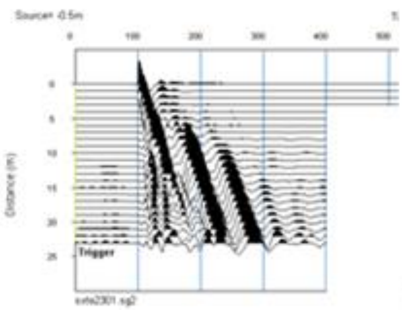
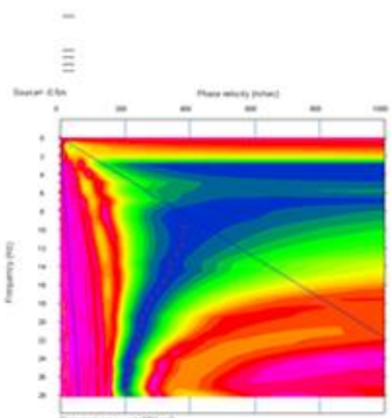
SEISIMAGER/SW USER'S MANUAL

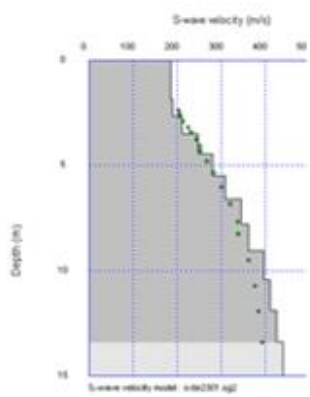
Software for the Analysis of Seismic Surface Waves

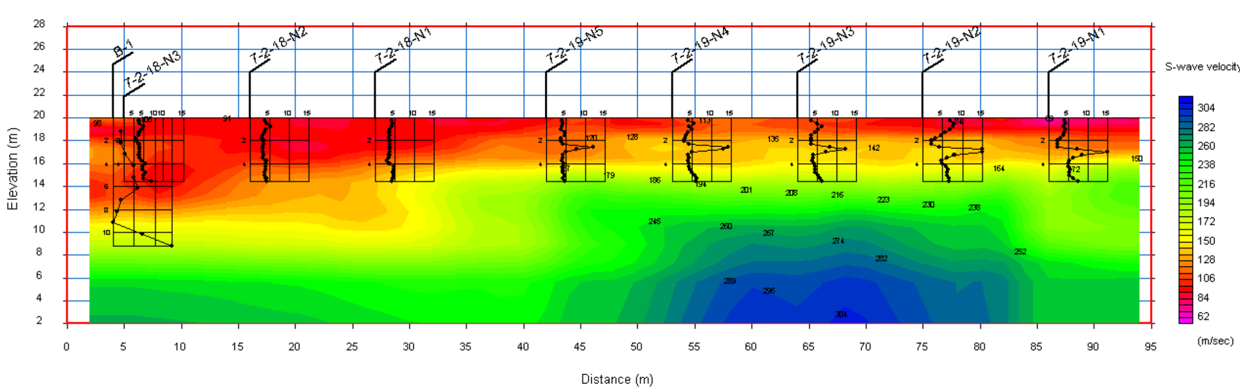
Version 4.0
P/N 770-00118-01

July 2024









Koichi Hayashi / Deb Underwood / Craig Lippus

TABLE OF CONTENTS

APPENDICES

1 INTRODUCTION

Welcome to SeisImager/SW™! SeisImager/SW is an easy-to-use, yet powerful program that allows you to analyze multi-channel active- and passive source (microtremor) surface wave data. SeisImager/SW includes functions to perform the following basic procedures, and more:

- Input and display data.
- Control how data is displayed.
- Make changes/corrections to data files and save them.
- Calculate and edit dispersion curves.
- Invert data for a one-dimensional shear-wave velocity curve.
- Invert data for a two-dimensional shear-wave velocity cross-section.
- Display results in graphical form.

SeisImager™ is the master program that consists of seven modules for refraction, downhole, and surface wave data analysis. The individual modules are Pickwin™, Plotrefa™, WaveEq™, PSLog™, SPACPlus™, and GeoPlot™. The Surface Wave Analysis Wizard™ is not a separate module but automatically calls on specific functions from Pickwin, WaveEq, and GeoPlot to walk you through the analysis process. The overall structure of SeisImager is shown below:

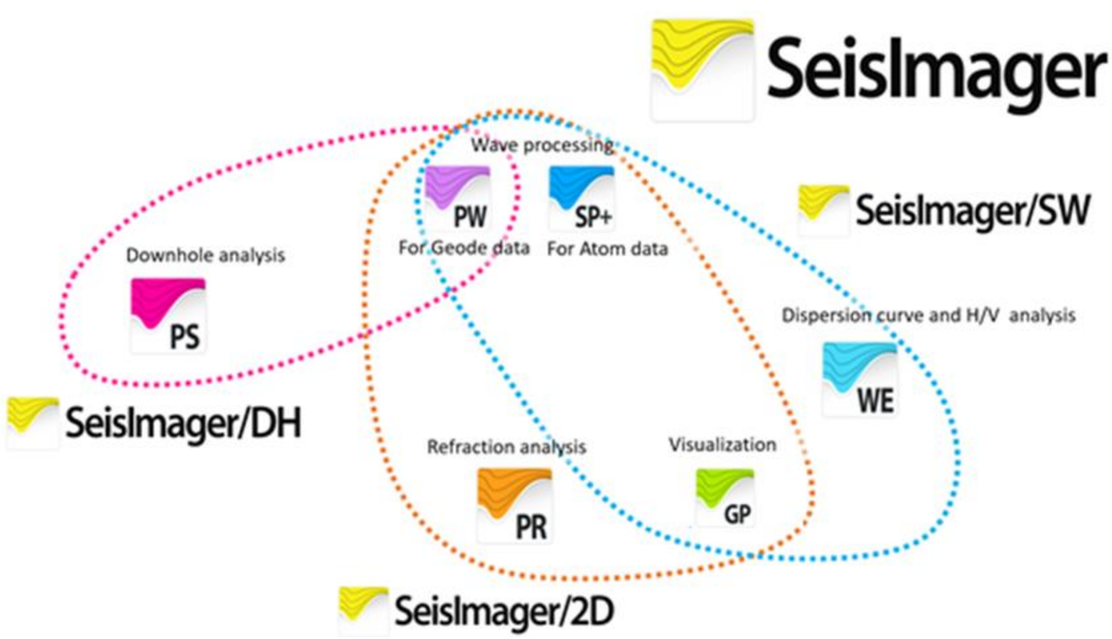


Figure 1: SeisImager family of applications.

Pickwin and WaveEq are the main modules used for surface wave data analysis, making up the program called SeisImager/SW, which is available in two packages. The first, SeisImager/SW-1D, is capable of one-dimensional (1D) analysis of multi-channel active- and passive source (microtremor) data, with output of a single curve of shear-wave velocity (V_S) viewed in WaveEq. The second package, SeisImager/SW-2D, is capable of two-dimensional (2D) analysis of multi-channel active- and passive source data, with output of a cross-section of V_S viewed in GeoPlot. Note that GeoPlot is its own standalone module for general data visualization. In this manual, only the GeoPlot functions needed in the 2D surface wave analysis process are covered. See the GeoPlot manual for full documentation of GeoPlot.

For refraction data analysis, Pickwin and Plotrefa make up the program called SeisImager/2D. A separate manual exists for SeisImager/2D, and due to the overlap of Pickwin with SeisImager/SW, reference is made to the SeisImager/2D manual for explanation of the common Pickwin menus.

SeisImager is also available for rent in run-time periods of 40, 75, and 250 hours. The rental package, by default, includes both SeisImager/2D and SeisImager/SW-2D.

Section 2 of this manual describes software installation. Section 3 describes data acquisition methods, and Section 4 describes data analysis using the wizard. Section 5 describes the features and capabilities of SeisImager/SW-Pro™. Section 6 explains the surface wave functions of Pickwin, and Section 7 describes the WaveEQ functions. Appendix A goes through the basic processing flows, and Appendix B discusses data quality control. Some theory is touched on (see Appendix C), but this manual is not meant to be a treatise on multi-channel analysis of surface waves (MASW) or microtremor array measurements (MAM). It is assumed that the user has a reasonable grasp of the main principles of seismology and mathematics to understand the principles behind the analysis techniques employed by the software. Appendix D provides links to online tutorials with example data, and Appendix E provides a list of links to short course material. Finally, see Appendix F for a list of recommended reading on surface wave theory and techniques.

Although this manual can be printed, **it was designed as an online resource, and includes many internal and external hyperlinks**. It will be updated on a semi-regular basis, and a current version will always be available for download on our site. Be sure to display the navigation tool bar in Acrobat Reader (as of this writing, the toggle switch was F8) to simplify navigation:

Figure 2: Acrobat Reader navigation tool bar.

If your version of Acrobat Reader does not have the above tool bar, use *Alt+Left Arrow* to return to the previous view after clicking on a link.

The manual makes liberal use of color, so if you elect to print it, using color is highly recommended.

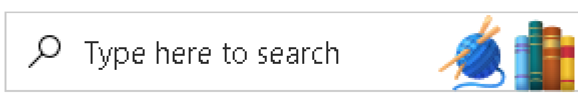
Finally, we are very interested in your constructive criticism of both this manual and the software itself. Please contact us at seismicsales@geometrics.com with any comments you might have.

Note: *This is a general manual covering all features of all versions of SeisImager/SW. There are several tiers of software available, all having different sets of features. If you see features described in the manual which are not present in your software, it is because the level of software you purchased does not include those features.*

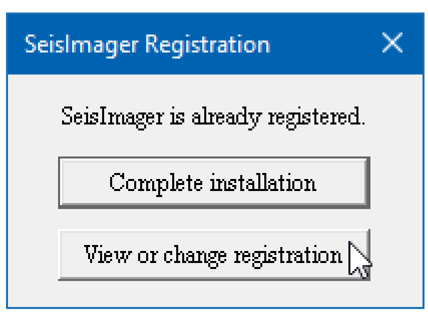
Note: *SeisImager/SW includes many features that are very rarely used, and only then by a select few, often only those who requested the features in the first place. The average user will generally have no need for them. In the interest of completeness, these features, although not described, are included in this manual, with a pointer to our support email. If you see something that you think you might wish to make use of, please contact SeisImager support.*

Note: *SeisImager/SW is very complex software "under the hood" and may grow unstable and give spurious results if many different models are run in one session or if there are unit conflicts between modules. It is therefore best to begin a new instance of the application to run new models. If the program does exhibit instabilities, follow this procedure:*

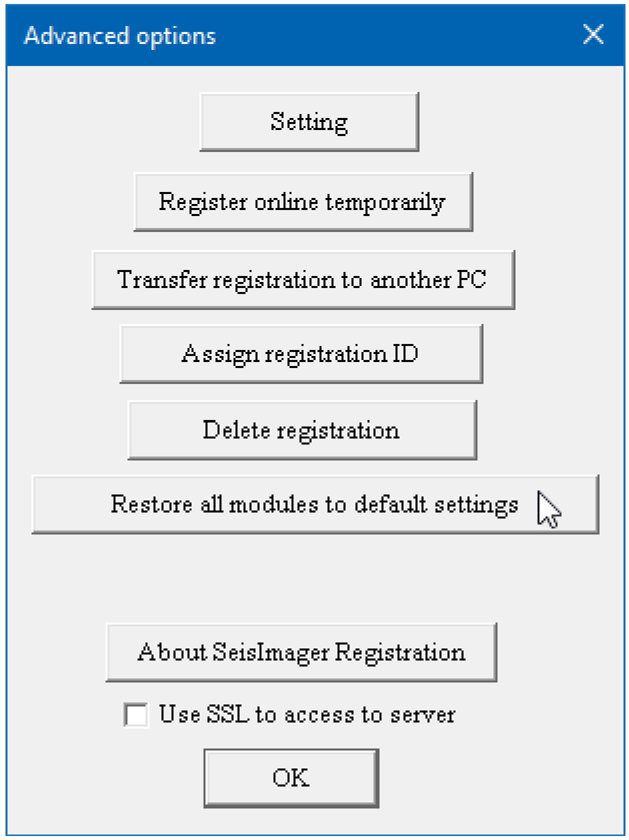
- Close all SeisImager modules.
- In the Windows search box,



Type in "SeisImager Registration." You will see the following:



- Select *View or change registration*. You will be presented with the **SeisImager Registration** dialog box.
- Select Advanced options (upper right) and then press Restore all modules to default settings and then press OK.



Note: *Throughout this manual, you will find that certain menu items are greyed out. There are two reasons for this. The most common is that the feature is not applicable to that dataset or that point in time. The other reason is that some items may not be available under your license.*

Prior to reading this manual, you might find it instructive to watch some videos on MASW, MAM, and H/V data acquisition and analysis:

Seismic Surface Waves Overview (5.48)

1D MASW (active source) Field Setup and Data Acquisition – Geode Seismograph (4:53)

1D MASW (active source) Data Processing using SeisImager/SW (30:53)

Atom Seismograph Field Operations and pro (9:37)

MAM and H/V Analysis of Atom Data (28.53)

1D MASW (active source) and MAM (passive source) Acquisition and Analysis using the Atom-1C Seismograph (50:40)

2 INSTALLING THE SOFTWARE

The SeisImager USB stick is supplied (1) for trial evaluation of the programs, (2) for purchase, rental, or upgrade of one or more of the programs, or (3) with purchase of an ES-3000™, Geode™, or StrataVisor NZXP™, or Atom™ seismograph, which all include the Lite version of SeisImager/2D. The USB contains all programs and all documentation.

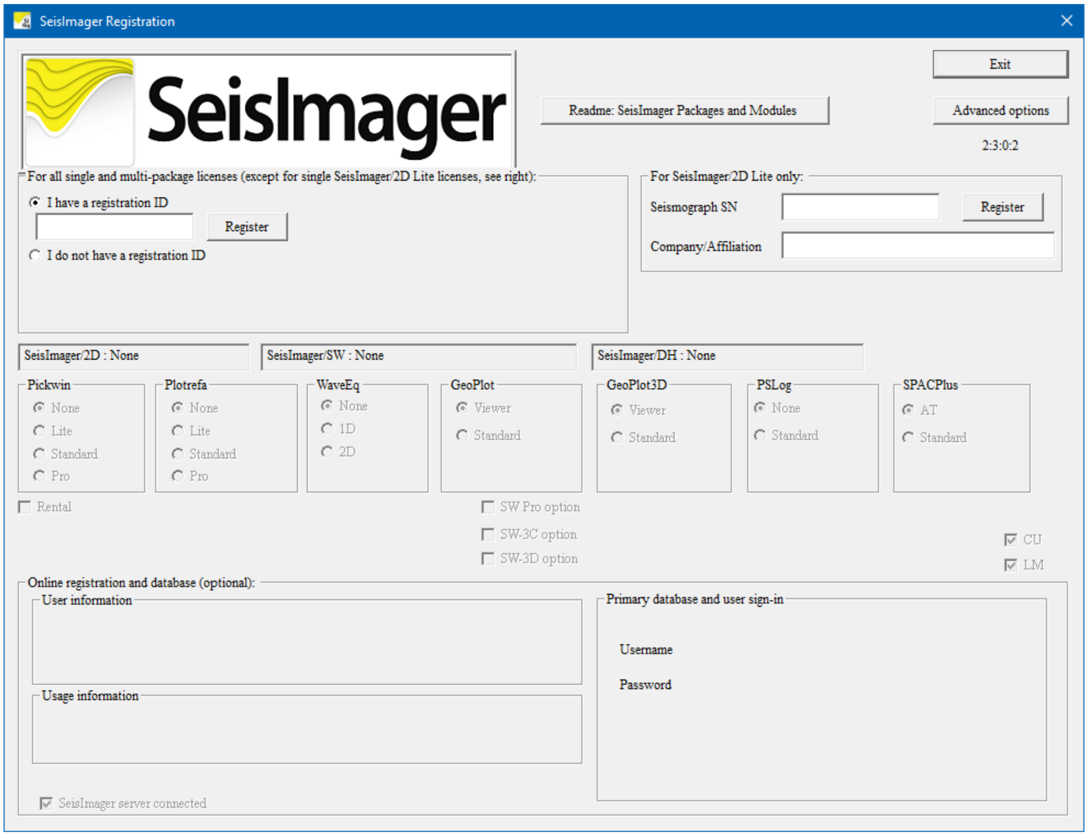
Occasionally, there will be a software release in between USB releases. In this situation, the USB will be labeled with a notice to download the latest version.

Note: *Even if the USB is not labeled with instructions to do so, it is best practice to download and install the latest software prior to installation, as SeisImager is updated frequently. The USB is convenient, especially if you do not have an internet connection. However, if you* ***do*** *have an internet connection, we highly recommend that you skip the USB for installation altogether. If you do so, be sure to download the newest manual as well.*

Note: *You must have administrator rights to install the software. After installation by an administrator, users with lower-level privileges can use the software.*

To install or update the software, click on the file named **SeisImager.msi** (or SeisImager_xxxx.msi). If SeisImager is already installed on your computer, you will be prompted to remove it or repair it. Remove the software, run SeisImager.msi again, and then simply follow the prompts.

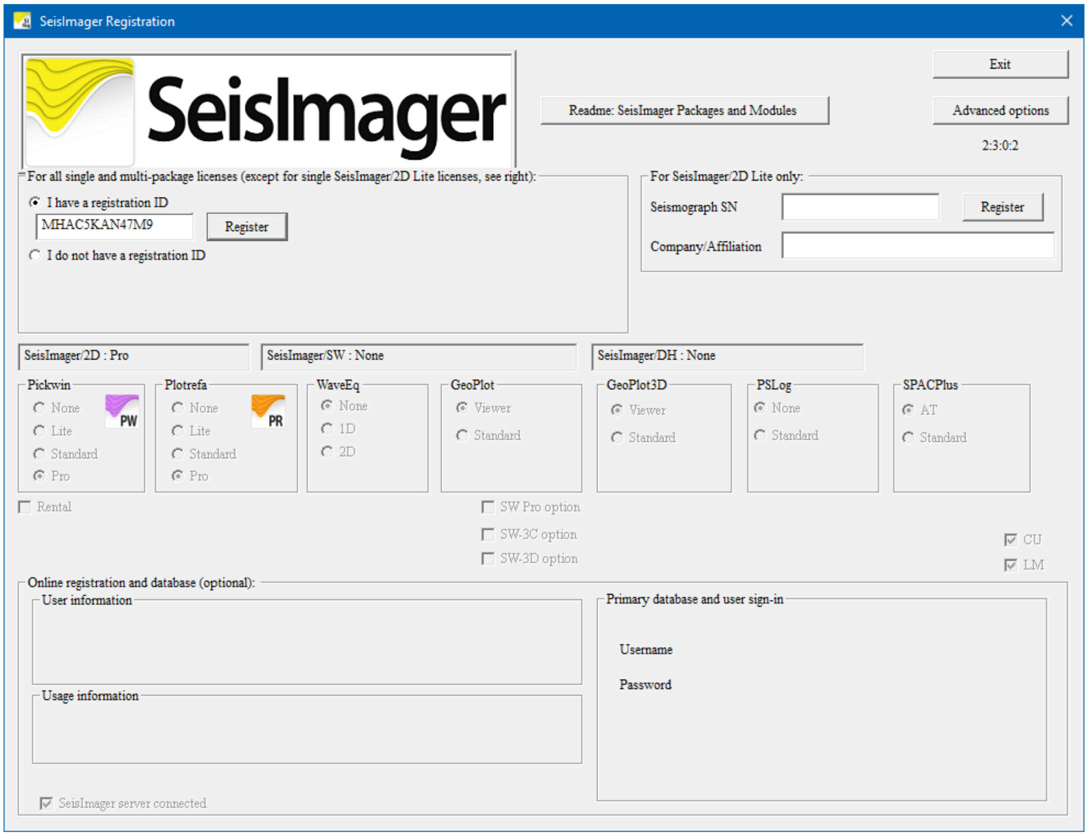
After the installation is complete, you will be presented with the registration screen:



If you already have a registration ID, indicate as such, type it in, and press *Register*. If you do not have an ID, *click I do not have a registration ID*, and send your keyword and order number or seismograph serial number to support@geometrics.com. You will be given a registration ID that will enable the products that you purchased or rented. You may return to this screen later by typing "SeisImager Registration" into the Windows search box at the lower left of your desktop:

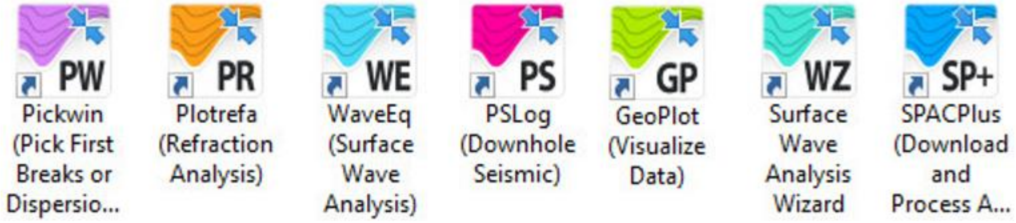
The programs enabled by the registration ID will be reported in a series of messages. Click *OK* to accept each message.

After these messages have appeared, the register will reflect the programs that have been registered, as shown below. In this case, Pickwin Pro™ and Plotrefa Pro™ are the programs that have been registered.



Typically, installing an upgrade of the software does not require re-registration, but if you are upgrading from a version older than April 2007, you will need to re-register.

Once installed, the program modules can be opened directly through the desktop icons shown below:

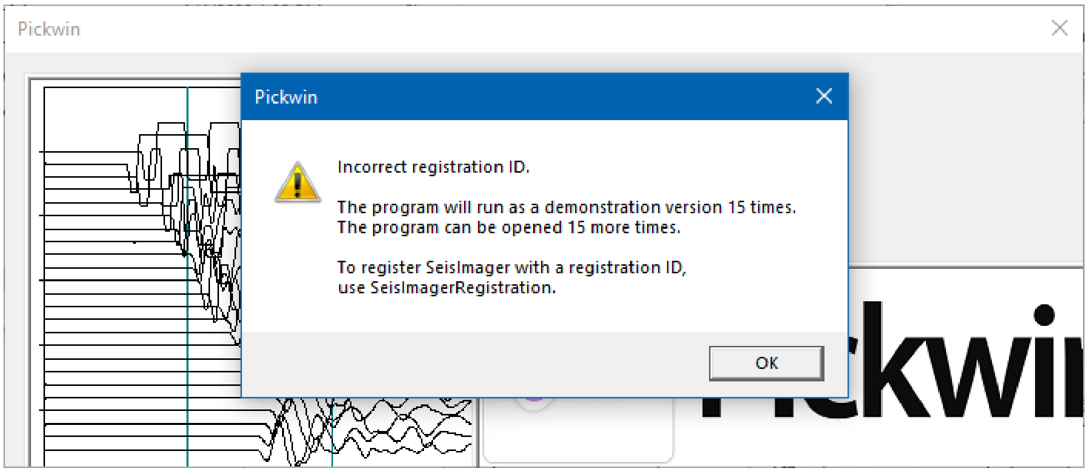


The Surface Wave Analysis Wizard is not a separate module but automatically calls on specific functions from Pickwin, WaveEq, and GeoPlot to walk you through the analysis process. All of the icons (shortcuts) will be copied to your desktop regardless of which program(s) has been purchased or will be used. You may wish to create a folder for the various shortcuts to avoid cluttering on your desktop. Alternatively, you may elect to simply delete the shortcuts that you did not purchase/rent the rights to.

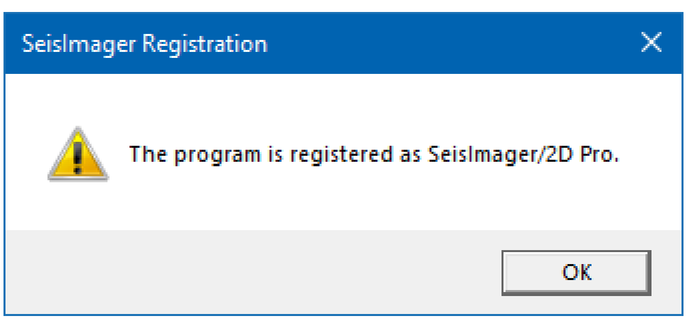
To begin using the software, double-click the appropriate shortcut.

For registered installations, the module opens and is ready for use. The other registered modules are ready for use as well.

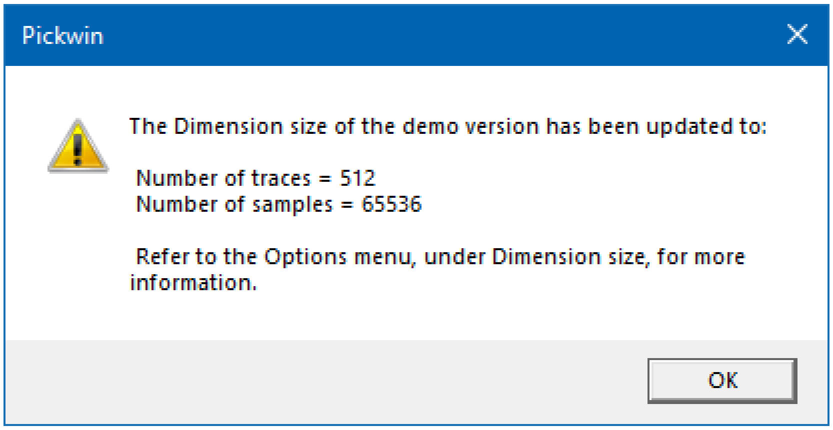
For unregistered installations running in demonstration mode, you will be presented with the message shown below. Press *OK*.



To enter a registration ID after your 15 times in demonstration mode, go to the Windows search box (lower left) and type “SeisImager” to find the SeisImager Registration  program as shown above. Open the register and email the keyword to support@geometrics.com with your order number and seismograph serial number (if you purchased the software with a seismograph), and we will reply with a registration ID to enable the version of the software you have purchased. Once received, enter the registration ID press OK. You will see a message like the following:



Once the software is registered, the data input dimensions of the demonstration version will be updated to reflect the limits of the program purchased. You will see a message like the one below. Press *OK*.



This completes the description of all possible registration pathways.

As mentioned previously, the Lite version of SeisImager/2D comes free with all seismograph purchases, so if you have purchased SeisImager/SW with a seismograph, you are also entitled to the Lite version of SeisImager/2D. If you do not already have a license for SeisImager/2D, Lite or otherwise, but would like to order a copy, please contact us at support@geometrics.com.

A general recommendation when using the SeisImager suite is to close and reopen the software modules or open a second instance of the software modules to start new, separate analyses. The programs are efficient and quickly launch so this is easy to do and will prevent complications when processing data.

Regarding making report graphics and documenting your data processing, SeisImager includes the ability to print graphics to a printer or pdf, as well as save images to PNG, JPG, BMP, or GIF format. You might also find it handy to have a screen capture program such as HyperSnap® from Hyperionics. Bitmap screen captures can be quickly and easily made at the desired stages of processing and saved for import into Microsoft Word or other applications.

For more advanced graphics, consider Geometrics GeoPlot.

3 DATA ACQUISITION

SeisImager/SW includes the functions for three main processing flows, two for analyzing active source datasets and a third for passive source datasets. Methods for collecting these data types for input to SeisImager/SW are discussed in this section with specific set up instructions using the ES-3000, SmartSeis ST, Geode, and StrataVisor NZ seismographs. The basics of running the acquisition and data analysis software are covered, with a brief introduction to surface waves. We recommend and refer you to the published body of literature for an in-depth discussion of surface wave theory and survey methods (See Appendix F, Page F-1.)

Dispersion, or change in phase velocity with frequency, is the fundamental property utilized in surface wave methods. Shear-wave velocity (V_S) can be calculated by mathematical inversion of the dispersive properties of surface waves. Surface wave dispersion can be significant in the presence of velocity layering, which is common in the near-surface environment. In this application, we are concerned with the Rayleigh wave, which is also called “ground roll”, since the Rayleigh wave is the dominant component of ground roll. Although there are other types of surface waves, the term “surface wave”, when used in the SASW (Spectral Analysis or Surface Waves), MASW (Multi-channel Analysis of Surface Waves), or MAM (Microtremor Array Measurement) context has come to mean the Rayleigh wave.

There are two ways surface waves are generated. “Active source” means that seismic energy is intentionally generated at a specific location relative to the geophone spread and recording begins when the source energy is introduced into the ground. This contrasts with “ passive source” surveying, also called “microtremor surveying”, or sometimes referred to as “refraction microtremor” (or the commercial term “ReMi”) surveying. In passive source surveying, there is no time break, and ambient vibrations from energy generated by cultural noise, wind, wave motion, etc. at various (and usually unknown) locations relative to the geophone spread is recorded.

Surface wave energy decays exponentially with depth beneath the surface. Longer wavelength (that is, longer period and lower frequency) surface waves travel deeper and thus contain more information about deeper velocity structure. Shorter wavelength (that is, shorter period and higher frequency) surface waves travel shallower and thus contain more information about shallower velocity structure.

In this context, by their nature and proximity to the geophone spread, it can be said that higher frequency active source surface waves resolve the shallower velocity structure and lower frequency passive source surface waves resolve the deeper velocity structure. When the total depth of interest is great enough to require use of passive source surveys, it is still very important to sufficiently sample the shallower depths. The shallower section will have a relatively large impact on average IBC V_S100 (UBC V_S30) curves and the usefulness of V_S cross-sections. In SeisImager/SW, the results from active- and passive source surveys can be combined to maximize the resolution and overall depth range of investigation.

3.1 1D MASW Data Acquisition

Seismic energy for active source surface wave surveys can be created in various ways, but a sledgehammer to strike the ground is recommended since it is a low cost, readily available item and tends to be energetic enough for most near-surface investigations. Of course, a sledgehammer may not be appropriate for all situations and the actual source used should be tailored to the survey scale and goals. To signal to the seismograph when the energy has been generated, a trigger switch is used as the interface between the hammer and the seismograph. When the sledgehammer hits the ground, a signal is sent to the seismograph to tell it to start recording.

Table 1 on Page 12 summarizes the parameters suggested for active source 1D MASW surveys. Most parameters are self-evident, but two settings to consider further, as they relate to the depth range of sampling, are the spread length and geophone interval.

Surface waves sample to an approximate depth of their wavelength divided by three. Furthermore, in surface wave surveying, it is assumed that the longest wavelength that can be sampled is as long as the spread length. So, to determine the spread length, two times your depth of interest is a good (and the accepted) rule of thumb. However, when combining active- and passive source results, since the passive source survey can be used to sample greater depths, the active source survey spread length need not always be as long as two times the depth of interest. To determine the active source survey spread length, it is suggested to consider the maximum distance that the source energy propagates and the shallowest depth of interest.

For an active source survey with a sledgehammer, a geophone interval of 1.5 to 3 meters (5 to 10 feet) is suggested. Using a 24-channel seismograph, this would give a spread length of 35 meters (115 feet) using the 1.5-meter (5-foot) geophone interval. Applying the ½ wavelength (or spread length) rule of thumb, the depth of sampling would be about 17.5 meters (58 feet). Depending on the site materials and conditions, source energy may not strongly propagate to an offset of 35 meters (115 feet), and stacking may be needed and/or the geophone interval may need to be reduced. You must find a balance between signal propagation, geophone interval, and the spread length. Site-specific testing and judgment should always be applied to confirm that the suggested recording parameters are appropriate.

If you are only doing an active source survey and will not have passive data to resolve greater depths, it is recommended that the spread length be equal to about two times the depth of interest. Additionally, the active source survey can include two (or more) spreads, one with a shorter spread and lighter weight hammer and one with a longer spread and heavier weight hammer (or other source), to sufficiently sample a range of depths.

Parameter	Setting
Spread configuration	Linear.
Spread length	About equal to depth of interest when supplementing with passive source data; about equal to two times depth of interest if no passive source data available.*
Geophone interval	1.5 to 3 m or 5 to 10 ft. *
Total number of geophones	12 or more, minimum of 16 preferred.
Geophone type	4.5 Hz vertical geophones, with base plates for surveys on paved ground.
Shot locations	Minimum of one shot, located in-line and off-end (either end) of spread; reverse shots suggested.
Shot near offset	About 10% to 20% of spread length; an additional shot located at about 40% of spread length is suggested.
Source equipment	Sledgehammer (most common), 8 lbs (3.6 kgs), 16 lbs (7.2 kg), 20 lbs (9 kg), scale hammer weight up with increase in spread length*, and striker plate.
Trigger	Hammer switch taped to sledgehammer handle and connected to seismograph trigger port.
Sample interval	0.5 ms.
Record length	1 to 2 seconds; long enough to capture the surface wave train.
Stacking	As needed to improve data quality, wait for quiet times to shoot.

*Also refer to preceding discussion in text.

Table 1: 1D MASW Acquisition Parameters.

3.1.1 1D MASW Survey Geometry

The geometry of a survey describes the spatial relationship of the shot and receivers. The spread of receivers will have some configuration and relative spacing to the shot(s). When there is one or just a few shots per survey, the geometry is simple and easy to track and record. When the number of shots grows, and especially if the spread locations change, like for a 2D MASW survey (Section 3.3, Page 38), recording the geometry requires more attention and effort.

3.1.1.1 1D MASW Survey Spread Configuration

For 1D MASW surveying, a linear spread configuration is used (Figure 3). The geophones are configured in a straight line on the ground and interconnected with a spread cable (black line). The distance between the first and last active geophones is the *spread length* and the distance between the shot location and the nearest active geophone is the *near offset*. The resultant V_S curve is an average over the spread and accordingly should be located at the center of the spread.

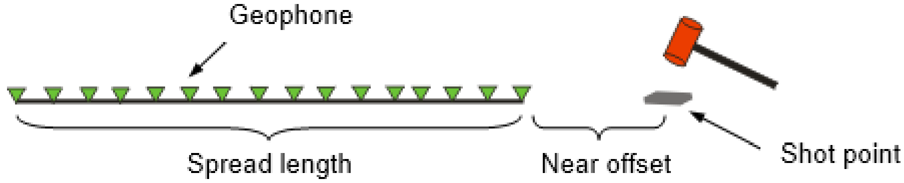
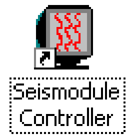


Figure 3: 1D MASW survey spread configuration.

3.1.2 1D MASW Survey Data Acquisition with Geometrics Seismodule Controller Software

The data acquisition setup is illustrated using the Geometrics Seismodule Controller Software (SCS) for the ES-3000, SmartSeis ST, Geode, and StrataVisor NZ seismographs. Other seismographs that record data in the SEG-2 file format can also be used. In this section, the essential software dialog boxes pertaining to acquisition of surface wave data are discussed, with the menu paths indicated in the *PATH* boxes. The menus and dialog boxes are addressed in order that they appear in the software, working from left to right on the menu bar. You may also want to set parameters in other dialog boxes not mentioned in this section. Please refer to the separate manual specific to your seismograph for a complete explanation of SCS. The seismograph manuals should also be referred to for instructions on how to set up the system hardware.

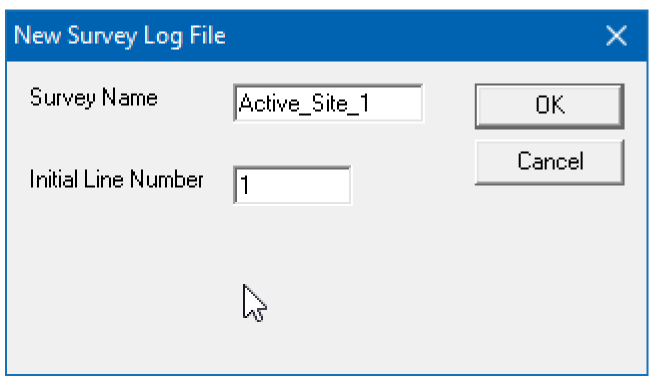
The first step is to install SCS. Once this is done, launch SCS from the icon on your desktop, or from the **Start** menu under *All Programs* **|** *Geometrics, Seismodule Controller*.



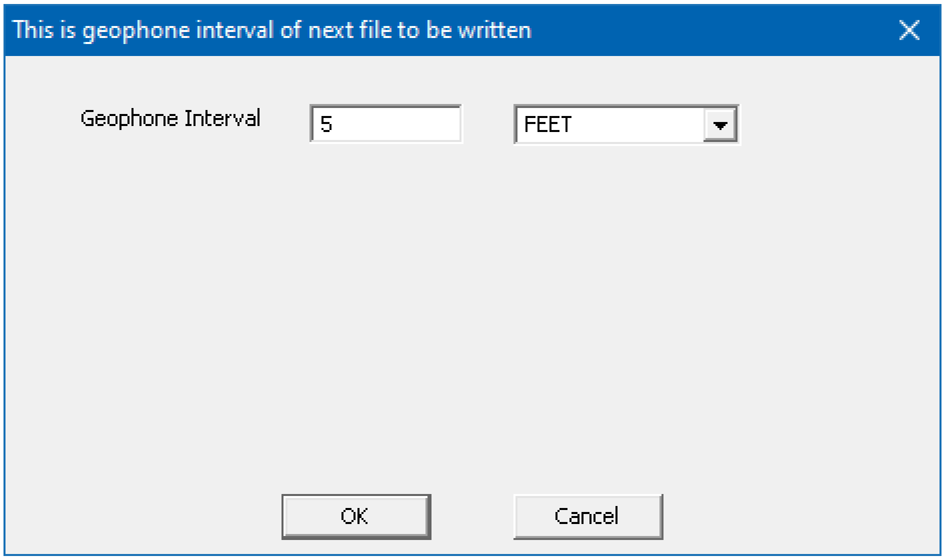
If this is the first installation of SCS on your PC, you will be presented with a 12-digit code and asked for a registration password. Copy and paste the 12-digit code in an email and send with the serial number of your seismograph to support@geometrics.com. You will be sent a 40-digit registration password. Email is recommended because it is easy to mistype or misspeak the code and registration password.

3.1.2.1 1D MASW Survey SCS Setup

First, select *Survey* | *New Survey* to assign a *Survey Name* and *Initial Line Number*. The *Survey Name* is used as the name for the survey log that is maintained during the survey. All software activities during the survey, such as parameters set or files written to the hard drive, are saved to the survey log. The survey log is a text file that you can recall for reference later. Press *OK* when done.

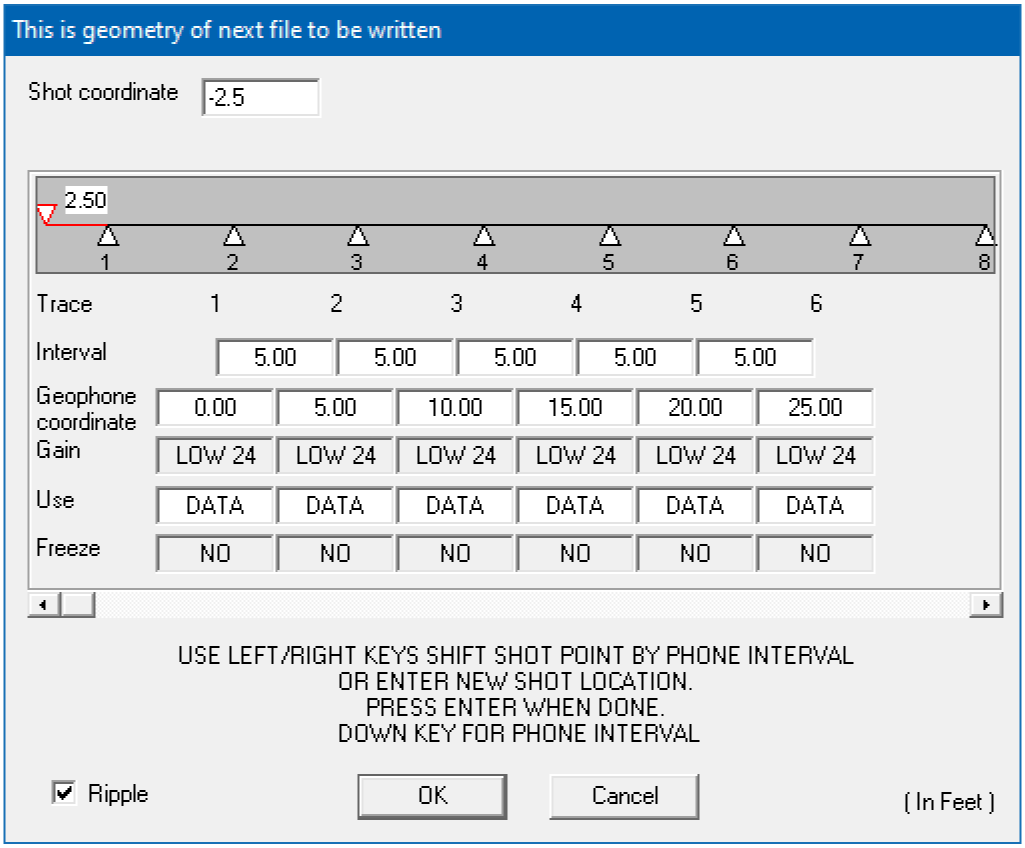


Next, select *Geom* | *Geophone interval* and set the distance between each geophone in the line, and the applicable units. Press *OK* when done.



Next, select *Geom* | *Group/Shot Locations* and set up the survey geometry. In the *Geometry* dialog box, it is recommended to navigate using the keyboard keys, not the mouse. The *up*- and *down-arrow* keys will move the cursor between rows and the *right*- and *left-arrow* keys will move the cursor between columns. Note that the *Backspace* key functions the same as the *left-arrow* key.

Below the graphical display of the spread, the parameters are viewed as rows and columns. The row names are shown on the left-hand side and the column names are the *Trace* numbers shown just below the spread graphic. The cells for *Interval* are offset to indicate that the entered value is the distance between *Trace* 1 and 2, 2 and 3, etc.



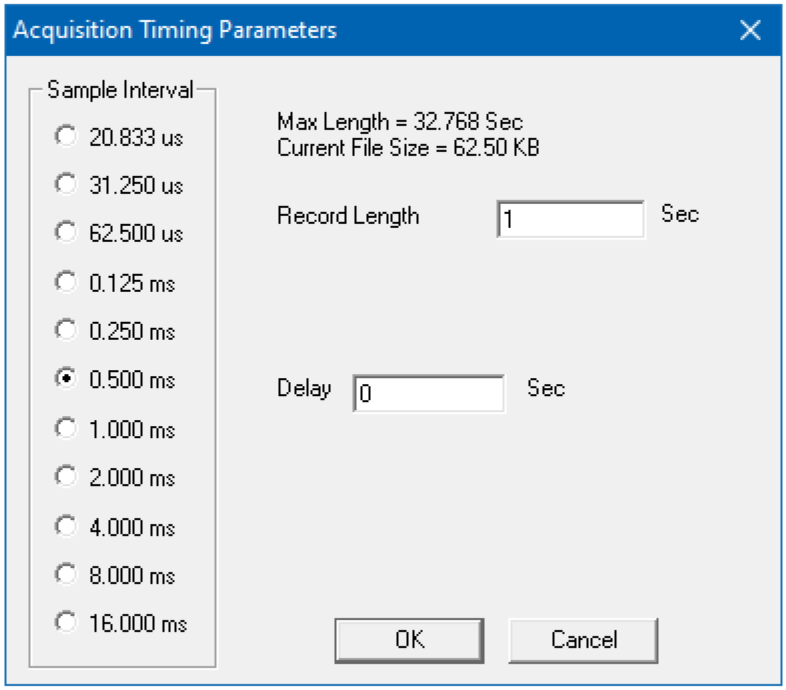
The *Geophone Interval* entered in the previous dialog box is shown. The default *Shot Coordinate* and starting *Geophone Coordinate* is zero, but you may use whatever numerical coordinate system you wish. If a value is changed, the change will "ripple" through the rest of the geophone coordinates if *Ripple* is checked (the default).

Note that the seismograph and geophone cable are wired so that the seismograph is always on the "high side". That is, in native configuration, the nearest channel or geophone to the seismograph is always the highest channel number. For example, with a 24-channel Geode seismograph connected to a standard 24-takeout spread cable, when the line is set up, the nearest geophone to the Geode will be connected to channel 24. Further on this point, if you want the source location to be off the end nearest the seismograph, the *Shot Coordinate* value will need to be changed from 0 to the appropriate value greater than the coordinate of geophone 24. Once it is determined at which end of the spread the shot is located, set the *Shot Coordinate* to reflect that location.

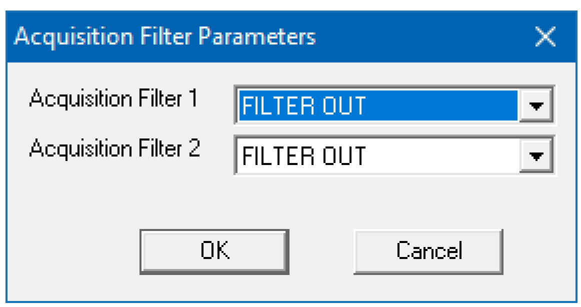
Note: *If the data is recorded with the wrong geometry, it can easily be reassigned in SeisImager/SW at the time of data processing.*

The default settings in the rows for *Gain* (how much the signal is boosted before digitization) and *Use* (how a channel is used), require no adjustment. If your settings do not match the default settings shown, go ahead and change them. For all channels, the *Use* row should be *Data*. *Gain* is changed in a subsequent menu. Press *OK* when done.

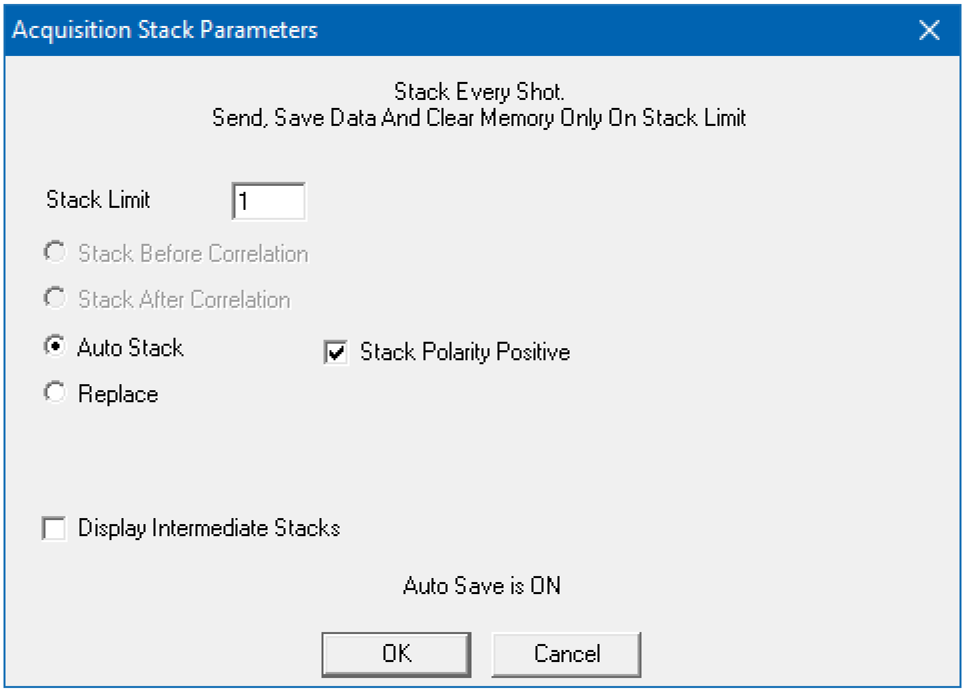
Next, select *Acquisition* | *Sample Interval/Record Length* and set the data acquisition timing parameters. *Delay* should be set to zero. Press *OK* when done.



Next, select *Acquisition* | *Acquisition filters*. Check the acquisition filter settings. Acquisition filters are permanent; any data filtered with an "acquisition" (versus "display") filter will be irreversibly so. Acquisition filters are not typically needed when collecting surface wave data, and thus, should be disabled with the setting *Filter Out*. Press *OK* when done.

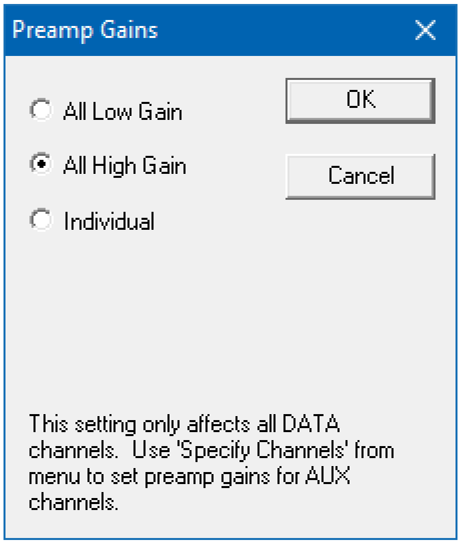


Next, select *Acquisition* | *Stack Options* and set the stacking parameters. Stacking is a way to increase the signal-to-noise ratio by hitting the striker plate repeatedly at each shot point and adding the files together as they are collected. Coherent signals will add, and incoherent noise will cancel. In many cases, stacking will not be needed, and thus, the *Stack Limit* default value is set to 1. If, however, you are in an urban environment and there is a high level of noise, or the signal quality on the distant traces is low, stacking will help (but remember that what is called "noise" in an active source survey is the "signal" recorded during a passive source survey). The benefits of stacking start tapering off after ~8-10 stacks, as the S/N ratio increases with the *square root* of the number of stacks. To stack 8 times, enter 8 as the *Stack Limit*. Press *OK* when done.



Next, select *Acquisition | Preamp Gains* and set the gains to *All High Gain*, which equals 36 dB. *All Low Gain* equals 24 dB and *Individual* applies when non-uniform gain settings are needed. There may be cases where the geophones nearest the shot location are close enough that they are overdriven by the signal and the recorded waveform is clipped. In this situation, *Individual* gain settings of 24 dB for the near channels and 36 dB for the rest of the channels can be used. Press *OK* when done.

Note: *Unlike refraction surveys, where only the first breaks are important, surface wave surveys require the* **entire** *waveform and clipping must therefore be strictly avoided. If clipping is still observed (signified by a red trace on the seismograph) even after setting the gains to the lowest value, get a smaller hammer and/or swing the hammer more softly. See the "freeze" function in the seismograph manual for more recording options if clipping becomes an issue.*

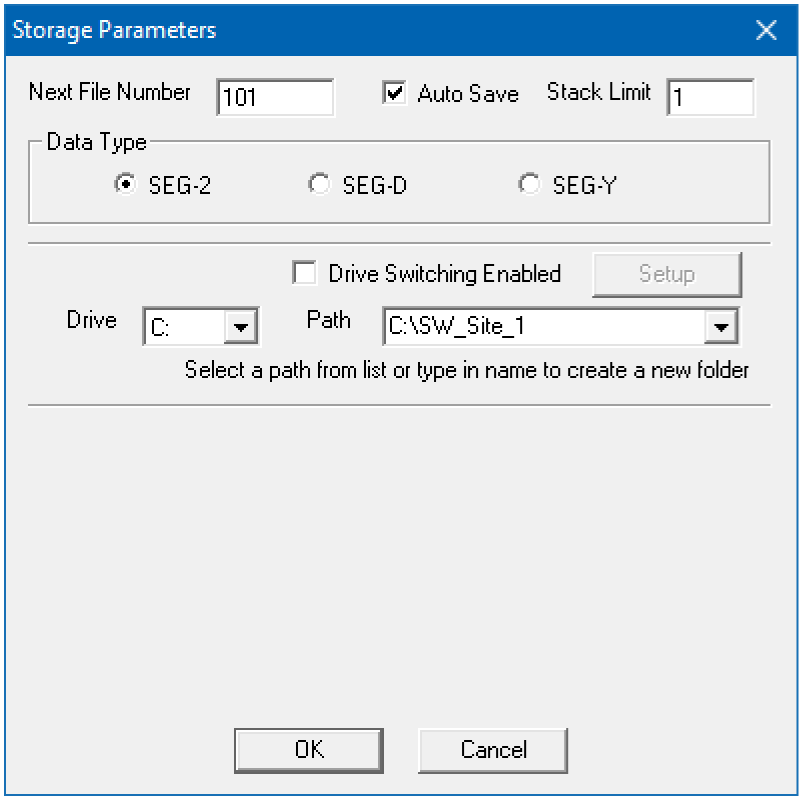


Next, select *File* | *Storage parameters* and set up the data storage parameters. The *Next File Number* should be a numerical value; after each save, the name will automatically increment by one. For the SEG-2 format, the file extension *.dat* is appended to the numerical name (Geometrics seismographs). Since the survey line is called Line 1, the suggested starting file number is 101.

Checking *Auto Save* will ensure that each file will be automatically saved after the *Stack Limit* is reached. If this is unchecked, you will need to manually save (and clear) each file. The *Stack Limit* reflects what was entered in the previous **Acquisition Stack Parameters** dialog box.

For the *Path* of saved data, enter the desired folder name. Press *OK* when done.

Note: *When creating a folder using SCS, you can only go one folder deep.*



This is the last essential dialog box in SCS for the 1D MASW survey setup.

3.1.2.2 After Setup – Acquiring, Displaying, and Quality Checking 1D MASW Data

Once the setup is complete, you are ready to begin data acquisition. An example of the main SCS window is shown below. The number of traces in the *Noise Monitor Window* matches the number of channels in the seismograph; this example shows 24 traces.

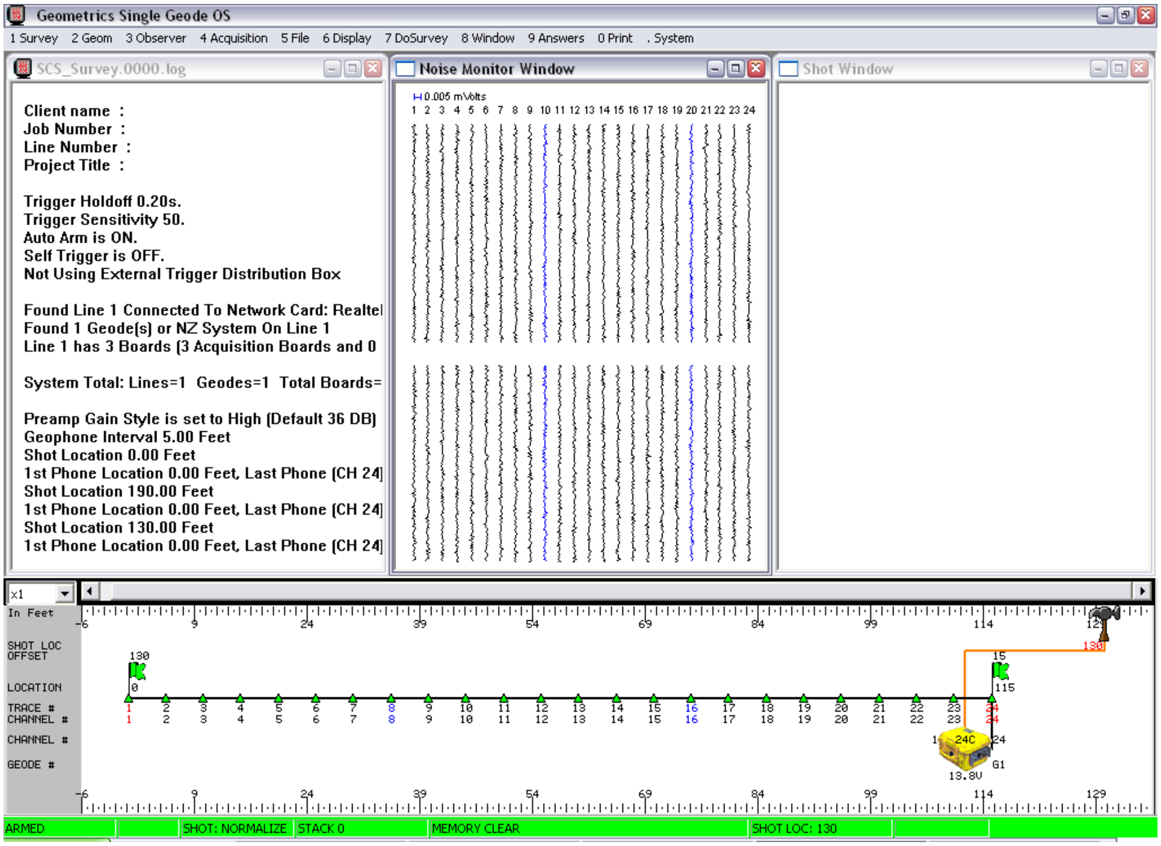


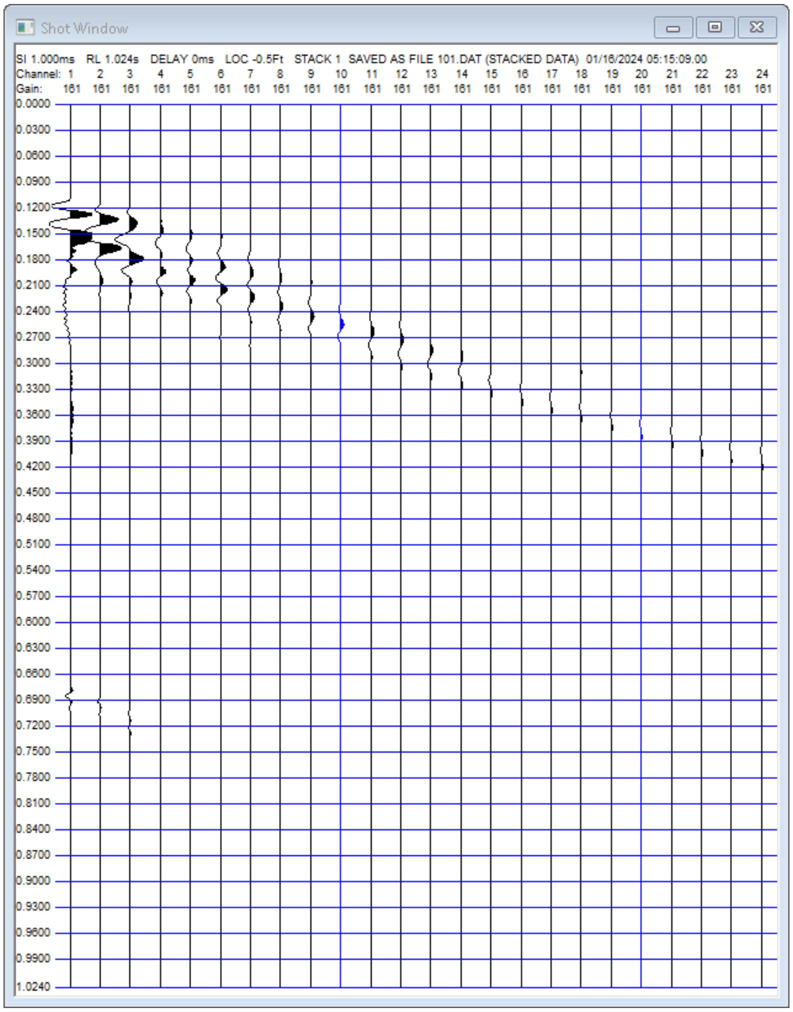
Figure 4: Main SCS Window

Before any data is recorded, use the *Noise Monitor Window* to check the line. Lightly tap the top of the nearest geophone and watch which trace shows the largest response; it should be the geophone with the highest channel number. Check that the response level of each geophone to a tap is about the same. If there is a trace with a dissimilar or atypical level of noise, walk down the line to check that the internal sensor element can oscillate freely (give a gentle shake up and down in the vertical orientation.) Make sure the geophone is correctly and vertically planted and that it is connected to the spread cable. It is best practice to make sure all traces are responding properly before collecting data.

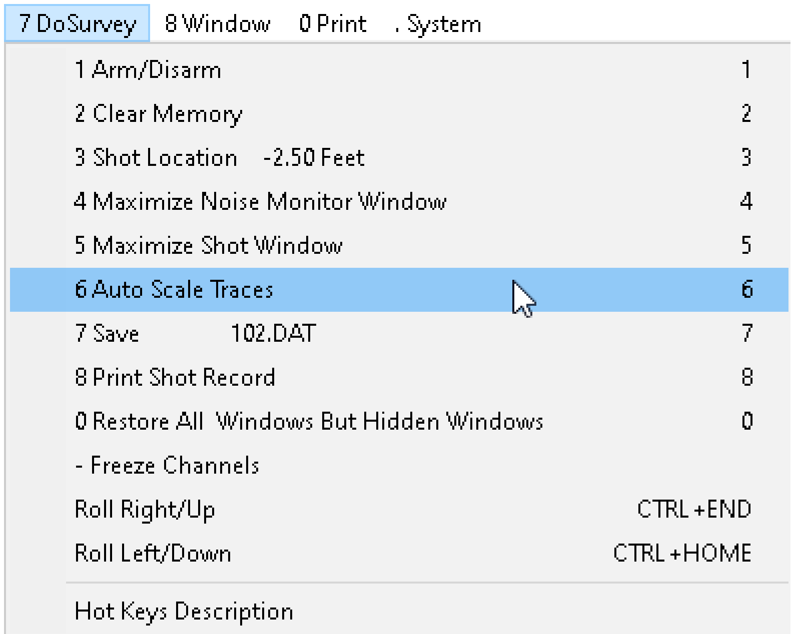
Next, check that the status bar on the bottom of the window shows an *Armed* condition and is colored green. You may want to first press the "*1*" shortcut key to toggle the armed state off and practice hitting the striker plate with the hammer.

When ready, press *1* to return the system to an armed state, and swing the hammer at the shot location. Check to confirm that the system triggered, and the shot was recorded. A typical active dataset consists of one (or more as needed) shot records. Make sure there are no red traces indicating clipping.

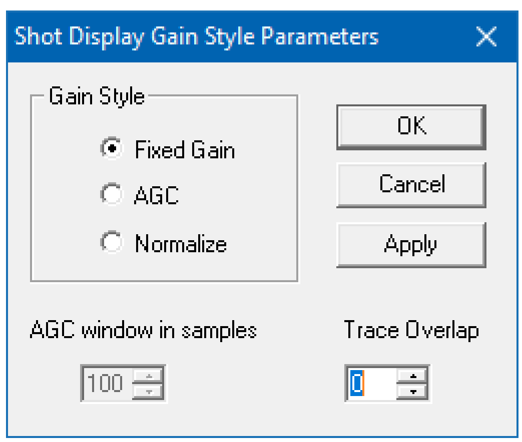
When you first view the data, the display gains will probably need adjustment. One condition that can occur is that the signal may not be visible for all traces as shown in the record below.



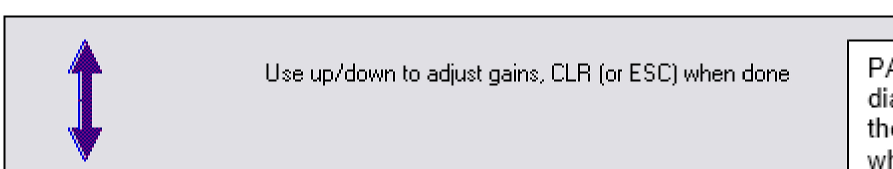
To adjust the display gains, select *Auto Scale Traces* or press the "*6"* shortcut key. Selecting *Auto Scale Traces* causes the software to find the gain that optimizes the allotted space for each trace in the *Shot Window*.



To further adjust the gain, highlight the *Shot Window* and use the *right-arrow* key to activate the display gain controls. If when you press the *right-arrow* key, the **Shot Display Gain Style Parameters** dialog box appears, choose *Fixed Gain*. Press *OK* when done.



Press the *right-arrow* key again, and as directed in the instruction box, use the *up*- and *down-arrow* keys to increase and decrease the gain by the same amount for all channels.



PATH: Access dialog box through the *right arrow* key when the *Shot Window* is selected.

Press the *Esc* key to end.

The *Shot Window* can also be zoomed in and out using the *Page Down* and *Page Up* keys and scrolled up and down using the *up*- and *down-arrow* keys.

The final display settings should provide a shot record looking like that shown below:

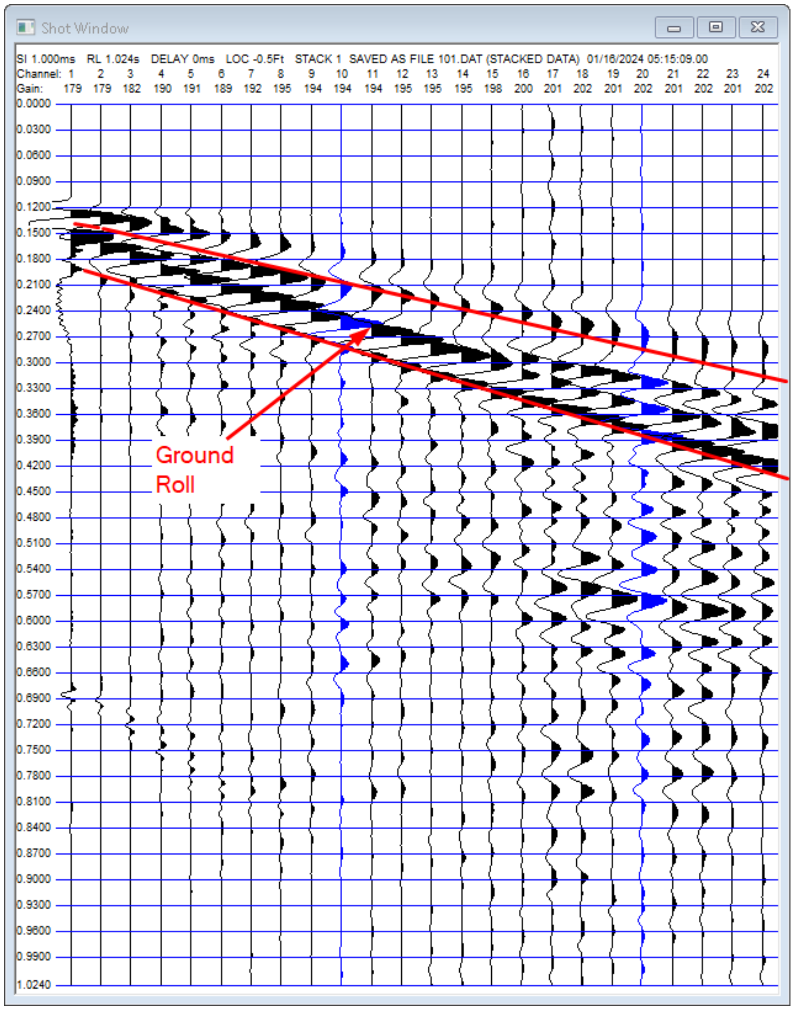


Figure 5: Ground roll.

Note: *Red traces indicate clipping. If any traces are clipped, you must adjust the acquisition gain settings and re-record the data.*

Once the display parameters are optimized, check for the presence of dispersive surface waves. Surface waves are relatively lower frequency, higher amplitude, and slower than other events in the record. Ground roll in a “wedge” or “fan” shape indicates dispersion. In addition to visual analysis, refer to Section 4 (Page 54) on how to run a field check of dispersion using SeisImager/SW.

After you have collected the active source record(s) and are satisfied with the data, continue to the passive source survey if applicable.

3.2 MAM Data Acquisition

During a passive source survey, the seismograph records ambient vibrations generated by cultural noise, traffic, factories, wind, wave motion, etc. There is no timing device to trigger the seismograph.

> The ideal vibration sources are steady, at a constant level, and far away relative to the array size. The fundamental assumption of microtremor data analysis using the spatial autocorrelation (SPAC) method of SeisImager/SW is that the signal wavefront is planar, stable, and isotropic (coming from all directions), making it independent of source location. A high level of intermittent noise (like nearby passing cars) is tolerable if the sources are relatively distant (approximately equal to or greater than one array length). Even if the intermittent noise sources are near, this is usually countered by recording at least 20 long records (32 seconds each). Long records make for smooth input when the records are converted from the time to frequency domain and many records provide a statistically robust representation of ambient vibrations.

Table 2 summarizes the recommended passive source acquisition parameters.

Parameter	Setting
Spread/array configuration	L-shape, Triangle, Circle, Linear, or custom.
Array size	Minimum of 1 times depth of interest.
Geophone interval	Up to 15 m or 45 ft; adjust to suit array configuration and size.
Total number of geophones	Various based on spread configuration.
Geophone type	4.5 Hz vertical geophones, with base plates for surveys on paved ground; alternatively, if available, 1 or 2 Hz seismometers can be used, especially if depth of interest is greater than 30 m (100 ft).
Trigger	Manual keyboard trigger.
Sample interval	2 milliseconds (ms).
Record length	32 seconds (s) each record, total of at least 20 records.

Table 2: MAM Acquisition Parameters.

3.2.1 MAM Survey Geometry

Continue.

3.2.1.1 MAM Survey Spread Configurations

SeisImager/SW allows four preset types of passive source spread or array configurations and a custom option. Figure 6 through Figure 10 (not drawn to scale) illustrate the various preset configurations. As in Figure 3, the black line represents the spread cable, and the green inverted triangles represent the geophones.

Of the four preset arrays, one is linear and three are 2D; that is, geophones are distributed in two dimensions versus a line, on the ground surface. 2D arrays provide the most rigorous distribution of data points for analysis; however, the SPAC method used by SeisImager/SW handles data from all array types because it is independent of source location.

Consider a linear array. If microtremors propagate parallel to the survey line, the surface wave phase velocity can be directly calculated. Conversely, if microtremors propagate perpendicular to the survey line and reach all the geophones at the same time, the phase velocity cannot be calculated. As the angle of propagation increases from parallel to perpendicular, the apparent phase velocity increases. In reality, source locations of microtremors vary and energy radiates from many directions at unknown angles to the geophones. Since angles of propagation are unknown, with a linear array, the calculated phase velocity may be higher than the actual phase velocity unless a method independent of the source locations such as SPAC is used.

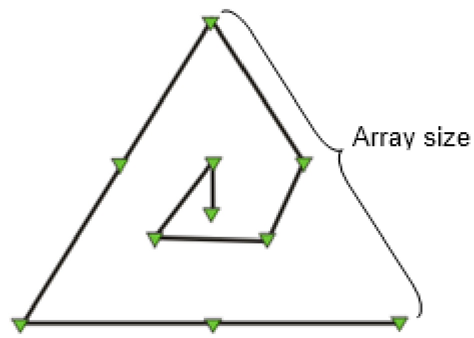


Figure 6: Map view of MAM survey equilateral triangle spread configuration with 10 geophones ("Triangle 10").

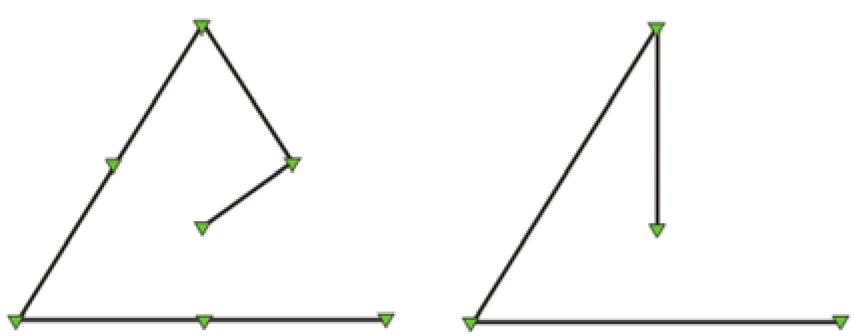


Figure 7: Map view of MAM survey equilateral triangle spread configurations with 7 ("Triangle 7") and 4 geophones ("Triangle 4").

For a triangular array (Figure 6 and Figure 7), the *Array size* is defined as the length of a side. The resultant V_S curve is an average over the array and, accordingly, should be located at the center of the triangle.

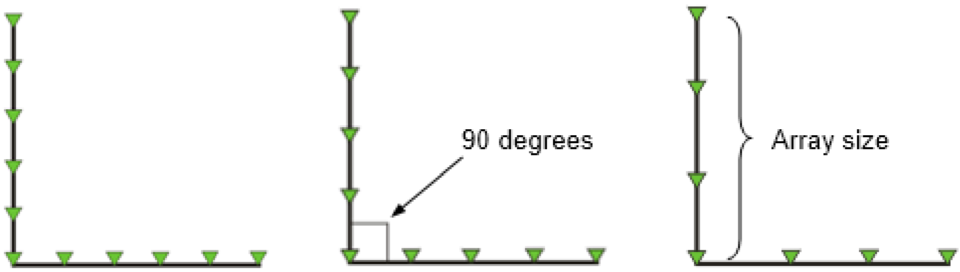


Figure 8: Map view of MAM survey L-shape spread configurations with 11 (“L11”), 9 (“L9”), and 7 (“L7”) geophones.

For an L-shaped array (Figure 8), the *Angle* between the branches of the L is typically 60 to 90 degrees, but technically can be as small as 0 degrees, which is a linear array. Both branches are the same length; the *Array size* equals the length of the branches. The resultant V_S curve is an average over the array and accordingly should be located essentially at the origin or near the origin between the two branches of the L. The L-shaped array is the two-dimensional array that is easiest to set up in the field. It can easily be constructed after an active source survey by turning one-half of the spread 90 degrees and adjusting the geophone intervals to span the required *Array size*.

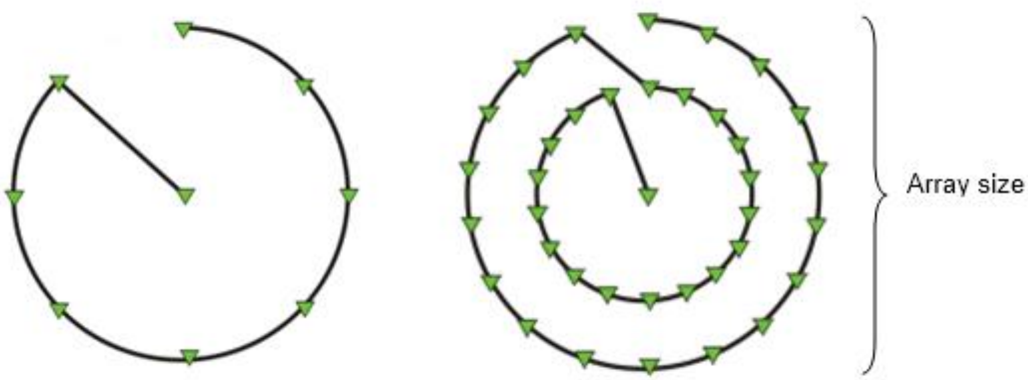


Figure 9: Map view of MAM survey circle spread configurations with 8 outer geophones on one circle and one center geophone (“Single circle 9”) and 18 geophones in two circles and one center geophone (“Double circle 37”).

For the *Double circle 37* array (Figure 9) the inner circle diameter equals one-half the outer circle radius. For all circle arrays, the *Array size* equals the diameter of the outer circle. The resultant V_S curve is an average over the array and accordingly should be located at the center of the circle.

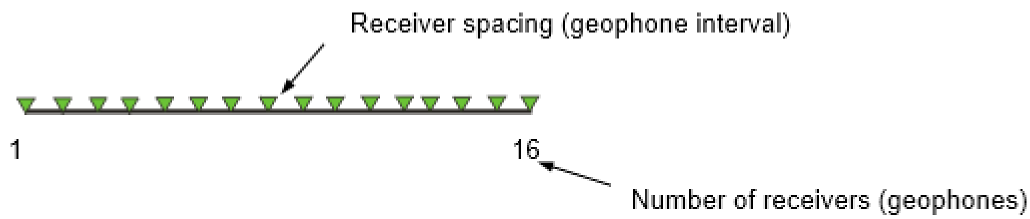


Figure 10: MAM survey linear spread configuration using all channels, one per geophone.

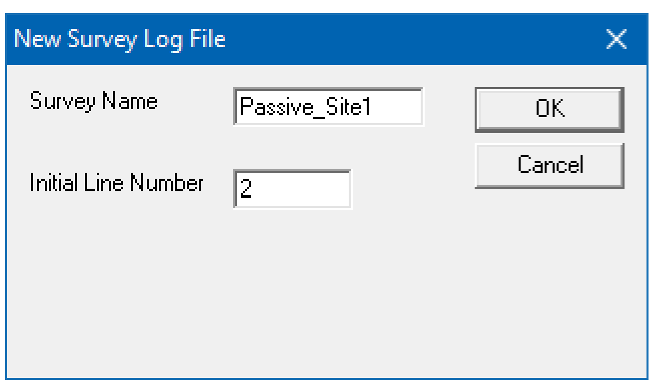
For a linear array (Figure 10), the *Receiver spacing* equals the geophone interval and the *Number of receivers* equals the number of geophones. The resultant V_S curve is an average over the array and accordingly should be located at the center of the spread.

3.2.2 MAM Survey Data Acquisition with Geometrics Seismodule Controller Software

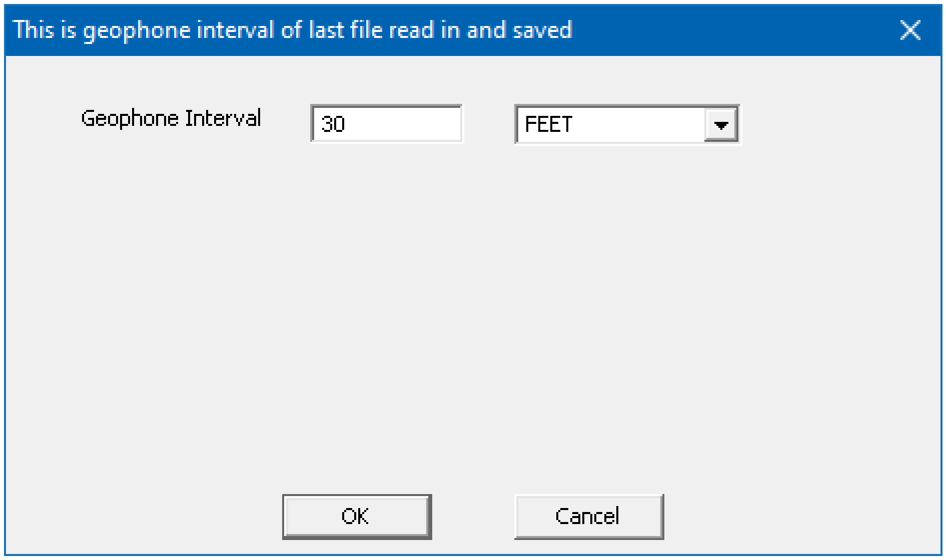
The data acquisition setup for MAM surveys involves the same dialog boxes used in the 1D MASW survey setup. This section assumes that you have already worked through the 1D MASW survey setup, that you are doing a MAM survey at the same site to supplement the 1D MASW survey, and that the MAM array type is *L11* for a depth of interest of approximately 30 meters (100 feet). MAM surveys can also be performed to supplement 2D MASW. Refer to Section 3.1.2, on Page 13, for an introduction to the 1D MASW setup process and for more detail on the dialog boxes common to both survey setups.

3.2.2.1 MAM Survey SCS Setup

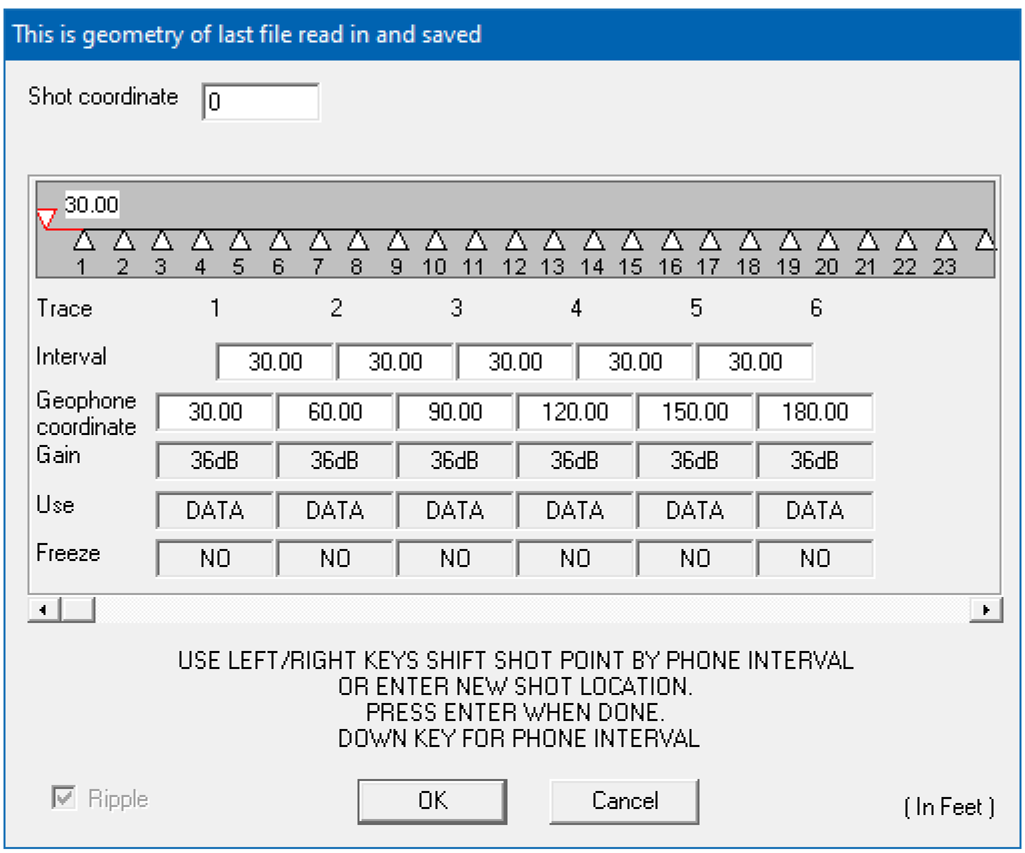
First, select *Survey* | *New Survey* and assign a *Survey Name* and *Initial Line Number*. An *Initial Line Number* of 2 indicates that this is a new line configuration with different geophone locations compared to Line 1.



Next, select *Geom* | *Geophone Interval* and set the *Geophone Interval* to reflect the distance between active geophones in the applicable units. Although it is common practice to set the geophone interval and units at the time of acquisition, this is not essential for MAM surveys because the full geometry (configuration and *Array size*) will be set in SeisImager/SW at the time of data processing.



Next, select *Geom* | *Group/Shot Locations* to set up the survey geometry:



Since there is no active source at a single location, the *Shot Coordinate* is not applicable and should be set to zero.

For most of the MAM array configurations that are 2D (L-shape, Triangle, Circle), you will likely be recording on fewer channels than the total number of channels in the seismograph. The unused channels should be deactivated. Deleting dead channels can be done in SeisImager/SW, but it is most efficient to deactivate them at the time of acquisition.

To deactivate/activate channels, selection Acquisition | Specify channels. The same dialog box as above will appear. Uncheck the *Ripple* box and in the row named *Use*, use the "*4"* key and the *right-arrow* key to individually deactivate the channels that have no geophone connected.

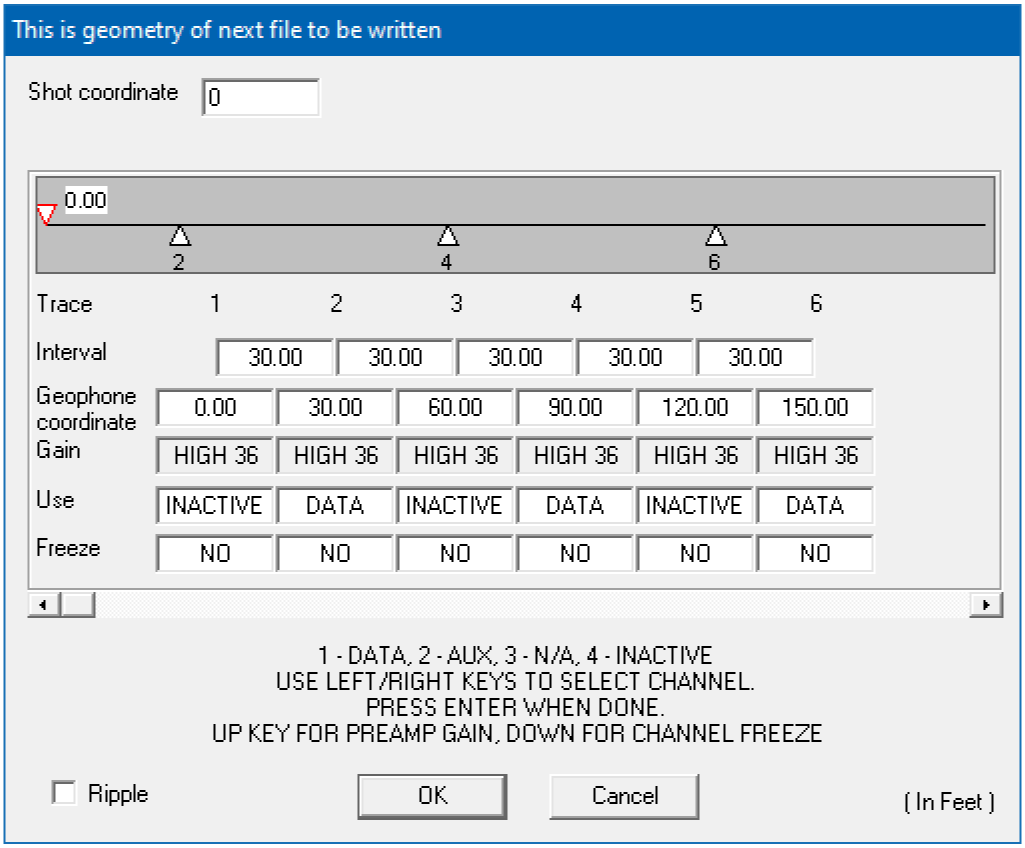
Example 1A:

For a 16-channel seismograph with a 30-foot interval spread cable, in an L11 array with geophones 30 feet apart, the channels on the end of the spread that are not connected to geophones are deactivated. This equals channels 1 through 5 if channel 11 is positioned at the corner of the L, or channels 12 through 16 if channel 6 is positioned at the corner of the L.

End Example 1A.

Example 1B:

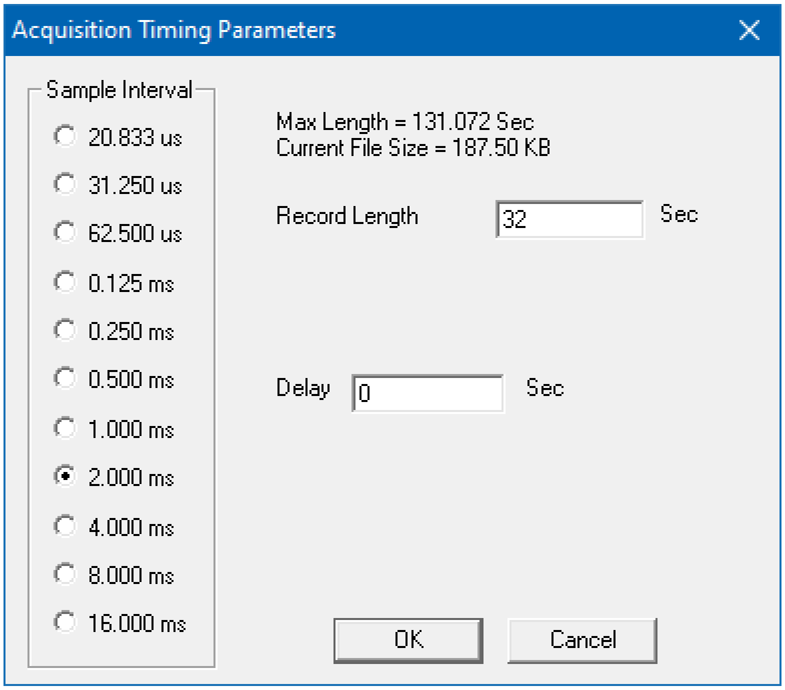
For a 24-channel seismograph with a 5-meter interval spread cable, in an L11 array with geophones 10 meters apart, with channel 12 positioned at the corner of the L, channels 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, and 24 are deactivated.



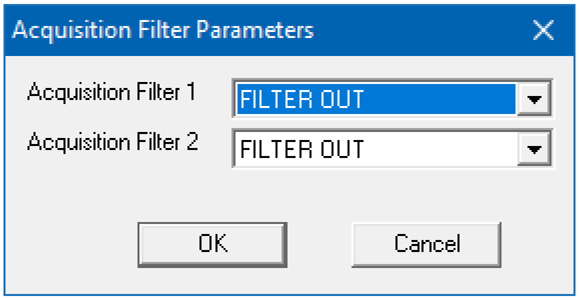
End Example 1B.

The **Geometry** dialog box only shows linear configurations of geophones; you will not see a graphic of the actual 2D array. This is fine; as mentioned previously, the full geometry is set in SeisImager/SW at the time of data processing. The main setting here is deactivation of unused channels.

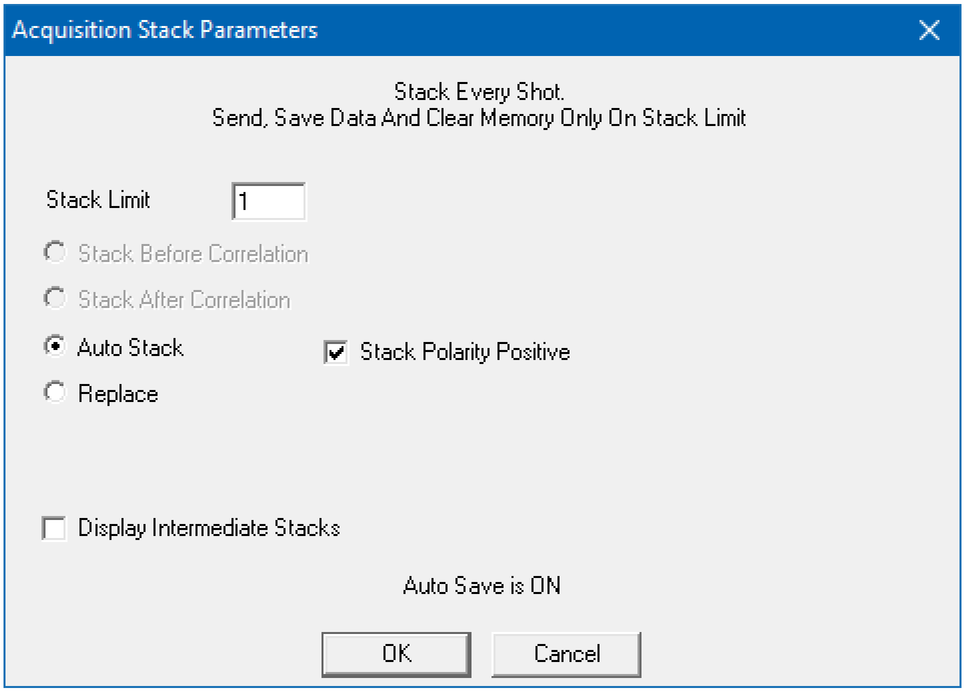
Next, select *Acquisition* | *Sample Interval/Record Length* and set the acquisition timing parameters:



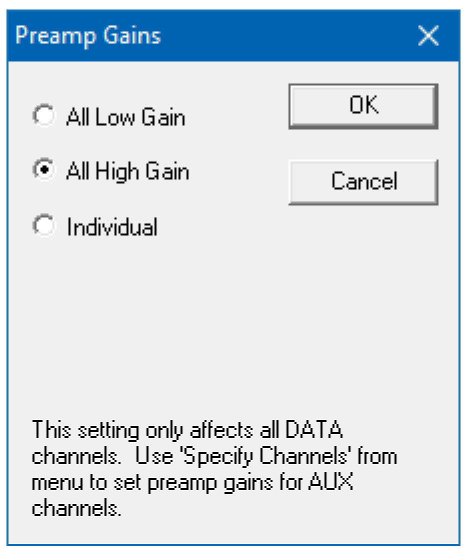
Next, make sure the acquisition filters are disabled by selecting *Acquisition* | *Acquisition Filters* and choosing *FILTER OUT* for each.



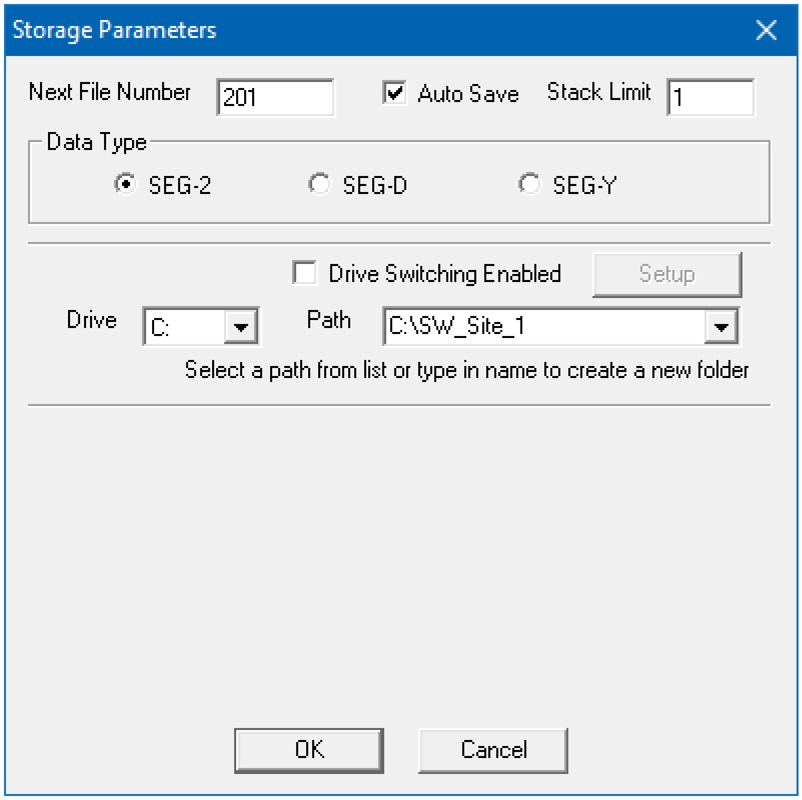
Next, select *Acquisition* | *Stack Options* and set the *Stack Limit* to 1 since stacking is not applicable to MAM surveys.



Next, select *Acquisition* | *Preamp Gains* and make sure the gains are set to *All High Gain*.



Next, select *File* | *Storage Parameters* and set the *Next File Number*. Since the survey line is called Line 2, set the *Next File Number* to 201. Leave *Auto Save* on and the *Stack Limit* set at 1. For the *Path* of saved data, enter the desired folder name.



This is the last essential dialog box in SCS for the MAM survey setup.

3.2.2.2 After Setup – Acquiring, Displaying, and Quality Checking MAM Data

Once the setup is complete, you are ready to begin data acquisition. An example of the main SCS window is shown below. As discussed for 1D MASW surveys, perform the same system checks before starting acquisition. Check that the status bar on the bottom of the window shows an *Armed* condition (colored green).

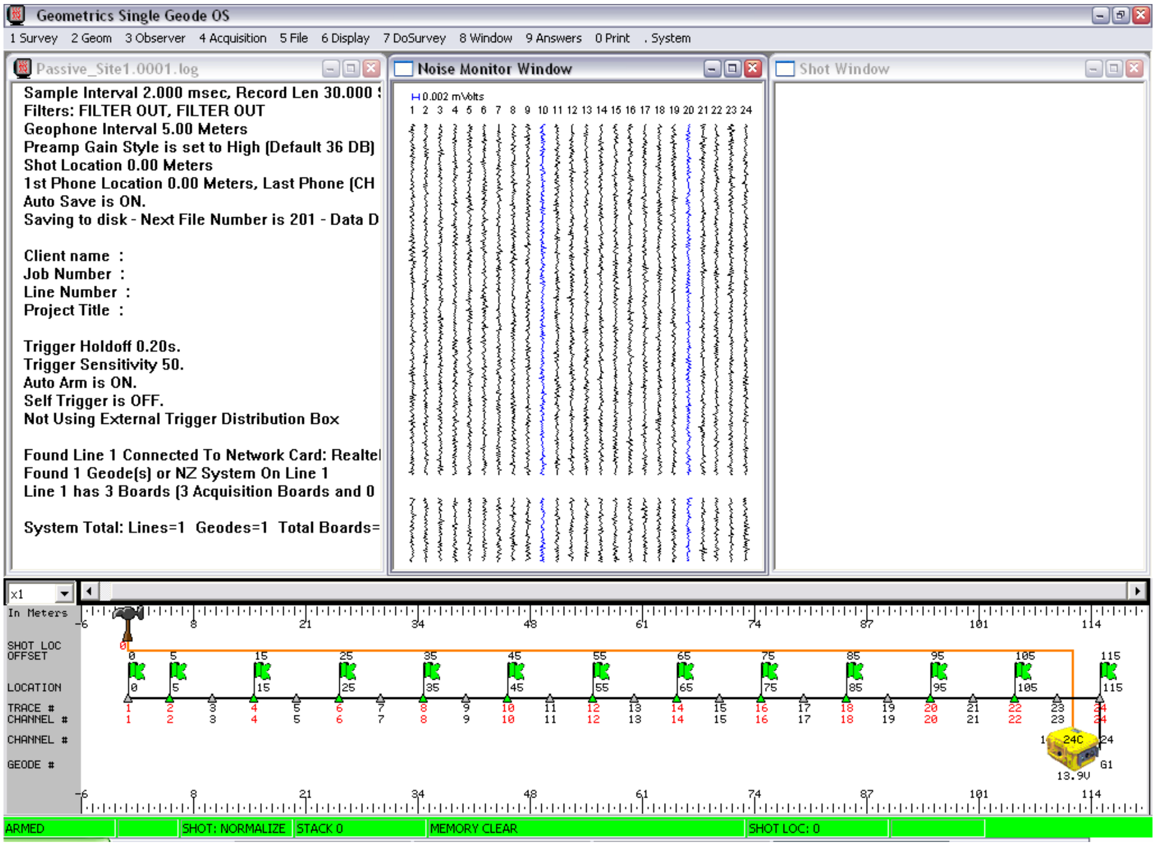
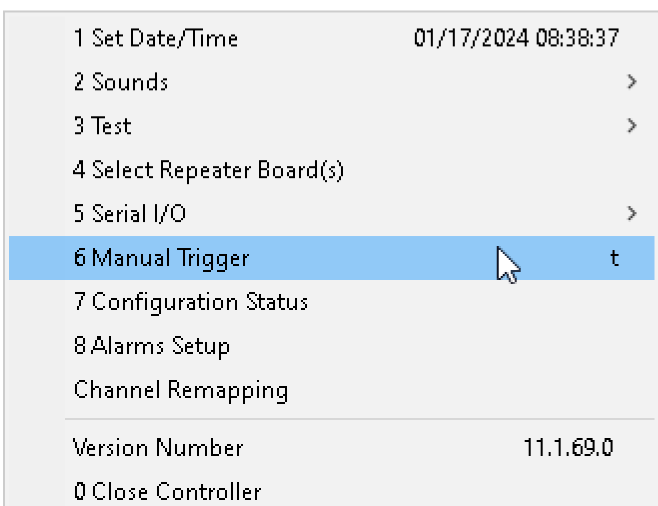


Figure 11: Main SCS window.

Once ready, trigger manually by pressing the "*t*" shortcut key or by selecting *System* | *Manual Trigger*.



After triggering, wait for the record to be acquired and saved. Repeat at least 19 more times. Refer to the status bar to monitor the stage of acquisition. A record length of 32 seconds, times 20 records, equals 640 seconds or about 10 minutes total.

A typical passive source record is shown below. You may need to adjust the display gains with *Auto Scale Traces* (“*6*” shortcut key).

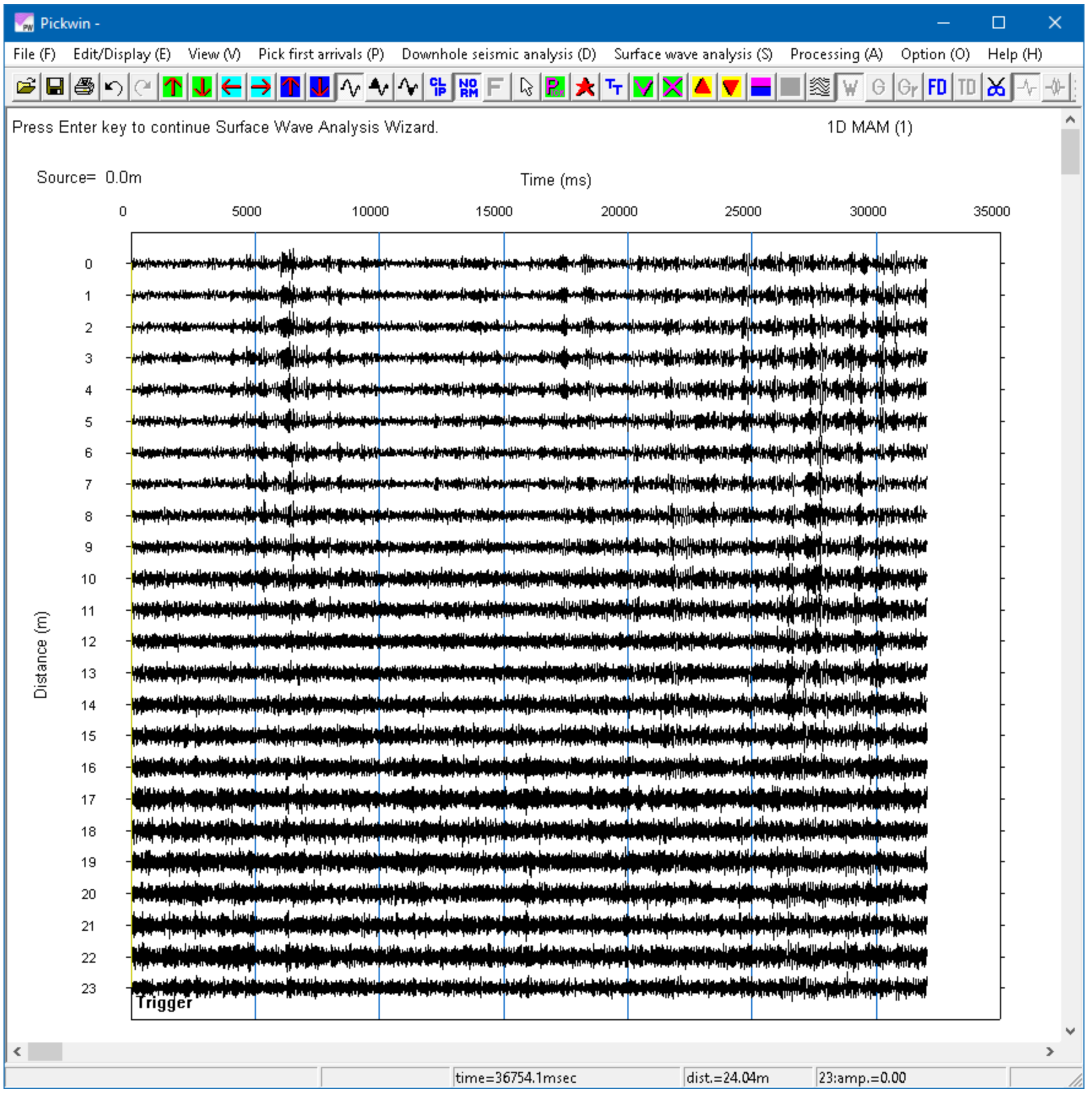


Figure 12: Typical passive source record.

