

PS — Overview

– "Description of General Procedure" –



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Preface



The multichannel analysis of surface waves (MASW) method provides one of the most critically important geotechnical parameters—the stiffness of ground materials. It gives this information in terms of seismic shear-wave velocity (V_s) distribution in both vertical and horizontal directions. From an elastic theory viewpoint, shear-wave velocity (V_s) is the most powerful indicator of a material's stiffness.

ParkSeis (PS) generates a shear-wave velocity (V_s) profile (1-D or 2-D) by analyzing fundamental-mode (M0) Rayleigh-type seismic surface waves. Although there has been a great deal of research and development in multi-mode utilization, software that takes full advantage of multi-mode while efficiently handling all the associated complications has not yet been developed. This is because of the modal characteristics of surface waves that are ultimately determined by the velocity (V_s) structure, the unknown that we attempt to know through the MASW analysis. Yet, the traditional approach of the fundamental-mode (M0) inversion provides an excellent outcome under most common overburden/bedrock settings, and can provide a 1st-degree approximation of other more complex settings. ParkSeis enables the user to utilize this most reliable approach.

This software presents the most up-to-date algorithms in the analysis of MASW data that have evolved over the last two decades of my own career as a researcher and practitioner in this particular field. Although I personally believe both aspects of my career have helped to make this software robust yet user friendly, I also know it would be an unrealistic expectation to hope it is completely free of bugs. To that effect, I would greatly appreciate your user feedback, and look forward to incorporating suggestions for further development.

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Overview

This user's guide provides a general understanding of the objectives and procedures covered by the ParkSeis (PS) program. If you are ready to start using the program, you can refer to "Getting Started" included in the "Help" on the main menu.

ParkSeis (PS) processes Rayleigh-type seismic surface waves acquired from MASW ("multichannel analysis of surface waves") surveys. PS will generate shear-wave velocity (V_s) profile (1-D or 2-D) by analyzing the fundamental-mode (M_0) dispersion curve of Rayleigh waves. The starting input data file should consist of one or more of raw field data sets, called "records", recorded by using a multichannel recording device; for example, a 24-channel engineering seismograph. Although the minimum number of channels for the input data tested with PS was four (4), it is highly recommended that the recording device have twelve (12) or more channels. The upper limit is virtually open within the scope of the data format adopted for this program (the "PS" format), in which the headers are 2-byte integers that can express a maximum integer up to about 32000.

The basic and minimum input data element for PS is one record that consists of a suite of individual channel recordings called "traces." The field records should be saved in the SEG-2 format, which is an engineering standard that most engineering seismographs adopt as the default output format. Other text data files can be converted to the PS format by using a conversion module ("TXT2PS") included in the "Utility" of the main menu. All SEG-2 records are internally converted to PS format as soon as they are imported by the program, and all intermediate and final outputs of seismic data sets will be in this PS format.

The overall procedure with the PS program to generate a V_s profile (1-D or 2-D) consists of the following steps:

1. Field Data (SEG-2 Format)
2. Internal Format (PS Format)
3. Source/Receiver (SR) Setup
4. Dispersion Image Generation
5. Dispersion Curve (M_0) Extraction
6. Inversion

The general flowchart of the procedure is displayed in Figure 1. Each of these steps is explained in the following.

