ParkSEIS-3D for 3D MASW Surveys

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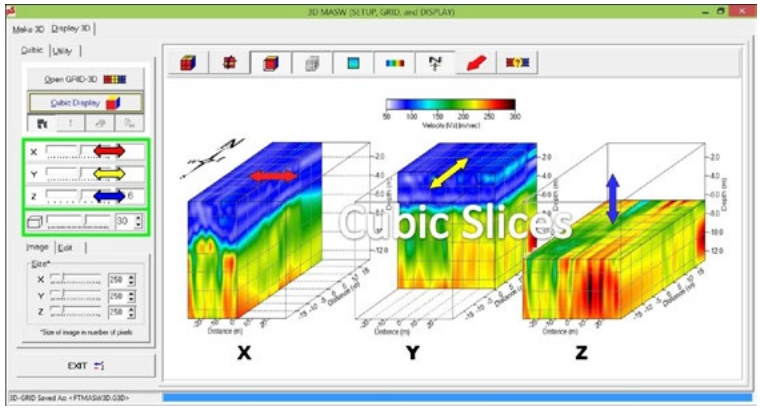

Figure 1. A 3D visualization mode by ParkSEIS-3D of the shear-wave velocity (Vs) data set obtained from a dedicated 3D MASW survey in Shelton, Connecticut.

Abstract

Despite the potential value and efficacy of 3D surveys using MASW, no software package has been able to handle all-in-one 3D data collection, analysis, and visualization. ParkSEIS-3D provides the first such software package. It represents the latest evolution of ParkSEIS, which has undergone continuous updates in underlying theoretical algorithms, empirical calibration, and graphical user interface (GUI), through field applications in several hundred different settings worldwide (conducted by Park Seismic LLC). While it is well-known that running conventional 2D/1D surveys at multiple locations can ultimately produce and display a 3D volume of shear-wave velocity (Vs) data by using multiple software packages, to date there has been no dedicated software package that can handle optimum 3D field operation, efficient data rearrangement, numerical analysis to create a 3D Vs data, and its visualization all in one package.

This article provides an overview of the ParkSEIS-3D software and its core theoretical properties and procedures. The most effective field logistics for dedicated 3D MASW surveys are described in terms of shot/receiver (SR) patterns. It describes how corresponding field coordinates are conveniently set up by importing either Cartesian coordinate (*.txt) or GPS (*.gpx) files, as well as how streamlined graphical interfaces (GUI's) incorporated at various critical steps of analysis ensure effective and user-friendly 3D analysis. Automatic algorithms for dispersion and inversion further simplify the procedure and ensure maximal consistency. Open-source vs. commercial software packages are also discussed briefly.

Introduction

As MASW (Park et al., 1999) expands its areas of application, one of the growing demands is the 3D survey. Although some earlier pioneers executed such applications by running conventional 2D surveys multiple times and displaying results by using separate visualization software packages (e.g., Miller et al., 2003; Suto, 2007; Park and Carnevale, 2009; Park and Taylor, 2010), there has so far been no dedicated software package that can handle all-in-one 3D data collection, analysis, and visualization. That is, the coordination of "true 3D" field acquisition, data re-arrangement for binning (Sheriff and Geldart, 1982), and 3D visualization of final shear-wave velocity (Vs) data– all in one package (Figure 1).

Although conventional 2D/1D surveys at different lines/points can be cobbled together to achieve an output that provides 3D analysis, a dedicated 3D survey requires well-defined field logistics with properly designed shot and receiver (SR) patterns. This ensures maximal effectiveness in surficial and depth coverage while minimizing field operation efforts with a given set of field equipment. A proper software package should thus be able to provide such logistics for a potential 3D project based not only on the size of 3D ground volume being investigated but also the desired spatial sampling (bin) size for a given number of acquisition channels.

Data analysis of a dedicated 3D survey requires special steps of shot/receiver (SR) setup and data rearrangement into common-mid-point (CMP) gathers. Location information of SR patterns should be able to be entered using either Cartesian (*.txt) or GPS (*.gpx) coordinate files. Subsequent data sorting into CMP gathers should take place with consideration of the applied SR patterns, a bin size and the 3D ground volume. To further simplify the process, it would be desirable for the dispersion and inversion analyses to proceed in a fully automated manner to produce a 3D grid data set (*.G3D) at the end. A visualization module should allow the user to freely display any part of the subsurface from all directions and perspectives (Figure 1). The software would ideally also allow the 3D grid to be exported into a user-defined format for further use if necessary. ParkSEIS-3D has been developed to provide all of these features.

