in the corresponding dispersion images processed with the method by Park et al. (1998) for inline-propagation-only and side-scattering included cases in Figures 3b and 3c, respectively. Extracted curves are shown in Figure 3d, indicating little difference between them. This experiment illustrates the effectiveness with the linear acquisition array and the subsequent dispersion imaging method in their robustness, focusing on inline plane-wave propagation.

Based on this property of minimized influence from the sideswipe energy with the common MASW survey for 2-D Vs maps, each set of Vs data from one survey line is used independently during the construction of a 3-D grid data set and no attempt is made to account for the possible interaction between them—for example, the similar to 3-D migration in the 3-D reflection method—appears to be necessary at the current level of the method.

3-D Interpolation with 2-D Data Sets from a Wind-Turbine Site

Vs data sets from three parallel lines surveyed at a proposed wind turbine site are used to illustrate the feasibility of constructing a cubic (3-D) grid data. Figure 4 shows the location of the lines and corresponding 2-D Vs maps obtained from the analysis of each line's data set, which was prepared by a 24-channel roll-along acquisition with 4-ft source and receiver spacing, moving twenty-four (24) times for each line.

Among many other schemes available, the tri-linear interpolation scheme (Press et al., 1992) was used to construct a 3-D grid data set because of its simplicity and the because the least amount of regional bias was introduced by the interpolation process itself. A brief description of this as well as other common methods (e.g., Kriging) can be found from many online resources (e.g., www.wikipedia.org).

Display of 3-D Vs Data

Several different types of display of 3-D (cubic) Vs data set have been attempted that seem possessing unique advantages: (1) display of the exterior of the cube from different viewing angles (Figure 5), (2) layer slicing (Figure 6), and (3) layer stripping (Figure 7). Display of the cubic surfaces can be useful to depict the regional trend of the subsurface properties, whereas the layer slicing can be valuable to depict a specific cross sectional image along the specified directions in a 3-D Cartesian coordinate system. The layer stripping has combined attributes of the previous two.

Discussions

Although parallel 2-D lines have been tested at this time of the manuscript preparation, other instances of multiple 2-D lines with arbitrary orientations will be tested soon, and will hopefully be presented at the conference. Furthermore, as an extreme extension of the case, multiple inputs of 1-D Vs data at random surface locations to construct a regional 3-D grid data set will have its own practical value and will be tested

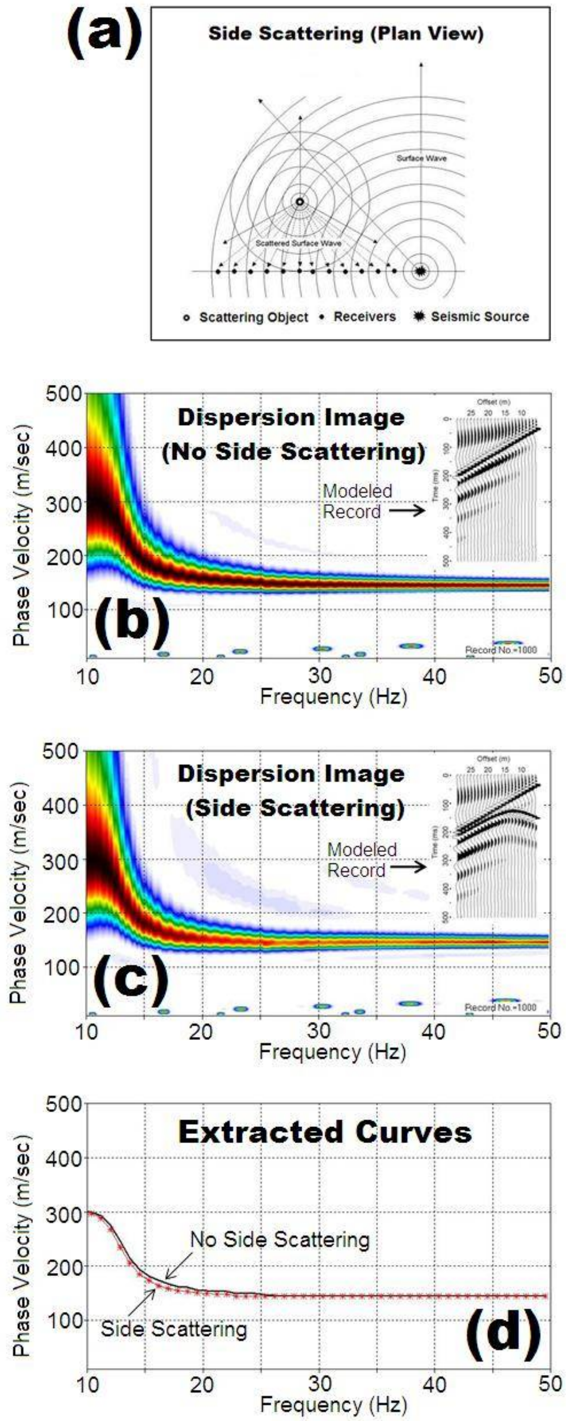

Figure 3. (a) Field layout diagram for the side scattering modeling, and modeled records and their dispersion images for the cases of (b) planar propagation only, and (c) side scattering included. Extracted dispersion curves are displayed in (d).

as well. In addition, testing with different types of interpolation schemes should also be included for the future improvement of the technique.