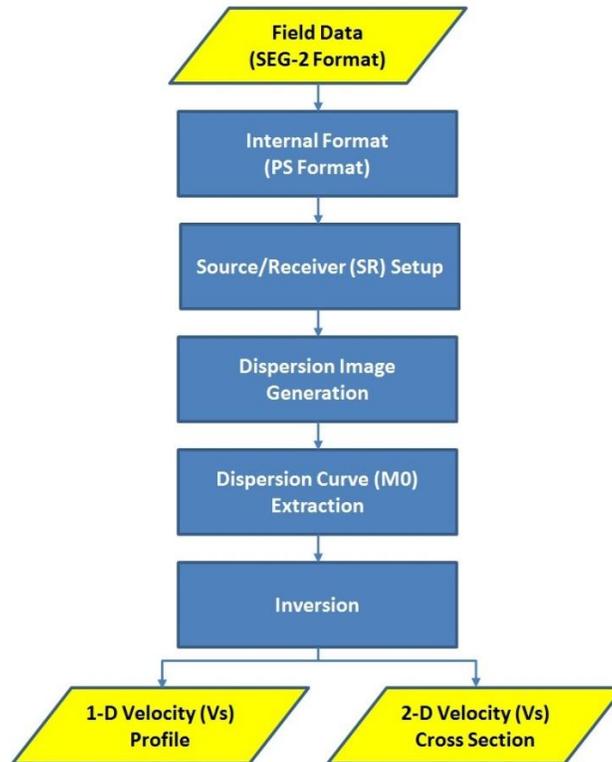


Figure 1. Generalized flowchart of ParkSeis (PS) software

1. Field Data (SEG-2 Format)

Multichannel (e.g., 24-channel) seismic data sets (called "records") are acquired in SEG-2 format, an engineering standard, by using a multichannel recording device (e.g., seismograph). Usually, multiple number of records (e.g., 20) are collected during both 1-D and 2-D MASW surveys. (Visit <http://www.masw.com> for information about MASW field surveys) If the operator chooses to do so at the beginning of the operation, the source/receiver (SR) configuration is usually encoded by the acquisition software in the proper parts of recorded SEG-2 records. If this choice is not made at the beginning of the operation, the acquisition software will encode default settings into the saved SEG-2 records that likely will not reflect the correct configuration for the particular survey being performed.

2. Internal Format (PS Format)

All SEG-2 records imported by PS are first internally converted to another format called "PS format" that is a modification of the "KGS format (or modified SEG-Y format)." This conversion is necessary to handle seismic data in a faster and more accurate manner for advanced and non-conventional wavefield operations commonly used in various stages of MASW data processing. In PS format, each channel's data set (called a "trace") is saved as a combination of a header (of 120 elements of 2-byte integer each) followed by data samples (of 4-byte floating-point value each). A complete list of the "PS Header" can be displayed by choosing the "PS Header" under

the main menu's "Info." All output types of seismic data are saved in PS format with a "DAT" extension (e.g., "Output.dat").

3. Source/Receiver (SR) Setup

Relative locations of seismic source and receivers are encoded into the header of each channel's data set ("trace"). Those critical parameters—receiver spacing (dx), source offset (X1), movement of source and/or receivers, distance within the survey line of source and receivers, station numbers, etc.—are inserted into the proper headers. In reality, these parameters are usually set at the beginning of the survey in the acquisition software. If that is the case, then PS will inform it at the beginning of the SR setup so that the user can examine the encoded information of the imported SEG-2 records in a displayed chart. If user confirms the displayed setup is correct, then this SR setup is skipped. If user finds the original field data set does not have proper information encoded, then this SR setup is crucial and cannot be skipped.

Output from this step will have the same extension as input seismic data (".DAT") with a post fix of "(SR)" at the end of the file name; for example, "Output(SR).DAT." Description about this step of analysis can be found in the PS User Guide "[Source-Receiver \(SR\) Setup](#)."

4. Dispersion Image Generation

Once SR setup is complete, the next step is to generate dispersion images; one dispersion image per record. Because the input seismic data file [e.g., "Output(SR).DAT"] usually has multiple (e.g., 20) records, the output dispersion image file will accordingly have many images. These dispersion "images" are actually another instance of numerical data similar to seismic data, and different from the ordinary graphical images (for example, BMP or JPG files). In fact, they have the same numeric data format as used in the seismic data (i.e., PS format) and therefore can be displayed using the seismic data display module (however, there is a dedicated module to display dispersion images). In this sense, these image data are also called (dispersion-image) records.

There are many parameters related to dispersion imaging processing, which is basically a wavefield transformation operation that converts seismic wavefields in offset-time (x-t) domain into those in phase velocity-frequency (Pv-f) domain. These parameters can influence the quality and size of the image. In most cases, however, the program will set them to the most optimal values through many internal automated analysis steps. Output will have the same extension as input seismic data (".DAT") with a post fix of "(ActiveOT)" at the end of the file name [or "(PassiveOT)" and "(COMOT)" for passive and combined survey cases, respectively]; for example, "Output(SR)(ActiveOT).DAT." More information about this step of analysis is provided in the PS User Guide "[Dispersion Image Generation](#)."

5. Dispersion Curve (M0) Extraction

For 1-D Vs Profiling

This step extracts and saves the fundamental-mode (M0) dispersion curve from each dispersion image generated from previous step. Although there may be multiple dispersion images

generated, usually they all originated from the receiver array that stayed at the same surface location. Therefore, it will have little meaning to extract separate M0 curves from each of these images. Even if all separate M0 curves are extracted, it will be very unlikely they will all look identical because each image has slightly different dispersion characteristics dominating over different frequency and phase velocity ranges. This is because they all had different source locations and are therefore influenced to a different extent by near-field effects and lateral subsurface variation. Instead, these images should be stacked (i.e., averaged) to produce one image that has the most accurate dispersion characteristics over the broadest frequency and phase velocity ranges through the constructive interference of coherent dispersion trends, while suppressing inconsistent random noise energy patterns.