3D MASW – Data Acquisition

Common MASW surveys use a 1D linear receiver array (RA) to generate a 2D shear-wave velocity (Vs) cross section through a roll-along approach. Although surface waves spread into all azimuths, only the propagation along the path of the 1D RA is used to generate a 1D velocity (Vs) profile being placed at the RA center. Multiple such surveys can ultimately accomplish an equivalent 3D survey; e.g., by running parallel 2D lines. The most effective 3D survey, however, can take place only by using a 2D RA accompanied with a proper 2D shot pattern, similar to the 3D reflection survey. In this way, surface waves generated from one shot point and propagating into multiple azimuths can be

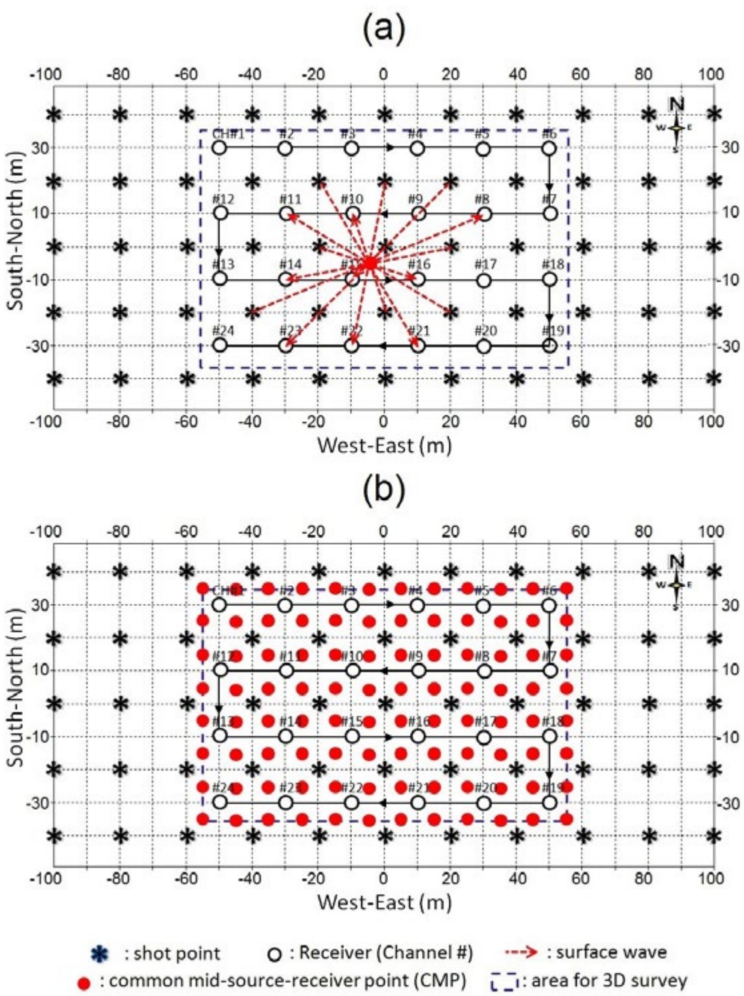

Figure 2. (a) Illustration of a dedicated 3D MASW survey with a stationary 24-channel 2D (X-Y) receiver array and a pattern of multiple shots. A common-mid-point (CMP) is marked that has multiple (8) shot-receiver raypaths sharing the same point. (b) CMP's (red dots) that have six (6) or more traces created from the shot/ receiver (SR) pattern in (a).

used to generate velocity (Vs) profiles at multiple locations. Efficiency of surface wave energy is therefore maximized. In addition, if acquired field records are sorted into common-mid-point (CMP) gathers, the surficial sampling size (bin size) can be controlled not only by the pattern of receivers but also by the shot pattern. Controlling the shot pattern is a lot more convenient than controlling the pattern of whole receivers. This allows the bin size to become smaller than a receiver spacing used in the field. As a consequence, a relatively small number of acquisition channels (e.g., 24 channels) can still be used for a dedicated 3D survey by using a stationary 2D RA of a long receiver spacing (e.g., 10 m) to cover a relatively large area (e.g., 50 m x 50 m) with a relatively small (high) bin size (spatial resolution) (e.g., 2 m x 2 m).