There will likely be some coherent noise events representing when cars have passed or such. Some isolated variation in amplitude usually does not significantly impact data quality. A steady level of signal without strong changes in amplitude throughout the record and from trace-to-trace is ideal.

In addition to visual analysis, refer to Sections [4](#) (Page 54) and [5.3](#) (Page 212) on how to run more sophisticated checks of data quality.

3.3 2D MASW Data Acquisition

As with 1D MASW surveying, 2D MASW surveys use an active source with a linear spread of geophones. Instead of one shot, however, numerous shots are taken at incrementing locations, and the geophone spread may not be fixed, depending on the total survey line length. (Remember here that 1D and 2D refer to the type of results, that is, V_S curve or cross-section, respectively, not to the spread configuration.) Acquisition of numerous shot records allows SeisImager/SW to calculate a V_S cross-section.

Table 3 summarizes the parameters used for active source 2D MASW surveys. The discussion on selecting geophone interval and spread length in Section 3.1 (Page 11) applies. passive source data may not be available, or if available, will only supplement a 1D V_S curve, so the active source energy level will have a larger bearing on the maximum possible depth of penetration.

Parameter	Setting
Spread configuration	Linear.
Spread length	About equal to two times depth of interest assuming that no passive data is available; about equal to depth of interest when supplementing with passive source data.
Total number of geophones	12 or more, minimum of 16 preferred.
Geophone interval	1.5 to 5 m or 5 to 20 ft; adjust according to number of channels available and to suit required spread length.
Geophone type	4.5 Hz vertical geophones, with base plates for surveys on paved ground; optionally configured in a land streamer for a towed spread.
Parameter	**Setting**
Shot locations	Depending on spread configuration, multiple in-line locations at appropriate offset and interval.
Shot near offset	About 10% to 20% of spread length (applies to configurations where this parameter does not equal one-half the geophone interval, such as the *roll-along end-on spread*).
Source equipment	Sledgehammer (most common), 8 lbs (3.6 kgs), 16 lbs (7.2 kg), 20 lbs (9 kg), scale hammer weight up with increase in spread length, and striker plate.
Trigger	Hammer switch taped to sledgehammer handle and connected to seismograph trigger port.
Sample interval	0.5 milliseconds.
Record length	1 to 2 seconds, long enough to capture the surface wave train.
	As needed to improve data quality, wait for quiet times to shoot.

Table 3: 2D MASW Acquisition Parameters.

3.3.1 2D MASW Survey Geometry

The basic linear geometry of MASW surveys is described in Section 3.1.1, Page 13. The linear spread is simple, but with the addition of numerous shots and possibly an incrementing geophone spread, the geometry of 2D MASW surveys is more involved. To illustrate the 2D MASW geometries, the following sections use more sophisticated plots generated by Pickwin. The figures are based on 24-channel examples. Table 4 explains the symbols used in the Pickwin geometry plots shown in this section.

Circle/Dot Color	Meaning
Teal blue	Shot point.
Yellow	Receiver for which a trace (waveform) has been read.
Black	Grid point (no meaning in actual geometry).

Table 4: Selected 2D MASW Geometry Plot Attributes.

The geometries used in 2D MASW surveying, especially the *roll-along end-on spread* configuration, may look familiar, as they are adopted from reflection seismology. SeisImager/SW also utilizes the reflection concept of the *mid-point*, which is the point midway between a source-receiver pair, and the *common mid-point* (*CMP*) *gather*, which is an assembly of traces that have the same mid-point. For any given spread configuration, SeisImager/SW cross-correlates every pair of traces in a shot record, gathers all correlated traces by CMP, then stacks those traces having equal spacing in the time domain (Hayashi and Suzuki, 2004). These additional steps advance the original MASW technique by effectively increasing the lateral resolution and accuracy of the final V_S cross-section.

In Figure 13, the top row (1) illustrates the distribution of CMPs for a shot record (1b) and a CMP gather (1c). Gathering by CMP (1c) and adding (stacking) focuses sampling and thus increases the signal-to-noise ratio and lateral resolution. The bottom row (2) illustrates how the CMP concept is applied to surface wave methods. Analysis by shot record (2b) for 1D MASW poses no resolution issues as 1D MASW provides a single V_S curve averaged over the total length of the spread. A series of 1D MASW V_S curves could be used to construct a V_S cross-section but processing first by CMP (2c) increases lateral resolution and accuracy.

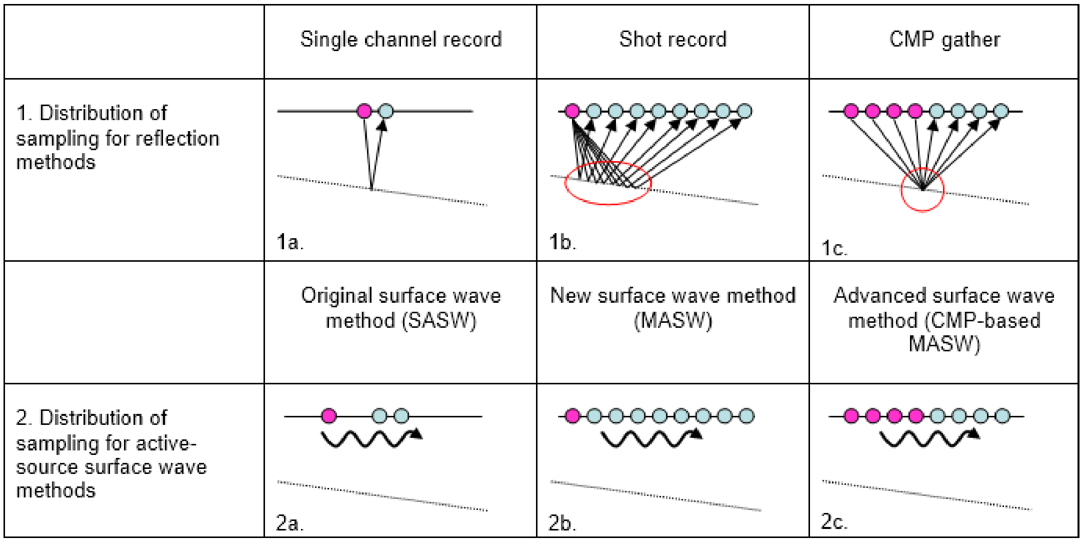


Figure 13: The CMP concept applied to 2D MASW.

Another issue, not necessarily a benefit but rather something to be aware of and account for if needed, is that the multiplicity of CMPs (the *fold*) tapers down toward the ends of the survey line. Note that the higher the fold, the higher the signal-to-noise ratio. The effect is that the lateral sampling decreases from the mid-point(s) of maximum fold to the ends of the survey line. Methods to account for this in survey design are discussed below.

3.3.1.1 FIXED RECEIVER SPREAD CONFIGURATION

The simplest configuration for 2D MASW surveys is the *fixed receiver spread* (Figure 14). The geophones are set up in a line at fixed locations and the shot is moved through the spread. The first shot is located off-end at a near offset of one-half the geophone interval. The shot is then advanced at an increment equal to the geophone interval so subsequent shots are located midway between geophones. As the *Shot number* increases, the shot location advances by one interval across the *Survey distance*.

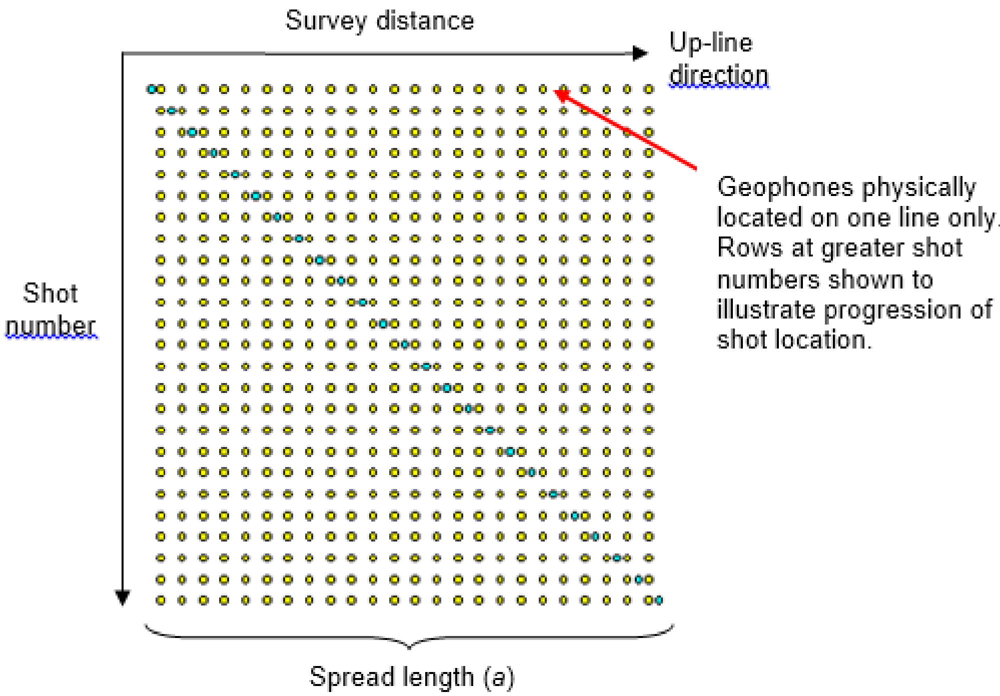


Figure 14: 2D MASW fixed receiver spread configuration.

The last shot is located off the opposite end by the same near offset of one-half the geophone interval.

The *Spread length* (*a*) equals the survey line length over which there are active geophones. The survey depth is approximately *a/4* to *a/2*.

The *fixed receiver spread* is useful if the survey line length of interest is not very long, if the survey area is confined, or if there are limited channels or time/labor resources available.

With a shot interval equal to the geophone interval, the fold will be highest at the center shot; that is, in between the two middle geophones, and will taper down on either side. The effect of tapering is to reduce the accuracy of analysis at depth. If full fold is desired for the entire survey line of interest, the *continuous fixed receiver spread* (Section 3.3.1.2) or the *roll-along end-on spread* (Section 3.3.1.3) should be used.

3.3.1.2 Continuous Fixed Receiver Spread Configuration

In many cases, one fixed receiver spread is not sufficient to cover the survey line length of interest. So, the fixed receiver spread can be used continuously, by taking a set of shots, moving the past receivers up-line, then resuming with another set of shots (Figure 15). First, Spread A is set up, then 12 shots (one end-shot and 11 inner-spread shots) are taken. Receivers from sub-spread A1 are advanced up-line to become sub-spread B1. Shooting resumes for 12 more (inner-spread) shots, then sub-spread A2 is advanced up-line to form sub-spread B2. There will be 24 live channels for each shot. This process continues until the survey line length of interest has been covered.

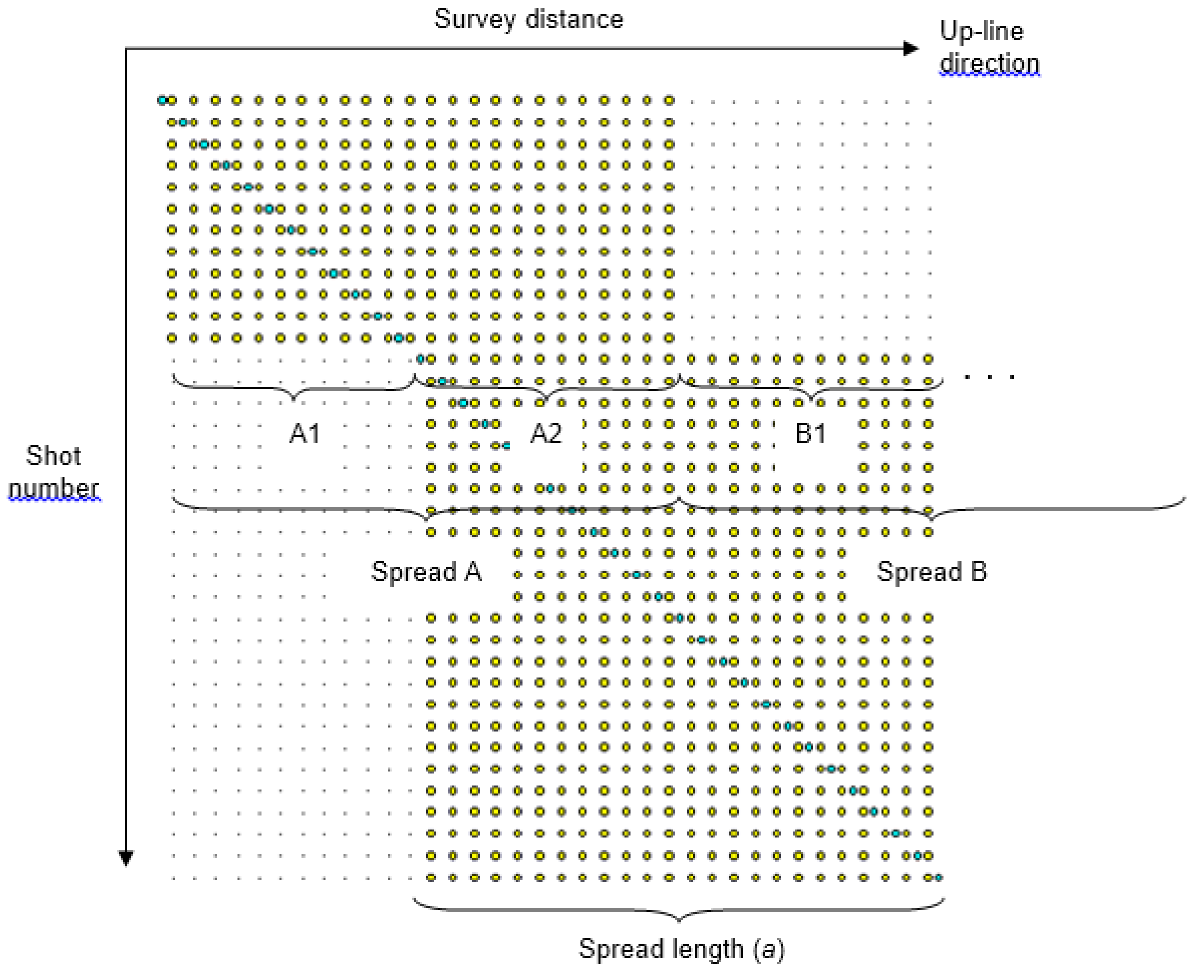


Figure 15: 2D MASW continuous fixed receiver geometry.

The *Spread length* (*a*) equals the survey line length over which there are active geophones. The survey depth is approximately *a/2*.

The fold will be at full value when the number of shots from the start of the line equals half the number of active geophones per shot; full fold starts tapering down when the number of shots remaining to the end of the line equals half the number of active geophones per shot (again, if the shot interval equals the geophone interval). For the example in Figure 15, full fold will begin at shot 13 in between geophones 12 and 13 (between sub-spreads A1 and A2). It is best practice to leave space at the survey site so the locations of full fold can be positioned at the beginning and end of the survey line of interest. The fold tapering over 12 geophone intervals of 2 m equals 24 m; where the survey line of interest equals *x*, then the total survey line equals 24 m + *x* + 24 m.

This method of acquisition requires spread cables with the number of takeouts equal to one-half the seismograph channels. This allows for the first spread cable and associated geophones to be picked up and advanced at the halfway point. For the example in Figure 15, with a 24-channel seismograph, you would need two 12-takeout cables. Furthermore, having a third spread cable and set of geophones would allow you to set up sub-spread B1 in advance and minimize downtime in between each set of shots.

The *continuous fixed receiver spread* becomes tedious if your survey line is very long. An advancement in this method with increased efficiency is the *roll-along end-on spread* configuration.

3.3.1.3 Roll-along End-on Spread Configuration

For long survey lines, the spread needs to be efficiently advanced by a more automated means compared to the *continuous fixed receiver spread*. There are three methods to achieve this using the *roll-along end-on spread* configuration.

Method A: Software roll-along: most modern seismographs are capable of rolling an active spread of channels via software. The seismograph will require more channels than the actual number of live channels per shot, typically 50% to 100% more. For example, if 24 channels are the desired number of live channels, a 48-channel seismograph with 48 geophones is set up. Using software roll-along, the 24 live channels are rolled through the total of 48. For the first shot, channels 1-24 are active, for the second shot, channels 2-25 are active, etc. After the last shot with channels 25-48 active, the first half of the spread is picked up and moved up-line similar to the *continuous fixed receiver spread*. Note that software roll-along is not only for rolling an active spread; it is also used with the other methods to roll geometry coordinates.

Method B: Land streamer: geophones are affixed to a “streamer” that makes gravity contact with the ground and is towed, typically by hand or an ATV or other vehicle. The streamer connects to a seismograph positioned on the vehicle, the number of geophones equals the number of recording channels, and all channels are kept active for each shot. The source is usually located in between the vehicle and the streamer or on the down-line end of the streamer, and its location is incremented together with the streamer after each shot.

Method C: Mechanical roll box (also called roll-along switch): a separate box is connected between the spread cables and seismograph, interfaced with a set of input/output cables. The number of spread cable takeouts is larger than the number of seismograph channels, usually by 100%. The roll box allows the seismograph channels to be advanced up-line by mechanical rotation of the connections between the channels and takeouts. For example, spread cables with a total of 48 takeouts are connected to a roll box with input of 48 channels and output of 24 channels, which are transmitted to a 24-channel seismograph. For the first shot, channels 1-24 are connected to takeouts 1-24 and takeouts 25-48 are disconnected. After the first shot, the channel connections are advanced by turning a dial on the roll box, which disconnects channel 1 and connects channel 25. The source location is incremented together with the active spread.

For all scenarios, the shot will usually have some near offset equal to about 10% to 20% of the survey line length.

Figure *16* illustrates the roll-along end-on spread configuration with a fixed receiver spread configuration used at the end of the line.

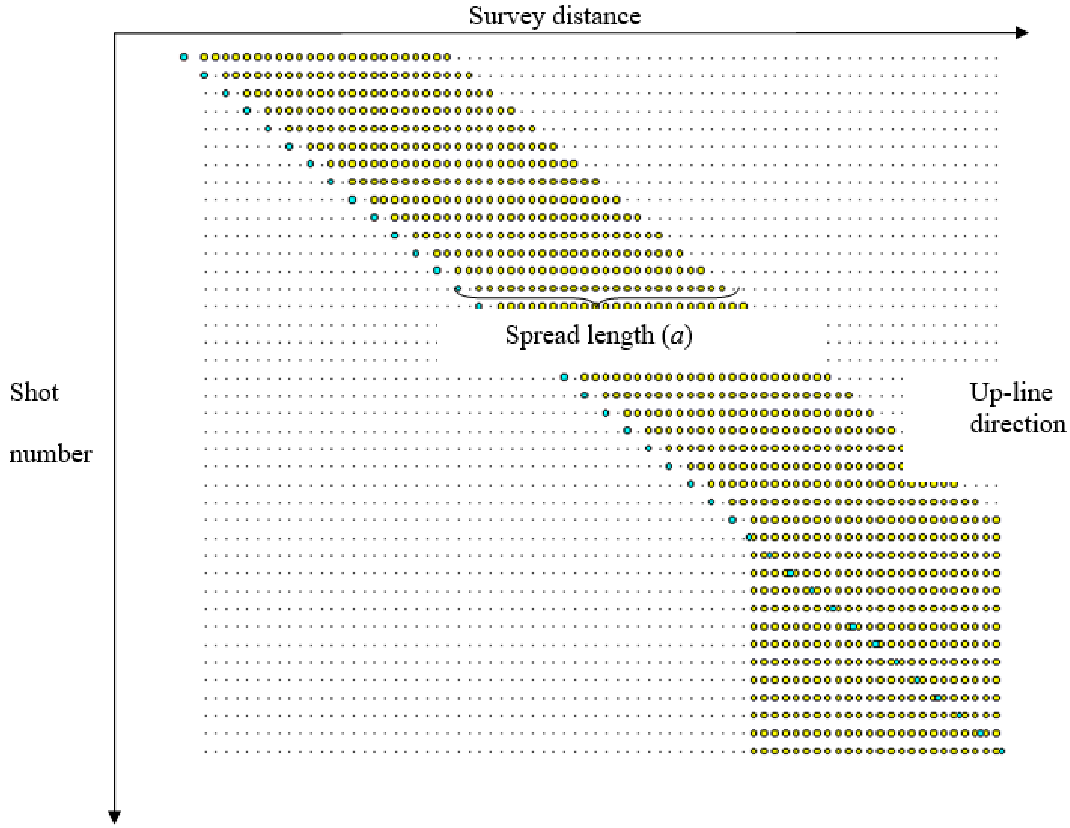


Figure 16: 2D MASW roll-along end-on geometry.

The *Spread length* (*a*) equals the survey line length over which there are active geophones. The survey depth is approximately *a/2*. The fold value is determined the same as for the other spread configurations.

3.3.2 2D MASW Survey Data Acquisition with Geometrics Seismodule Controller Software

The data acquisition setup for 2D MASW surveys involves the same dialog boxes used in the 1D MASW survey setup plus a few more for advanced geometry settings. This section assumes that you have already worked through the 1D MASW survey setup and only covers the dialog boxes that are new for 2D MASW surveying. Refer to Section 3.1.2, Page 13, for an introduction to the 1D MASW setup process and for more detail on the dialog boxes common to both survey setups.

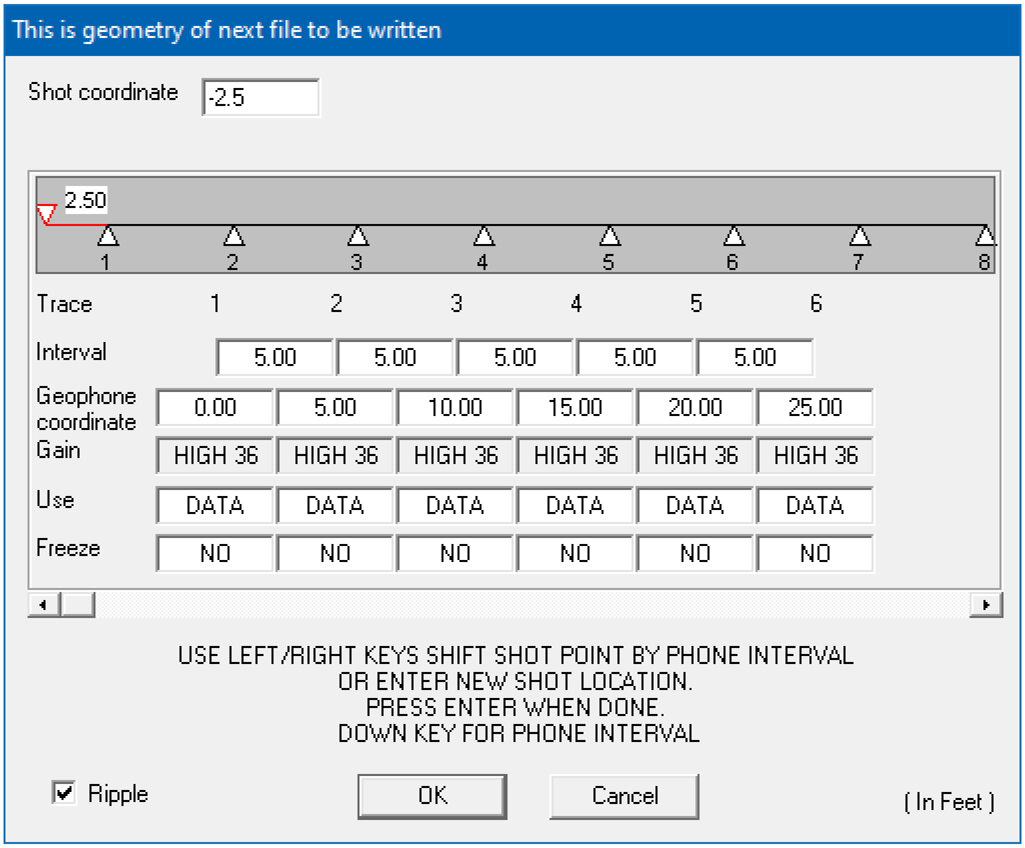
3.3.2.1 2D MASW Survey SCS Setup

The difference between the 1D and 2D MASW survey setups is the geometry. As mentioned previously, 2D MASW surveying involves numerous shots at incrementing locations, and the geophone spread may or may not be fixed. The geometry can be automatically updated and recorded to the file headers during acquisition, or it can be tracked and recorded separately by hand in observer's notes and assigned in SeisImager/SW during data processing. It is also possible to manually update the geometry in the software after each shot, but this is not recommended as it usually slows production down.

SCS can be set up to automatically increment just the shot coordinate, or both the shot and receiver coordinates, depending on the type of spread configuration used and if the SCS roll-along function is available. If you have the SCS roll-along function and choose to record the geometry in the file headers during acquisition, continue with this section to set up SCS. If you do not have the SCS roll-along function and/or choose to assign the geometry in SeisImager/SW at the time of data processing, skip this section.

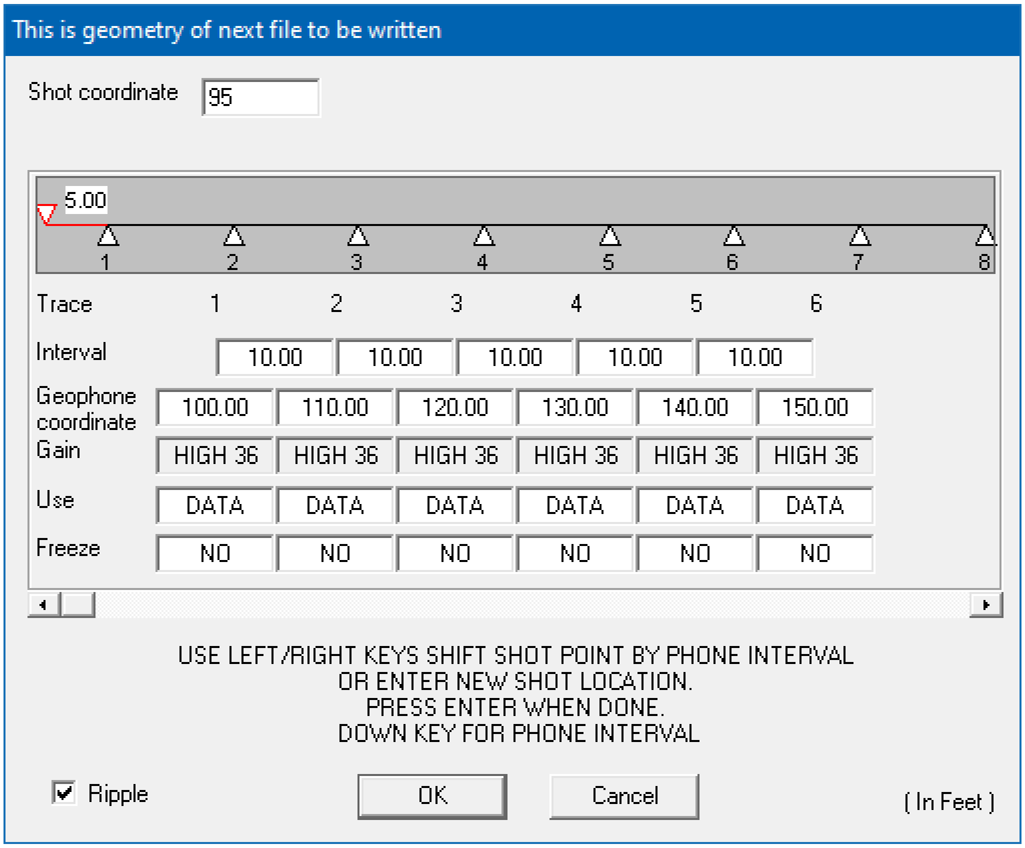
Once Section 3.1.2.1 (beginning on Page 14) has been completed, the shot and receiver coordinates can be set up to automatically increment, depending on the configuration: *fixed receiver spread*, *continuous fixed receiver spread*, or *roll-along end-on spread*.

For a *fixed receiver spread* configuration, the shot coordinate is set to automatically advance after each shot. First, check that the starting shot location is set off from the spread by one-half the geophone interval using the **Geometry** dialog box. Select *Geom* **|** *Group/Shot Locations*:



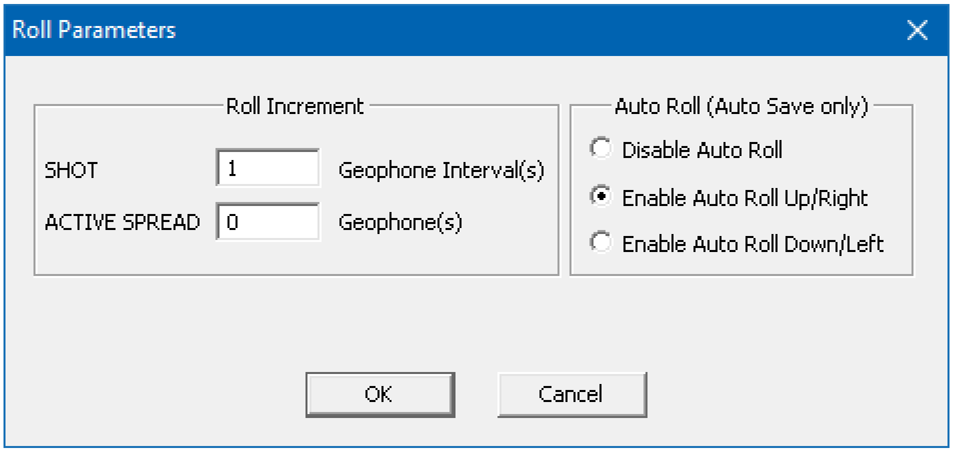
Example 1C:

For a *fixed receiver spread*, with a geophone interval of 10 feet and first geophone coordinate of 100 feet, the first shot is set at 95 feet:

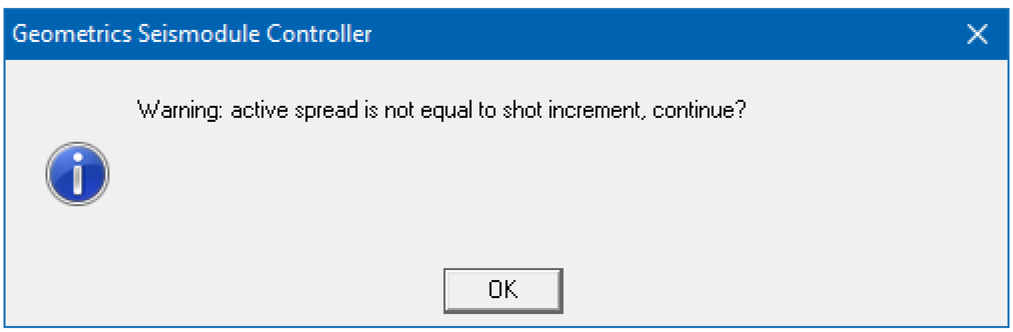


End Example 1C.

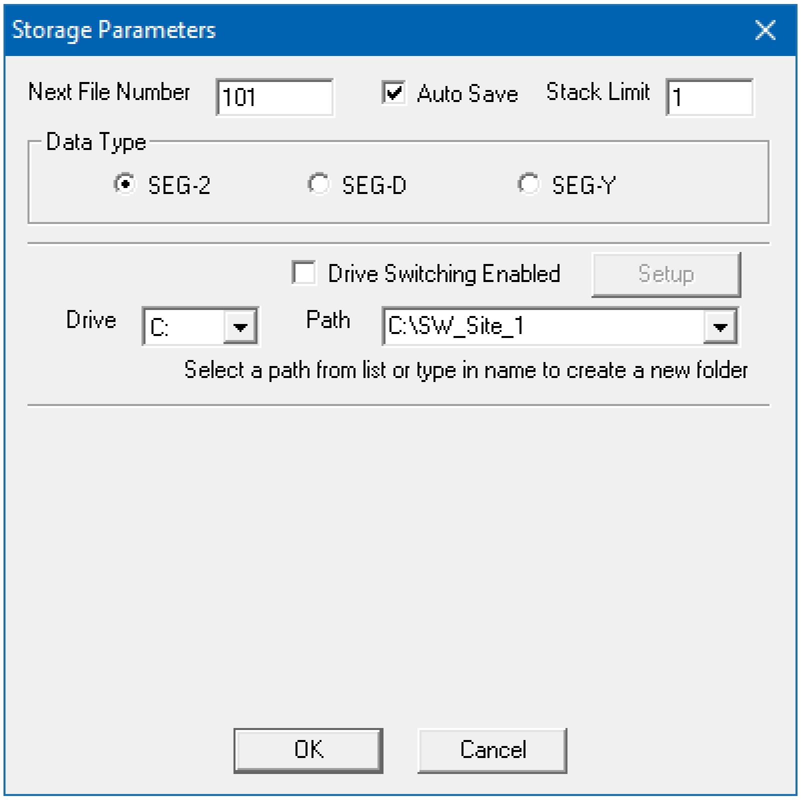
Next, set up rolling of the shot coordinate in the **Roll Parameters** dialog box. Select *Geom* **|** *Roll Parameters*. The *Shot Roll Increment* should equal 1 to advance the shot by one geophone *Interval* after the previous file is saved. With a starting shot coordinate that is off-end by one-half the geophone interval, a *Shot Roll Increment* of 1 will position the rest of the shots midway between the geophones. Check *Enable Auto Roll Up/Right* to advance the shot to the “right” or up-line. If your shot was on the right of the geophone spread, you would roll “left” or down-line. Press *OK* when done.



When the *Shot Roll Increment* is not equal to the *Active Spread Roll Increment*, a warning appears. Since the receiver spread is fixed in this case and should not roll with the shot; ignore the warning and press *OK*.



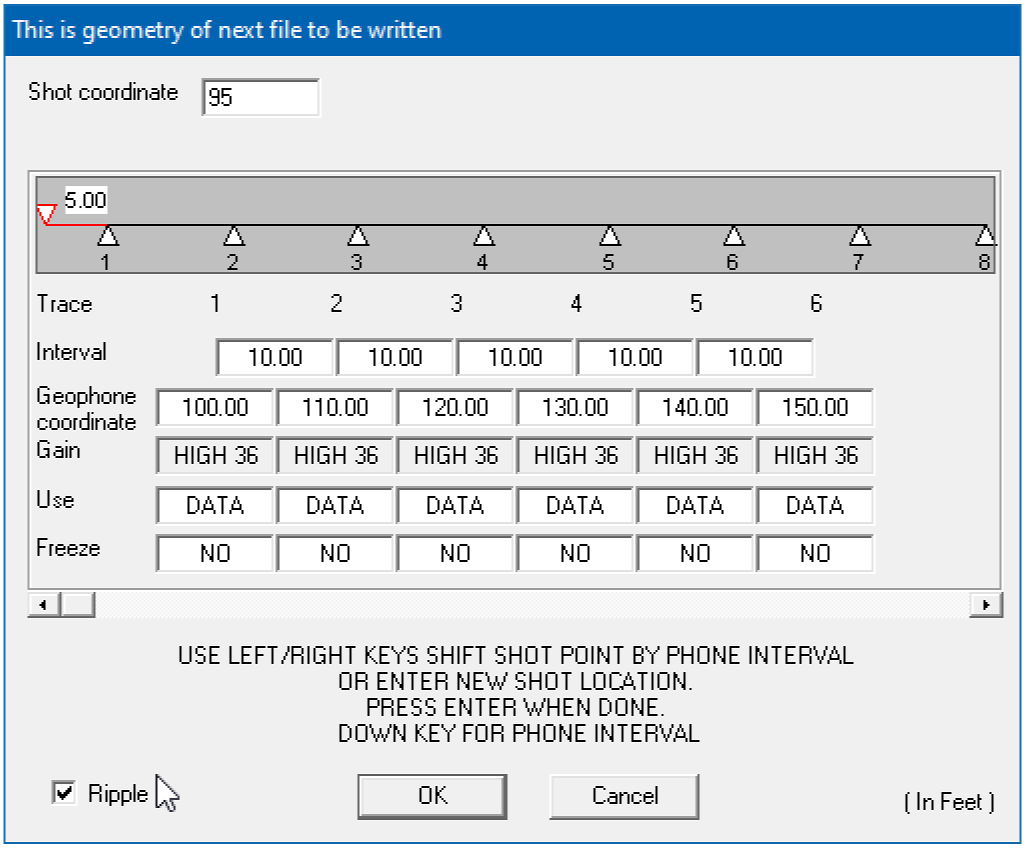
Next, activate *Auto Save* as required with automatic rolling. Select *File* | *Storage Parameters*:



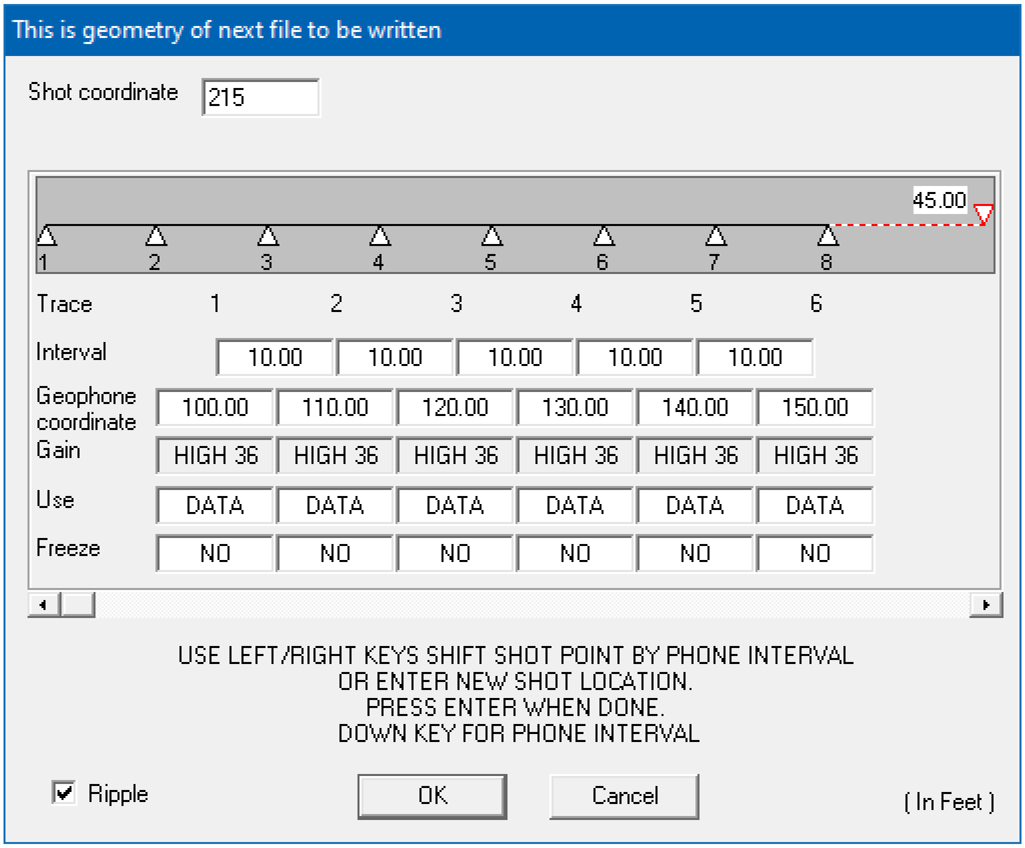
- For the *continuous fixed receiver spread* configuration, the shot coordinate will be set to automatically advance after each shot in the same way as for the *fixed receiver* spread. In addition, after the first half of the geophones are advanced up-line, the coordinates for the new locations occupied by geophones will need to be assigned through the **Geometry** dialog box.

Example 1D:

For a *continuous fixed receiver spread*, with a geophone interval of 10 feet and first geophone coordinate of 100 feet, the starting shot coordinate is set to 95 feet. The geophone coordinates are set to 100 feet for geophone 1, 210 feet for geophone 12, and 330 feet for geophone 24.



After the first half of the geophones are advanced up-line, the continuing coordinates are set to 220 to 450 feet and the next starting shot coordinate to 215 feet.



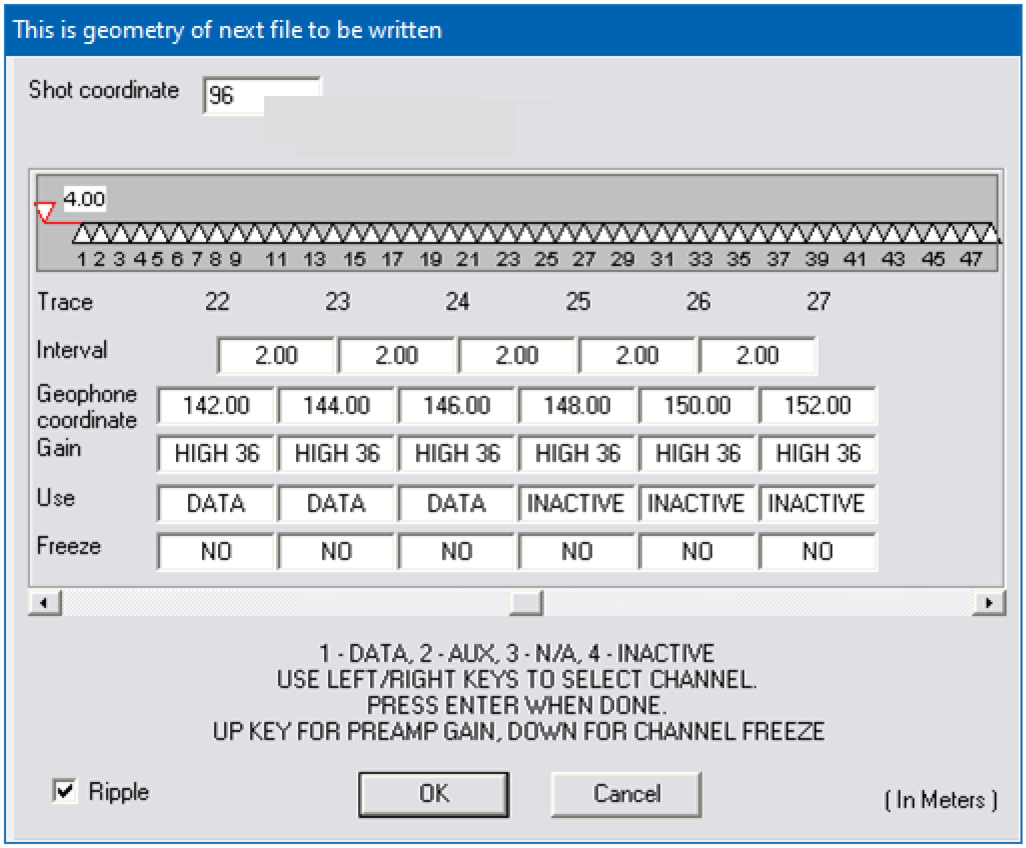
End Example 1D.

For a *roll-along end-on spread* configuration, the geometry setup will depend on the rolling method (Section 3.3.1.3, Page 44), using either software roll-along (Method A), a land streamer (Method B), or a mechanical roll box (Method C).

To set up using Method A, a subset, usually one-quarter or one-half of the channels, are deactivated so that there is a uniform channel number per shot record. The active spread of geophones is rolled through the deactivated channels. The inactive spread is continuous in the beginning, but as the active spread advances up-line, there will be an increasing number of inactive channels down-line and a decreasing number of inactive channels up-line.

Example 1E:

For a *roll-along end-on spread* using Method A, with 48 total channels and 24 live channels for each shot, channels 25 through 48 are deactivated.



After pressing *OK*, the *Geometry Tool bar* in the main SCS window reflects the deactivation by greying out the symbols for geophones 25 through 48 (circled in red).

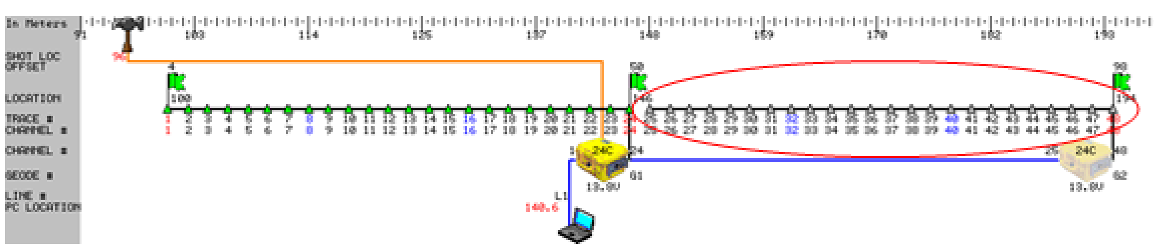
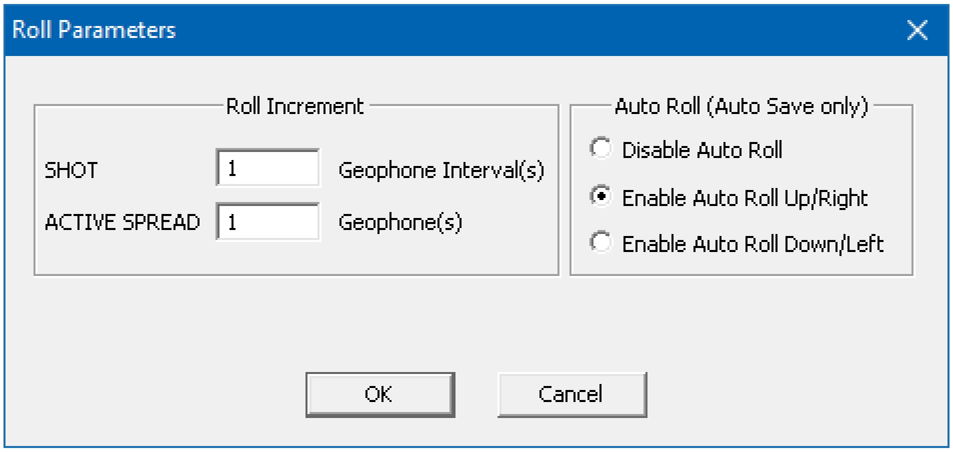


Figure 17: Geometry tool bar.

The *Shot Roll Increment* and *Active Spread Increment* are both set to 1, so that the shot coordinate and the active set of geophones are advanced by one interval after each shot. *Enable Auto Roll Up/Right* is checked to roll to the “right” or up-line.



End Example 1E.

To set up using Method B and Method C, none of the channels would be deactivated via software, and both the shot and geophone coordinates would be advanced after each shot. For Method C with a mechanical roll box, the dial that sets the connections between channels and geophones also needs to be advanced in sync with the coordinates after each shot.

For a complete explanation of the SCS roll-along function, please refer to the separate manual specific to your seismograph.

3.3.2.2 After Setup – Acquiring, Displaying, and Quality Checking 2D MASW Data

Once the setup is complete, you are ready to begin data acquisition. As discussed for 1D MASW surveys, perform the same system checks before starting acquisition, make the same adjustments to optimize the data display, and run the same data quality analyses.

After you have collected the active source records and are satisfied with the data, continue to the passive source survey if applicable.

4 Data Analysis Using the Wizard

SeisImager/SW is capable of 1D and 2D MASW for active sources and MAM data analysis for passive sources. The 1D analysis outputs a V_S curve and the 2D analysis outputs a V_S cross-section.

Note: *If you change units, you may have to change the limits of some of the axes in the phase velocity plots in WaveEQ – this is not automatic.*

Note: *In general, it is best to confirm the units in Pickwin, WaveEQ, and GeoPlot and close all three modules prior to running the wizard. Neglecting to do this can lead to errors and cause the* *program to become unstable. If this happens, the fix is to reset the modules to the factory defaults. See Note on Page 3.*

4.1 SURFACE WAVE ANALYSIS WIZARD

As discussed in Sections 1 (Page 1) and 2 (Page 5), the Pickwin, WaveEq, and GeoPlot modules comprise SeisImager/SW and the Surface Wave Analysis Wizard automatically calls on functions from these three modules to walk you through the processing flows. There is a flow for processing 1D MASW active source data (Section 4.1.1, Page 55), MAM passive source data (Section 4.1.2, Page 78) and 2D MASW active source data (Section 4.1.3, Page 90).

This section provides an explanation of the wizard's operation, processing flows, and basic dialog box parameters. Please refer to Sections 5.3 (Page 212) and 7 (Page 320) for a complete description and explanation of menu items and dialog box parameters (including some of the items in the **Advanced** *menu*), and Section Appendix A (Page A-2) for an ordered list of the functions used in the wizard so the processing flows can be manually reproduced.

The general processing flows as follows:

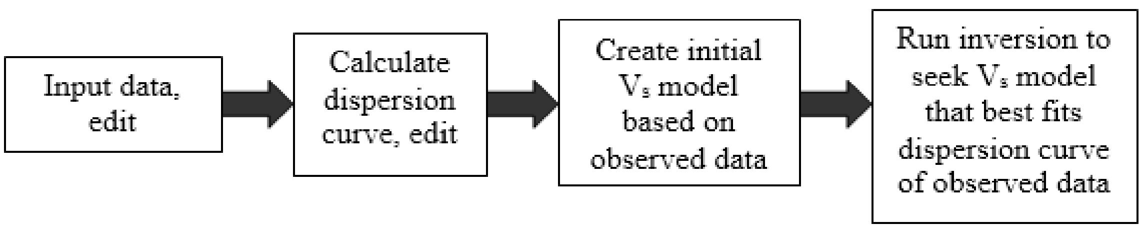


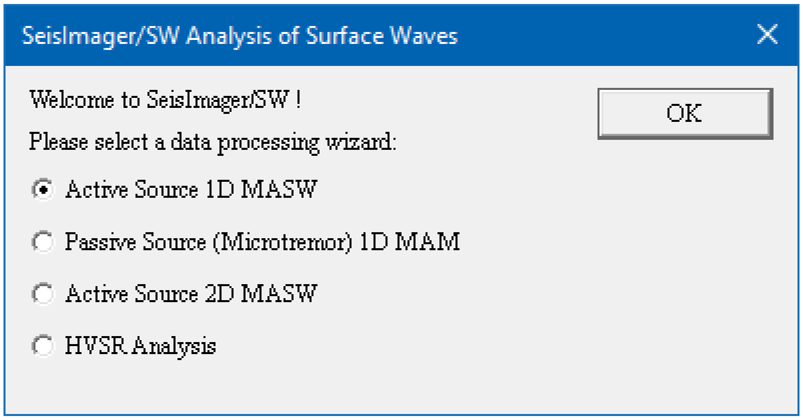
Figure 18: Surface wave processing flow.

The wizard is based on the *Enter* key. At any time, you can manually override the wizard by entering the menus. A complete 1D dataset is considered to consist of at least one active source file and a set of passive source files, and a complete 2D dataset consists of a series of active source files (the total number will vary depending on the survey). passive source results can also be integrated with 2D MASW datasets for deeper control. Integration of datasets is done manually outside of the wizard (Section 4.2, Page 156).

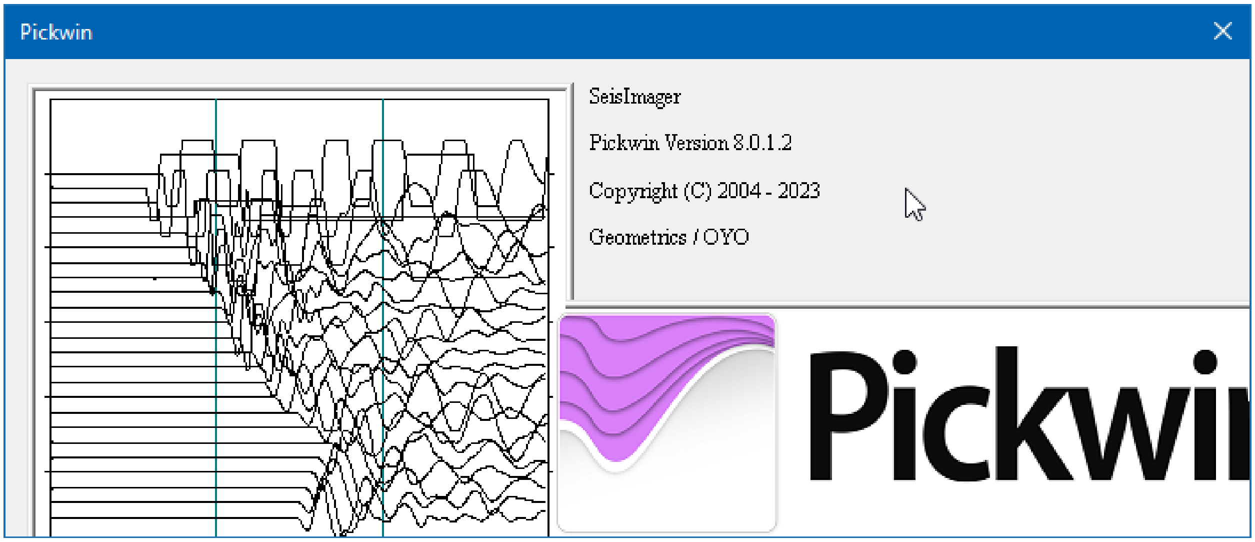
4.1.1 ACTIVE SOURCE 1D MASW WIZARD

Double-click on the **Surface Wave Analysis Wizard** icon.

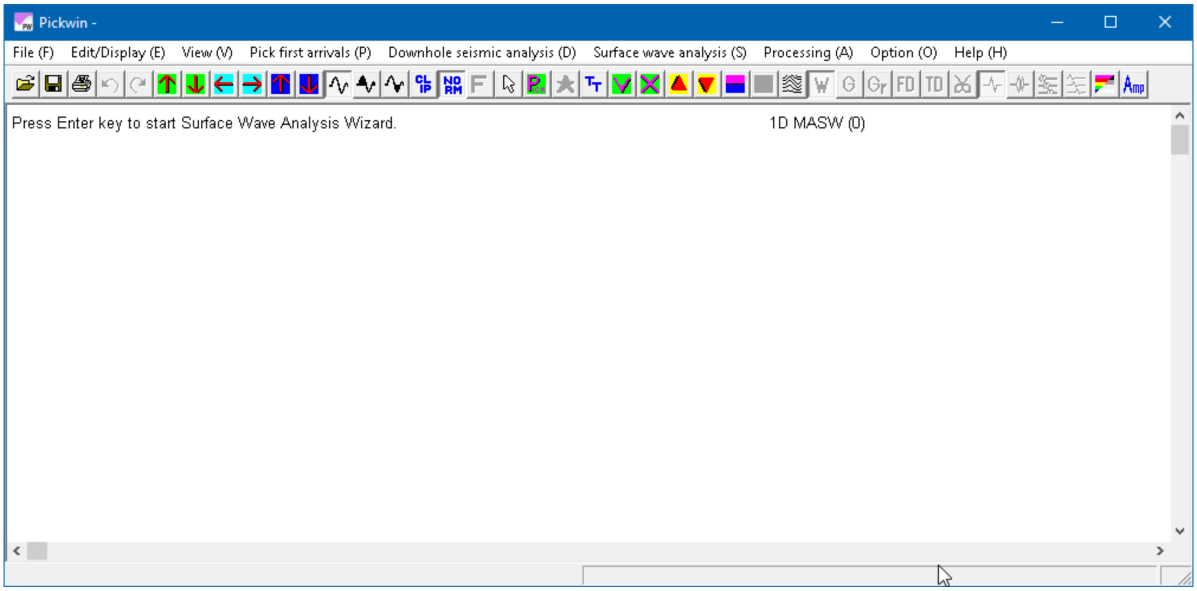
The **SeisImager/SW Analysis of Surface Waves** dialog box appears. Select *Active source 1D MASW* and press *OK*.



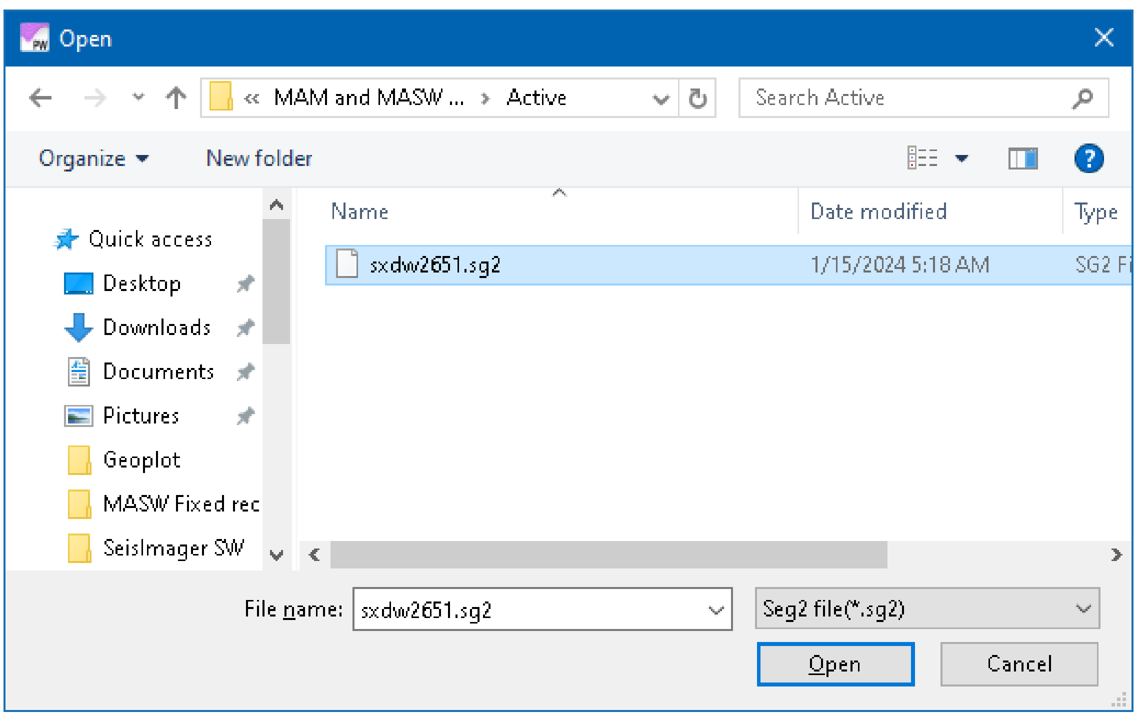
The **Pickwin** module will be launched.



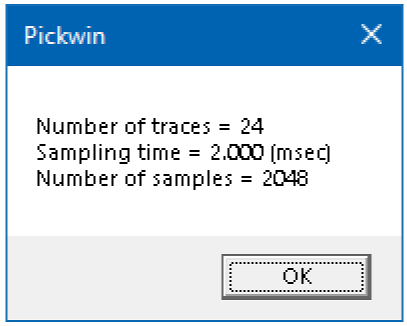
The main Pickwin window appears. The wizard calls functions from the **File** and **Surface Wave Analysis** menus. Press the *Enter* key as instructed in the upper left-hand corner of the window to begin.



The first step is to input the active source data file. Highlight the file and press *Open.* (You may use the *Enter* key.)



The waveform file is displayed.



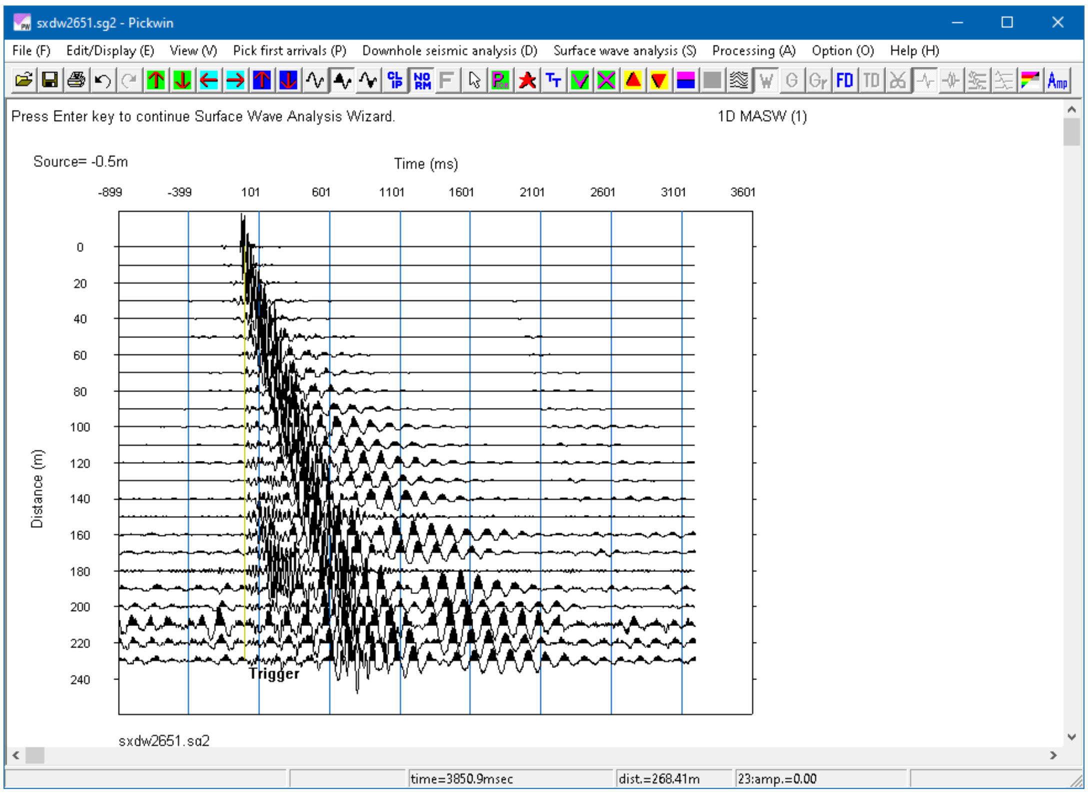
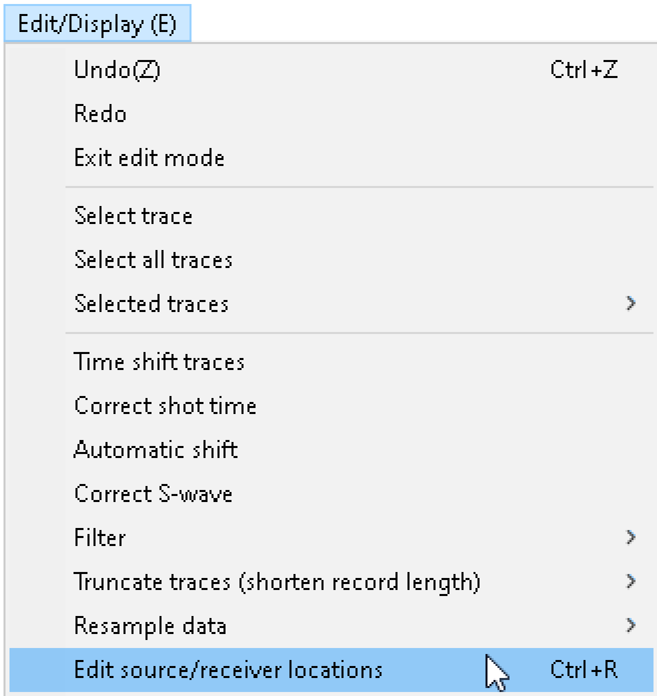


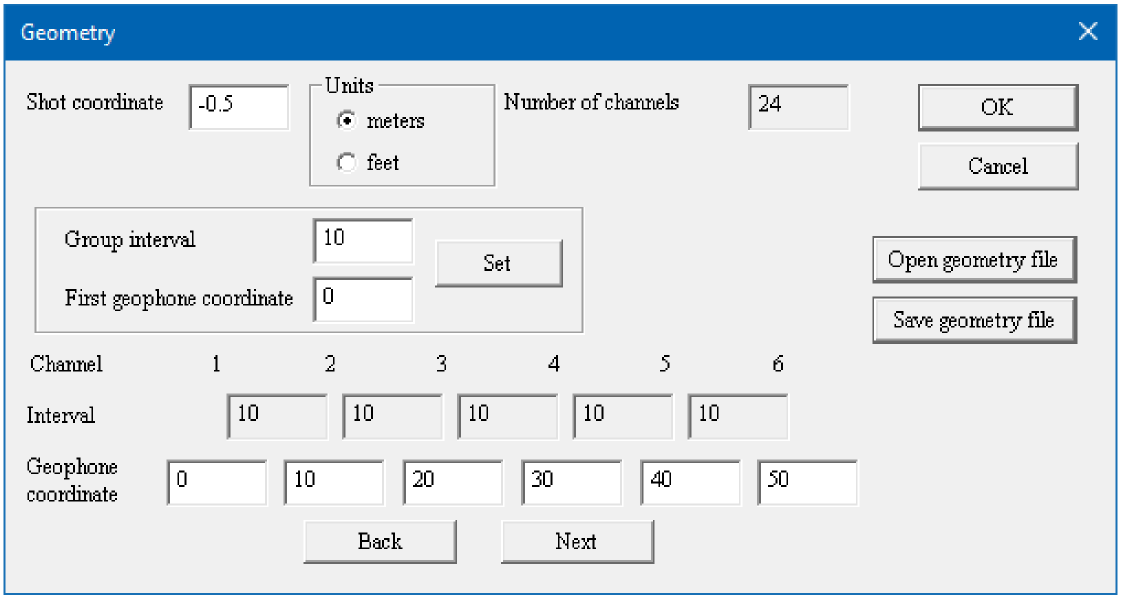
Figure 19: Shot record.

If the unit labels displayed are incorrect, open the **Edit/Display** menu and select *Edit source/receiver locations*.

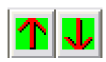
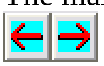
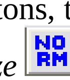


The **Geometry** dialog box appears and the *Units* setting allows selection between *meters* and *feet*. The *Units* setting will affect the unit labels shown in the dialog boxes as well as update the *Minimum phase velocity* default value used for picking the dispersion curve, which is 35 m/s or 150 ft/s. Once set (and Pickwin is closed), the assigned units will be recalled for subsequent uses of the wizard. (**It is necessary to close Pickwin to register the new *Units* setting**. At the end of the wizard, simply close Pickwin to register the new *Units* setting.)

The **Geometry** dialog box also reports the source and receiver coordinates saved in the file header at the time of acquisition. If there are errors, correct them here by entering the correct values for *Shot coordinate* and *Group interval*. Press *Set* to apply the new *Group interval* and to recalculate the *Geophone coordinates.* Press *OK* when done.



In the waveform view, the settings can be modified to optimize the display. All these settings are common with SeisImager/2D for refraction data processing; refer to the SeisImager/2D manual for a complete explanation.

The main functions needed are the *Waveform amplitude*  buttons, the *Horizontal scale*  buttons, the *Vertical scale*  buttons, and the *Normalize* 

button.

When done, press the *Enter* key to continue.

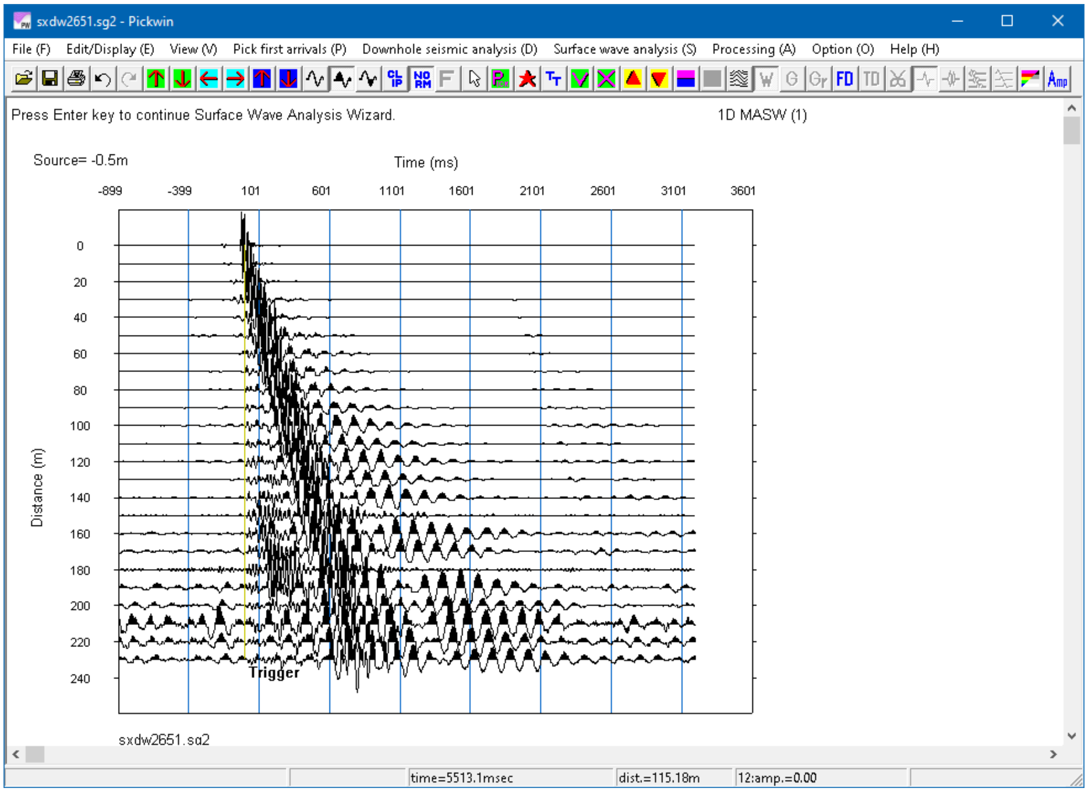
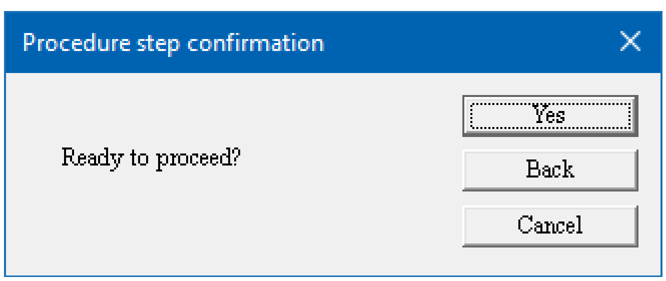


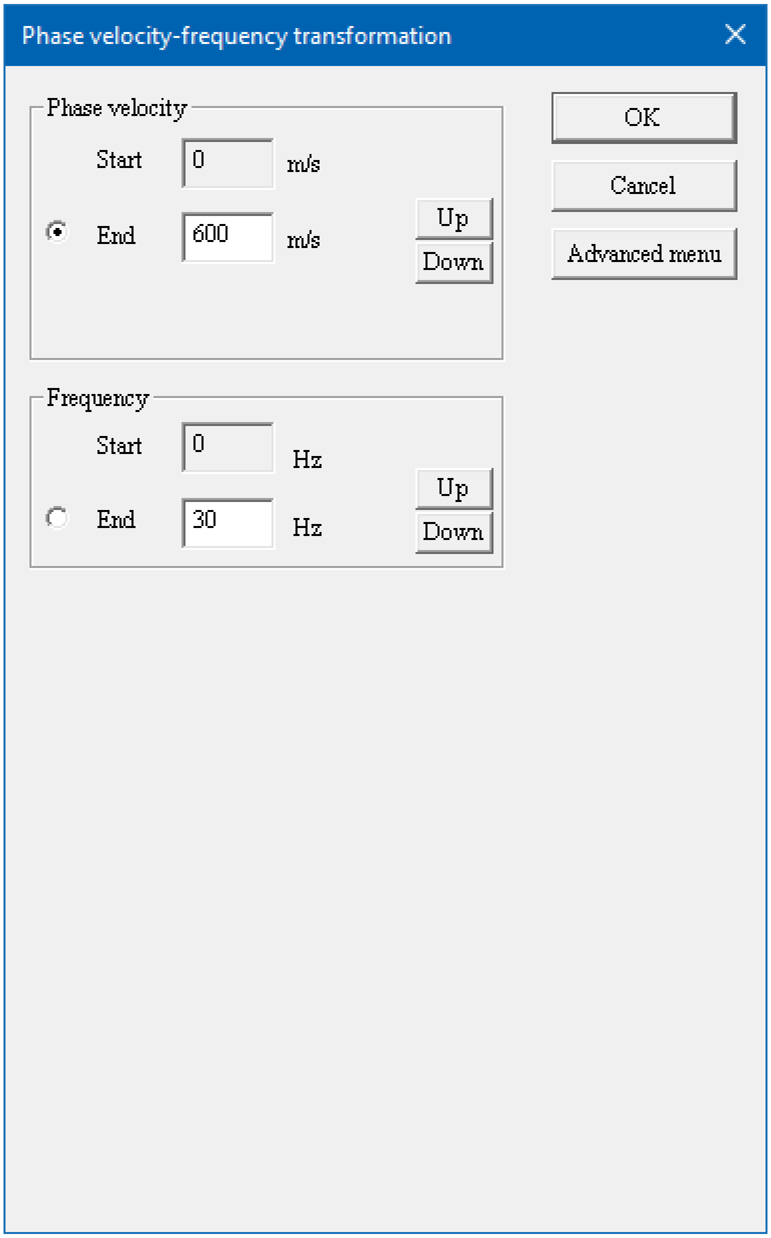
Figure 20: Waveform view.

Press *Yes* when ready to proceed.



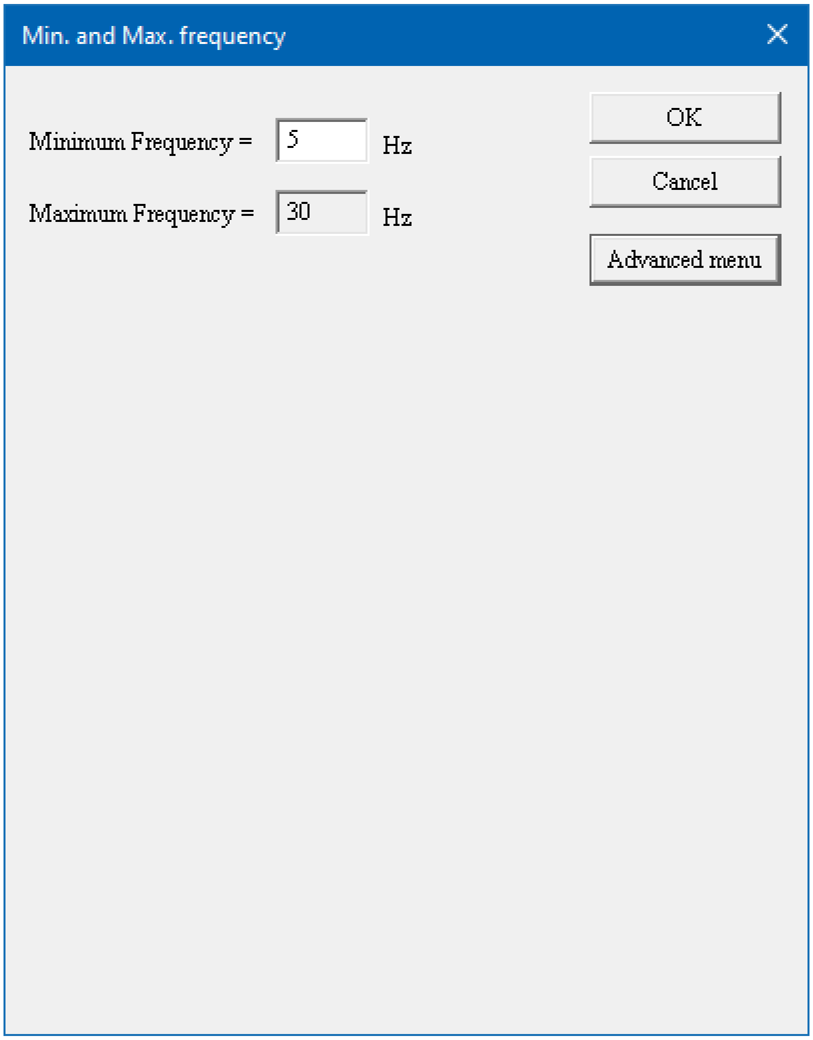
Next, set the parameters for calculation of phase velocity. Set *Phase Velocity End* to suit the maximum velocity you expect for your site.

The default value for *Frequency End* suits most cases. To see the extent of fundamental mode velocity on the high frequency end, a higher value can be entered. Press *OK* when done.



Next, set the parameters for picking the maximum amplitudes, which define the dispersion curve on the phase velocity-frequency plot. The *Minimum Frequency* default value is 5 Hz if 4.5 Hz geophones were used. If other geophones were used, their natural frequency can be entered, or use the default value to allow the software to attempt to pick amplitude maxima toward that end (any bad picks can be manually deleted later).

The *Maximum Frequency* reflects the value entered in the previous dialog box. Press *OK* when done.



Once the calculations are complete, a phase velocity-frequency plot is displayed with the automatically determined maximum amplitudes, shown as red points:

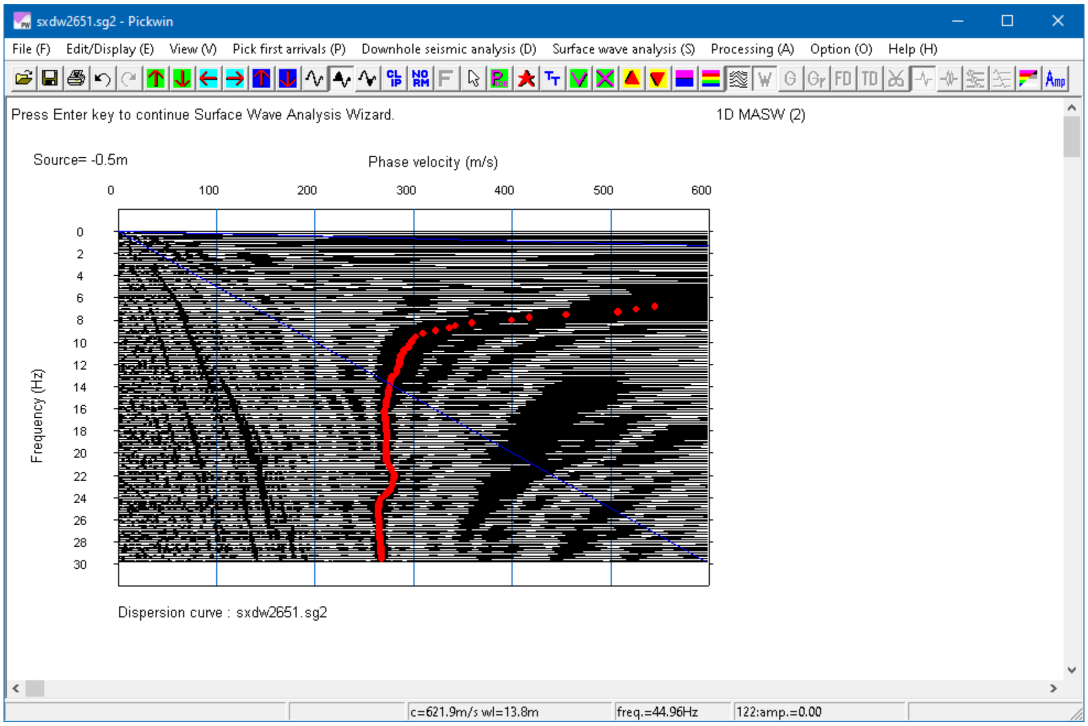


Figure 21: Phase velocity-frequency plot with picks.

The default display settings for the phase velocity-frequency plot are *Wiggle trace* *Shaded black*. Usually, the dispersion curve is more obvious in color contours. Select the *Fine color contour* button to switch to a color plot and use the *Waveform amplitude* buttons, the *Horizontal scale* buttons, and the *Vertical scale* buttons to optimize the display.

If you need to manually make or edit picks, you can do so by clicking at the desired pick location. To help identify maxima, as you drag the mouse over the plot, the actual amplitude values can be read on the taskbar 12:amp.=0.87285, where the value preceding the colon is the frequency and the value following is the amplitude. To restore the automatically determined picks, open the **Surface wave analysis** menu and select *Pick phase velocity (1D).*

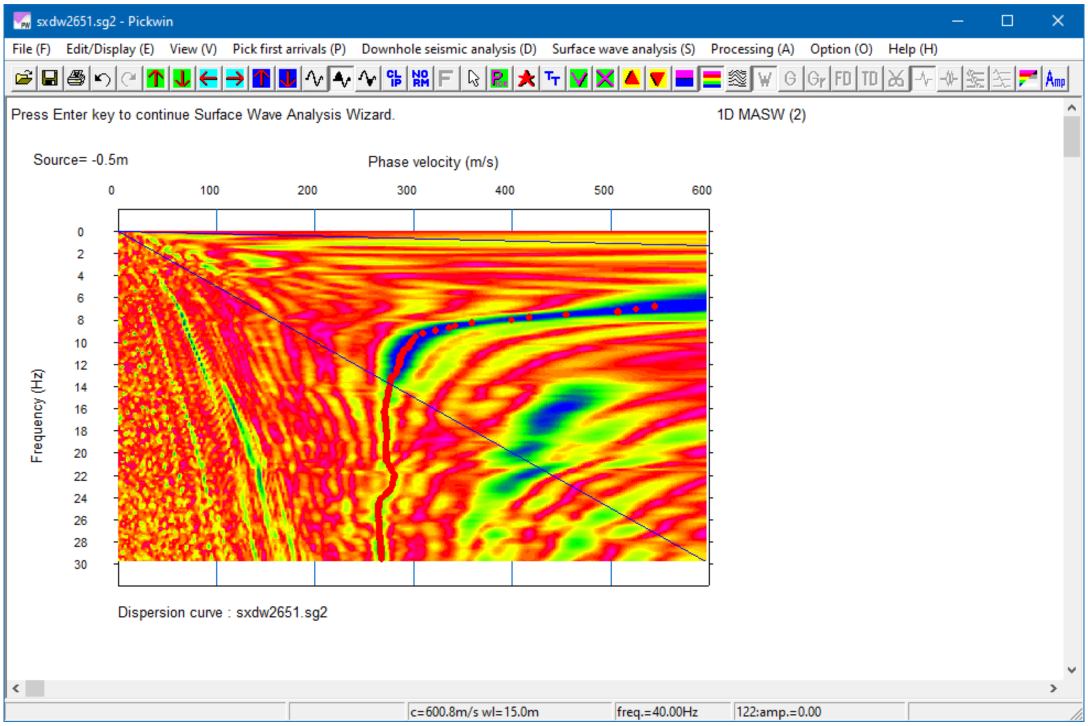
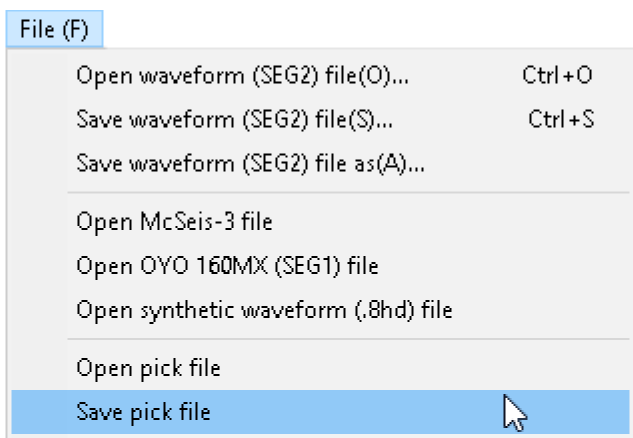
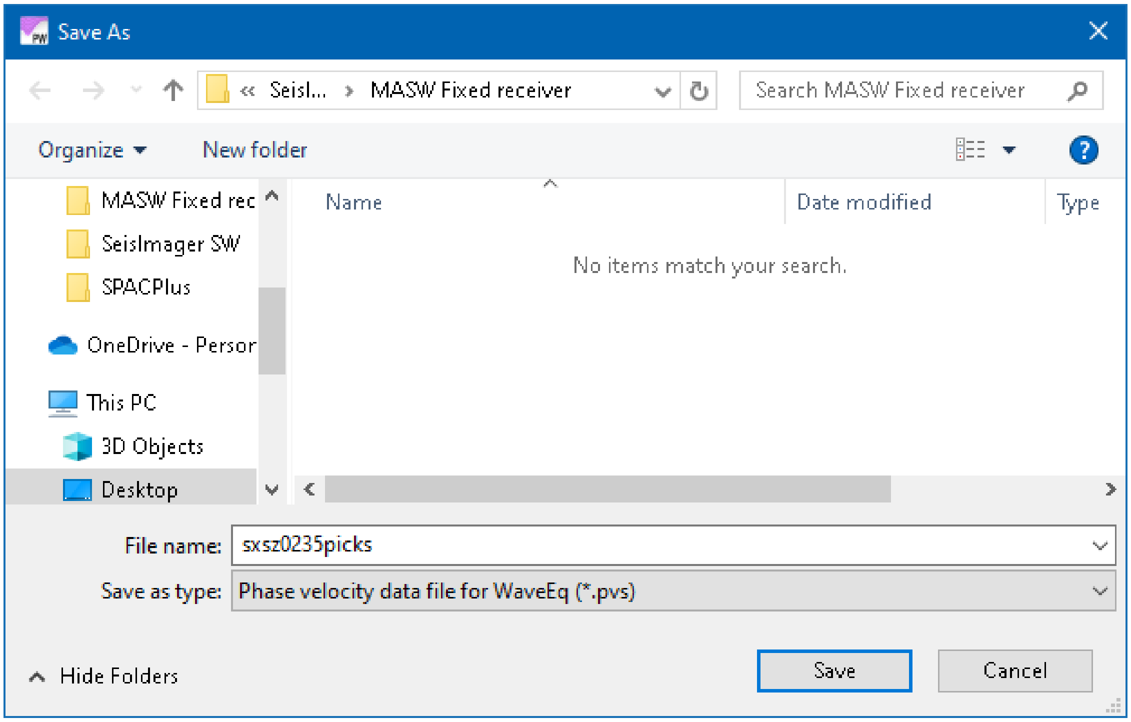


Figure 22: Color phase velocity-frequency plot with picks.

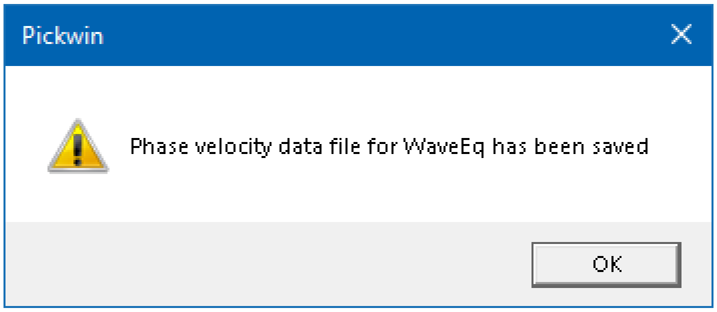
Save the dispersion curve picks if you would like to be able to input them again later. To do so, open the **File** menu and select *Save pick file*.



Assign a file name with the extension *.pvs* and press *Save*.



Once the file is saved, press *OK*.



After the file is saved, the dispersion curve is displayed with a pink line connecting the picks. Refer to Section 6.1.3, Page 216, on how to re-input saved picks.

Press the *Enter* key to continue.

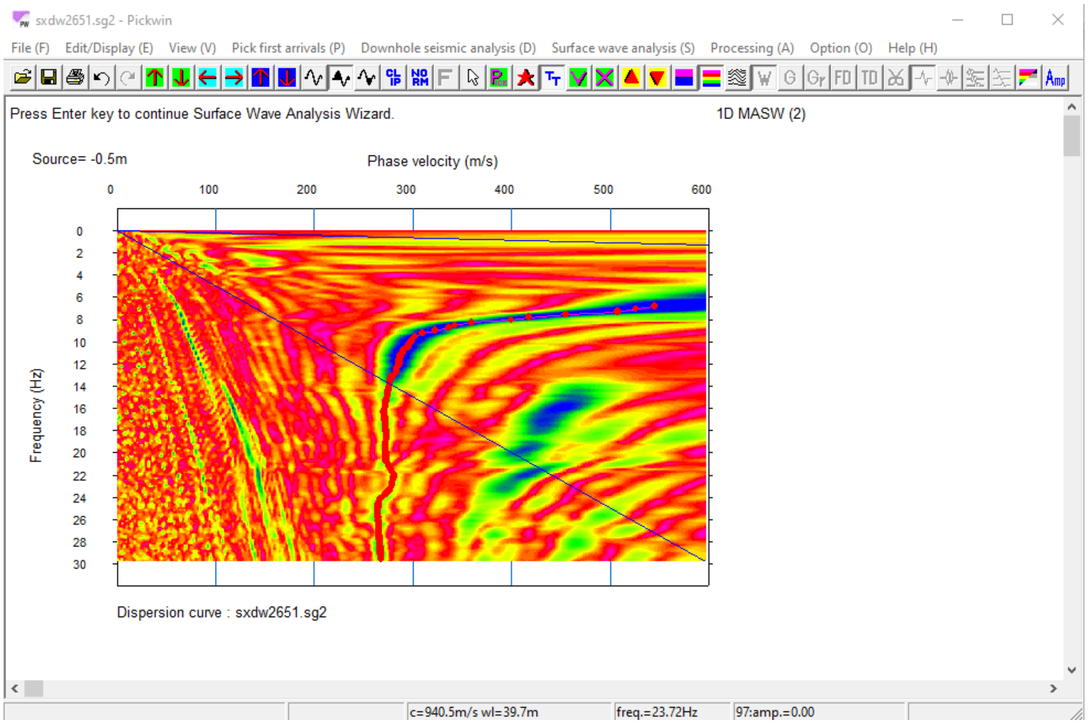
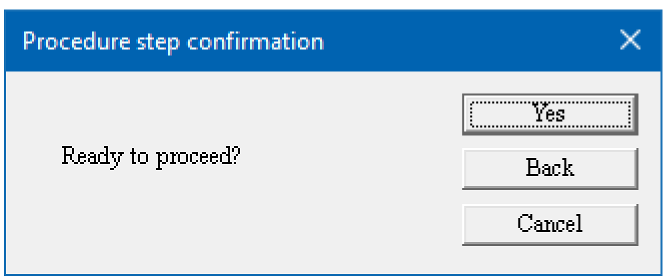
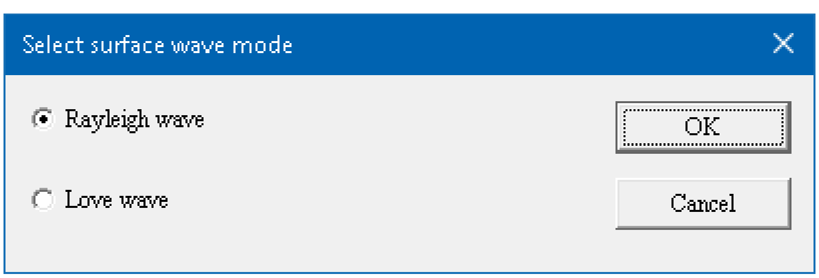


Figure 23: Phase velocity-frequency plot with picks connected by line.

Press *Yes* when ready to proceed.



You will be prompted for Rayleigh wave or Love wave. (The vast majority of surface wave work uses Rayleigh waves.)



Next, the **WaveEq** module launches, and the dispersion curve is displayed. Note that in WaveEq, *Phase velocity* is plotted on the vertical axis and *Frequency* is plotted on the horizontal axis. From this point on, the wizard calls functions from the **Dispersion curves** and **MASW (1D)** menus.

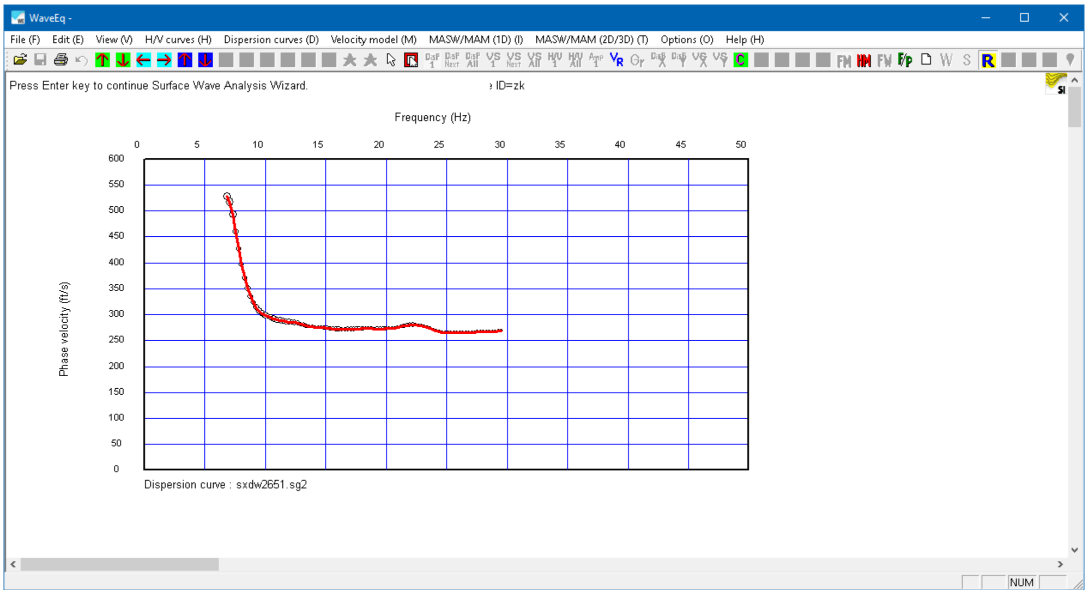
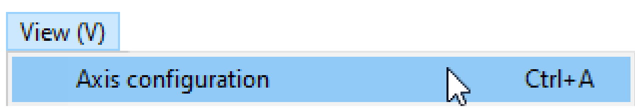
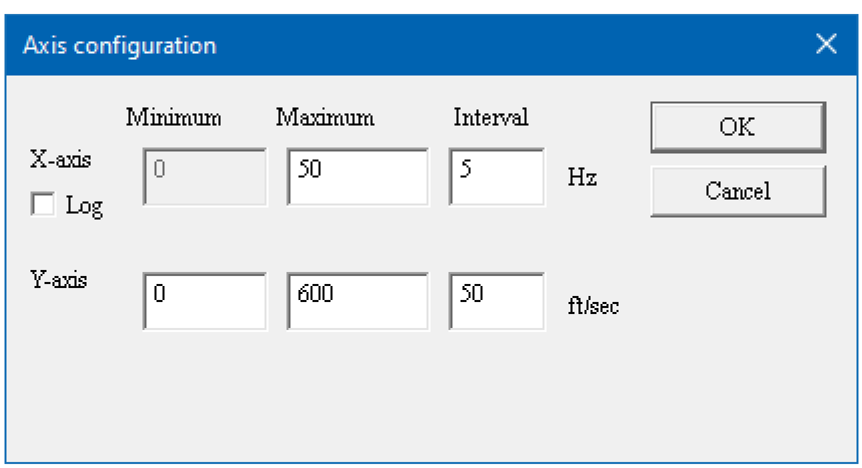


Figure 24: Dispersion curve plot.

If the plotting scales need adjustment, open the **View** menu and select *Axis configuration*.



Enter the desired values for the *X-axis* and *Y-axis Maximum* scale and *Interval*. Press *OK* when done.



Next, edit the dispersion curve as needed. Commonly, there are noisy picks on the low and high frequency ends of the curve; a gate provides easy editing.

Follow the instructions in the upper left-hand corner of the window. The red gate is the active gate. Use the *right*- and *left-arrow* keys to position the gate at the frequency up to which you want to delete. Press the *Enter* key to activate the right-hand side gate and position it the same way using the *arrow* keys. Press the *Enter* key when done.

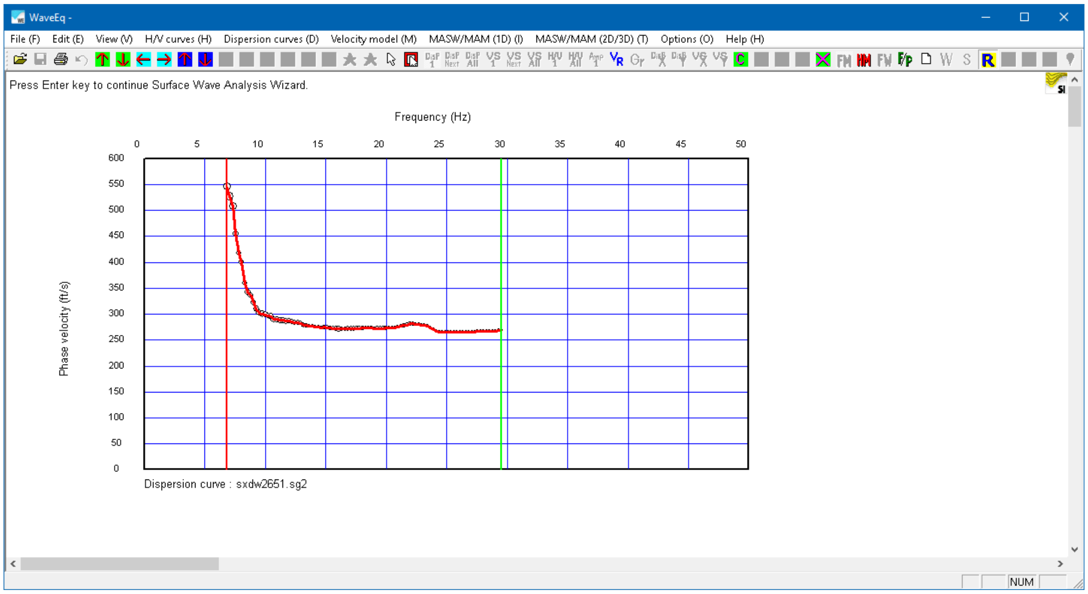
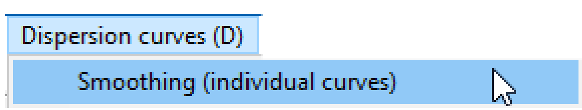


Figure 25: Dispersion curve plot with gate.

In addition to noisy picks on the ends of the curve, there may be outliers within the curve. Outliers can be deleted by pressing the *Selection*  button, selecting the outlying points on the curve, then pressing the *Delete* key. When done, press  again to disable the *Selection* button.

If the curve has noisy jitter, it can be smoothed by opening the **Dispersion curves** menu and selecting *Smoothing (individual curves)*. Upon selection, the curve will automatically be smoothed.



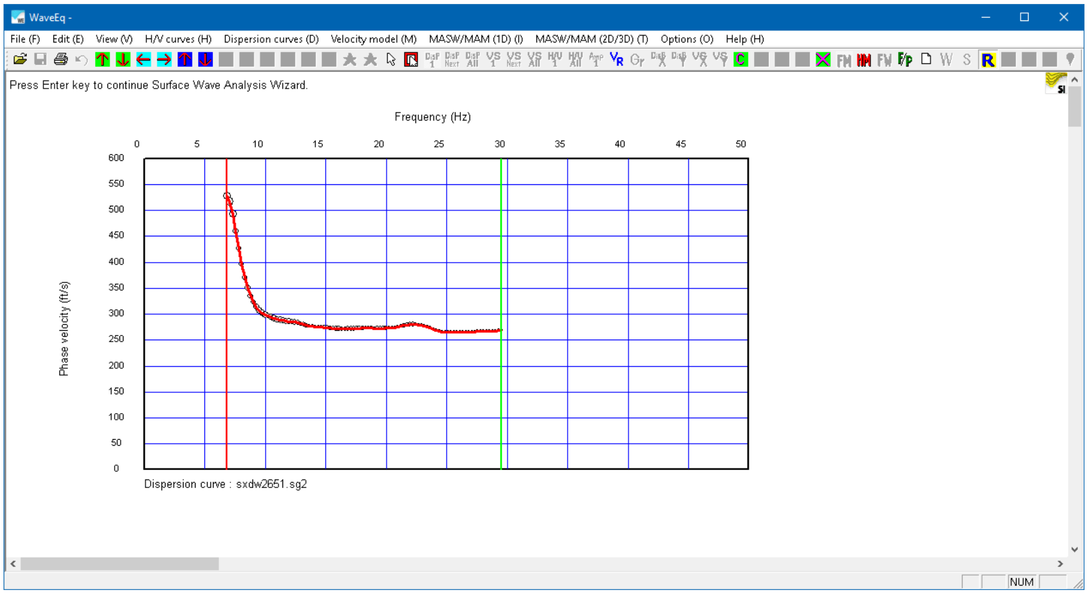
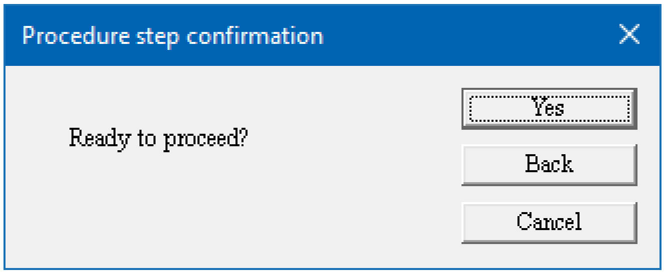


Figure 26: Smoothed dispersion curve.

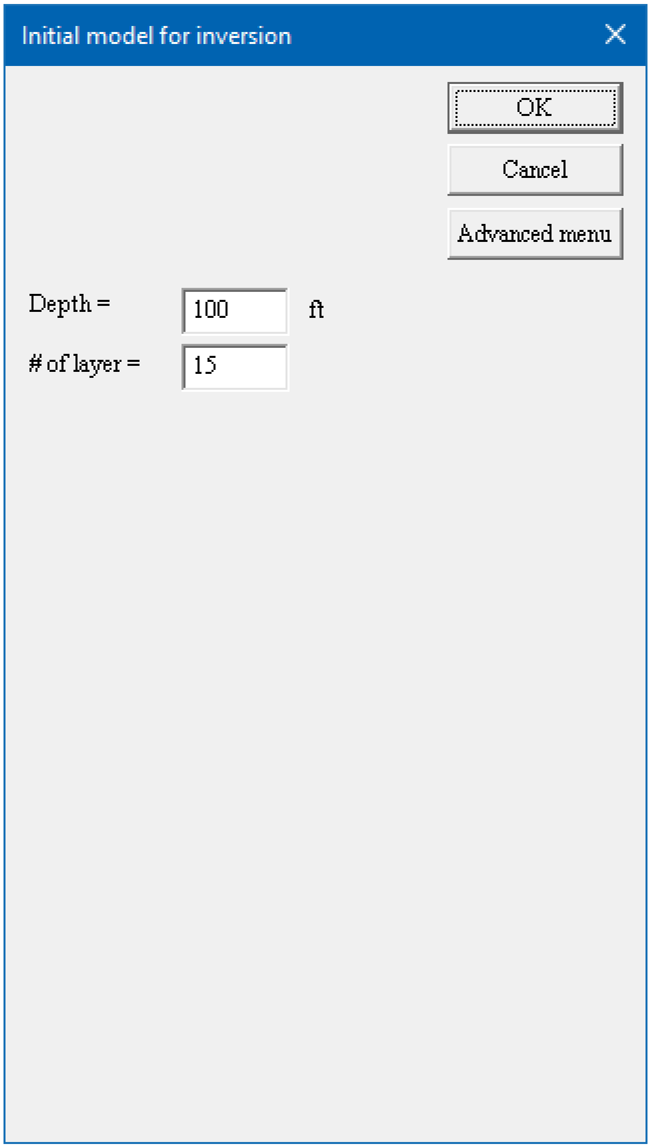
If necessary, use the *right*- and *left-arrow* keys to position the left-hand gate at the frequency below which you wish to delete data. Then press the *Enter* key to activate the right-hand gate and position it the same way using the *arrow* keys.