Conclusions

Construction of a set of 3-D Vs grid data from three independent sets of 2-D Vs data prepared from three parallel lines followed by various types of 3-D data presentations suggested a great potential to become a routine 3-D MASW approach at an affordable cost of field operation and data processing. Studies about the field logistics to assure operational efficiency as well as maximized lateral resolution will be necessary to take place in the future to understand both realistic and unrealistic features represented by the 3-D interpolation.

References

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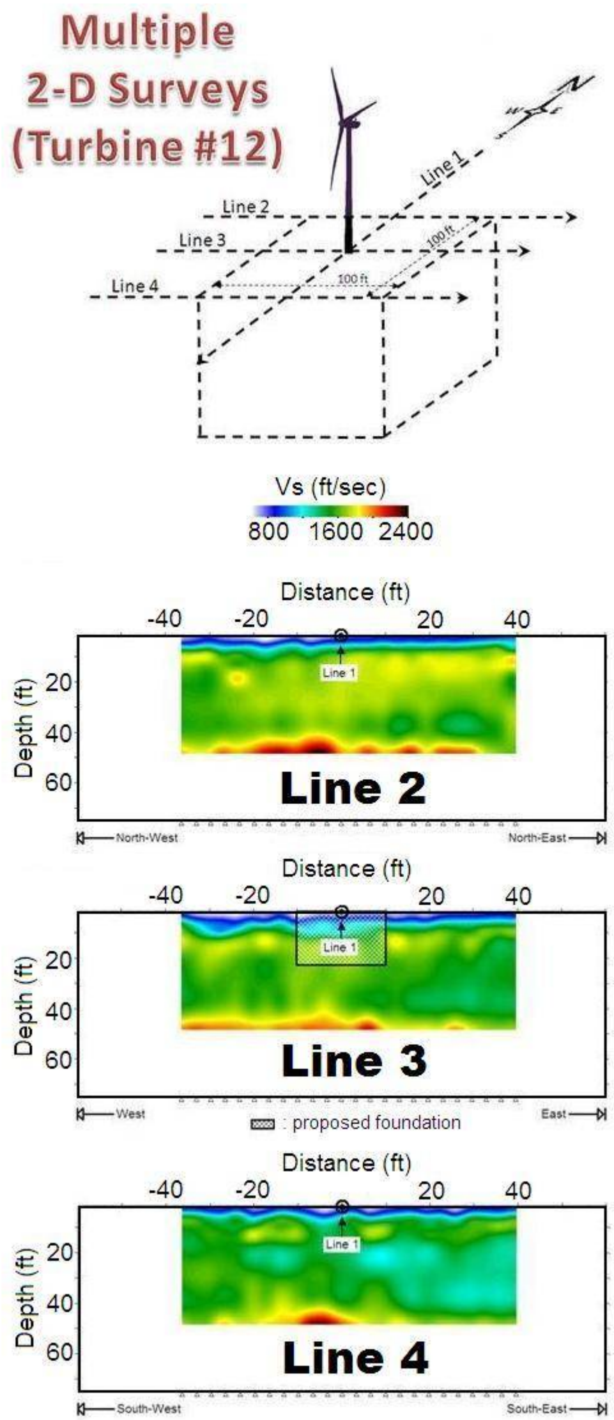

Figure 4. Location of 2-D MASW survey lines on a proposed wind-turbine site (top). 2-D Vs maps from the three parallel lines of 2, 3, and 4 are shown below the location diagram. These 2-D data sets are used for the construction of a 3-D grid.