The general scheme of a dedicated 3D MASW data acquisition is illustrated in Figure 2a. A 24-channel 2D RA is laid with a 20-m longitudinal (West-East) and transverse (South-North) spacing. A pattern of multiple shots, among many other possibilities, is also displayed. To illustrate how a CMP gather is created, eight (8) different shot-to-receiver raypaths are marked in red lines, which have different shot-receiver offsets while sharing the same (common) midpoint (CMP). This 8-trace CMP gather can go through the normal sequence of MASW analysis to generate a 1D velocity (Vs) profile to be placed at the corresponding CMP location. Figure 2b shows all such CMP's in red dots that are created from the given shot-receiver configuration displayed in Figure 2a and have six (6) or more shot-receiver pairs (traces) sharing the same CMP. Each CMP point will have its own 1D velocity (Vs) profile. It is noted that the CMP interval (10 m) is only half the shot interval (20 m) and more CMP's (96) are created than the number of shots applied (55). This example illustrates that a 3D survey can be simpler than multiple 2D surveys. In addition, a CMP gather contains surface wave propagations from multiple azimuths (Figure 2a), yielding a more realistic subsurface sampling than the conventional 2D/1D survey. Further details regarding the logistics for optimum shot patterns for a given 2D RA will be expanded in a forthcoming article (Park, 2020).

ParkSEIS-3D includes a module that can generate a template chart of shot and receiver patterns (similar to the ones in Figure 2) based on acquisition-related parameters such as investigation dimension, number of seismograph channels, takeout spacing of seismic cable, and degree of desired spatial resolution. This type of chart can be useful in designing potential 3D projects.

3D MASW – Data Analysis

The first step in 3D analysis is to set up spatial (X and Y) configuration of shot/receiver (SR) patterns into each of the acquired multichannel field records (i.e., SR setup). Encoding these 2D coordinates during field acquisition is almost prohibitive because most of engineering seismographs do not provide such options. There are two ways to accomplish the SR setup in ParkSEIS-3D. One is to use a Cartesian coordinate system adopted during the field operation and therefore logged in the field notes. This information can be prepared in a text file (*.txt). Another is to use GPS coordinate files (e.g., *.gpx) saved for all shot and receiver locations.

The next step is to sort field shot gathers into 2D (i.e., X-Y) CMP gathers. All shot-to-receiver mid points are first mapped on a fictitious chart for all possible combinations. Then, those points within a given bin size (e.g., 2 m x 2 m) are grouped together as the same CMP. Next, only those CMP gathers are selected for subsequent analysis that meet certain conditions such as an aperture size (e.g., 30 m), minimum number of traces (e.g., 6), and source-receiver offset distributions. The aperture size (D) is determined by the maximum investigation depth being sought (Zmax); e.g., D = 2Zmax. These selected CMP gathers then go through the normal MASW analysis sequence to generate 1D velocity (Vs) profiles being placed at the corresponding CMP locations. Finally, a 3D grid data set is created by using an appropriate interpolation scheme. Once this 3D grid is prepared, it can be visualized in various ways (e.g., Figure 1) and exported into a user-defined format if necessary.

ParkSEIS-3D provides a highly convenient graphical-user-interface (GUI) for shot/receiver (SR) setup, which can be accomplished simply by importing two files prepared for receivers and shot points in the form of either Cartesian (*.txt) or GPS (*.gpx) format (Figure 3a). Remaining steps of dispersion and inversion followed by 3D grid generation proceed in a fully automated manner without user intervention. The 3D grid can also be created from multiple 2D and/or 1D surveys as illustrated in Figure 3b. Multiple 2D cross sections can be imported by specifying surficial trajectories either by using mouse or by importing location files (*.txt or *.gpx). Multiple 1D profiles can also be added in the same way.

Algorithm and Graphical User Interface (GUI)

The importance of GUI cannot be overstated, especially in applied settings where the average users (e.g., civil engineers) are not members of the technical community developing the methods (e.g., geophysicists). In ParkSEIS-3D, the shot/receiver (SR) setup is accomplished through a convenient Graphic Wizard (GW) approach that can avoid unnecessary confusion, due to for instance heavy reliance on technical jargon.

There are two main steps in numerical analysis of MASW data: dispersion and inversion. The purpose of dispersion analysis is to extract a fundamental-mode (M0) [or an apparent mode (AM0), as explained below] dispersion curve from field record. The following inversion analysis automatically generates a 1D velocity (Vs) profile by using the measured M0 curve. Correct extraction of M0 curve is therefore critically important directly influencing the accuracy of the profile. The proper extraction, however, requires operator's ability to accurately interpret energy patterns observed in the dispersion image, which often requires theoretical knowledge and significant observation experience with diverse field data sets. ParkSEIS-3D has incorporated an automatic algorithm (AUTO) similar to artificial intelligence (AI) that detects the correct M0 pattern in a mixture of complicated energy trends. The algorithm evolved through extensive self-learning process by using diverse field data sets over the past two decades.