When done, press the *Enter* key to continue.

Press *Yes* when ready to proceed.



Next, set up the initial model of V_S with depth. The software default setting is to calculate the initial model from the one-third-wavelength approximation. For the *Depth* value, a good estimate to start with is one-half the spread length. The default value for the *Number of layers* is suitable for most cases. Press *OK* when done.


Initial model for inversion
OK
Cancel
Advanced menu
Depth =
100
ft
# of layer =
15

The initial model is displayed. Press the *Enter* key to continue.

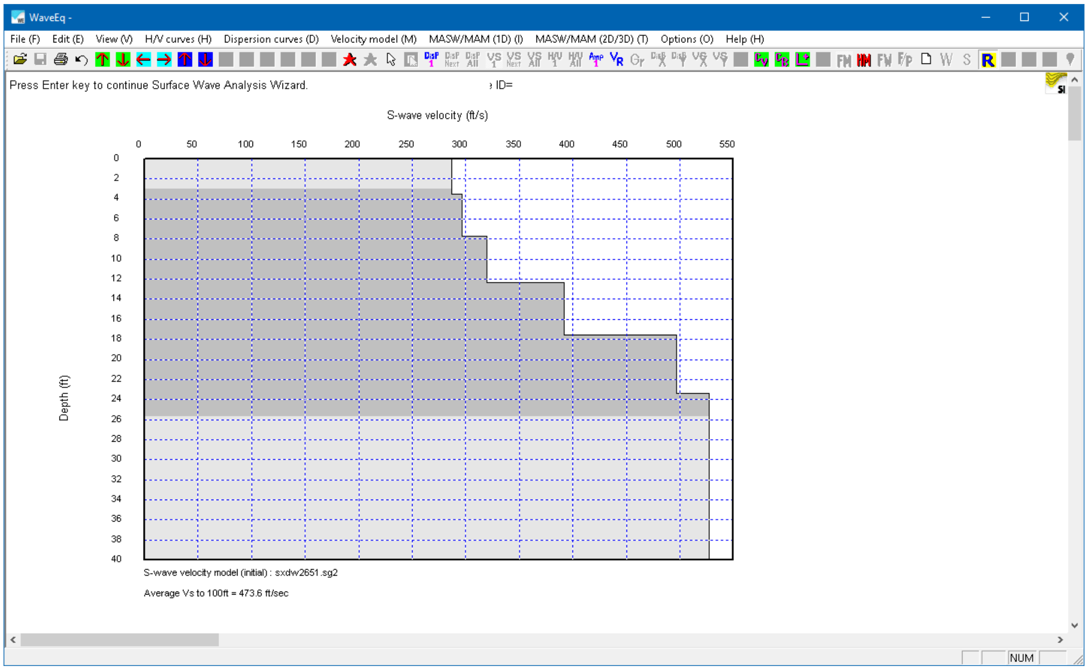
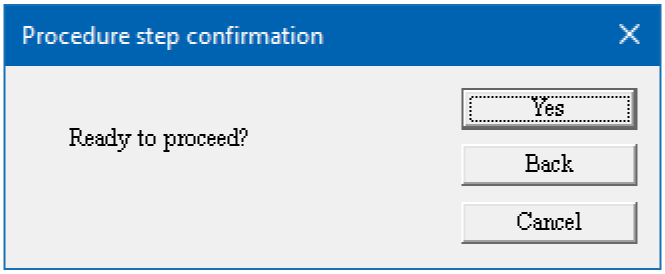
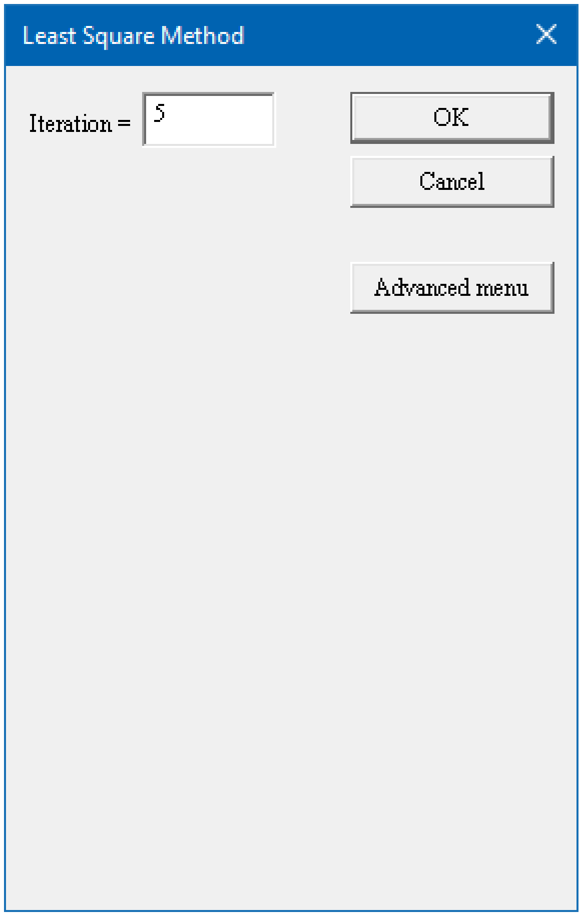


Figure 27: Initial velocity model.

Press *Yes* when ready to proceed.



Next, set the number of iterations for the inversion. The software will iterate the number of times indicated to converge on the best fit of the modified initial model data with the observed data. The default value of 5 for *Iteration* is suitable for most cases (generally, no more than 10 iterations are needed). Press *OK* when done.



Once the inversion is complete, the final V_S curve is displayed:

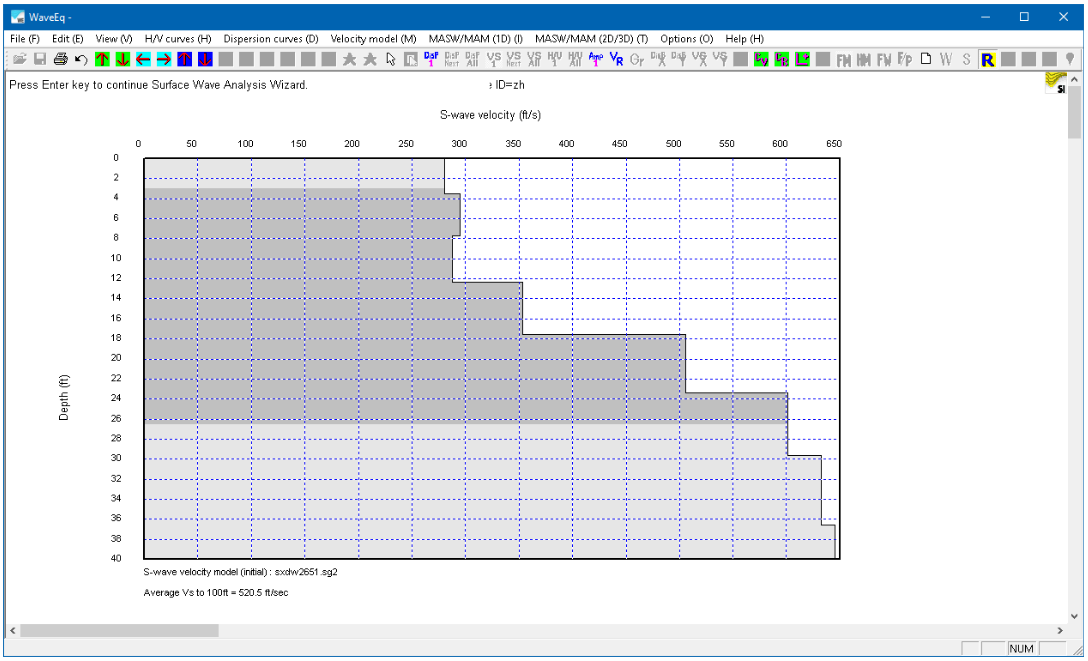


Figure 28: Final V_S curve.

Press the *Show apparent velocity model*  button to overlay the one-third-wavelength approximation (red points), which is the best indicator of the actual depth range of penetration. By default, the shade of the model changes to light grey, starting at the deepest apparent velocity, to call attention to the limits of the data.

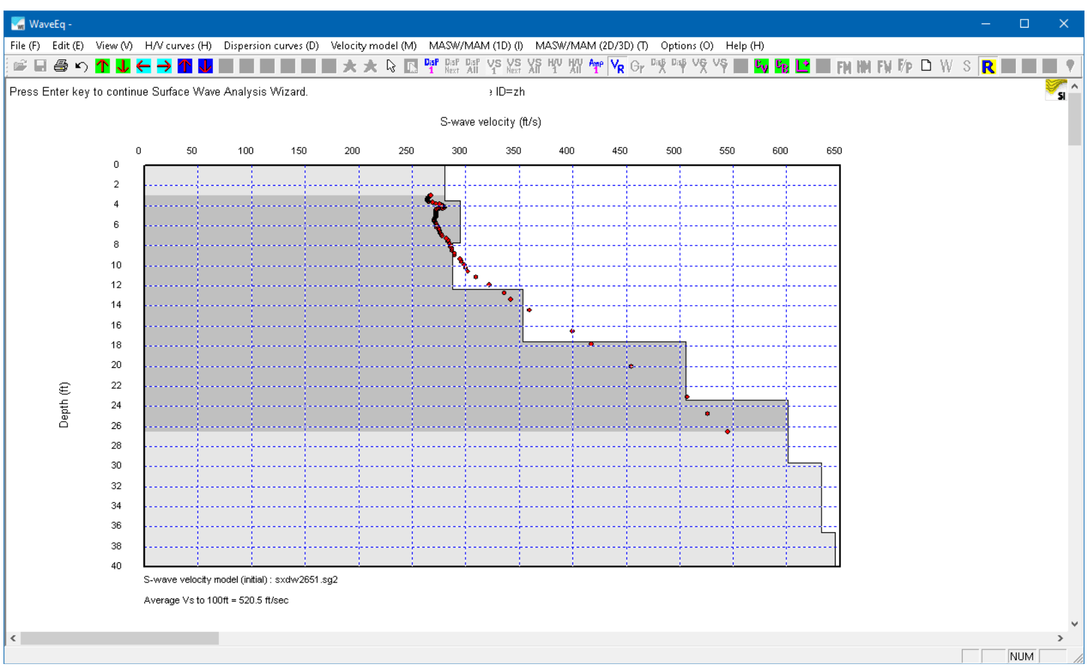
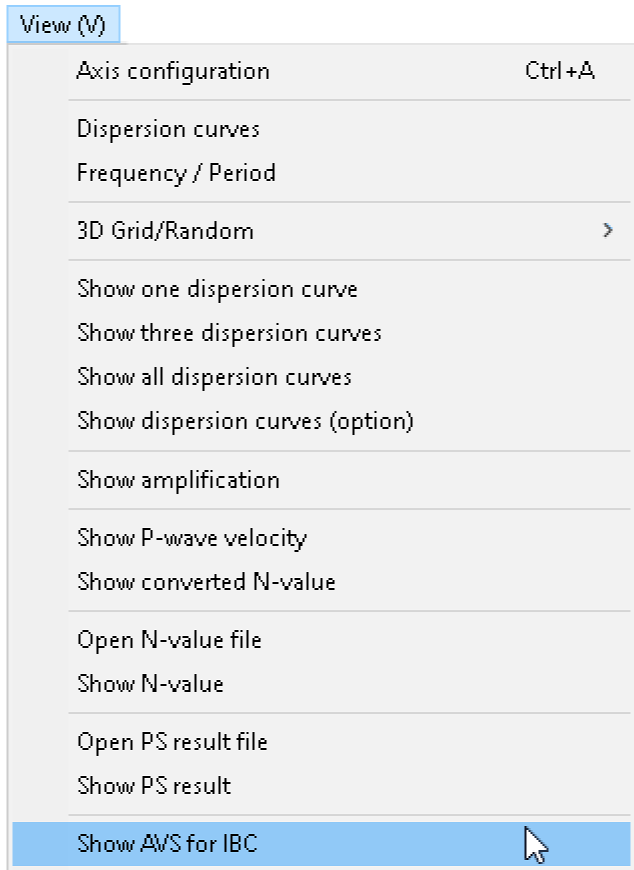
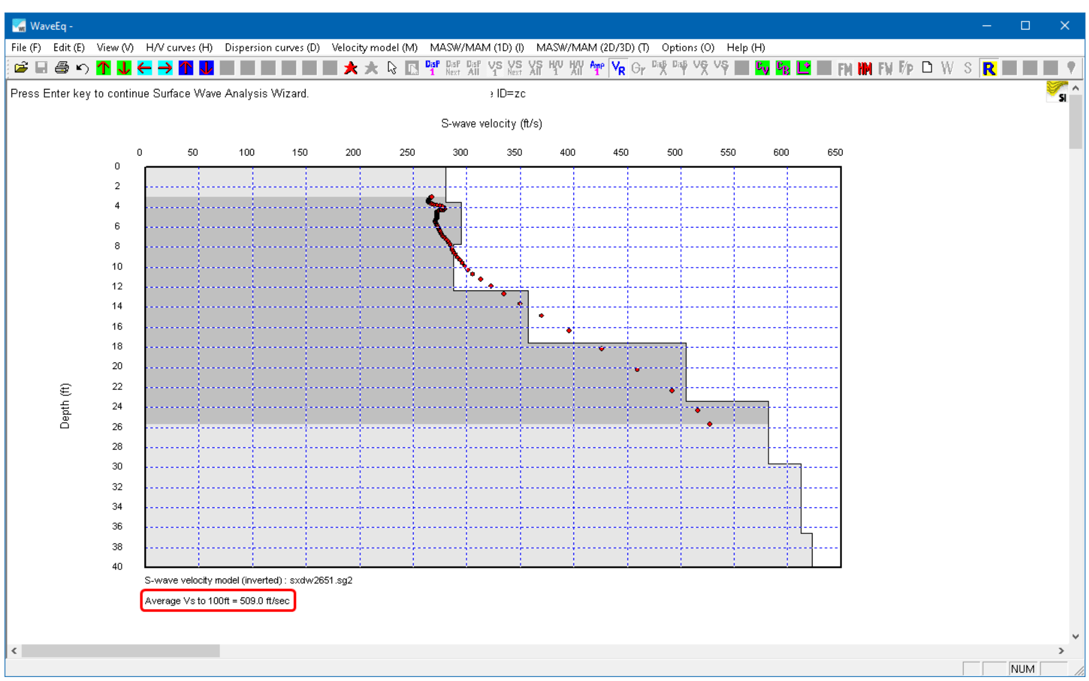


Figure 29: Final V_S curve with apparent velocity overlay.

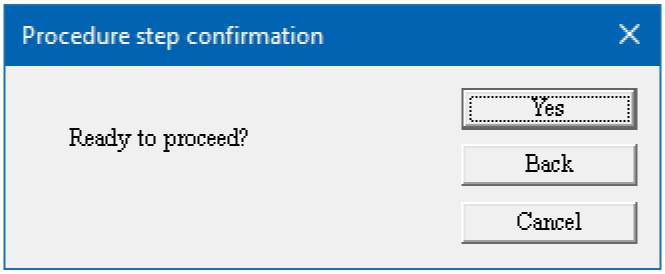
If there is good control to a depth of 30 m (100 ft), open the **View** menu and select *Show AVS for IBC* to calculate and display the average V_S value.



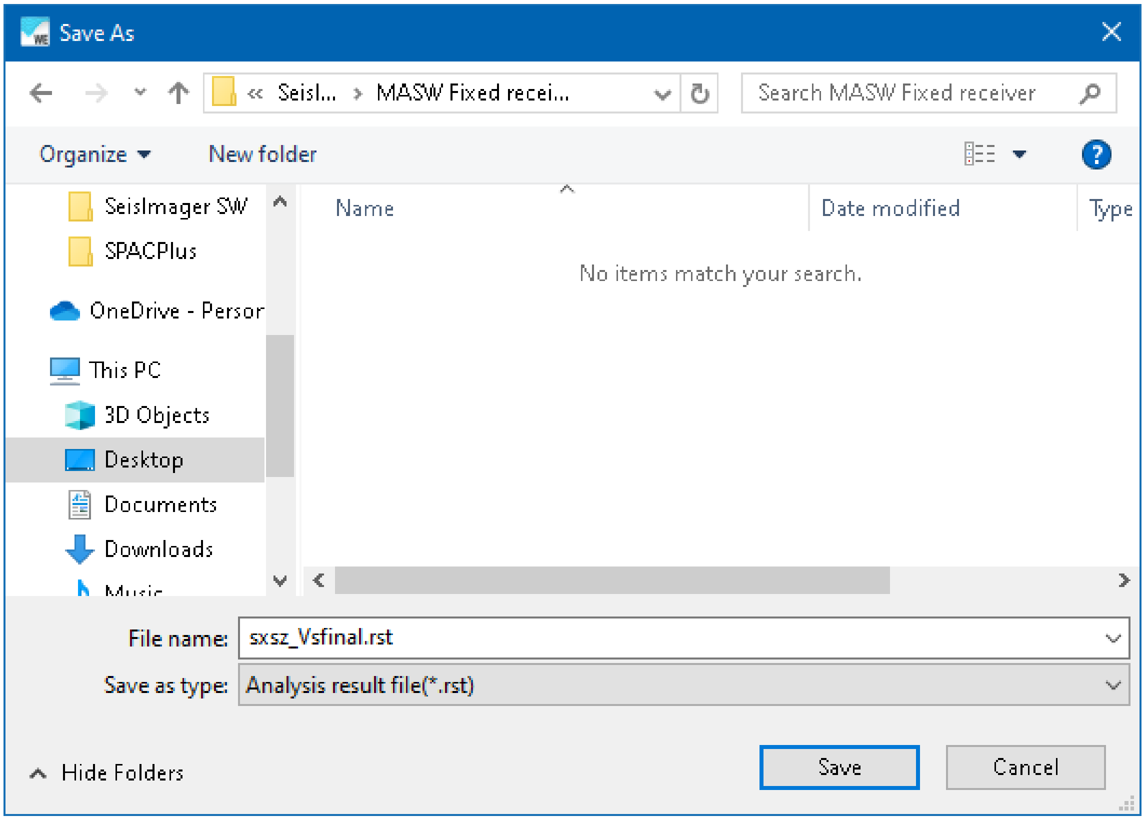


When done, press the *Enter* key to continue.

Press *Yes* when ready to proceed.



Lastly, save the result. Assign a file name with the extension *.rst* and press *Save*.



After the file is saved, check the fit of the calculated and observed dispersion curves. Press the *Show one dispersion curve* button to display the original dispersion curve. Press the *Comparison* button to overlay the calculated dispersion curve (black line) and visually assess the degree of mismatch. The matching error between the two curves in units of time (ms) and as a percentage is also saved to a file called *RMSE.txt* in the dataset directory. The error should be less than about 5% but will vary depending on the dataset.

If there is a high degree of mismatch, it is likely due to dispersion curve anomalies, such as sharp changes and/or outliers, or due to low quality, noisy picks on the low and high frequency ends of the curve. The mismatch will also be evident in the final V_S curve, usually as an unrealistic velocity inversion or gradient. Although the mathematical inversion may be able to model these aspects of the dispersion curve, surface waves, by their physical nature, cannot resolve relatively abrupt or small-scale velocity anomalies. The dispersion curve should be double-checked and the process re-run to improve the match.

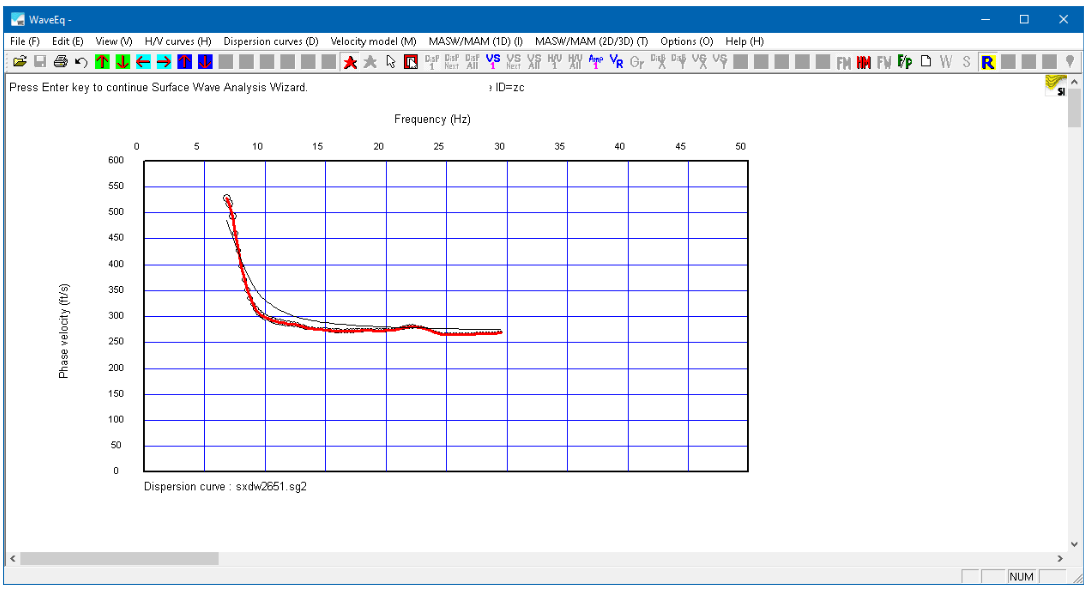
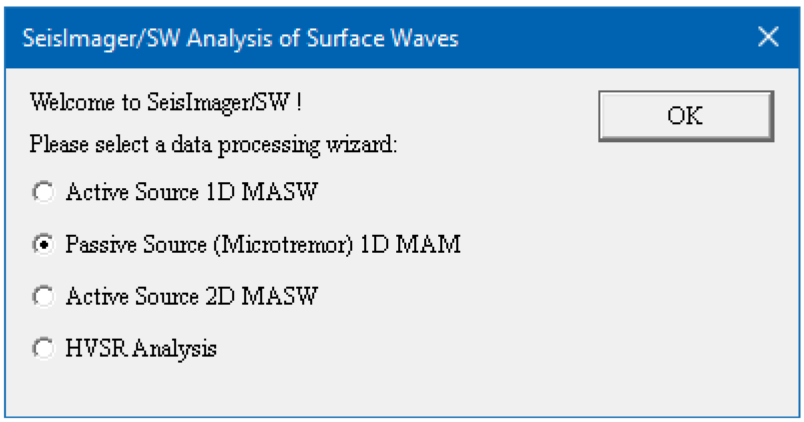


Figure 30: Comparison between calculated (black) and observed (red) dispersion curves.

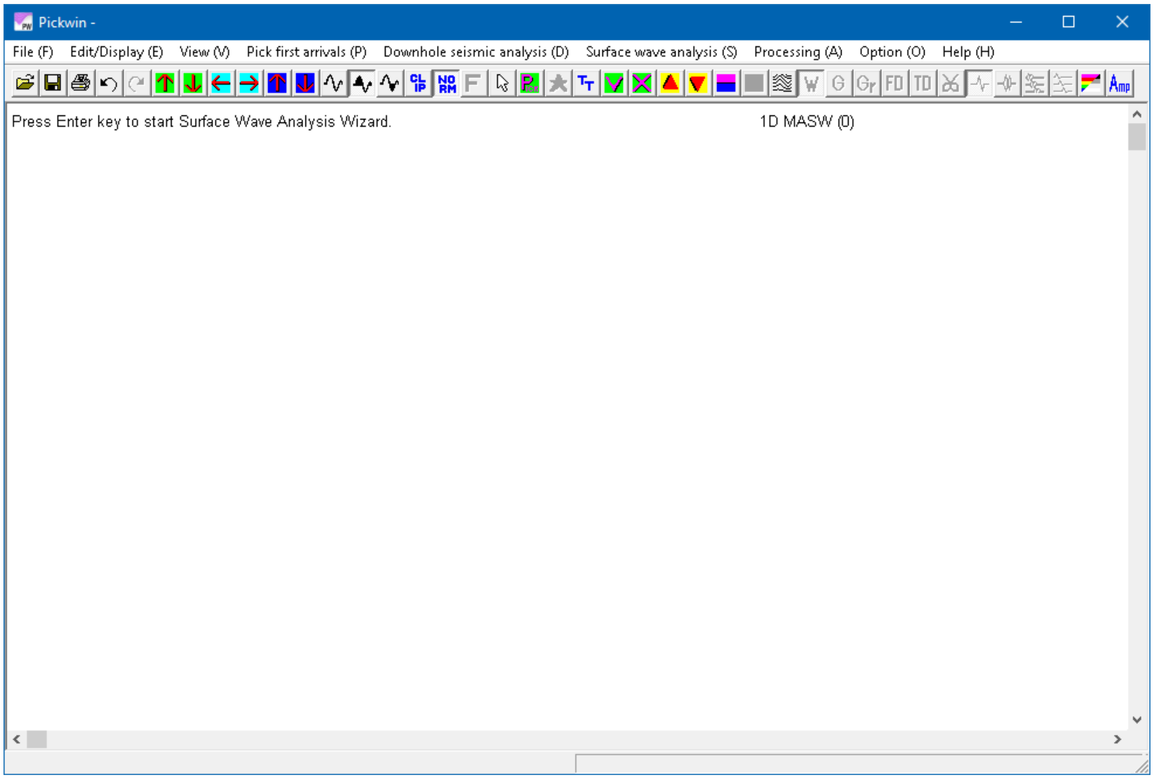
4.1.2 PASSIVE SOURCE (MICROTREMOR) 1D MAM WIZARD

The *passive source 1D MAM Wizard* process is essentially the same as for the *Active source 1D MASW Wizard* (Section 4.1.1, Page 55), with additional steps for setting up the MAM survey geometry. This section assumes that you have already worked through the *Active source 1D MASW Wizard* and are familiar with the steps and general functionality of the wizard. The new parts of the process are covered in detail, but Section 4.1.1 should be referred to for complete explanation of the common steps. The main difference between the two processing flows is the number of data files and how they are input.

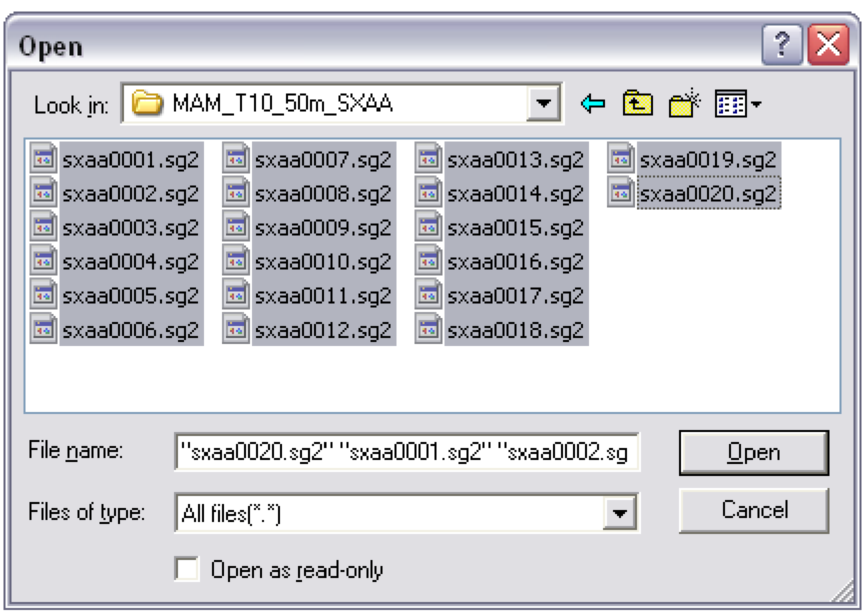
Double-click on the **Surface Wave Analysis Wizard** icon. Select *passive source (Microtremor) 1D MAM* and press *OK*.



The main Pickwin window appears. Press the *Enter* key to begin.



The first step is to input the dataset; all the data files are input at one time. Use the *Shift* key to highlight the first through last file in the dataset and press *Open*.



Once the selected files are open, press *OK*.

The first in the group of waveform files is displayed. Set the units if necessary.

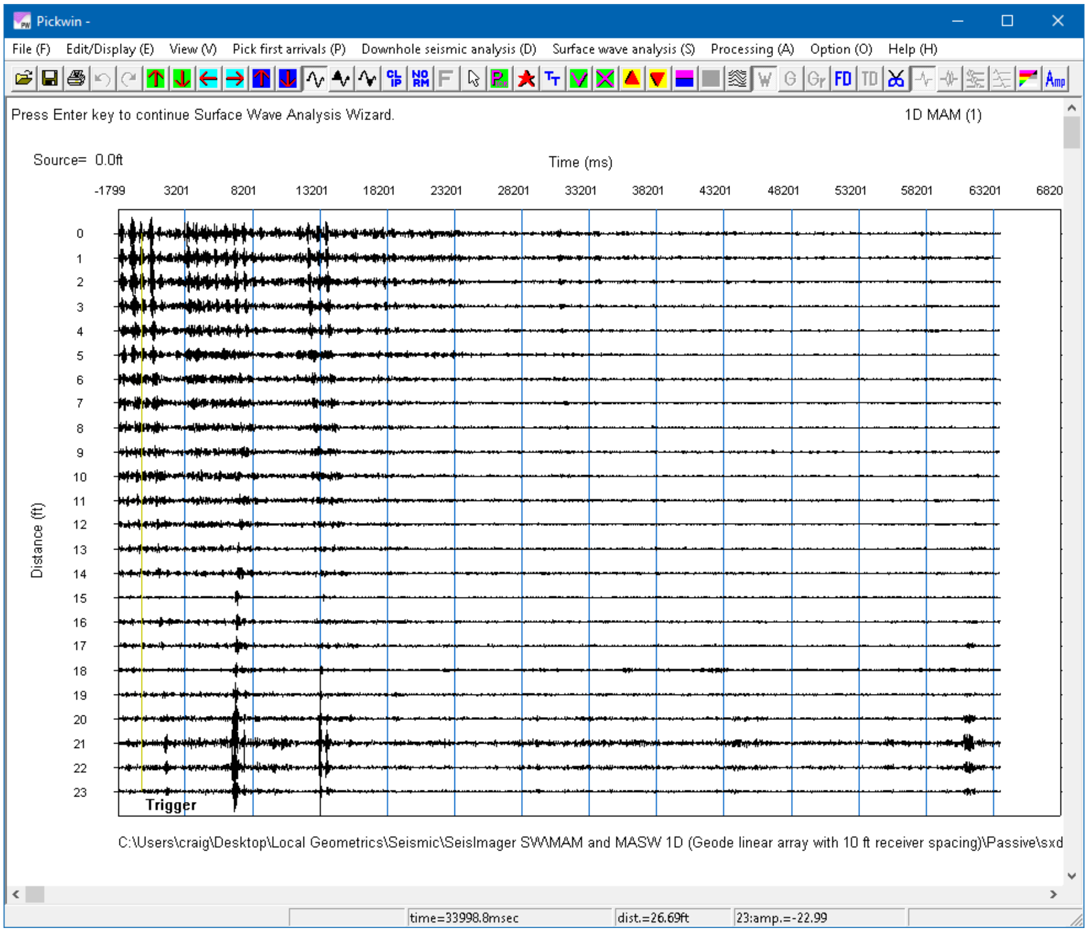
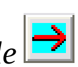
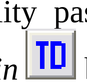
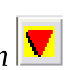


Figure 31: MAM record.

Unlike most active source data, it is usually difficult to evaluate the quality of passive source data by viewing the shot record in the time domain. You can quickly transform the data into the frequency domain by pressing the *Frequency domain*  button. The view will change to a plot of the frequency content or spectrum for each trace.

After pressing the *Frequency domain* button, press the right *Horizontal scale*  button or press the *right-arrow* key a few times to expand the frequency scale. What is ideal is similar frequency content from trace-to-trace and dominant energy in the lower end of the frequency scale. The example spectrum plot shot in Figure 32 indicates high-quality passive source data.

To toggle back to the waveform view, press the *Time domain*  button.

To scroll through the files, use the *Show previous waveform*  and *Show next waveform*  buttons.

When done, from the waveform view, press the *Enter* key to continue.

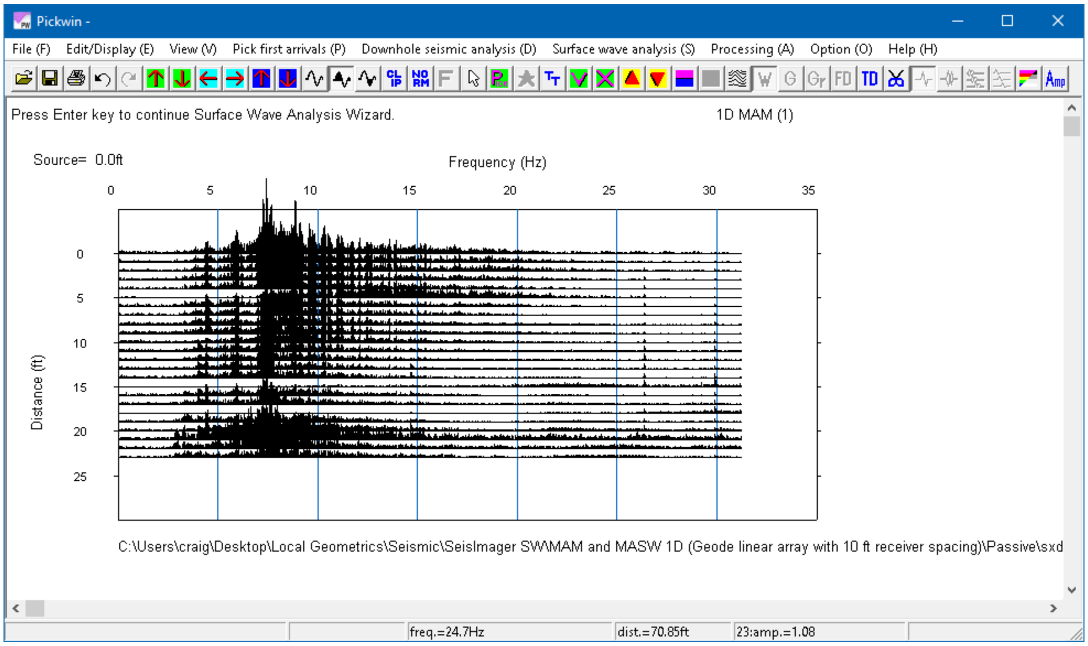
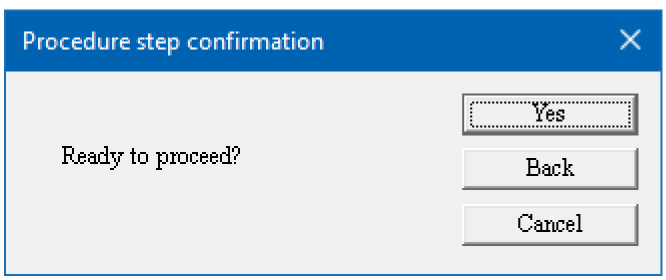
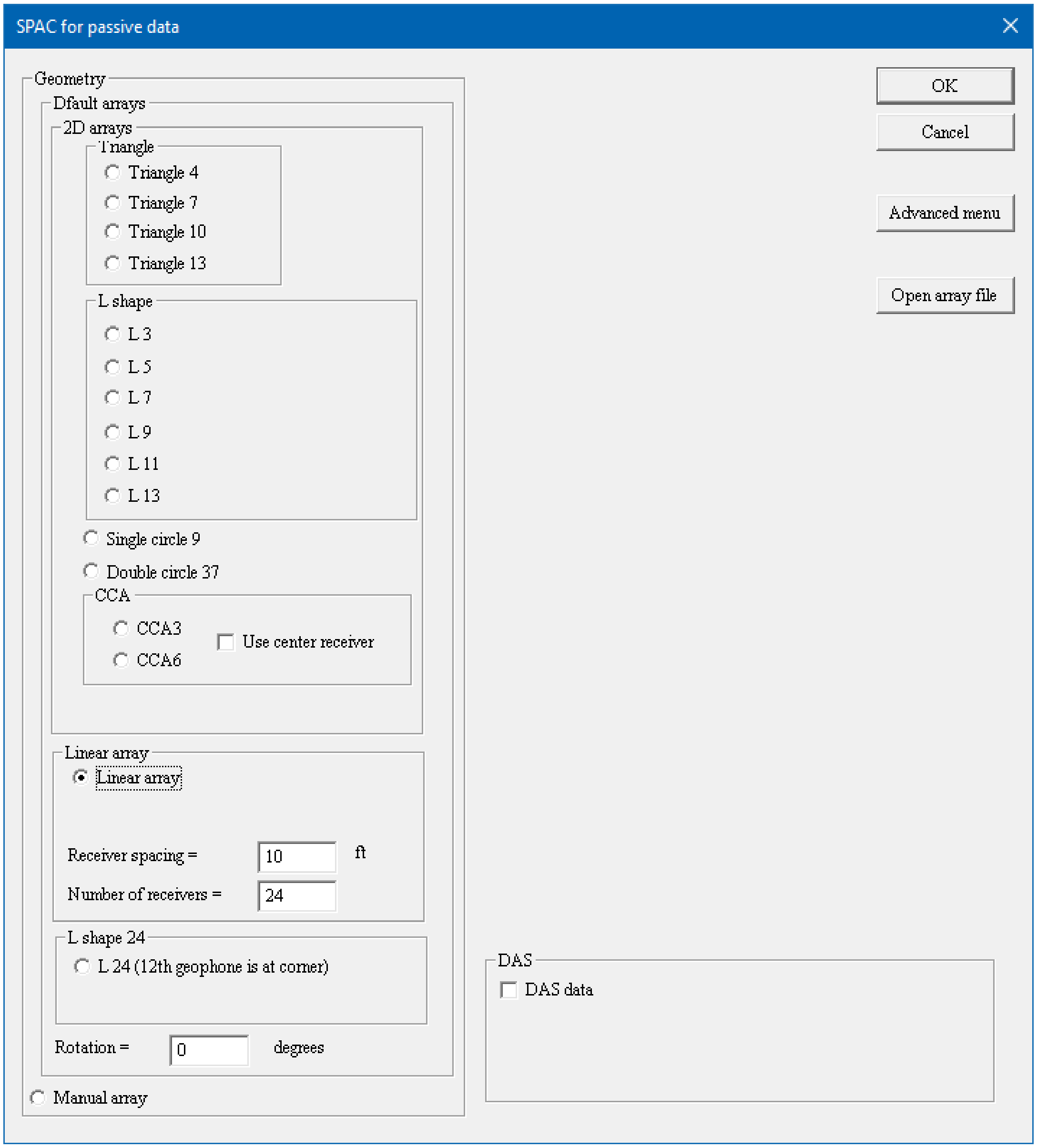


Figure 32: Example spectrum plot.

Press *Yes* when ready to proceed.



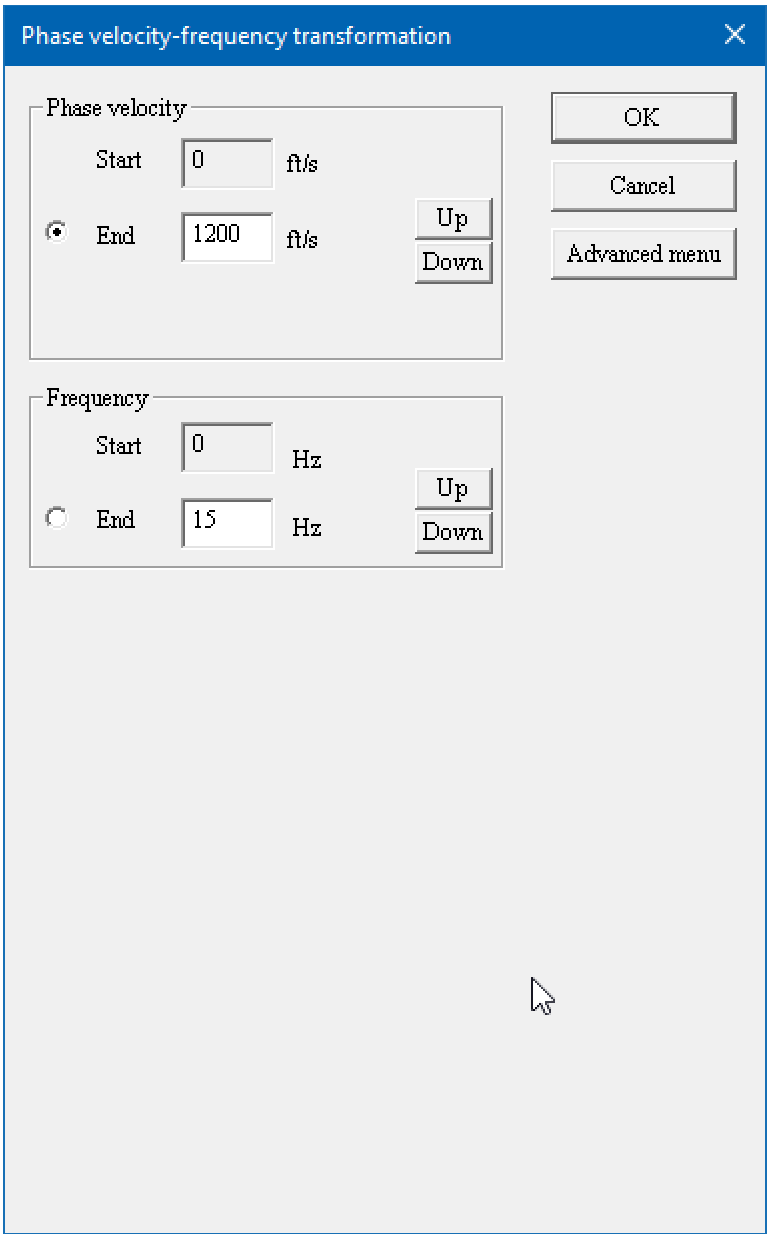
Next, set the array geometry for the SPAC calculation. Select which *2D array* type was used and the *Array size* or select *Linear array* and enter the *Receiver spacing* and *Number of receivers*. This example is based on a *Triangle 10* array with an *Array size* of 50 meters. Press *OK* when done.


SPAC for passive data
Geometry
Dfault arrays
2D arrays
Triangle
Triangle 4
Triangle 7
Triangle 10
Triangle 13
L shape
L 3
L 5
L 7
L 9
L 11
L 13
Single circle 9
Double circle 37
CCA
CCA3
CCA6
Use center receiver
Linear array
Linear array
Receiver spacing =
10
ft
Number of receivers =
24
L shape 24
L 24 (12th geophone is at corner)
Rotation =
0
degrees
Manual array
OK
Cancel
Advanced menu
Open array file
DAS
DAS data

The rest of the steps are identical to the *Active source 1D MASW Wizard*. Proceed to calculate phase velocity and pick the dispersion curve.

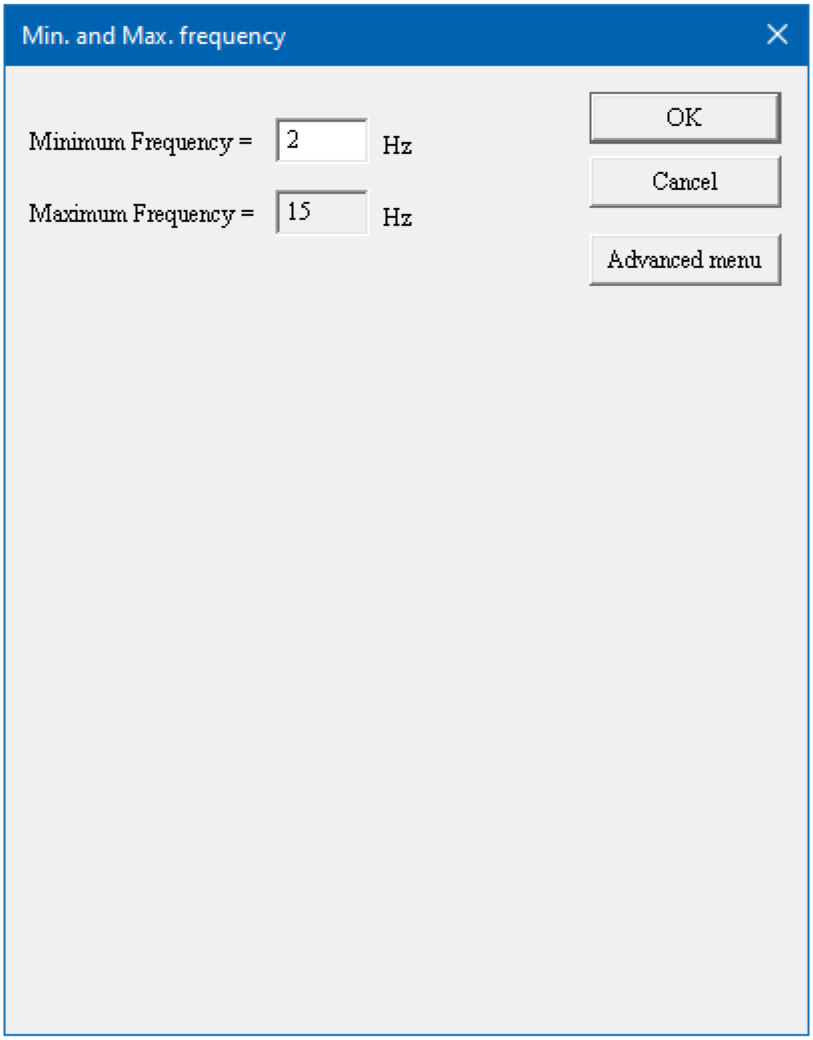
Set the *Phase Velocity End* to suit the maximum velocity you expect for your site. passive source energy is generally traveling deeper and thus at higher velocities, so you will likely want to set a higher *Phase Velocity End* than what was used in the active source wizard.

The default value for *Frequency End* suits most cases. To see the extent of fundamental mode velocity on the high frequency end, a higher value can be entered. Press *OK* when done.



The *Minimum Frequency* default value is 2 Hz. If 4.5 Hz geophones were used, energy below 4.5 Hz may have been recorded, though dampened according to the characteristics of the geophone.

It is suggested to leave the default value of 2 Hz to allow the software to attempt to pick the amplitude maxima to this end (any bad picks can be manually edited later).



Convert the phase velocity-frequency plot to fine color contours, adjust the gain, and check the automatically determined dispersion curve picks. Save the dispersion curve picks if desired.

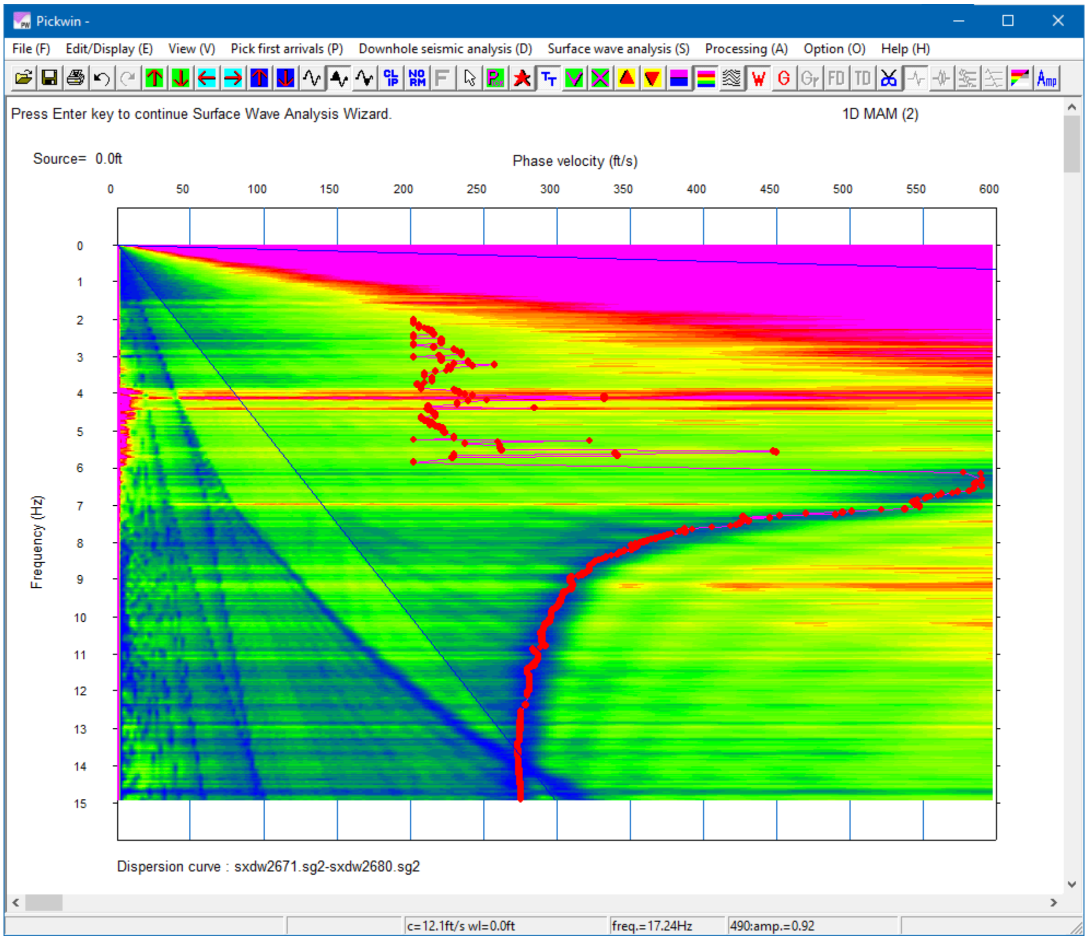
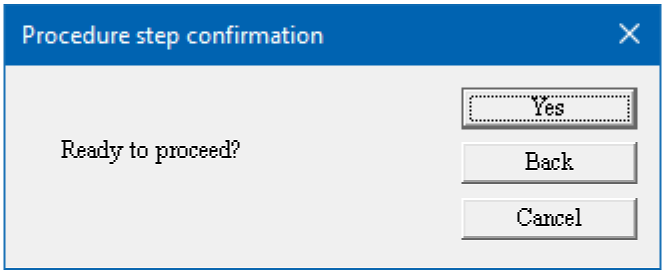


Figure 33: Phase velocity-frequency plot with dispersion curve picks.



Once the dispersion curve is imported to WaveEq, edit the curve as necessary using the gates, the *Selection* button, and/or *Smoothing (individual curves)*.

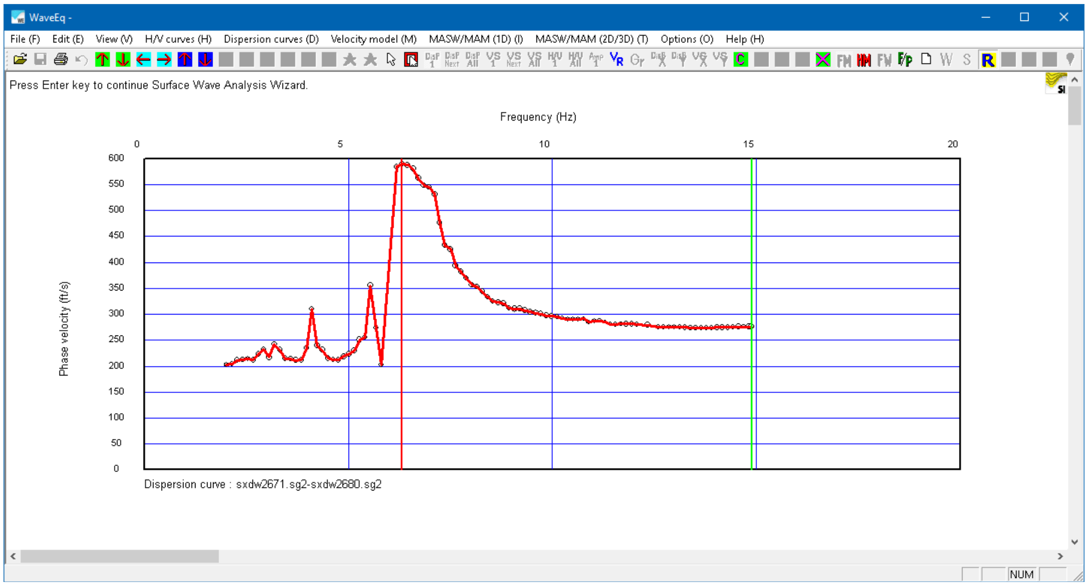


Figure 34: Dispersion curve and gate for removing spurious or noisy picks at the ends of the curve.

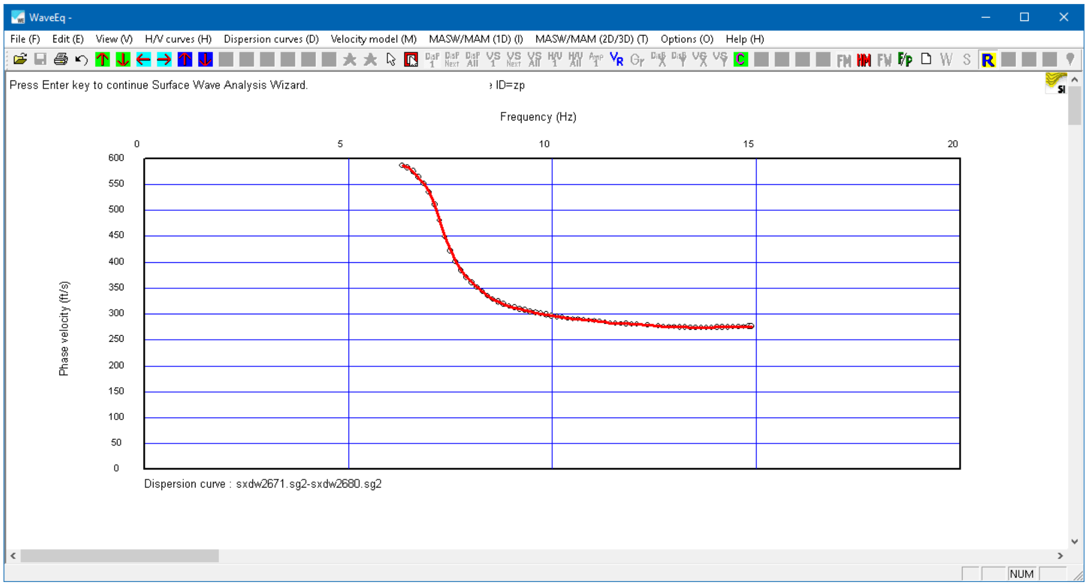
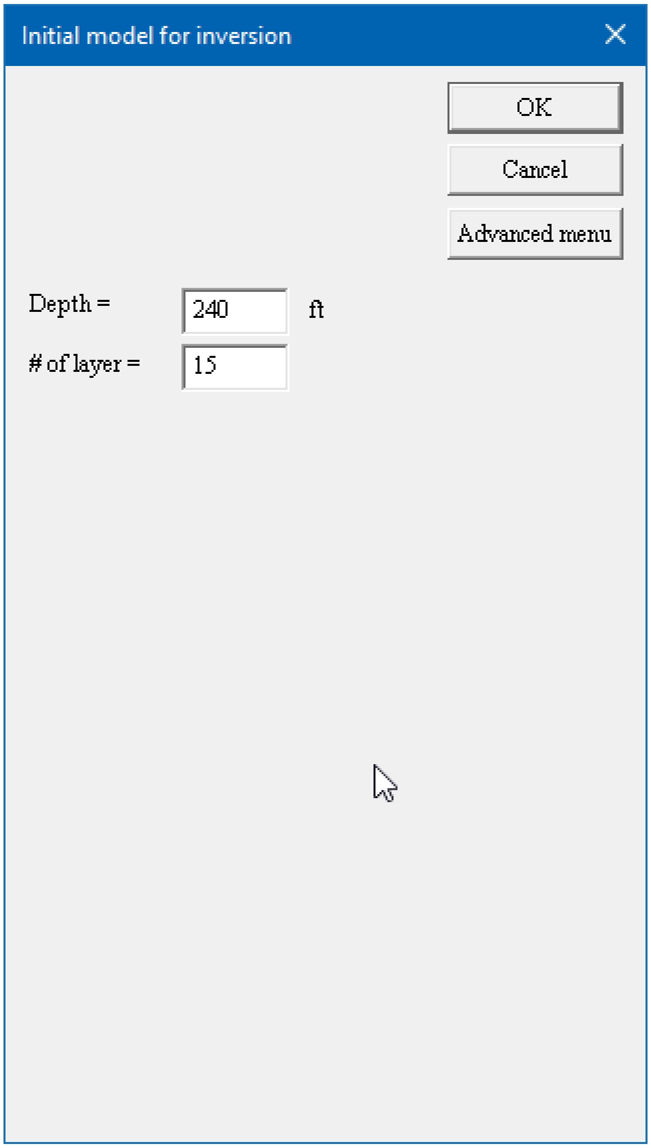


Figure 35: Trimmed and smoothed dispersion curve.

Set the maximum depth for the initial V_S model. A good *Depth* estimate to start with is the length of the array. Accept the default value or increase as desired for *Iteration*.


Initial model for inversion
OK
Cancel
Advanced menu
Depth =
240
ft
# of layer =
15

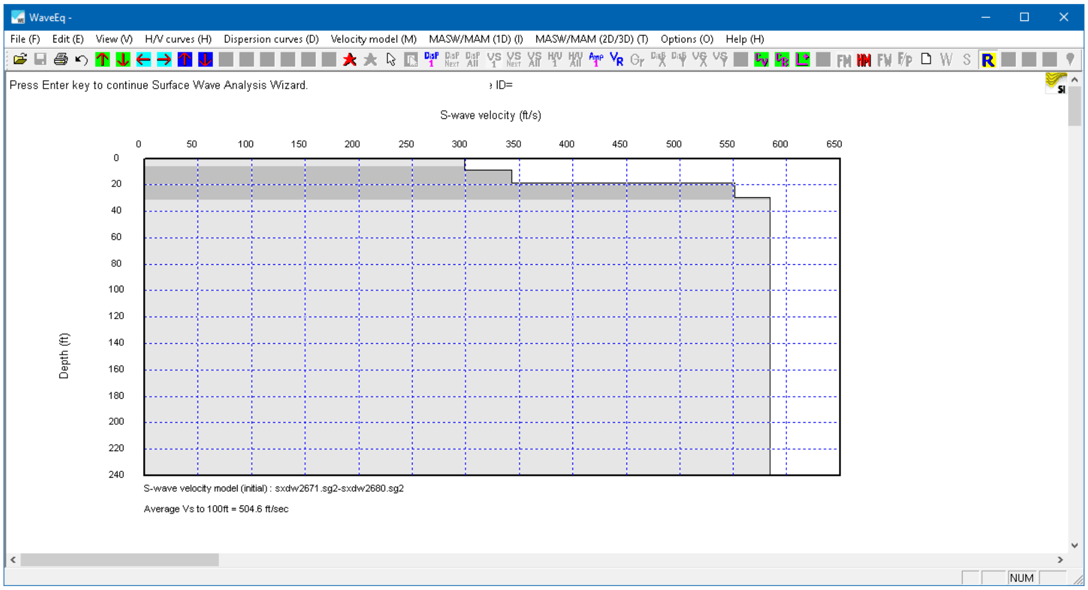
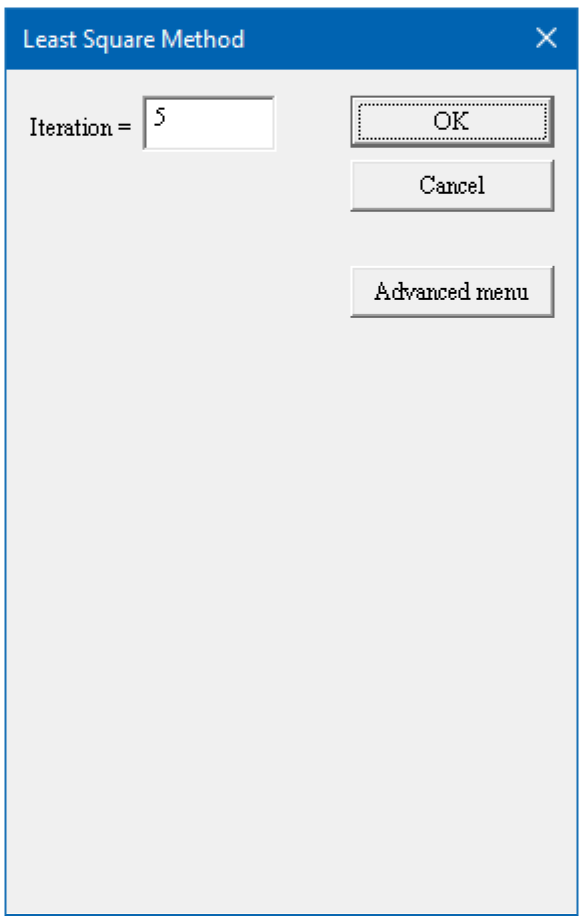


Figure 36: Initial V_S model.



Once the inversion is complete, the final V_S curve is displayed. For an indication of the actual depth range of penetration, press the *Show apparent velocity model* button to overlay the one-third-wavelength approximation. If there is good control to a depth of 30 m (100 ft), open the **View** menu and select *Show AVS for IBC* to calculate and display the average V_S value.

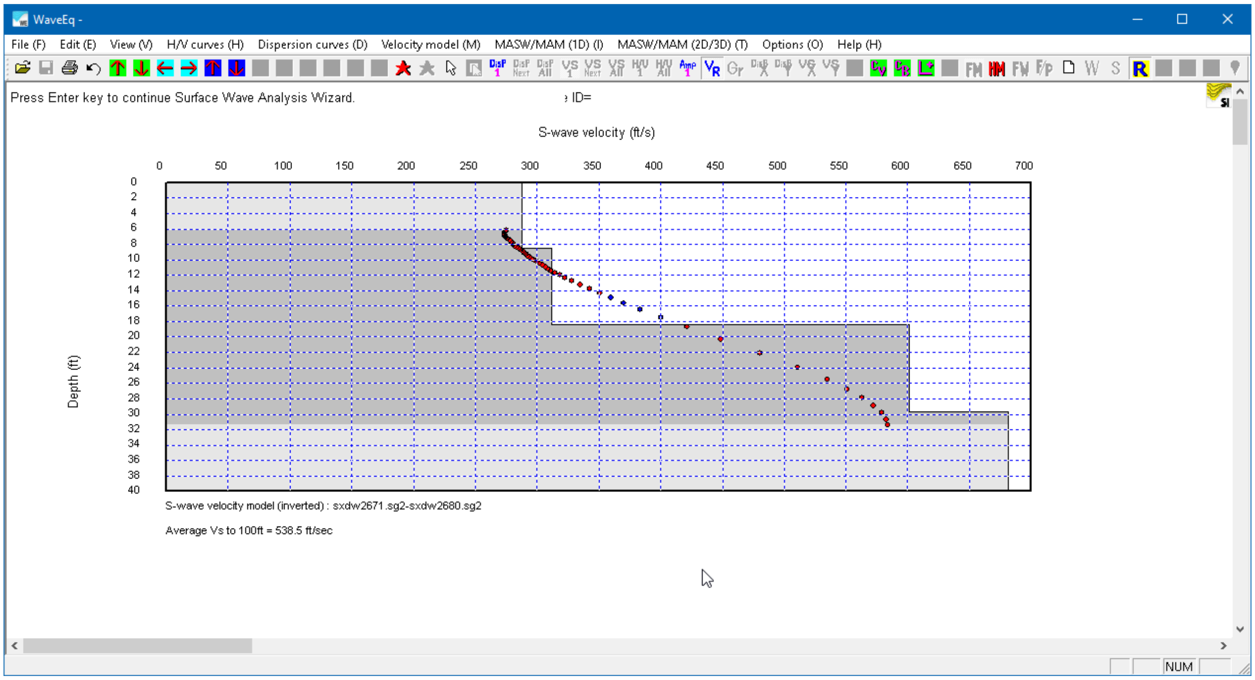


Figure 37: V_S curve with V_R shown (red dots).

Lastly, complete the wizard by saving the results and check the fit between the calculated and observed dispersion curves.

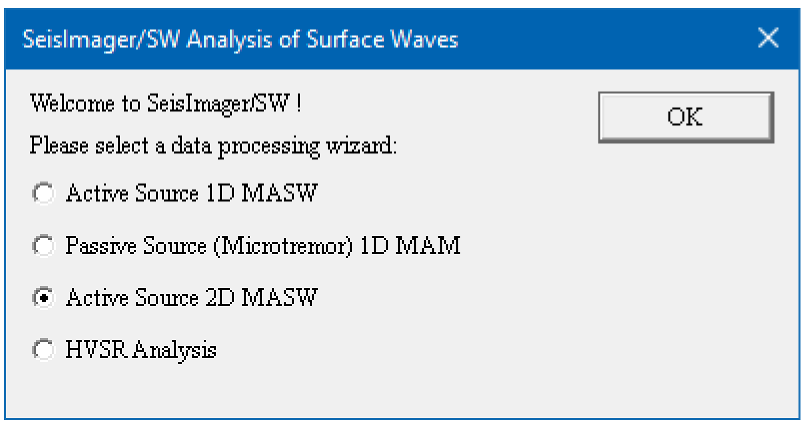
Refer to Section 4.2, Page 156, on how to combine active- and passive source dispersion curves from a given site and obtain one high-resolution V_S curve over the entire sampled depth range.

4.1.3 Active source 2D MASW Wizard

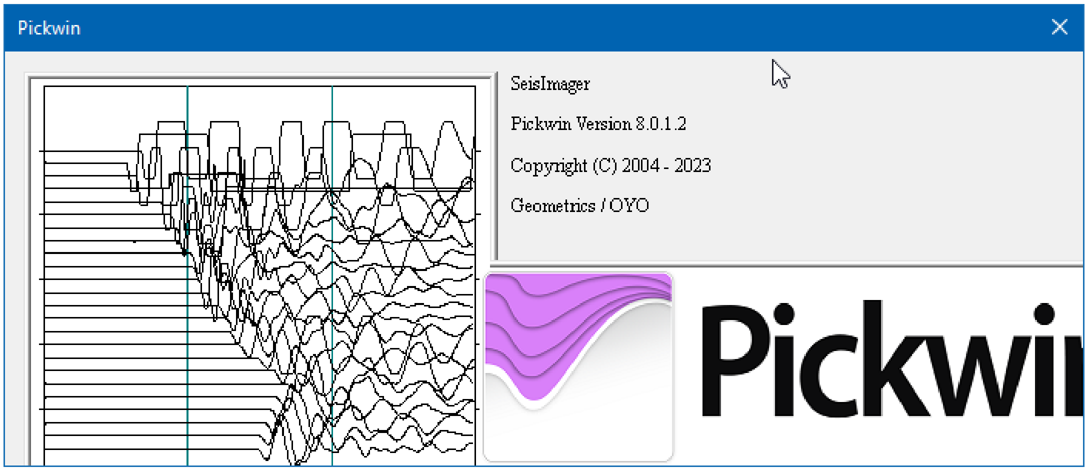
The *Active source 2D MASW Wizard* process is essentially the same as for the *Active source 1D MASW Wizard* (Section 4.1.1, Page 55) and *passive source 1D MAM Wizard* (Section 4.1.2) with additional steps for setting up the 2D MASW survey geometry. This section provides a complete treatment of the 2D MASW wizard process covering Pickwin, WaveEq, and GeoPlot, so much of the detail will be familiar if you have already run the other processing flows. Note that GeoPlot is its own standalone module for general data visualization. In this manual, in Section 4.1.3.1 (Page 119), only the GeoPlot functions needed for viewing 2D MASW initial and final V_S cross-sections are covered. See the GeoPlot manual for full documentation of GeoPlot.

Double-click on the **Surface Wave Analysis Wizard** icon.

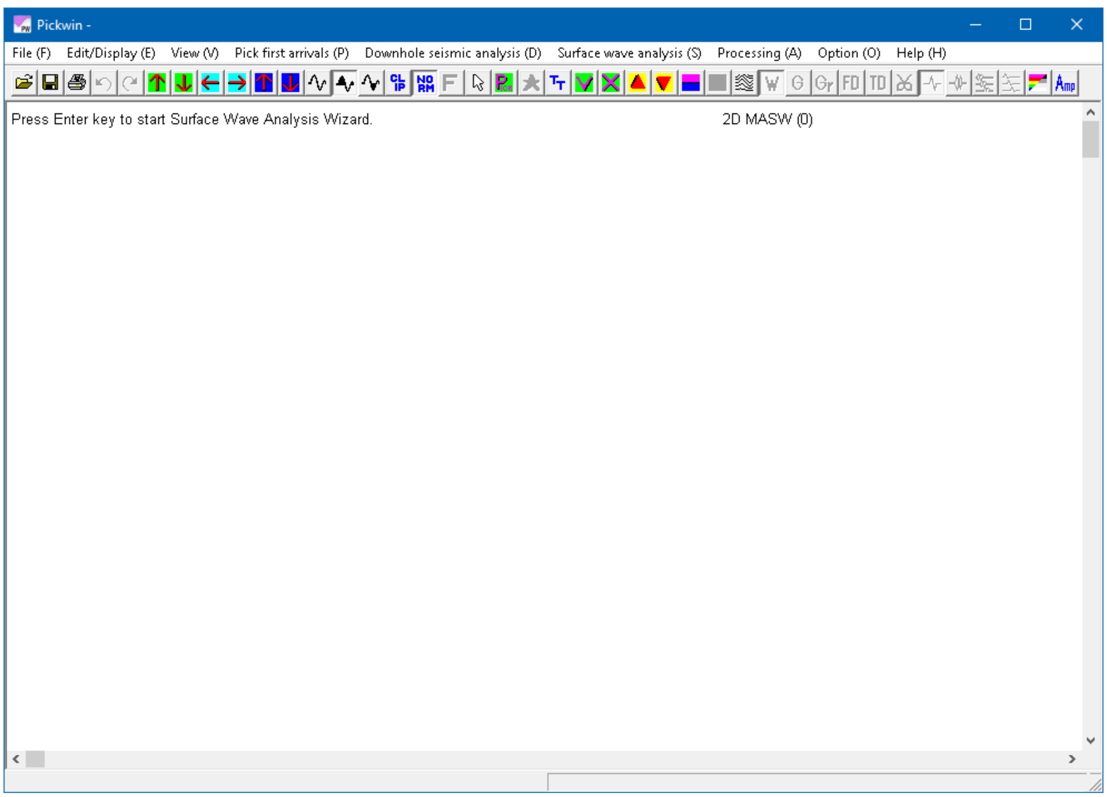
The **SeisImager/SW Analysis of Surface Waves** dialog box appears. Select *Active source 2D MASW* and press *OK*.



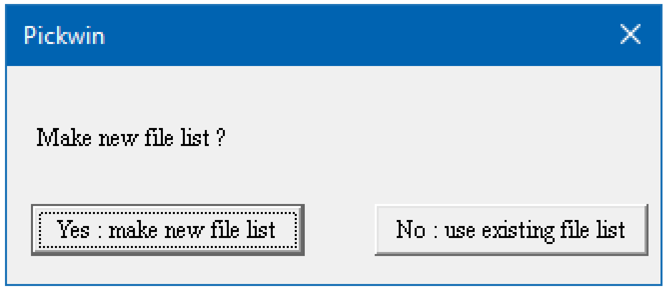
The Pickwin module will be launched.



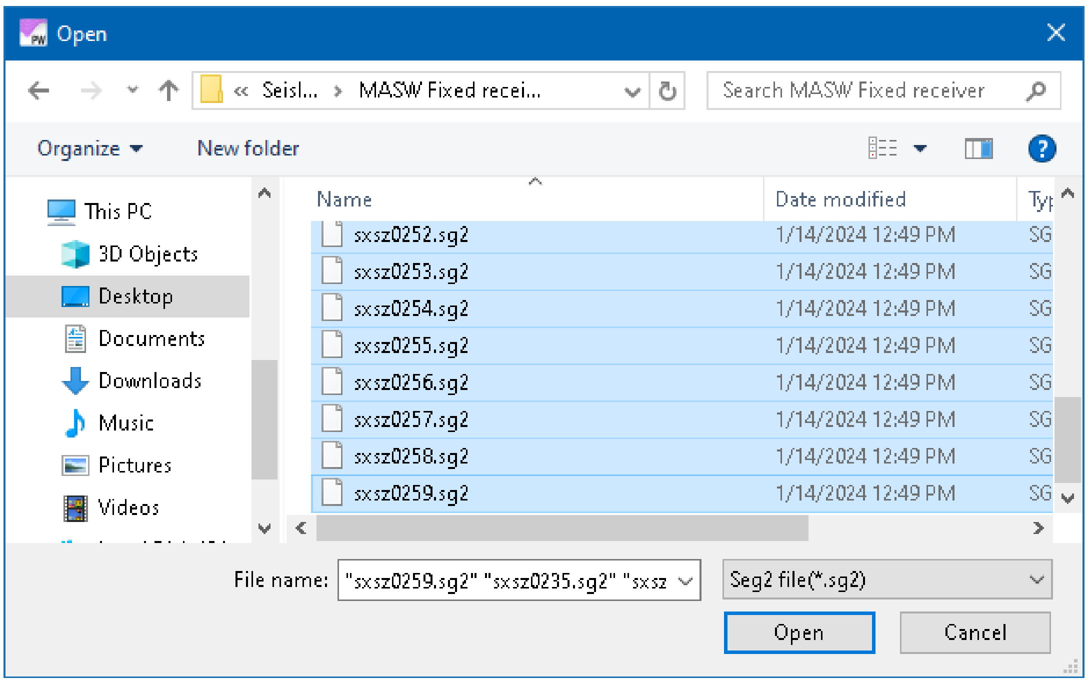
The main Pickwin window appears. The wizard calls functions from the **File** and **Surface Wave Analysis** menus. Press the *Enter* key as instructed in the upper left-hand corner of the window to begin.



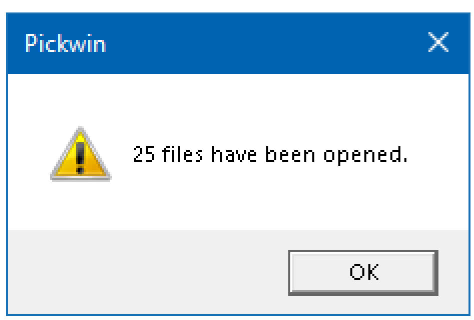
The first step is to input the dataset; all the data files are input at one time. This is done by making a new file list. Select *Yes: make new file list*.



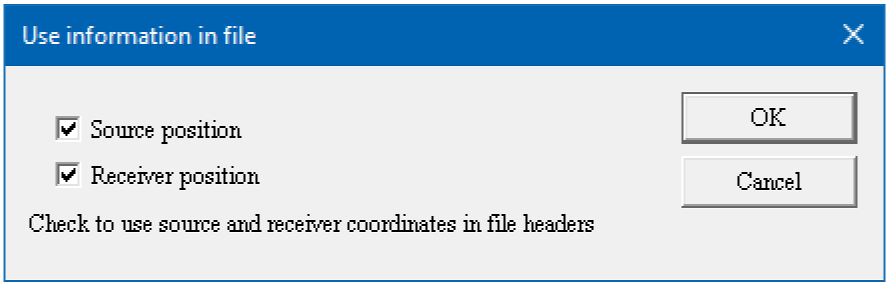
Use the *Shift* key to highlight the first through last file in the dataset and press *Open*.



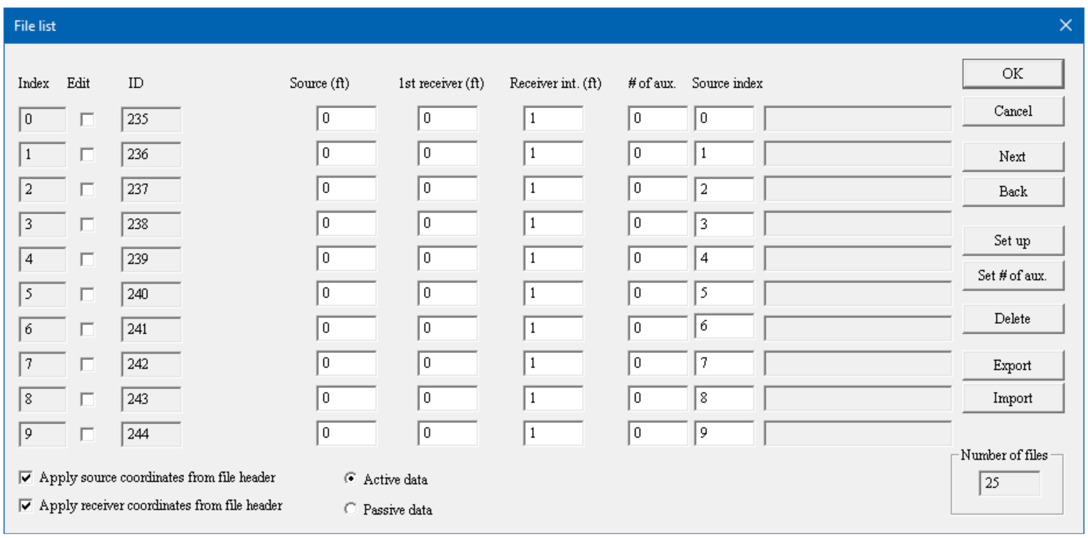
Once the selected files are open, press *OK*.



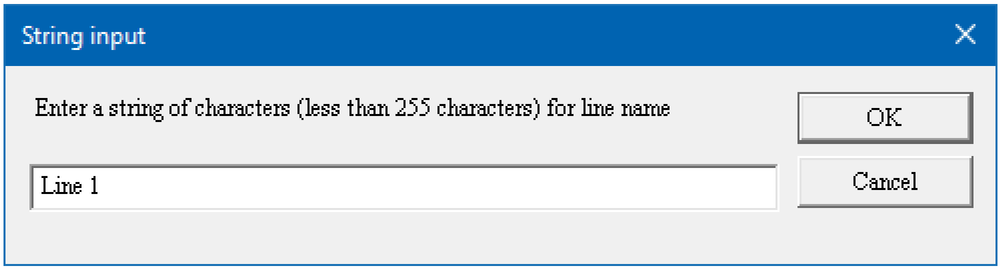
Next, indicate whether the source and receiver coordinates stored in the file headers should be used for the geometry. Explanation of the wizard assumes that the correct source and receiver coordinates were saved to the file headers; working on that assumption, check *Source position* and *Receiver position* to apply the header information to the geometry. Press *OK* when done.



A list of the files is presented in the **File list** dialog box. Note that if the coordinates from the header are to be applied, they will not be reflected here in the *Source*, *1st Receiver*, and *Receiver int.* columns; the *Apply source coordinates from file header* and *Apply receiver coordinates from file header* boxes will be checked. (If coordinates need to be entered manually, press *Set up* to enter the pattern that describes the geometry. Refer to Page 223 for a full explanation of how to enter coordinates manually.) Press *OK* when done.



Next, assign the file list a unique line name:



The first in the group of waveform files is displayed:

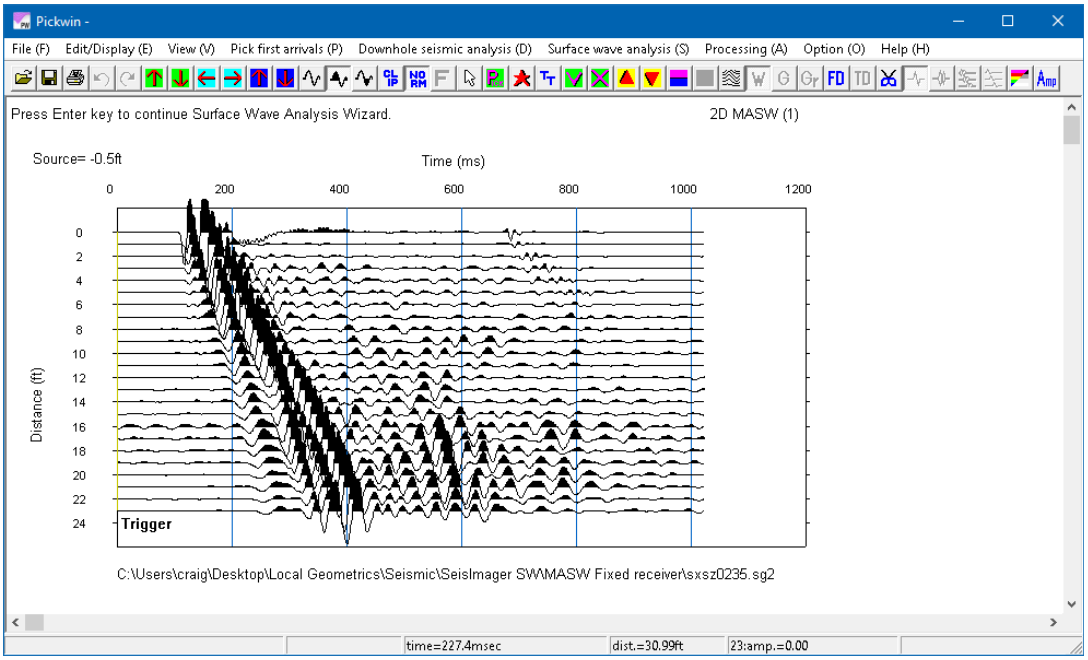
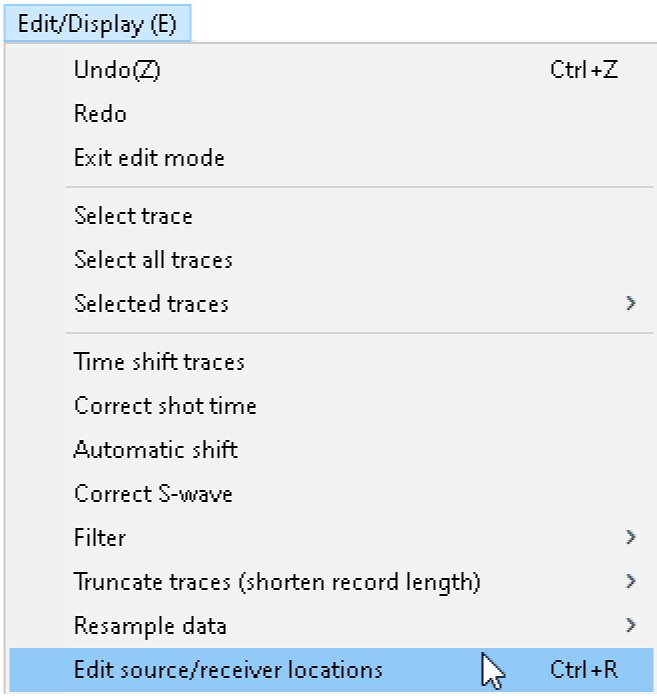
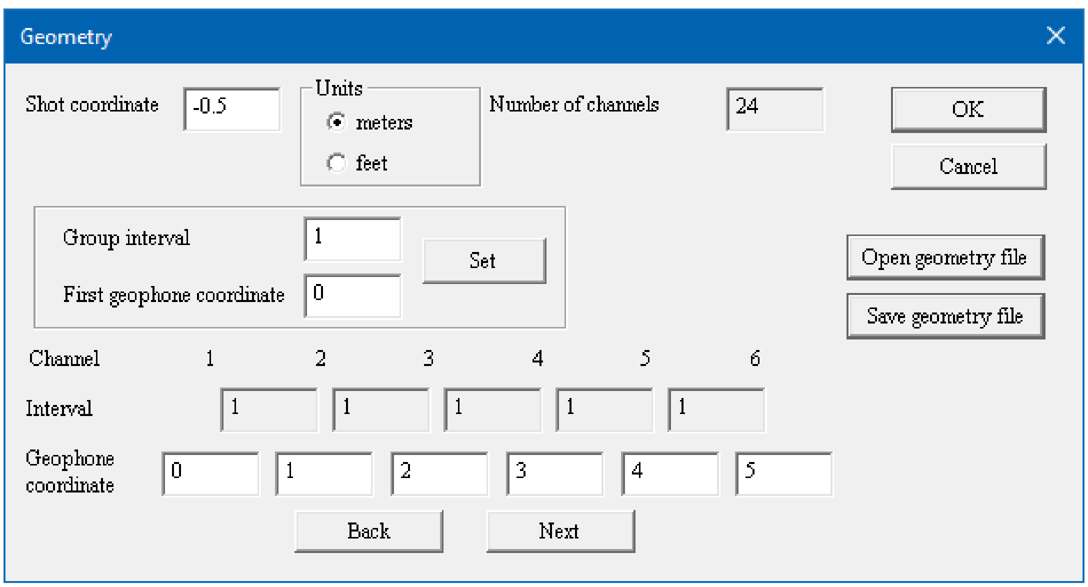


Figure 38: Waveform plot, 2D active source, fixed spread.

Check the units. If the unit labels are incorrect, open the **Edit/Display** menu and select *Edit source/receiver locations*.

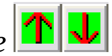
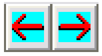
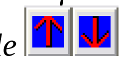


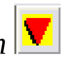
The **Geometry** dialog box will appear and the *Units* setting allows selection between *meters* and *feet*. The *Units* setting will affect the unit labels shown in the dialog boxes as well as update the minimum phase velocity default value, which is 35 m/s or 150 ft/s. Once set (and Pickwin is closed), the assigned units will be recalled for subsequent uses of the wizard.



Note: *Assigning the wrong units will cause errors in the calculations of dispersion curves, so it is important to make sure they are correct.*

At the end of the Pickwin wizard (when WaveEQ opens), simply close Pickwin to register the new *Units* setting.

In the waveform view, the settings can be modified to optimize the display. All these settings are common with SeisImager/2D for refraction data processing; refer to the SeisImager/2D manual for complete explanation. The main functions needed are the *Waveform amplitude*  buttons, the *Horizontal scale*  buttons, the *Vertical scale*  buttons, and the *Normalize*  button.

To scroll through the files, use the *Show previous waveform*  and *Show next waveform*  buttons.

When done, press the *Enter* key to continue.

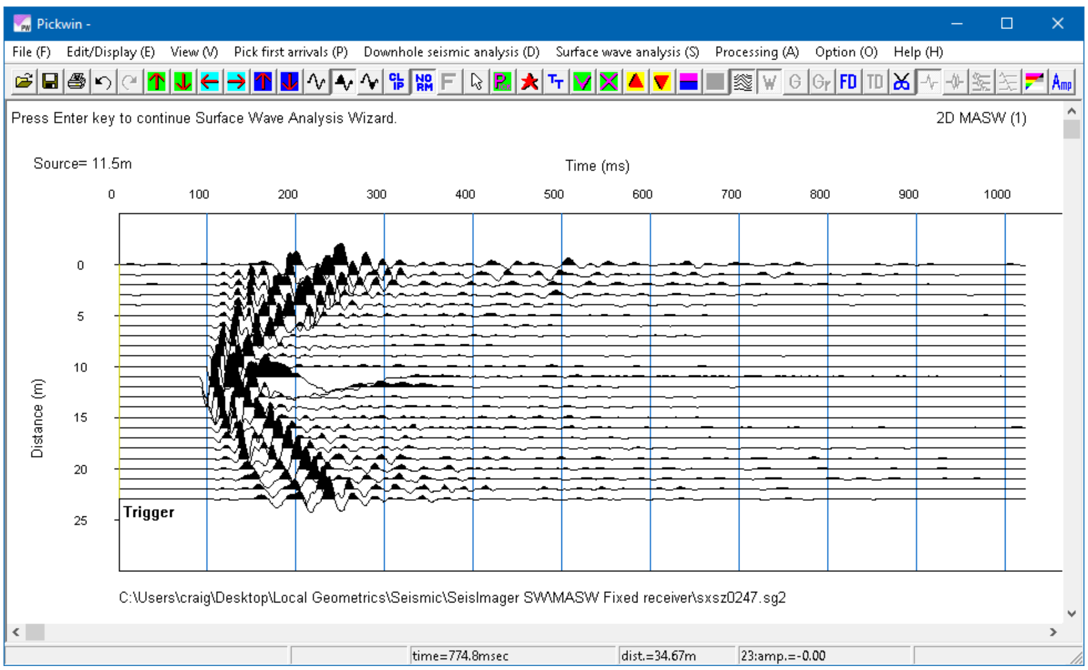
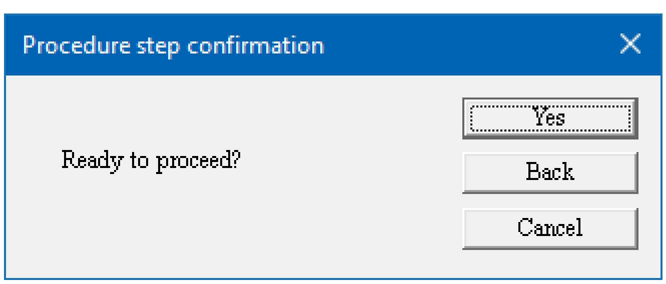
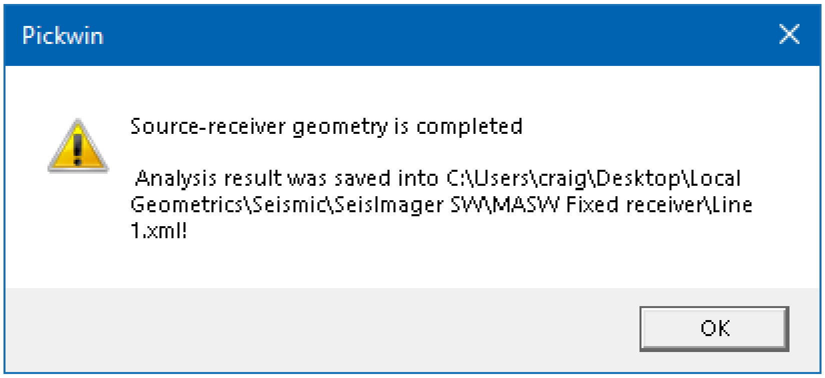


Figure 39: Waveform plot, 2D active source, fixed spread.

Press *Yes* when ready to proceed with calculation and assignment of the geometry.



Once the geometry calculation is complete, the file list with geometry assignments is saved as an *.xml* file named with the tag set earlier in the process. Press *OK*. This list can later be opened directly without having to reassign the geometry.



A plot of the geometry will be displayed. Press the *Enter* key to continue.

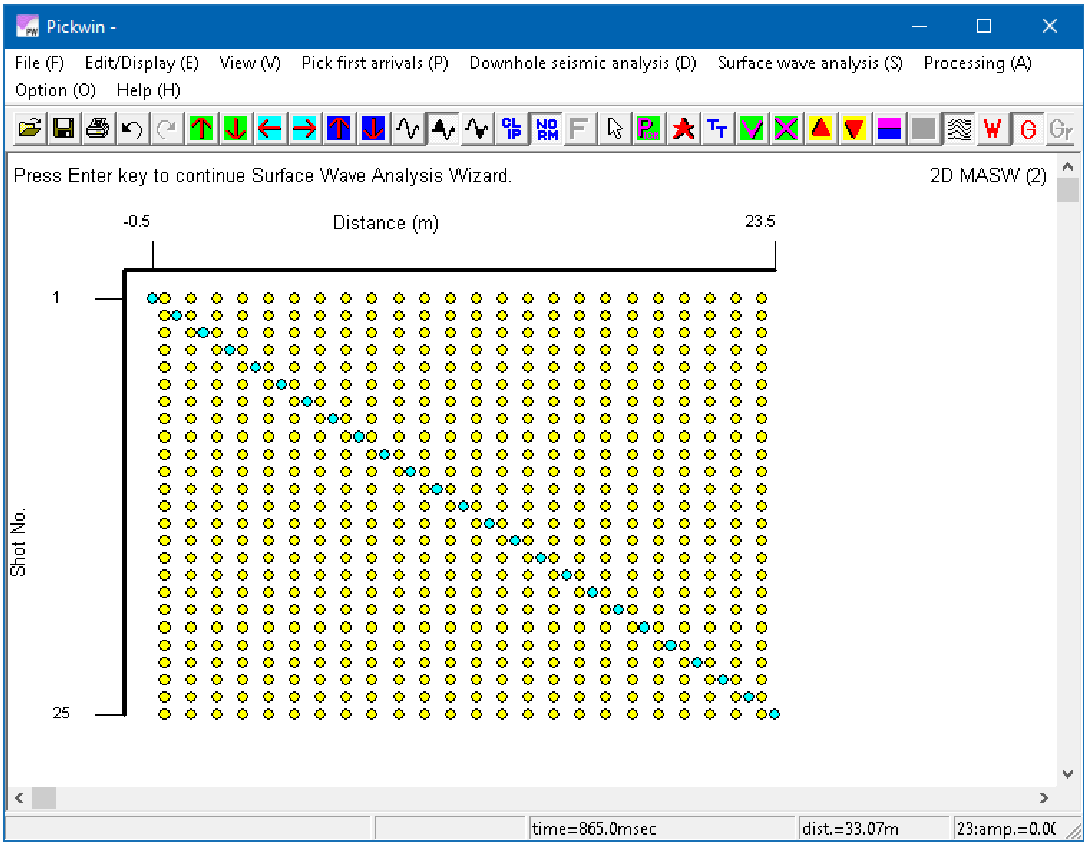
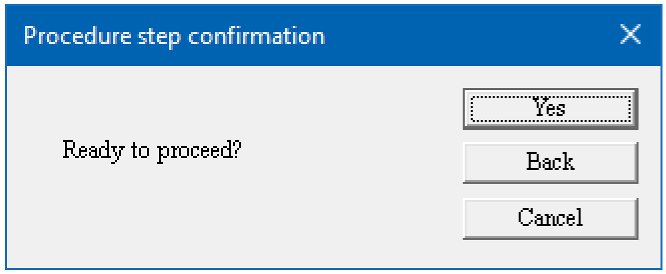
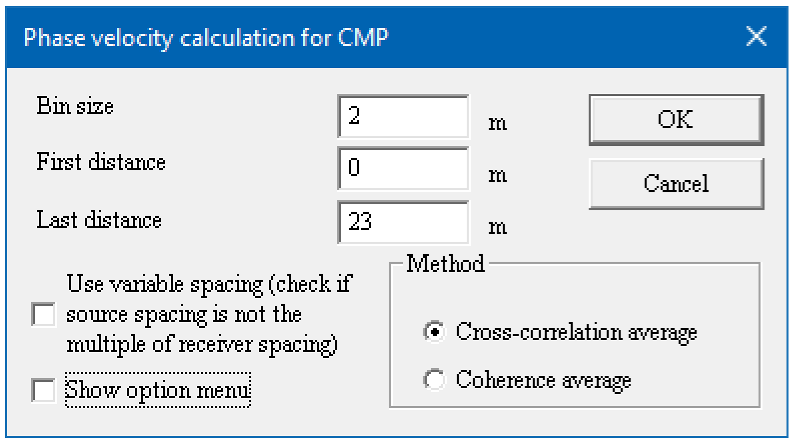


Figure 40: Geometry plot, 2D active source, fixed spread.

Press *Yes* when ready to proceed.



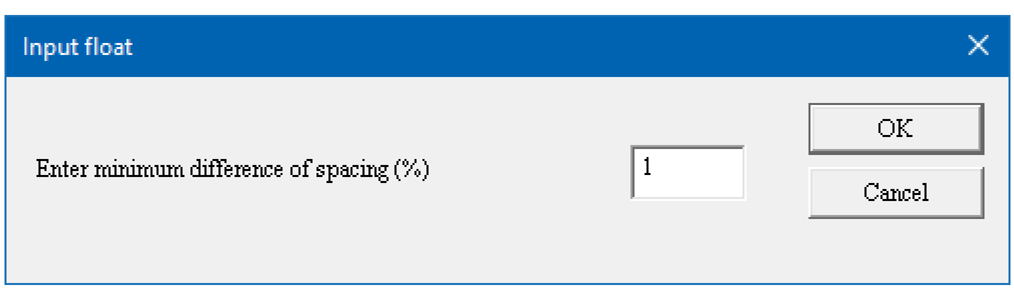


Next, calculate the CMP cross-correlation gathers. The *First distance* and *Last distance* are taken from the first and last coordinates of the geophone spread, and the *Bin size* is automatically calculated as two times the geophone interval. The default value for *Bin size* is recommended. The effect of increasing the *Bin size* is to reduce the resolution of the final V_S cross-section.

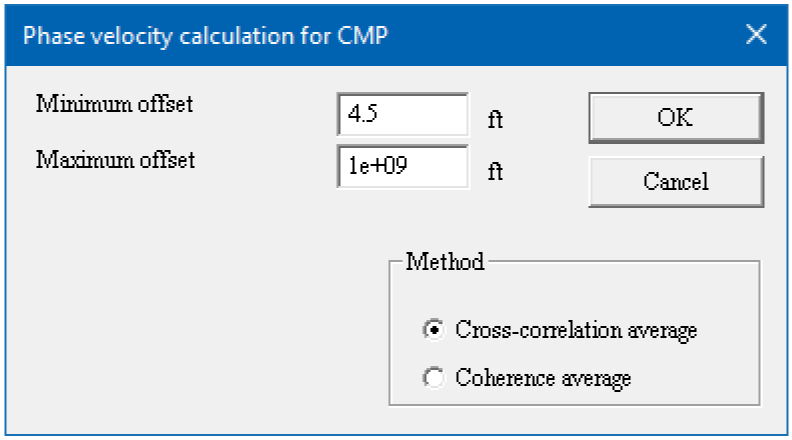
Check the *Use variable spacing* box if your source interval is not a constant – you will be prompted for the "minimum spacing difference" in percent. The meaning of this parameter is best illustrated by example:

Assume your receiver spacing varies about a nominal spacing of 3 meters. If this parameter is set to 10%, then a spacing of 3.2 meters or 2.9 meters would be considered to be 3 meters. However, a spacing of 3.4 meters would be considered to be 3.4.

In general, we recommend you use a constant source interval that is a multiple of the geophone interval.

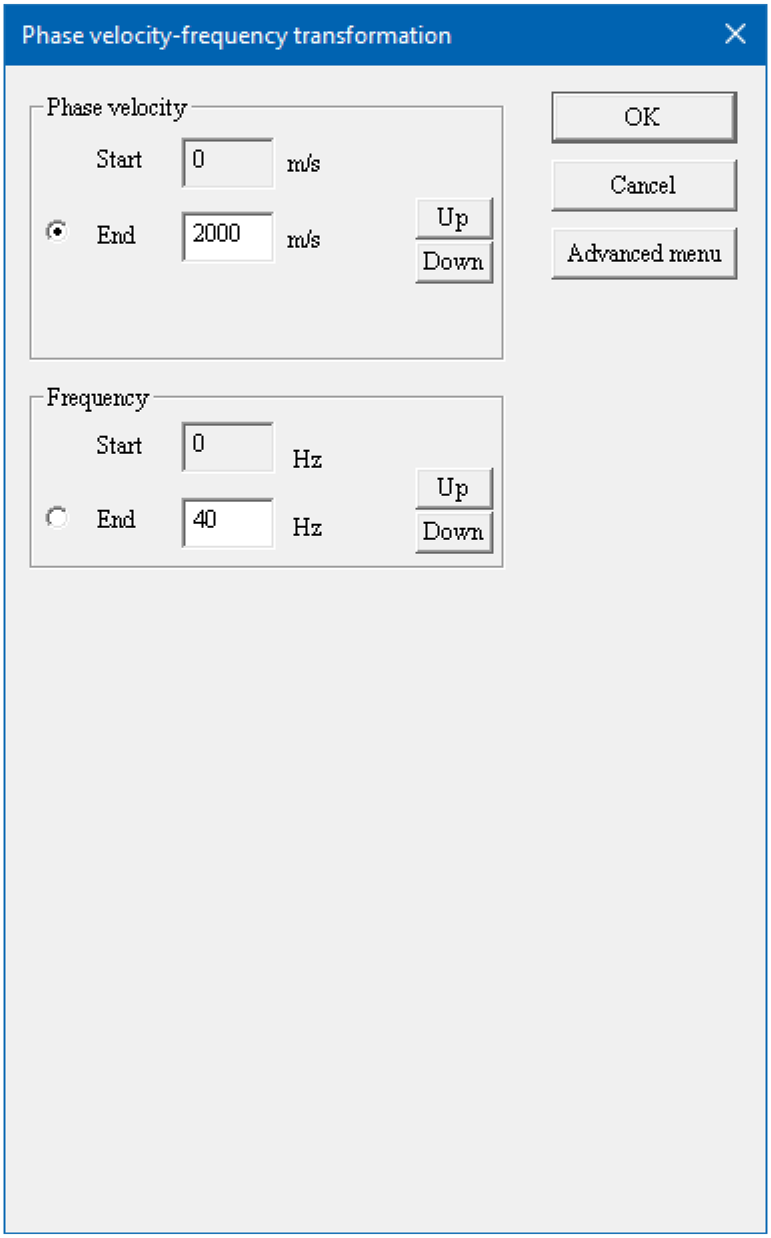


If you check *Show option menu*, you will be prompted to supply a minimum and maximum offset:



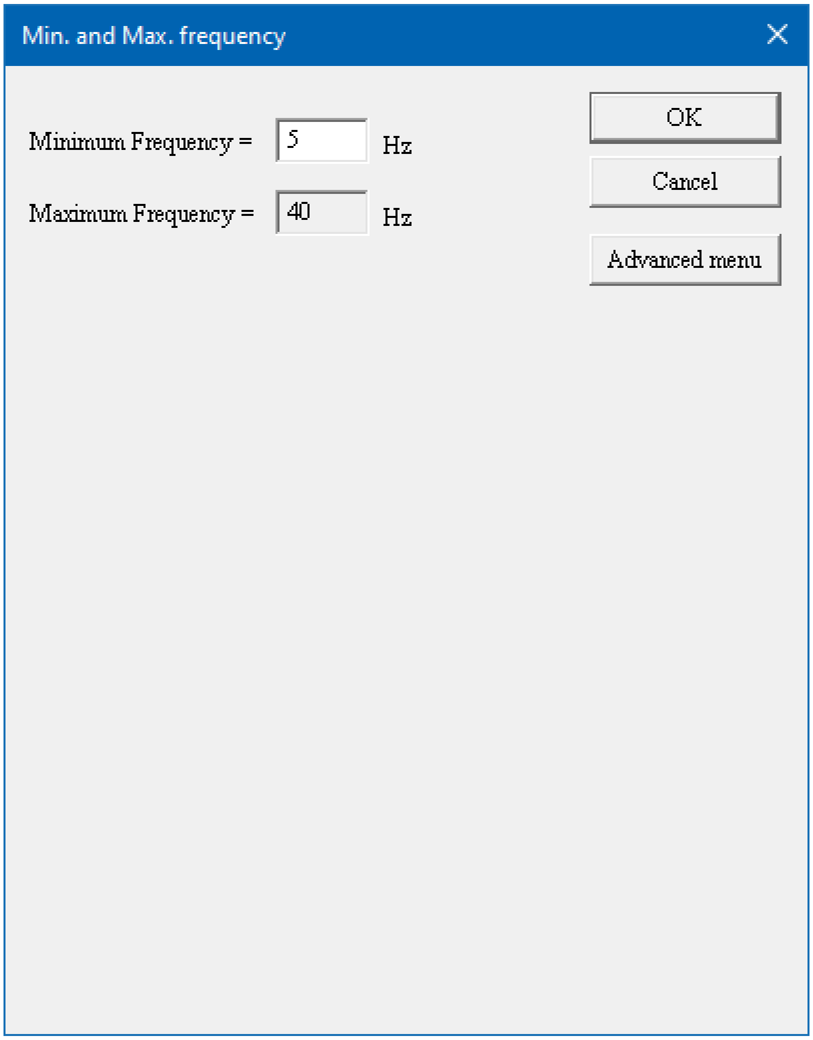
The most common *Method* used is the *Cross-correlation average.* The main difference between *Cross-correlation average* and *Coherence average* is that the former is a time domain calculation, and the latter is frequency domain. The outcome is essentially the same 98% of the time, and *Cross-correlation average* is the recommended method.