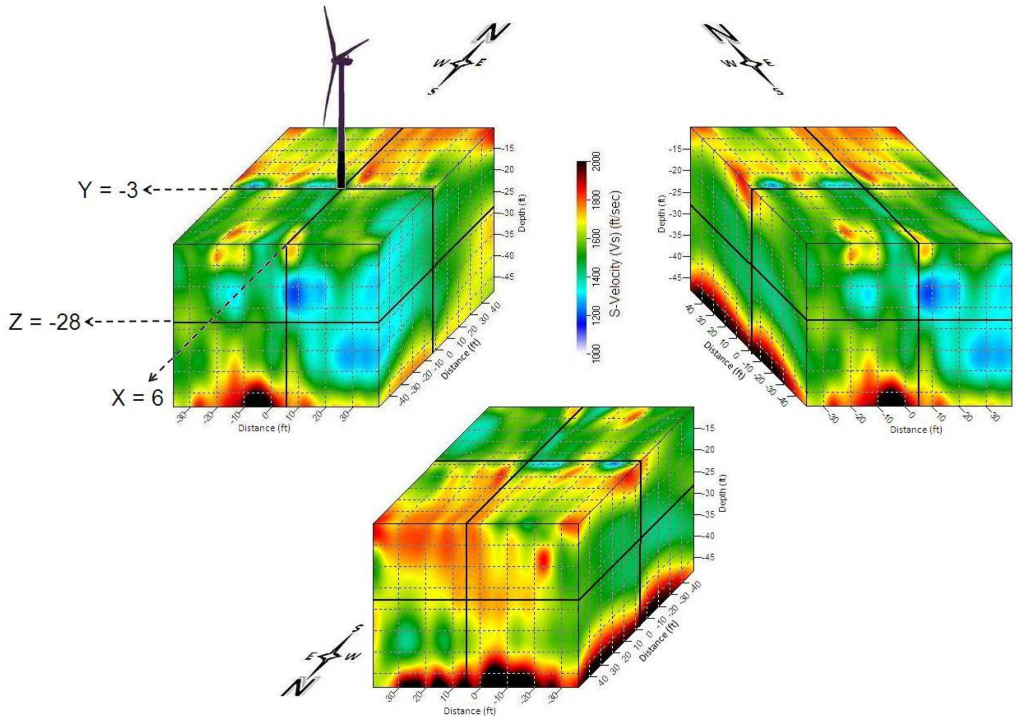

Figure 5. Display of 3-D (cubic) data set in different view angles. Thick black lines drawn along the three orthogonal axes on the cube indicate lines for layer slicing displayed in Figure 6 and layer stripping in Figure 7.

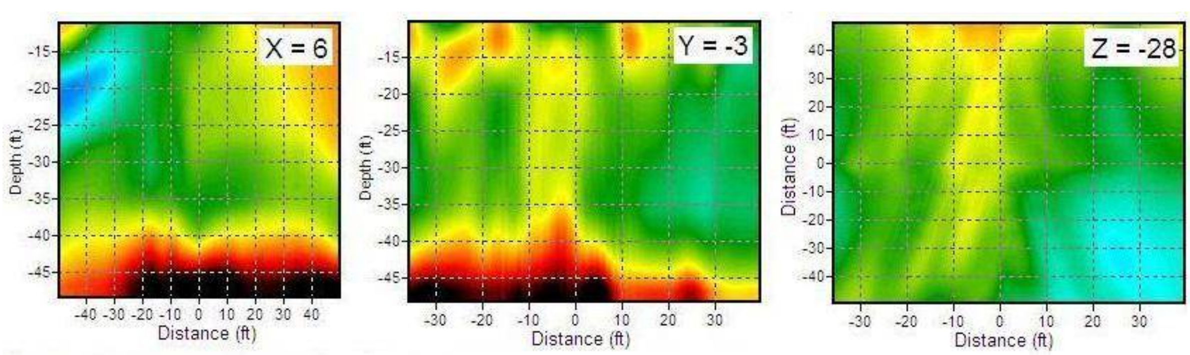

Figure 6. Layer slices along lines marked on cube in Figure 5.

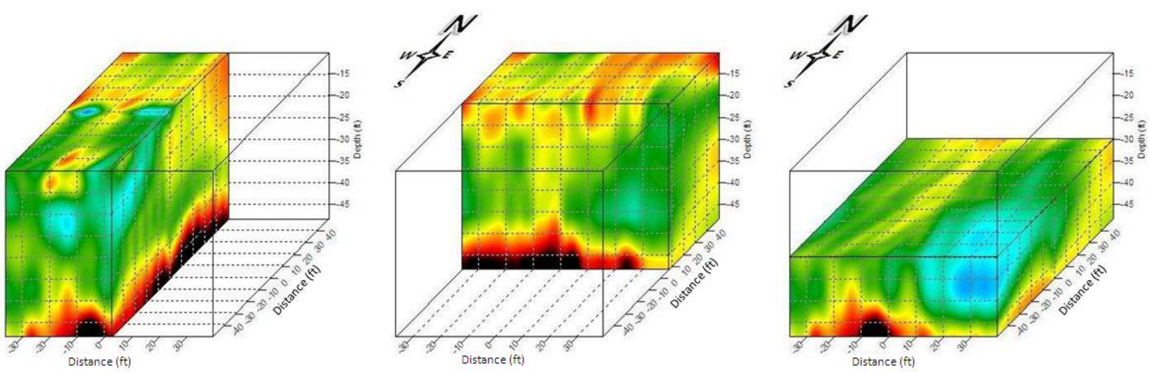

Figure 7. Layer stripping along lines marked on the cube in Figure 5.