Generated dispersion image data [*(ActiveOT).DAT] will be displayed by a dedicated module. Then, the program will ask if you want to stack the images to produce one final image to be used for the extraction of an M0 curve. If 'stacking' is not chosen, then the remaining procedure will be identical to generating a 2-D velocity (Vs) cross section after extraction of all M0 curves. In this case, the record number (instead of surface distance) will be used as the horizontal coordinate for the 2-D cross section. However, it is highly recommended that you choose the stacking option until you become fairly well experienced in recognizing complicated dispersion patterns. At that point, you will be able to decide if any of the individual images possess the dispersion pattern superior to that of the stacked image, as is sometimes the case.

Once the stacked image is displayed, then first it will be necessary to visually examine the image and make an interpretation for the M0 trend. This interpretation usually will be simple and easy when there is only one obvious trend of coherent energy, which is often the case in most overburden/bedrock settings (except for "too" shallow bedrock). Once this identification has been made, then you can define the approximate M0 trend by clicking multiple points (e.g., 5-10) along the identified image trend. The program will then draw both lower and upper bound curves within which it will try to extract the most probable M0 curve by examining energy levels at each frequency. You can freely change these curves to refine the zone of examination.

The extracted dispersion curve will be saved as a text file of its own format with an extension of ".DC" with a post fix of the record number within parentheses [e.g., "Output(SR)(ActiveOT)(1).DC"]. There will be only one dispersion curve file (*.DC) saved at the end of this step. More information about this part of the analysis can be found in the PS User Guide "[Dispersion Curve Extraction \(1-D Profile\)](#)."

For 2-D Vs Cross Section

This step extracts and saves one fundamental-mode (M0) dispersion curve from each dispersion image generated from the previous step of "Dispersion Image Generation." First, generated dispersion image data [*(ActiveOT).DAT] will be displayed by a dedicated module. Then, it will be necessary to visually examine the image and make an interpretation for the M0 trend. This interpretation usually will be simple and easy when there is only one obvious trend of coherent energy, which is often the case in most overburden/bedrock settings (except for "too" shallow bedrock). Once this identification has been made, then you can define the approximate M0 trend by clicking multiple points (e.g., 5-10) along the identified image trend. The program will then draw both lower and upper bound curves within which it will try to extract the most

probable M0 curve by examining energy levels at each frequency. You can freely change these curves to refine the zone of examination.

The extracted dispersion curve will be saved as a text file of its own format with an extension of ".DC" with a post fix of the record number within parentheses [e.g., "Output(SR)(ActiveOT)(1).DC"]. At the end of this step there will be as many files saved as there are input dispersion images (e.g., 20). More information about this part of the analysis can be found in the PS User Guide "[Dispersion Curve Extraction \(2-D Cross Section\)](#)."

6. Inversion

For 1-D Vs Profiling (Automatic 1st Phase)

This step will generate one 1-D (i.e., depth variation) shear-wave velocity (Vs) profile from the input M0 dispersion curve previously saved [e.g., "Output(SR)(ActiveOT)(1).DC"].

There are many parameters that can influence the reliability of inversion output. Among them is the most important, the maximum depth (Zmax) of output, which is the depth to the half space (i.e., depth to the top of the last layer of infinite thickness, the half space). Zmax is determined by the program based on the minimum (Xmin) and maximum (Xmax) distances of the receiver from the source that were used during data acquisition. However, you can always modify it, as needed, according to your own experience and knowledge. Other inversion parameters, such as number of layers and searching-algorithm related parameters, are set to default values by the program although they can always be manually changed by the user. During the inversion process, the program will display both measured and modeled dispersion (M0) curves to indicate how closely they match for the solution found by the program.

There will at least two (2) output files saved at the end of the inversion process, all in text files but with different extensions; 1-D Vs profile file [*(1DVs).LYR] and its modeled dispersion (M0) curve [*(Model).DC]. The processing history of all inversion parameters (for example, number of layers, number of iterations, final match between measured and modeled dispersion curves, etc.) is included in the Vs profile (*.LYR). The Vs profile will show depth variation of shear-wave velocity (Vs) within the maximum investigation depth (Zmax), whereas the modeled dispersion curve will show the theoretical M0 curve corresponding to the velocity (Vs) profile.