Press *OK* when done.



Next, set the parameters for calculation of phase velocity for the CMP cross-correlation gathers. Set the *Phase Velocity End* to suit the maximum velocity you expect for your site.

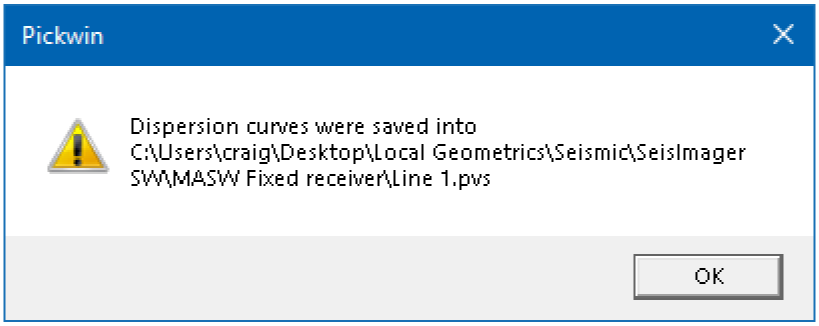
The default value for *Frequency End* will suit most cases. To see the extent of fundamental mode velocity on the high frequency end, a higher value can be entered. Press *OK* when done.



Next, set the parameters for picking the maximum amplitudes, which define the dispersion curve on the phase velocity-frequency plot. The *Minimum Frequency* default value is 5 Hz, if 4.5 Hz geophones were used. If other geophones were used, their natural frequency can be entered or use the default value to allow the software to attempt to pick amplitude maxima toward that end (any bad picks can be manually deleted later).

The *Maximum Frequency* reflects the value entered in the previous dialog box. Press *OK* when done.

Once calculation of phase velocity and picking of dispersion curves is complete, the picks are automatically saved as a *.pvs* file named with the applicable tag. Press *OK*. Refer to Section 6.1.2, Page 215, on how to re-input saved picks.



The first in the group of CMP cross-correlation gathers is displayed. To scroll through the files, use the *Show previous waveform* and *Show next waveform* buttons.

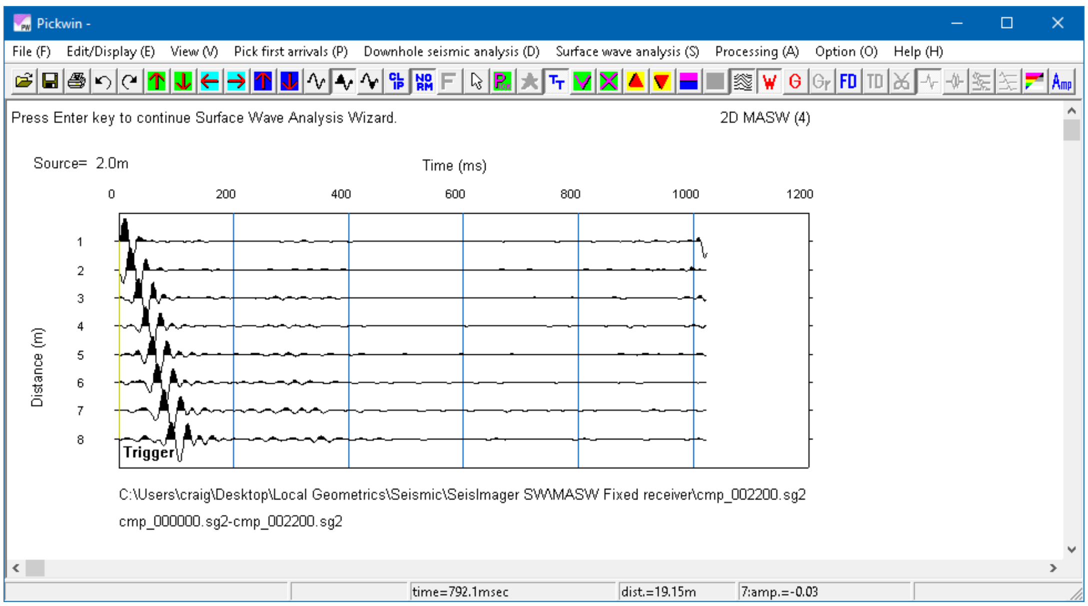


Figure 41: CMP cross-correlation gather.

To display a file with a specific geometry, press the *Geometry* button to toggle to the geometry view. The geometry of the waveform file currently displayed in the waveform view is highlighted in red.

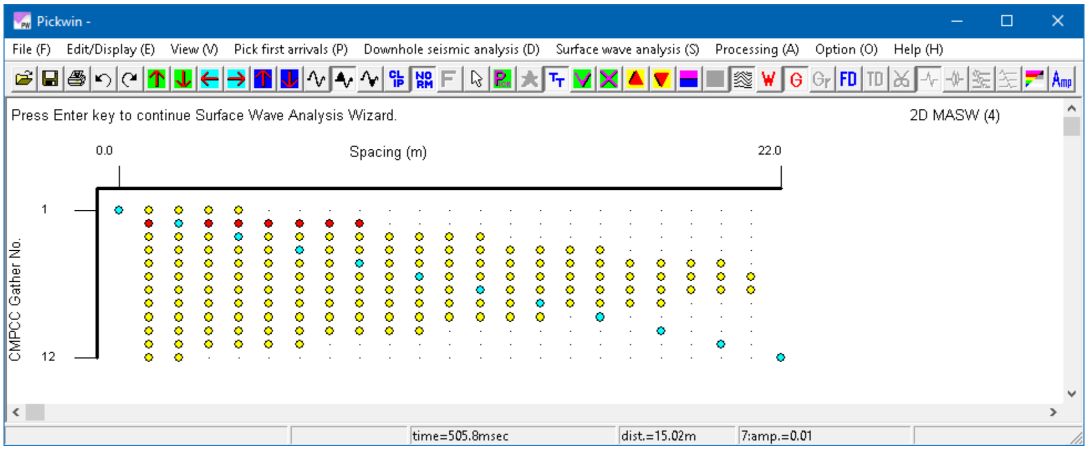


Figure 42: Geometry plot. Trace locations of Figure 41 shown in red.

Use the *Show previous waveform* and *Show next waveform* buttons to select the geometry of a waveform file to display.

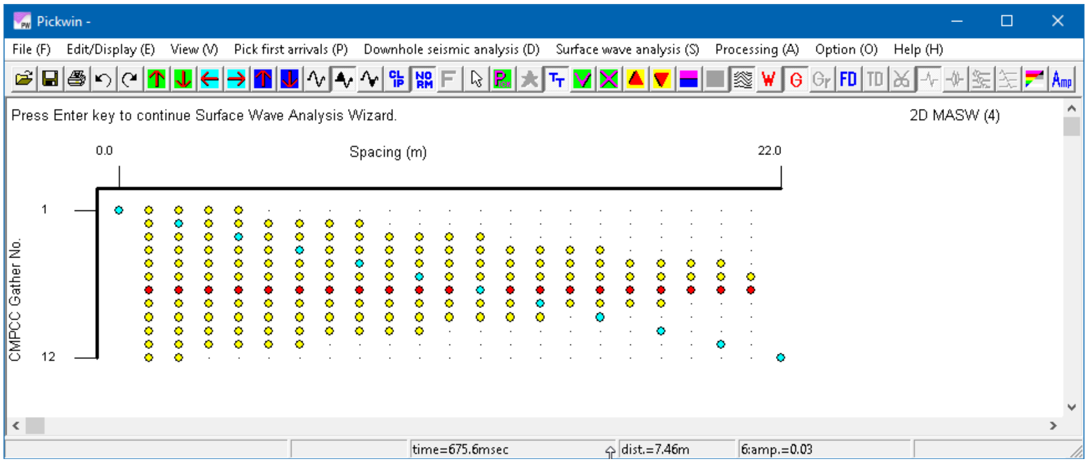


Figure 43: Paging through the geometry file.

Toggle back by pressing the *Waveform* button to display the selected file.

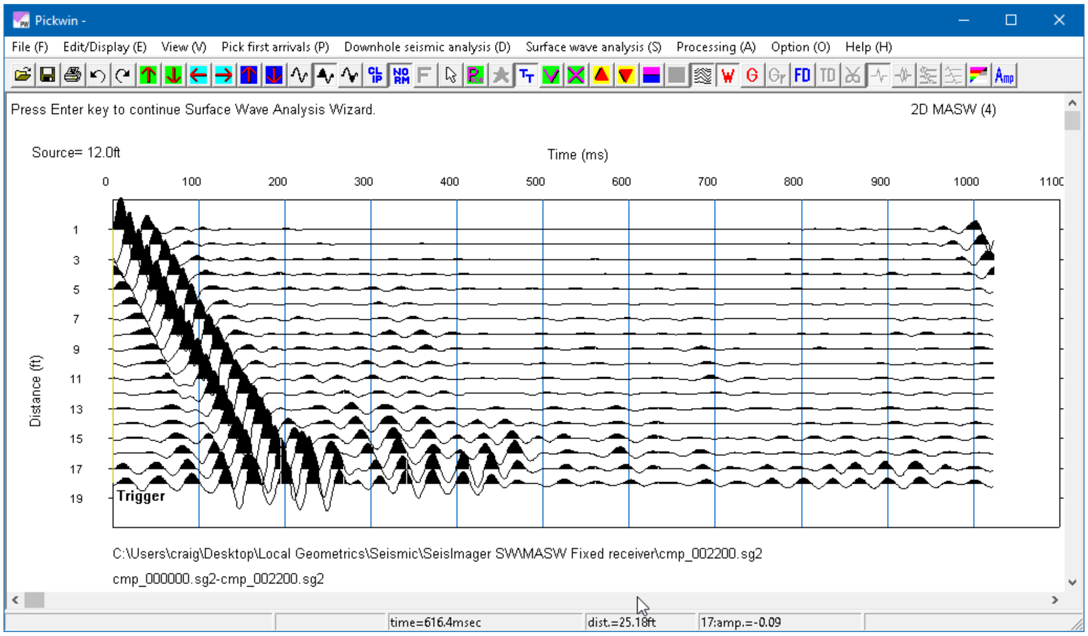
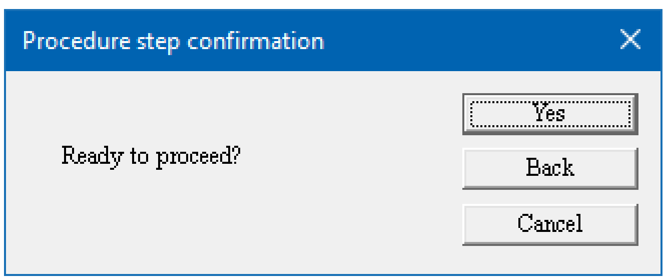


Figure 44: Pressing waveform button to display the file corresponding to red dots in Figure 43.

Press the *Enter* key to continue.

Press *Yes* when ready to proceed.



Next, the WaveEq module launches, and the dispersion curves are displayed. From this point on, the wizard calls functions from the **Dispersion curves** and **MASW (2D)** menus.

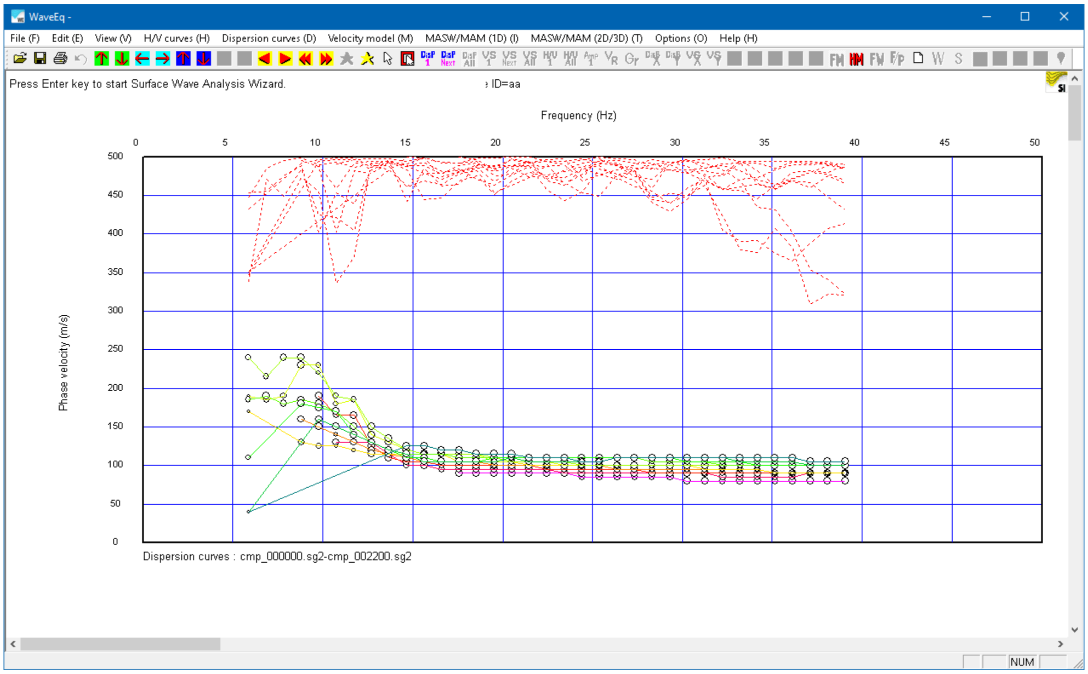
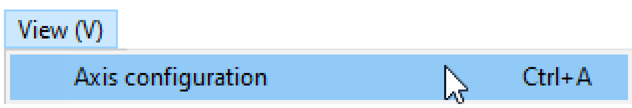
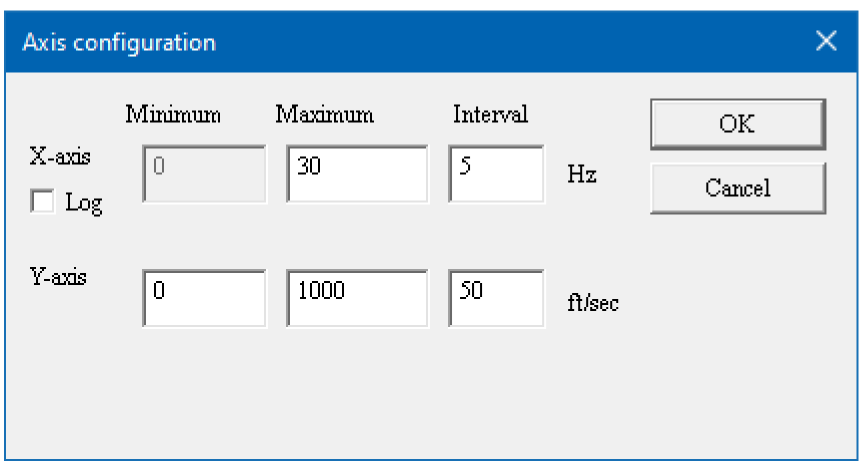


Figure 45: Dispersion curves.

If the plotting scales need adjustment, open the **View** menu and select *Axis configuration*.



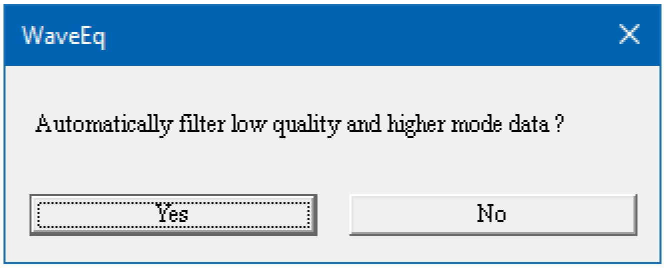
Enter the desired values for the *X-axis* and *Y-axis Maximum* scale and *Interval*. Press *OK* when done.



Press the *Enter* key to continue.

Next, there is a series of three dispersion curve editing functions to remove low quality, noisy, and higher mode picks that are typically present on dispersion curves and can skew or cause instabilities in the inversion. The default settings for these functions are suitable for most cases. Any of the editing steps can be skipped by pressing *No*. Refer to Section 7.5, Page 433, for a complete explanation of the dispersion curve editing functions.

Select *Yes*.



The edited dispersion curves are displayed. Press the *Enter* key to continue.

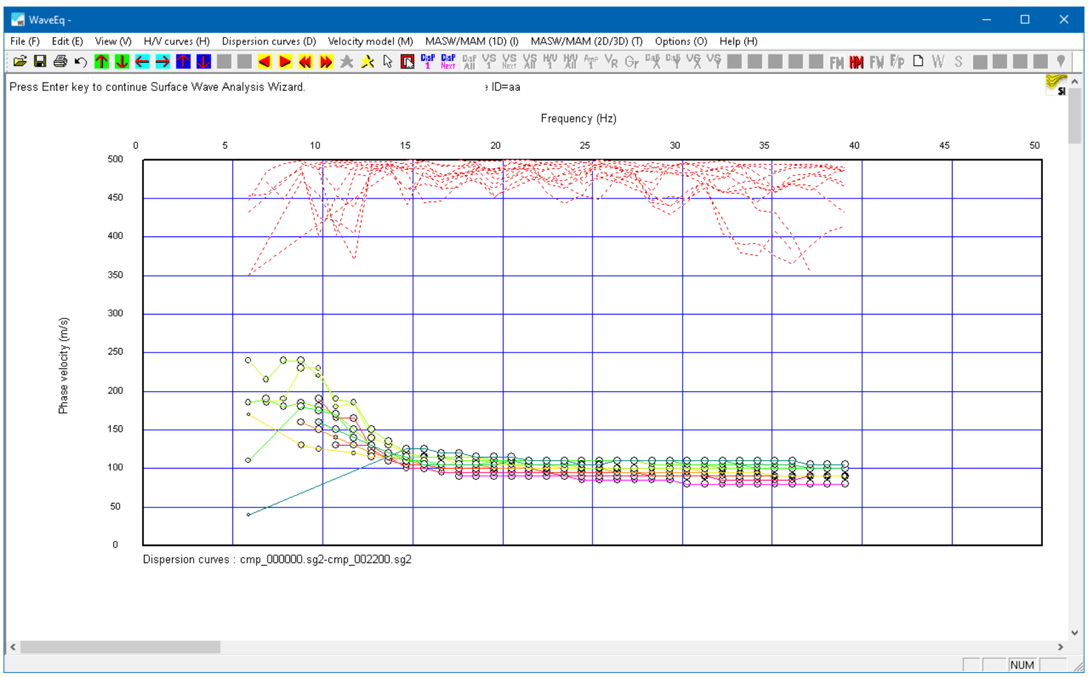
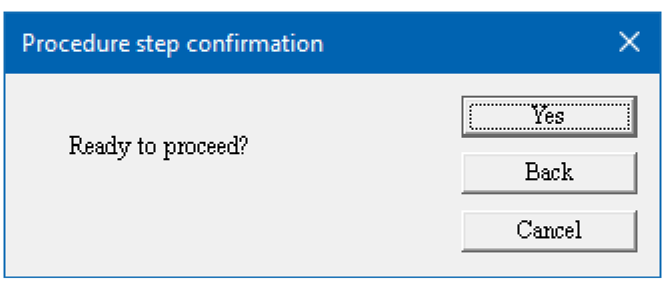
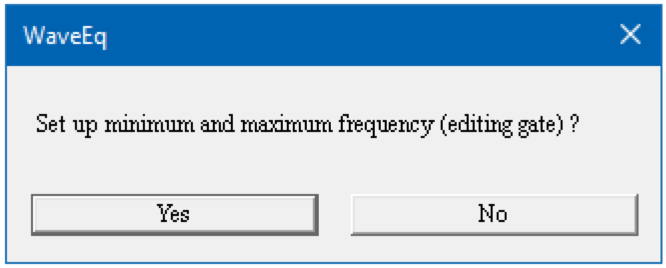


Figure 46: Filtered dispersion curve; low-quality, higher mode data removed.

Press *Yes* when ready to proceed.



Select *Yes*.



Follow the instructions in the upper left-hand corner of the window. The red gate is the active gate. Use the *right*- and *left-arrow* keys to position the gate at the frequency-phase velocity point up to which you want to delete. Press the *Enter* key to activate the right-hand side gate and position it the same way using the *arrow* keys. When done, press the *Enter* key to delete the picks outside of the gates.

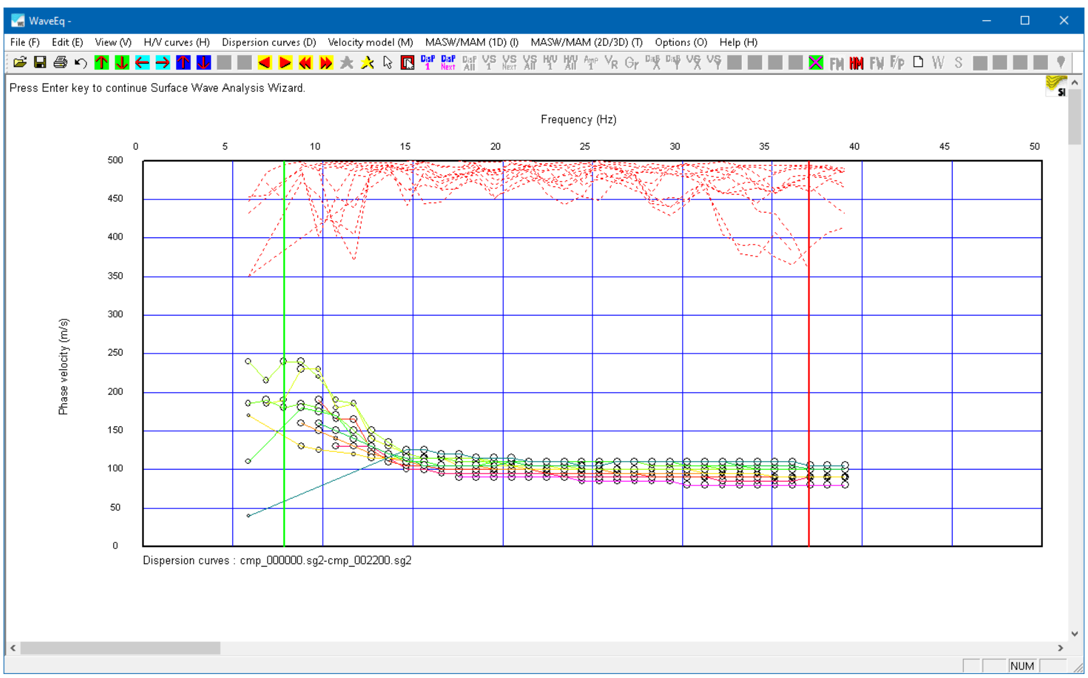


Figure 47: Editing the dispersion curves using gate.

The edited dispersion curves are displayed. Press the *Enter* key to continue.

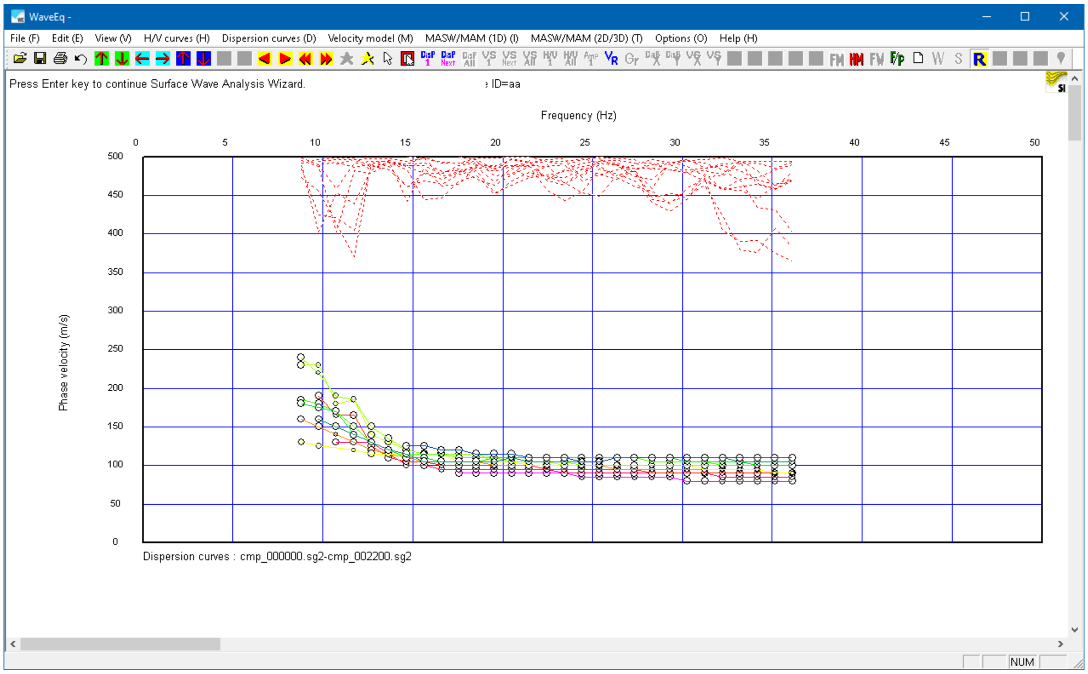
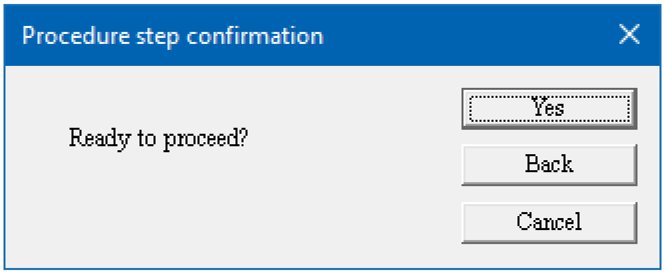
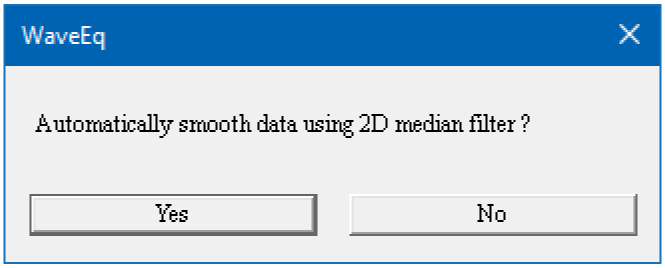


Figure 48: Trimmed dispersion curves.

Press *Yes* when ready to proceed.



Select *Yes*.



The edited dispersion curves are displayed.

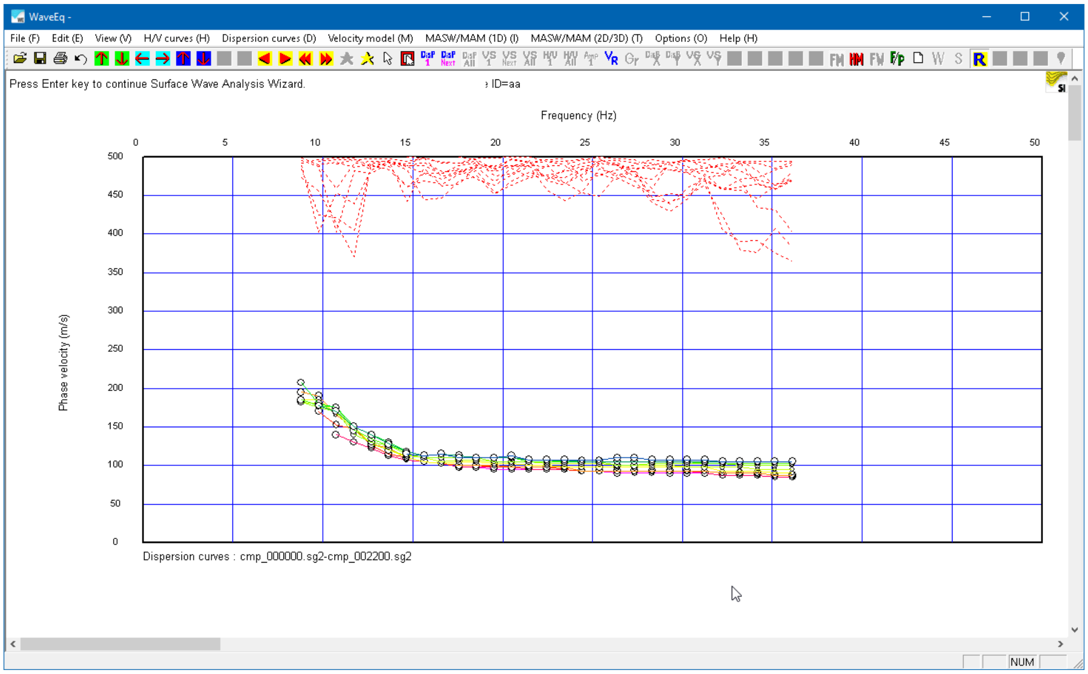
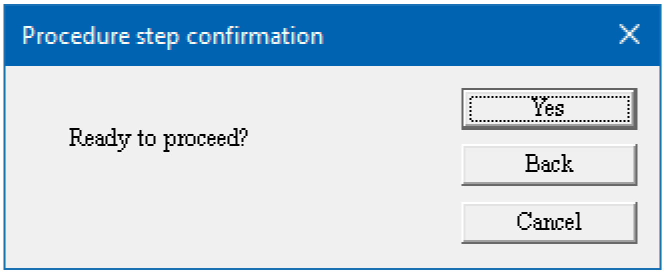


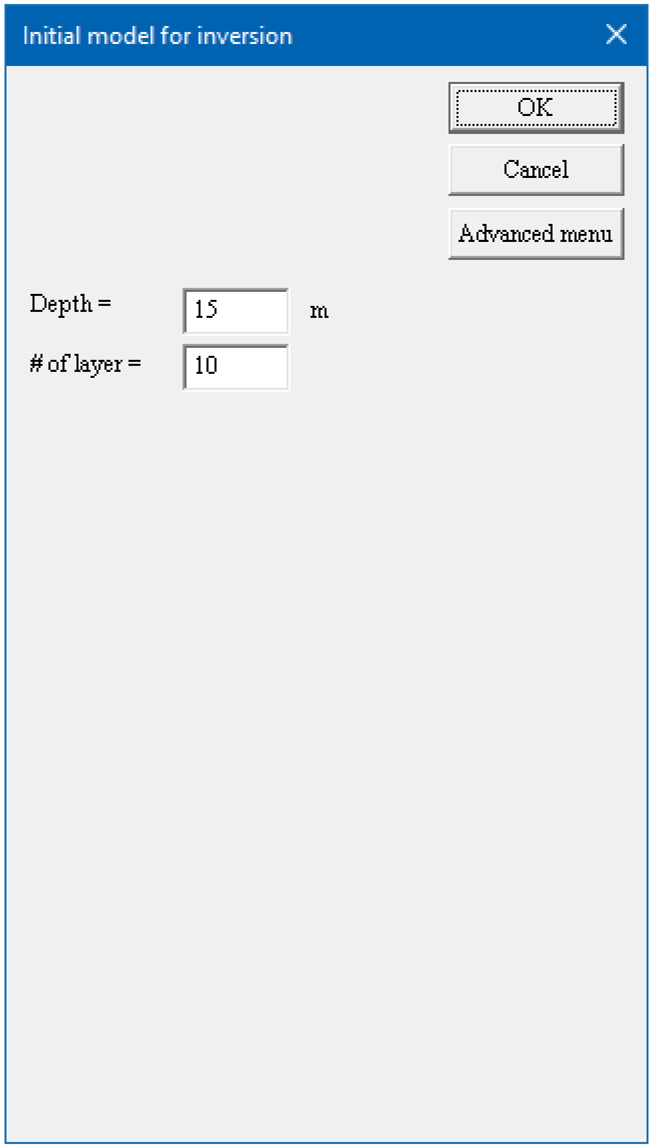
Figure 49: Smoothed dispersion curves.

This is the last editing step. Press the *Enter* key to continue.

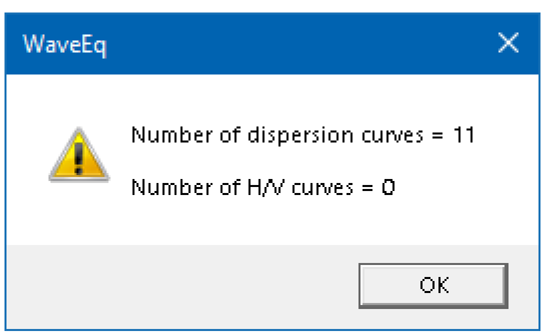
Press *Yes* when ready to proceed.



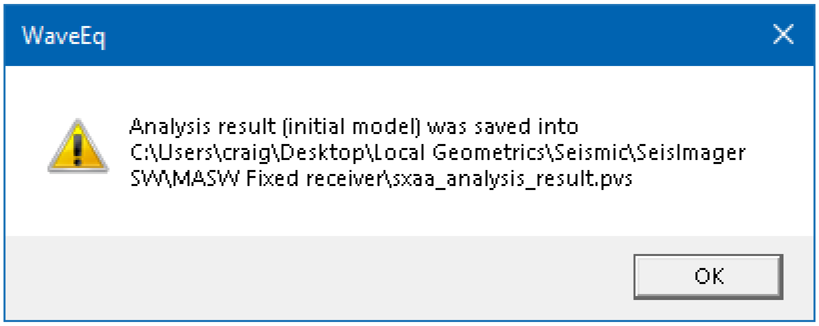
Next, set up the initial models of V_S with depth. These individual curves are used to interpolate an initial cross-sectional model. The software default setting is to calculate the initial models from the one-third-wavelength approximations. For the *Depth* value, a good estimate to start with is one-half the spread length. The default value for the *Number of layers* is suitable for most cases. Press *OK* when done.



Once the initial cross-sectional model is calculated, the number of curves used in the model is reported. Press *OK*.



The initial model file is automatically saved. Press *OK*.



The first in the group of individual initial models is displayed.

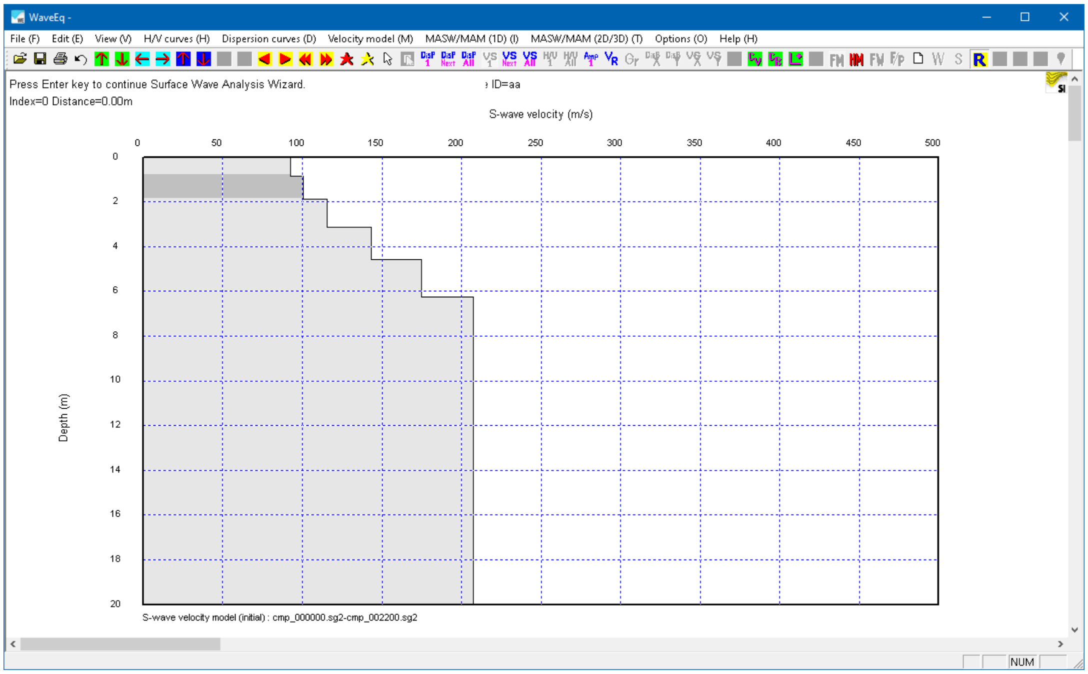


Figure 50: One of several initial velocity models.

To control the velocity curve display, use the *Velocity section 1* and *Velocity section next* buttons to view one, or three curves at a time, respectively. With either setting, the *Show previous* and *Show next* buttons and the *Home* and *End* buttons allow you to move through displays. The *Velocity section all* button displays all velocity curves.

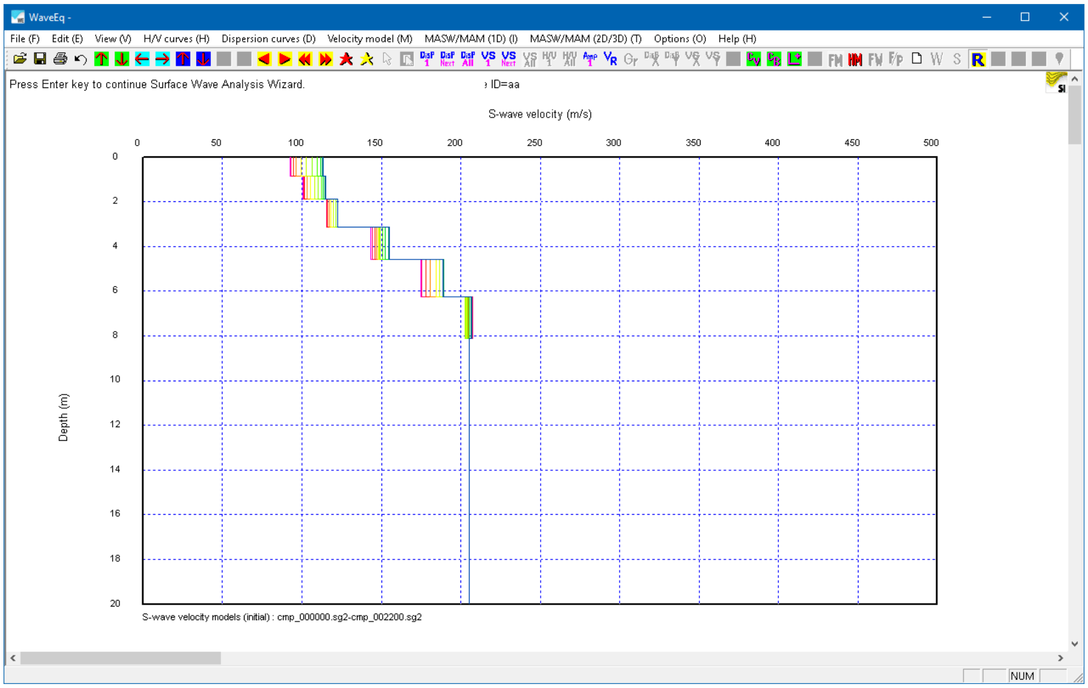


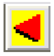
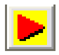
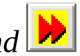
Figure 51: Display of several initial velocity models.

Press the *Show apparent velocity model*  button to overlay the one-third-wavelength approximation (red points), which is the best indicator of the actual depth range of penetration. By default, the shade of the model changes to light grey, starting at the deepest apparent velocity, to call attention to the limits of the data.

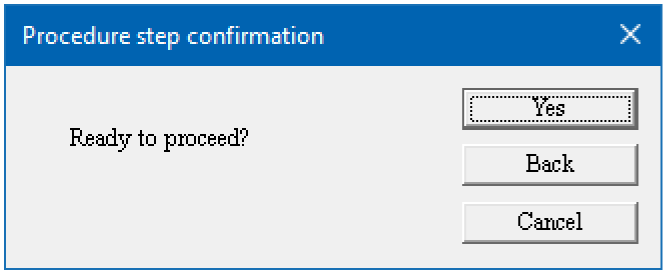
Figure 52: Velocity model showing 1/3 wavelength approximation.

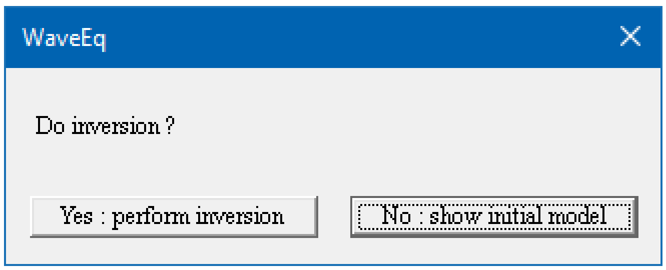
For the dispersion curves, the *Dispersion curve 1* 

and *Dispersion curve next* 

buttons, the *Show previous*  and *Show next*  buttons, the *Home*  and *End*  buttons, and the *Dispersion curve all* 

button, function the same as described for the velocity curve display.





Select *No: show initial model* to display the initial cross-sectional model in GeoPlot (to skip this step, select *Yes: perform inversion*).

The GeoPlot module launches. Press *OK*. Refer to Section 4.1.3.1, Page 119, for an explanation of the GeoPlot functions used for viewing initial V_S cross-sections.

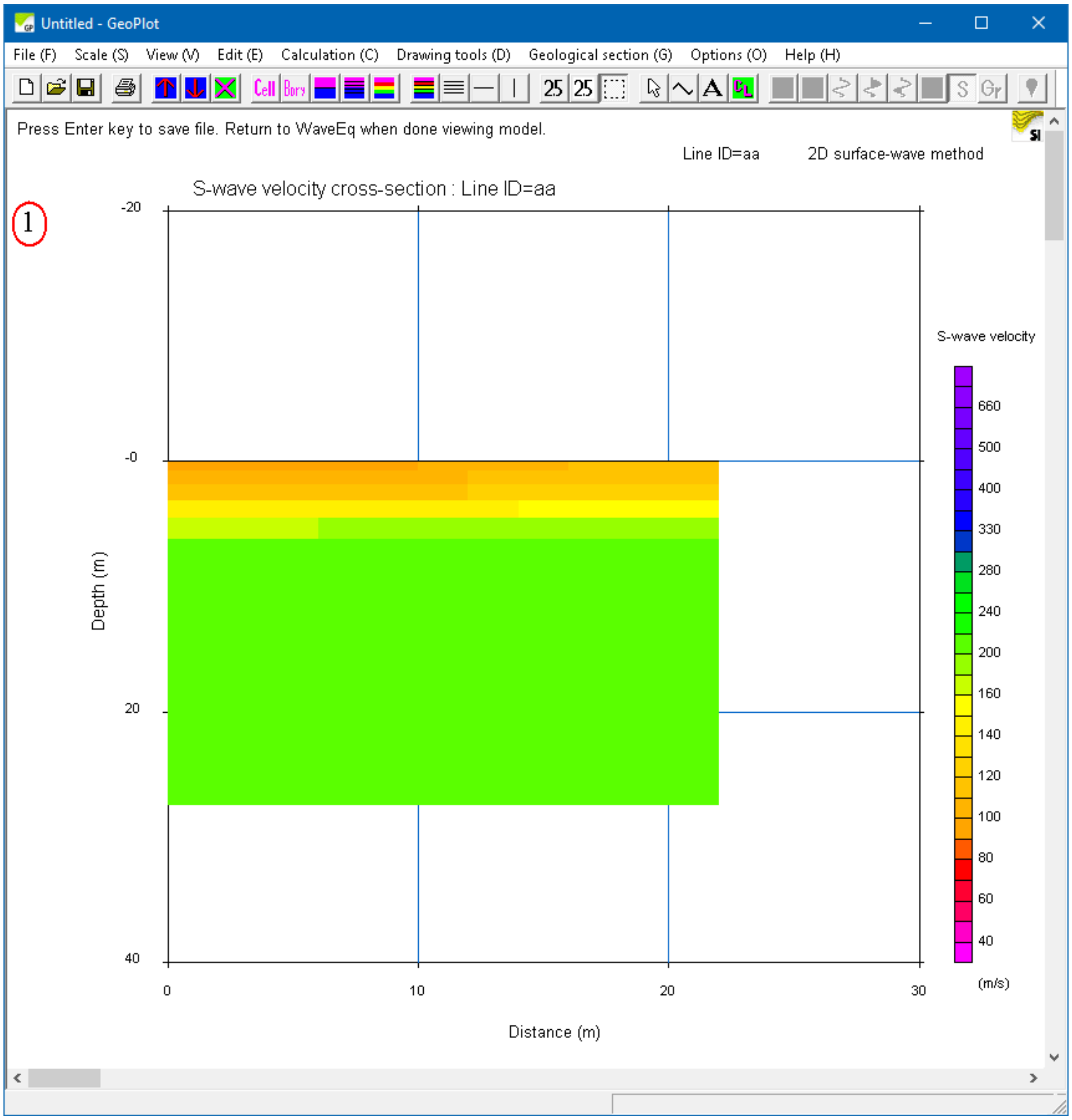
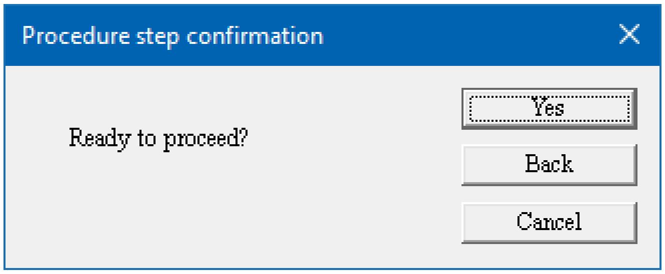


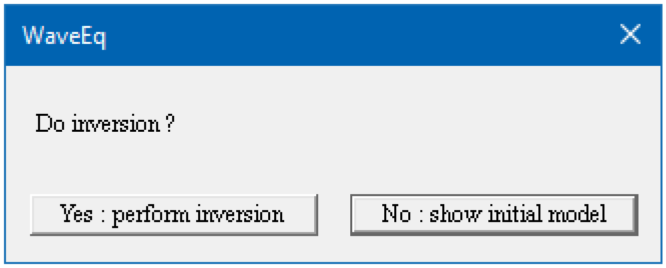
Figure 53: Initial model.

When done viewing the initial model in GeoPlot, press the *Enter* key to save the file and then return to WaveEq to run the inversion.

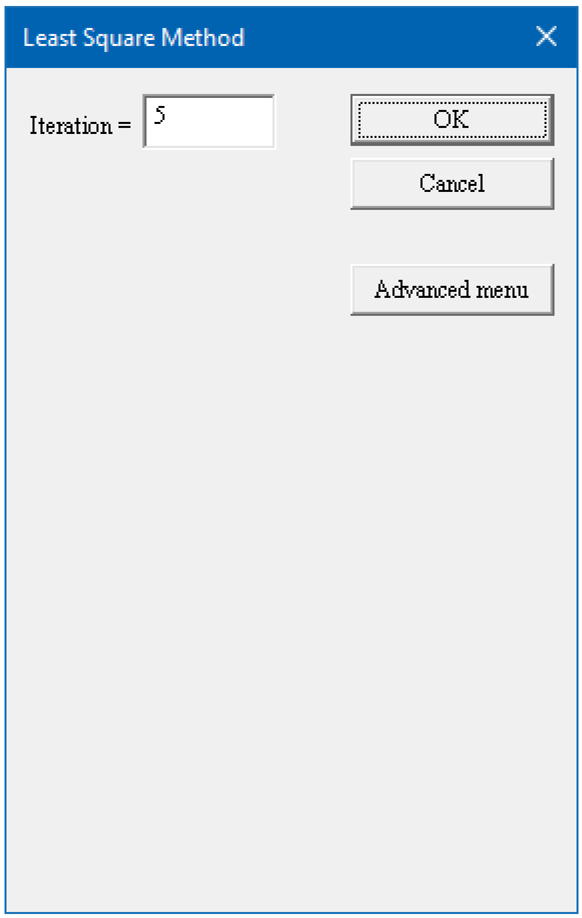
In WaveEq, press the *Enter* key and press *Yes* when ready to proceed.



Select *Yes: perform inversion.*

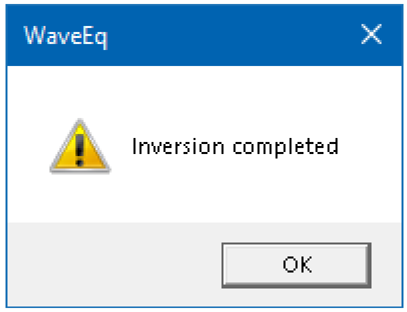


Set the number of iterations for the inversion. The software will iterate the number of times indicated to converge on the best fit of the modified initial model data with the observed data. The default value of 5 for *Iteration* is suitable for most cases. Press *OK* when done.

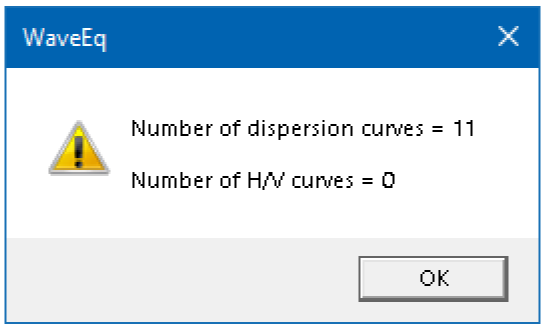


Note that depending on the dataset size, the inversion can be computationally intensive and may take some time to complete. Also, the higher the *Iteration* value, the longer the process will take. In the Windows Task Manager, WaveEq may report as "Not Responding", but if the memory usage is dynamically changing, this indicates the process is running properly.

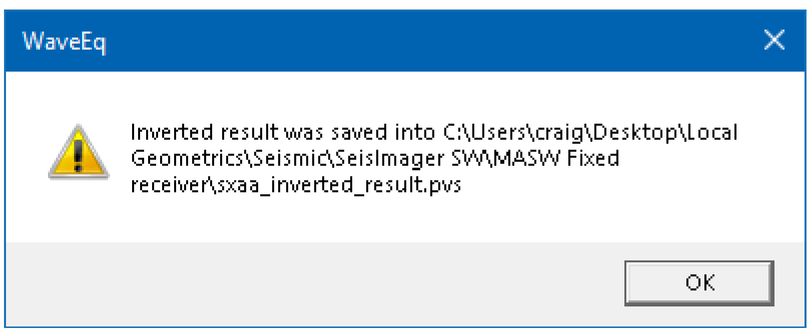
Once the inversion is completed, press *OK*.



Once the final cross-sectional model is calculated, the number of curves used in the model is reported. Press *OK*.



The final model file is automatically saved. Press *OK*.



The first in the group of individual final models is displayed.

Figure 54: Plot of several individual final models.

Check the fit of the calculated and observed dispersion curves. Press the *Show one dispersion curve* button to display one of the original dispersion curves. Then press the *Comparison* button to overlay the calculated dispersion curve (black line) and visually assess the degree of mismatch. The matching error between the two curves in units of time (ms) and as a percentage is saved to a file called *RMSE.txt* in the dataset directory. The error should be less than about 5% but will vary depending on the dataset. You can page through the various dispersion curve comparisons by using the buttons.

If there is a high degree of mismatch, it is likely due to dispersion curve anomalies such as sharp changes and/or outliers or due to low quality noisy picks on the low and high frequency ends of the curve. The mismatch will also be evident in the final V_S curve, usually as an unrealistic velocity inversion or gradient. Although mathematical inversion may be able to model these aspects of the dispersion curve, surface waves, by their physical nature, cannot resolve relatively abrupt or small-scale velocity anomalies. The dispersion curves should be double-checked and the process re-run to improve the match.

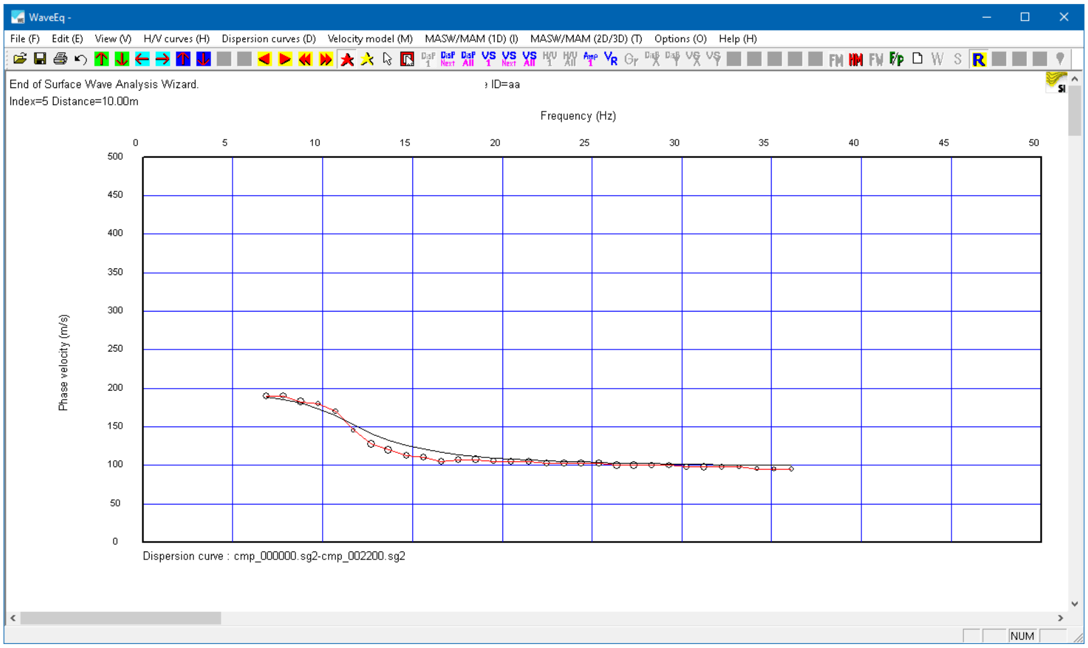
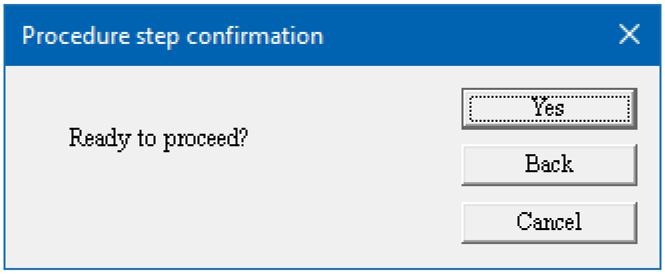


Figure 55: Original (red) vs. calculated (black) dispersion curve.

Press the *Enter* key to continue.

Press *Yes* to proceed.



The GeoPlot module launches again to display the final V_S model. Press *OK*. Refer to the next Section (4.1.3.1) for an explanation of the GeoPlot functions used for viewing final V_S cross-sections.

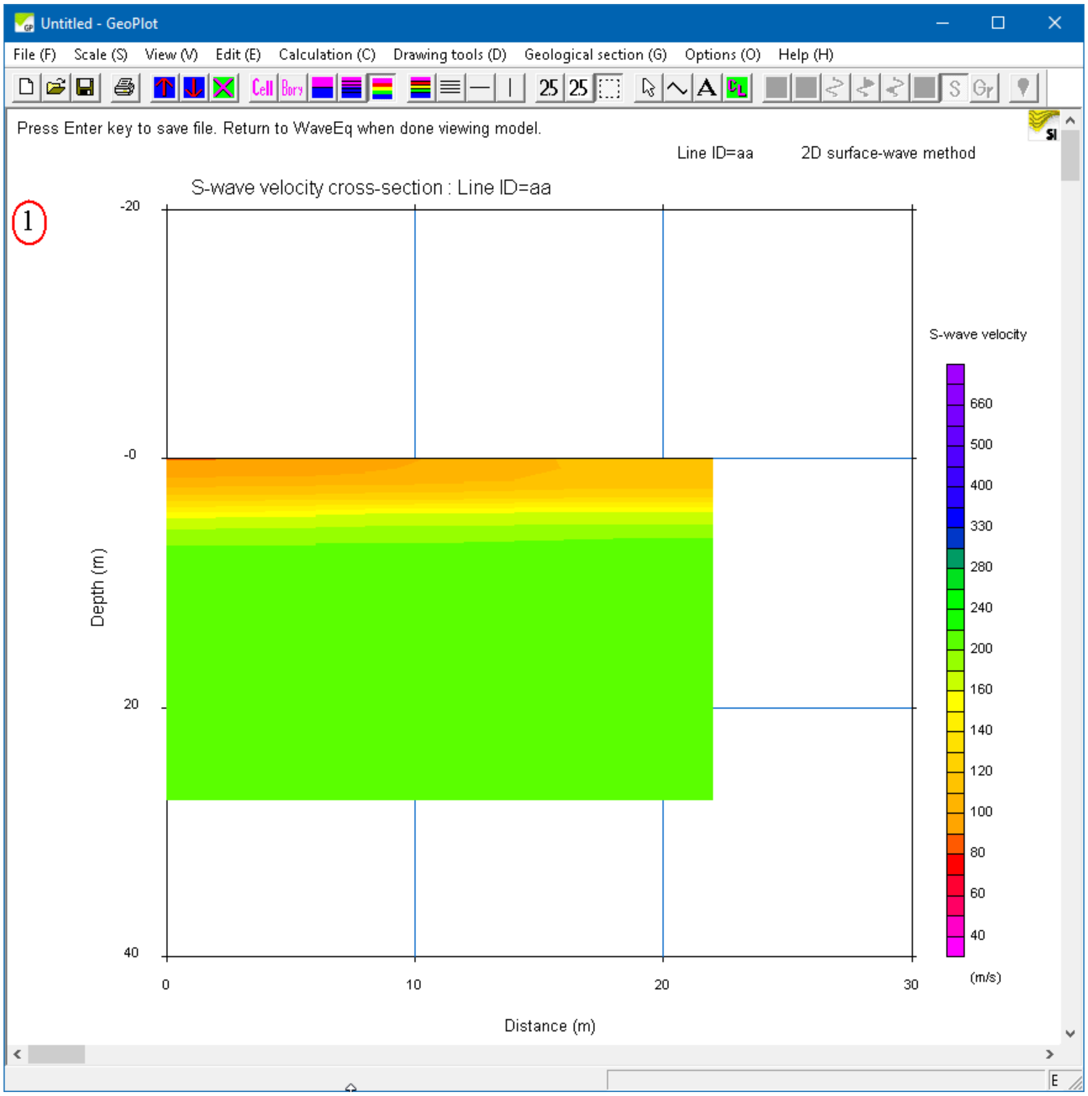


Figure 56: Final Vs model.

Refer to Section 4.2, Page 156, on how to combine active and passive source dispersion curves for a given site and maximize the depth range of the cross-section.

4.1.3.1 The GeoPlot Module Surface Wave Analysis Functions

After the Surface Wave Analysis Wizard launches GeoPlot, the main GeoPlot window appears, and the subject model is displayed. The subject model may be an initial or final model. The model is outlined in red to indicate is it active for editing.

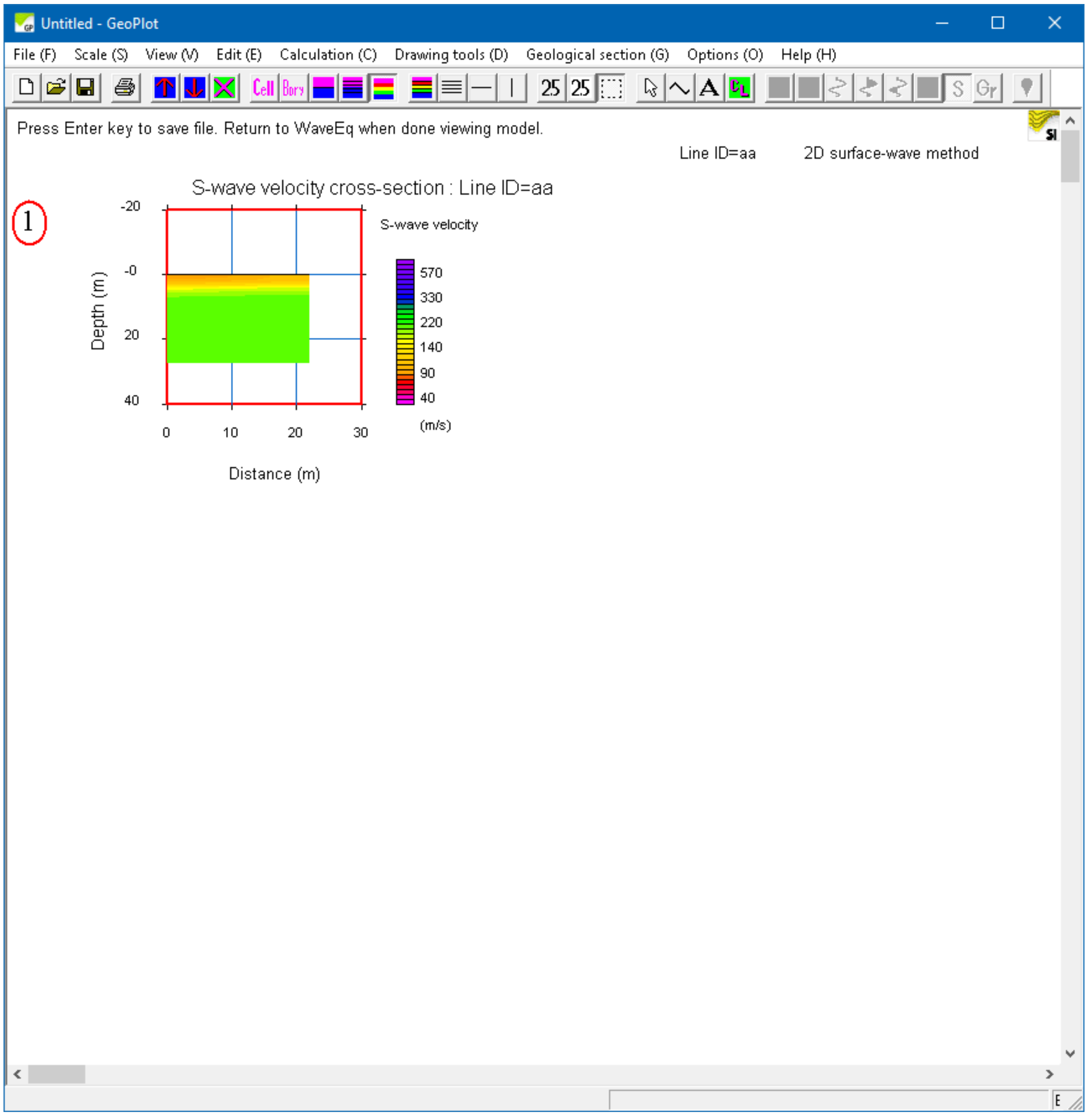
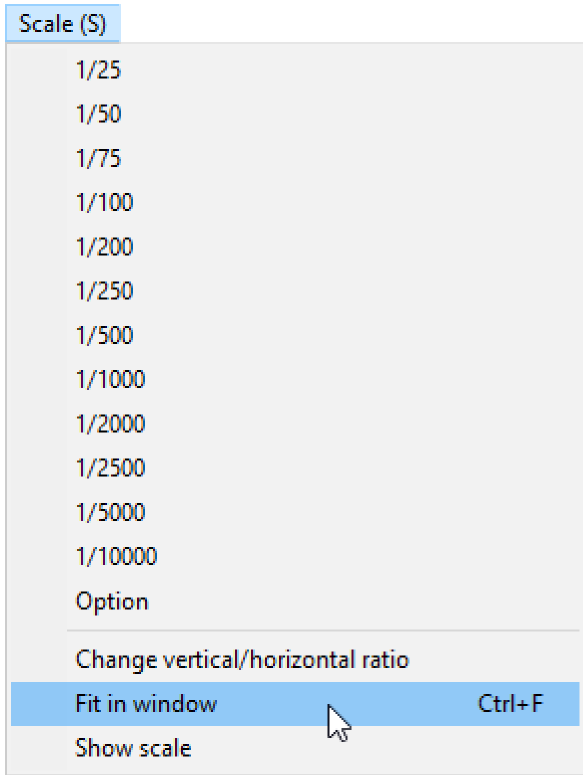
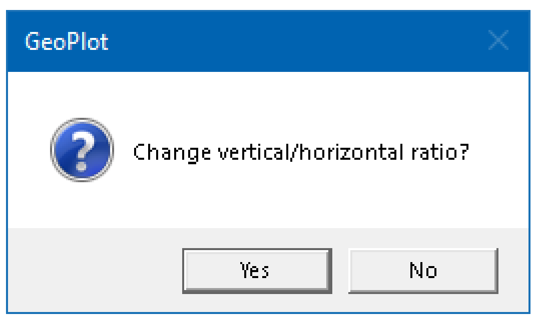


Figure 57: 2D velocity model.

To optimize the display of the model, first select the **Scale** menu and select *Fit in window* to maximize the display area.



Press *Yes* to auto-scale the display.



Use the *Enlarge scale*  and *Reduce scale*  buttons to further adjust the plot size.

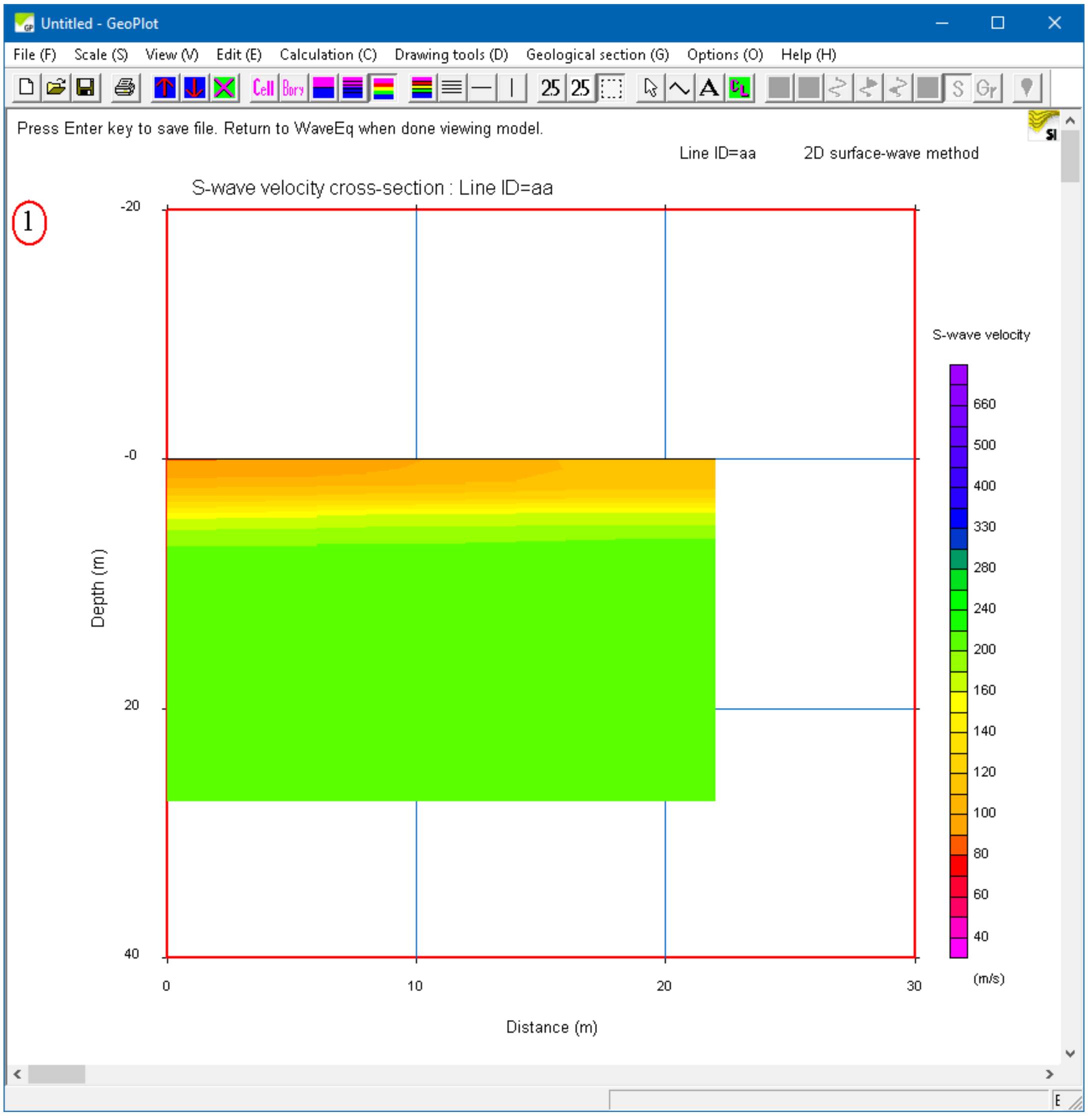
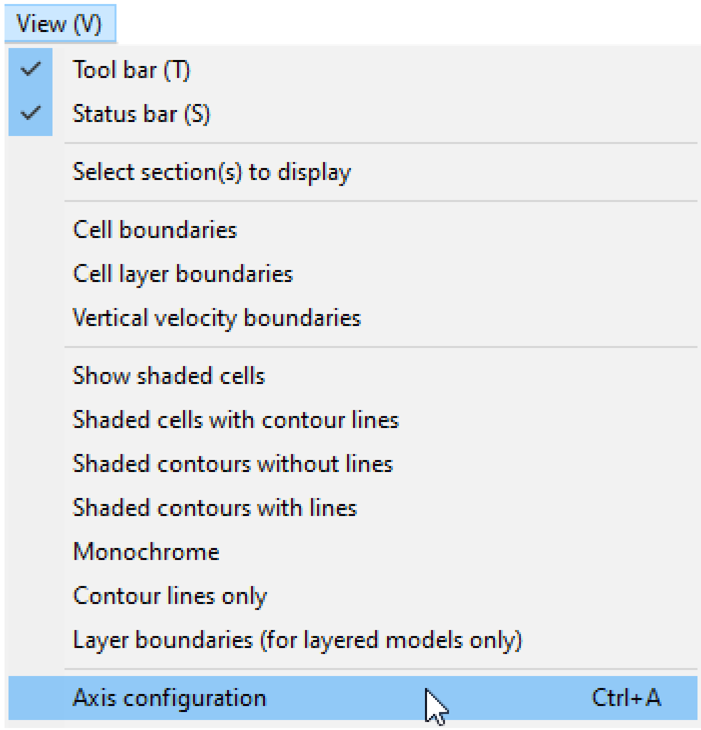
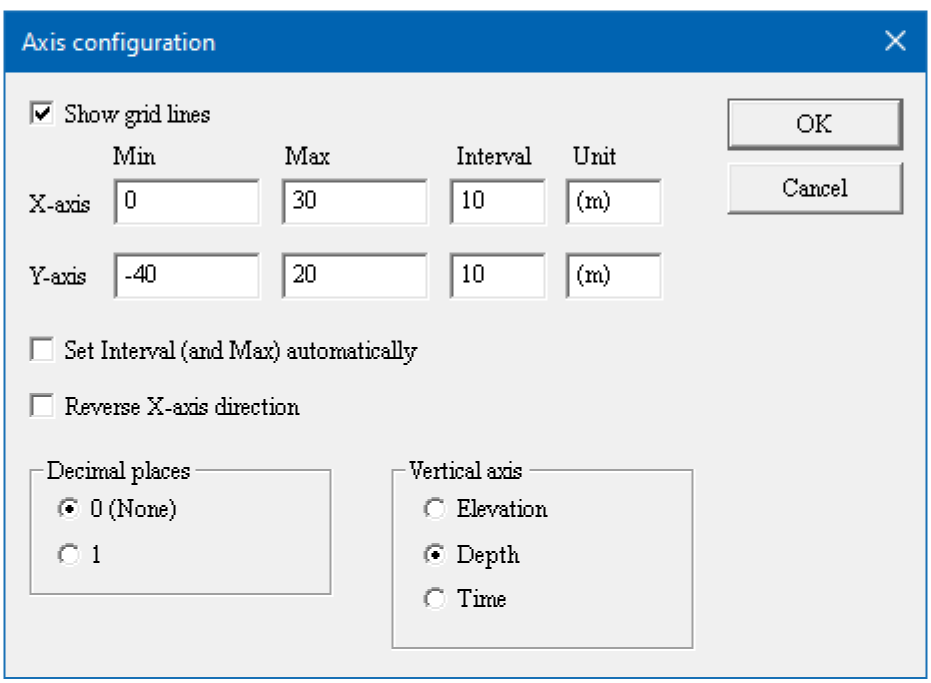


Figure 58: Re-scaled 2D velocity model.

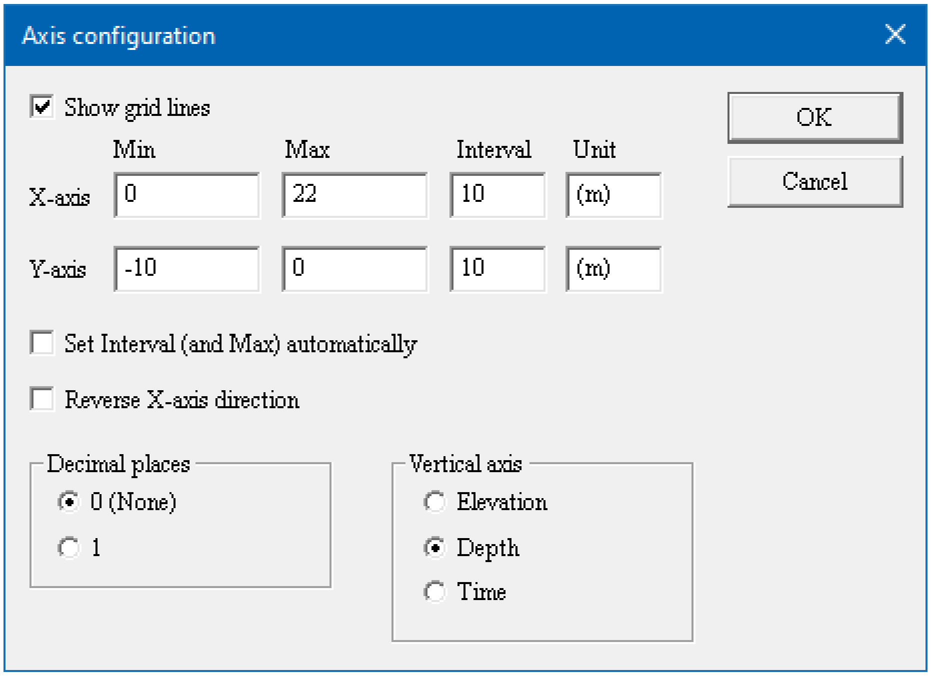
If the axes need adjustment, open the **View** menu, and select *Axis configuration*.



Enter the desired values for the *X-axis* and *Y-axis Min*, *Max*, and *Interval*. The unit label fields reflect the units imported with the model from WaveEq. To make changes to the labels, enter the desired text in the *Unit* fields.



When *Show grid lines* is checked, blue horizontal and vertical lines will be displayed at each tick mark. Checking *Set Interval (and Max) automatically* will allow the tick intervals to dynamically increase when the scale is reduced to prevent the axis labels from overlapping; the *Max* values cannot be fixed in this mode. *Reverse X-axis direction* causes the horizontal scale to decrease to the right. *Decimal places 0 (None)* or *1* sets the number of significant digits for the axis tick interval values. When *Depth* (the default) is selected for the *Vertical axis*, the values are positive below zero; conversely, when *Elevation* is selected, the values are negative below zero.



If you wish, you may indicate the approximate depth of penetration along the cross-section. Refer to Figure 52. Note that according to the 1/3 wavelength rule, penetration at that location (left end of section) is significantly less than is shown above in Figure 58. In general, penetration tends to be deepest near the center of the spread, tapering off toward the ends. This is because the frequency range toward the ends of the line is relatively narrow, limiting depth penetration.

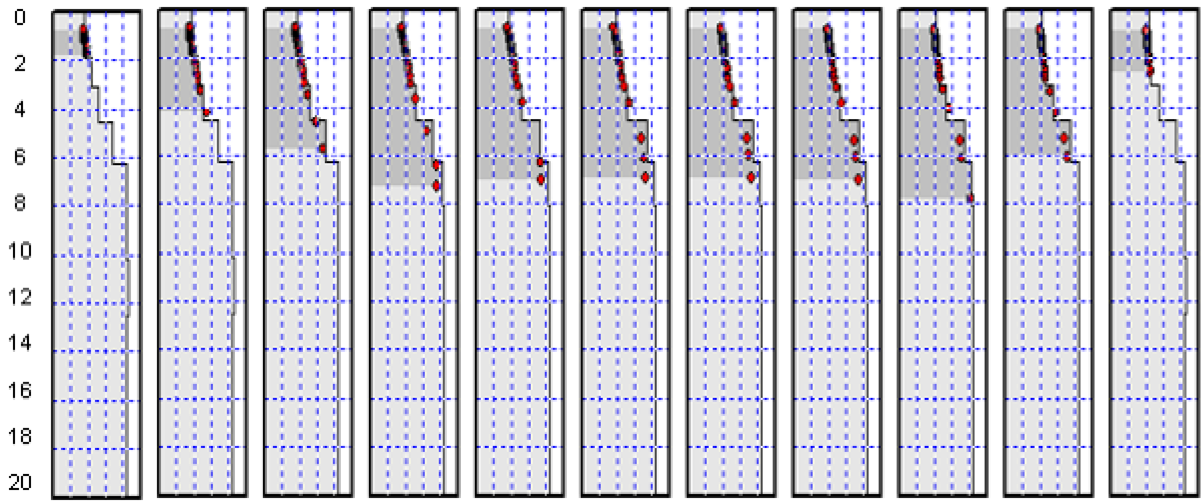


Figure 59: All 11 V_S profiles plotted side-by-side.

Figure 59 shows each V_S profile along the survey line. Note the tapering of max V_R (max depth of red dots, marked by a transition from dark to light grey) toward the ends. Max V_R is a measure of data "reliability" and is a good estimate of the depth of penetration. If we select *View* | *Advanced options* | *Show reliability* (this is toggle switch), we can see this reflected in the cross section:

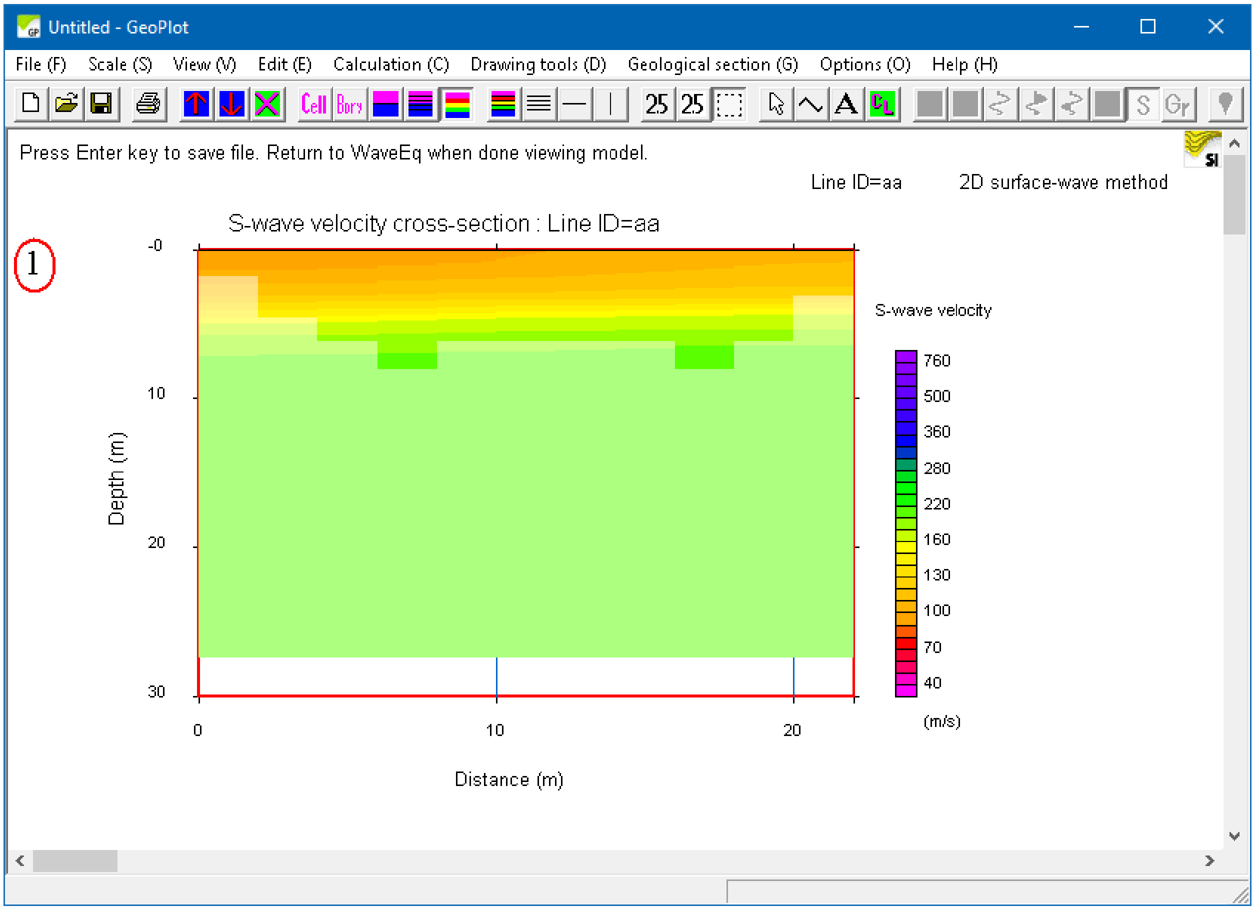


Figure 60: S-wave velocity section with ***Show reliability*** *enabled. Compare to Figure 59.*

The pale-colored zone is the "zone of unreliability". The top of this zone represents the *approximate* depth of penetration based on the 1/3 wavelength approximation (max V_R).

If you wish, you may remove the unreliable data and only display the zone of reliability. To do so, select *Edit | Advanced options | Delete unreliable data:*

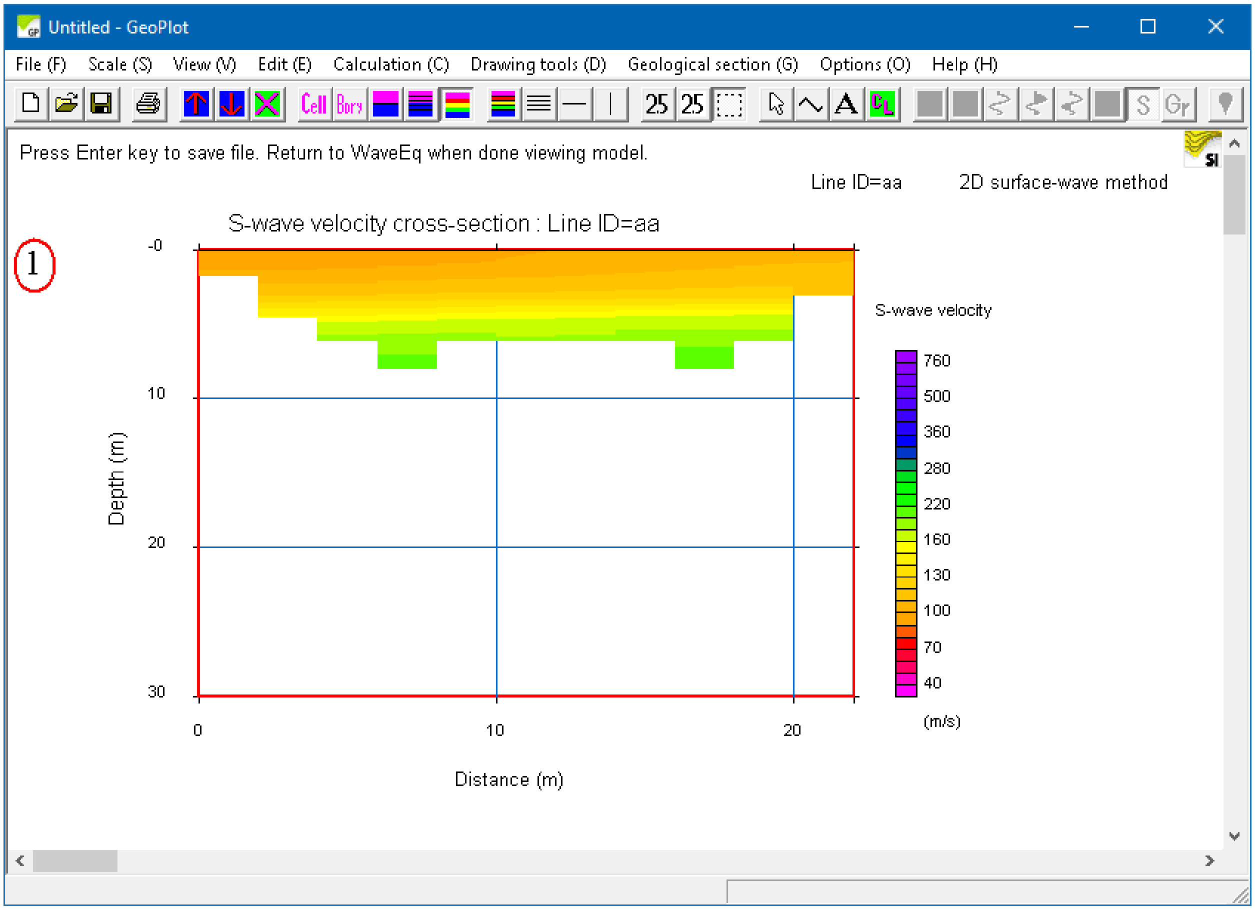
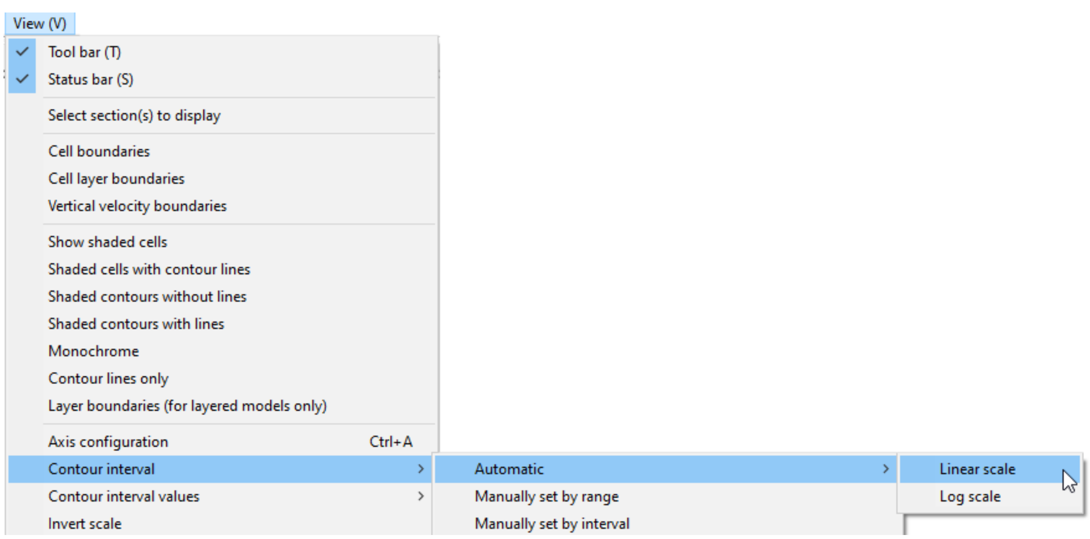


Figure 61: S-wave velocity section with unreliable data deleted.

Next, if you wish, open the **View** menu and select *Contour interval | Automatic | Linear scale* to automatically adjust the contour interval.



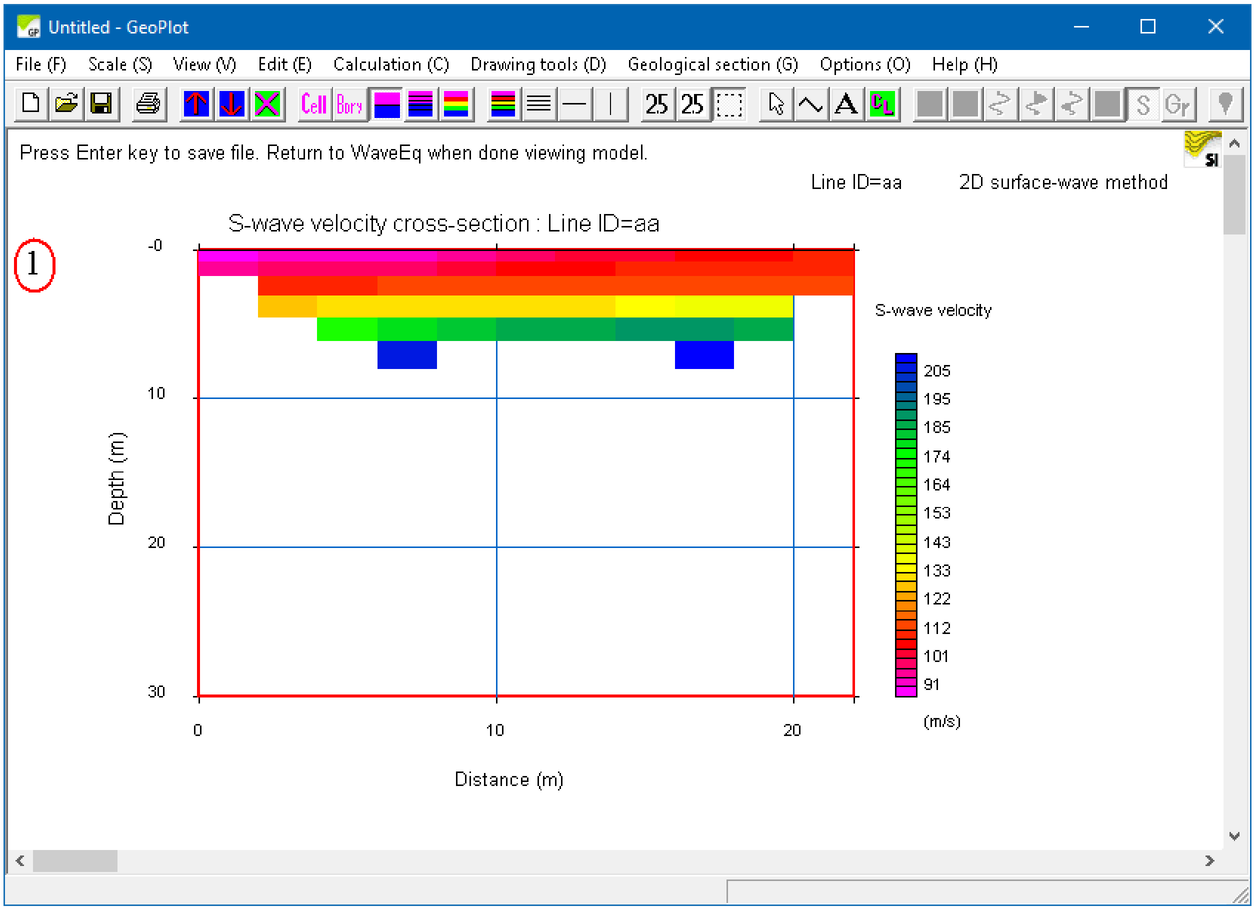


Figure 62: 2D velocity model, coarse velocity contours. Red outline and red-circled number indicate that section is active and available for editing.

Press the *Fine color contour*  button to increase the display resolution.

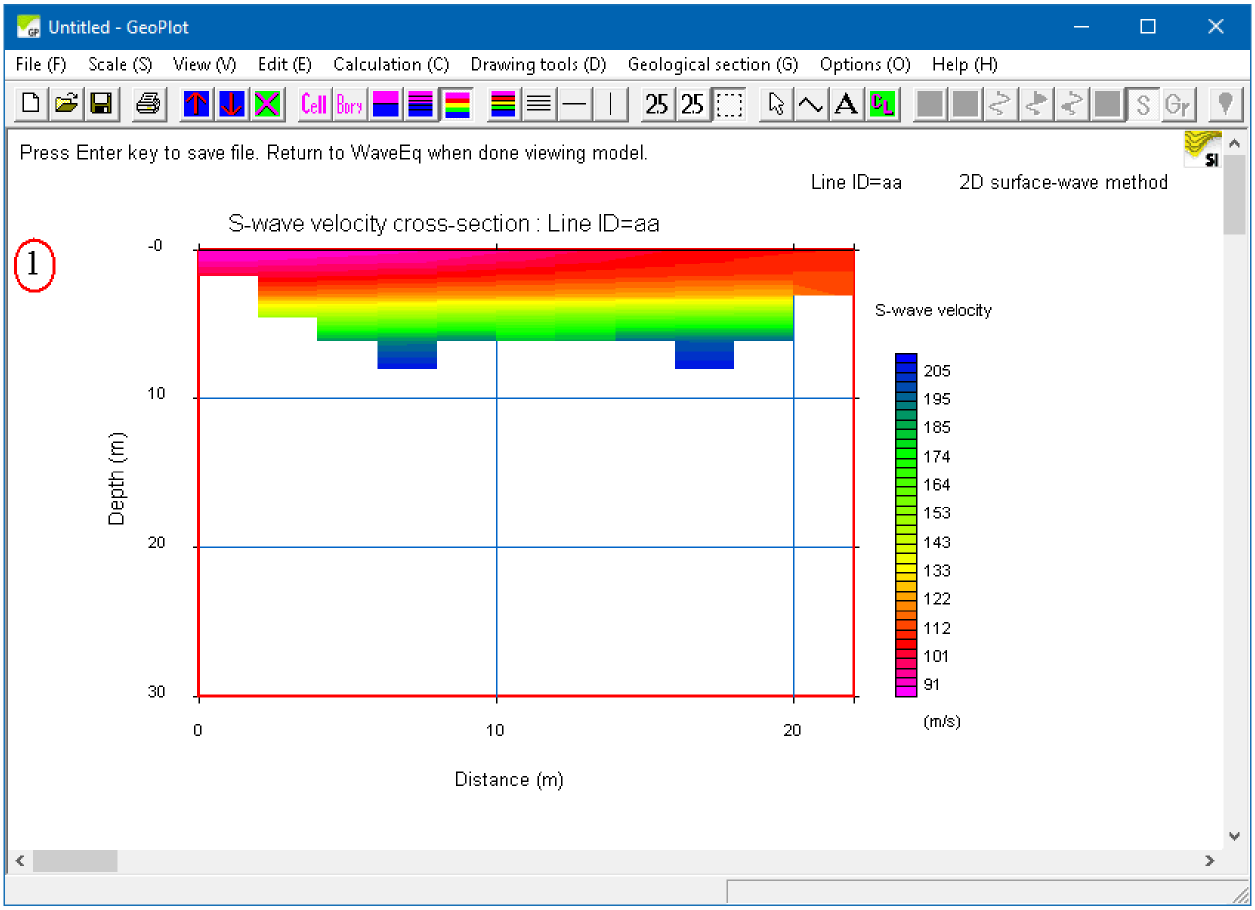


Figure 63: 2D velocity model, fine velocity contours.

Repeating Figure 59 for convenience, we can compare the series of 1D V_S curves to the 2D velocity section:

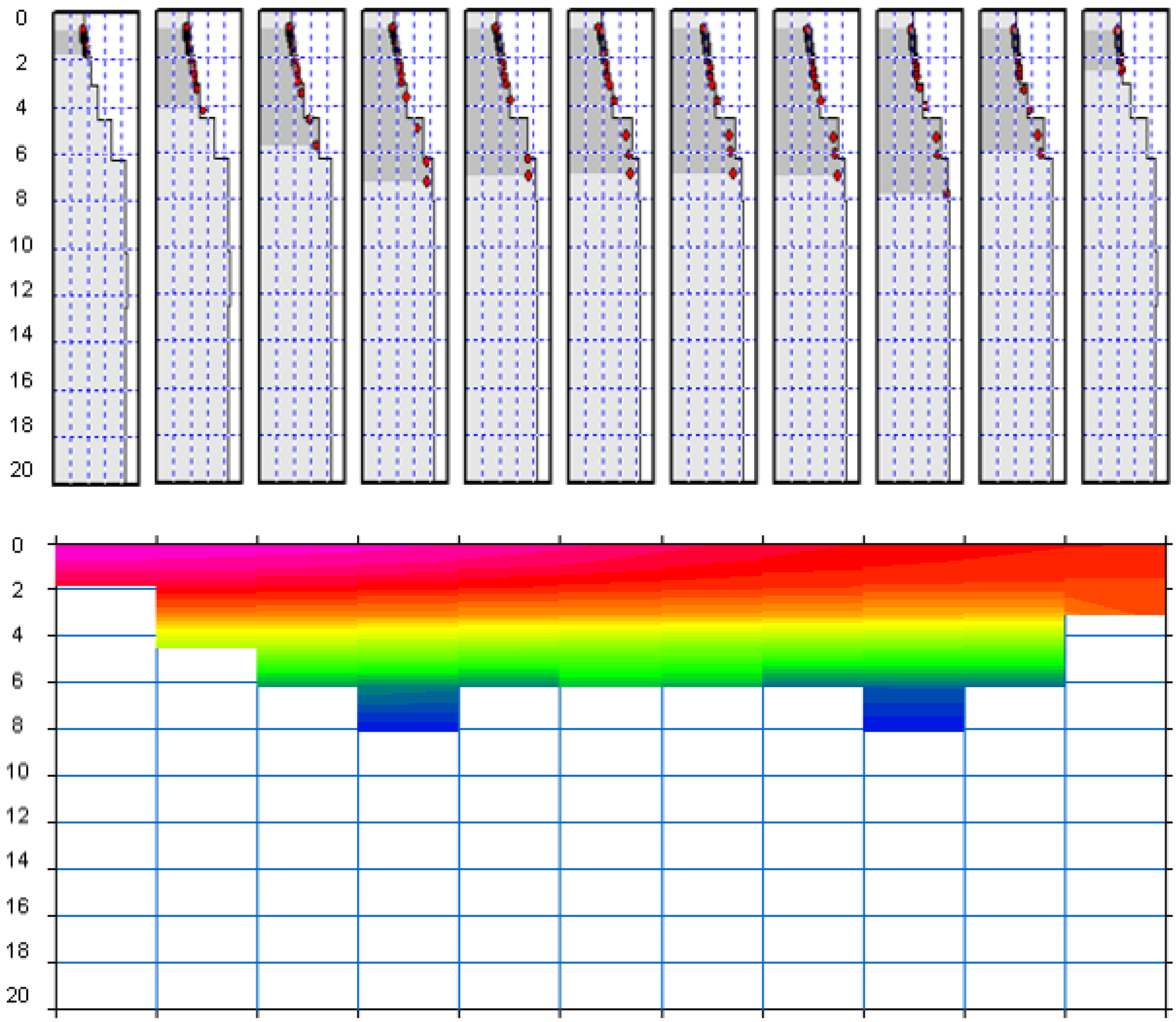


Figure 64: Comparison of 1D VS curves to S-wave velocity section with unreliable data deleted.