ParkSEIS-3D uses two approaches for inversion of the measured dispersion curve; (1) fundamental-mode (M0) and (2) apparent-mode (AM0) methods. Although there has been a great deal of research and development in the higher modes inversion, software that takes full advantage of multi modes while efficiently handling all the associated complications has not yet been developed, at least to the level of commercial software package. This is because of the modal characteristics of surface waves that are ultimately determined by the velocity (Vs) profile of subsurface materials, the unknown that we attempt to know through the MASW analysis. On the other hand, energy of the fundamental-mode (M0) surface waves almost always dominates the measured seismic wavefields. In this sense, the traditional approach of the fundamental-mode (M0) inversion provides an excellent outcome under most common overburden/bedrock settings. On the other hand, it is well known that a velocity inversion, a layer of higher velocity (Vs) than the layer below, often results in an abnormal dispersion trend where phase velocities increase (instead of decrease) with frequencies. The trend usually appears to be one coherent mode, and therefore is called an apparent mode (AM0). Existence of AM0 trend is automatically detected in ParkSEIS-3D and a different inversion method is used; e.g., either mode-jump or Lamb-wave approach

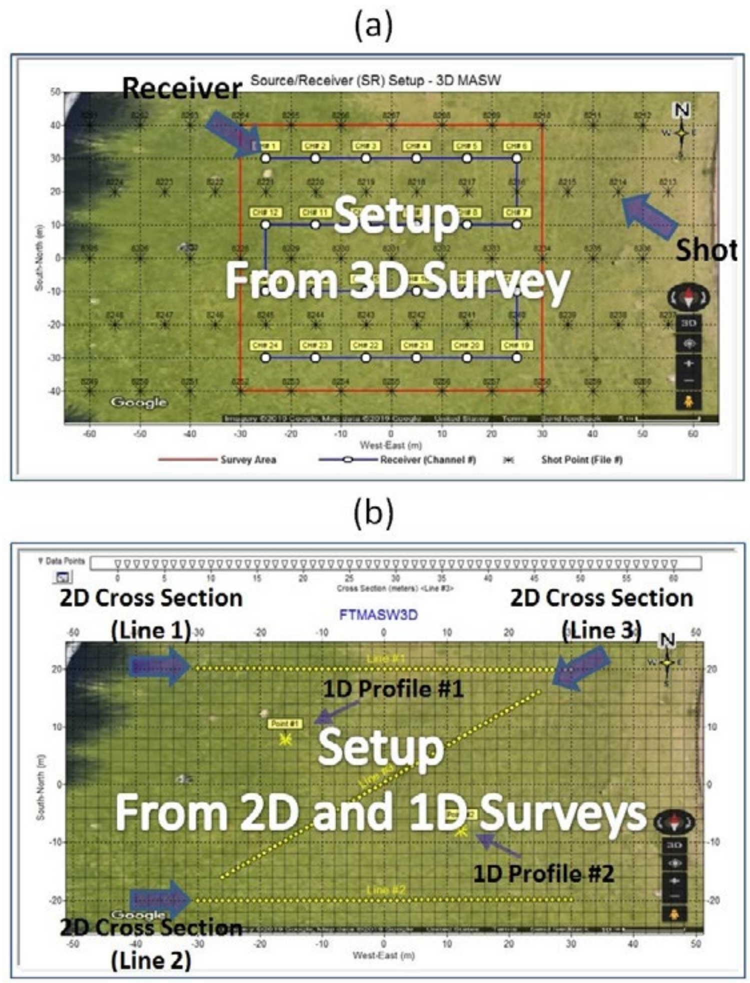

Figure 3. Illustration of setting the shot/receiver (SR) patterns in ParkSEIS-3D (a) for a data set from a dedicated 3D survey by importing two separate files of receiver and shot patterns in either a Cartesian (.txt) or a GPS (*.gpx) file, and (b) for multiple data sets from conventional 2D/1D surveys by using mouse or importing location files (*.txt or *.gpx).*

is used depending on the velocity-inversion type. In consequence, the inverse-velocity layers are more accurately handled than by the traditional approach. In addition, the seismic modeling can always provide an ultimate inversion tool for any type of subsurface model.

Figure 4 presents the algorithmic flowchart of ParkSEIS-3D that shows general procedures from both conventional multiple 2D/1D surveys and a dedicated 3D survey.

Discussion

The broader trend toward open-source software appears to be influencing the geotechnical community as well. When available, open-source software may be preferred among researchers and students as it usually implements core theories, saves coding time, and provides room for customization.

In many commercial settings, however, open-source software carries important risks. Proper calibration and optimization, established from real-world applications, and well-designed GUI are critical to ensure a reliable performance of the software under diverse conditions. In this sense, applying open source codes to commercial settings can often involve a great deal of back-end customization, calibration, and modification especially in terms of user interface as well as algorithmic optimization.