The Vs profile will be displayed automatically at the end of the inversion process. This will be the velocity (Vs) model found automatically by the program without user's intervention, based on its own searching algorithm, and is usually sufficient to dictate the reality. Then, this completes the entire procedure to generate the 1-D Vs profile. More information about this part of the analysis can be found in the PS User Guide "[Inversion \(1-D Profile\)](#)."

For 1-D Vs Profiling (Optional 2nd Phase)

However, it is often beneficial to attempt one or more rounds of the inversion process through a manual searching process possibly followed by another automatic inversion process. This can often lead to finding a profile whose theoretical (modeled) M0 curve matches the measured M0 curve even better (i.e., a higher match), or a profile that appears more realistic. This is

especially true under two possibilities. First, due to the non-uniqueness of inversion, a property inherent to all types of inversion processes, the Vs profile found automatically by the program may appear very unrealistic (for example, a highly oscillating profile) although its M0 curve matches very closely to the measured one. In this case, it is necessary to manually update the profile until it looks more realistic while maintaining a comparable (or even improved) match between the two M0 curves. Second, due to the possible error at one or more data points in the measured M0 curve (that in turn may be a result of noisy data or analysis error), the inversion process can sometimes generate an unrealistic Vs profile in response to the searching algorithm trying to find a solution that satisfies all data points in the input M0 curve as much as possible. Again, in this case, it will be necessary to manually update the profile, possibly followed by another automatic inversion after the update. Whenever either or both of these two possibilities are suspected, another round of inversion will be necessary that should start with the manual update of the profile by using the computer mouse. The risk of the non-uniqueness issue in inversion will be significantly reduced if the manual update is followed by another execution of the automatic inversion that will use the updated profile as the initial velocity model. Extending the degree of freedom in inversion variables by choosing the 'Variable Depth' option on the "Layer (Earth) Model" tab in the control dialog can significantly improve the effectiveness of the new searching process. More information about this part of the analysis can be found in the PS User Guide "[Inversion \(1-D Profile\)](#)."

For 2-D Vs Cross Section

This step will generate one 1-D (i.e., depth variation) shear-wave velocity (Vs) profile (*.LYR) from one input M0 dispersion curve (*.DC), and then produce a 2-D (i.e., depth and surface) Vs cross section by using multiple 1-D Vs profiles through a proper 2-D interpolation.

There are many parameters that can influence the reliability of this inversion output. Among them is the most important the maximum depth (Zmax) of output, which is the depth to the half space (i.e., depth to the top of the last layer of infinite thickness, the half space). Zmax is determined by the program based on the minimum (Xmin) and maximum (Xmax) distances of the receiver from the source that were used during data acquisition. However, you can always modify it according to your own experience and knowledge. Other inversion parameters, such as number of layers and searching-algorithm related parameters, are set to default values by the program although they can always be manually changed by the user. During the inversion process, the program will display both measured and modeled dispersion (M0) curves to indicate how closely they match for the solution found by the program. The overall matching variation from one file to another file of the input dispersion curves will also be displayed.

There will be at least three (3) output files saved at the end of an inversion process for 2-D Vs cross section, all in text files (*.TXT); 2-D Vs cross section file [*(2DV).TXT], 2-D Vs confidence file [*(2DConf).TXT], and processing history file [*(HST).TXT]. The Vs cross section file will show 2-D distribution of shear-wave velocity (Vs) within the surveyed surface distance and maximum investigation depth (Zmax) set during the inversion. The confidence file will show distribution of relative reliability (%) of analyzed velocity (Vs) values within the cross section. This confidence concept is directly linked to the sensitivity of modeled dispersion curve [*(Model).DC] to the velocity (Vs) change at a particular part of the cross section by a certain amount (e.g., $\pm 10\%$). Therefore, it purely reflects the relative level of reliability (0-100%) in the solution-seeking process with the premise that the input (measured) M0 curve is error free. The history file will

contain all parameters set at the beginning of the inversion process as well as some parameters related to output Vs values, such as matching degree (%) of the two M0 curves. Some other types of output can also be chosen at the beginning of the inversion process as secondary outputs. They may include modeled dispersion curves [*(Model).DC] and 1-D Vs profile [*(Model).LYR] for each input (measured) M0 curve. Variation of the match between the two M0 curves [*(Match).DC] can also be saved with the same file format as dispersion curves so that it can be displayed by using the dispersion-curve display module. Variation of average 1-D Vs confidence can also be saved as a file [*(AveConf).DC] so that it can be displayed by using the same display module.

Both Vs cross section [*(2DVs).TXT] and confidence [*(2DConf).TXT] maps will be displayed at the end of the inversion process. More information about this part of the analysis can be found in the PS User Guide "Inversion (2-D Cross Section)."