Adjusting the axes and rescaling, we get the following:

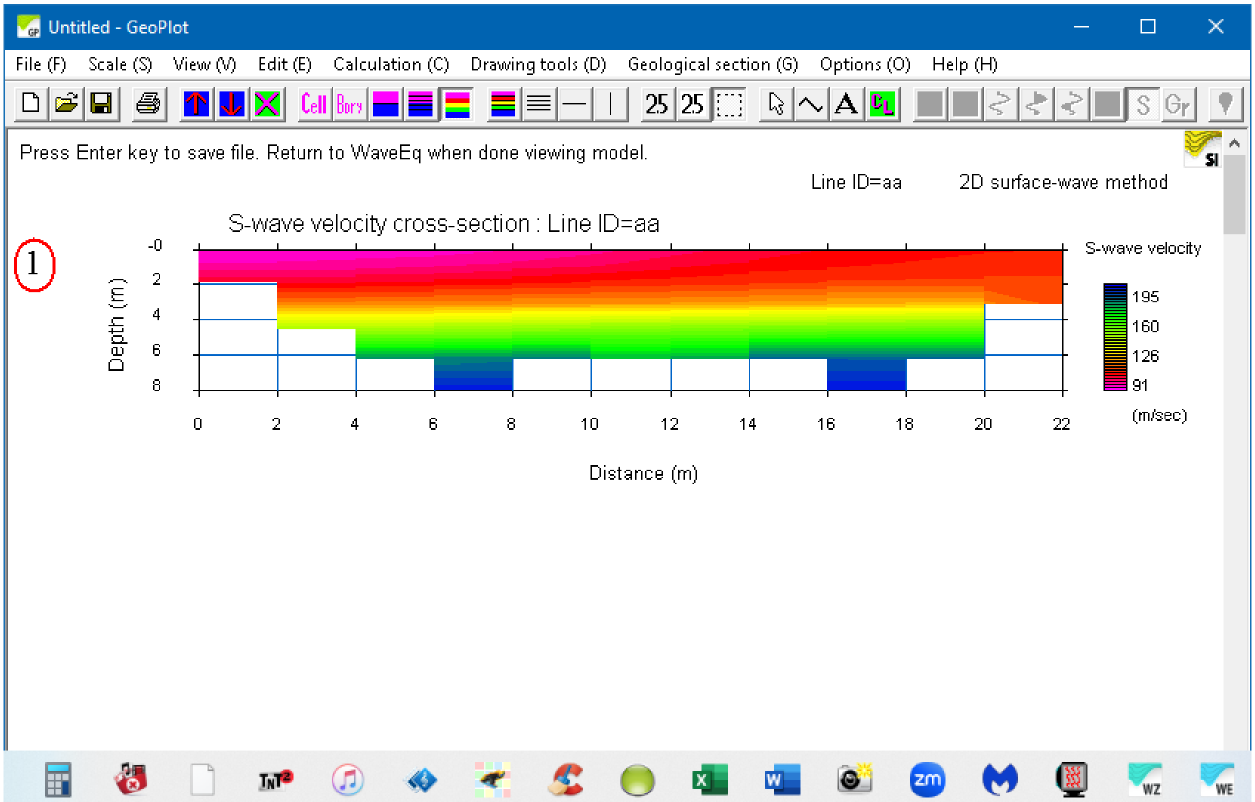
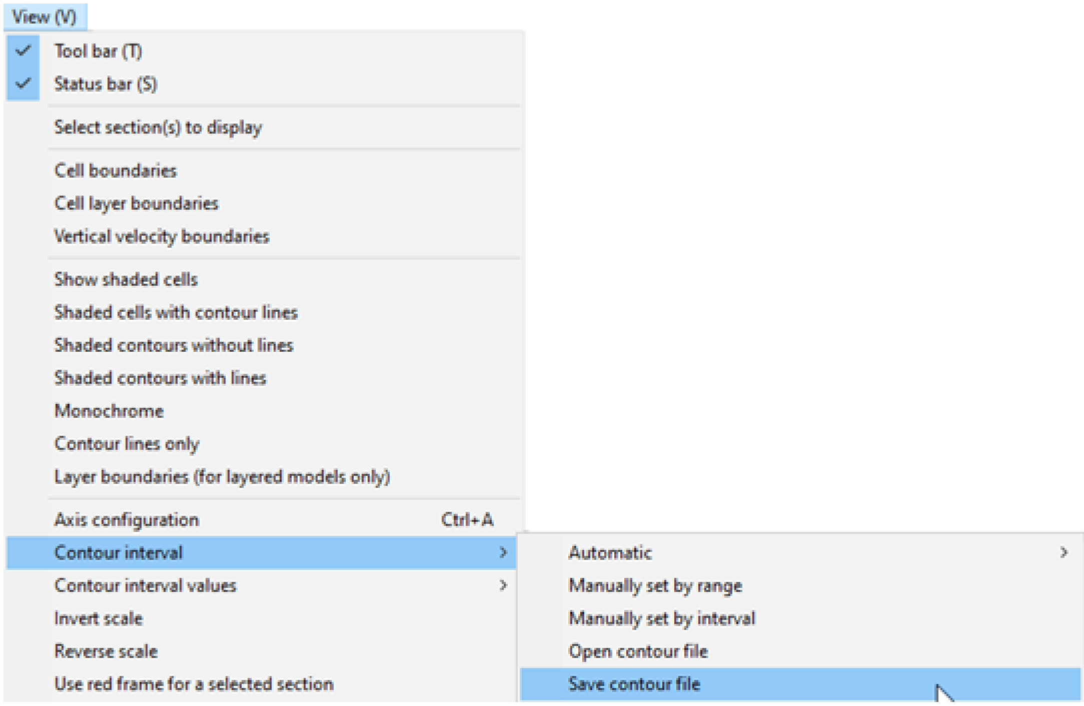


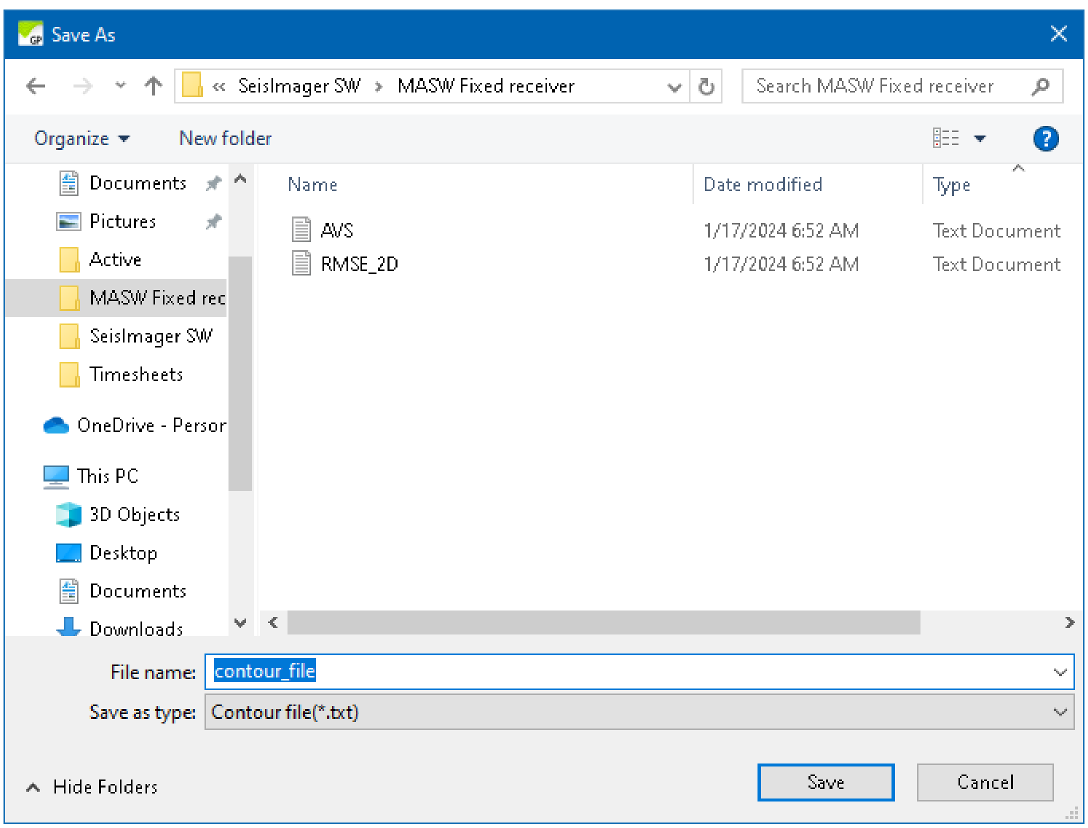
Figure 65: Final S-wave velocity section.

This would be a good time to save your velocity section.

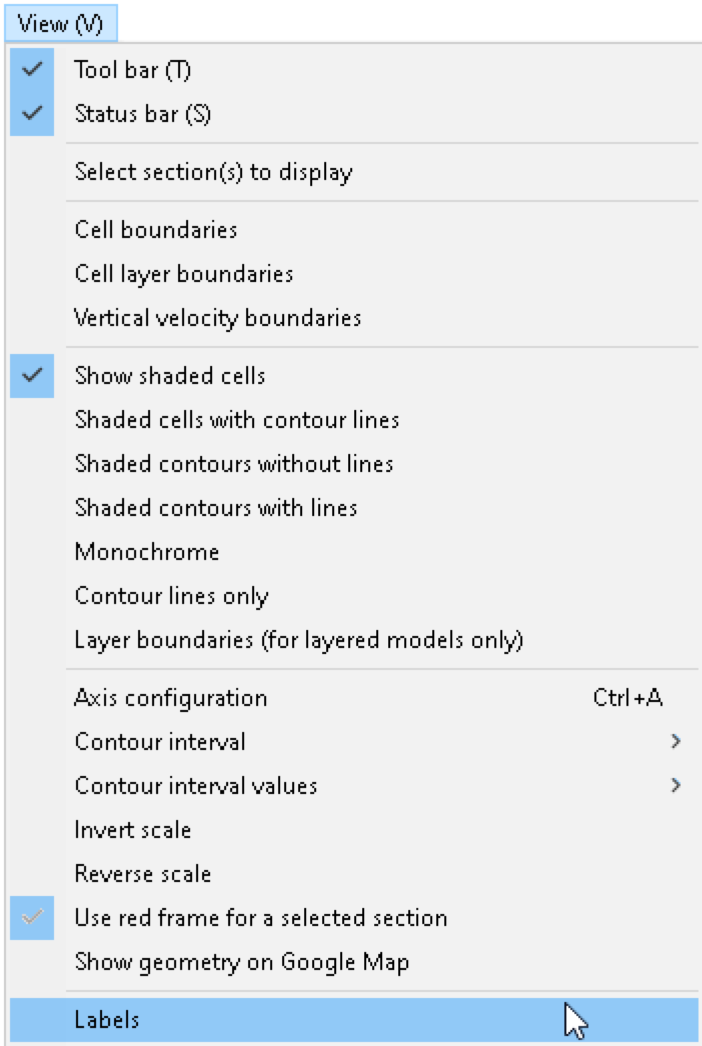
To save a custom contour file so that it can be applied again later, open the **View** menu, and select *Contour* | *Save contour file*.



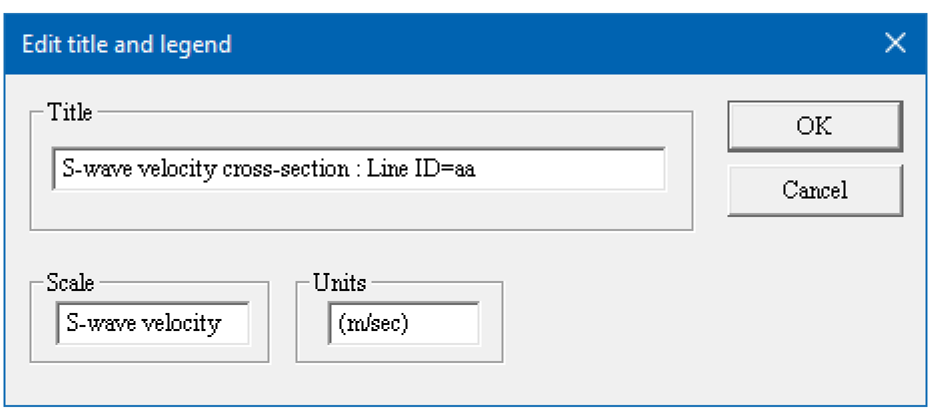
Assign a file name and press *Save*.



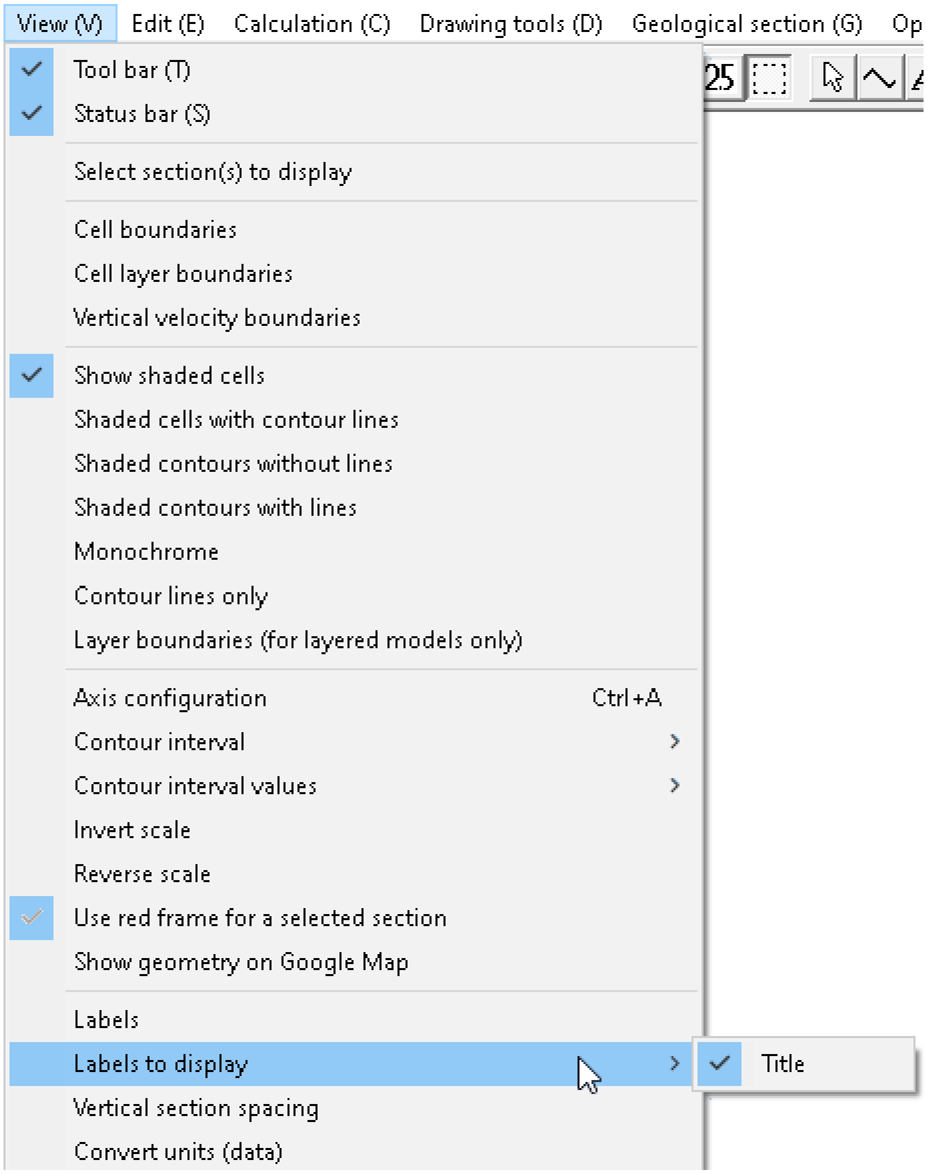
Next, edit the title of the cross-section by opening the **View** menu and selecting *Labels*.



Enter the desired text in the *Title*, *Scale*, and *Units* fields and press *OK* when done.

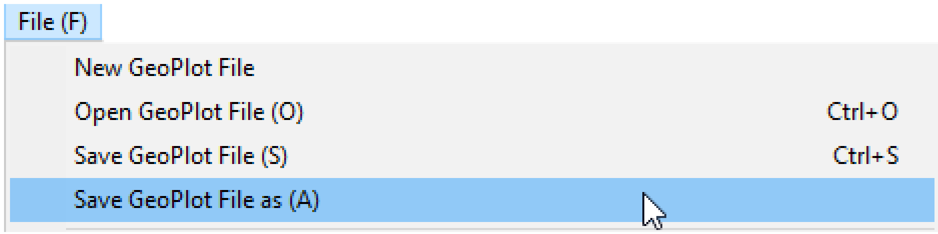


If you do not want to display the *Title*, open the **View** menu, select *Labels to display*, and uncheck *Title*.

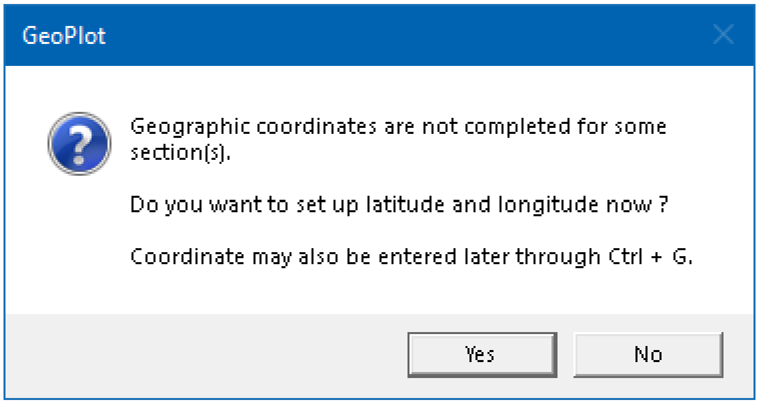


Now is a good time to save the GeoPlot file. If you are running the wizard, press the *Enter* key, and the file will be automatically named and saved with the extension *.geo*. Press *OK* and return to WaveEq to continue the wizard.

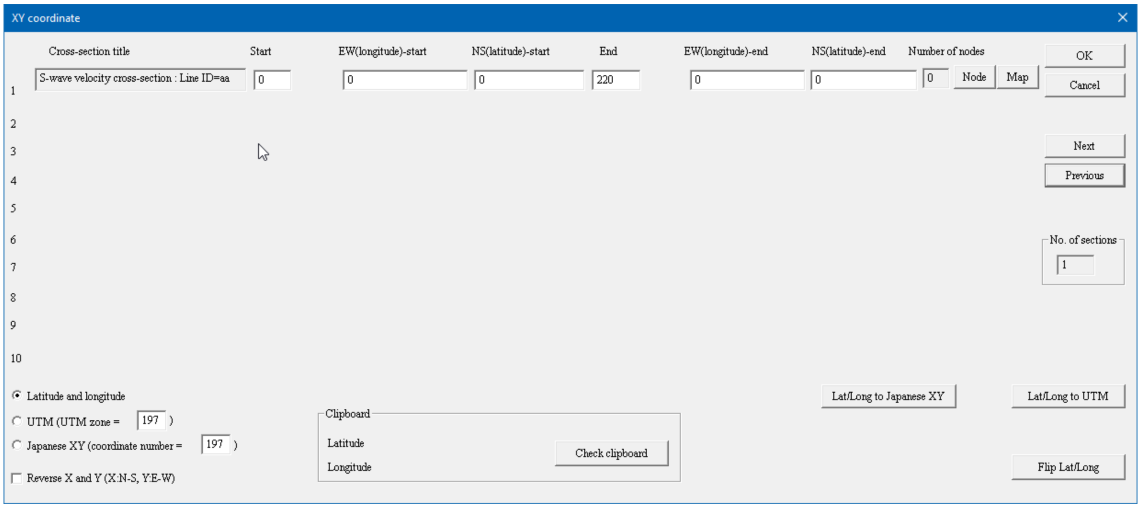
To save the file manually, open the **File** menu and select *Save GeoPlot file as*.



At this point you may be asked if you wish to add latitude and longitude coordinates to your survey line:

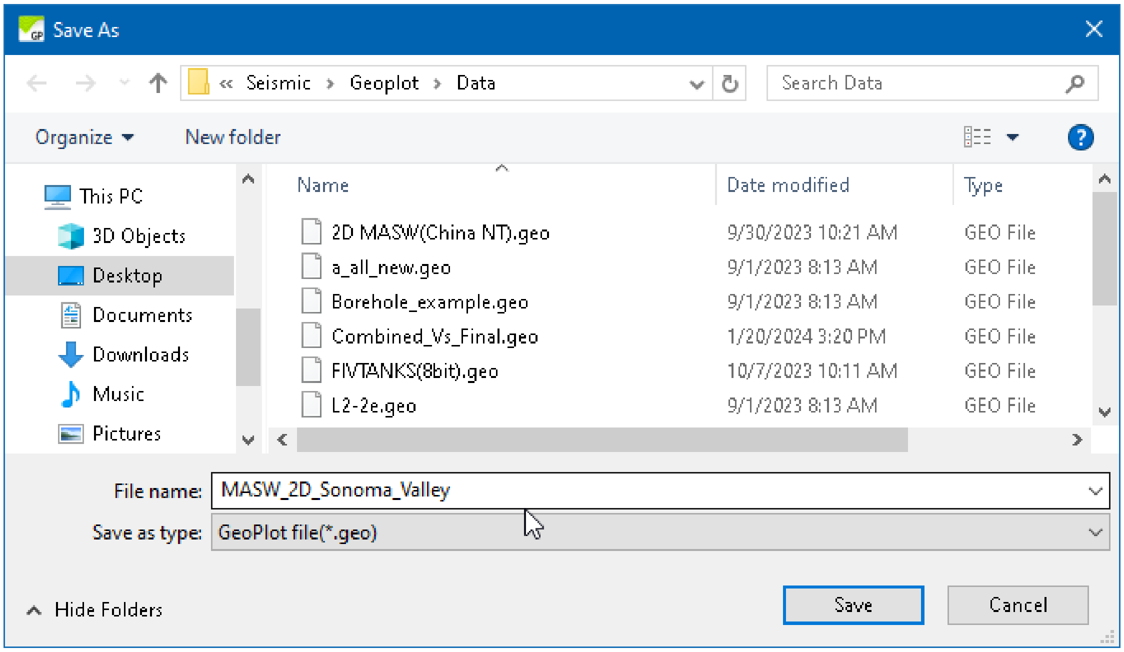


If you answer *Yes*, the following dialog will appear:

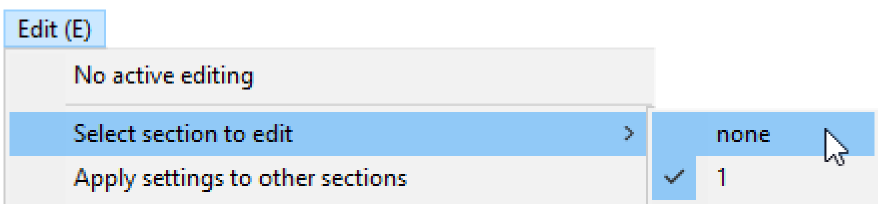


Enter the coordinates and press *OK*. If you choose UTM coordinates, be sure to indicate the correct UTM Zone.

Assign a file name with the extension *.geo* and press *Save*.



When you are done editing, open the **Edit** menu and choose *Select section to edit* | *none* to deactivate the cross-section and turn off the red outline.



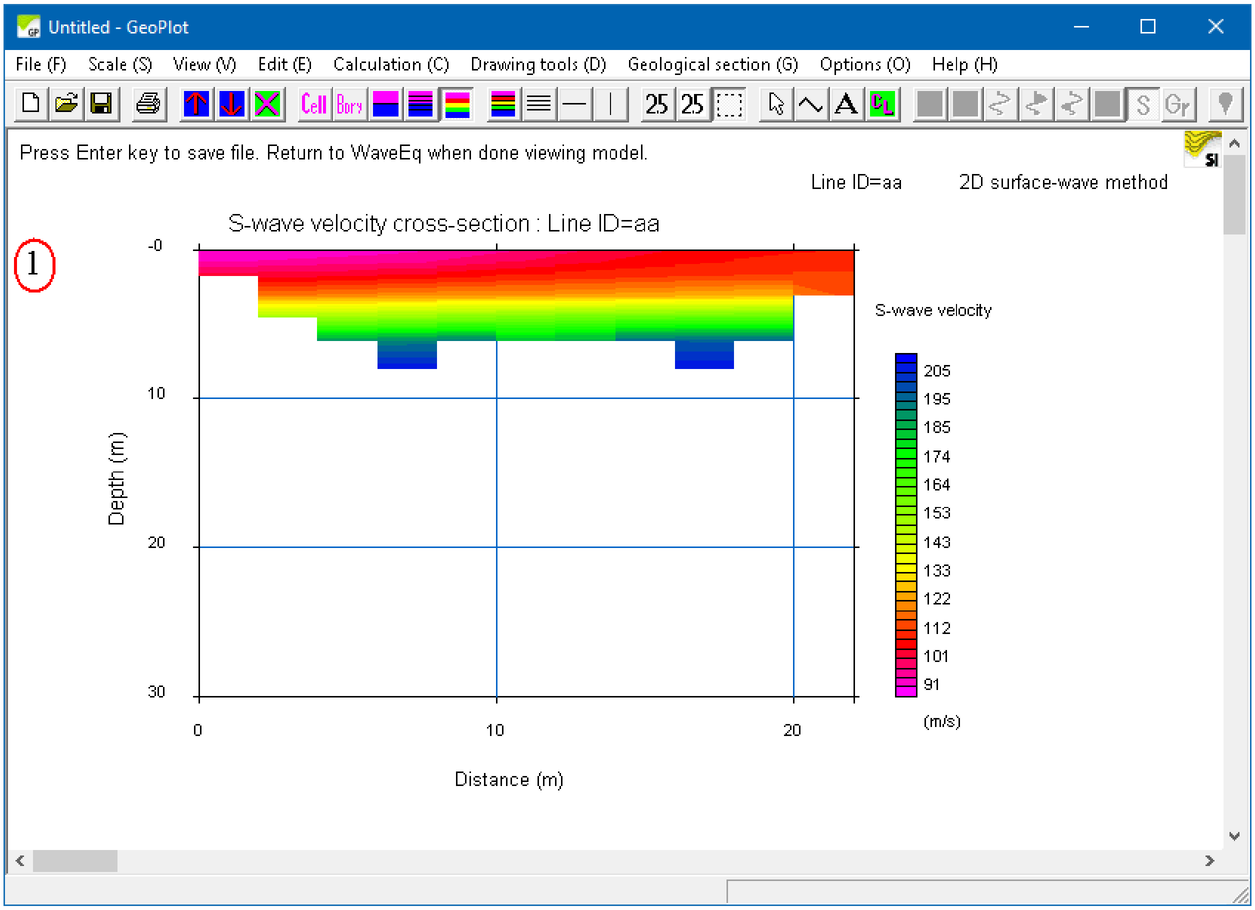
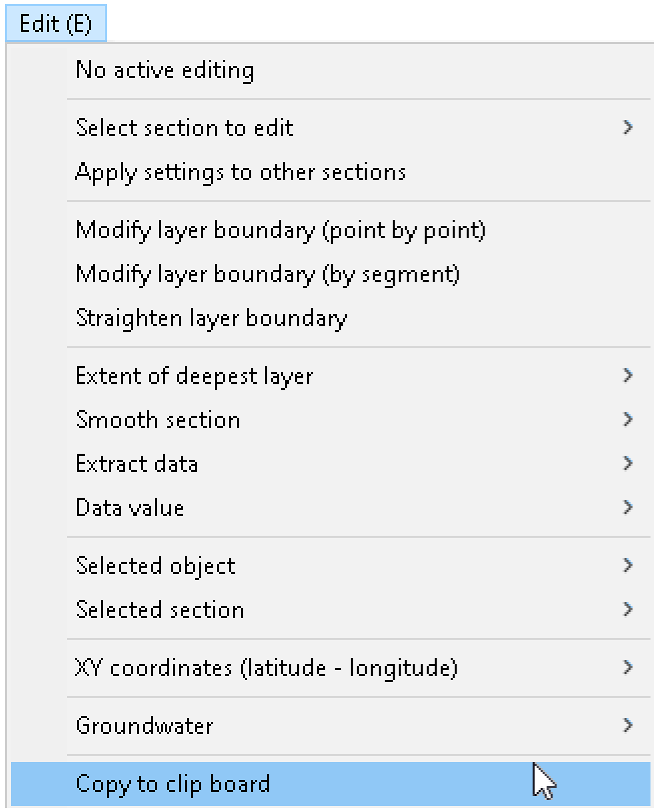
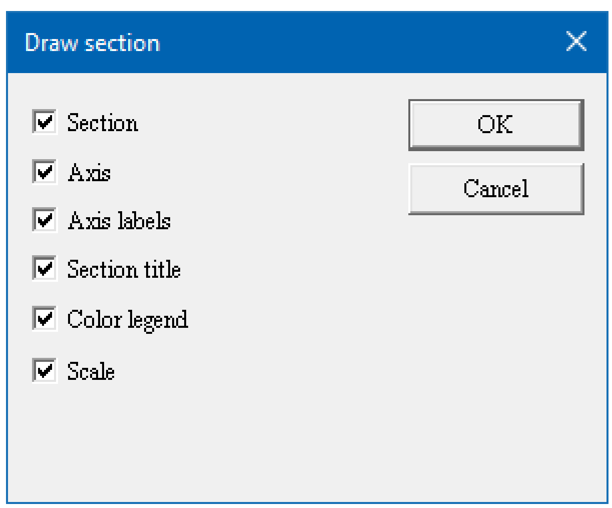


Figure 66: Deactivated velocity section (red outline removed).

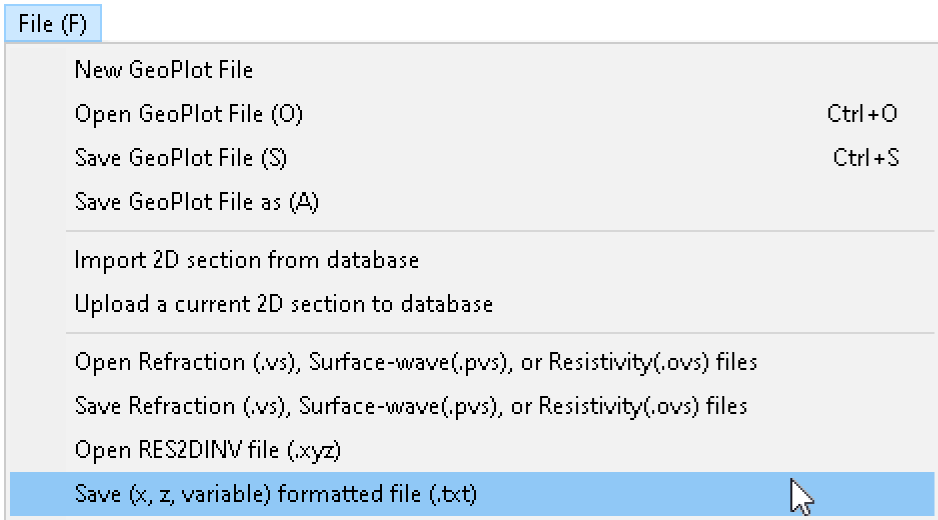
To capture an image of the cross-section for report graphics, open the **Edit** menu, select *Copy to clipboard*, and then paste the image into the program of choice.



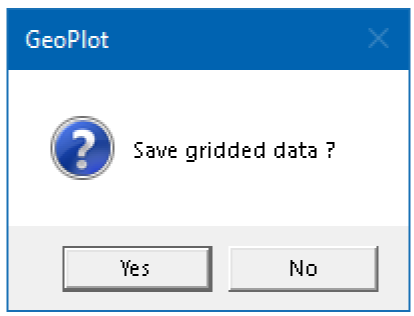
Copy to clipboard (option) allows you to select which features are included with the image capture.



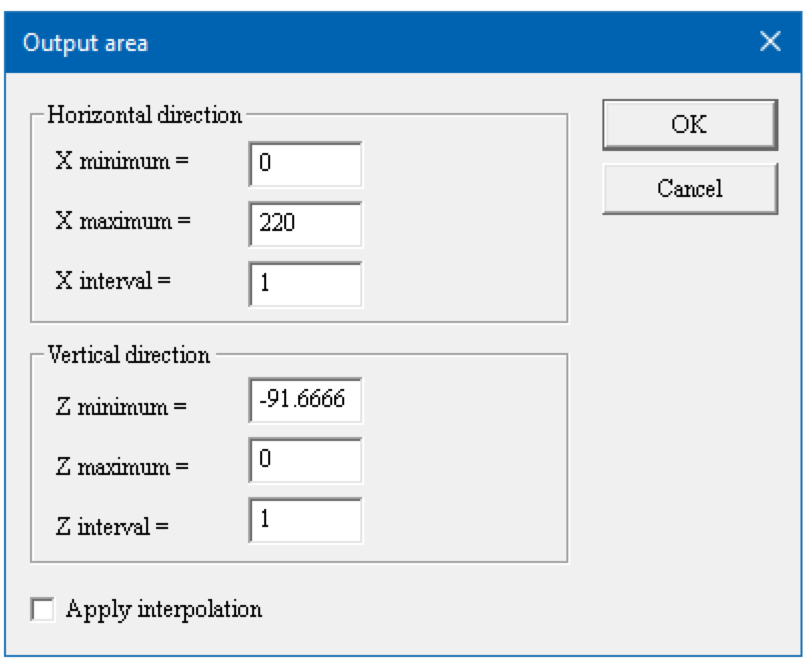
To output the cross-section data in text format for input into other data visualization programs, open the **File** menu and select *Save (x, z, variable) formatted file (.txt)*.



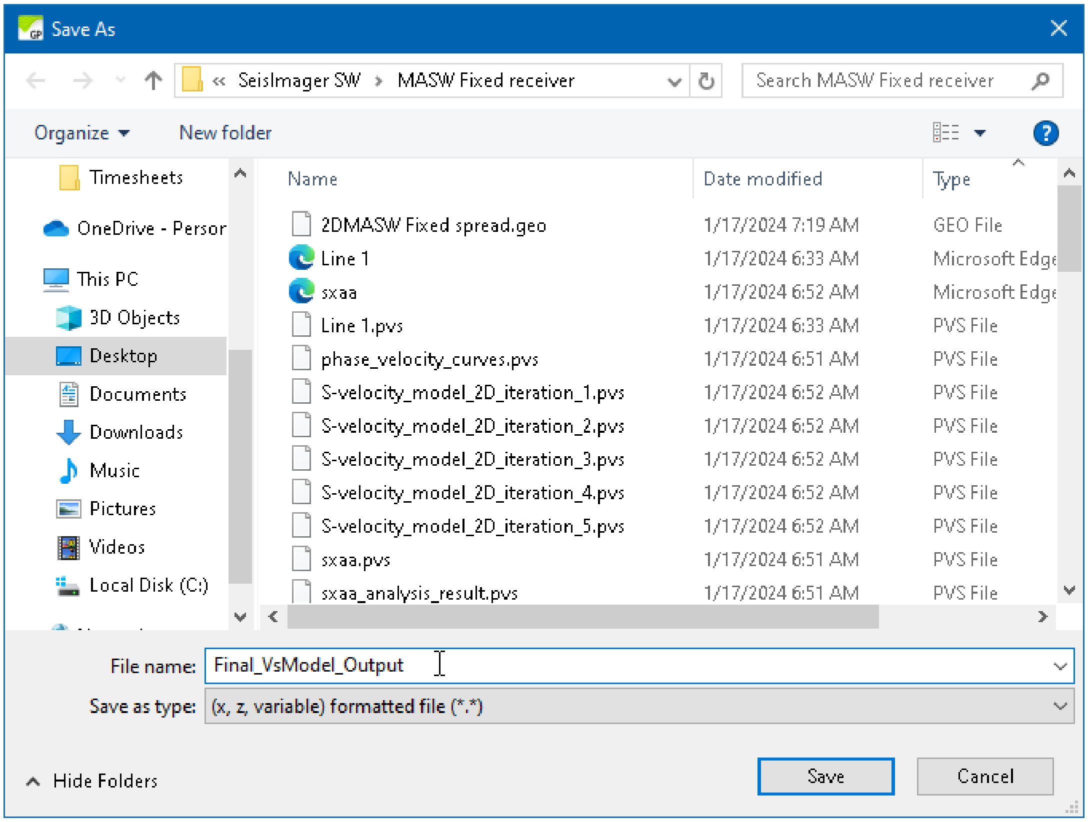
Assign a file name with the extension *.txt* and press *Save*. You will be given the option to save gridded data:



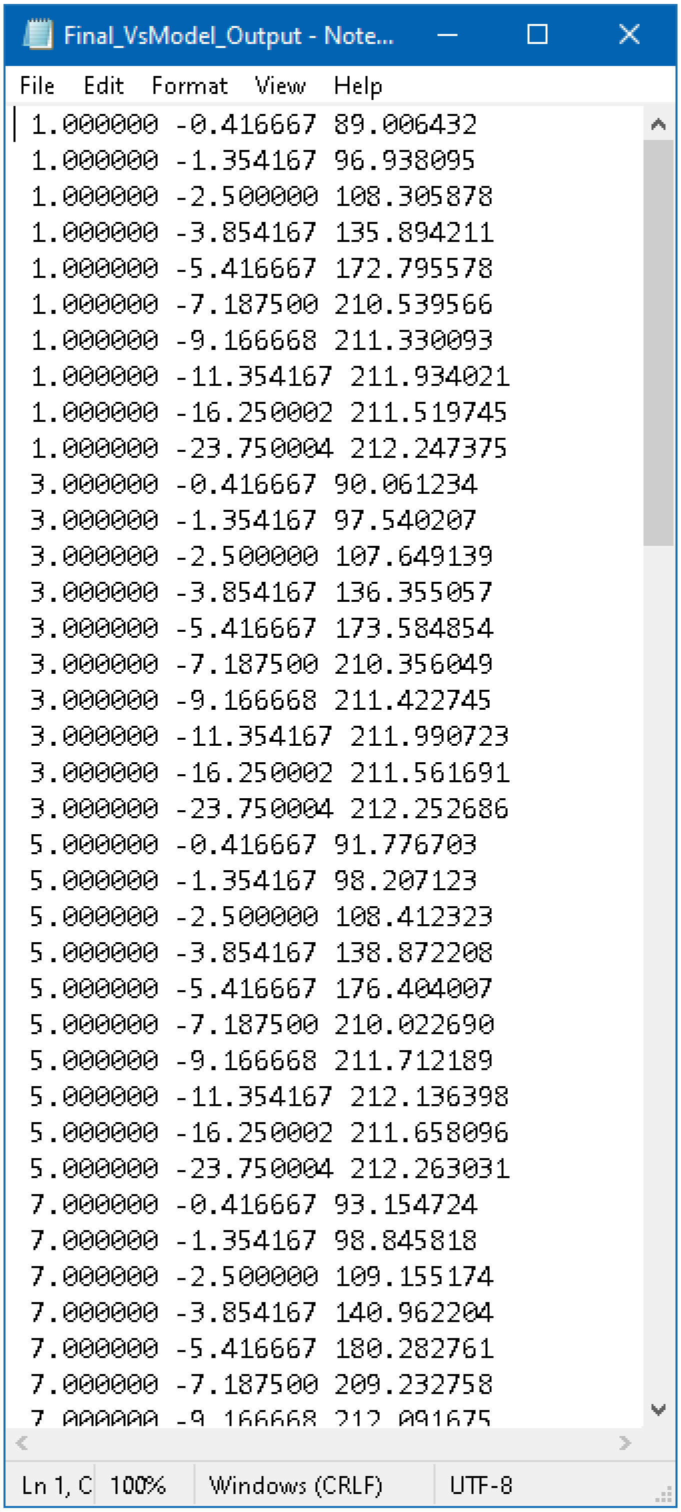
If you choose *Yes*, you will be presented with the following dialog box:



Enter the minima, maxima, and interval and whether you wish to apply interpolation. Press *OK*. The effect of interpolating is to smooth the V_S model. To see the effect, try it both ways.



The file has a space-delimited format with the x-value, z-value, and velocity at that z-value listed in rows.


Final_VsModel_Output - Note...

File Edit Format View Help

```
1.000000 -0.416667 89.006432
1.000000 -1.354167 96.938095
1.000000 -2.500000 108.305878
1.000000 -3.854167 135.894211
1.000000 -5.416667 172.795578
1.000000 -7.187500 210.539566
1.000000 -9.166668 211.330093
1.000000 -11.354167 211.934021
1.000000 -16.250002 211.519745
1.000000 -23.750004 212.247375
3.000000 -0.416667 90.061234
3.000000 -1.354167 97.540207
3.000000 -2.500000 107.649139
3.000000 -3.854167 136.355057
3.000000 -5.416667 173.584854
3.000000 -7.187500 210.356049
3.000000 -9.166668 211.422745
3.000000 -11.354167 211.990723
3.000000 -16.250002 211.561691
3.000000 -23.750004 212.252686
5.000000 -0.416667 91.776703
5.000000 -1.354167 98.207123
5.000000 -2.500000 108.412323
5.000000 -3.854167 138.872208
5.000000 -5.416667 176.404007
5.000000 -7.187500 210.022690
5.000000 -9.166668 211.712189
5.000000 -11.354167 212.136398
5.000000 -16.250002 211.658096
5.000000 -23.750004 212.263031
7.000000 -0.416667 93.154724
7.000000 -1.354167 98.845818
7.000000 -2.500000 109.155174
7.000000 -3.854167 140.962204
7.000000 -5.416667 180.282761
7.000000 -7.187500 209.232758
7.000000 -9.166668 212.091675
```

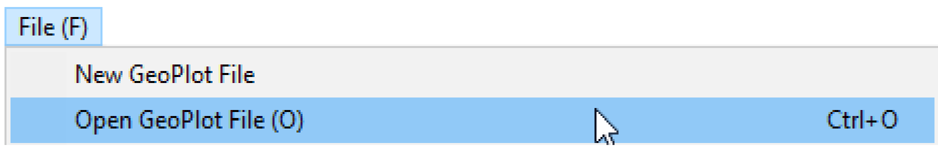
Ln 1, C | 100% | Windows (CRLF) | UTF-8

Some other useful GeoPlot functions include the following:

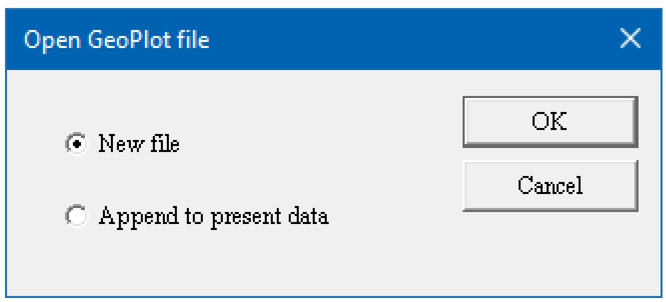
- opening and appending other cross-sections.
- applying a saved contour file.

- displaying the contour interval values.
- inverting and reversing the velocity scale.
- applying settings from one cross-section to others.

More than one cross-section may be displayed at one time: for example, the initial and final models for a given dataset. With one cross-section already open, open the **File** menu and select *Open GeoPlot file* to open and append another cross-section to the display.



Select *Append to present data* and press *OK*.



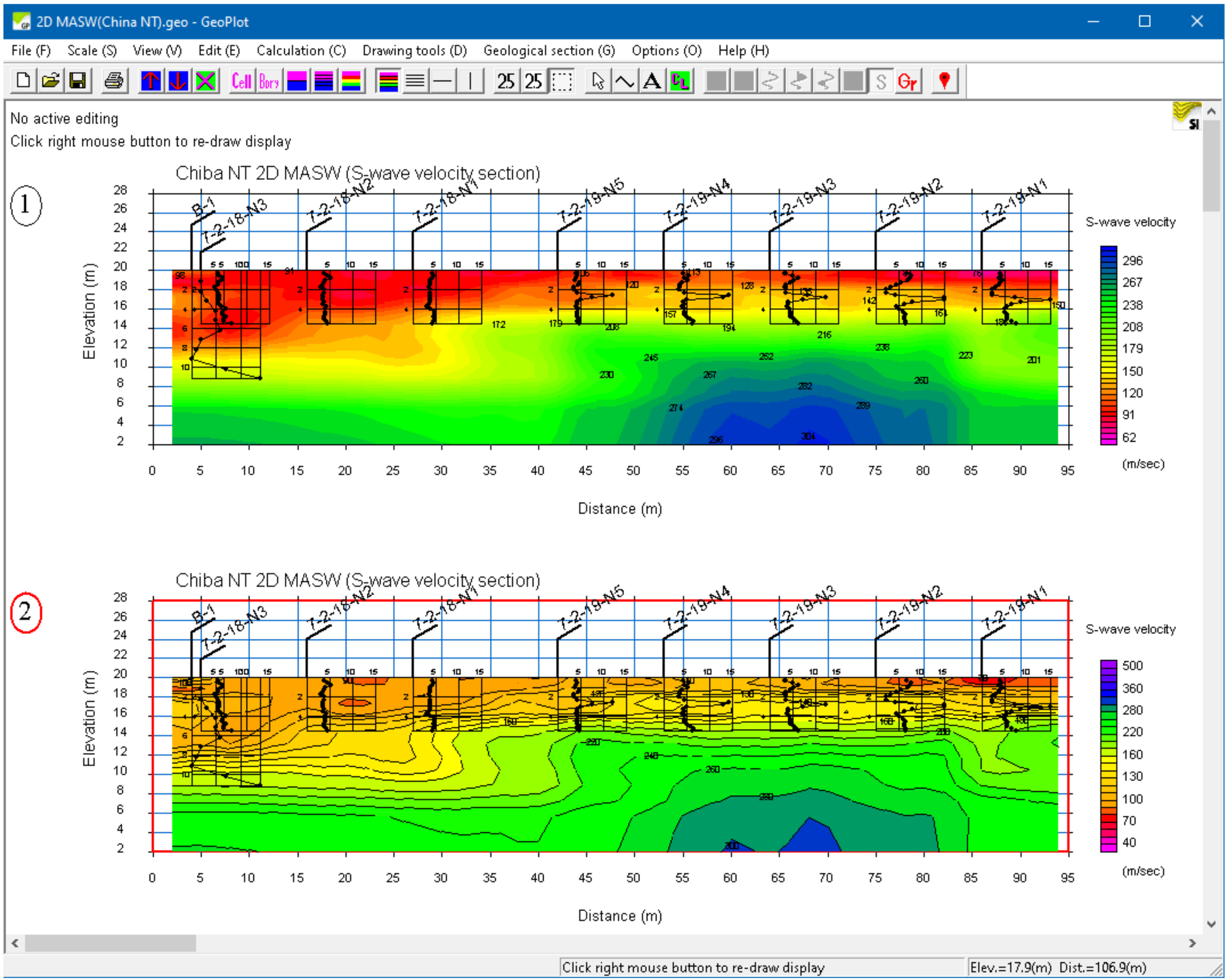
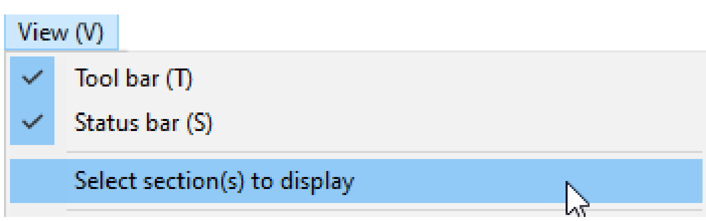
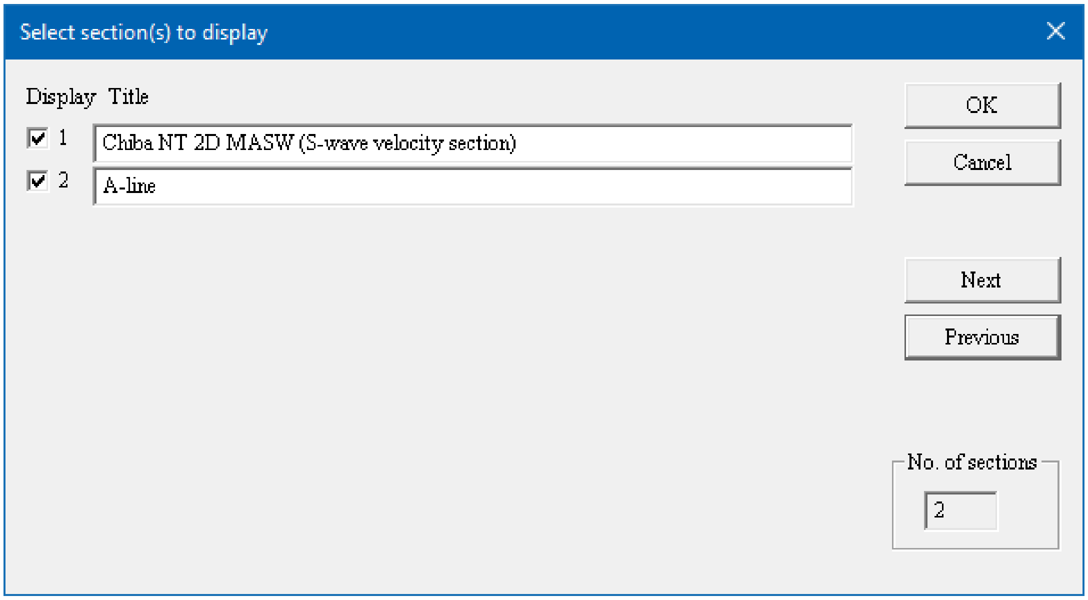


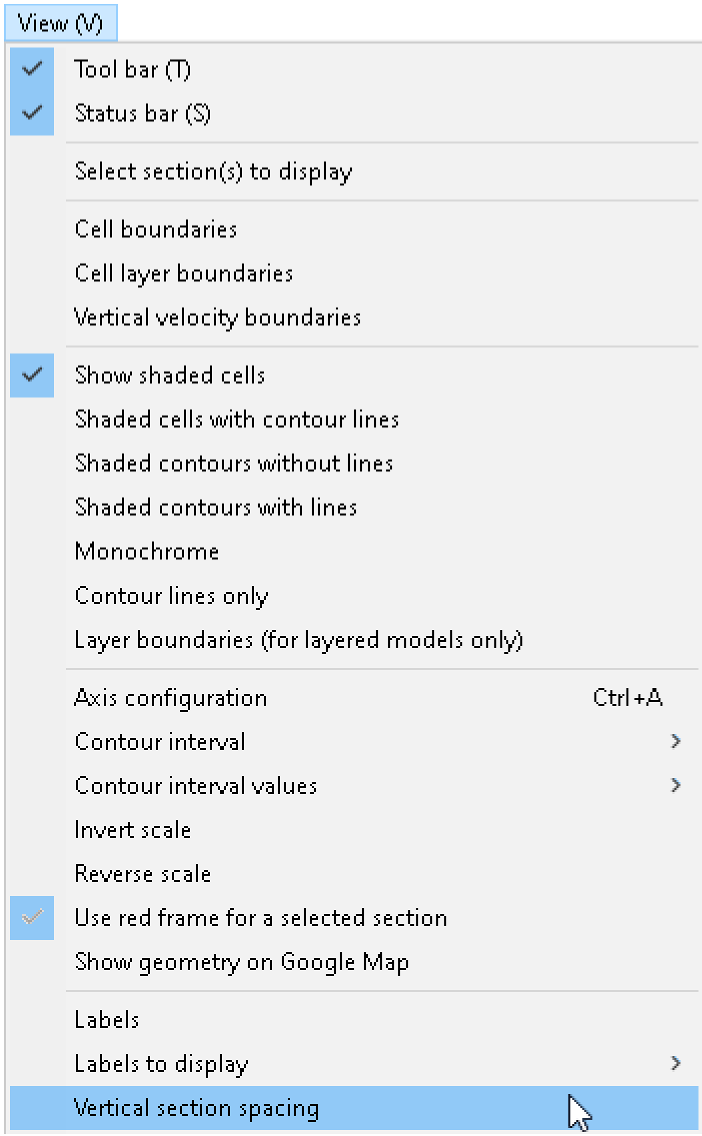
Figure 67: Appending a velocity cross-section to display more than one at once. The circled number and red outline indicate which section is active now.

To select between cross-sections, click on the cross-section number. When selected, the circle around the cross-section number and the cross-section outline turns red. When there is more than one cross-section displayed, open the **View** menu and choose *Select section(s) to display* should you wish to uncheck a cross-section to remove it from the display.

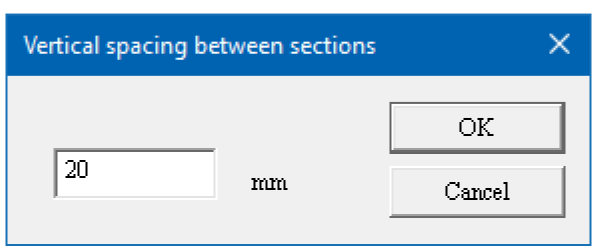




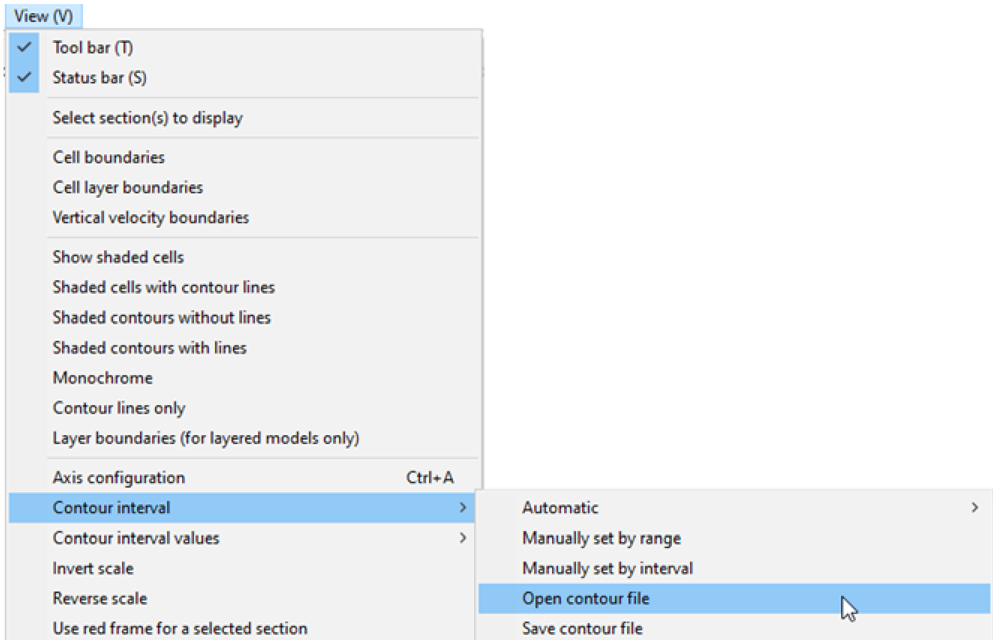
To change the vertical separation between the cross-sections, Open the **View** menu and select *Vertical section spacing*.



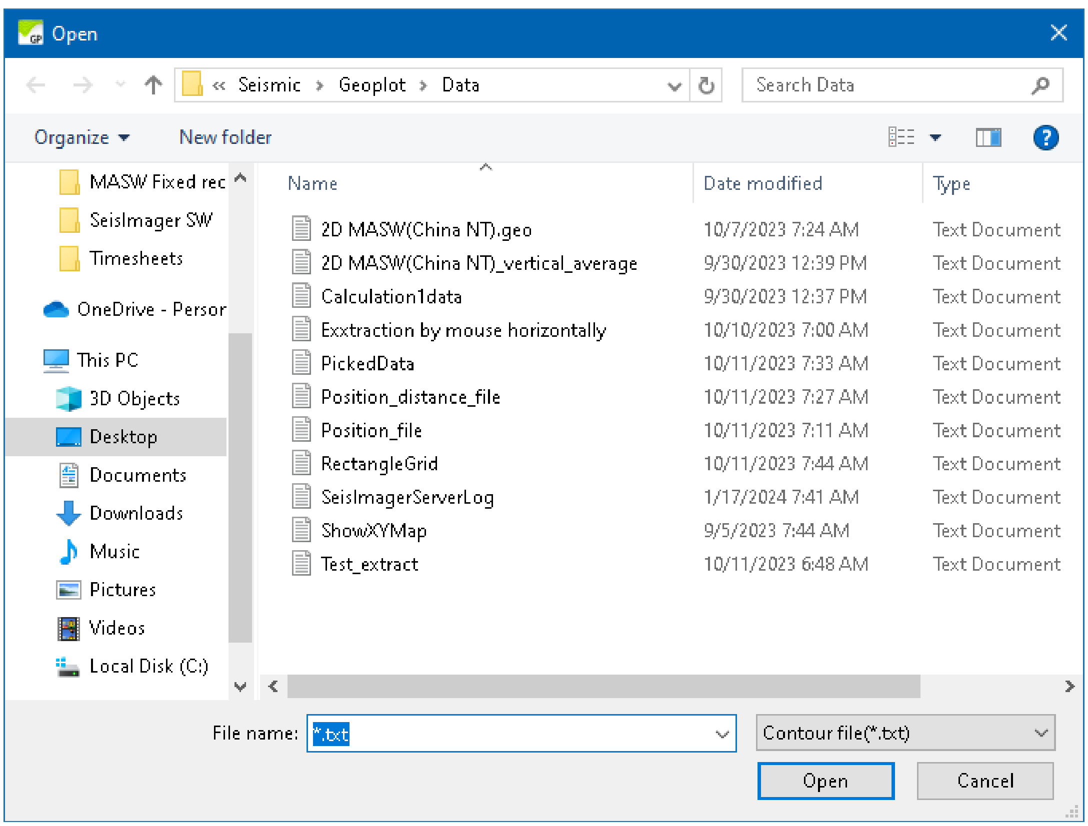
Enter the desired spacing and press *OK*.



To apply a saved custom contour file to another cross-section, open the **View** menu and select *Contour interval* | *Open contour file*.



Highlight the contour file and press *Open*.



To overlay the values of the contour intervals, open the **View** menu and select *Contour interval values | Show values*.

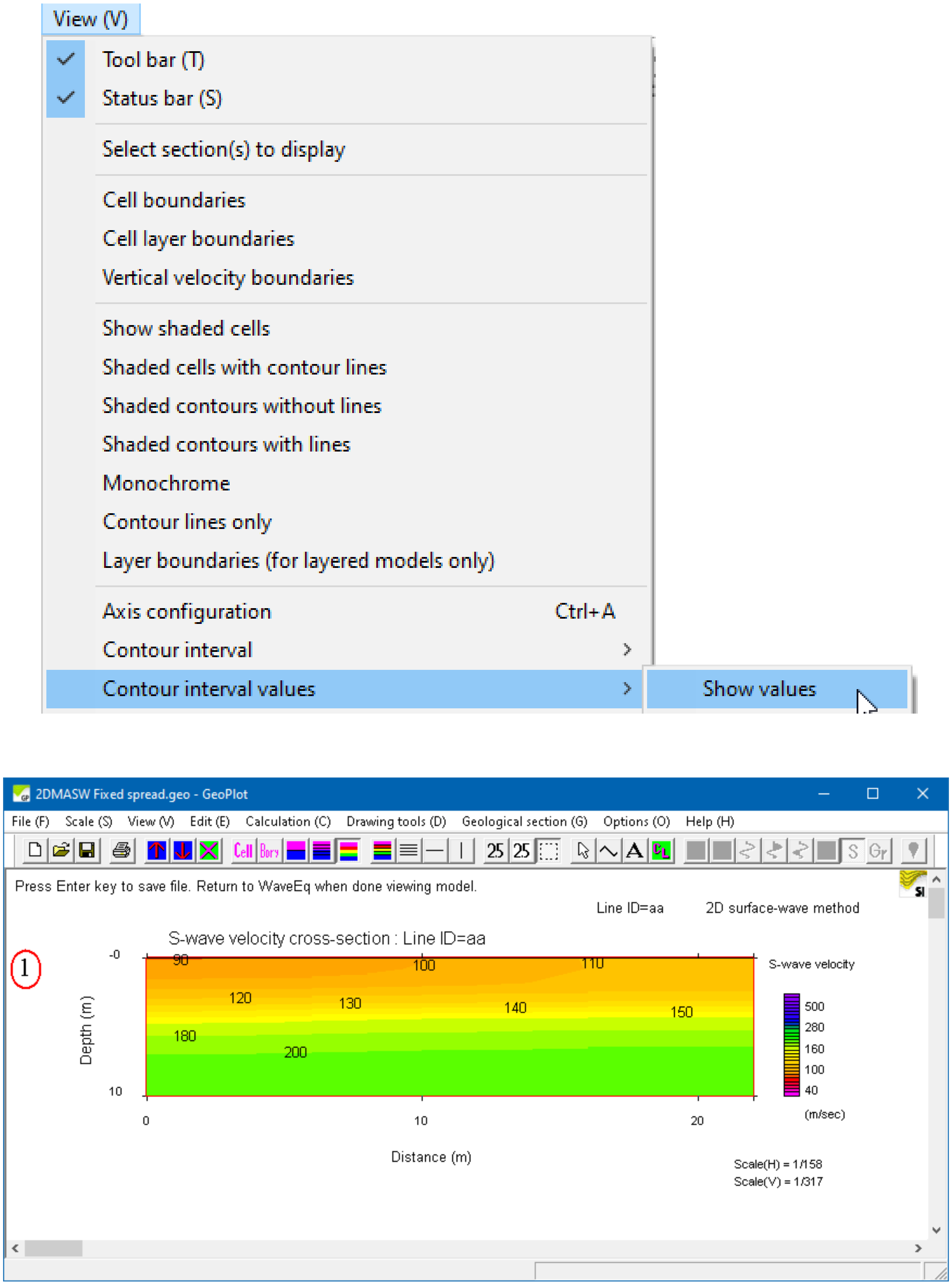
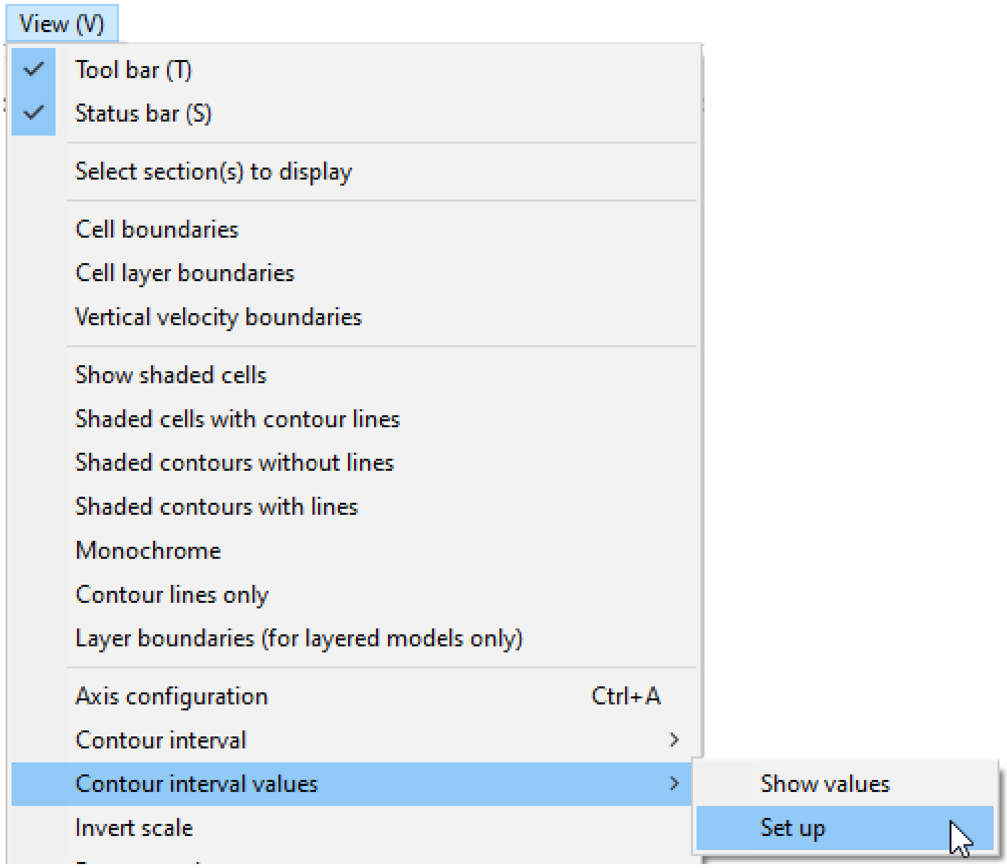
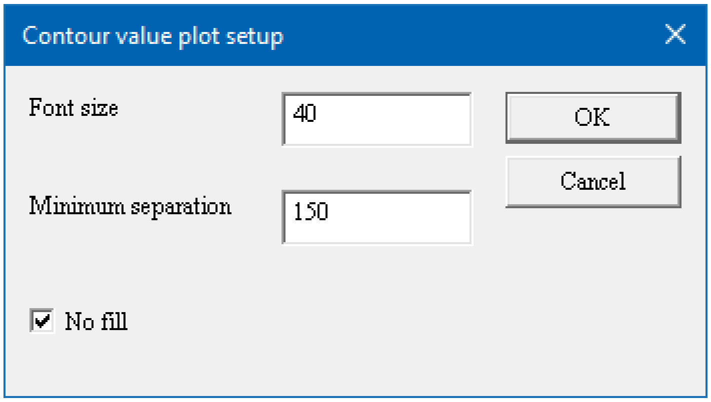


Figure 68: Displaying contour interval labels.

If the font size of the contour interval values needs to be increased, open the **View** menu and select *Contour interval values* | *Set up*.



Increase or decrease the *Font size* as desired. The default *Minimum separation* at which the values appear suits most displays. If *No fill* is checked (the default), there will be no background behind the values.



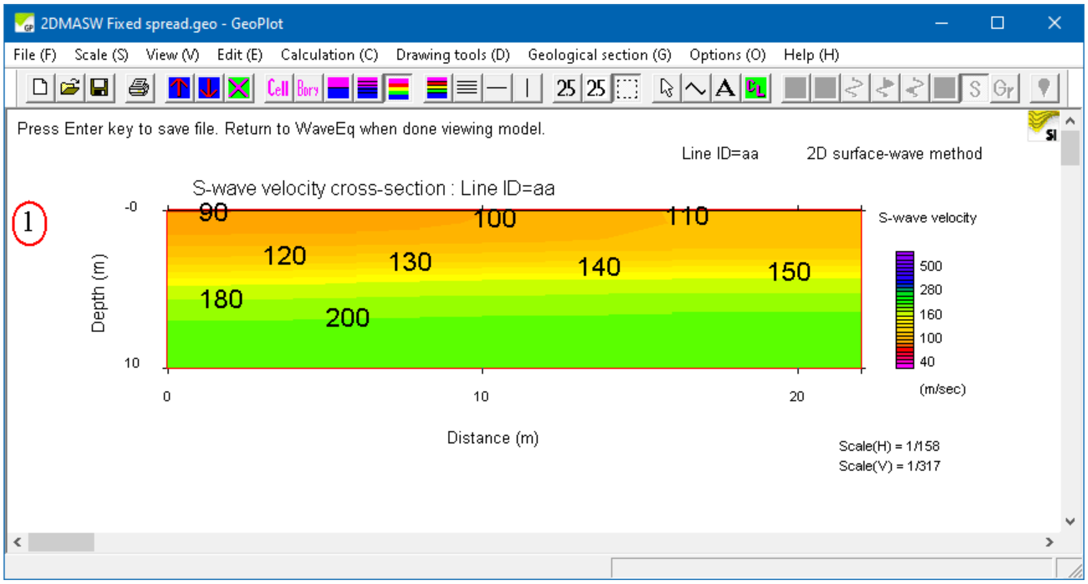


Figure 69: Modifying contour interval labels to make them more visible by increasing font size.

Uncheck *No fill* to turn on a white background:

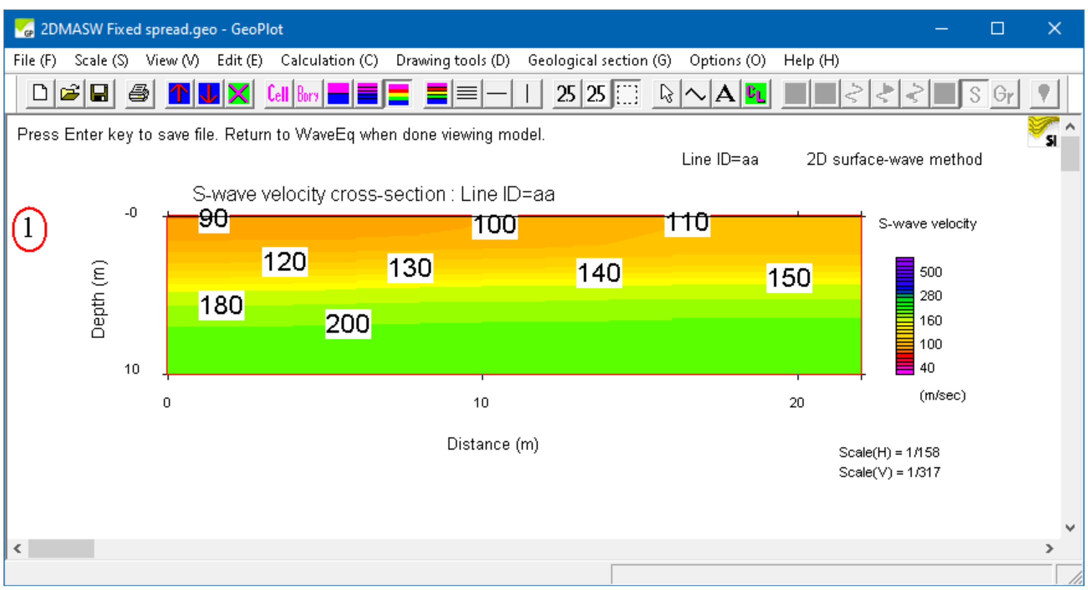
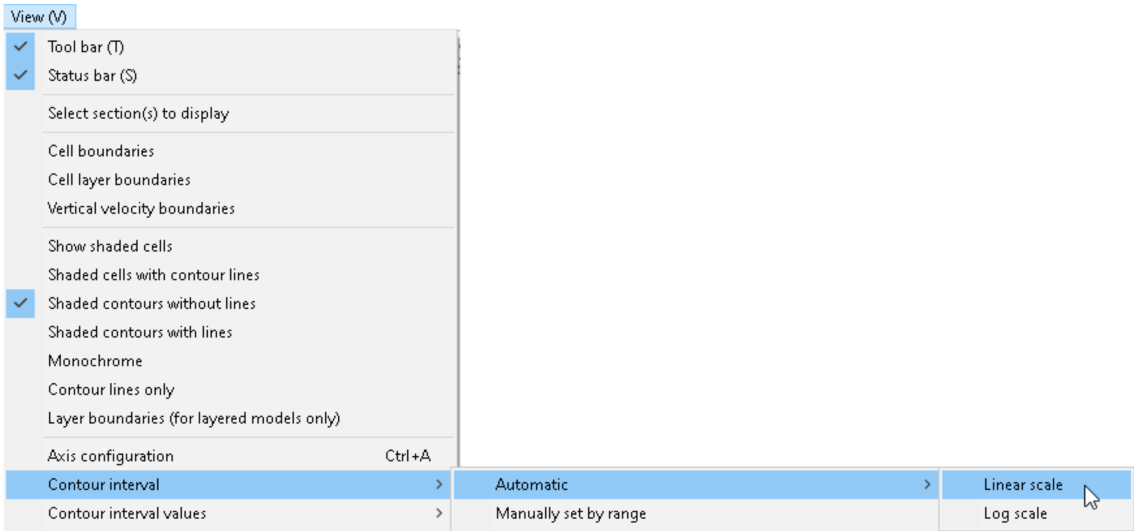


Figure 70: Modifying contour interval labels to make them more visible by adding a white background.

The colors and contours used in the above section are “standard” surface wave colors. These can be changed if you like. A quick way to do so is to open the **View** menu and select *Contour interval | Automatic | Linear scale*.



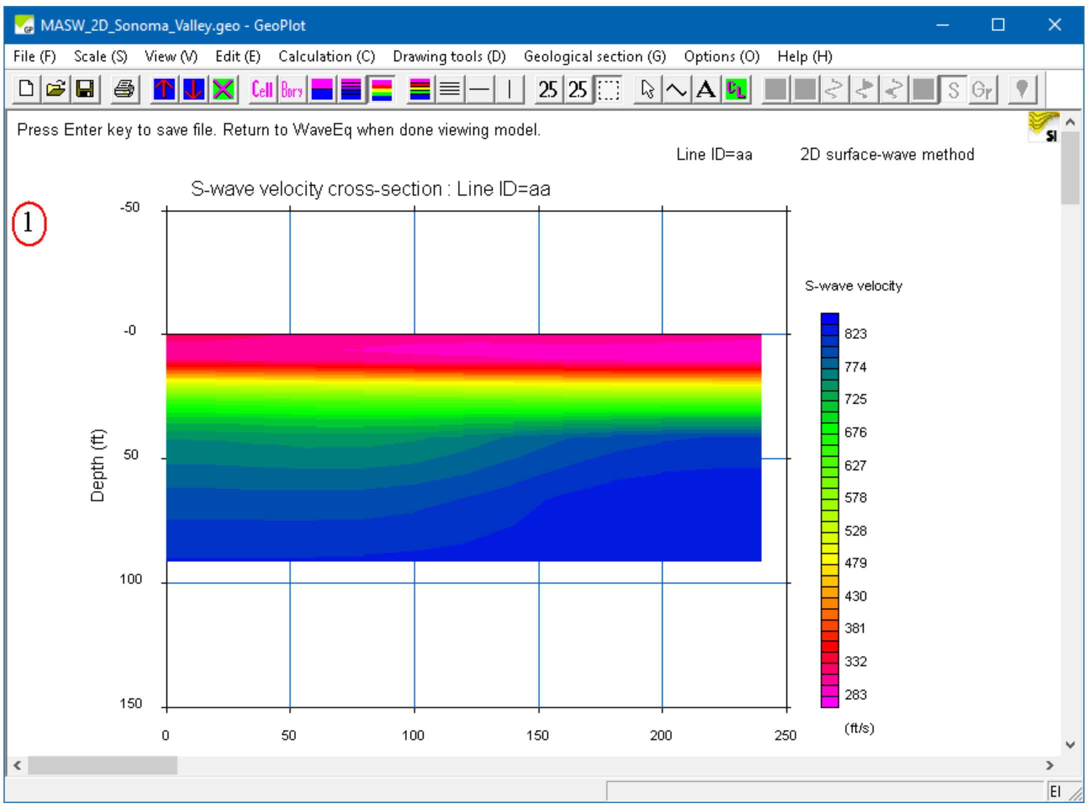
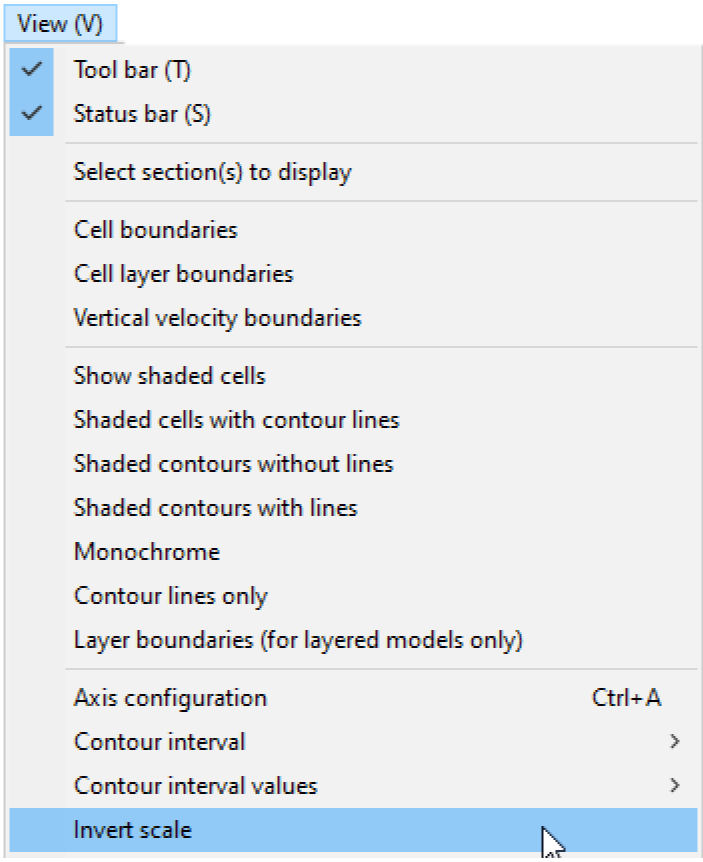


Figure 71: Cross-section displayed with non-standard colors.

To invert the color gradient of the scale, open the **View** menu and select *Invert scale*.



Note: *This function does not work on standard surface wave contours and colors (Figure 69 and Figure 70).*

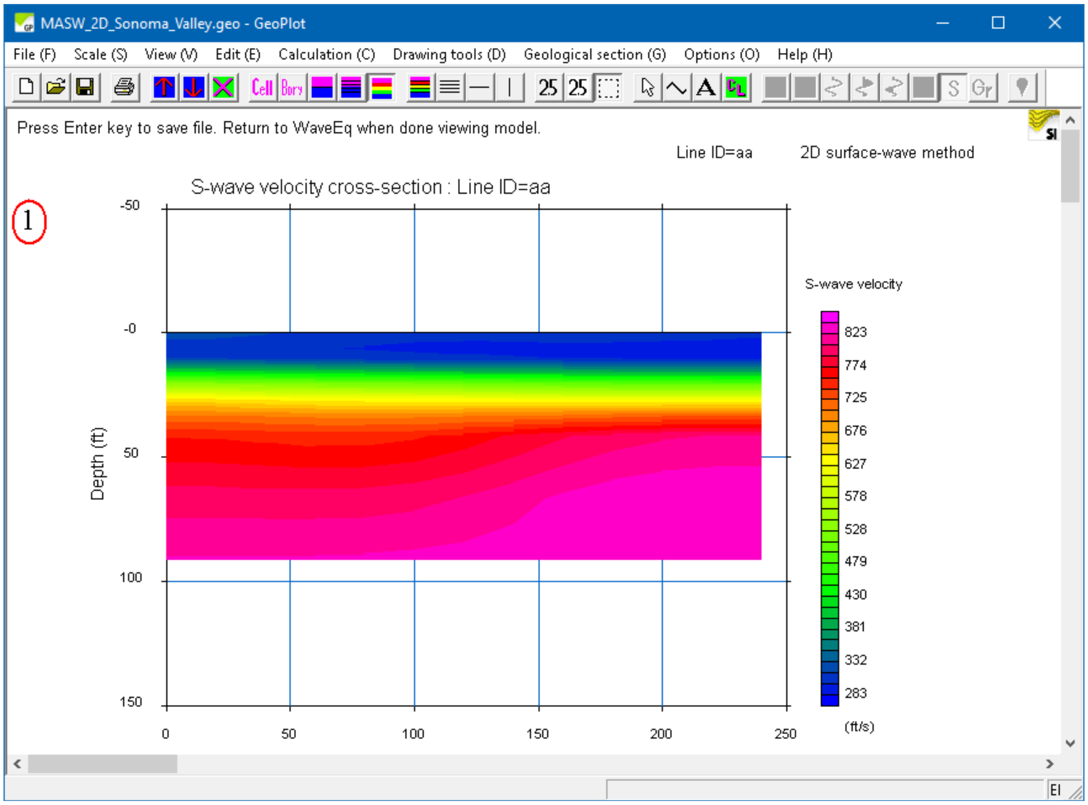
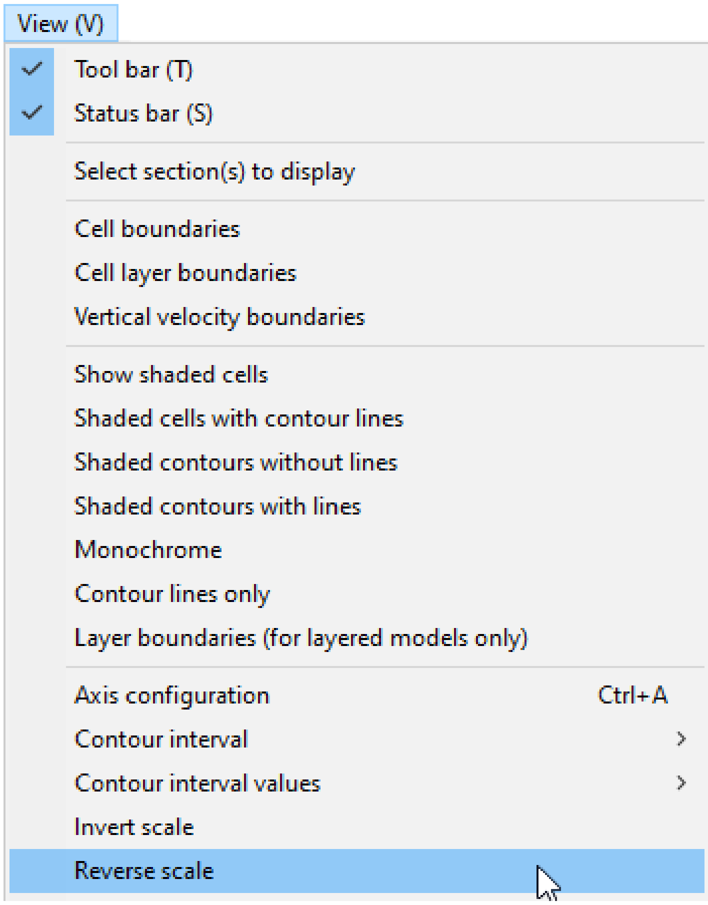


Figure 72: Inverting the velocity color scale (compare to Figure 71: Cross-section displayed with non-standard colors.).

To flip the direction of the scale so that it increases downwards, open the **View** menu, and select *Reverse scale*.


View (V)
Tool bar (T)
Status bar (S)
Select section(s) to display
Cell boundaries
Cell layer boundaries
Vertical velocity boundaries
Show shaded cells
Shaded cells with contour lines
Shaded contours without lines
Shaded contours with lines
Monochrome
Contour lines only
Layer boundaries (for layered models only)
Axis configuration
Ctrl+A
Contour interval
Contour interval values
Invert scale
Reverse scale

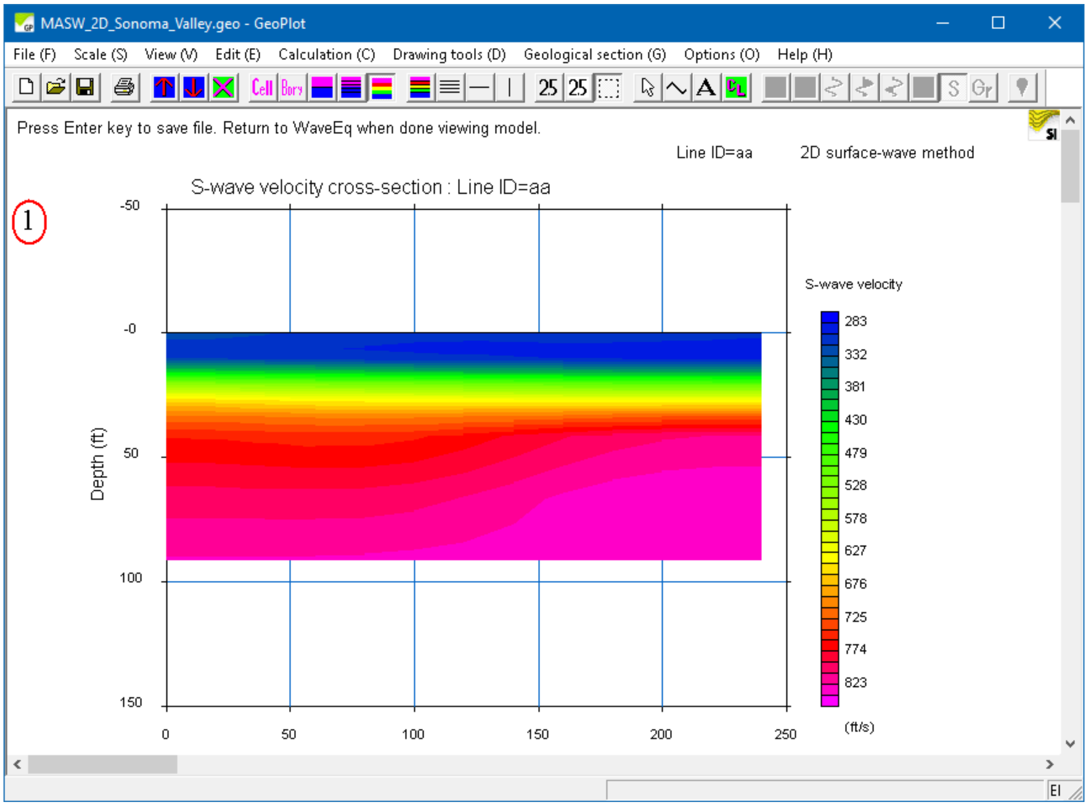
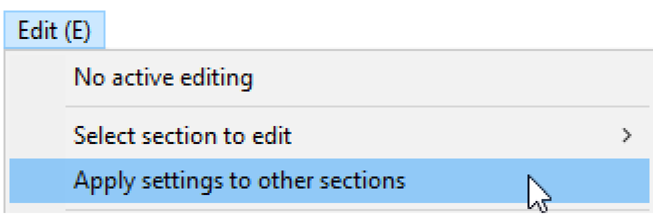
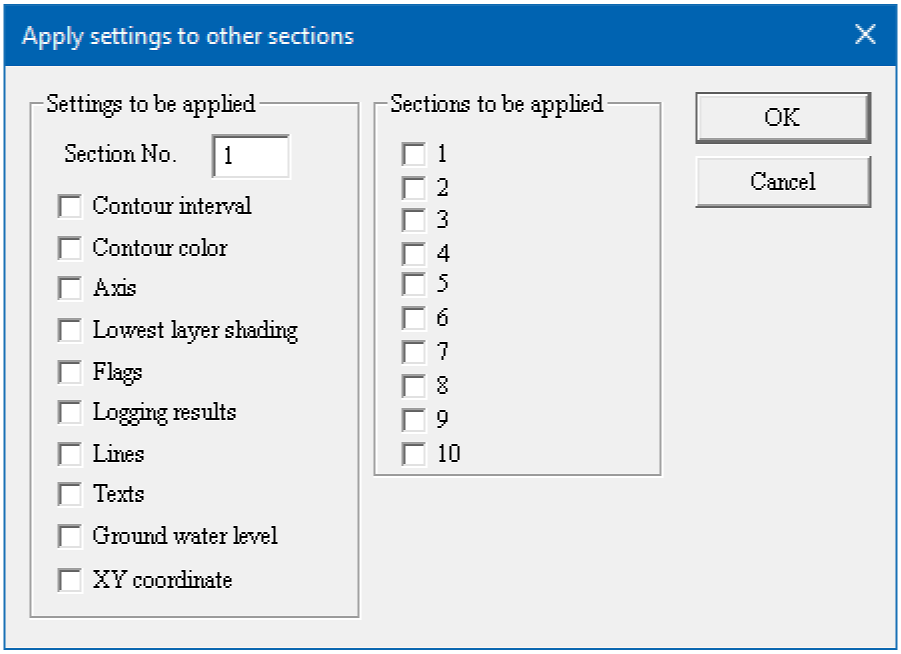


Figure 73: Reversing the polarity of the velocity scale bar (compare to Figure 72).

To apply the settings for a given cross-section to the current display, open the **Edit** menu and select *Apply settings to other sections*.



Check the *Settings to be applied* from the active *Section No.* to indicate which attributes should be applied to other cross-sections checked under *Sections to be applied*.


Apply settings to other sections
Settings to be applied
Section No.
1
Contour interval
Contour color
Axis
Lowest layer shading
Flags
Logging results
Lines
Texts
Ground water level
XY coordinate
Sections to be applied
1
2
3
4
5
6
7
8
9
10
OK
Cancel

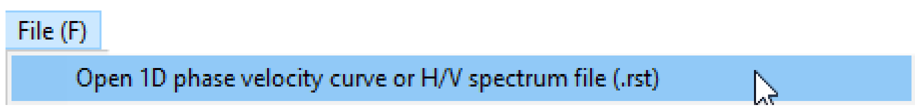
4.2 Combining Active and Passive Source Results

Typically, MASW datasets will have higher frequency content and MAM datasets will have lower frequency content. Once the active- and passive source dispersion curves are picked for a given site, it is simple to combine the curves to obtain the highest resolution over the entire sampled depth range. This section assumes that you have already worked with the wizard and are familiar with the processing flow.

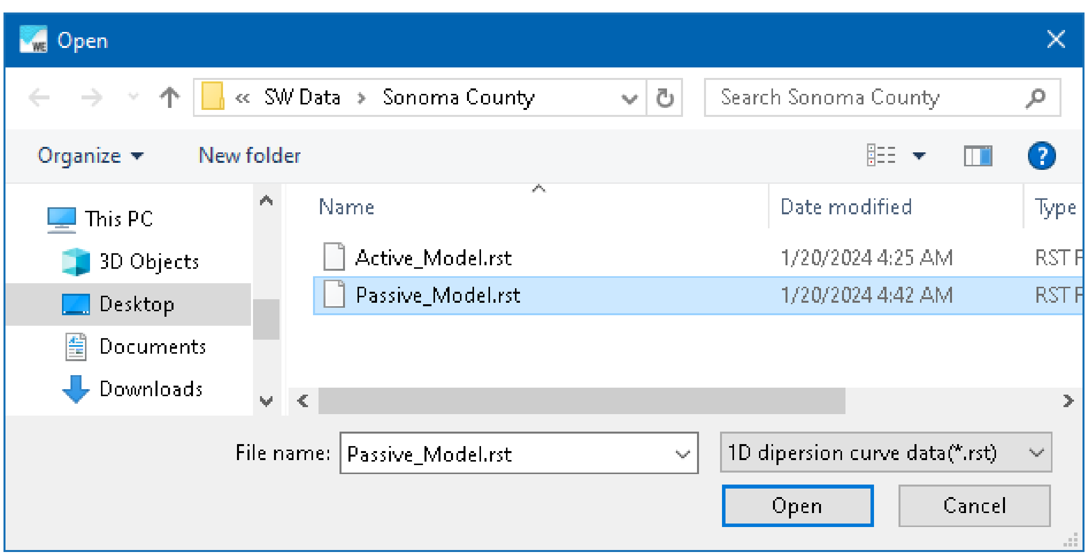
4.2.1 Combining 1D MASW and MAM Results

Double-click on the **WaveEq** icon:

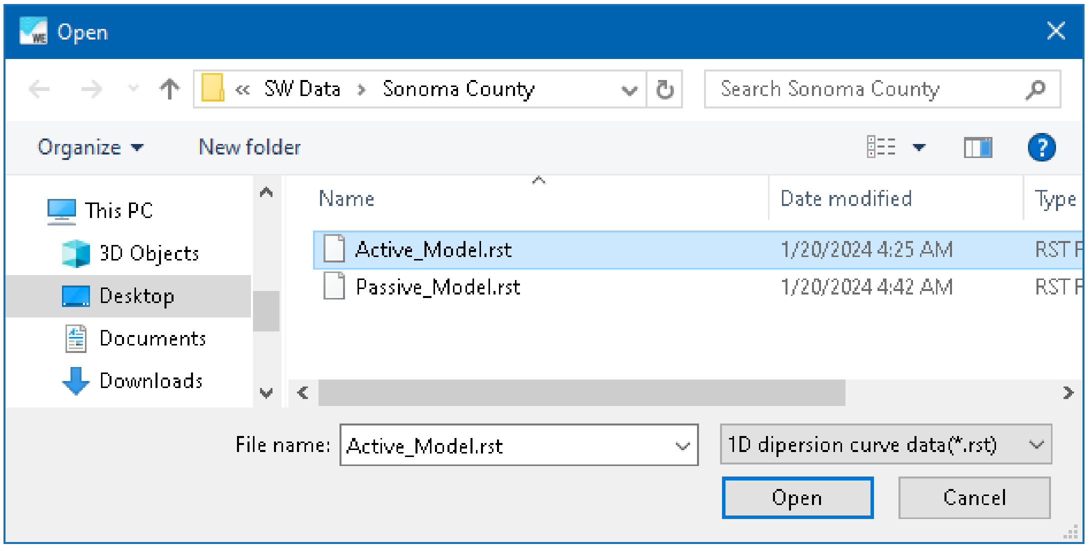
Open the dispersion curve result file for either the 1D MASW active- or MAM passive source dataset by opening the **File** menu and selecting *Open 1D phase velocity curve or H/V spectrum file (.rst)*.



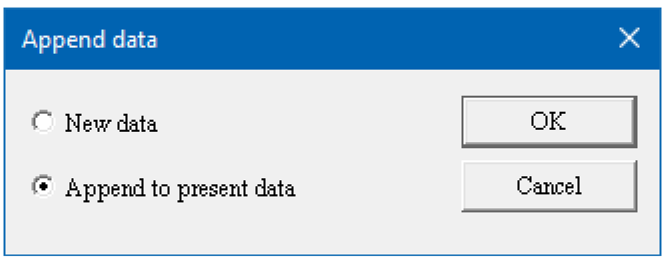
For this example, the passive source result file is opened first. In general, it is best to input raw dispersion curves so that any smoothing is applied to the composite curve. Highlight the file and press *Open*.



Use the same **File** menu function to open the result file for the 1D MASW dataset.



To combine the 1D MASW dispersion curve with the MAM curve, select *Append to present data*. Press *OK* when done.



If you have more dispersion curves to append, say from additional active source shots for the same spread, repeat these steps.

The dispersion curves will typically have some overlap. If the curves are not aligned, double-check the picks. Usually, the problem lies in noisy or spurious picks on the high frequency end of the passive source dispersion curve and/or the low frequency end of the active source dispersion curve.

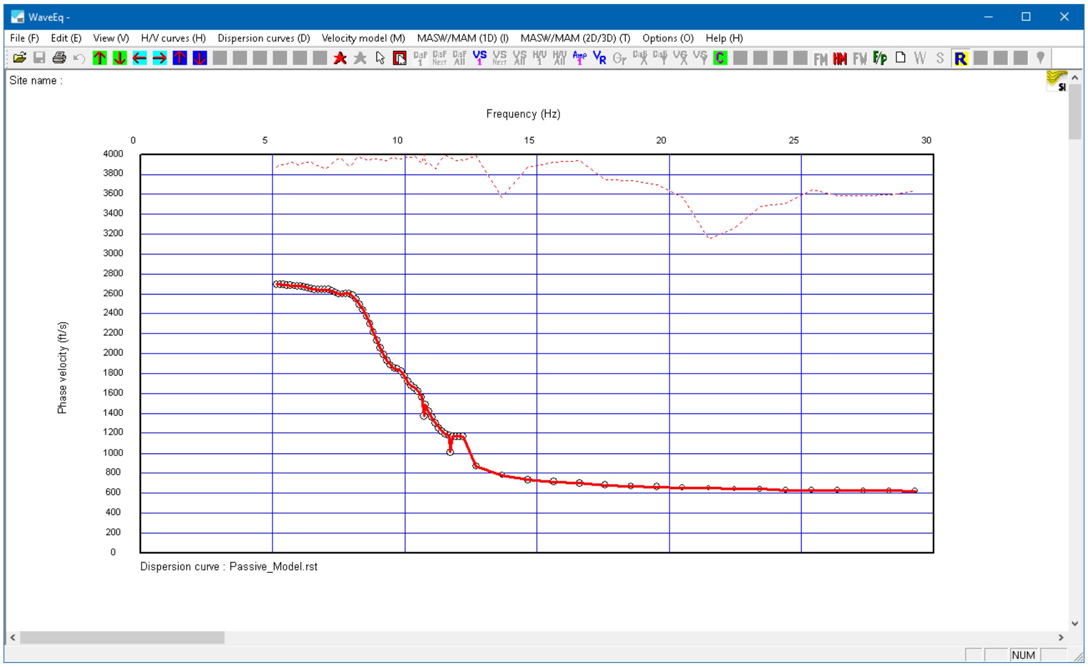
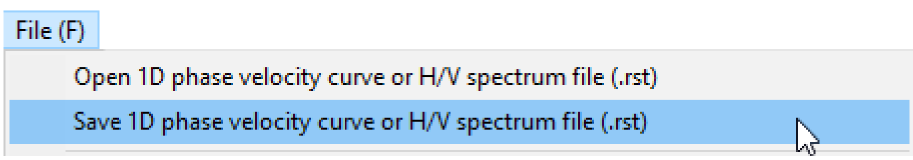
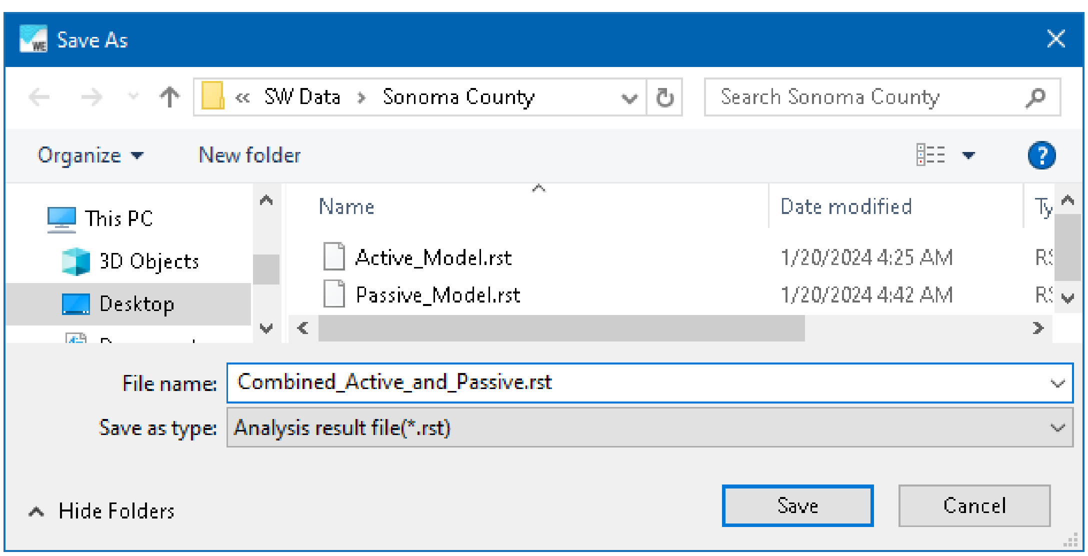


Figure 74: Combined 1D MASW and MAM dispersion curve.

Open the **File** menu and select *Save 1D phase velocity curve or H/V spectrum file (.rst)* to save the combined results as a new file.



Assign a file name with the extension *.rst* and press *Save*.



Edit the dispersion curve as needed and save the edited results as a new file if desired.

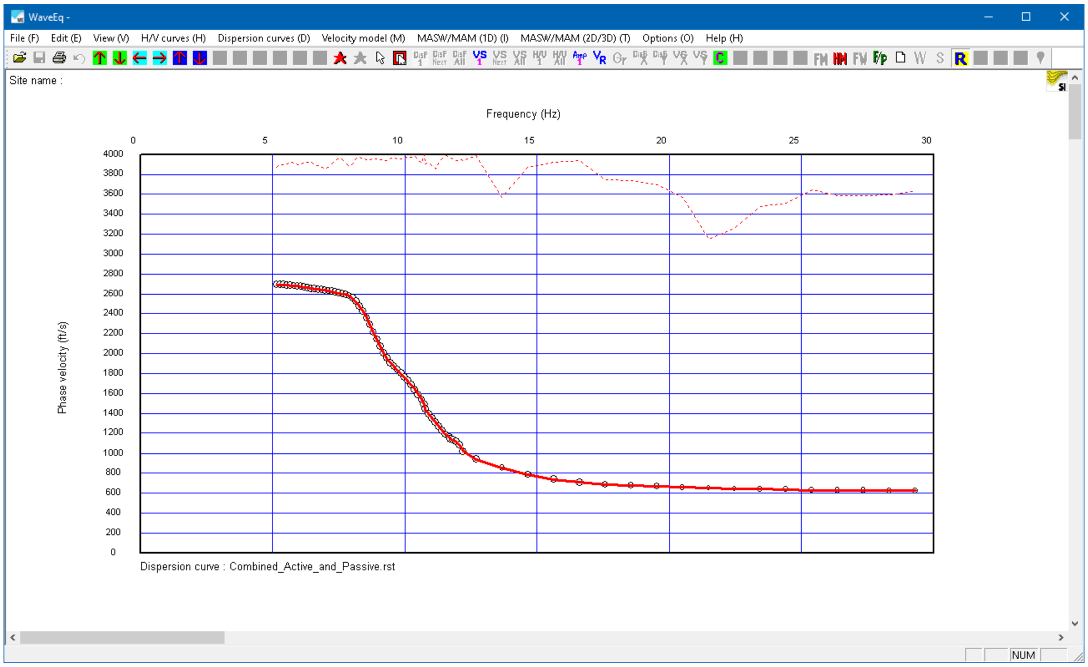
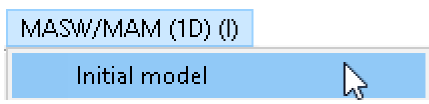
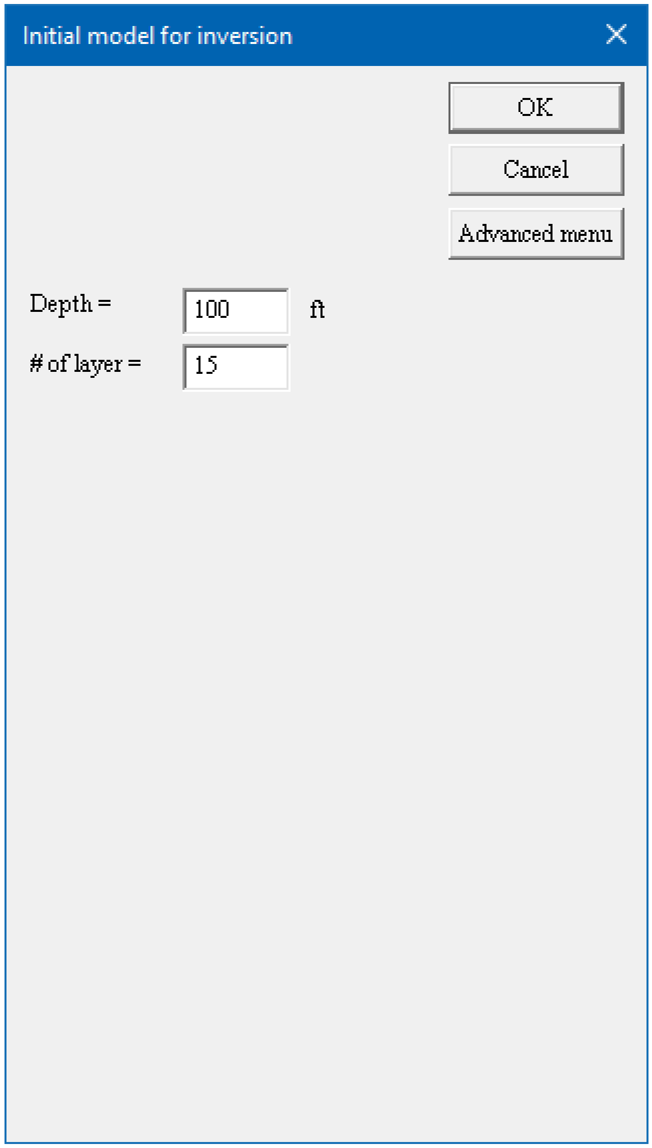


Figure 75: Edited combined dispersion curve.

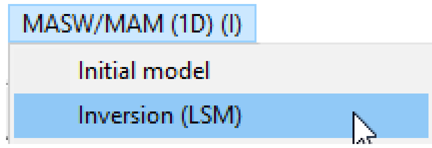
Generate an initial model by opening the **MASW (1D)** menu and selecting *Initial model*.



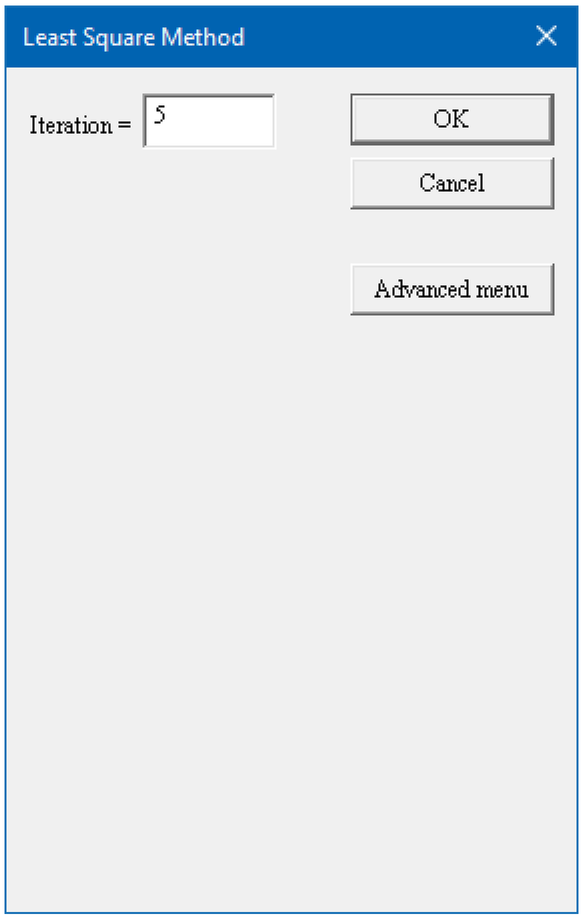
Set the maximum depth for the initial model.


Initial model for inversion
OK
Cancel
Advanced menu
Depth =
100
ft
# of layer =
15

Run the inversion by opening the **MASW (1D)** menu and selecting *Inversion (LSM)*.



Accept the default value or increase as desired for *Iteration*.



Once the inversion is complete, the final V_S curve is displayed.