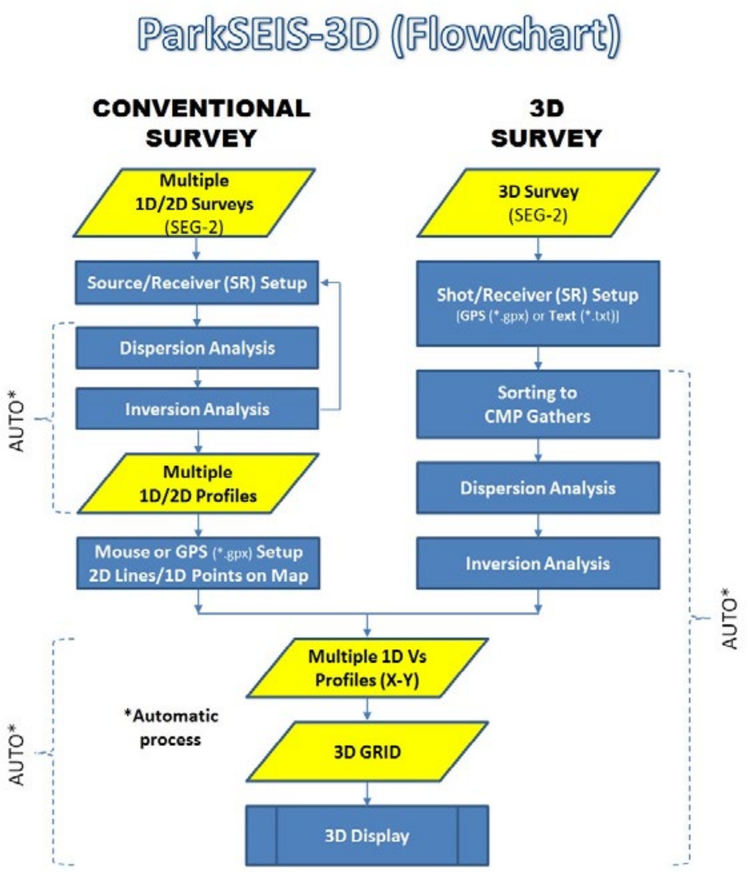

Figure 4. Algorithmic flowchart of ParkSEIS-3D for 3D MASW analysis from both conventional 2D/1D surveys and a dedicated 3D survey.

For many engineering applications, the barriers to using open source materials can therefore be prohibitive, and may include not only lack of in-house expertise but also time pressure and concerns about consistency in analysis results. An analogy would be a home-made car with one engine sitting on a 4-wheel frame versus a commercially available car with all high-tech safety and convenience features installed; most would-be drivers are mainly interested in safe and reliable driving, less in the process of tinkering with the parts and settings.

Conclusions

ParkSEIS-3D is a software package designed to enable 3D MASW surveys (in addition to 1D and 2D surveys). It includes the following important features which may be particularly important in enabling reliable all-in-one 3D survey and analysis:

Shot and receiver (SR) setup is conveniently accomplished through Graphic-Wizard approach.

Coordinates of SR patterns are imported simply by preparing a Cartesian (*.txt) or a GPS (e.g., *.gpx) file.

Field logistics for a potential 3D project are provided by a template chart of SR patterns that account for survey dimension, desired spatial sampling, and a given set of field equipment.

Data rearrangement into CMP gathers takes place automatically based on required depth of investigation and surficial dimension of survey area for given SR patterns applied in the field.

Dense shot patterns can be generated so that conventional field equipment (e.g., 24 channels) can be used to cover a relatively large area (e.g., 100 m x 100 m) with a sufficient spatial resolution (e.g., 2 m x 2 m) from one survey.

Diverse 3D visualization modes are available; i.e., cubic maps in different directions and perspectives.

Output 3D velocity (Vs) grid data can be exported into a user-defined format.

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Dr. Choon Park is lead author of the MASW technique published in GEOPHYSICS in 1999 while he was working at the Kansas Geological Survey (KGS). He is the author of the ParkSEIS software for MASW analysis. He is also author/co-author of other near-surface seismic data-processing software packages developed at the KGS (SurfSeis, WinSeis, and Eavesdropper). Dr. Park founded Park Seismic LLC in 2007 to provide services and Research and Development (R&D) in MASW method where he is currently working as the principal geophysicist. He holds a B.S. in physics and science education from Seoul National University, an M.S. in Geophysics from Ohio University, and a Ph.D. from the University of Kansas.