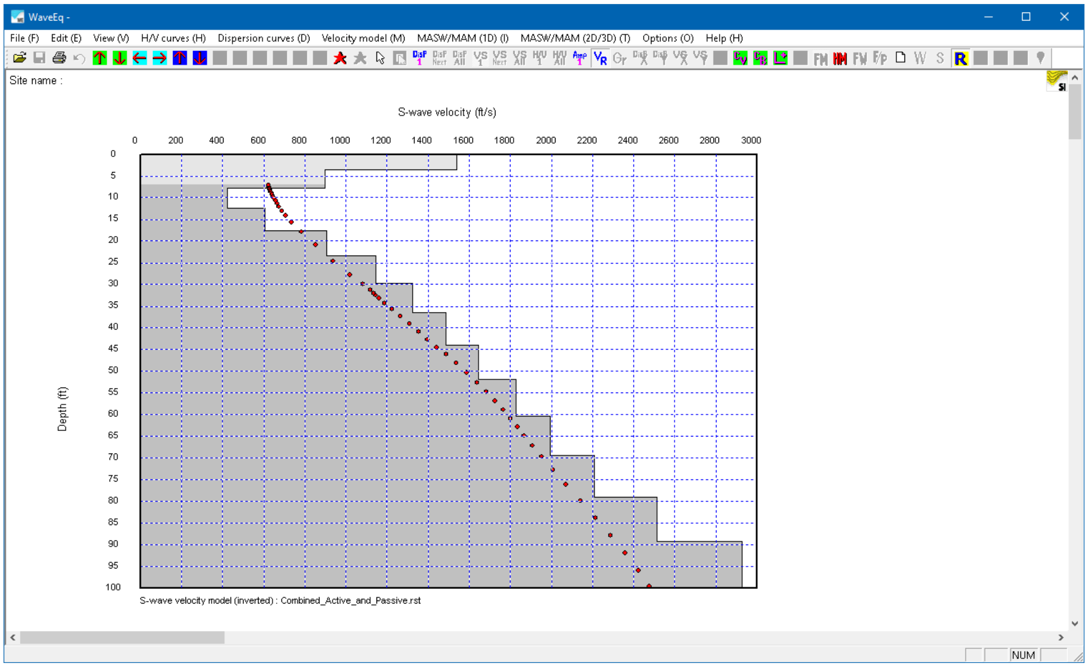


Figure 76: Final V_S curve.

In the dispersion curve view, compare the observed and calculated dispersion curves.

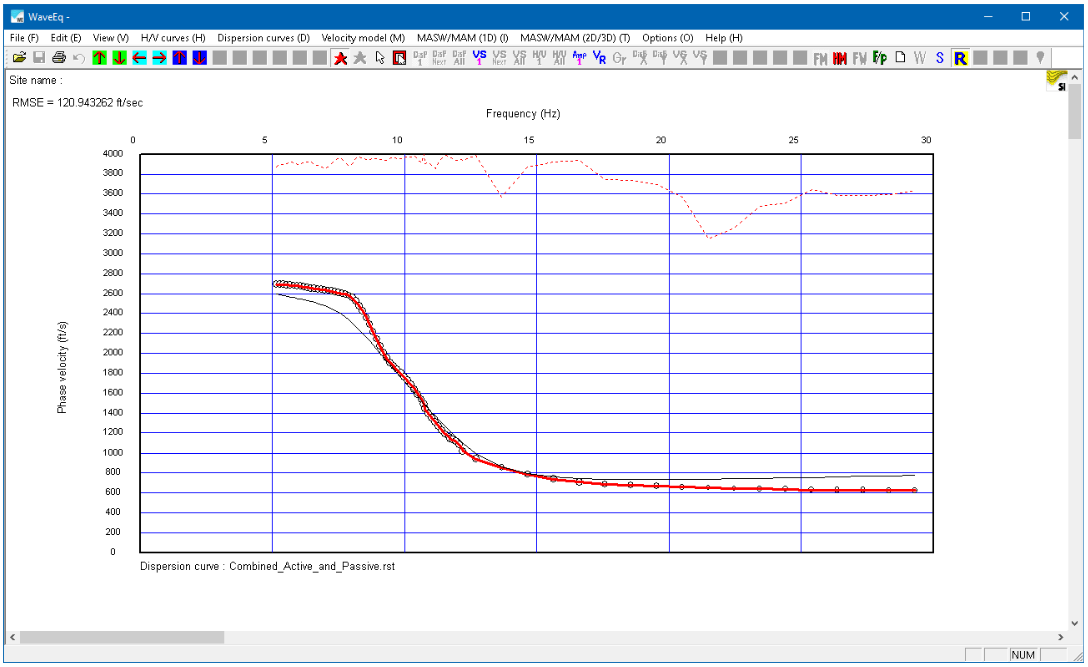


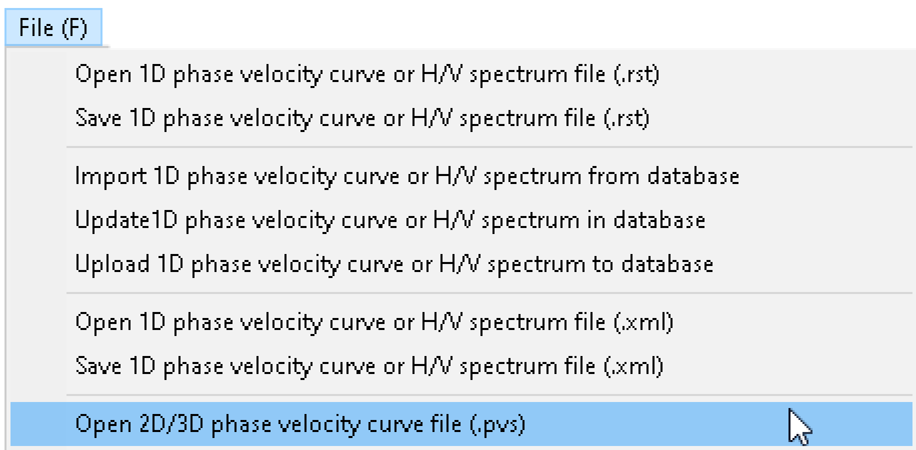
Figure 77: Observed vs. calculated dispersion curves.

Save the final result by opening the **File** menu and selecting *Save 1D phase velocity curve file (.rst)*.

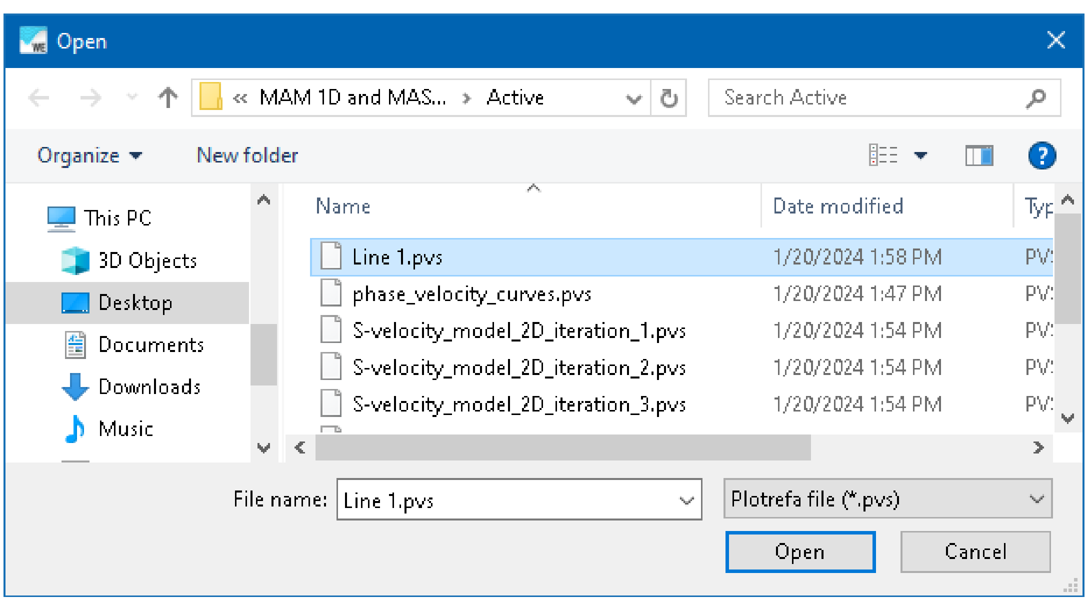
4.2.2 COMBINING 2D MASW AND MAM RESULTS

Double-click on the **WaveEq** icon.

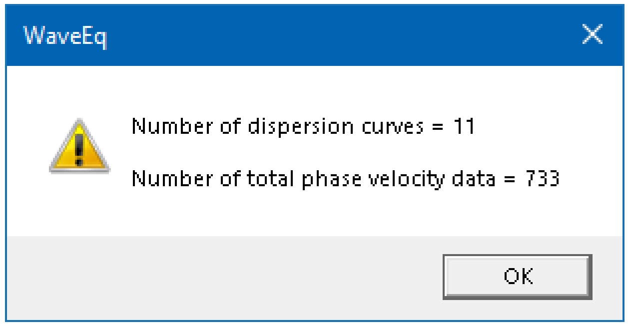
Open the dispersion curve result file for a 2D MASW dataset by opening the **File** menu and selecting *Open 2D/3D phase velocity curve file (.pvs)*.



In general, it is best to input raw dispersion curves so that any smoothing is applied to composite curves. Highlight the file and press *Open*.



The number of imported dispersion curves is shown. Press *OK*.



The first in the group of dispersion curves is displayed.

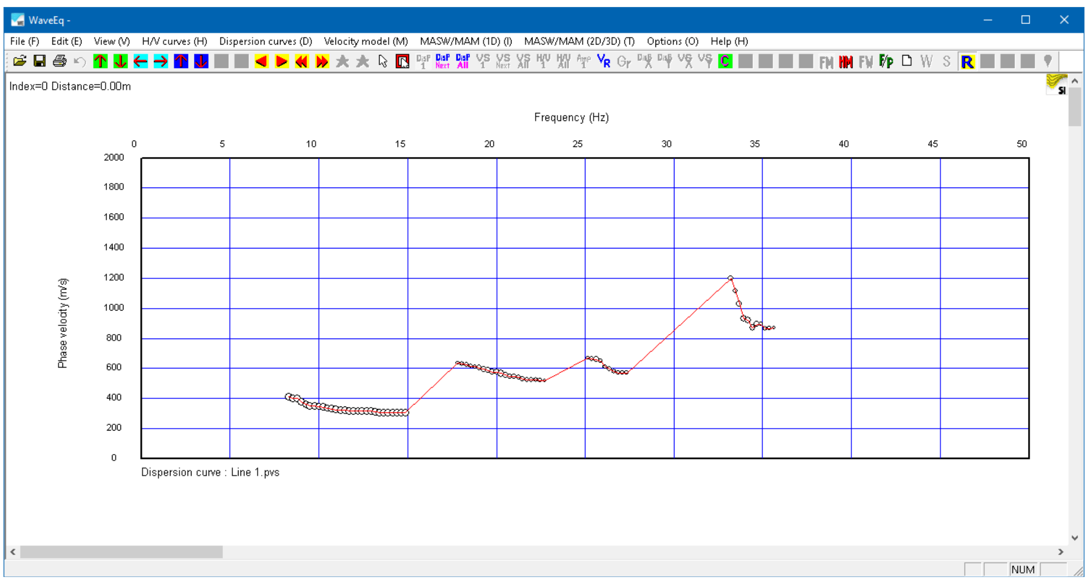
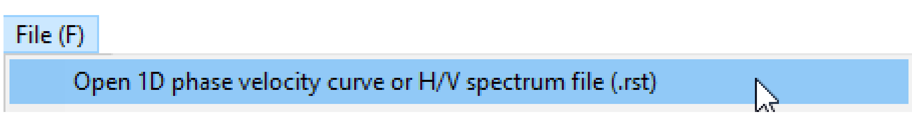


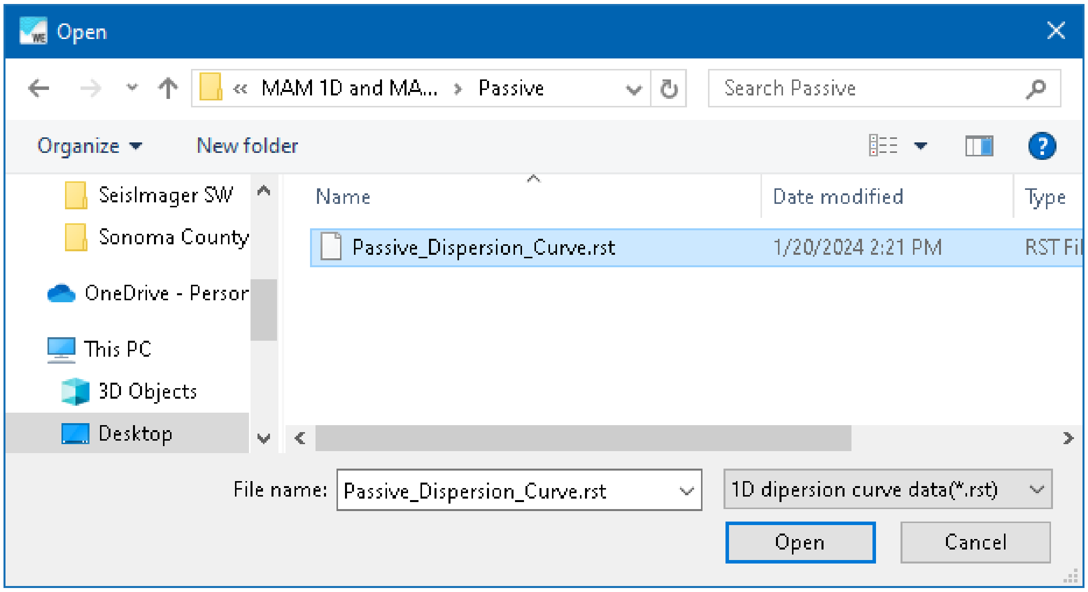
Figure 78: One of a group of raw, unedited 2D MASW dispersion curves. Note higher modes.

Edit the dispersion curves as needed.

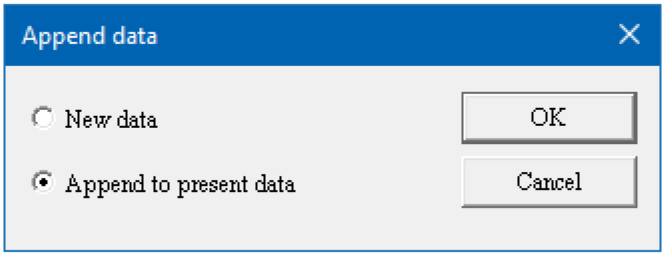
Open the dispersion curve from the MAM dataset by opening the **File** menu and selecting *Open 1D phase velocity curve or H/V spectrum file (.rst)*.



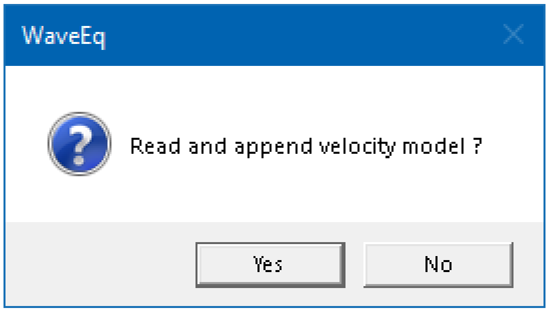
Highlight the file and press *Open*.



Select *Append to present data* to combine the MAM dispersion curve with the 2D MASW dispersion curves. Press *OK* when done.



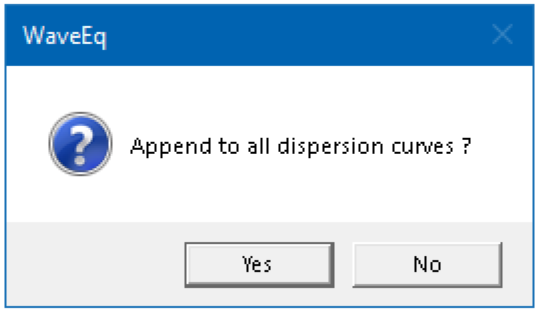
If a velocity model is detected, it is recommended that you append it as well:



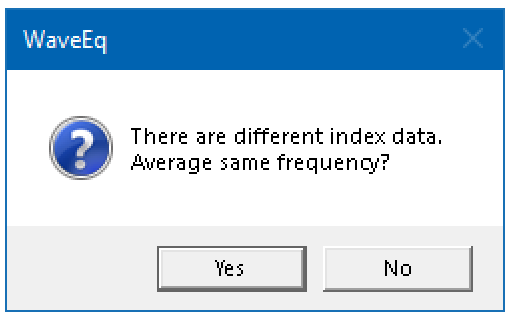
Next, a prompt asks whether the MAM dispersion curve should be appended to only the currently displayed 2D MASW dispersion curve or to all the 2D MASW curves. The MAM dispersion curve should be appended to each MASW curve. If it is only appended to one MASW curve, it will create a velocity anomaly at depths with no adjacent data. Note that appending the

MAM dispersion curve to all MASW curves effectively extrapolates the MAM dispersion curve across the 2D MASW survey line. Considering that the horizontal resolution of MAM data is approximately equal to the sampled depth, extrapolating MAM results across a 75 or 100 m long 2D MASW survey line is reasonable. However, as this is an extrapolation, it should be done with care and is not recommended where large variations in velocity are thought to exist.

Press *Yes* to append the MAM dispersion curve to each of the 2D MASW dispersion curves.



The first in the group of composite dispersion curves is displayed. The MAM and MASW dispersion curves will typically have some overlap. If so, you may see the following message:



If the curves are not well-aligned, double-check the picks. Usually, the problem lies in noisy or spurious picks on the high frequency end of the passive source dispersion curve and/or the low frequency end of the active source dispersion curve. If they are essentially aligned, the most common course of action is to take the average by answering *Yes* to the prompt above.

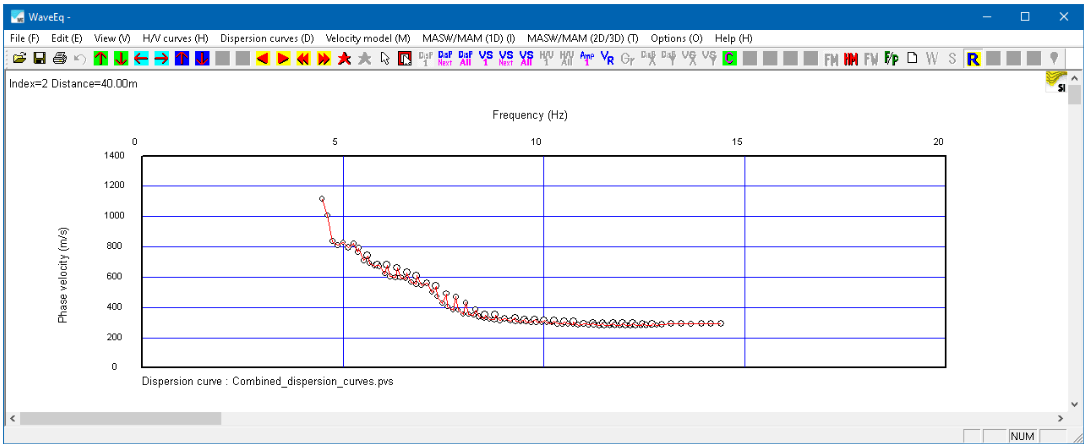
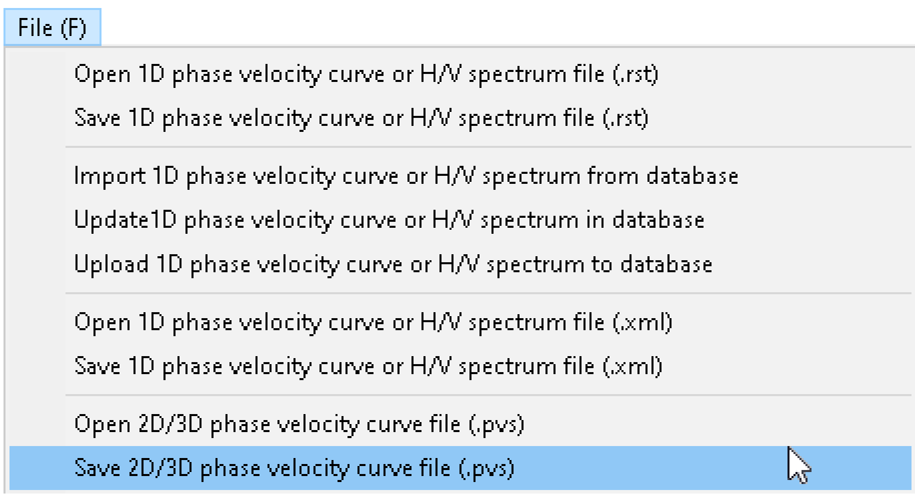
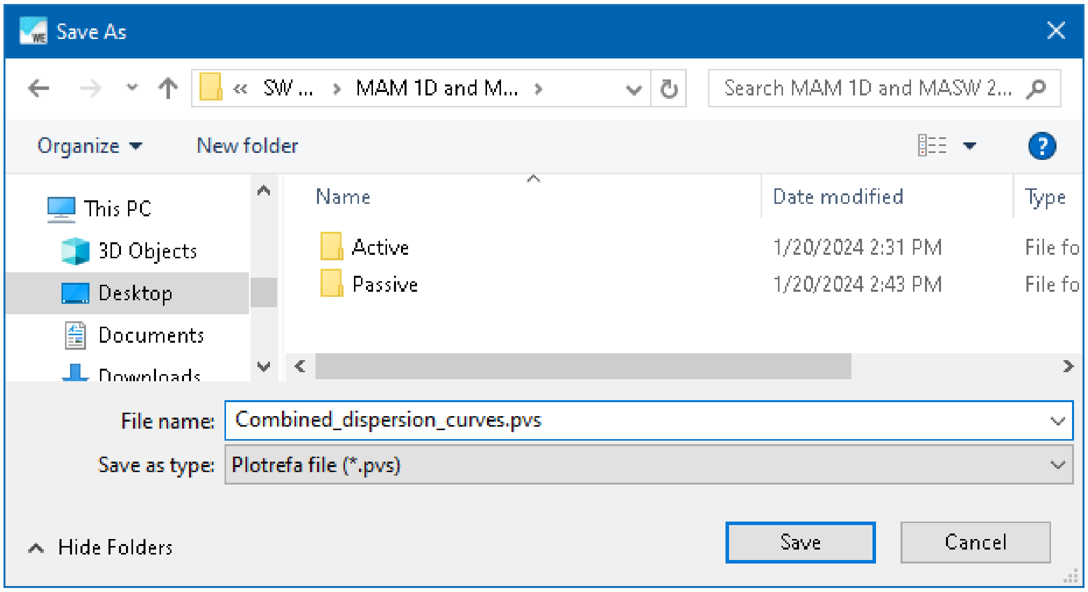


Figure 79: Combined 2D MASW and MAM dispersion curves.

Open the **File** menu and select *Save 2D/3D phase velocity curve file (.pvs)* to save the combined results as a new file.



Assign a file name with the extension *.pvs* and press *Save*.



Edit the dispersion curves as needed and save the edited results as a new file if desired.

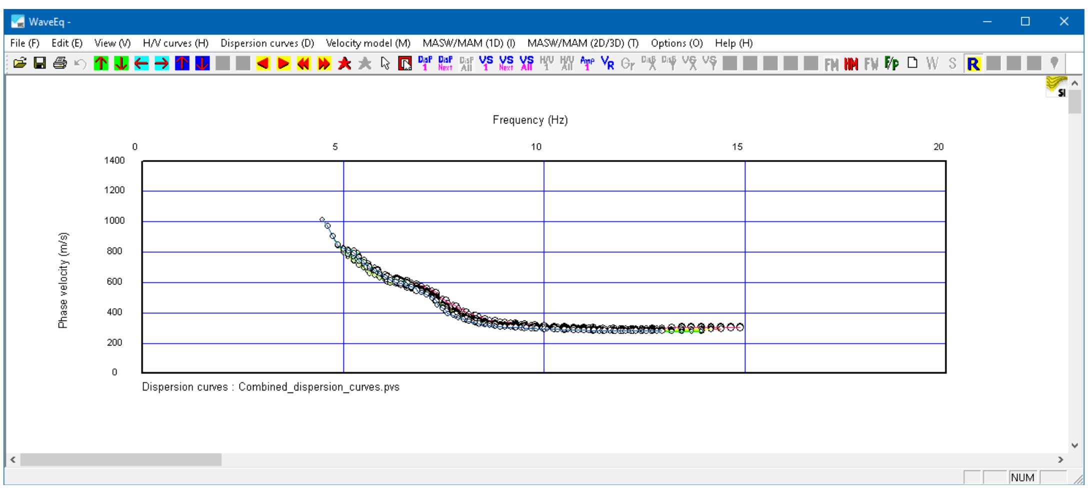
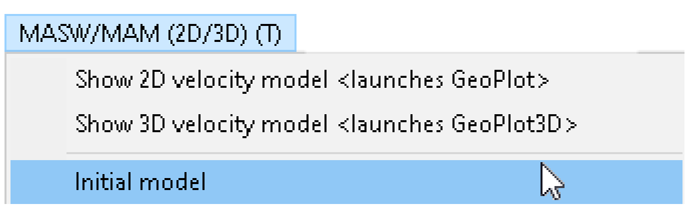
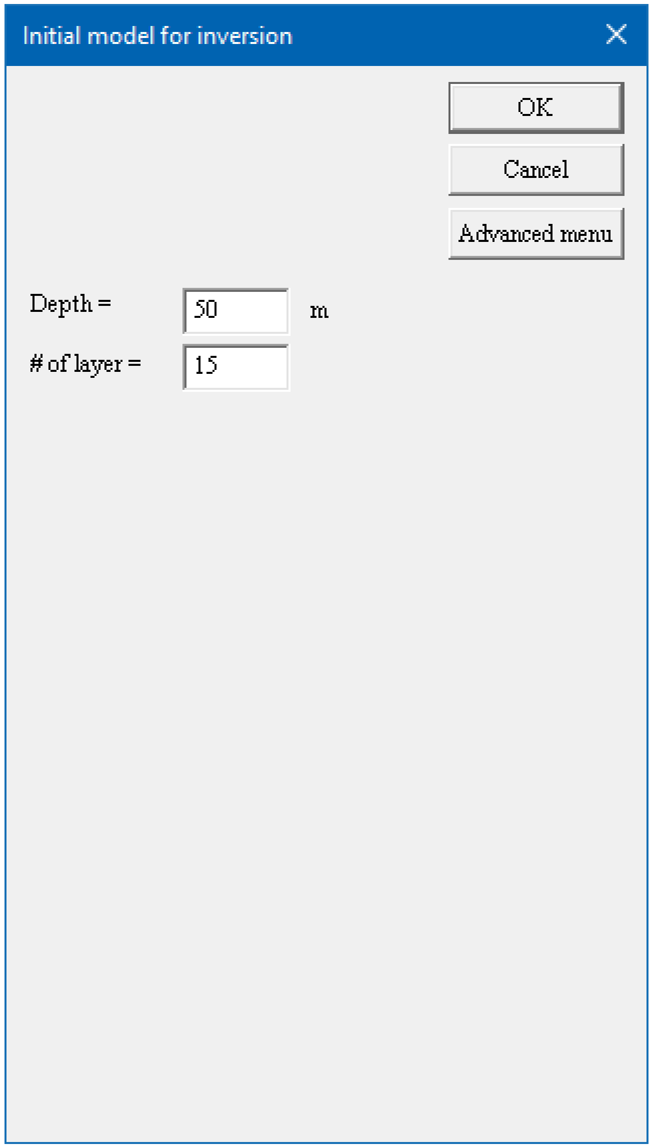


Figure 80: Edited and combined 2D MASW and MAM dispersion curves.

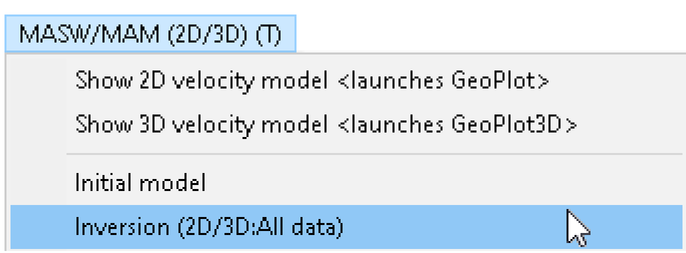
Generate an initial model by opening the **MASW/MAM (2D/3D)** menu and selecting *Initial model*.



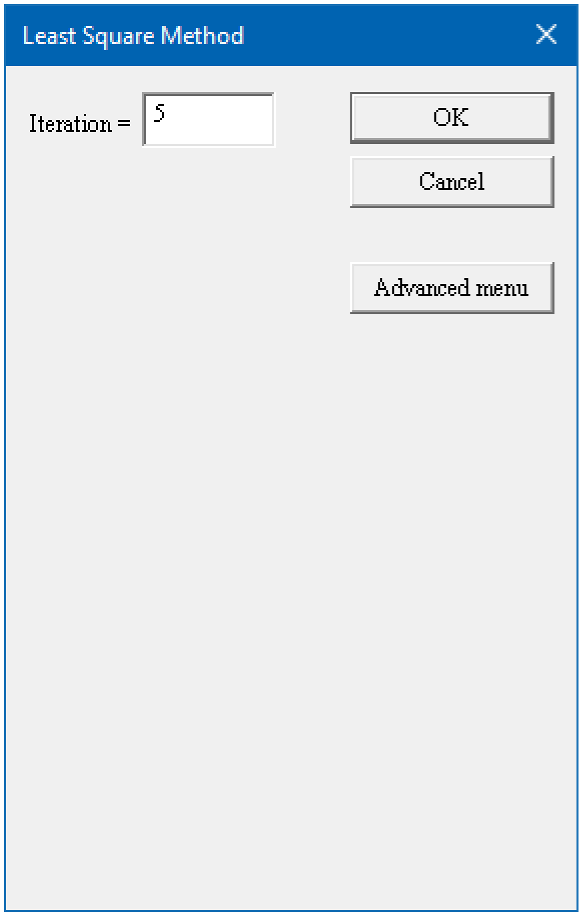
Set the maximum depth for the initial model.



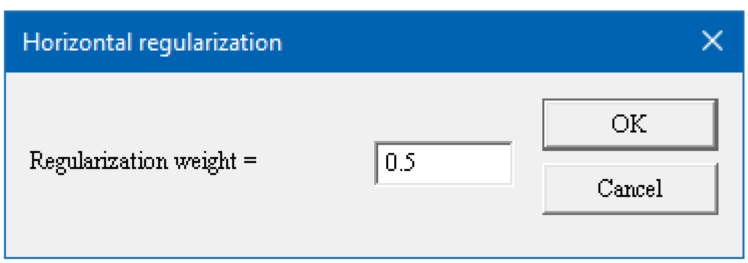
Run the inversion by opening the **MASW/MAM (2D/3D)** menu and selecting *Inversion (2D/3D: All data)*.



Accept the default value or increase as desired for *Iteration*.



Since you are working with a line of 1D V_S models that can vary significantly, you will be prompted for a "regularization weight":



This sets the degree of "smoothness" of the resultant 2D section. In most cases, the default value of 0.5 will suffice.

Note that depending on the dataset size, the inversion can be computationally intensive and may take some time to complete. Also, the higher the *Iteration* value, the longer the process will take. In the Windows Task Manager, WaveEq may report as "Not Responding", but if the memory usage is dynamically changing, this indicates the process is running properly.

Once the inversion is complete, the first in the group of individual final models is displayed.

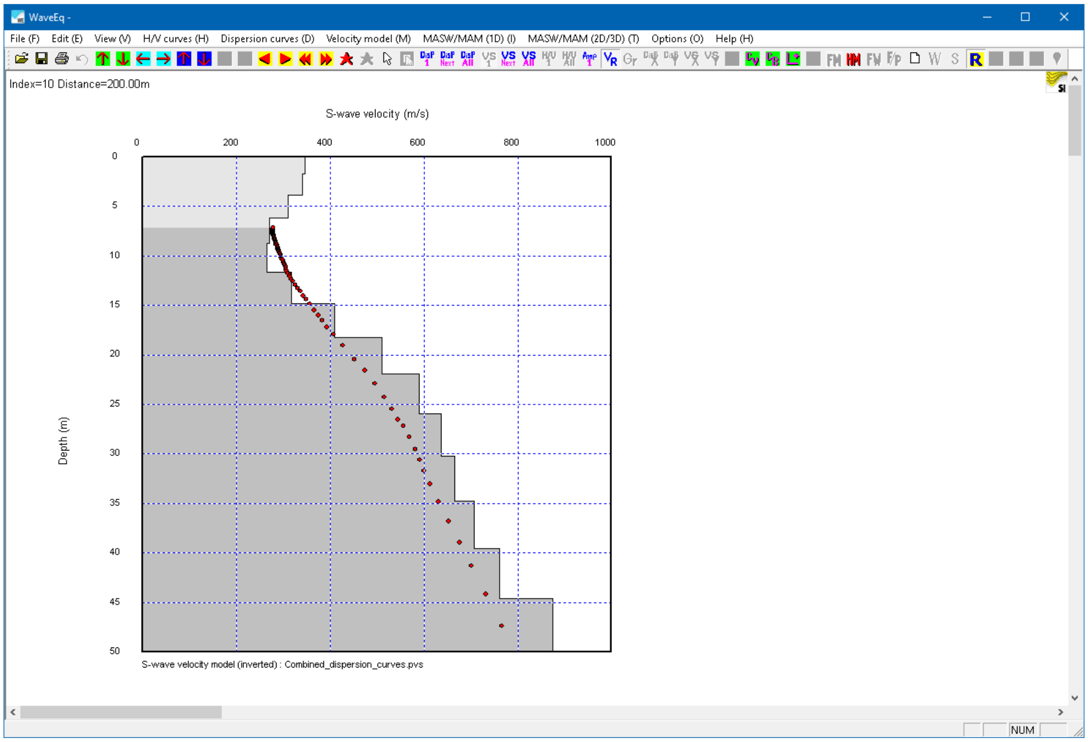
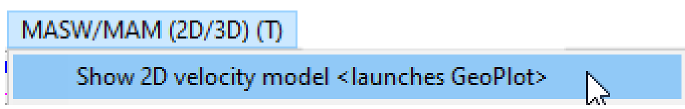


Figure 81: First in the group of final V_S models.

Display the final cross-sectional model in GeoPlot by opening the **MASW/MAM (2D/3D)** menu and selecting *Show 2D velocity model*.



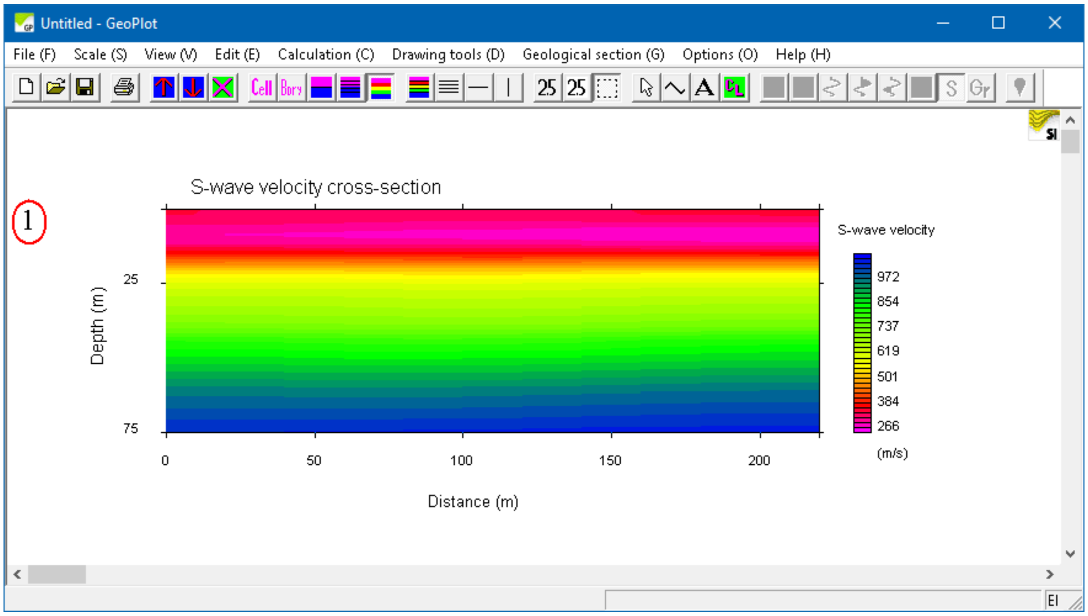
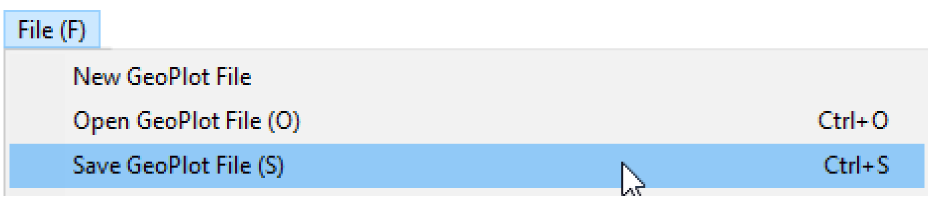
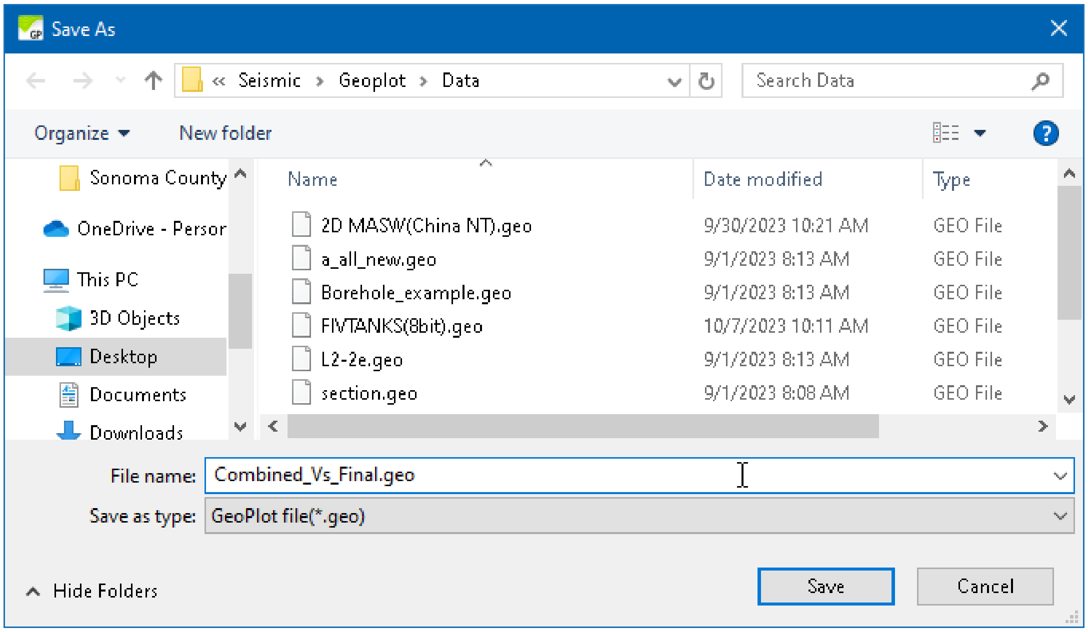


Figure 82: Final velocity cross-section.

Save the final model display as a *.geo* file by opening the **File** menu and selecting *Save GeoPlot File*.



Assign a file name with the extension *.geo* and press *Save*.



In the dispersion curve view, compare the observed and calculated dispersion curves.

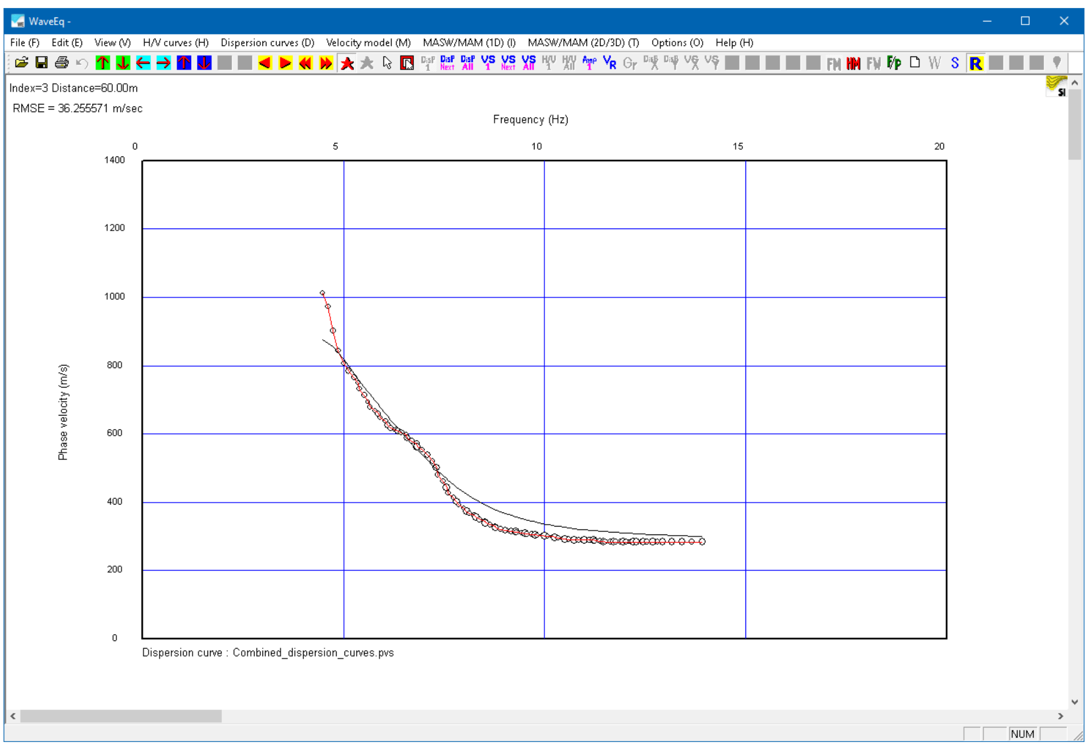


Figure 83: Observed and calculated dispersion curves.

Save the final result by opening the **File** menu and selecting *Save 2D phase velocity curve file (.pvs)*.

5 SEISIMAGER/SW- PRO: FEATURES AND CAPABILITIES

SeisImager/SW-Pro adds

1) The ability to invert H/V data for S-wave velocity (next sections).
2) Include higher mode data in the analysis (Section 5.2, Page 192).
3) Joint inversion of H/V and dispersion curve (Section 5.3, Page 212).

These features are described below.

5.1 INVERSION OF H/V

In SeisImager/SW-Pro, an H/V curve can be used for inversion of S-wave velocity similar to using a dispersion curve. Currently, H/V curve processing is only available for one dimensional analysis. It should be noted that inversion of the H/V curve for V_S is not as robust as inversion of dispersion curve data. So, it is difficult to obtain accurate S-wave velocity models from H/V data alone. However, prior information may be used to estimate an appropriate initial model and to increase inversion accuracy. H/V data can also be integrated with dispersion curve data to carry out a joint inversion. Integrating H/V data can increase the accuracy and penetration depth in the dispersion curve inversion. See Section 5.1.1, beginning on Page 174.

5.1.1 H/V DATA ACQUISITION AND PROCESSING

Continue.

5.1.1.1 THEORY OF THE H/V SPECTRUM

A three-component microtremor measurement at a single station has been widely used for estimating site characterization of earthquakes. The method has been referred to as the Nakamura method, HVSR (Horizontal Vertical Spectral Ratio) or simply H/V. In the SeisImager/SW application and this manual the word "H/V" is used for referring to the three-component microtremor measurement.

Over the last few decades, the theory of H/V has been the subject of controversy. Conventional theory of H/V was that microtremors mainly consisted of body waves and a peak frequency of H/V corresponded to the resonant frequency of site. Based on this theory, the depth to bedrock (D_2) is calculated from the peak frequency of H/V (f) as follows:

$$D_2 = \mathrm{Vs}_1 \div f \div 4$$

Here, V_{S1} is the S-wave velocity of the first layer.

Recently, it is generally agreed that microtremors mainly consist of surface waves and the H/V corresponds to ellipticity of the Rayleigh waves. SeisImager/SW assumes the latter theory and has introduced an inversion of H/V in which observed H/V data is compared with theoretical ellipticity of Rayleigh waves. In a calculation of theoretical H/V, higher modes of Rayleigh and Love waves can be considered. The conventional and latest theories of H/V are comparatively illustrated in Figure 84.

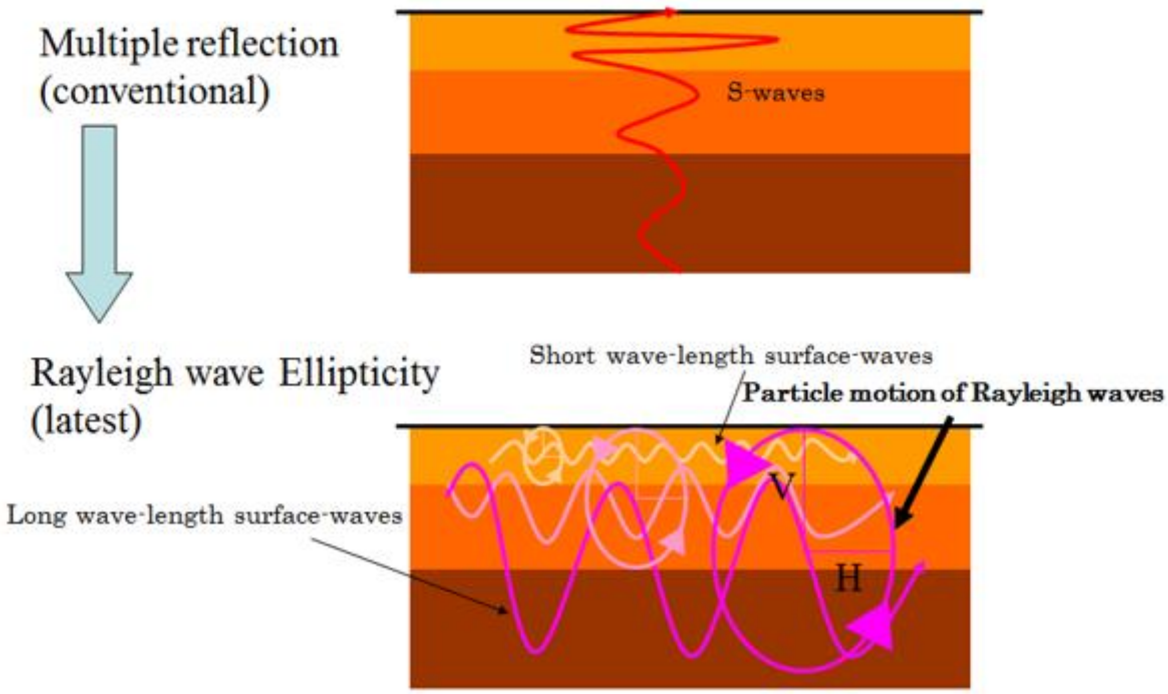


Figure 84: Conventional (top) and latest (bottom) theories of H/V.

5.1.1.2 H/V Data Acquisition

A typical H/V Spectrum dataset is shown below:

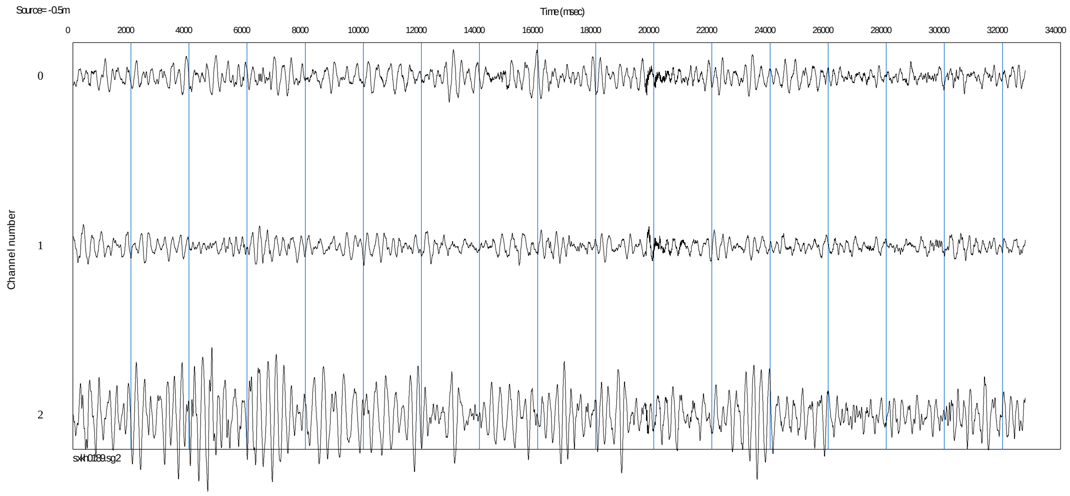


Figure 85: Typical H/V dataset.

An H/V analysis uses three-component ambient vibrations generated by cultural noise, traffic, factories, wind, wave motions, etc. The ideal vibration sources are steady and at a constant level. The fundamental assumption of the H/V analysis is that sources are located at an infinite distance, and seismic energy is stable and isotropic (coming from all directions). To best accommodate and approximate this assumption, the H/V analysis requires a long record length. The required record length depends on the depth of investigation. The greater the depth of investigation, the longer the required record length. Table 5 shows typical required record length versus depth of investigation.

Depth of Investigation (m)	Required Total Record Length (min)	Sample Interval (ms)	Number of Samples	File Record Length (sec)	Number of Files
<5	5	2	16384	32	10
2-30	10	4	16384	64	10
30-100	20	8	16384	128	10
100+	30	8	16384	128	15

Table 5: Typical required record length vs. depth of investigation.

Depth of investigation relates to a frequency range of processing. Deeper investigation requires long-period geophones or seismometers. The required frequency range and sensor depending on the depth of investigation is shown in Table 6.

Maximum Depth of Investigation (m)	Minimum Frequency (Hz)	Sensor
100	0.5	4.5Hz
1000	0.2	1Hz or 2Hz
> 1000	< 0.2	Long-period seismometer

Table 6: Required frequency range and sensors based on desired depth of investigation.

5.1.1.3 H/V Data Analysis

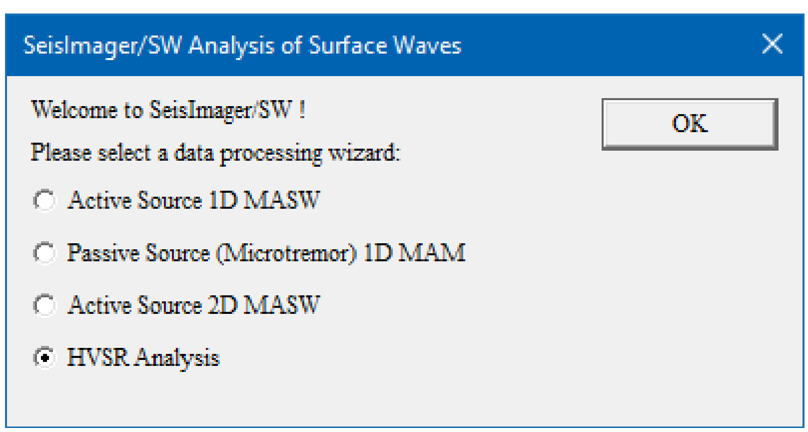
This section provides a description of the H/V Spectrum Data Analysis Wizard and associated functions. The wizard automatically calls on specific functions from the Pickwin and WaveEq modules to walk you through the analysis process. The H/V wizard and associated functions are included in both the SeisImager/SW-1D and SeisImager/SW-2D packages.

Some theory is touched on, but this manual is not meant to be a treatise on the H/V Spectrum (Nakamura) method. It is assumed that the user has a reasonable grasp of the main principles of seismology and mathematics to understand the principles behind the analysis techniques employed by the software. See Appendix F for a recommended reading list.

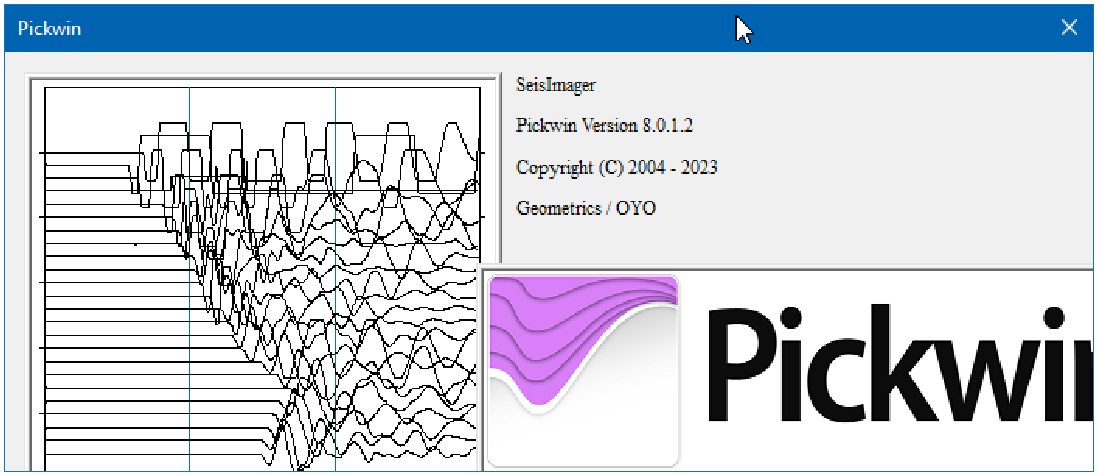
5.1.1.4 H/V Spectrum Data Analysis Wizard

Double-click on the Surface Wave Analysis Wizard icon:

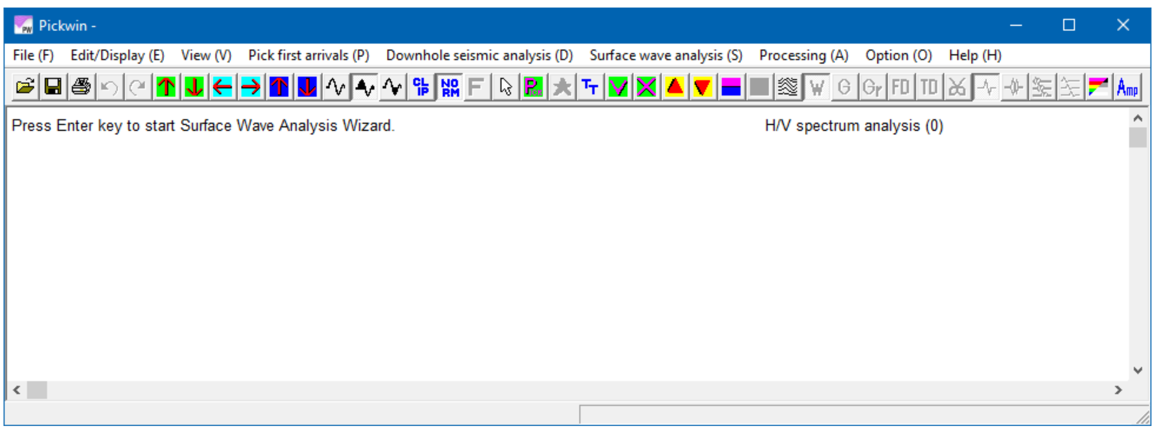
The **SeisImager/SW Analysis of Surface Waves** dialog box appears. Select *HVSR Analysis* and press *OK*:



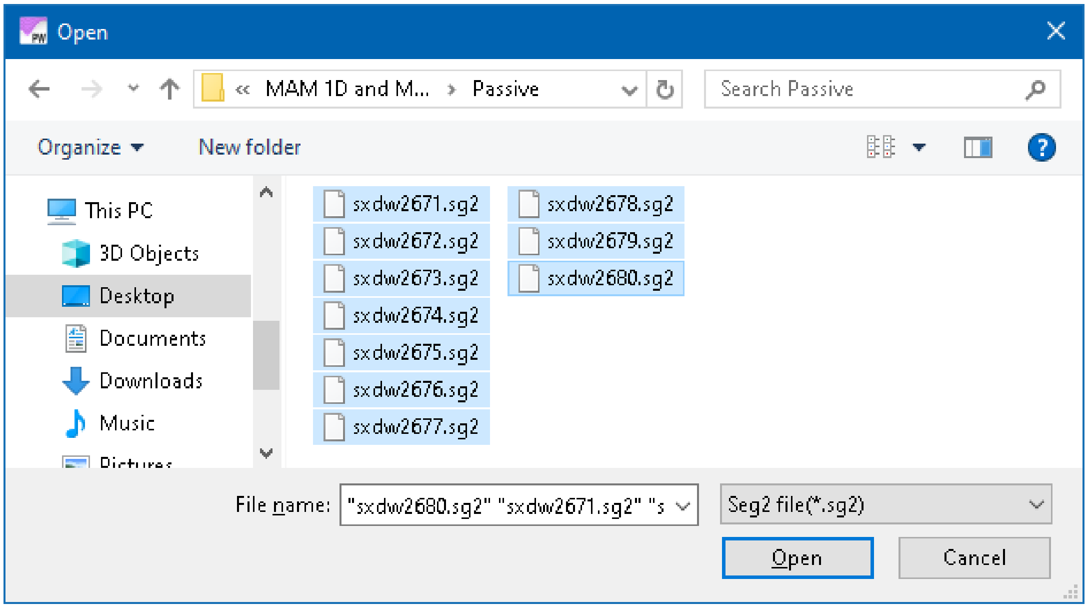
The Pickwin module is launched:



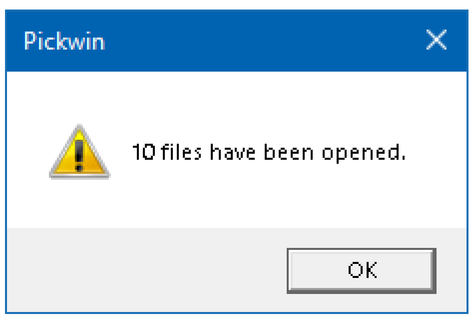
The main Pickwin window appears. The wizard calls functions from the **File** and **Surface Wave Analysis** menus. Press the *Enter* key as instructed in the upper left-hand corner of the window to begin.



The first step is to input the dataset; all the dataset files are input at one time. Use the *Shift* key to highlight the first through last file in the dataset and press *Open*.



Once the selected files are open, press *OK*.



The first in the group of waveform files is displayed. In this example, a 24-channel seismograph was used, and the files contain 21 traces of system noise in addition to the traces from the two horizontal and one vertical geophone components. The noise traces will be deleted at a later stage of the wizard.

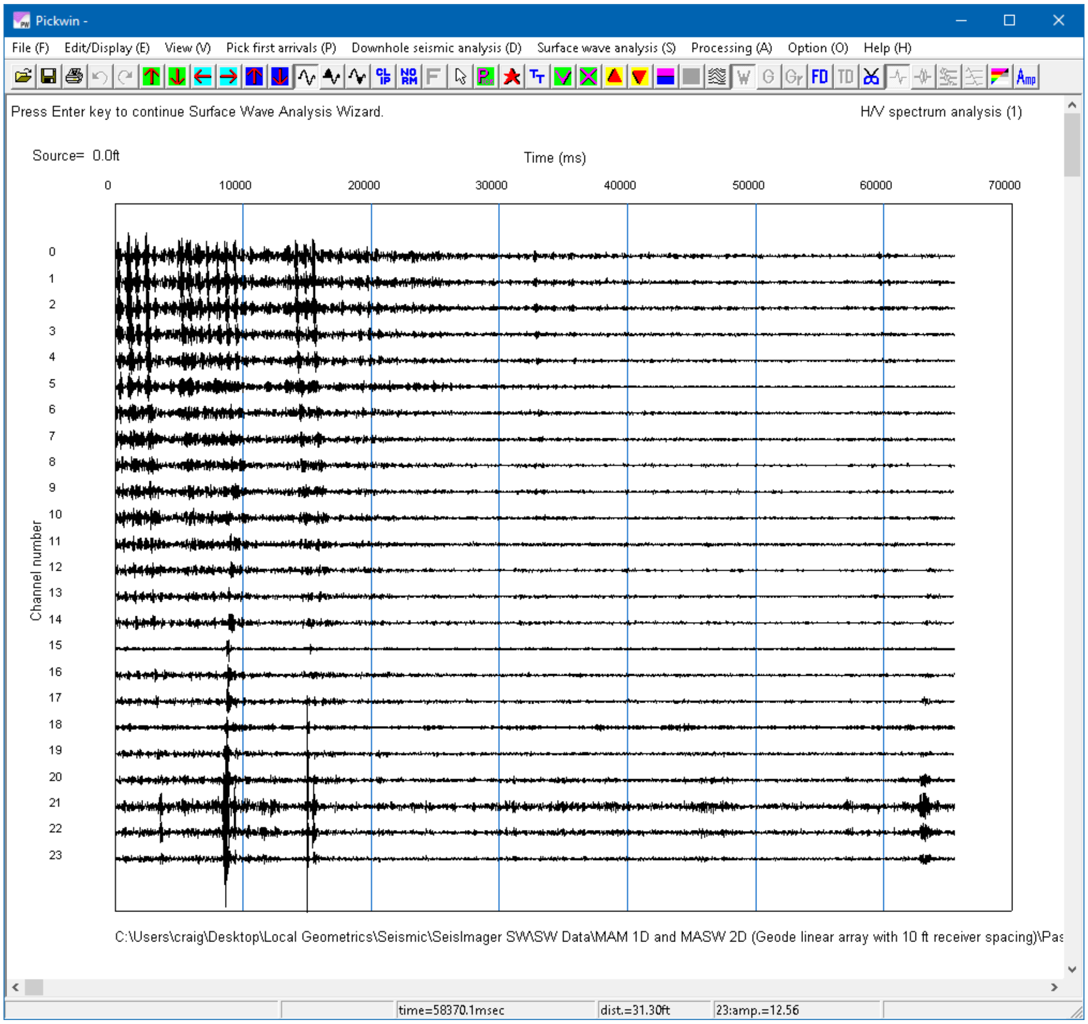
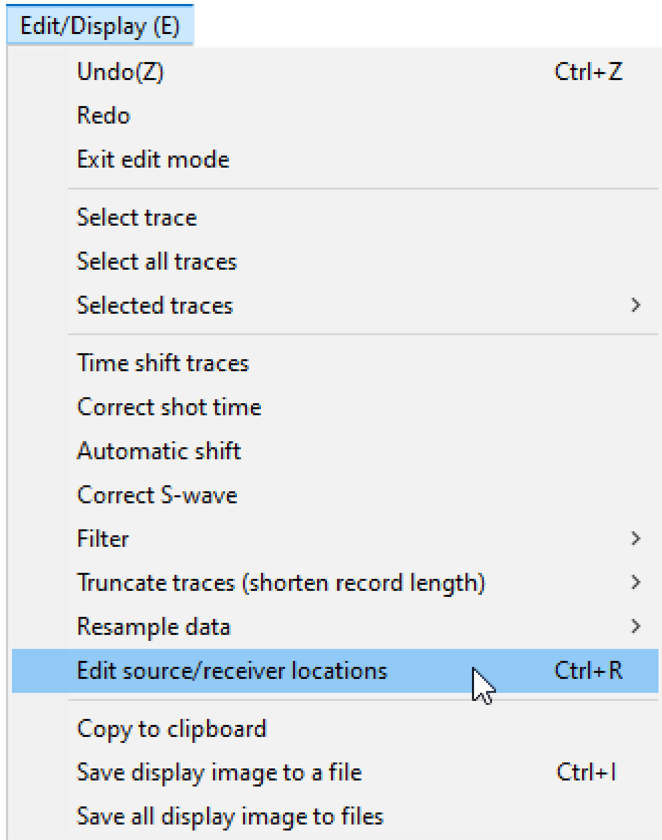


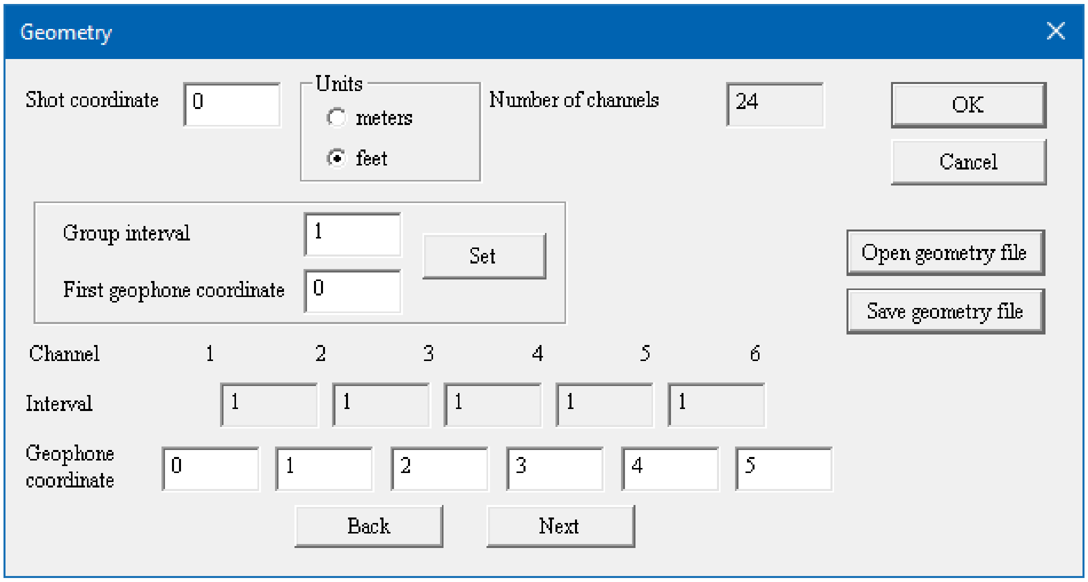
Figure 86: MAM waveform file.

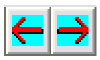
If the unit labels displayed are incorrect, open the **Edit/Display** menu and select *Edit source/receiver locations*:



The **Geometry** dialog box appears and the *Units* setting allows selection between *meters* and *feet*. The *Units* setting will affect the unit labels shown in the dialog boxes. Once set (and Pickwin is closed), the assigned units will be recalled for subsequent uses of the wizard. (**It is necessary to close Pickwin to register the new *Units* setting.** At the end of the wizard, simply close Pickwin to register the new *Units* setting.)

The **Geometry** dialog box also reports the source and receiver coordinates saved in the file header at the time of acquisition. This is not applicable for H/V spectrum datasets. Press *OK* when done.



In the waveform view, the settings can be modified to optimize the display. All these settings are common with SeisImager/2D for refraction data processing; refer to the SeisImager/2D manual for complete explanation. The main functions needed are the *Waveform amplitude*  buttons, the *Horizontal scale*  buttons, and the *Vertical scale*  buttons. When done, press the *Enter* key to continue.

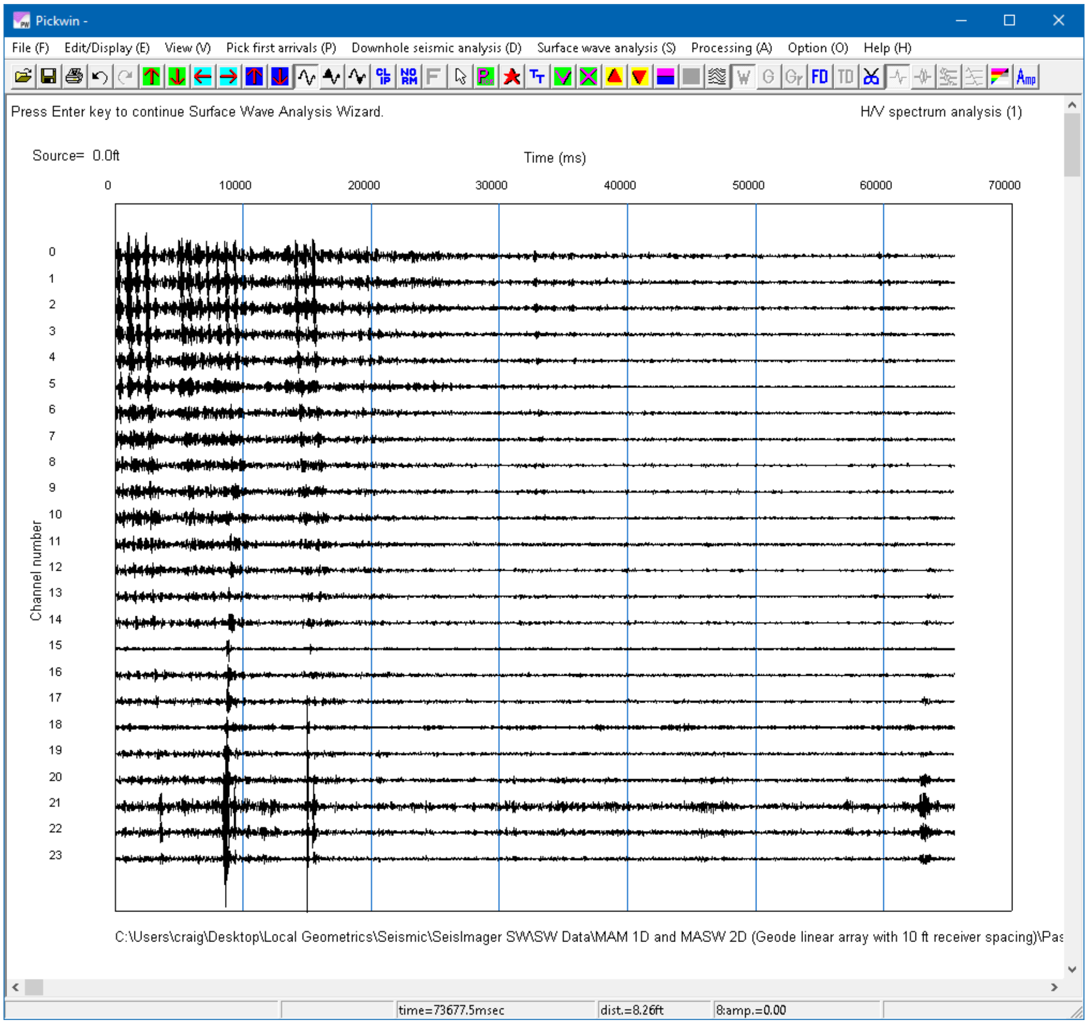
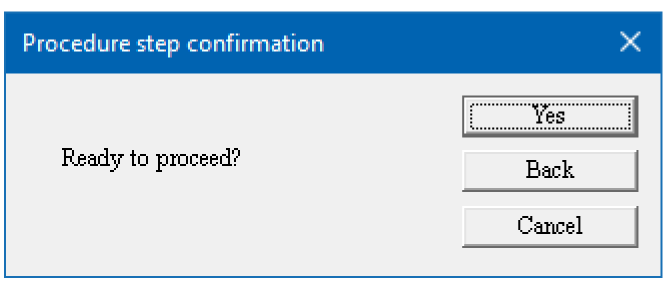
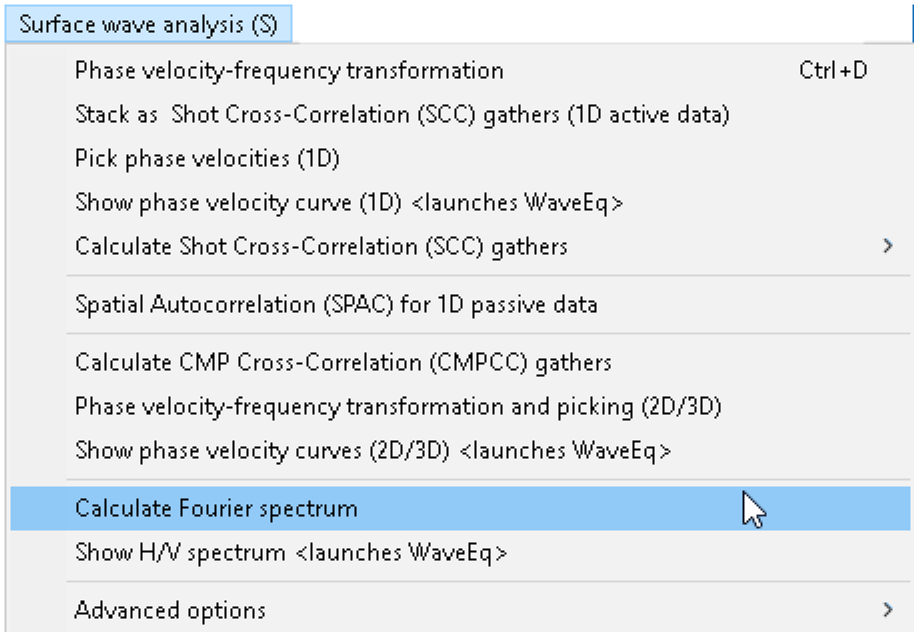


Figure 87: MAM waveform file.

Press *Yes* when ready to proceed.



Next, the Fourier spectrum is calculated. To run this function outside of the wizard, select *Surface wave analysis | Calculate Fourier spectrum*:



Once the calculation is complete, the spectrum is displayed. Press the *Enter* key to continue.

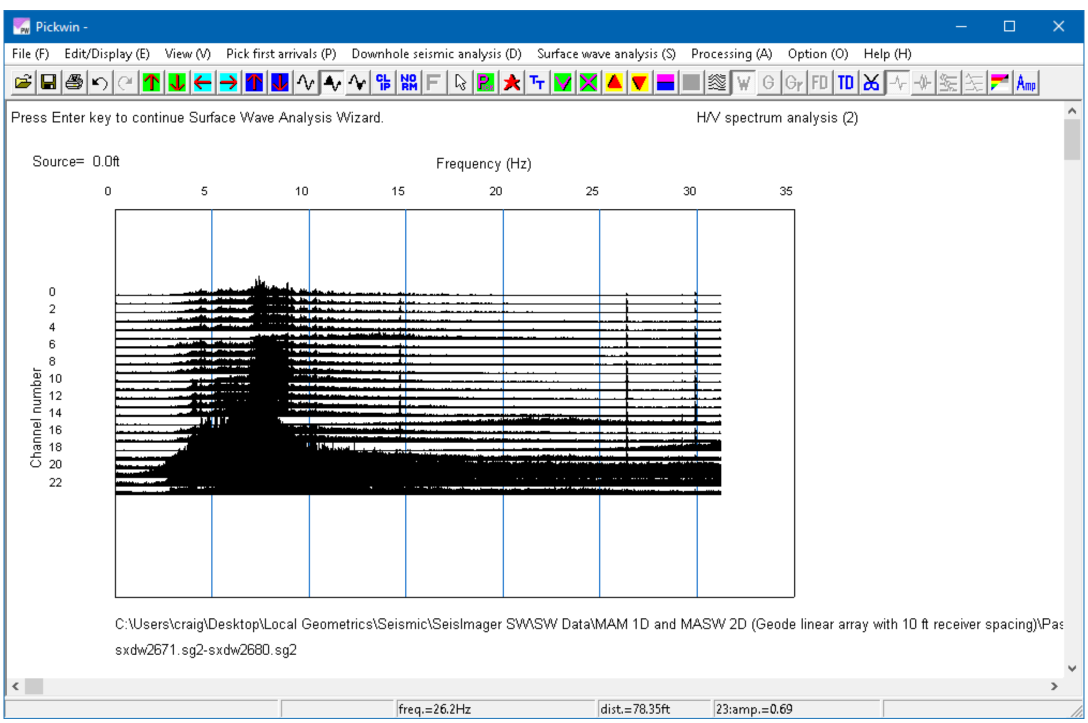
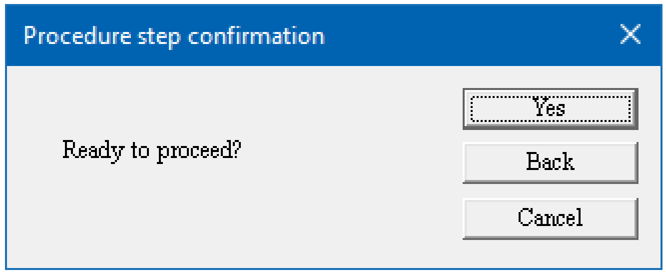
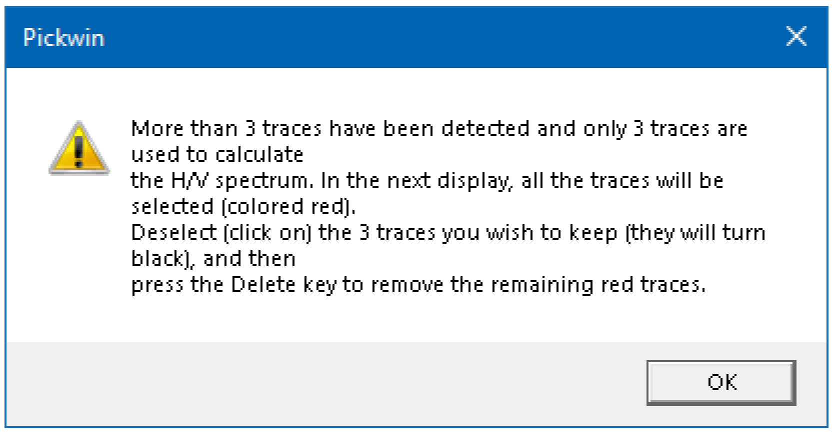


Figure 88: Frequency domain view of waveform view of Figure 87.

Press *Yes* when ready to proceed.



If there are more than 3 traces, the following message will appear. In H/V analysis, only three traces (two horizontal components and one vertical component) are used. Unnecessary traces must be deleted as follows:



Press *OK* and all traces will be selected (colored red).

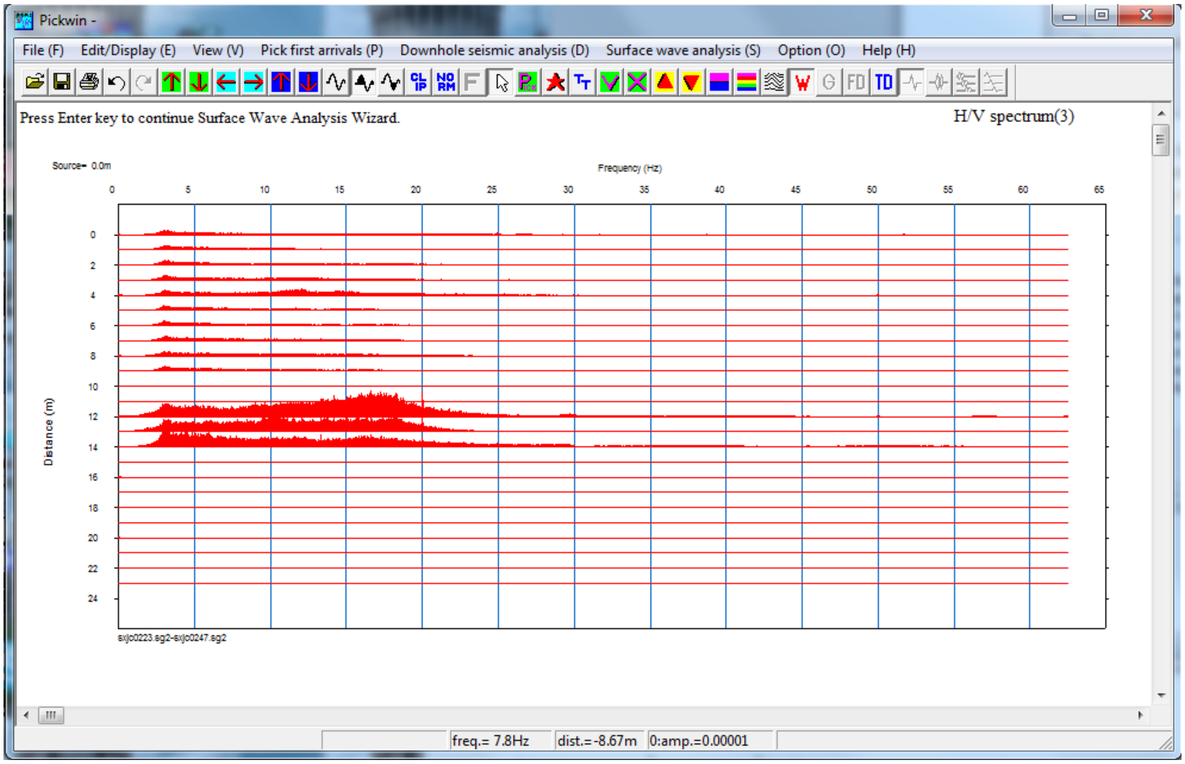


Figure 89: Spectrum plot, all traces selected.

Deselect (click on) the three traces you wish to keep (they will turn black).

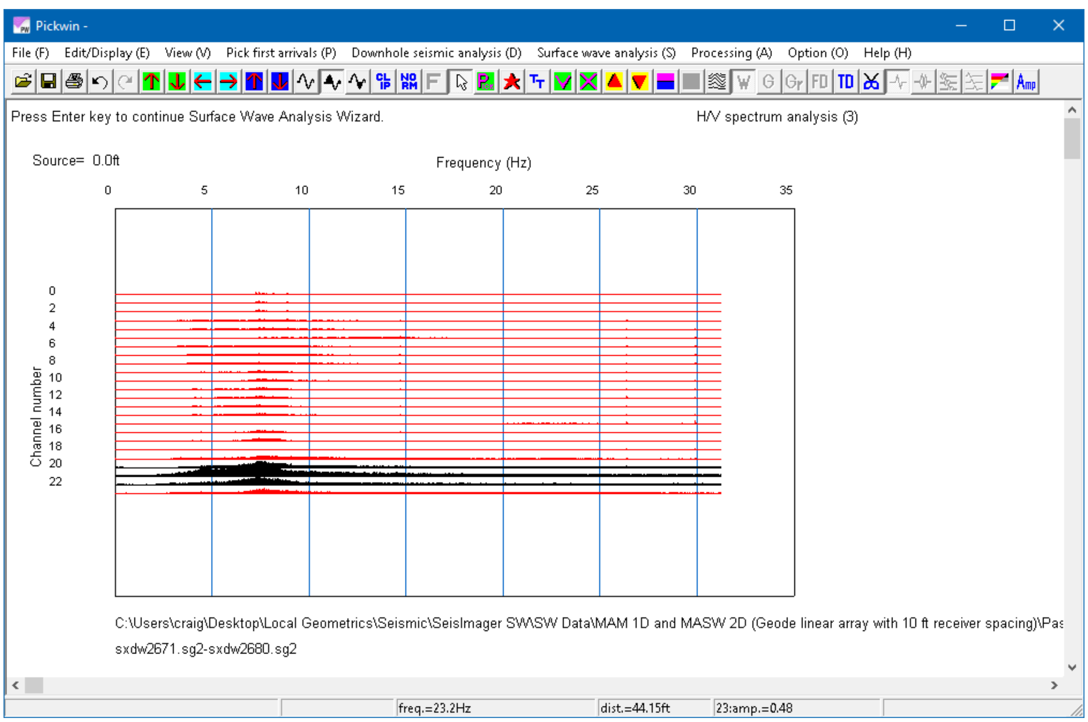


Figure 90: Spectrum plot, three traces selected.

Press the *Delete* key to delete the remaining red traces. Three traces will remain.

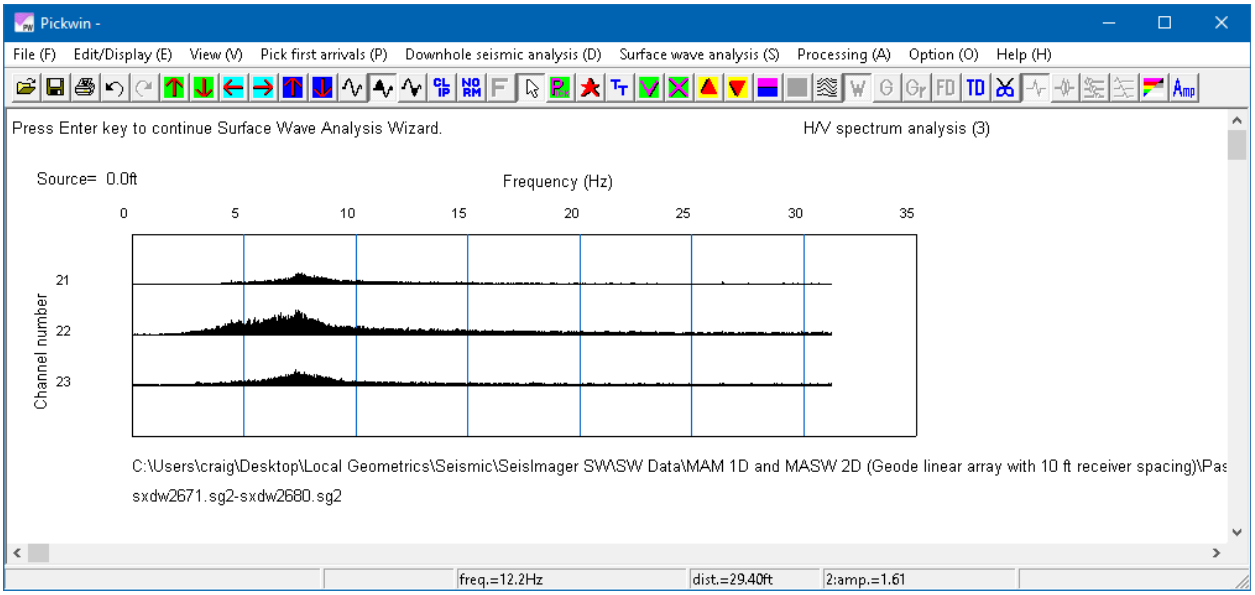
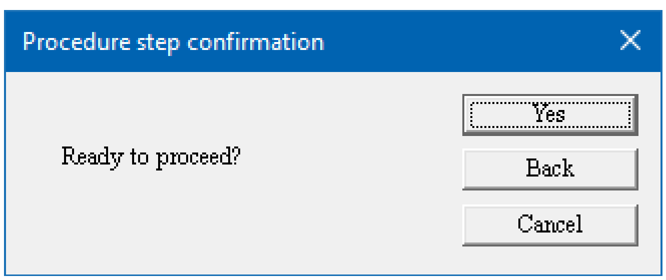
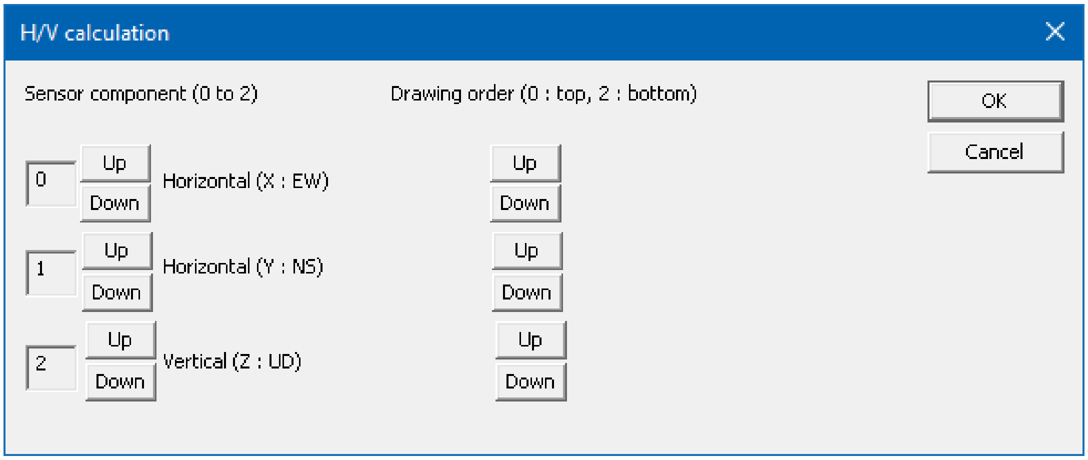


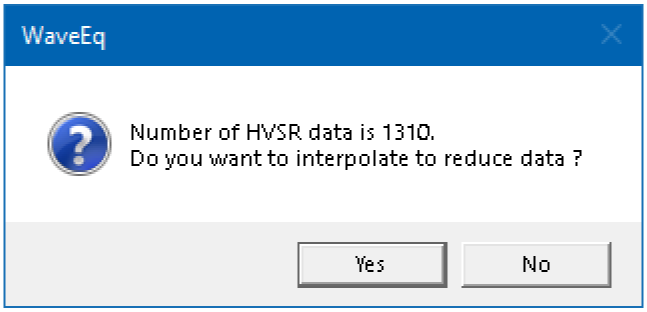
Figure 91: Spectrum plot, all selected traces deleted.

Press the *Enter* key to continue. Press *Yes* when ready to proceed.



The **H/V calculation** dialog box appears. Set each component using the *Up* and *Down* buttons. The index of the channel number must start at 0 and it must be 0, 1 or 2 when three traces remain. Press *OK* when ready to proceed.





Once the Fourier spectrum is calculated in Pickwin, the spectrum is held in memory for import to WaveEq. WaveEq is used for detailed editing, analysis and making figures for the final report. WaveEq can be opened separately and can read in the text file that contains the 3-component spectrum data. But this single step is the easiest way to automatically launch WaveEq and import a spectrum just calculated in Pickwin. In this step, H/V is automatically calculated and shown in WaveEq.

Below is an example of an H/V curve shown in WaveEq. The peak frequency of H/V is marked as an orange circle, and the value of the peak frequency is shown in the bottom left corner of the window:

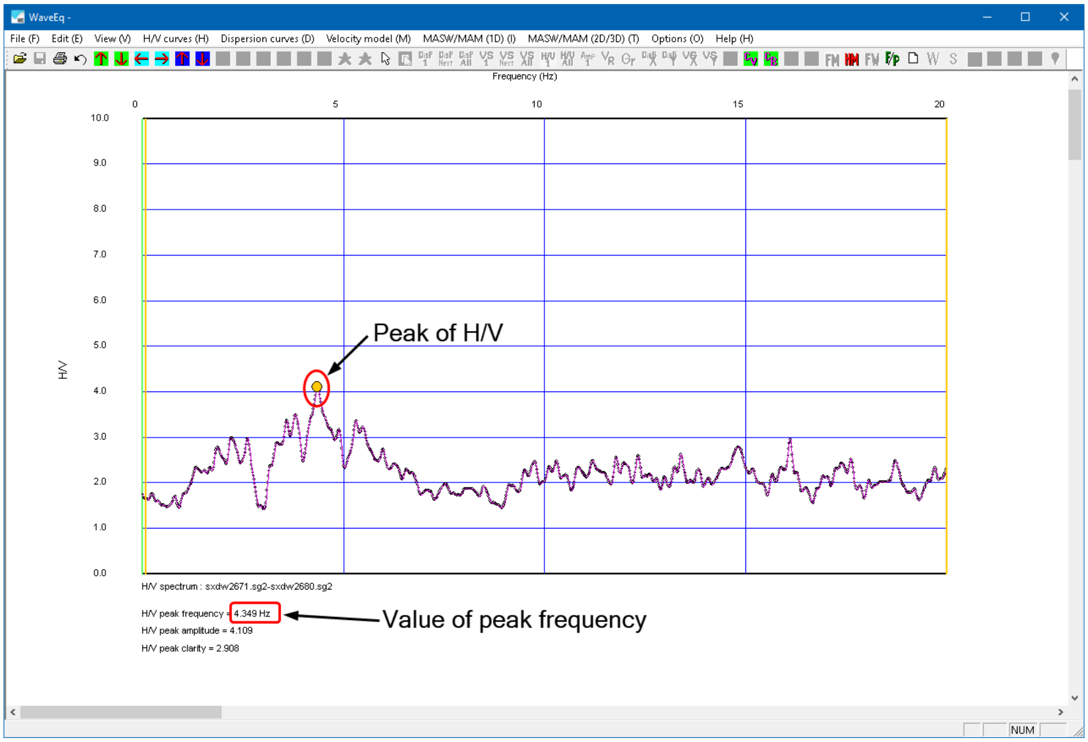
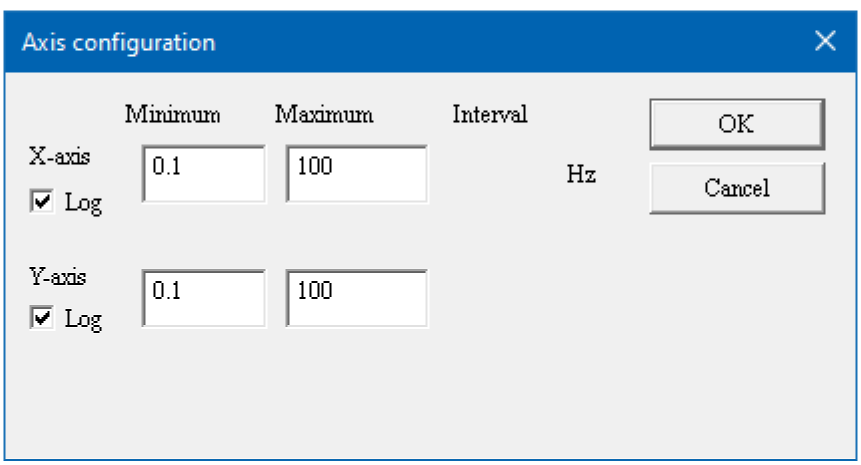


Figure 92: H/V plot showing peak frequency.

If the plotting scales need adjusment, select *View* | *Axis configuration* or press *Ctrl+A*.

Enter the desired values for the *X-axis* and *Y-axis Minimum, Maximum* scales, and *Interval*. Both axes can be plotted in linear or log scale. Press *OK* when done.



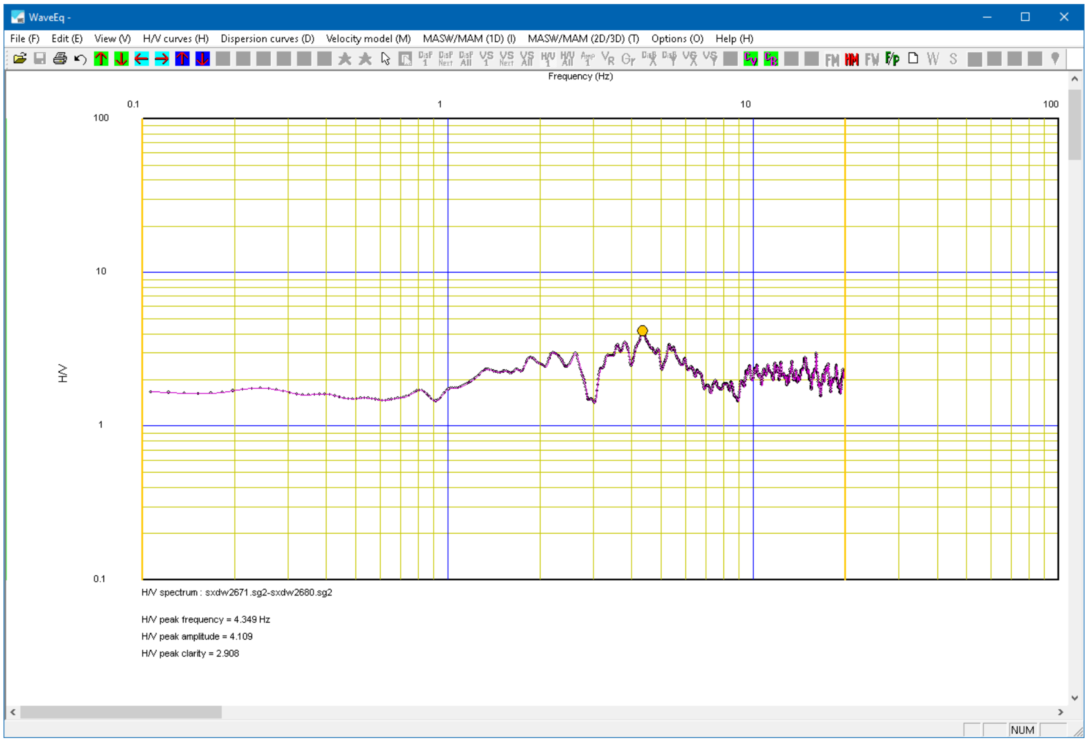


Figure 93: H/V plotted with log scale.

Next, edit the H/V curve as needed. In the H/V curve, lower frequency data contains information of deeper structure and higher frequency data contains information of shallower structure. Table 7 summarizes the general guideline of frequency and depth of interest.

Frequency (Hz)	**Depth of interest (meters)**
0.1 to 0.5	> 100
0.5 to 2	20 to 100
2 to 10	2 to 20
> 10	< 2

Table 7: Frequency vs. depth of interest.

H/V data outside of the depth of interest is meaningless and it is better to remove it. Follow the instructions in the upper left-hand corner of the window.

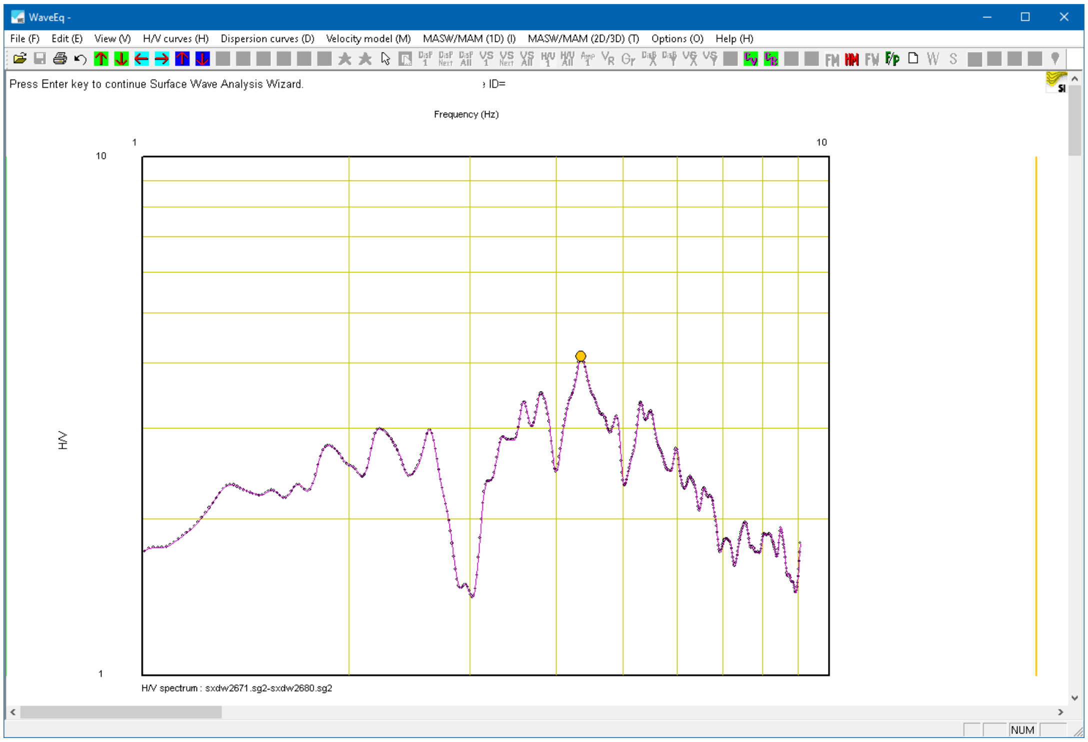
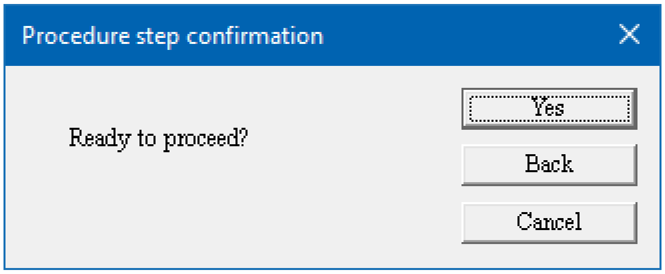
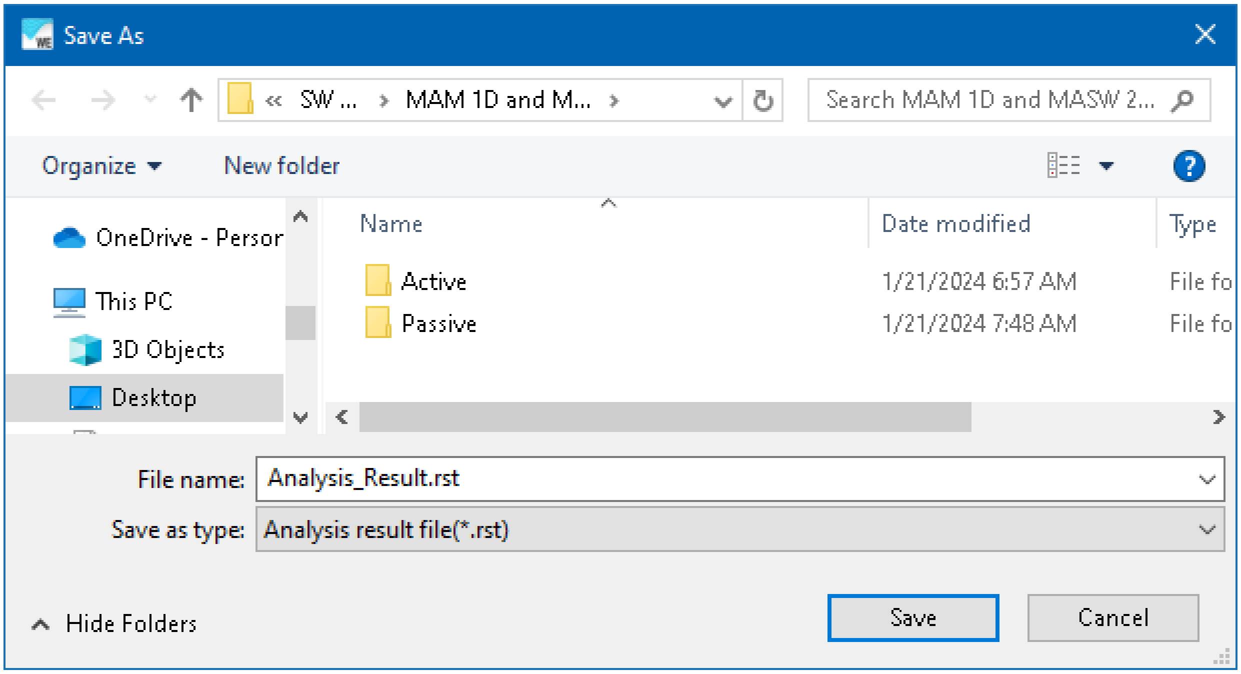


Figure 94: Final H/V plot.

Press *Yes* when ready to proceed.



Lastly, save the result. Assign a file name with the extension .rst and press *Save*.



5.2 INVERSION USING HIGHER MODES

Traditional analysis of surface wave data generally assumes that a dispersion curve mainly consists of a fundamental mode. Higher modes may dominate in several types of velocity structures, such as a model in which a high-velocity layer overlays a low-velocity layer or a model in which a high-velocity layer is embedded in low-velocity layers. To include higher modes in inversion, SeisImager/SW-Pro introduced several new algorithms, such as a Genetic Algorithm (GA) and inversion with variable layer thickness. Figure 95 below shows a phase velocity-frequency plot that includes higher modes.

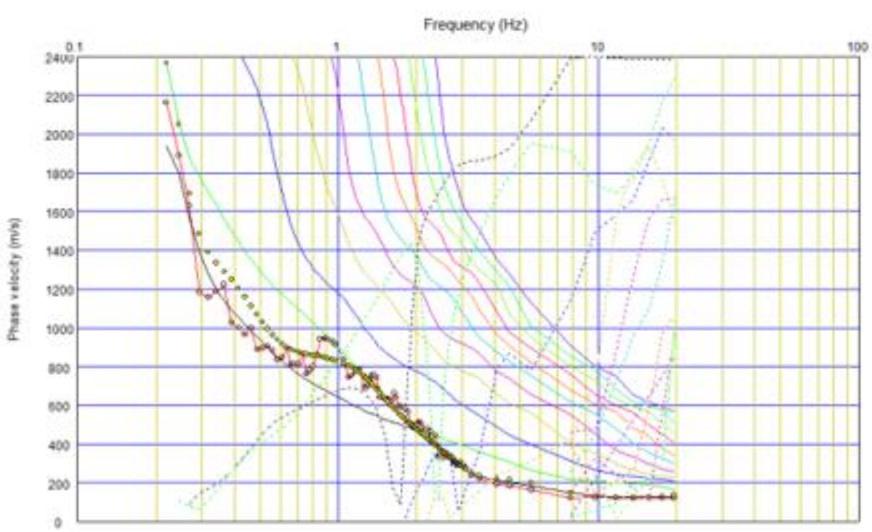


Figure 95: Fundamental mode (dots) along with higher modes.

SeisImager/SW (Pro only) allows users to include higher modes in the inversion and therefore to analyze complex velocity structures more accurately. Observed and theoretical phase velocity modes are not identified by SeisImager/SW-Pro analysis.

In an active surface wave method, observed data is defined as the maximum amplitude phase velocity calculated at each frequency using the multi-channel analysis of surface waves (MASW) method (Park et al., 1999). In the passive surface wave method, observed data is defined as the phase velocity that yields the minimum error between observed coherence and the Bessel function calculated through the Spatial Autocorrelation (SPAC) method (Aki, 1957). Examples of phase velocity images for active and passive surface wave data are shown in Figure 96 below.

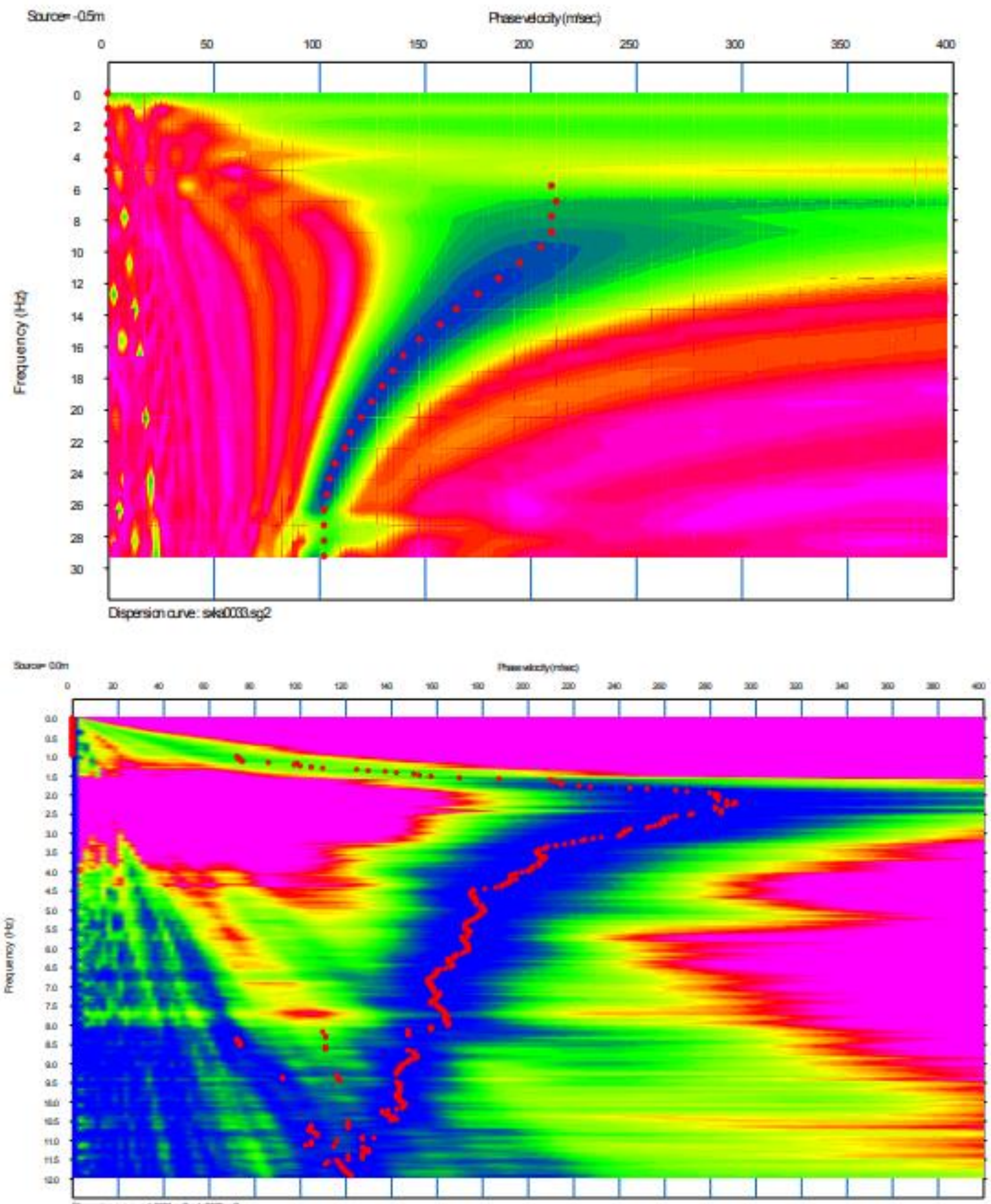


Figure 96: Examples of phase velocity images for active (top) and passive (bottom) surface wave data.

In calculation of higher mode phase velocities, both phase velocity and its relative amplitude (medium response) are calculated simultaneously. Theoretical phase velocity is defined in the following two ways. First, the phase velocity is defined as the velocity that has the maximum relative amplitude at each frequency. Secondly, the phase velocity is defined as the weighted average of all modes. The relative amplitude is used for calculating weighted average data. “Maximum” will correspond to phase velocities calculated with the first method, and “averaged” will refer to phase velocities calculated with the second method. In WaveEq, in the case of Rayleigh waves, maximum amplitude-calculated phase velocities are shown as light blue circles, and averaged phase velocities are shown as yellow circles. They are shown as blue and green, respectively, in the case of Love waves. Figure 98 shows an example of theoretical “maximum” and “averaged” phase velocities for the velocity model shown in Figure 97. See Hayashi (2012) for some examples of higher modes.

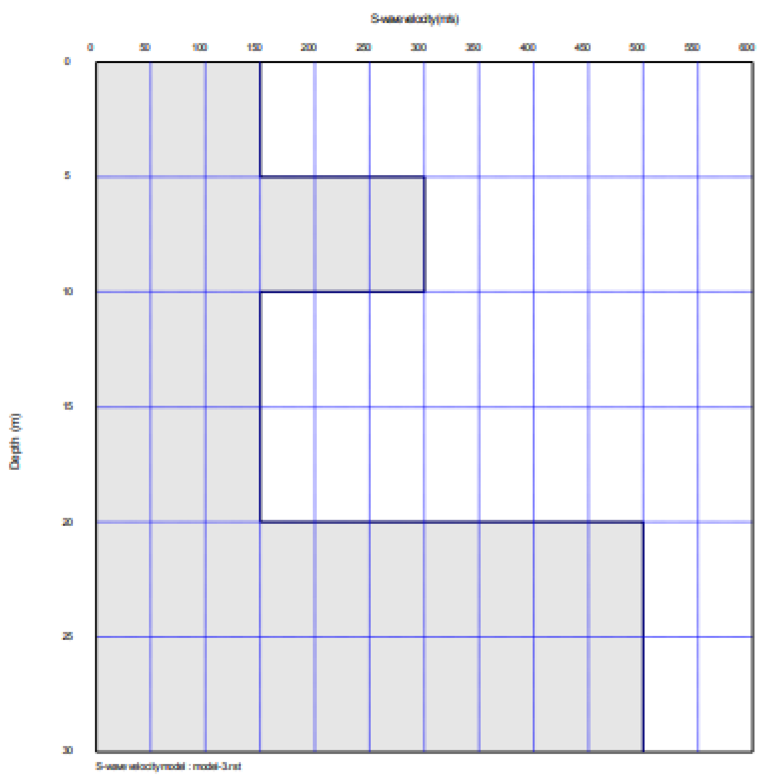


Figure 97: Example velocity model.

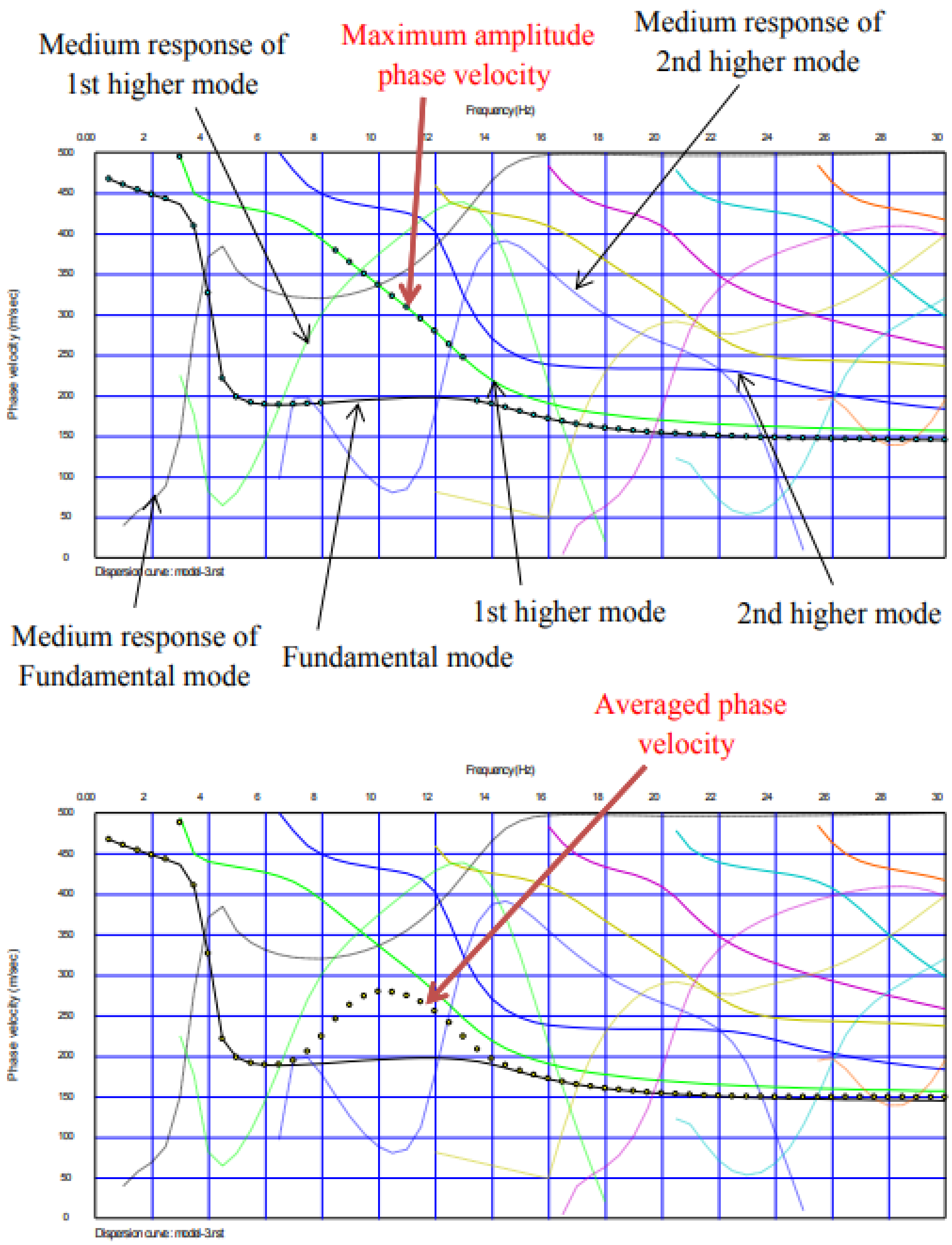
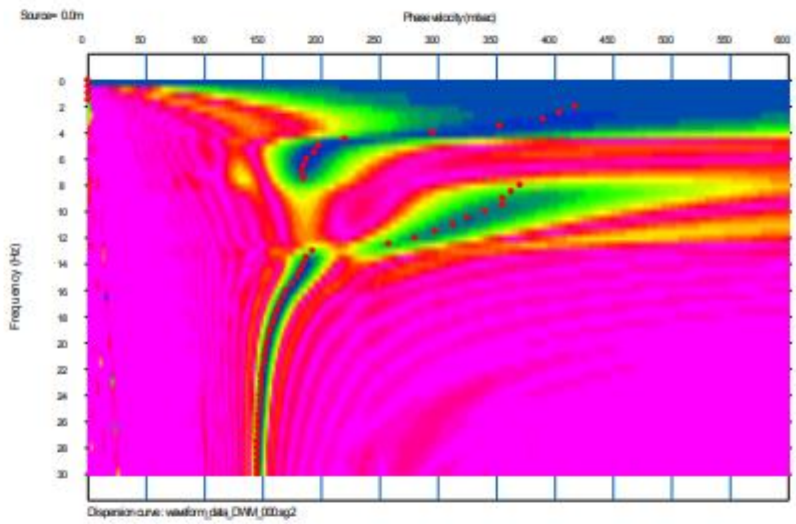


Figure 98: Example of theoretical "maximum" (top) and "averaged" (bottom) phase velocities for the velocity model shown in Figure 97. Medium response curves shown in the top image correspond to the relative amplitude of the designated mode with respect to the fundamental mode.

There is no established rule for how to calculate theoretical phase velocities including higher modes. In observed data, different modes can be isolated if the geophone array size is relatively bigger than the wavelength of interest. Generally speaking, active surface wave methods use relatively larger arrays in terms of wavelength of interest compared to passive methods. Therefore, we propose using "maximum" phase velocity for active method processing and "averaged" phase velocity for passive surface wave data.

Figure 99 shows theoretical phase velocity images for the velocity model shown in Figure 97. The top and bottom figures correspond to the dispersion curve calculated with Multichannel Analysis of Surface Waves (MASW) and the passive method (SPAC) respectively. The MASW data was acquired with a 96m linear array, and the SPAC data was acquired with a 10m triangular array. It is clear that MASW dispersion curves appear similar to “maximum” phase velocities and SPAC results are more similar to “averaged” phase velocities. Figure 100 shows an example of phase velocity change due to array size or geometry. In the example, synthetic data for the velocity model shown in Figure 97 is used. It is obvious that an increase in array size results in clear separation of different mode phase velocities.



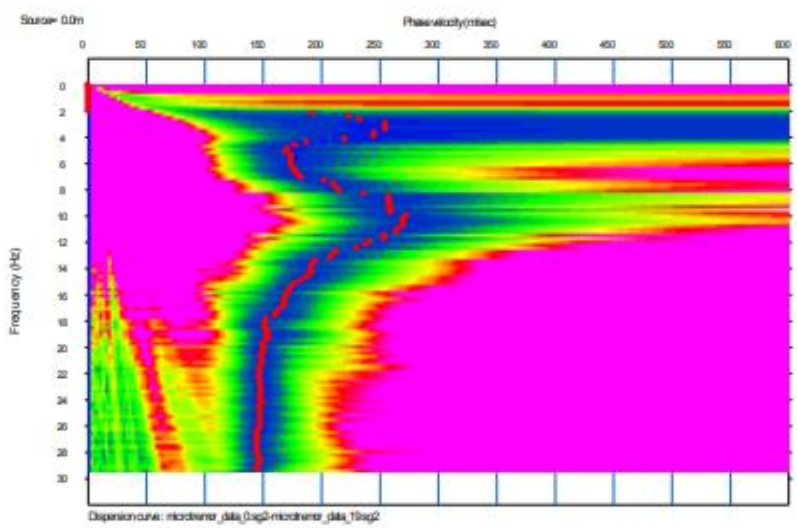
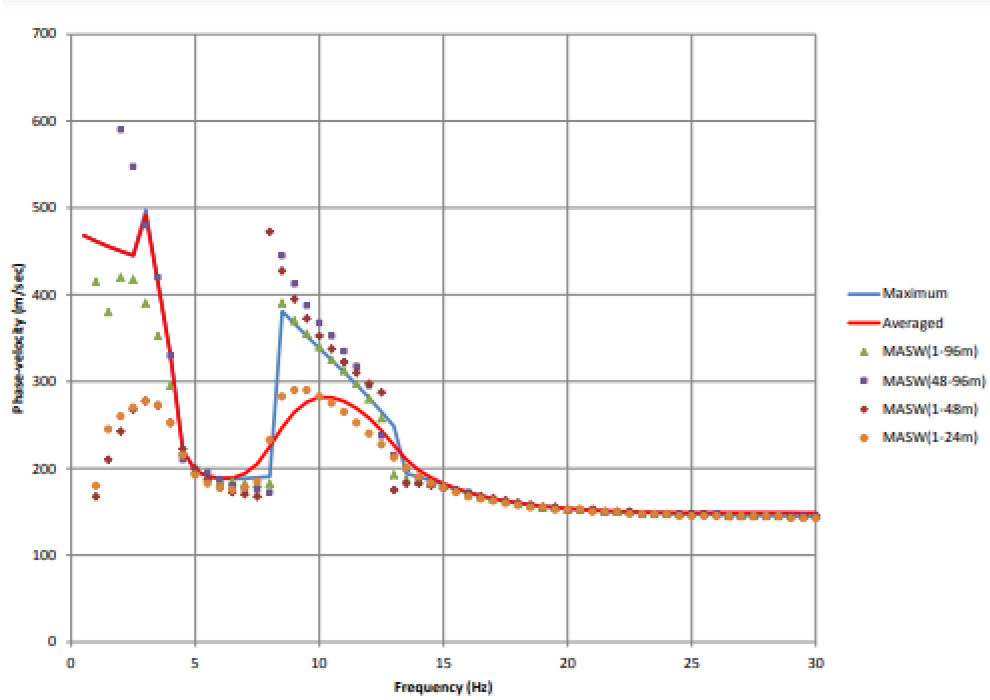


Figure 99: Theoretical phase velocity images for the velocity model shown in Figure 97. Top image corresponds to phase velocity curve derived from the active method (MASW) and bottom is that of passive method (SPAC).



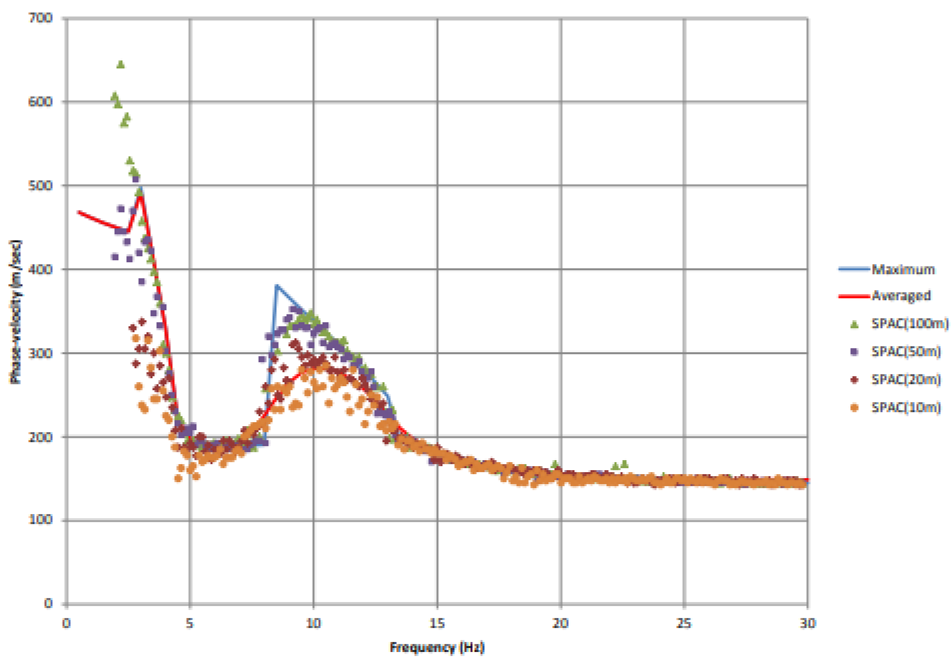


Figure 100: Change of phase velocities calculated by MASW and SPAC due to array sizes or geometry. Synthetic data for the velocity model shown in Figure 97 is used in the calculation.

Higher mode data is also important in the calculation of theoretical H/V. In SeisImager/SW, theoretical H/V is defined in two ways. The first definition of H/V corresponds to the Rayleigh wave fundamental mode, and the second method assumes Rayleigh and Love wave higher modes. In the higher order method, the ellipticity of the Rayleigh wave and medium response (relative amplitude) of Rayleigh and Love waves are calculated for each mode. Horizontal and vertical amplitudes are calculated from the ellipticity and medium response values. Figure 101 shows an example of theoretical H/V. The solid black line indicates an H/V of Rayleigh wave fundamental mode, and the yellow circles indicate Rayleigh and Love wave higher modes.

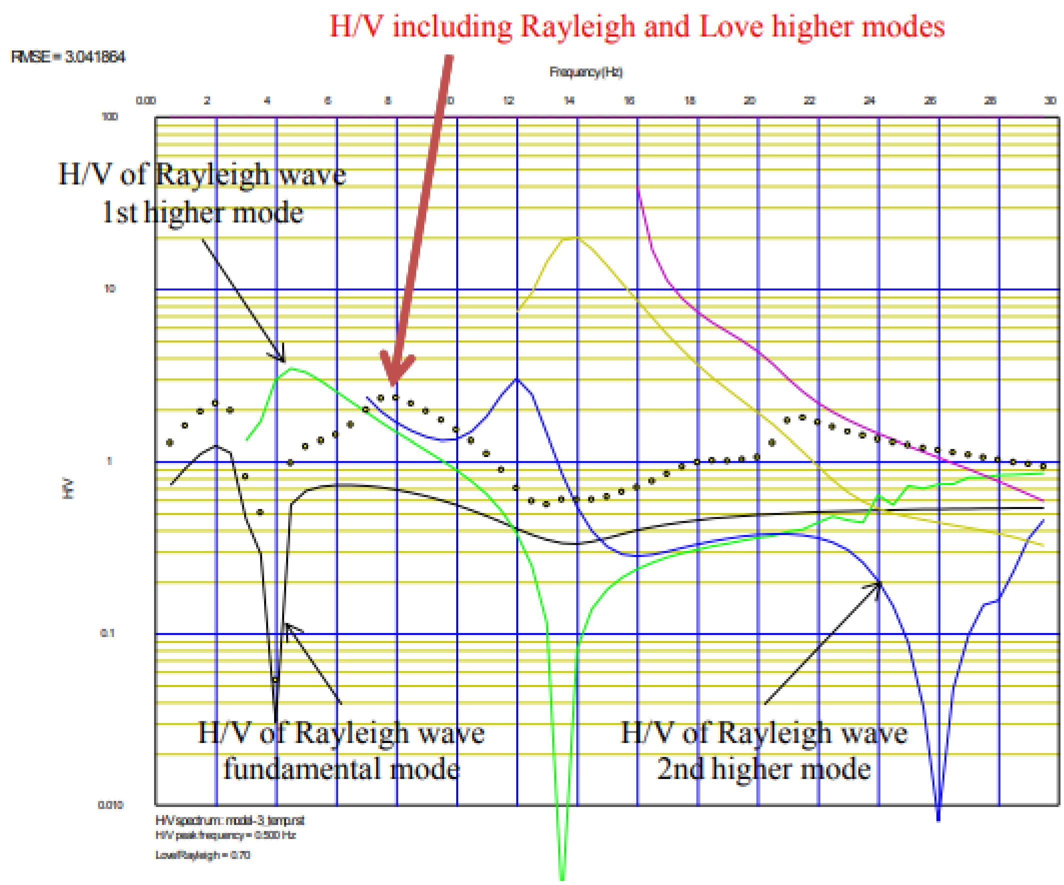
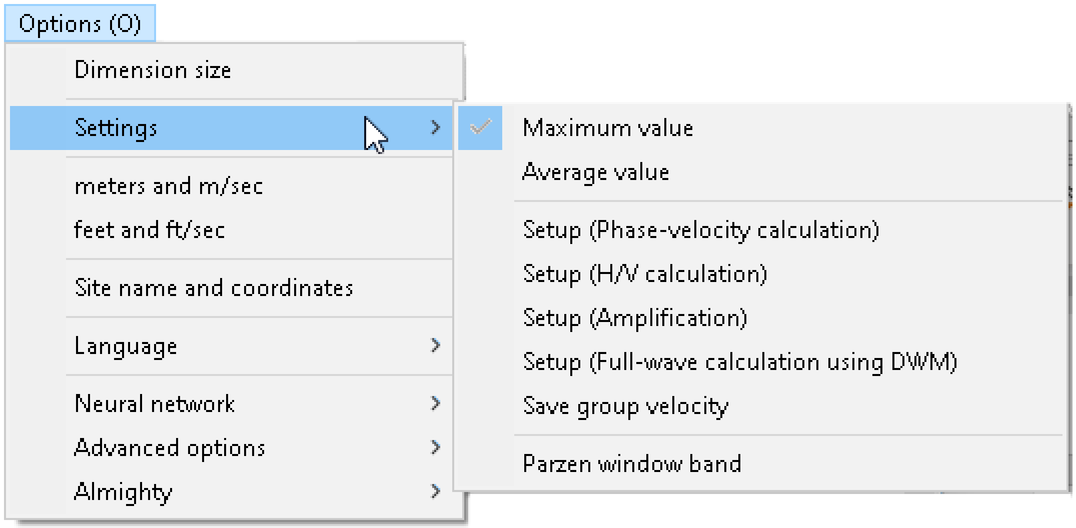


Figure 101: Example of theoretical H/V for the velocity model shown in Figure 97.

5.2.1 How to Handle Higher Modes in SeisImager/SW

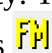
Calculation of the fundamental and higher modes can be activated by selecting the FM and HM buttons on the tool bar. Once the fundamental mode or higher mode button is activated, select the Calculate Theoretical Dispersion Curves button and WaveEq calculates the designated mode. Note that the setting for the calculation of theoretical dispersion curves is applied to forward modeling the theoretical data used in inversion processing as well. The detailed setting of higher modes calculation can be changed under *Options* | *Settings*:



5.2.1.1 MAXIMUM AND AVERAGE VALUE

As mentioned earlier, the theoretical phase velocity may be calculated under "averaged" or "maximum" dispersion curve assumptions. Activate *Maximum value* or *Average value* in the **Settings** sub-menu to switch methods. We recommend using *Maximum value* or *Average value* for MASW and SPAC respectively.

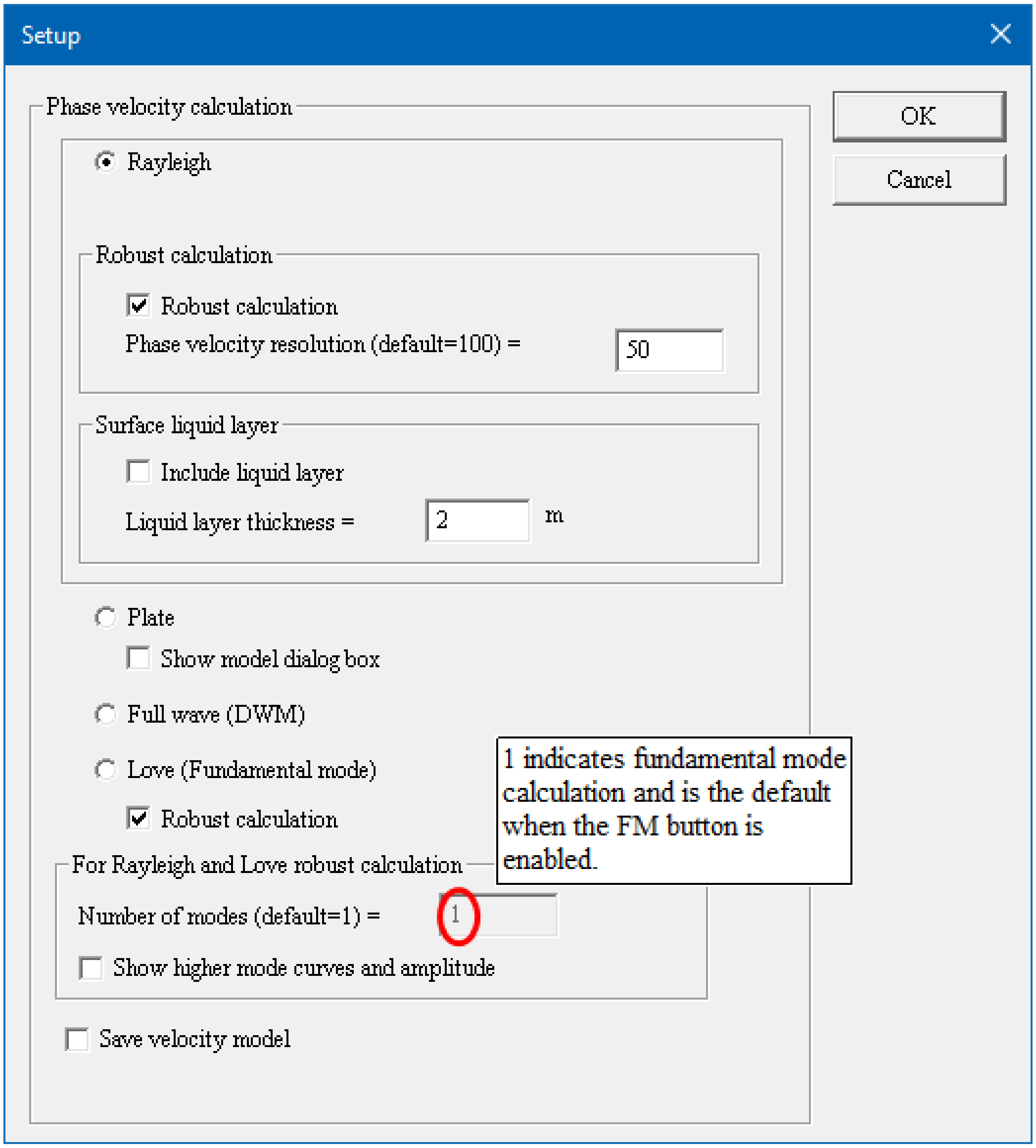
5.2.1.2 SETUP (PHASE VELOCITY CALCULATION)

Select *Options* | *Settings* | *Setup (Phase velocity calculation)* to change the settings for higher mode calculations of phase velocity. The following dialog box appears when the fundamental mode calculation is selected (press 

on the tool bar). Note that the *Number of modes* is hardwired to one.

When 

is selected, the *Number of modes* is changeable and will be a larger number. Use 5 to 20 for the number of modes. The computation time is proportional to the number of modes integrated. Calculating five to ten modes is suitable for most cases. Use 20 to 50 if the data includes significant higher modes that are due to a high-velocity thin layer underlying a low-velocity layer.



5.2.1.3 Inversion With Changing Thickness

In SeisImager/SW, S-wave values are calculated while assuming a fixed number of layers and thicknesses. Inversion requires many layers, typically 10 to 20, and the flexibility of the inversion is somewhat restricted. In SeisImager/SW-Pro, the thickness of each layer can also be optimized in the inversion. Parameterizing layer thickness allows you to use a velocity model with a smaller number of layers, such as 2 to 5. You can choose an appropriate velocity model parameterization and inversion method depending on the data characteristics and purpose of investigation. Table 8 summarizes the suggested selection of model parameterization and inversion methods.

		Model Parameterization	
		Small layer number (<7 layers)	Multi-layer model (≥10 layers)
Data	1D dispersion curve	VS and thickness	VS only
	1D H/V	VS and thickness Thickness only	VS only
	1D dispersion curve and H/V	VS and thickness	VS only
	2D dispersion curves	VS only	VS only

Table 8: Suggested selection of unknowns in inversions depending on model parameterization.

5.2.1.4 INVERSION USING GENETIC ALGORITHM

As mentioned before, in complex velocity structures, higher modes may dominate in a particular frequency range and cause dispersion curves to look discontinuous. Higher modes can be represented as "maximum" and "averaged" phase velocities. As shown in Figure 99, "averaged" phase velocity is generally smooth and continuous while "maximum" phase velocity is discontinuous. SeisImager/SW uses a non-linear least squares method (LSM) for inversion and cannot handle discontinuous dispersion curves, such as those in "maximum" phase velocity curves, which may contain higher modes. It is generally difficult to separate the fundamental mode and the higher modes correctly, and traditional inversion methods based on the Jacobian matrix cannot be applied.

To overcome these difficulties, SeisImager/SW-Pro introduced a new inversion method using a Genetic Algorithm (Yamanaka and Ishida, 1995). Genetic Algorithm (GA) 17 is a search method that mimics the process of natural evolution and is routinely used to generate useful solutions to optimization and search problems. The method is characterized as a global search method and can mitigate convergence upon local minima. One clear disadvantage of GA is that the method requires a large amount of forward modeling compared to the conventional iterative non-linear least squares method.

Computation time of inversion generally increases as the amount of data increases, the number of layers increases, whether GA is used, and higher modes are included. Select the appropriate inversion method depending on character of data, model parameterization, and purpose of investigation. Summary of calculation methods of dispersion and H/V curves are shown in Table 9. General guidelines for selection are summarized in Table 10.

Data	Acquisition method	Modes	Appearance	Forward modeling	Inversion
Dispersion curve	Active (MASW)	Fundamental	Discontinuous	Fundamental	LSM
		Higher	Continuous	Maximum	GA
	Passive (MAM)	Fundamental	Discontinuous	Fundamental	LSM
		Higher	Continuous	Averaged	LSM or GA
H/V	Passive	Fundamental	Discontinuous	Fundamental	GA
		Higher	Discontinuous	Averaged	GA

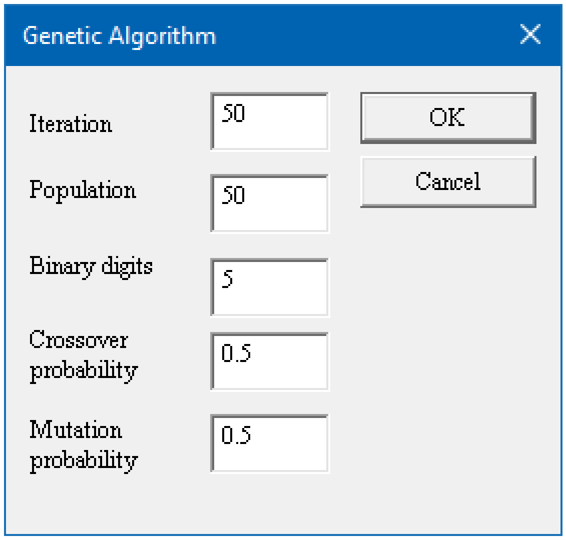
Table 9: Calculation methods of dispersion and H/V curves.

Data	Data acquisition	Forward modeling	Model	
			Small layer number (<7 layer)	Multi-layer model (10 layer <)
1D dispersion curve (fundamental mode)	MASW or MAM	Fundamental	LSM, GA	LSM
1D dispersion curve (higher mode)	MASW	Maximum	GA	GA
	MAM	Averaged	LSM, GA	LSM
1D H/V	H/V	Fundamental	GA	GA
	H/V	Averaged	GA	GA
1D dispersion curve and H/V	MAM and H/V	Fundamental	GA	GA
		Averaged	GA	GA
2D dispersion curve (fundamental mode)	MASW	Fundamental	LSM	LSM
2D dispersion curve (higher mode)	MASW	Maximum	GA	GA

Table 10: Selection of inversion methods depending on model parameterization and higher modes.

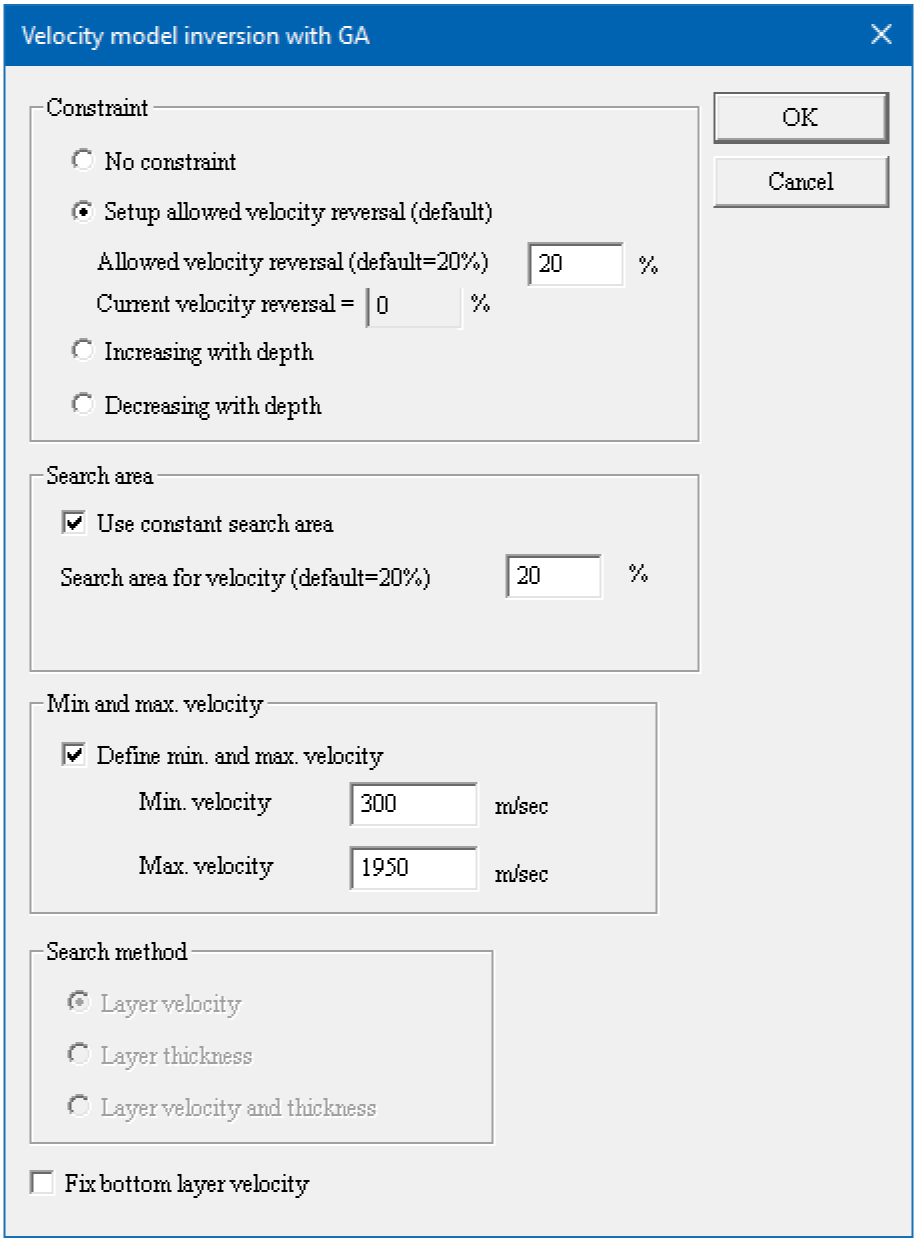
5.2.1.4.1 PARAMETERS FOR INVERSION USING GENETIC ALGORITHM

The following dialog box appears when carrying out inversions using the Genetic Algorithm (GA). The GA is a random search in which many models are randomly created. The degree to which the final model fits the observed data depends on how many models were used in the inversion and several other factors. The total number of models calculated in the GA is equal to the number of “iterations” times the “population”. Computation time of the GA is directly proportional to the total number of models incorporated. Both the number of iterations and the number of populations can be between 20 and 100. Default values (50) are suitable for most cases.



5.2.1.4.2 CONSTRAINTS FOR INVERSION USING GENETIC ALGORITHM

After the initial GA parameter setup, the following dialog appears:



A) Constraint

Four different velocity models can be assumed. Typical dispersion curve and velocity models considered are summarized in the figures shown below. Note that the bottom layer (the deepest layer) must have the highest velocity in all models.

A.1) *No constraint*

The velocity of each layer can be of any value except that of the bottom layer. The inversion with no constraint tends to be unstable and it is advised to use this option with caution.

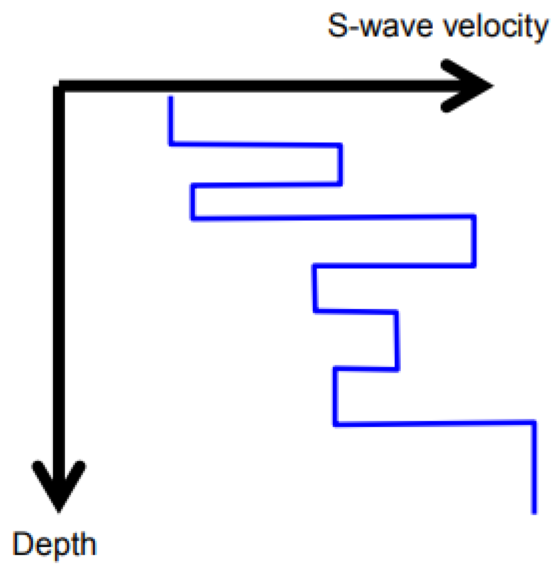


Figure 102: S-wave velocity model with no constraint.

A.2) *Setup allowed velocity reversal*

Define the total velocity reversal (inversion) against the maximum velocity in percent. The total velocity reversal (inversion) is the summation of the velocity decrease (a+b+c). The *Allowed velocity reversal* (P) is expressed by the following equation using the maximum velocity d.

$$P(\%) = \frac{a+b+c}{d} \times 100$$

The *Allowed velocity reversal* (P) option allows a percentage of velocity inversion. Natural ground may have a slight velocity reversal, particularly in the shallow (shallower than 100 m) region. So, a default value of 20% of the *Allowed velocity reversal* is selected. S-wave velocity is generally increasing at greater depths, and it is recommended to use the *Increasing with depth* option if the investigation depth is greater than 100 m.

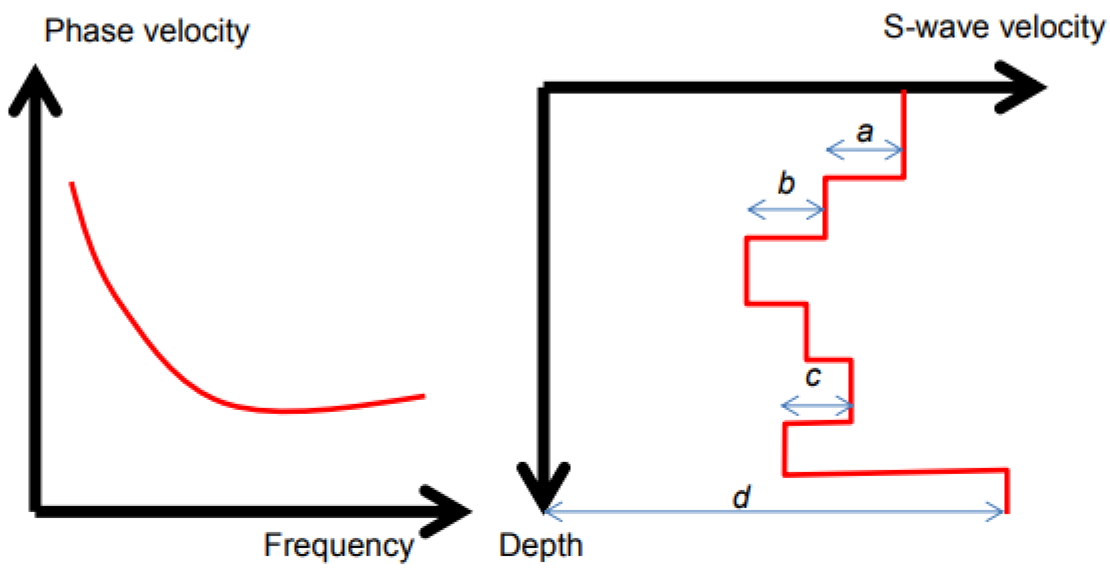


Figure 103: S-wave velocity model with allowed velocity inversion.

A.3) *Increasing with depth*

Velocity must increase with depth with this option. This option is suitable when the phase velocity smoothly increases as frequency decreases or if the depth of investigation is greater than 100 m.

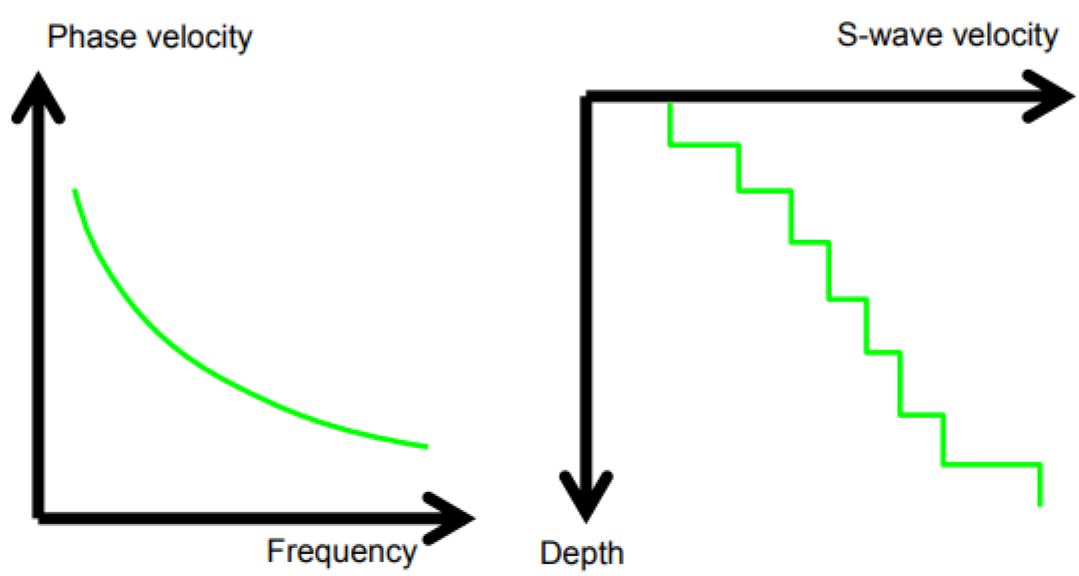


Figure 104: S-wave velocity model having increasing velocity with depth.

A.4) Decreasing with depth

Velocity must decrease with depth with this option except for the bottom layer. Use this option when phase velocity increases as frequency increases. S-wave velocity generally increases with depth in the natural ground, so phase velocity is usually inversely proportional to frequency. The dispersion curves and S-wave velocity structures associated with this option are quite unusual. S-wave velocity values that decrease with depth are usually associated with artificial structures such as paved surfaces, embankments, soil modification, etc.

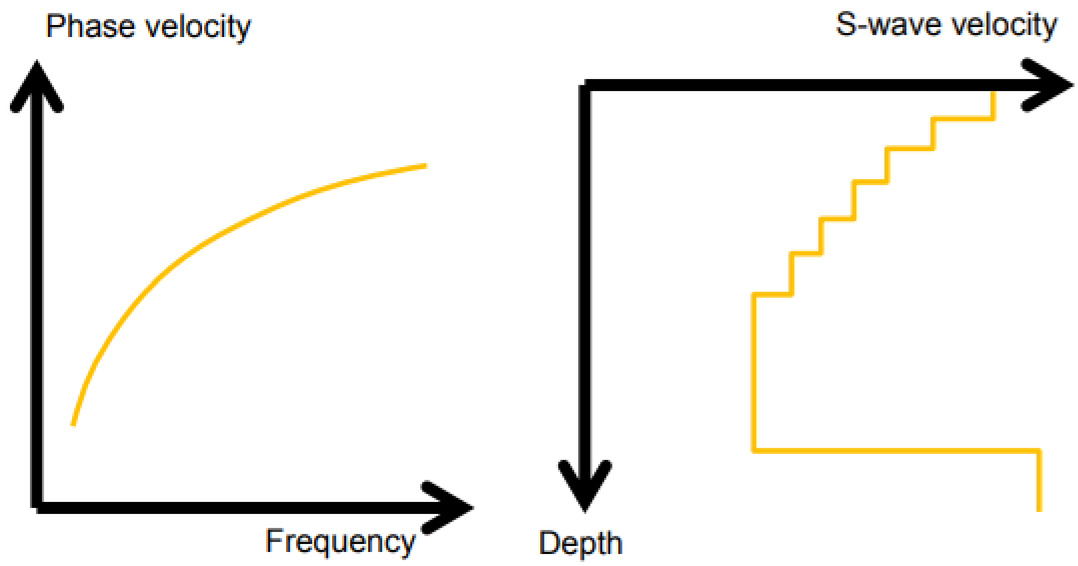


Figure 105: S-wave velocity model having decreasing velocity with depth. All methods assume the bottom layer has the highest S-wave velocity.

5.2.1.5 2D Inversion including higher modes using Genetic Algorithm

The Genetic Algorithm is the recommended inversion procedure for incorporating higher mode data. As mentioned in Section 5.2.1.4 (Page 201), higher mode dispersion curves are discontinuous and may not be handled optimally by traditional inversion procedures. A Genetic Algorithm approach may handle discontinuous, higher mode data more optimally. Since the Genetic Algorithm is time consuming compared to the non-linear least squares method, SeisImager does not simply apply it to all dispersion curves. The Genetic Algorithm is only applied to one location – one dispersion curve and associated 1D model – out of all data along a survey line. Velocity models at other locations are modified with the calculation result of the Genetic Algorithm applied to one location. For this reason, it is better to call the inversion a "pseudo 2D inversion". Figure 106 below shows the processing flow of a 2D inversion using the Genetic Algorithm. The inversion procedure is summarized as follows: At first, theoretical phase velocities are calculated for dispersion curves and associated 1D velocity models at all locations (Figure 107). Observed and theoretical phase velocities are compared and residuals (RMSE:

root-mean-square error) are calculated for all locations. A dispersion curve and an associated 1D velocity model that has the largest residual (RMSE) is selected. An inversion using the Genetic Algorithm is applied to the 1D model that has the largest residual. The Genetic Algorithm randomly generates many velocity models and calculates theoretical phase velocities for the models. All velocity models and associated theoretical phase velocities are stored in memory during the inversion (Figure 108). The result of the Genetic Algorithm for the 1D model that has the largest residual is used for that location. For other locations, memorized theoretical phase velocities are compared with each observed dispersion curve and a 1D model that yields minimum error is used for the model at each location (Figure 109). Refer to Section 5.2.1.4 on Page 201 for further details of inversion using Genetic Algorithm.

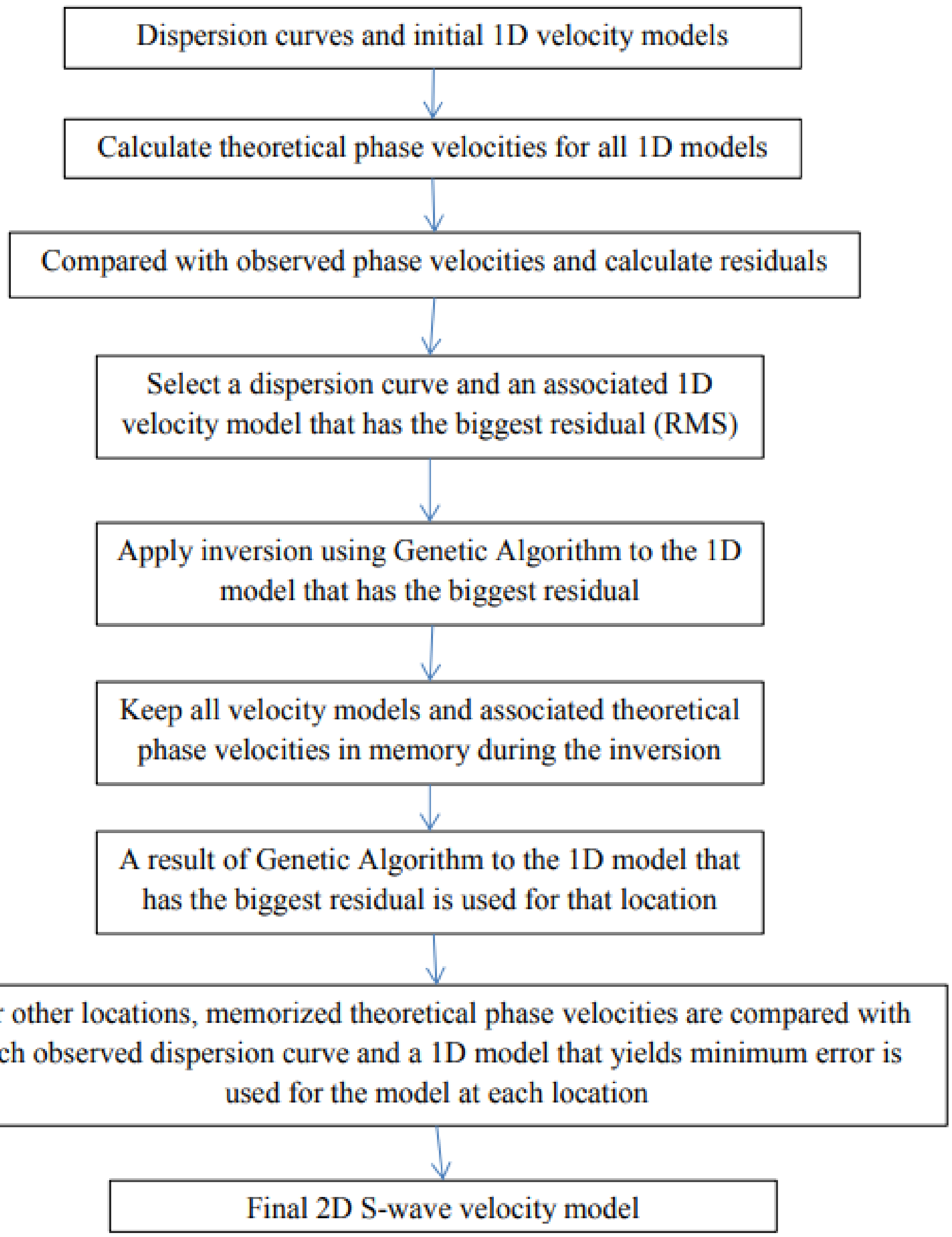


Figure 106: Processing flow of a 2D inversion using Genetic Algorithm.

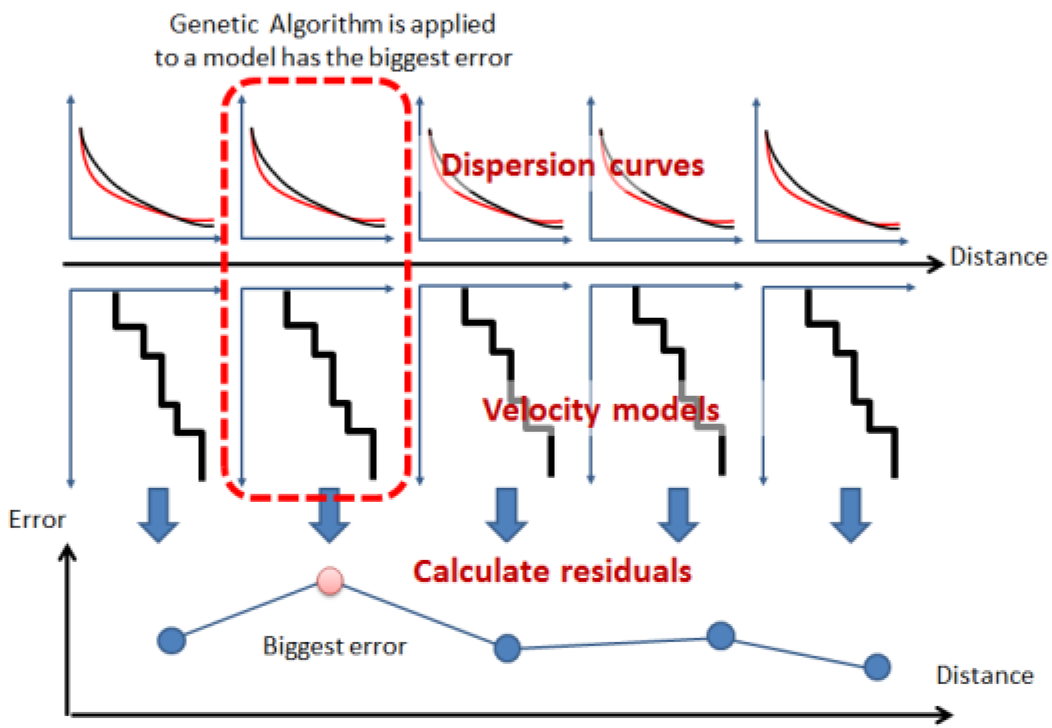


Figure 107: Selection of dispersion curve and velocity model for Genetic Algorithm in 2D.

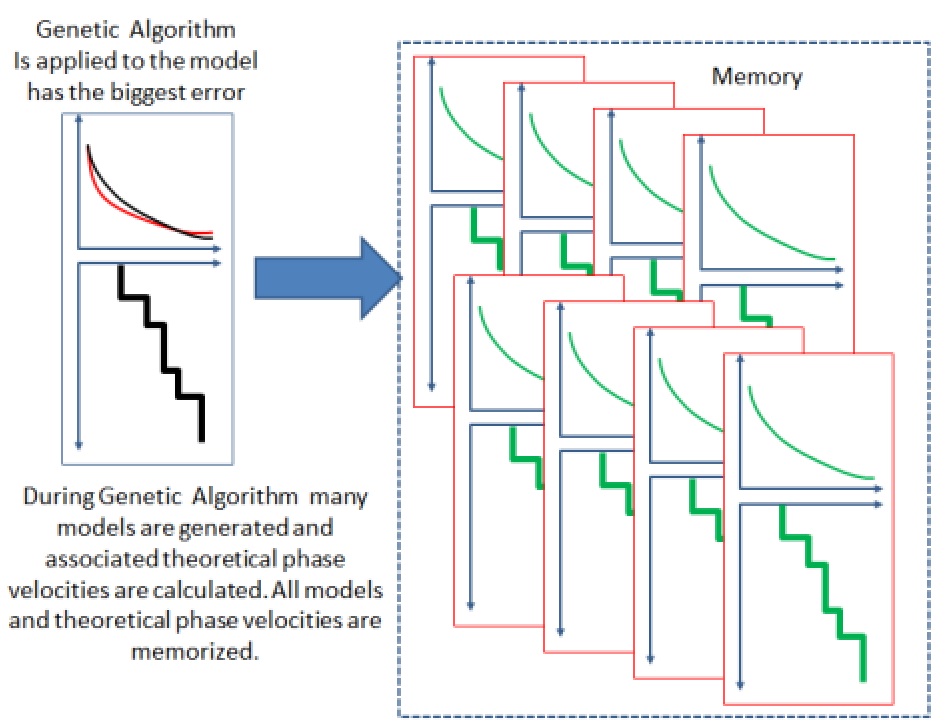


Figure 108: All velocity models and associated theoretical phase velocities are kept in memory during inversion using Genetic Algorithm.

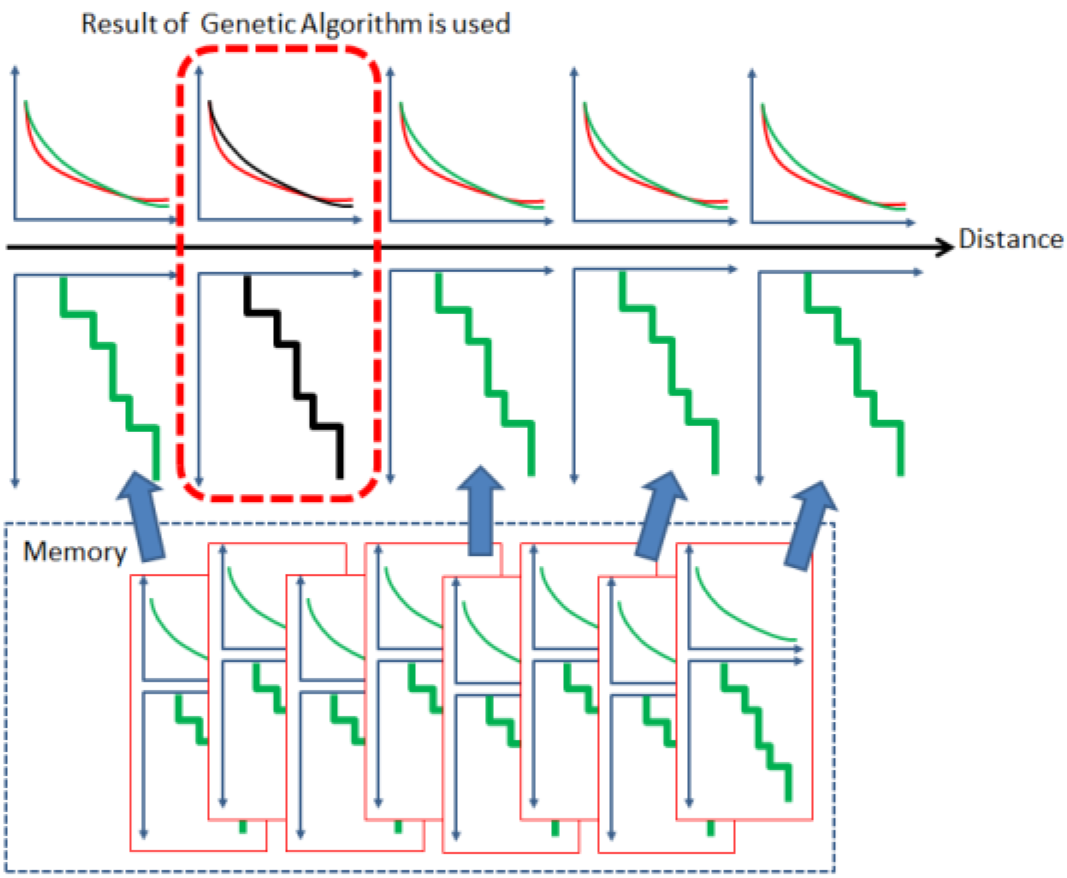
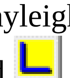


Figure 109: Memorized theoretical phase velocities are compared with each observed dispersion curve and a 1D model that yields minimum error is used for the model at each location.

5.2.1.6 Higher Modes of Love Waves

The higher modes of Love waves can be calculated and used in inversions. Rayleigh and Love waves can be switched by buttons on the toolbar ( for Rayleigh waves and  for Love waves). In Figure 110, the fundamental mode of Love waves is shown as a blue line. For higher mode calculation, “maximum” and “averaged” modes are shown as blue and green respectively.

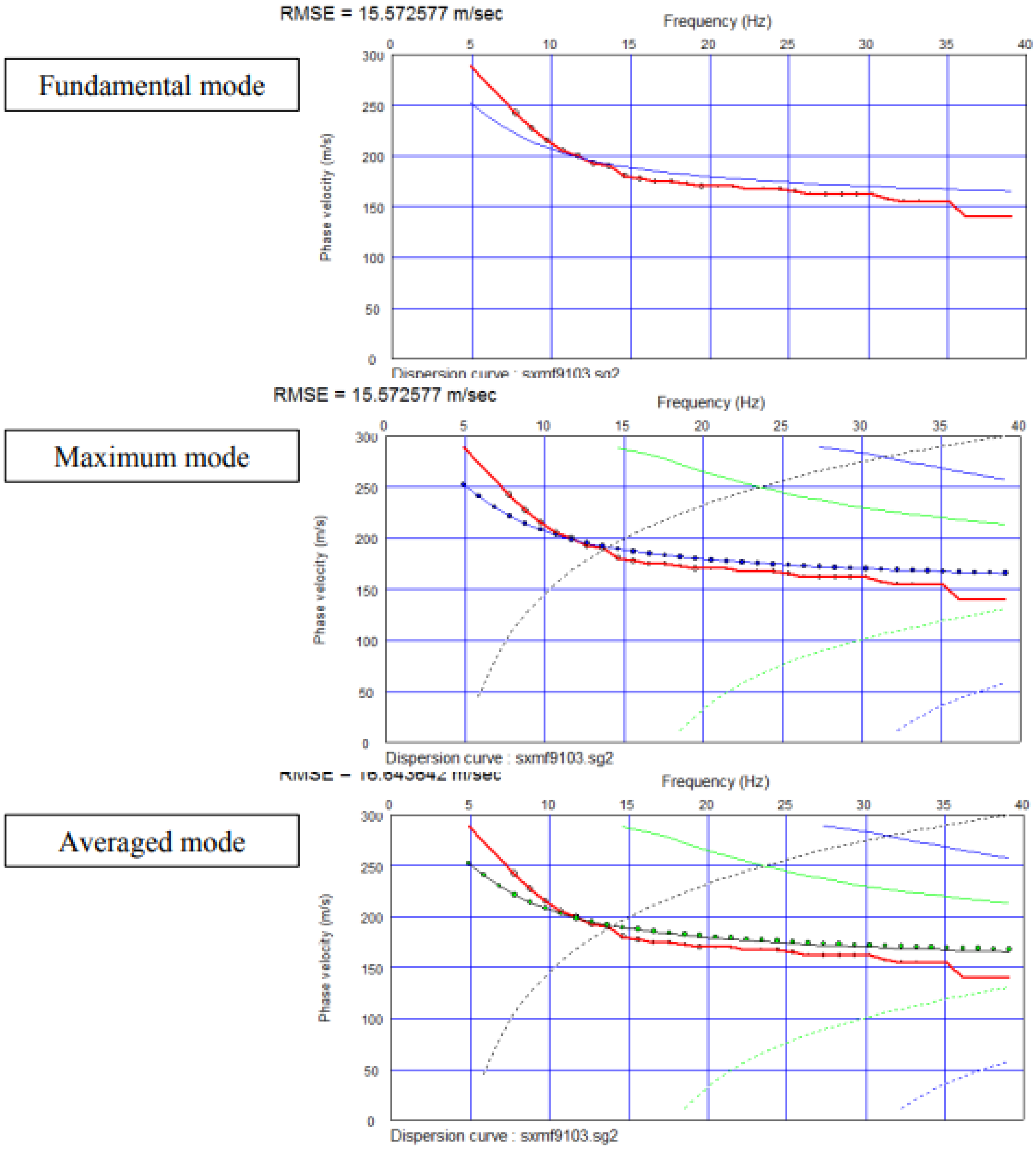


Figure 110: Display of theoretical dispersion curve for Love waves.

5.3 JOINT INVERSION OF DISPERSION CURVE AND H/V

Phase velocity data and H/V data can be used in an inversion simultaneously to further constrain the model (Suzuki and Yamanaka, 2010). As mentioned before, it is difficult to obtain an accurate velocity model from H/V data alone. Dispersion curve inversion solutions are generally non-unique and may not always be accurate. Incorporating H/V and phase velocity data in a joint inversion scheme allows for the production of a more constrained final model and may also increase depth of investigation. Generally speaking, information contained in H/V data is limited compared to dispersion curve data. Therefore, if there are both phase velocity and H/V data, it is better to use phase velocity data to construct the S-wave velocity model, until data misfit is sufficiently low. Once the error between observed and theoretical phase velocities is deemed small enough, H/V data may be incorporated into the inversion process. The suggested processing flow is shown below (Figure 111). See Section 7.7.4.3 on Page 493 for an example of a joint inversion.

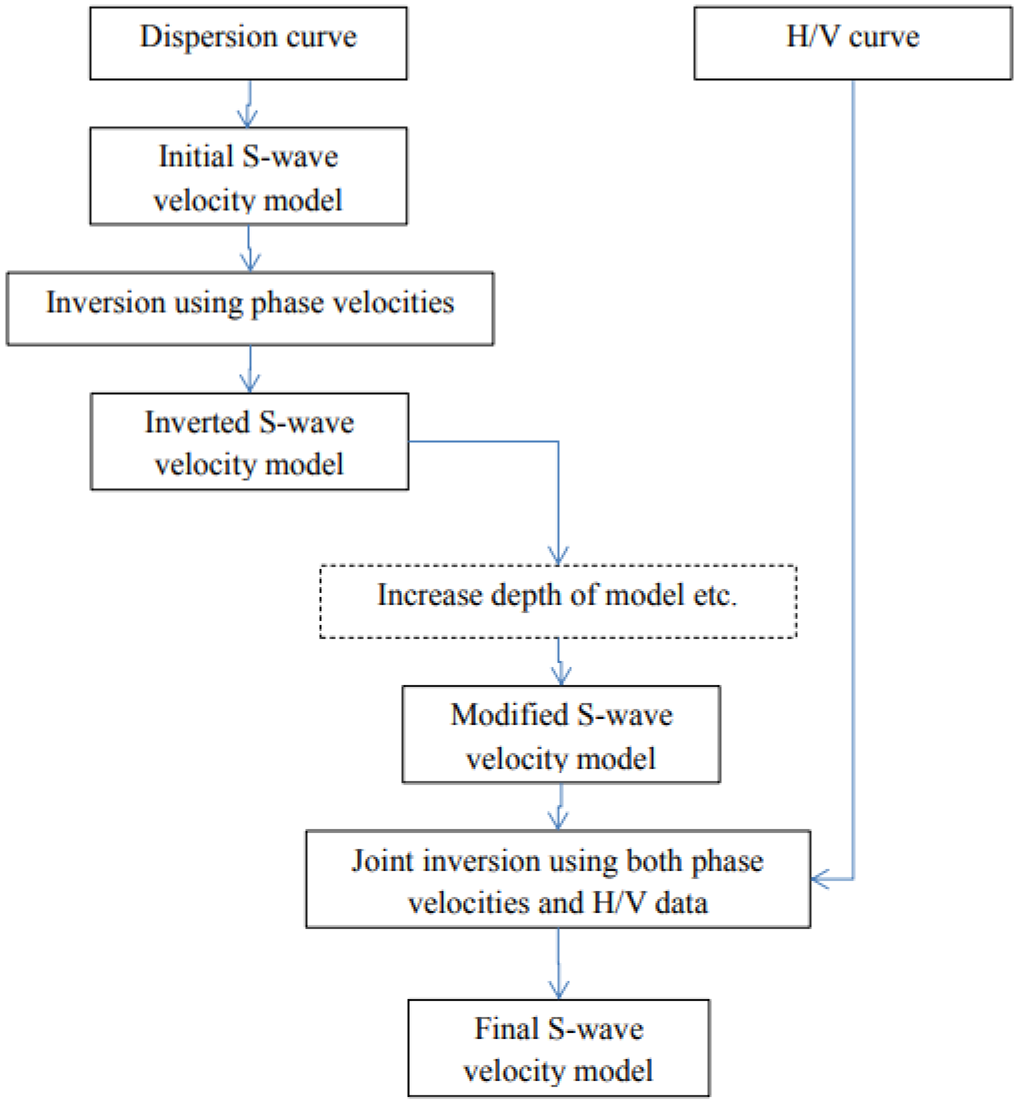


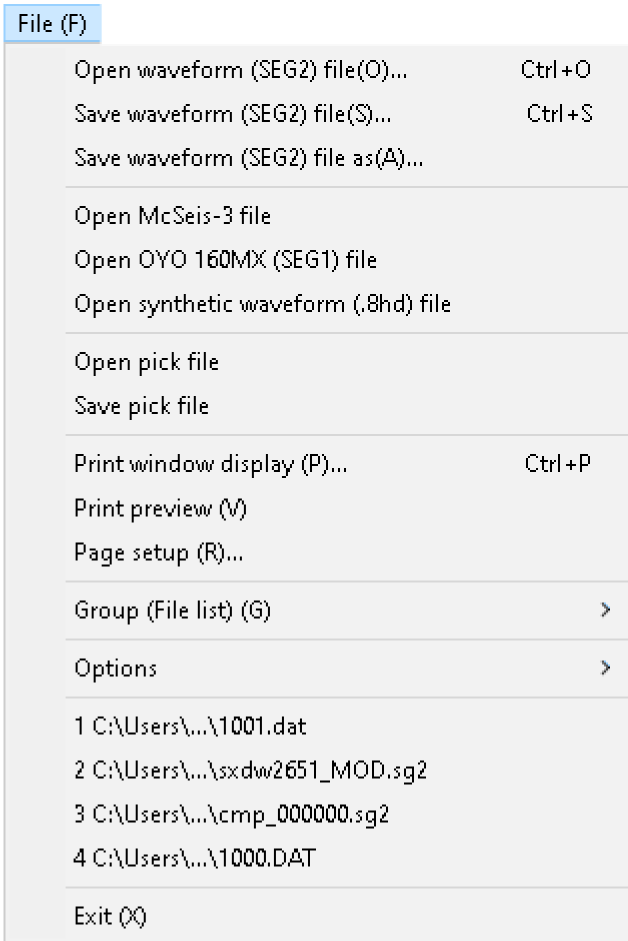
Figure 111: Suggested processing flow for joint inversion.

6 THE PICKWIN MODULE SURFACE WAVE ANALYSIS FUNCTIONS

Continue.

6.1 FILE MENU

The **File** menu functions essential or uniquely used for surface wave data processing are covered in this section. For a complete description of the **File** menu functions common to SeisImager/SW and SeisImager/2D, please refer to the separate SeisImager/2D manual.

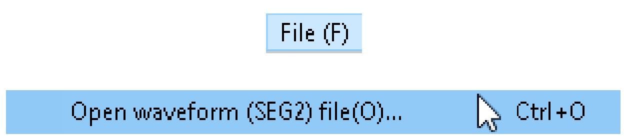


See Section 6.1.1, Page 214

See Sections 6.1.2, 6.1.3, and 6.1.4 (starting on Page 215)

See Section 6.1.5, Page 219

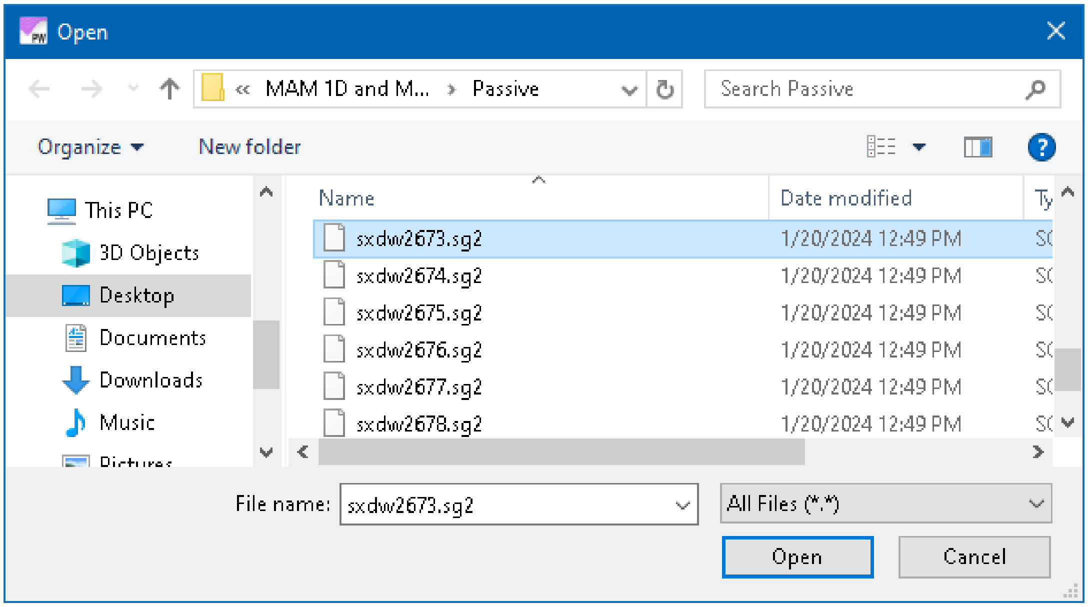
6.1.1 Open Waveform (SEG2) File [ctrl+O] 



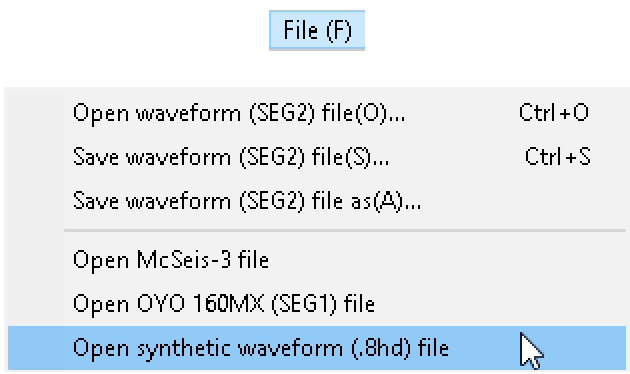
To open a 1D MASW active source data file in SEG-2 format, select *Open Waveform (SEG2) file*.

Depending on the model of seismograph used to collect the data, the *Files of type* setting may need adjustment for SEG-2 formatted files. Geometrics seismographs use the file extension *.dat* and OYO seismographs use the extension *.sg2*.

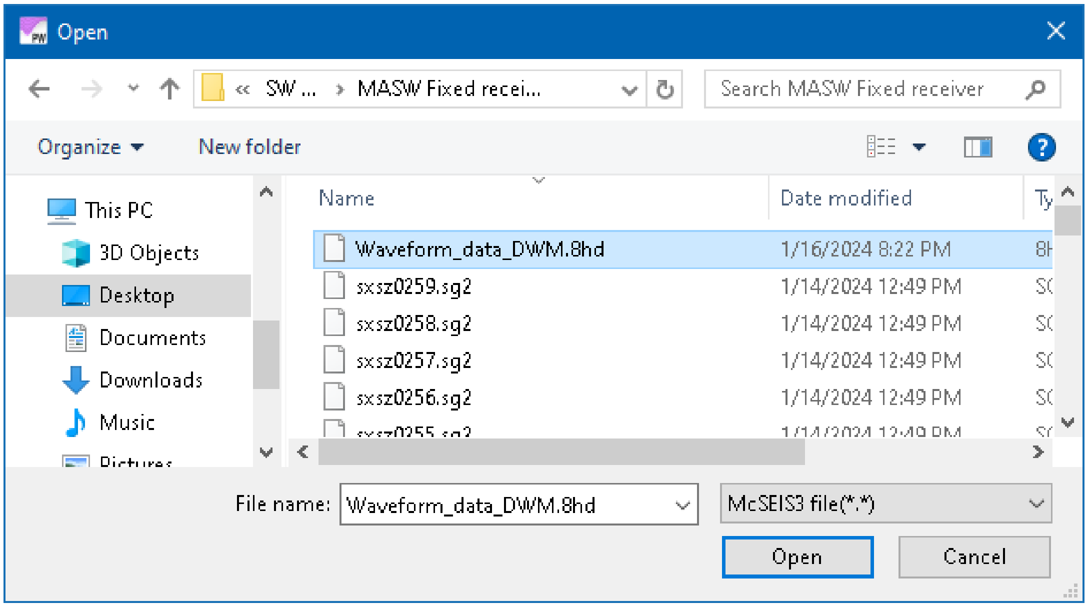
After setting the *Files of type*, highlight the file and press *Open*.



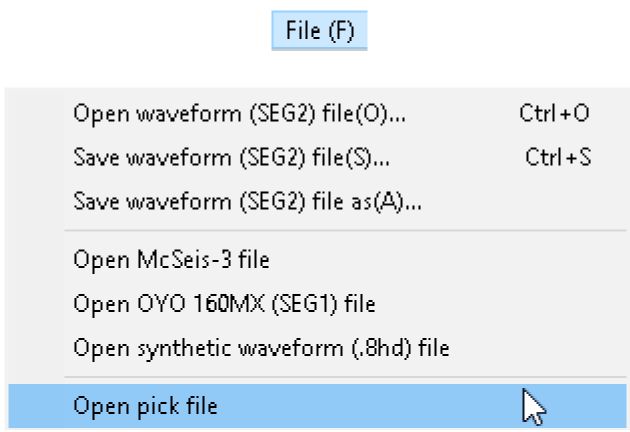
6.1.2 Open Synthetic Waveform (.8hd) File



To open a waveform file generated from a synthetic velocity model, select *Open synthetic waveform (.8hd) file*. Highlight the file and press *Open*.

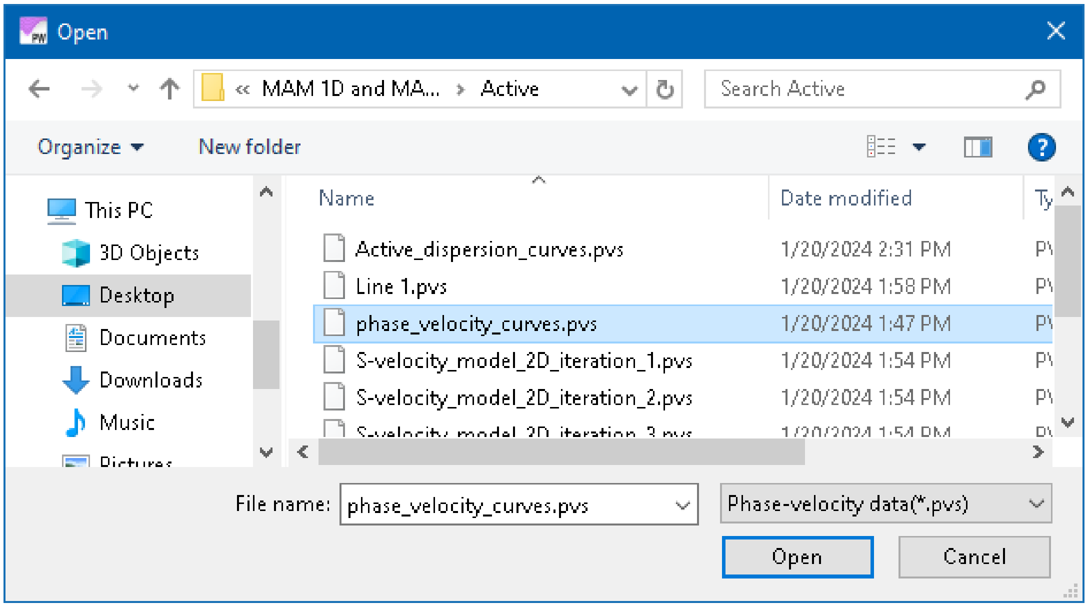


6.1.3 Open Pick File



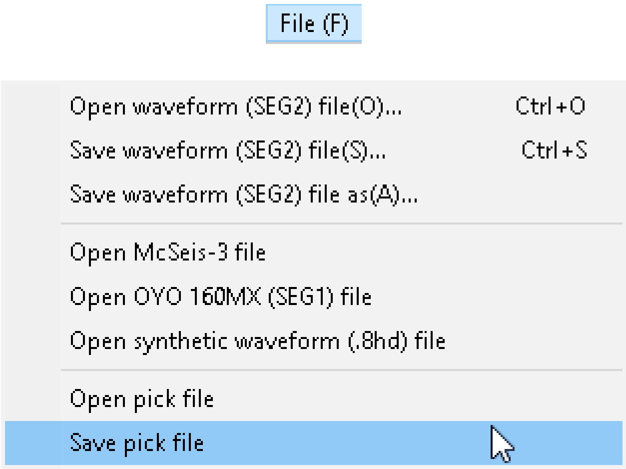
To use this function properly you should start with a new instance of Pickwin, not one in which data has already been processed. Double-click on the Pickwin icon to start a new instance; you need not close any other open Pickwin windows beforehand.

Open pick file is used to open a file of saved dispersion curve picks with the file extension *.pvs*. First the waveform file(s) from which the dispersion curve picks were derived should be opened by selecting the applicable *Open <___> file* function or the *Open file list* function. Next, select *Open pick file*. Adjust the *Files of type* setting to show *Phase velocity data (*.pvs)* types, highlight the file, and press *Open*.

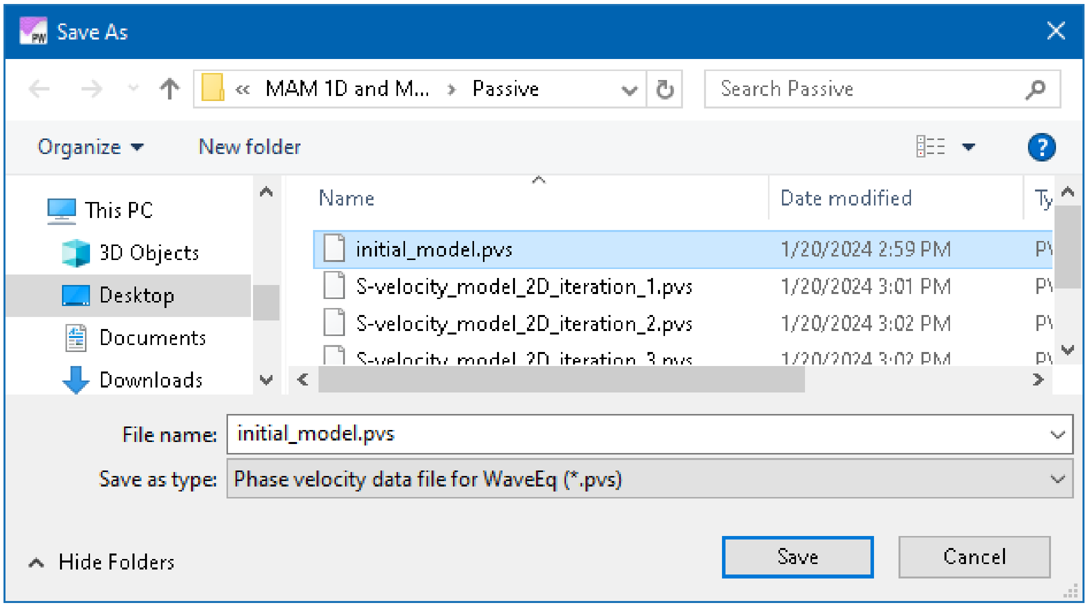


The dispersion curve picks will not be visible until the phase velocity is recalculated. Refer to Section 6.2.2, Page 254, on how to calculate phase velocity.

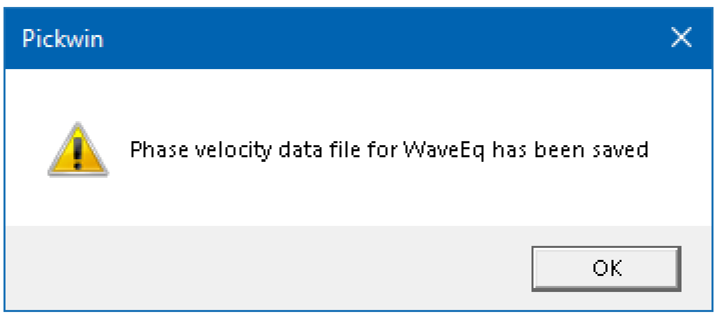
6.1.4 Save Pick File



To save dispersion curve picks, select *Save pick file*. Assign a file name with the extension *.pvs* and press *Save*.



Confirmation that the file has been saved is displayed. Press *OK*.



In the phase velocity-frequency plot view, the picks will be connected by a pink line.

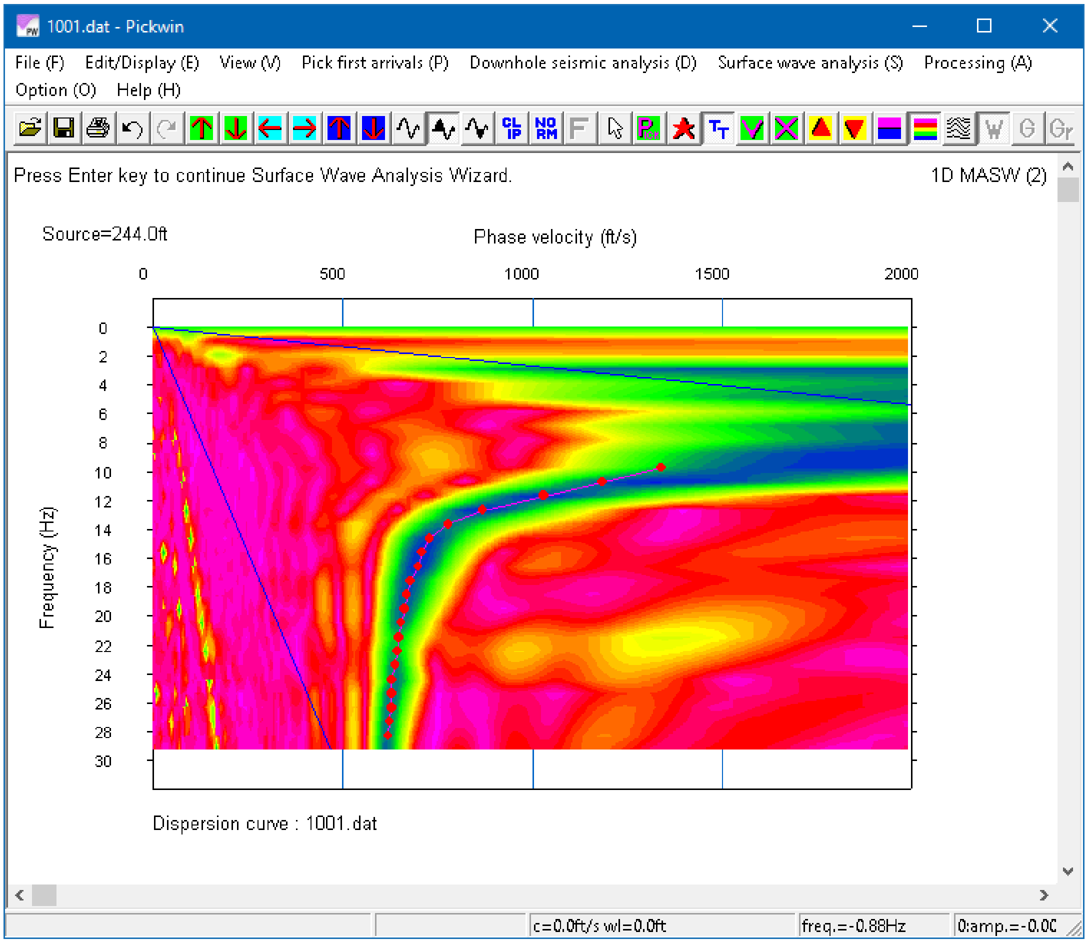
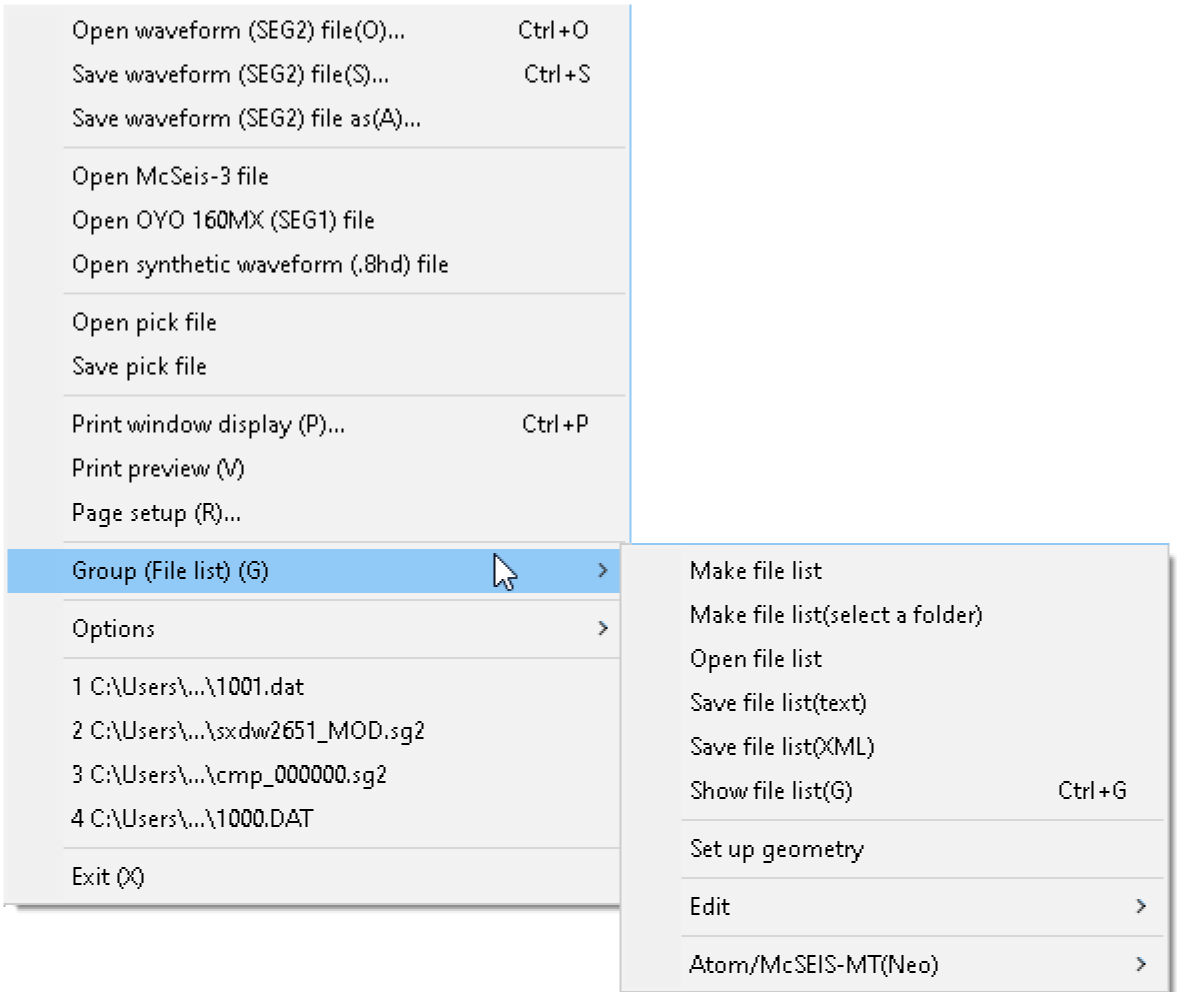


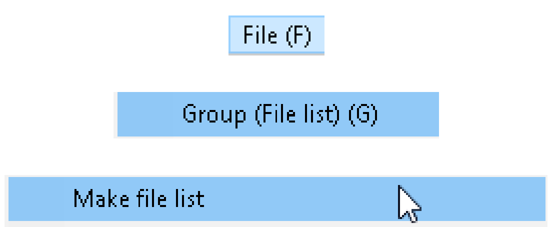
Figure 112: Phase velocity-frequency plot.

6.1.5 GROUP (FILE LIST)

The functions included in *Group (File List)* allow processing of a range of records, as with a MAM or 2D MASW dataset.

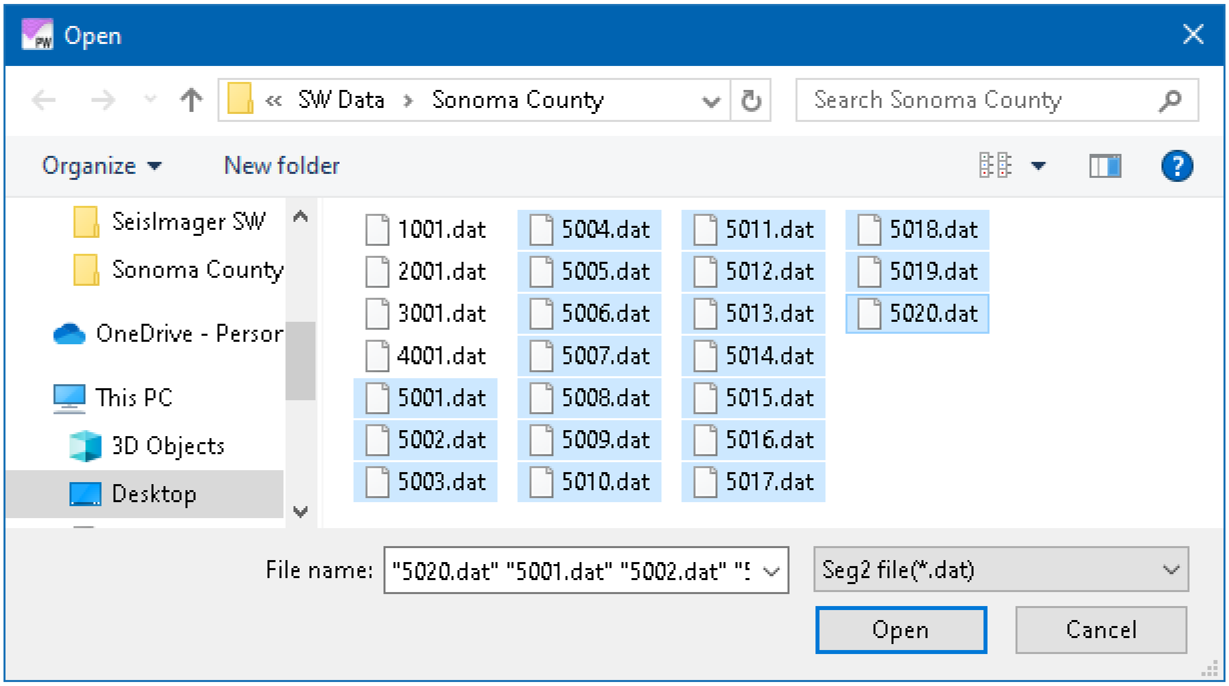


6.1.5.1 Make File List

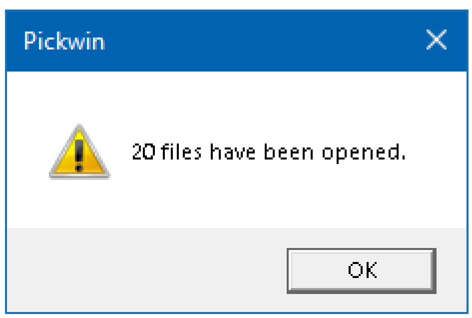


A *File list* is an inventory of data files from any given survey, and includes essential information for each waveform trace, such as the associated field file identification number and source and receiver locations. For surveys where multiple files are processed together, such as MAM or 2D MASW, the dataset must be input by making a file list.

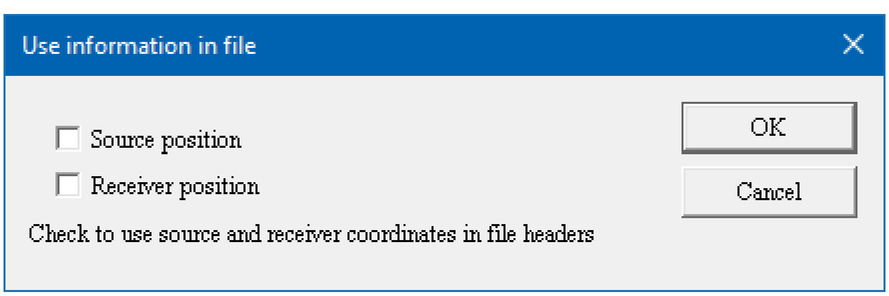
To make a list of files, select *Make File List*. After setting the *Files of type*, highlight the set of data files to be opened by using the *Shift* key to select a range of files or the *Control* key to select individual files. If *All files* is showing for the *Files of type* setting, take care not to inadvertently select non-data files as this will cause an analysis error.



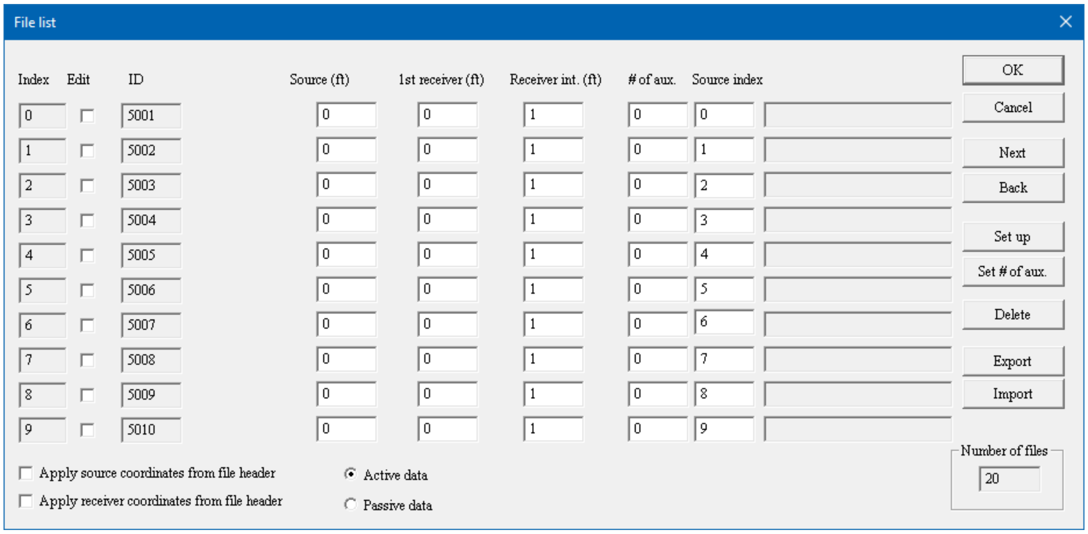
Confirmation that the files are input is displayed. Press *OK*.



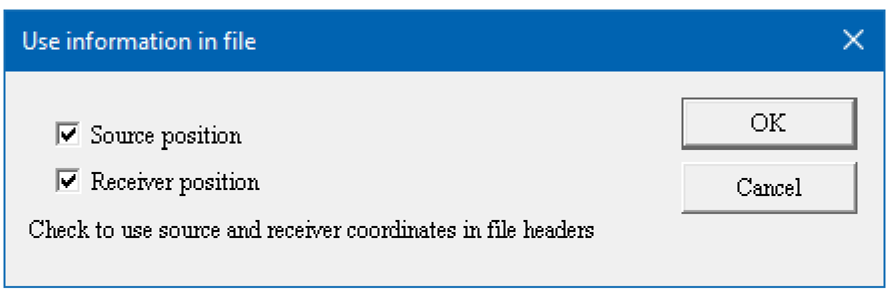
Next, you will be prompted to set up the geometry. For MAM datasets, the source locations are not applicable, and the geometry of the spread/array is set in a separate dialog box. Any coordinates saved in the file headers are not needed, so leave the boxes for *Source position* and *Receiver position* unchecked and press *OK*.



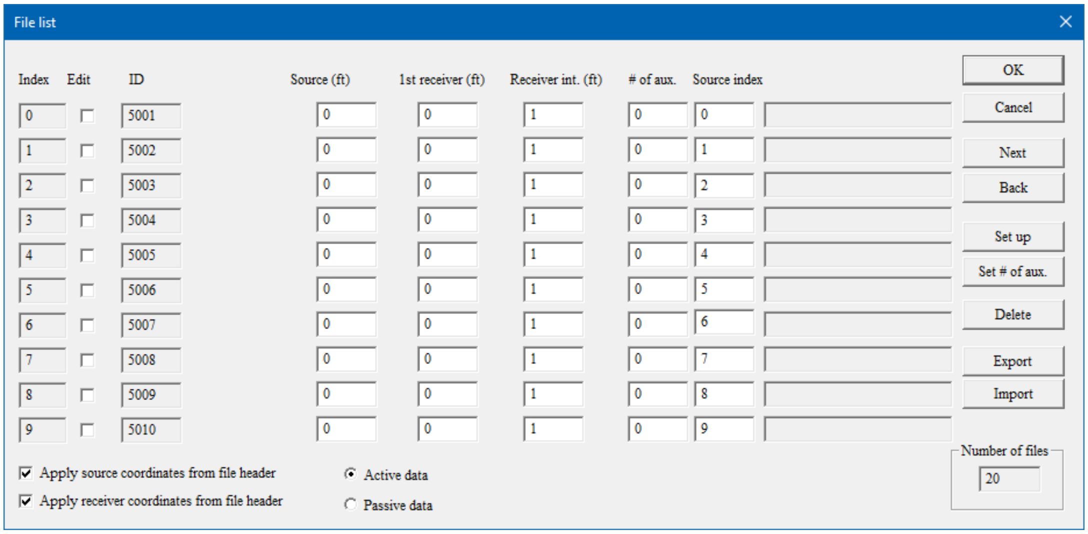
Next, the **File list** dialog box presents the data files listed by file *ID*. No action is needed for MAM datasets. Press *OK* to proceed to viewing the waveform files.



For 2D MASW datasets, if the geometry was saved in the file headers during acquisition, check *Source position* and *Receiver position* to apply those coordinates and press *OK*.

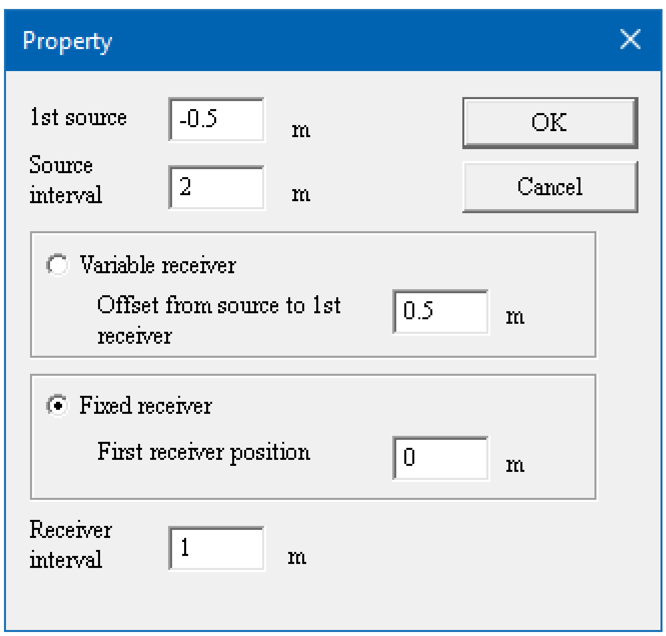


Next, the **File list** dialog box presents the data files listed by file *ID*. Even if *Source position* and *Receiver position* were checked in the previous dialog box, note that the actual values from the file headers will not yet be shown here in the *Source*, *1st Receiver*, and *Receiver int.* columns. Checking *Source position* and *Receiver position* in the previous dialog box activates the *Apply source coordinates from file header* and *Apply receiver coordinates from file header* options in this dialog box. If those options are checked, the coordinates from the file headers will be applied.



If coordinates are to be imported from the file headers, confirm that *Apply source coordinates from file header* and *Apply receiver coordinates from file header* are checked. Press *OK* to proceed to viewing the waveform files.

If coordinates are not to be imported from the file headers, coordinate values can be entered here in the *Source*, *1st Receiver*, and *Receiver int.* columns individually or by setting up and applying a geometry pattern via the *Set up* button. The default setup parameters are as shown below.



1st Source is the location of the first shot. The *Source interval* is the spacing between each shot.

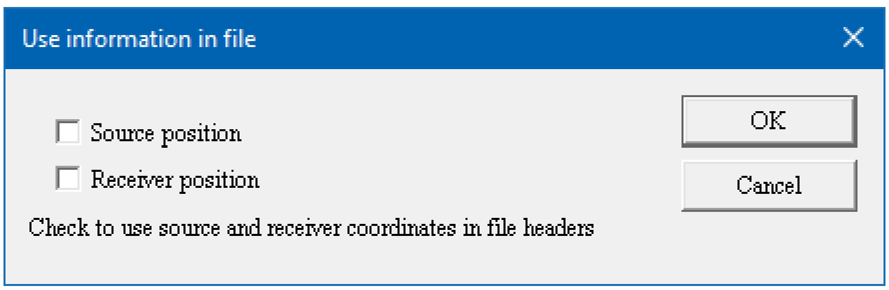
For a dataset collected with a rolling spread, that is, the geophone locations were not fixed, check the *Variable receiver* option. The *Offset from source to 1st receiver* is the distance from the shot to the nearest live geophone (the near offset). It is assumed that the line has been shot from lowest to highest channel number, indicated by a positive number for the *Source interval*. If the data was shot toward the lowest channel number, the *Source Interval* should have a negative number to indicate that the source rolled in this direction. This case can occur when using a Geometrics seismograph where the channel nearest the seismograph (and PC controller) is the highest by default, and the first shot was located at this end of the line.

For a dataset acquired with a fixed receiver spread, where the shot was moved through the spread, check the *Fixed Receiver* option. The *First receiver position* is the location of the first live geophone.

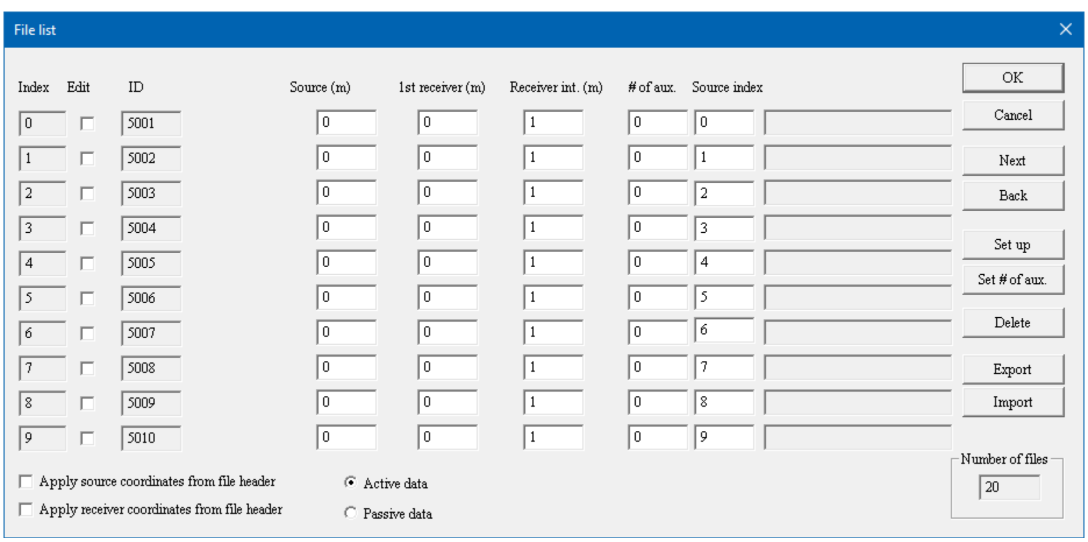
The *Receiver interval* is the spacing between geophones.

Example 2A: Set up a *Fixed receiver* geometry for the sample 2D MASW dataset with no file header coordinates. The dataset consists of 97 shots with the first and last shots off-end at 0.5 m near offsets, 24 geophones located at 0 to 23 m, and equal source and receiver intervals of 1 m.

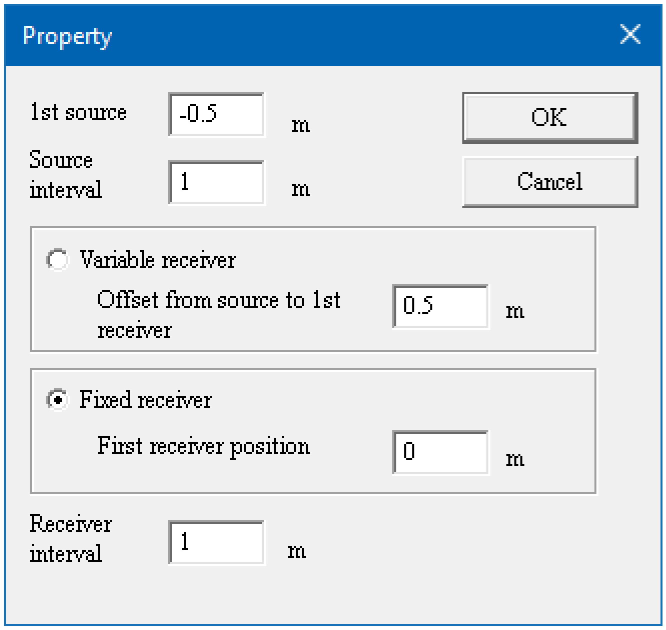
Starting at the geometry prompt, *Source position* and *Receiver position* are left unchecked.



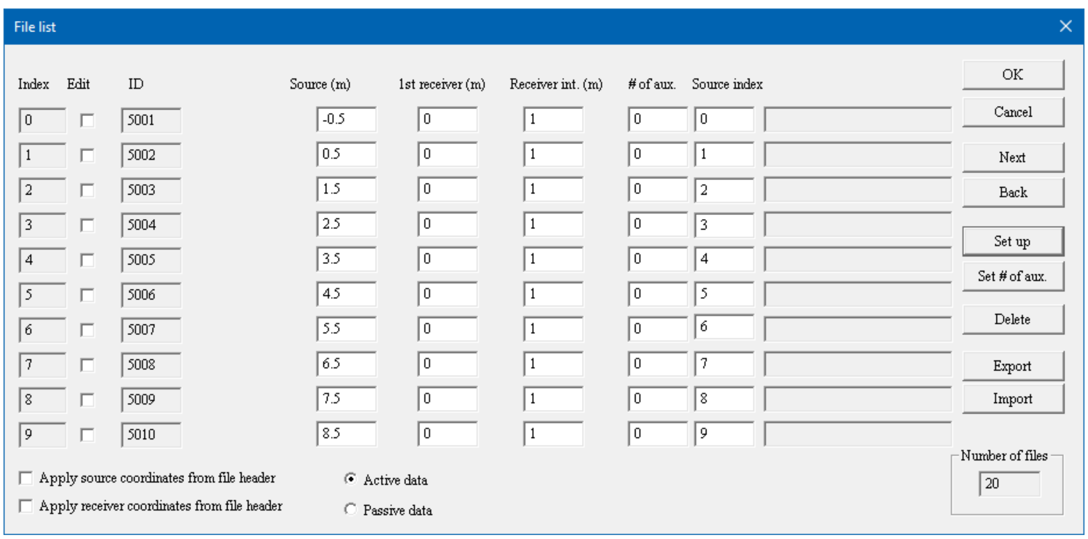
The **File list** dialog box shows the file IDs, but only default values for the *Source*, *1st Receiver*, and *Receiver int.* columns. Also, *Apply source coordinates from file header* and *Apply receiver coordinates from file header* are unchecked.



Through the **Set up** dialog box, enter and apply the applicable geometry values.



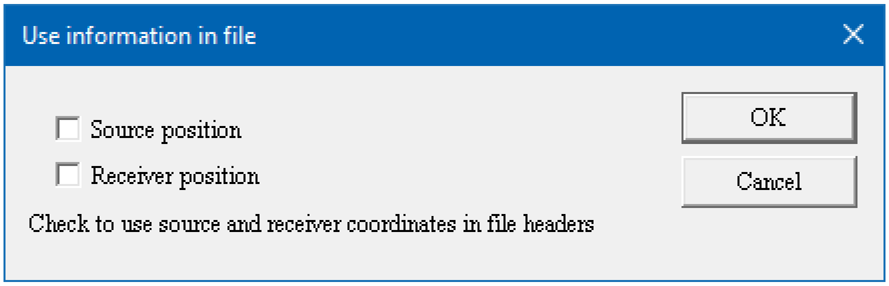
The **File list** dialog box now reflects the geometry pattern.



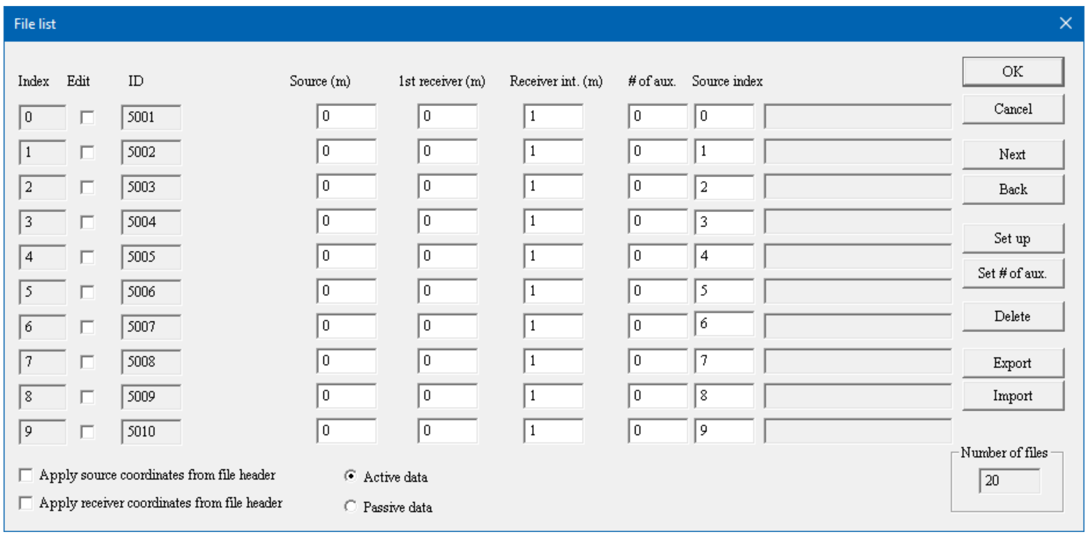
End Example 2A.

Example 2B: Set up a *Variable receiver* geometry for a sample 2D MASW dataset with no file header coordinates. The dataset consists of 25 shots with a near offset of 4 m, 24 geophones located at 0 to 46 m, and equal source and receiver intervals of 2 m.

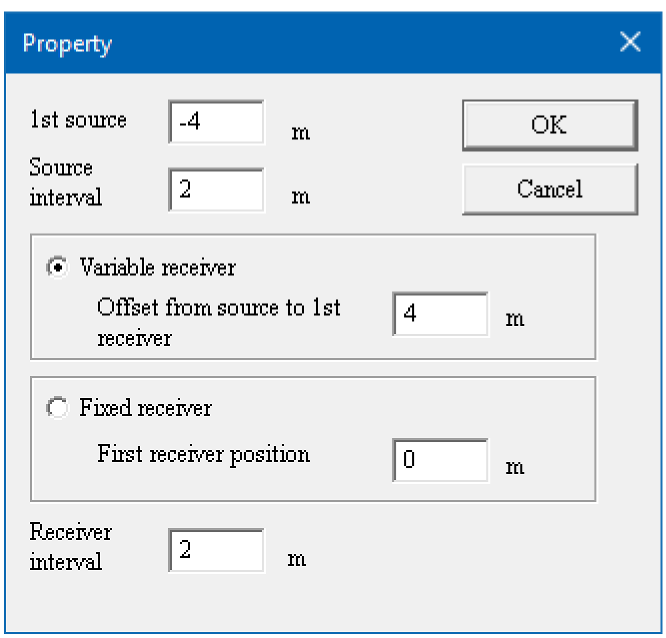
Starting at the geometry prompt, *Source position* and *Receiver position* are left unchecked.



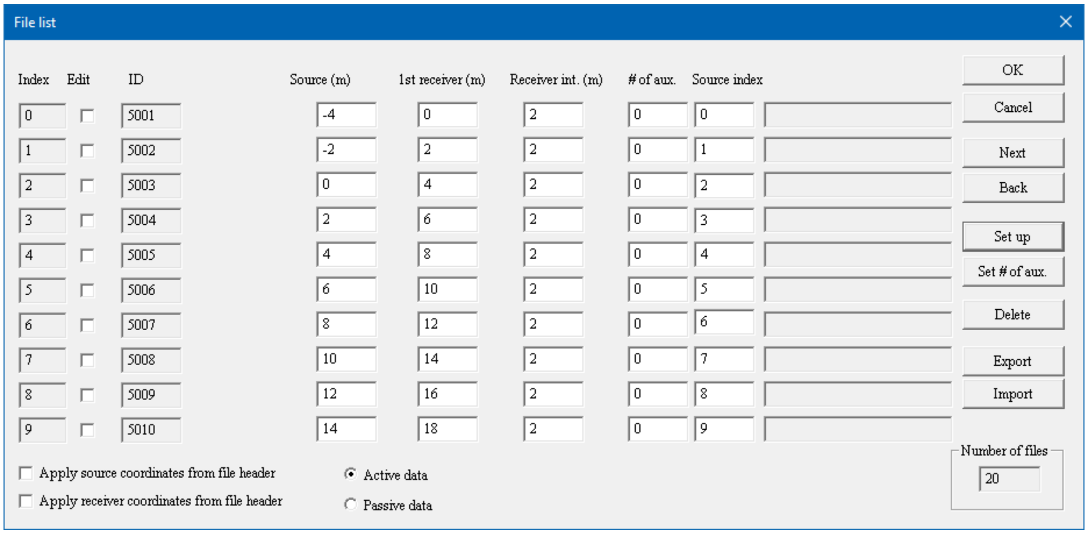
The **File list** dialog box shows the file IDs, but only default values for the *Source*, *1st Receiver*, and *Receiver int.* columns. Also, *Apply source coordinates from file header* and *Apply receiver coordinates from file header* are unchecked.



Enter and apply the applicable geometry values in the following dialog box:



The **File list** dialog box now reflects the geometry pattern.



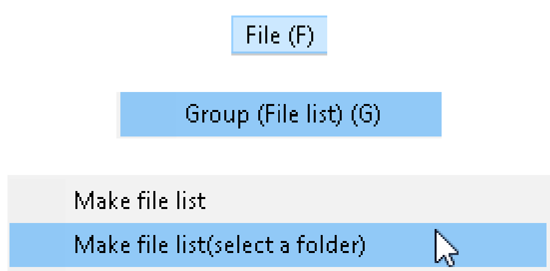
End Example 2B.

Additional functions in the **File list** dialog box include the *Next* and *Back* buttons, which allow scrolling through the next, or last, ten file *ID*s, respectively. For users of OYO seismographs, an auxiliary channel is automatically recorded; the number of the auxiliary channels can be indicated by pressing on the *Set # of Aux.* button. If any file needs to be deleted from a list, check the *Edit* box next to that file *ID* and press the *Delete* button.

Once the geometry assignment in the **File list** dialog box is complete, press *OK* to save the changes and proceed to viewing the waveform files.

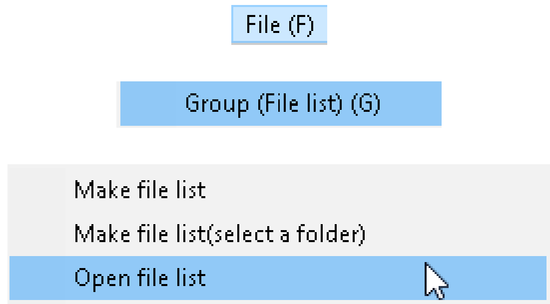
To view the assigned geometry again, the **File list** dialog box can be directly accessed at any time through the *Show File List* function.

6.1.5.2 Make File List (Select a Folder)

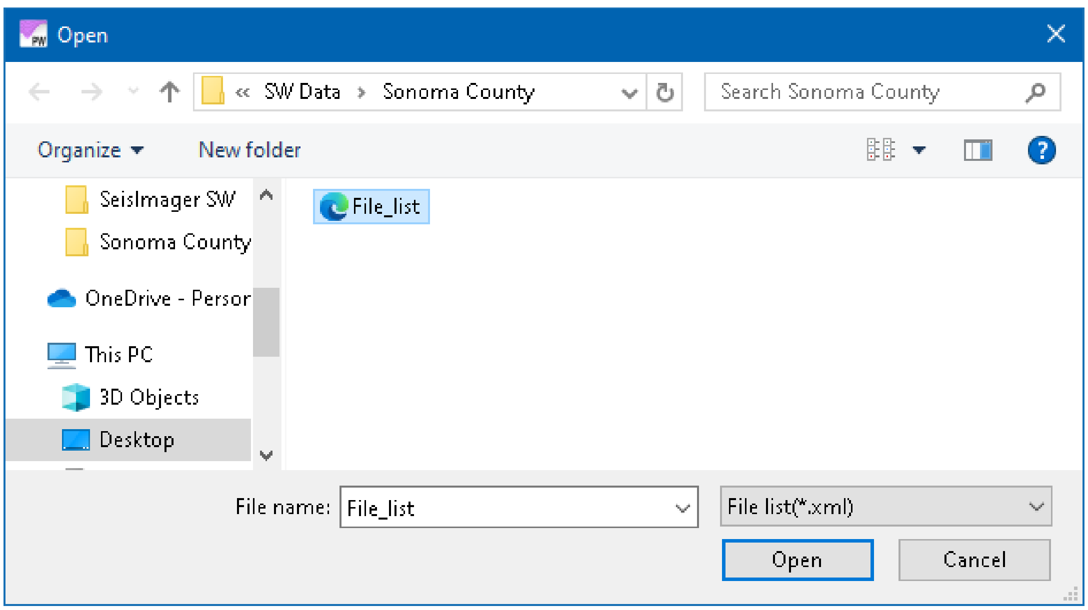


This feature is identical to *Make File List* above, except that in this case, all you must do is choose the folder that the seismic waveform files are in. You do not need to choose the files – all the waveform files in the folder will be read in. This is convenient when you have a large number of waveform files in a folder.

6.1.5.3 OPEN FILE LIST



To open an existing file list that was previously saved in a *.txt* or *.xml* format, select *Open File List*. Highlight the file list and press *Open*.



The waveform files with assigned geometry are displayed.

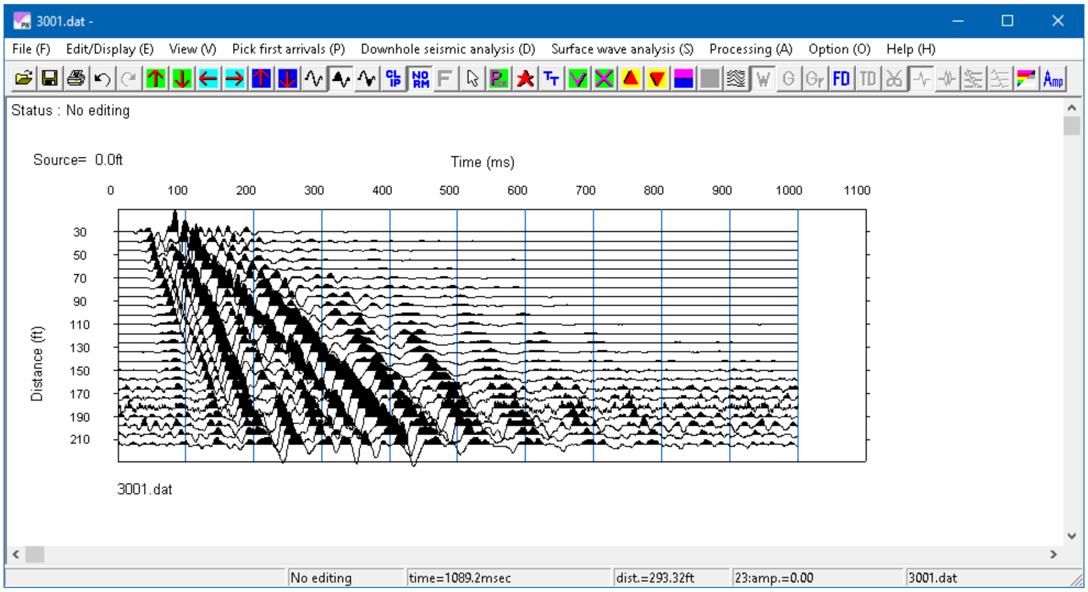
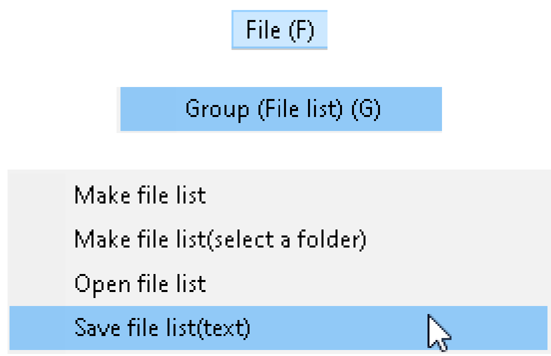


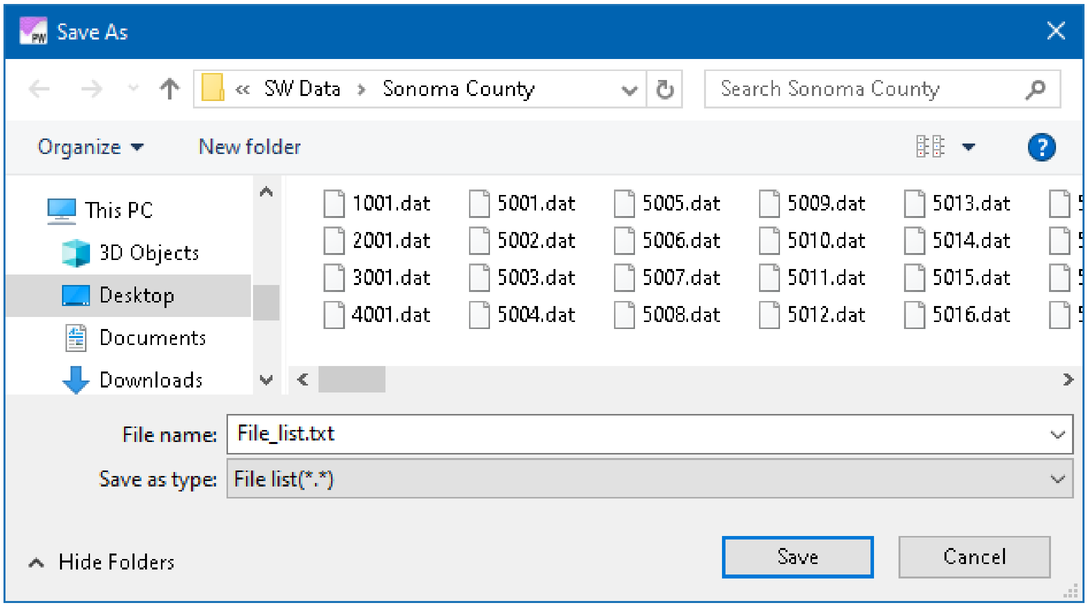
Figure 113: Waveform display.

6.1.5.4 Save File List (Text)

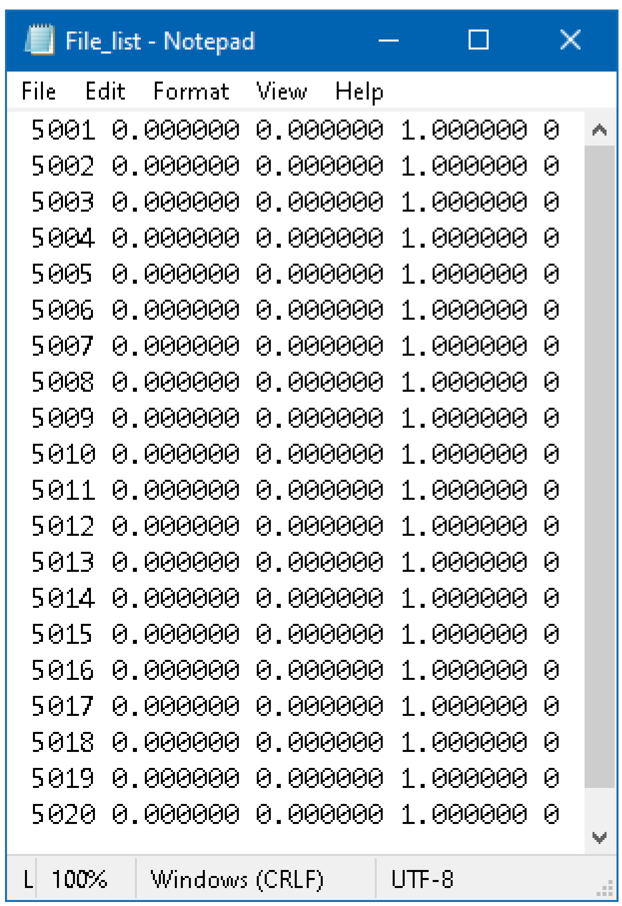


Once a file list has been generated, it can be saved as a text file by selecting *Save file list (text)*. File lists should always be saved in the dataset directory.

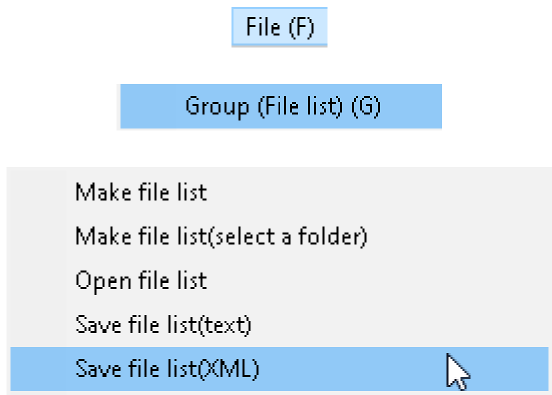
Assign a file name with the extension *.txt* and press *Save*.



The file is formatted in space-delimited columns by file ID, shot location, geophone location, receiver interval, and auxiliary channel number.

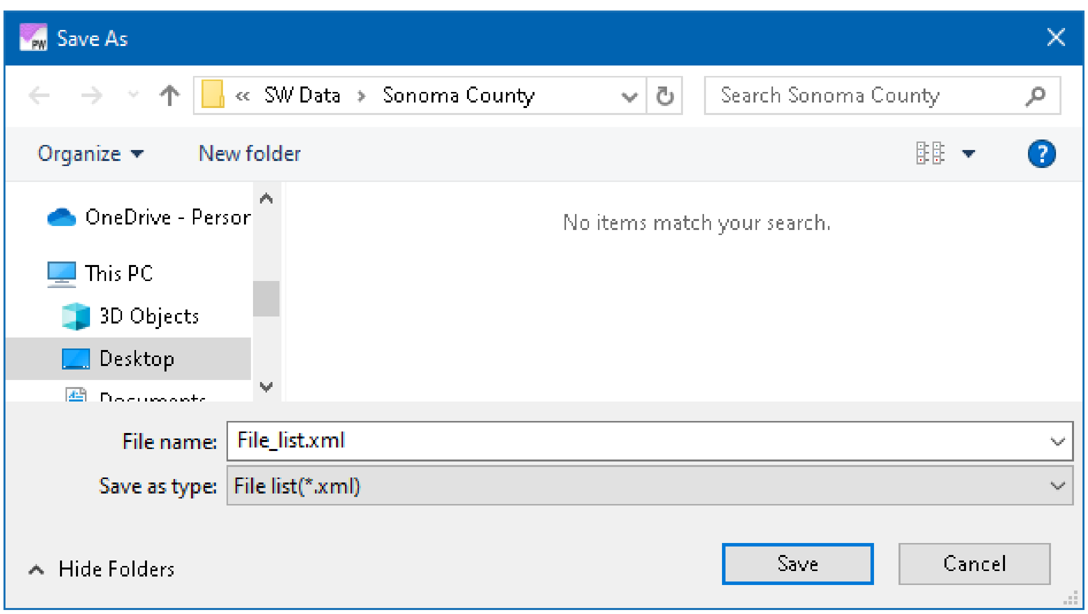


6.1.5.5 Save File List (XML)



Once a file list has been generated, it can be saved as an *.xml* file by selecting *Save file list (xml)*. File lists should always be saved in the dataset directory. The XML format and the dataset directory are the default format and file location used by the 2D MASW wizard.

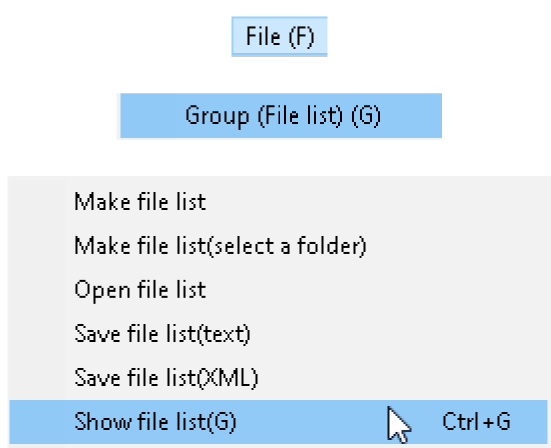
Assign a file name with the extension *.xml* and press *Save*.



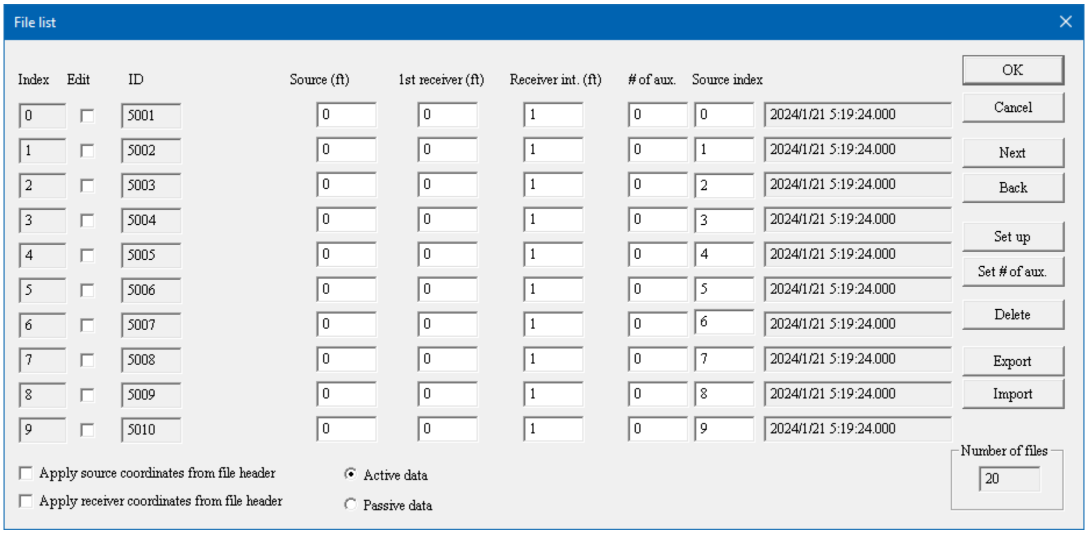
The file is formatted in XML with general line information at the top followed by the shot location, geophone location, receiver interval, and auxiliary channel number for each file ID.

```
  <?xml version="1.0" encoding="Shift_JIS" ?>
- <line>
    <line_name>line_name</line_name>
    <line_id>0</line_id>
    <sxw_menu>0</sxw_menu>
    <file_type>0</file_type>
    <apply_source_position>0</apply_source_position>
    <apply_receiver_position>0</apply_receiver_position>
  - <file_list>
    - <file>
        <file_name>sxlb0201.sg2</file_name>
        <id>201</id>
        <file_type>0</file_type>
        <shot_distance>-0.500000</shot_distance>
        <first_receiver>0.000000</first_receiver>
        <receiver_interval>1.000000</receiver_interval>
        <number_of_auxiliary>0</number_of_auxiliary>
      </file>
    - <file>
        <file_name>sxlb0202.sg2</file_name>
        <id>202</id>
        <file_type>0</file_type>
        <shot_distance>0.500000</shot_distance>
        <first_receiver>0.000000</first_receiver>
        <receiver_interval>1.000000</receiver_interval>
        <number_of_auxiliary>0</number_of_auxiliary>
      </file>
```

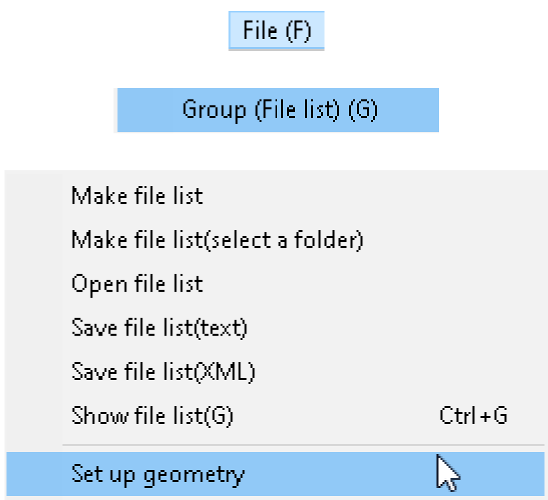

6.1.5.6 SHOW FILE LIST [CTRL+G]



To open the **File list** dialog box, select *Show file list*. The **File list** dialog box is displayed and reflects the current geometry assignment for the subject dataset.

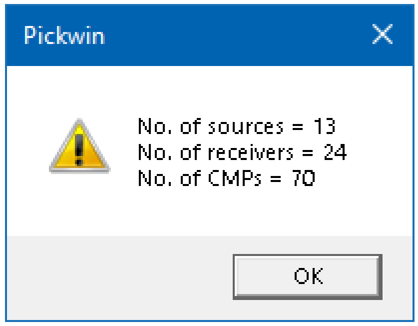


6.1.5.7 SET UP GEOMETRY

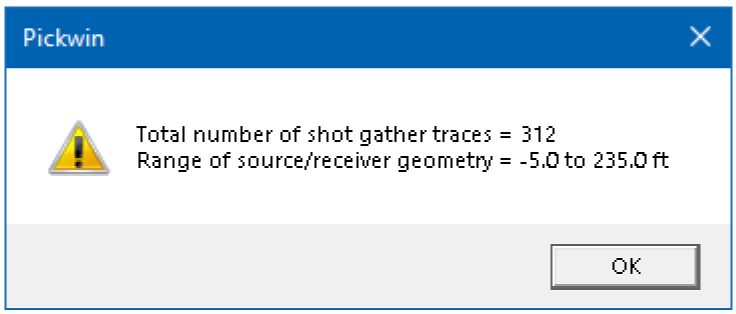


In SeisImager/SW, the 2D MASW process requires calculation of CMP locations (refer to Section 3.3.1, Page 40, for explanation) before the dispersion calculation. The 2D MASW file list with source and receiver locations is used to find the CMP locations.

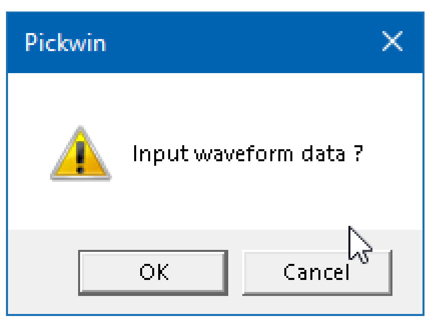
To calculate CMP locations for a 2D MASW file list, select *Set up geometry*. First, the number and location of CMPs are calculated using the source and receiver coordinates. A report of the number of sources and receivers detected in the file list and the number of CMPs calculated from the source and receiver coordinates is displayed. Press *OK*.



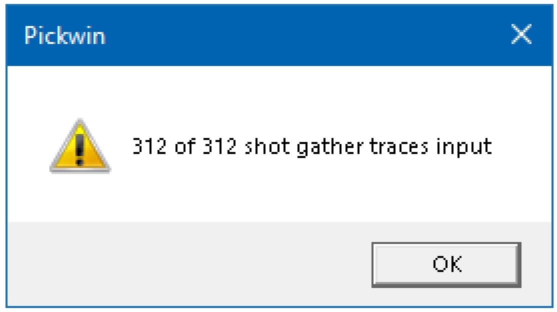
Next, the total number of waveform traces and the maximum range of the survey geometry are calculated and reported. Press *OK*.



Up to this point, the waveforms have been handled as an assembly of traces as opposed to individual traces. Obviously, at the time of acquisition, traces are assembled in a shot record (or "shot gather") by common shot location. At this point, the waveform for each trace will be individually assigned a CMP coordinate so that at a later step the traces can be assembled into CMP cross-correlation gathers by CMP location. If no errors were detected in the previous calculations, press *OK* to *Input waveform data*.



The number of traces assigned a CMP coordinate is reported and should equal the *Total number of shot gather traces* reported previously. Press *OK*.



Once complete, a plot of the source-receiver geometry is displayed.

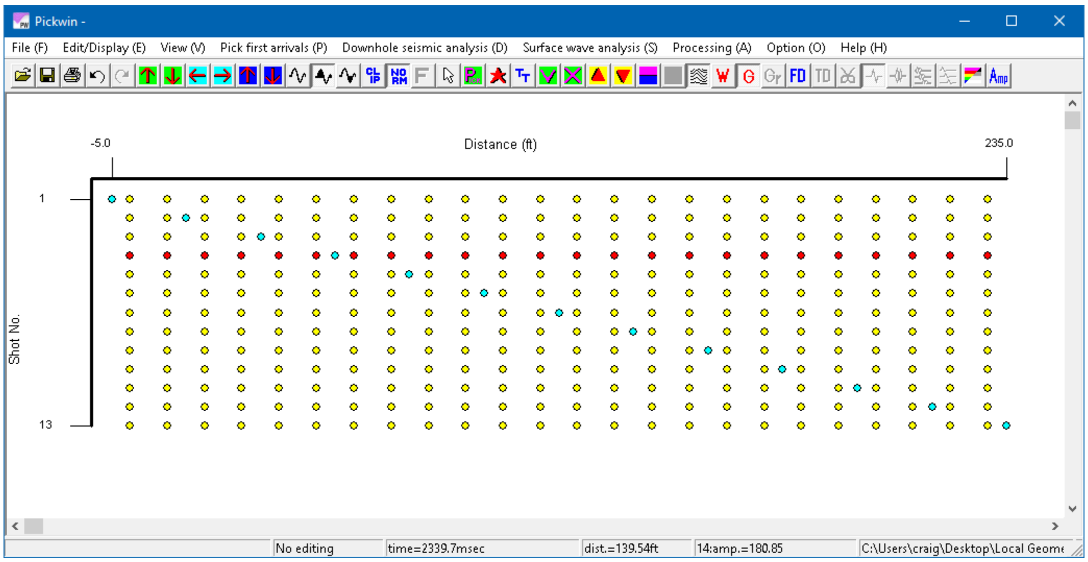
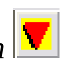


Figure 114: Source-receiver geometry.

Table 11 summarizes all the attributes used in geometry plots. The horizontal axis – *Distance* – is the distance along the survey line. The vertical axis – *Shot No.* – is the number of the shot as the data was sequentially collected.

Circle/Dot Color	Meaning
Teal blue	Shot point.
Yellow	Receiver for which a trace has been read.
Dark blue	Receiver for which no trace has been read.
Red	Receiver for which traces are selected and can be viewed in the waveform display.
Black	Grid point (no meaning in actual geometry).

Table 11: 2D MASW Geometry Plot Attributes.

The *Show previous waveform*  and *Show next waveform*  buttons can be used in the geometry view to select a waveform shot record to display; these buttons can also be used to scroll through waveform files in the waveform view. Press the *Waveform*  and *Geometry*  buttons to toggle between the views.

If there is an error and no waveform data is input, the geometry plot will appear with a dark blue circle for each receiver missing a waveform trace. If an input error occurs, double check that all the dataset files are in one directory and that the geometry assignment is correct; then start over with the *Set up geometry* process.

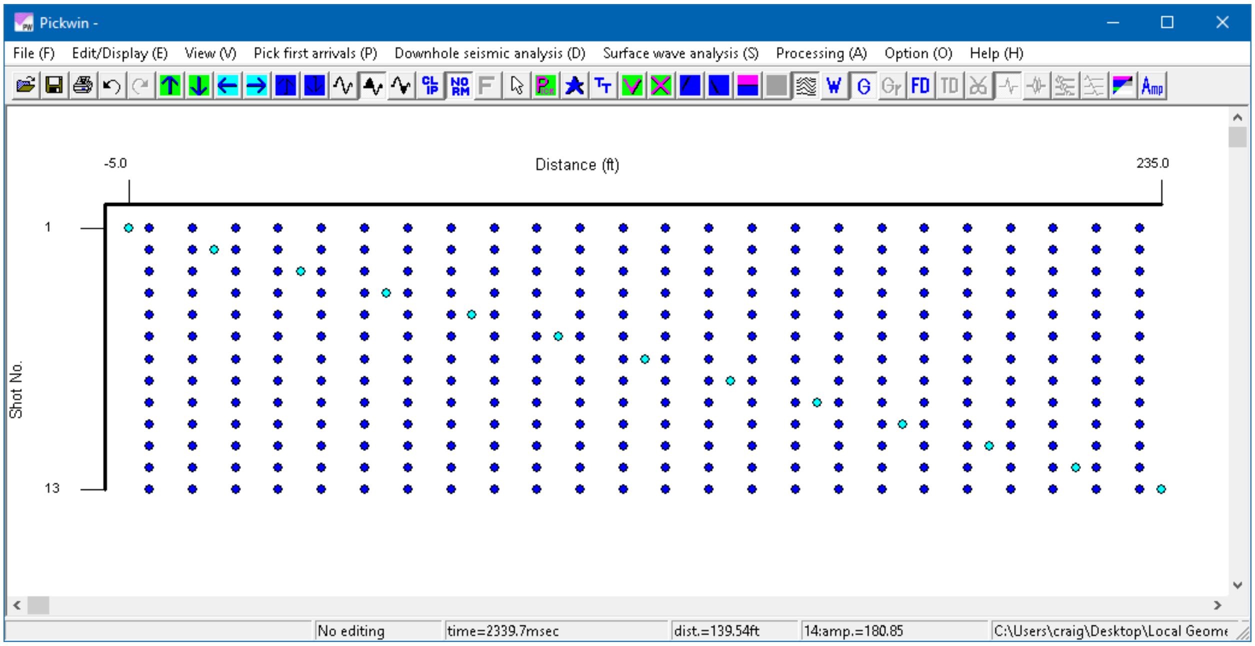
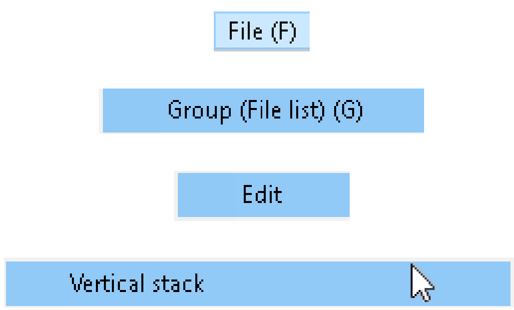


Figure 115: Source-receiver geometry. Blue circles indicate missing traces for those points.

6.1.5.7.1 VERTICAL STACK



Vertical stacking is most employed after MASW data acquisition using Atom or McSeis-MT Neo acquisition units, both of which record continuously. Vertical stacking is part of a process leading up to MASW inversion. The general process is as follows:

1. Detect events in Atom files (SPACPlus).

2. Cut out shot gathers and save them as SEG-2 files (SPACPlus). The files are saved as a file list.

3. Use the file list created by SPACPlus or create a file list of the SEG-2 files in Pickwin.

4. **Stack the shot gathers in Pickwin.**

5. Set up acquisition geometry.

6. Process as usual (Section 4, Page 54).
   To stack the data, you must first assign source indices to the shot gathers. Each set of shot records to be stacked must have the same source index:

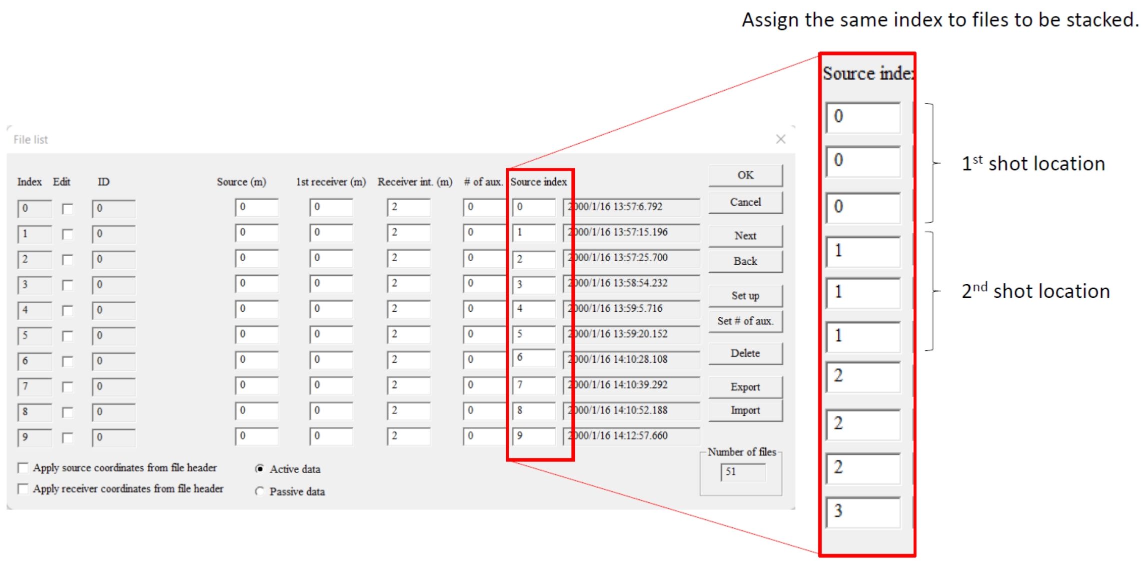
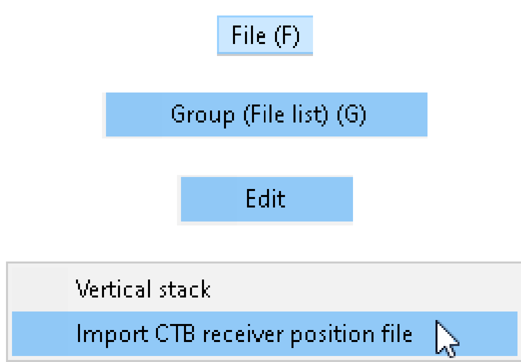


Figure 116: Setting up source indices prior to vertical stacking.

Once the source indices have been updated, simply select *File* | *Group (File List)* | *Edit* | *Vertical stack.* The records will be stacked and displayed, and the path and file name of the stacked record will be displayed beneath the waveform display.

6.1.5.7.2 IMPORT CTB RECEIVER POSITION FILE



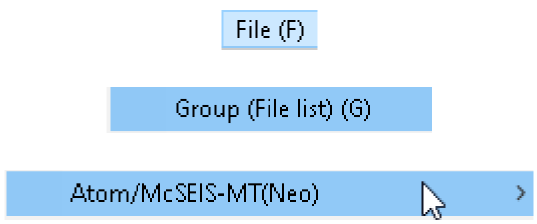
As mentioned above, Atom and McSeis MT Neo seismographs record continuously. Each seismic sample is tagged with a GPS-referenced UTC time. In the process of setting up a survey using these single- or three-channel modules, the modules are powered up asynchronously, with some beginning data recording earlier than others. Once all modules are up and recording, actual *data* acquisition may start. This means that much of the data on each module is garbage, and to varying degrees from module to module.

This is much different from the conventional method using a seismograph like a Geode, where all the channels begin recording simultaneously and are often referenced to a source trigger.

Before Atom or McSeis MT Neo data can be processed, it must be pre-processed and saved to a conventional SEG-2 format, as if it were acquired using a Geode or other conventional seismograph.

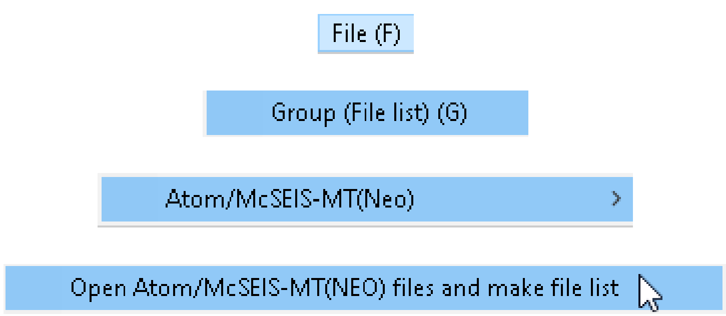
SPACPlus reads raw Atom or McSeis MT Neo files. It then automatically examines the data from all the modules and divides it into "common time blocks". In a typical MASW survey, there are three common time blocks: one for the "huddle test" (see the Atom/SPACPlus manual), one for active data, and one for passive data. These common time blocks can then be saved in SEG-2 format for MASW processing using SeisImager/SW and WaveEQ.

6.1.5.8 Atom/McSEIS-MT(Neo)



Continue.

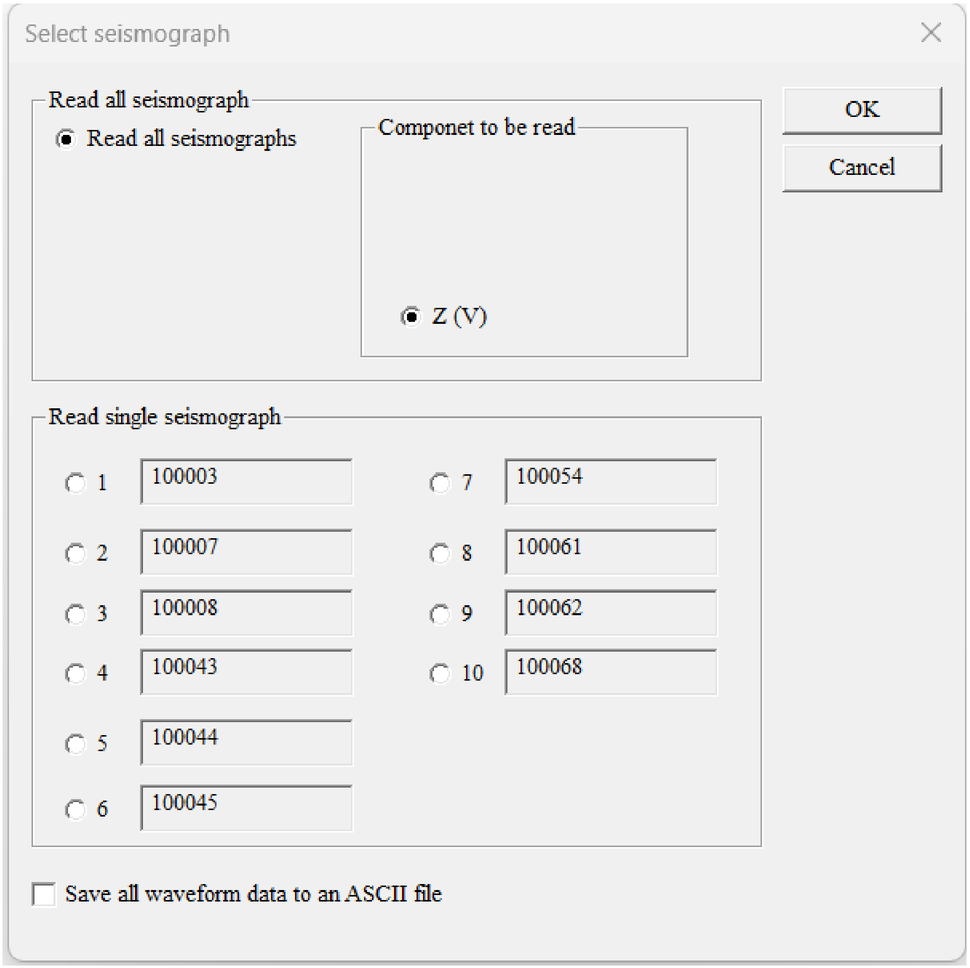
6.1.5.8.1 Open Atom/McSEIS (NEO) Files and Make File List



Note: *This feature is included here for convenience, but it is recommended that you use SPACPlus to pre-process the data into "common time blocks" and save them to SEG-2 files. SPACPlus provides useful tools, including tools to remove noise events from passive data, such as passing vehicles. Those tools are not available here (see the SPACPlus manual).*

This feature opens a group of raw Atom or McSeis MT Neo files and creates a file list, which is automatically saved as a series of SEG-2 files.

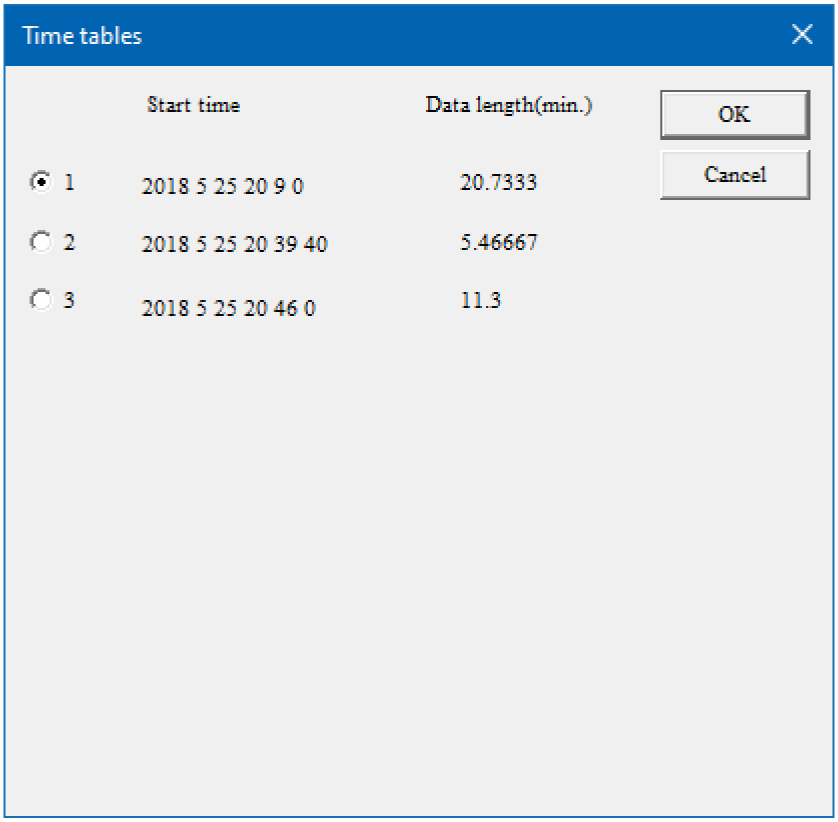
Select the folder containing the files. You will be presented with the following screen:



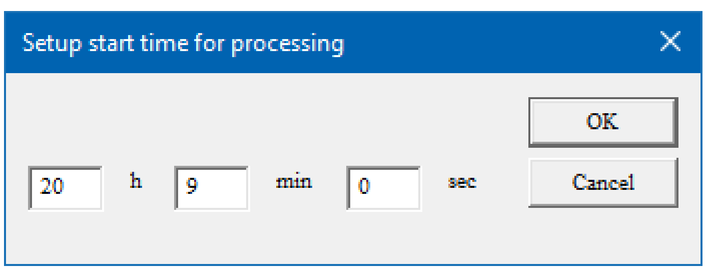
Choose which seismograph's data you wish to read (generally, you will want to read all of them at once; this is the default). Next, indicate which component to read. Most often, you will be working with single-channel units, in which case the single component detected will be assumed to be Z (vertical).

In the process of creating the group file, you may choose to save all the Atom/McSeis data to ASCII waveform files – simply check the box.

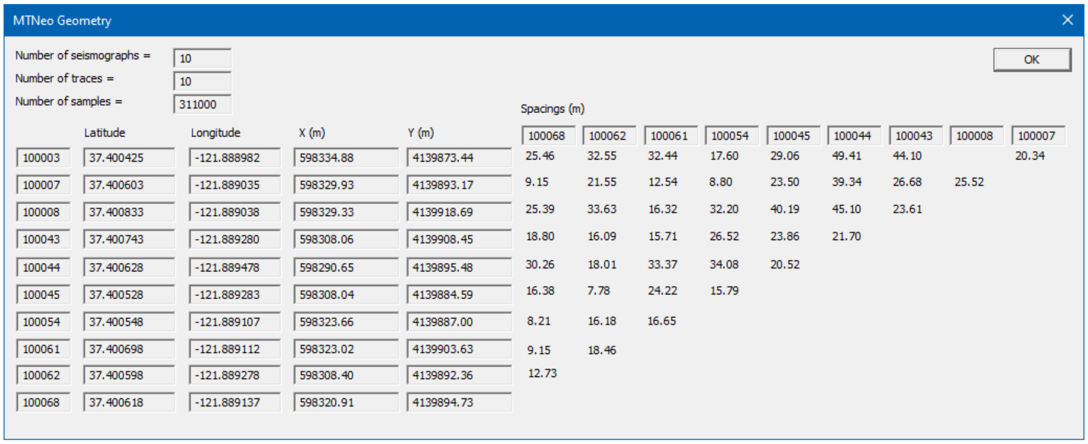
Pressing *OK* will reveal the following:



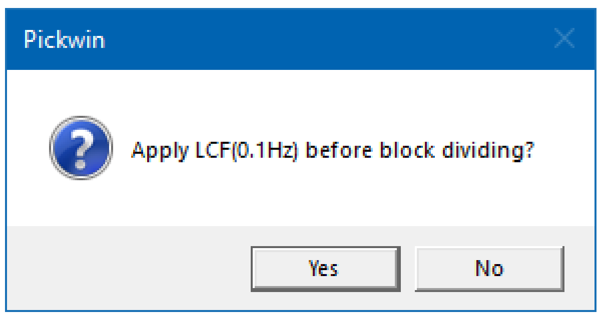
This indicates that three blocks of data have been detected – each seismograph was turned on and off three times. Each is designated by the date and UTC time at the beginning of the time block. In this case, we will begin with the first data block. Press *OK*, and you will be given the opportunity to edit the start time:



Press *OK* again, and the following geometry display will be presented.



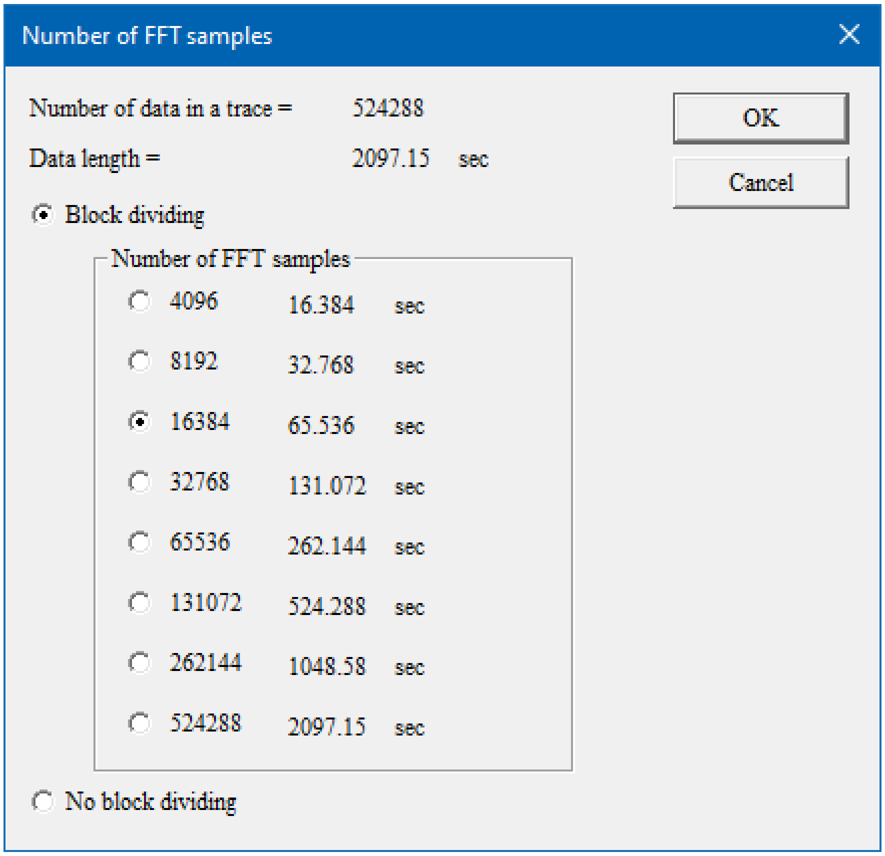
Surface wave files, particularly those for passive data, tend to be very long (and large). It is usually desirable to divide each trace up into a series of shorter traces to make them more manageable. Before doing so, you are given the opportunity to apply a 0.1 Hz low-cut filter to the data:



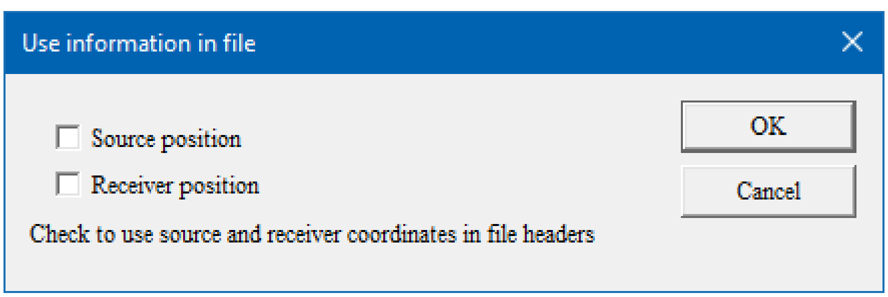
In general, a filter is not necessary, and unless you have a strong DC component, you should press *No* here.

The next dialog box allows you to enable/disable "block dividing" and to set the length of each "sub" trace. In general, it is desirable to work with traces of 16k or 32k samples (or less); at the standard passive data sample interval of 4 msec, this works out to 1 or 2 minutes.

Select a trace length and press *OK*.

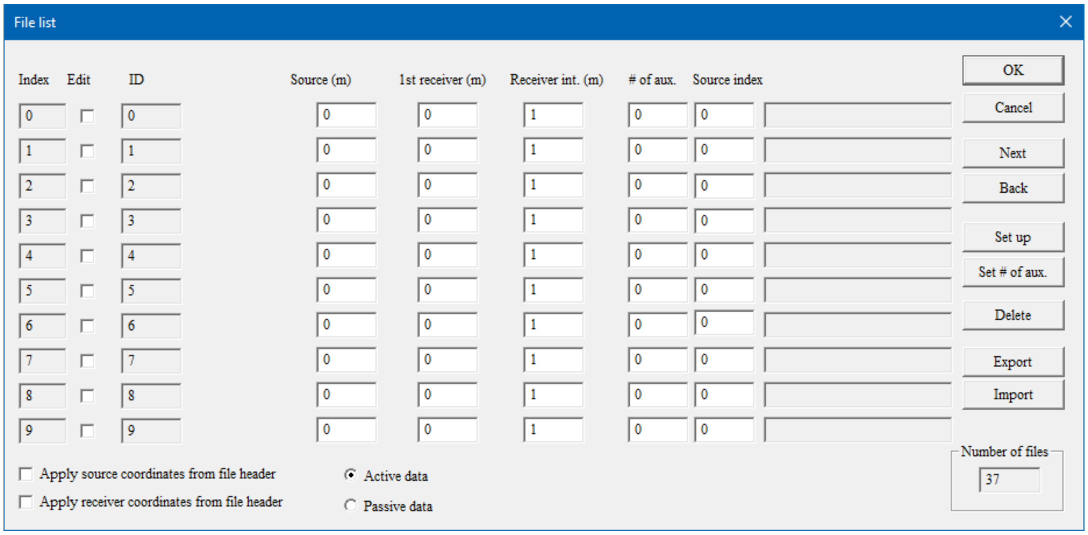


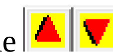
Next, you will be asked if you wish to read the source and receiver positions from the file header. Do not check the boxes; this information will be incorporated prior to the spatial autocorrelation.



Press *OK*.

You will now be presented with the file list. Indicate whether the data is passive or active and press *OK*.



The first block of data for each trace will be displayed. In this case, there are 10 Atoms of one channel each, and 37 time blocks. You may scroll through the time blocks using the  buttons. Each time block has already been saved as a SEG-2 file; the path is displayed below the trace display.

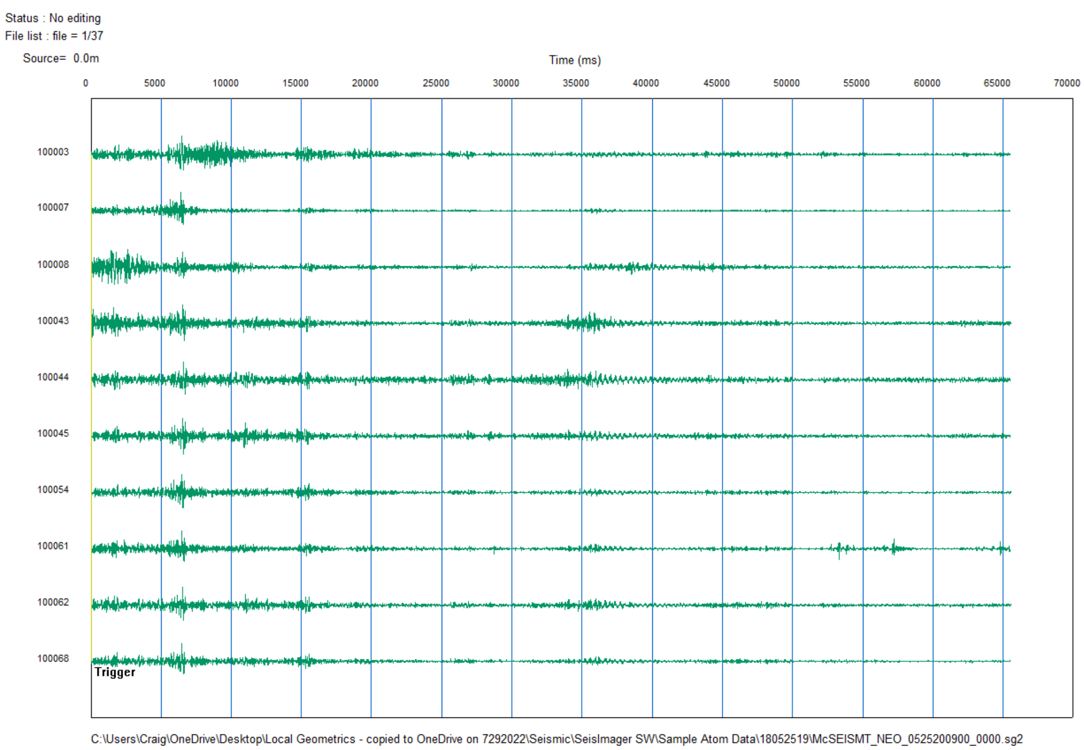
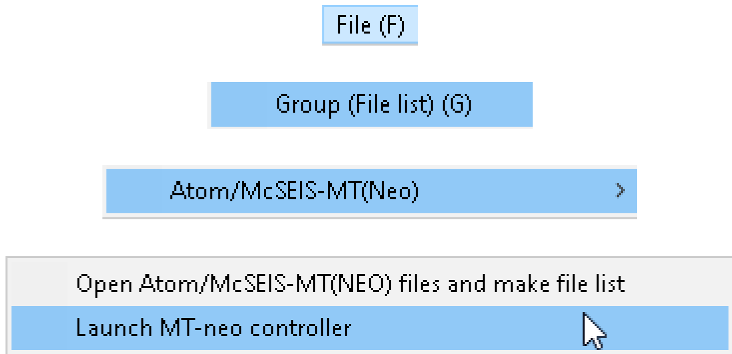


Figure 117: Waveform display from Atom or McSeis.

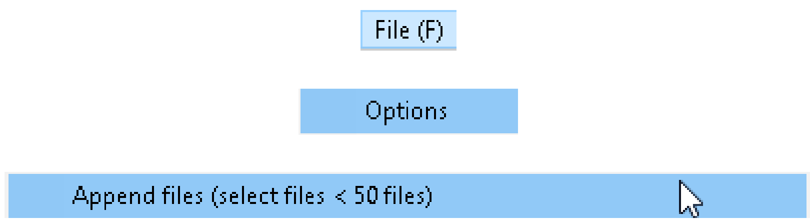
You may now process as usual. See Step 3 on Page A-5.

6.1.5.8.2 LAUNCH MT-NEO CONTROLLER



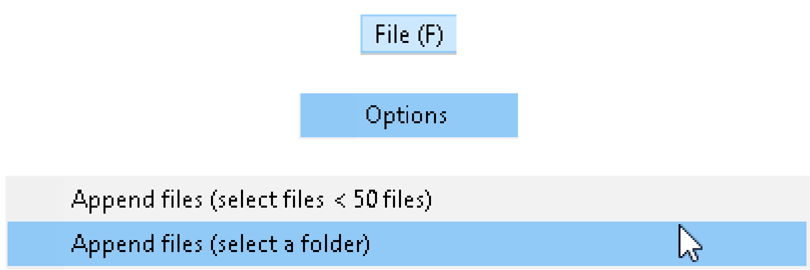
Pickwin can be used as a data acquisition controller for the McSeis MT Neo seismograph from OYO Corporation. This feature launches that controller.

6.1.5.9 APPEND FILES (SELECT FILES < 50 FILES)



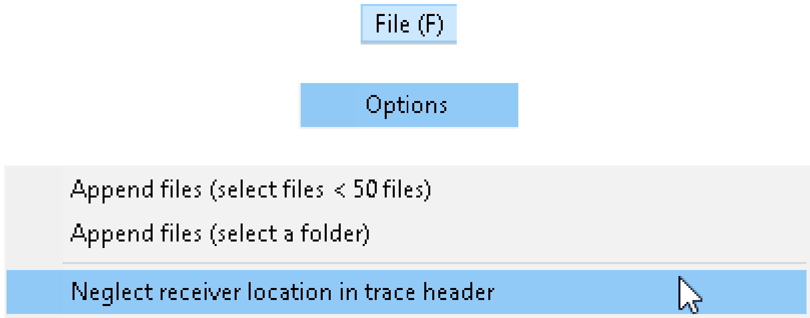
This feature opens a file-read dialog box and allows you to choose up to 49 SEG-2 files to append together.

6.1.5.10 APPEND FILES (SELECT A FOLDER)



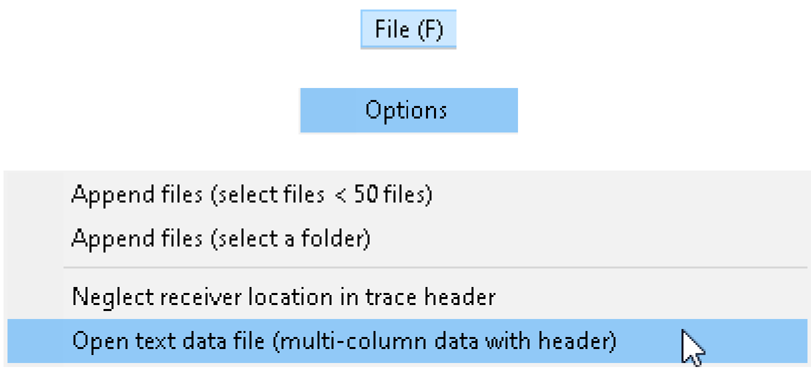
This feature appends together all the files in the selected folder. It is useful when you have a large number of files to append together.

6.1.5.11 NEGLECT RECEIVER LOCATION IN TRACE HEADER



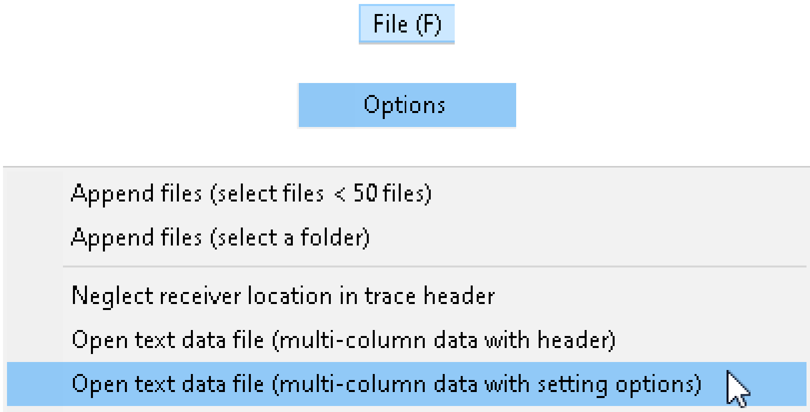
If you did not record the correct receiver locations in the trace headers while in the field, you can choose to ignore the trace headers by choosing this option.

6.1.5.12 OPEN TEXT DATA FILE (MULTI-COLUMN DATA WITH HEADER)

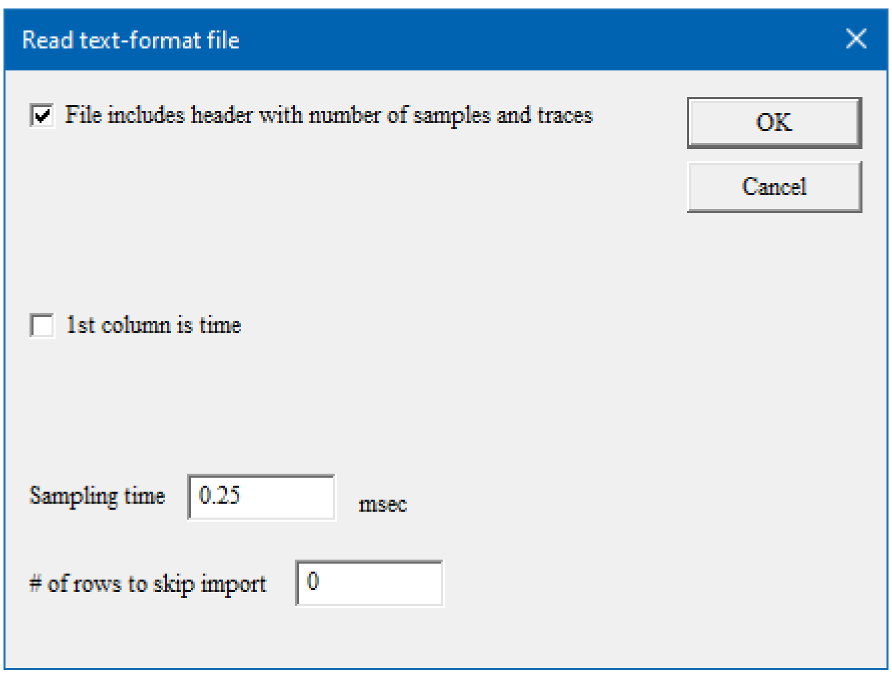


Select this option to open a previously saved waveform file that you have saved in ASCII text format (see Section 6.1.5.14 below).

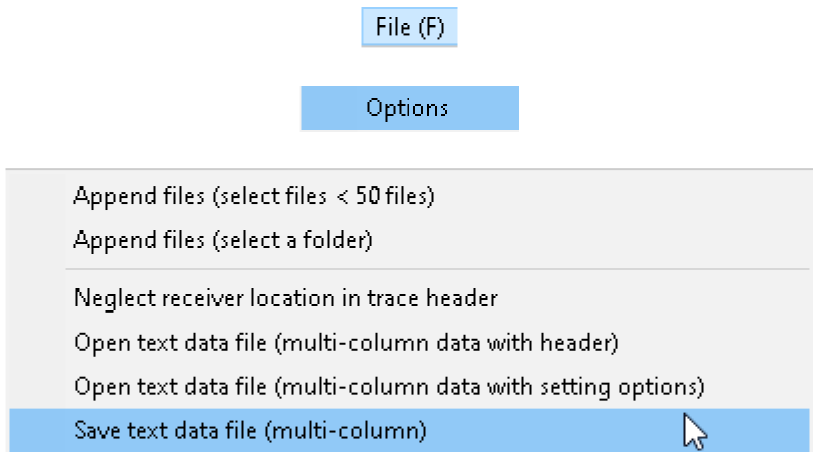
6.1.5.13 Open Text Data File (Multi-column Data With Setting Options)



Select this option to open a previously saved waveform file that you have saved in ASCII text format (see Section 6.1.5.14 below). In this case, you will be prompted for the following parameters:

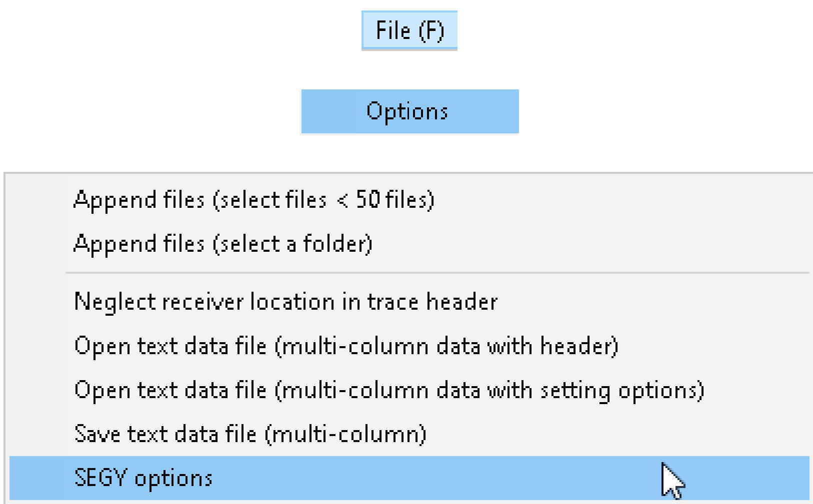


6.1.5.14 Save Text Data File (Multi-column)

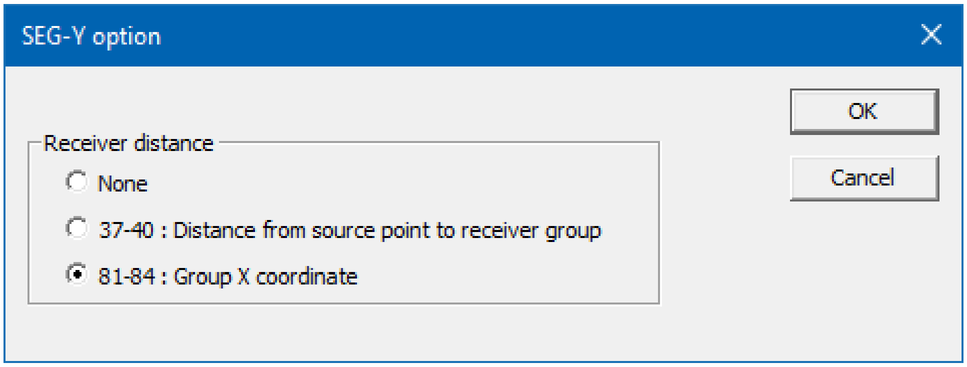


You may save any waveform file as an ASCII text file. Simply read in the waveform file and select *Save text data file (multi-column)*. You will be prompted for a file name.

6.1.5.15 SEGY Options

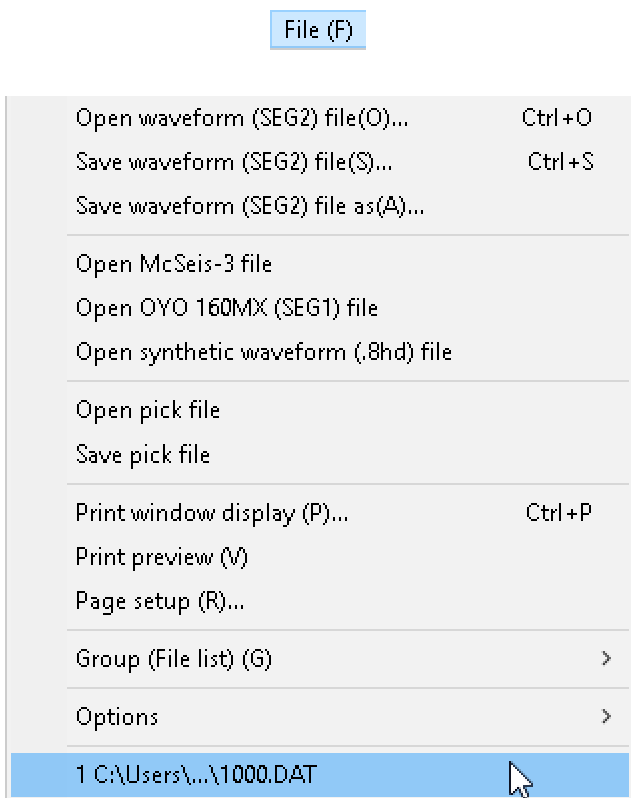


Selecting this item will reveal the following dialog:



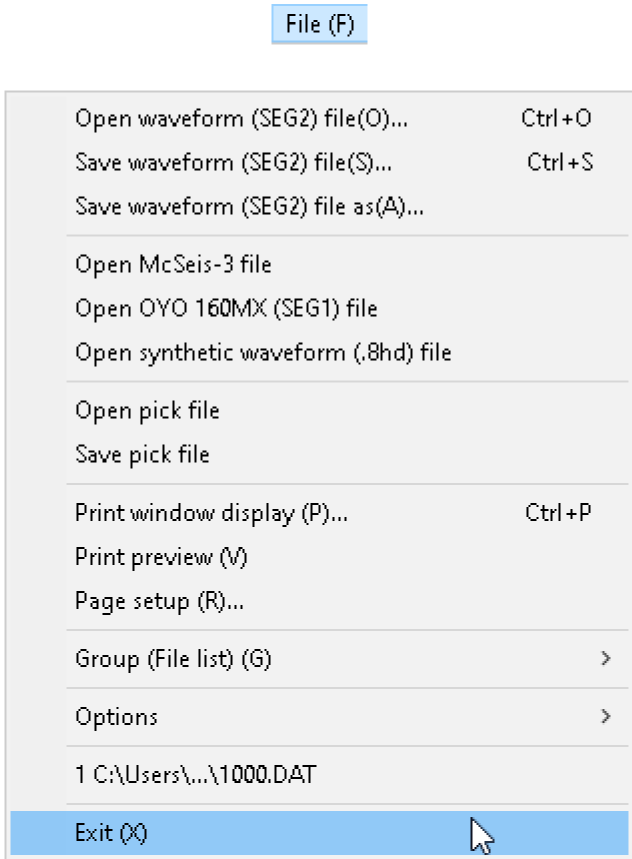
Choose the appropriate header locations for the receiver distances or coordinates. If they were not recorded in the field, select *None*.

6.1.6 RECENT FILES

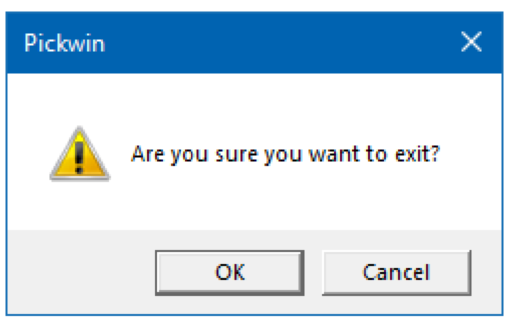


The last four files opened in Pickwin will be displayed in the **File** menu. To open any of these files, just click on the file.

6.1.7 EXIT



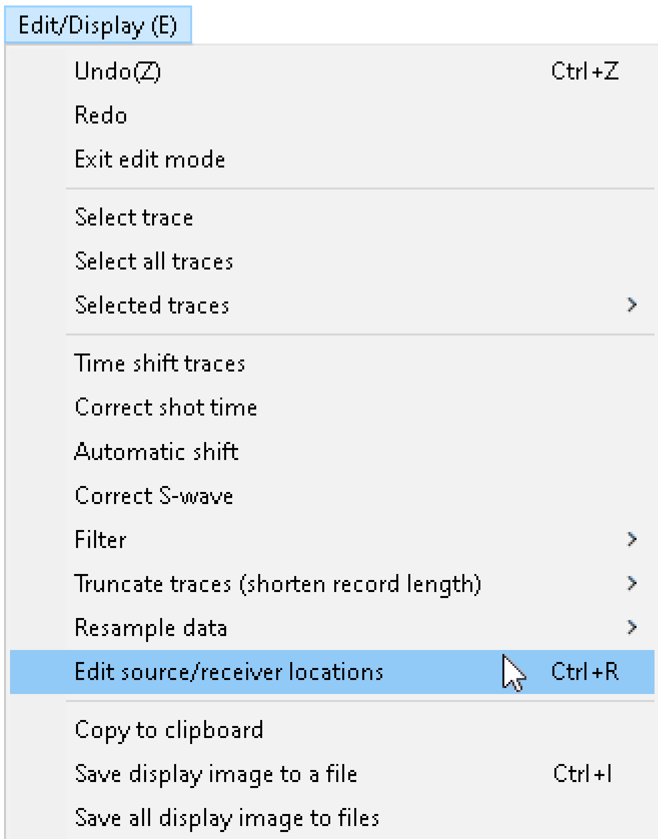
To exit the Pickwin module, choose *Exit*. You will see the following dialog box:



Press *OK* to exit Pickwin or press *Cancel* to continue using Pickwin.

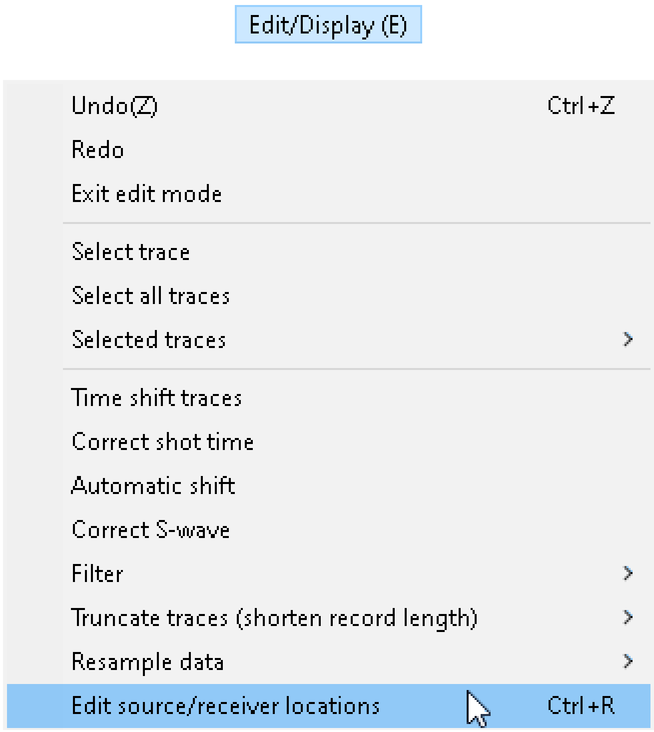
6.2 EDIT/DISPLAY MENU

The single **Edit/Display** menu function essential or uniquely used for surface wave data processing is covered in this section. For a complete description of the **Edit/Display** menu functions common to SeisImager/SW and SeisImager/2D, refer to the separate SeisImager/2D manual.



See next Section (6.2.1)

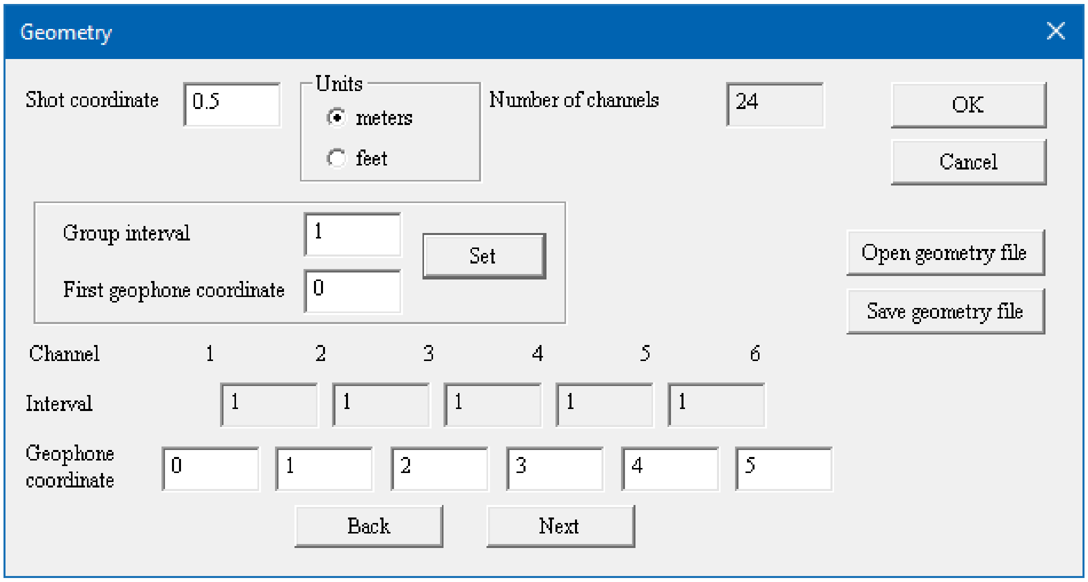
6.2.1 EDIT SOURCE/RECEIVER LOCATIONS [CTRL+R]



To change the unit labels shown in the displays and in the dialog boxes, select *Edit source/receiver locations* to open the **Geometry** dialog box.

The **Geometry** dialog box allows selection of units and reports the coordinates saved in the file header at the time of acquisition or in the file list for a single waveform file currently displayed.

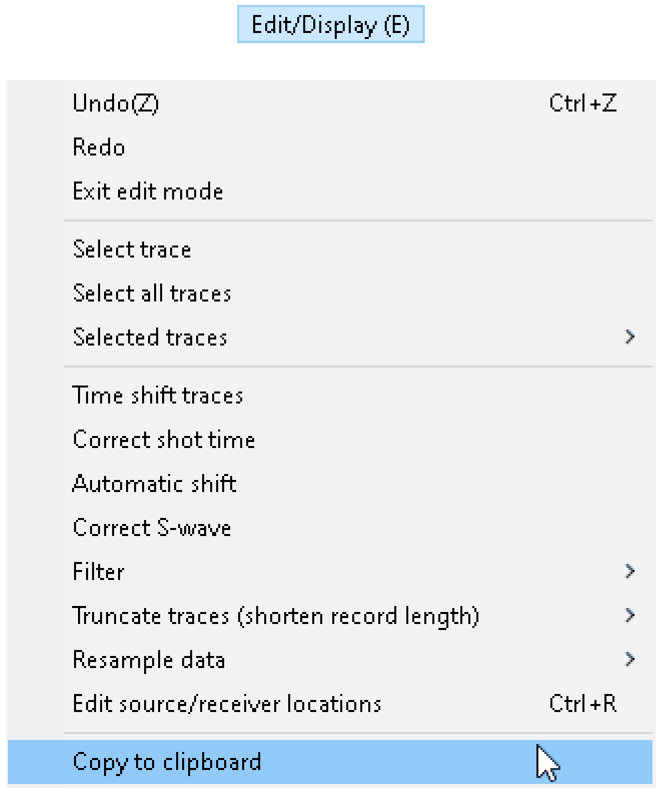
To set the unit labels, select between *meters* and *feet*. The unit setting also updates the minimum phase velocity default value, which is 35 m/sec or 150 ft/s. Once set (and Pickwin is closed), the assigned units will be recalled for subsequent uses of the program (**it is necessary to close Pickwin to register the new *Units* setting**).



The **Geometry** dialog box can also be used to set up or edit the source-receiver geometry for single shot records for 1D MASW. For 2D MASW, the *File list* and *Set up geometry* functions should be used.

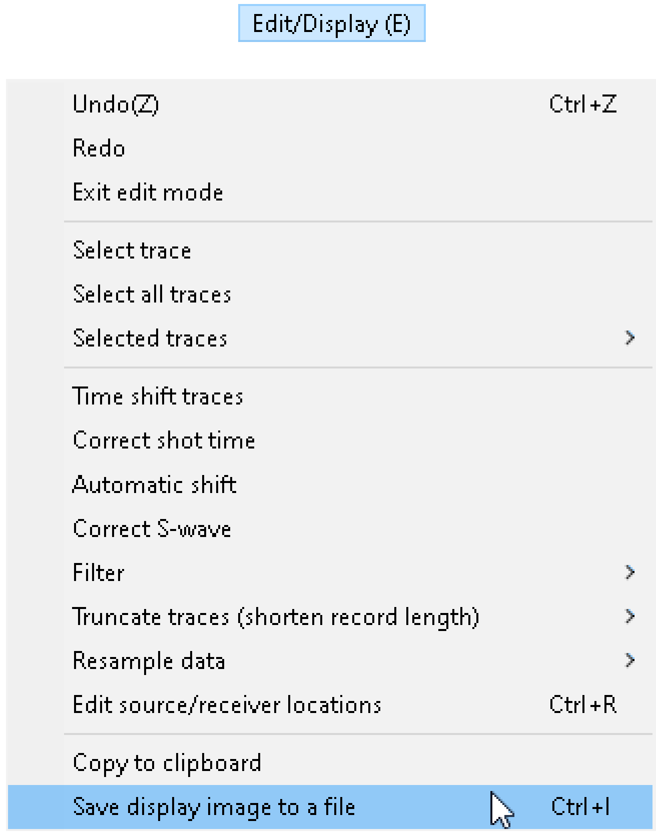
To set up or edit the geometry for a single 1D MASW shot record, enter the location of the shot in *Shot coordinate*. Enter the *Group interval* and *First geophone coordinate*, then press *Set* to calculate all the *Geophone coordinates*. *Next* and *Back* can be used to scroll through the coordinate values in sets of six channels. Press *OK* when done to apply the changes. A new SEG-2 file will need to be saved by opening the **File** menu and selecting *Save SEG2 file* to preserve the changes, otherwise they will need to be made each time the shot record is input.

6.2.2 Copy to Clipboard



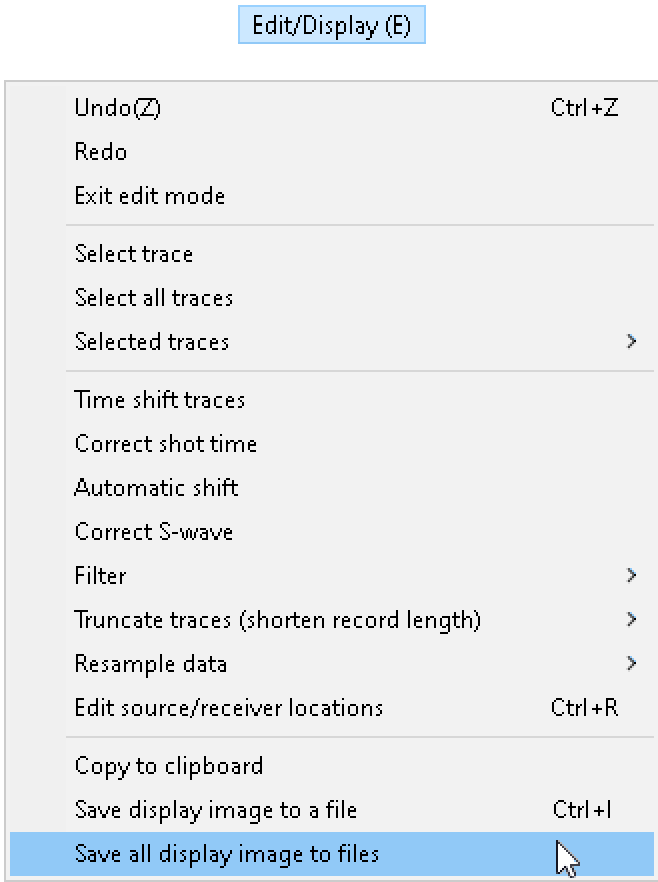
This feature copies whatever is on the screen to the clipboard. It can then be pasted into any third-party application, such as Microsoft Word®.

6.2.3 SAVE DISPLAY IMAGE TO A FILE [CTRL+I]



This feature saves whatever is on the screen to a PNG, JPG, BMP, or GIF file.

6.2.4 SAVE ALL DISPLAY IMAGES TO A FILE

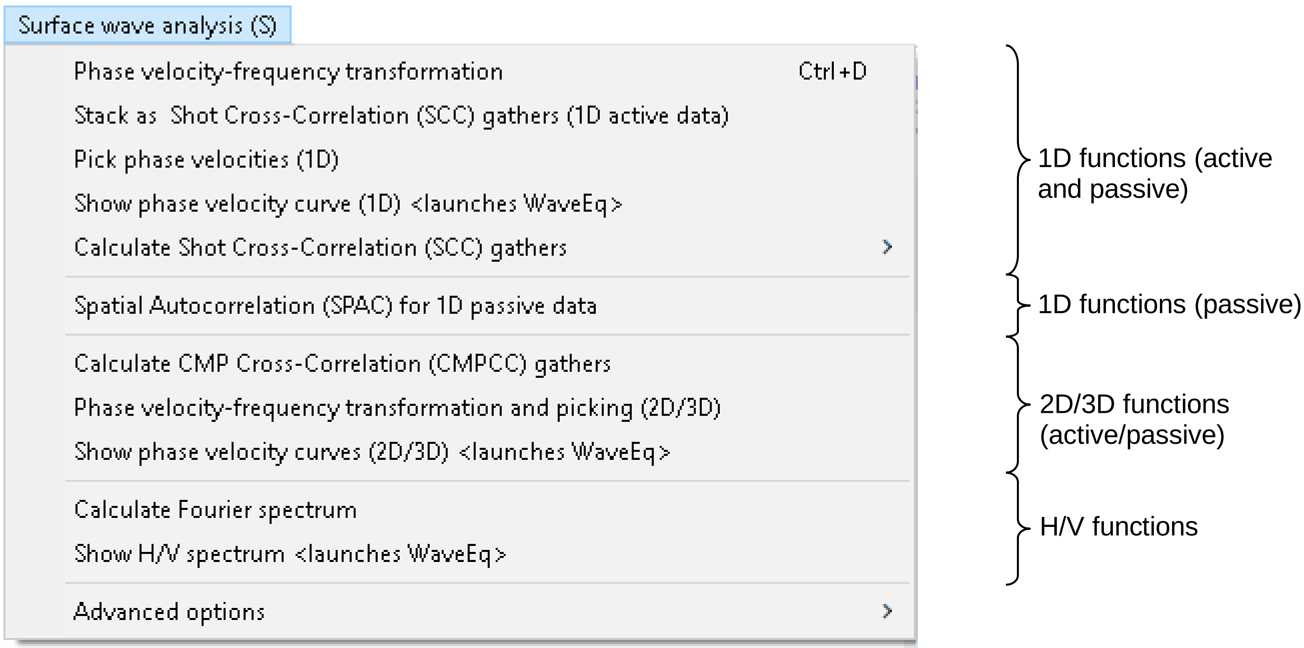


If you are working with a file list, this feature saves all shot gathers (or phase velocity images) in the file list to a PNG, JPG, BMP, or GIF file.

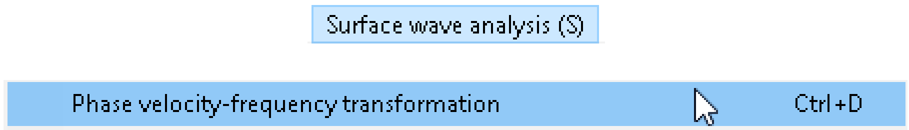
.

6.3 SURFACE WAVE ANALYSIS MENU

The **Surface wave Analysis** menu contains the functions needed for calculating phase velocity and picking dispersion curves. The menu is divided into five sections, the top for functions that pertain to 1D MASW (active) and MAM (passive) data processing, the second for 1D MAM (passive) data processing (SPAC), the third for 2D/3D MASW (active) and MAM (passive) data processing, the fourth H/V data processing, and the fifth for advanced options. For purchases of SeisImager/SW-1D, the third section is greyed out. For purchases of SeisImager/SW-2D, all five sections are active.


Surface wave analysis (S)
Phase velocity-frequency transformation Ctrl+D
Stack as Shot Cross-Correlation (SCC) gathers (1D active data)
Pick phase velocities (1D)
Show phase velocity curve (1D) <launches WaveEq>
Calculate Shot Cross-Correlation (SCC) gathers
Spatial Autocorrelation (SPAC) for 1D passive data
Calculate CMP Cross-Correlation (CMPCC) gathers
Phase velocity-frequency transformation and picking (2D/3D)
Show phase velocity curves (2D/3D) <launches WaveEq>
Calculate Fourier spectrum
Show H/V spectrum <launches WaveEq>
Advanced options
1D functions (active and passive)
1D functions (passive)
2D/3D functions (active/passive)
H/V functions

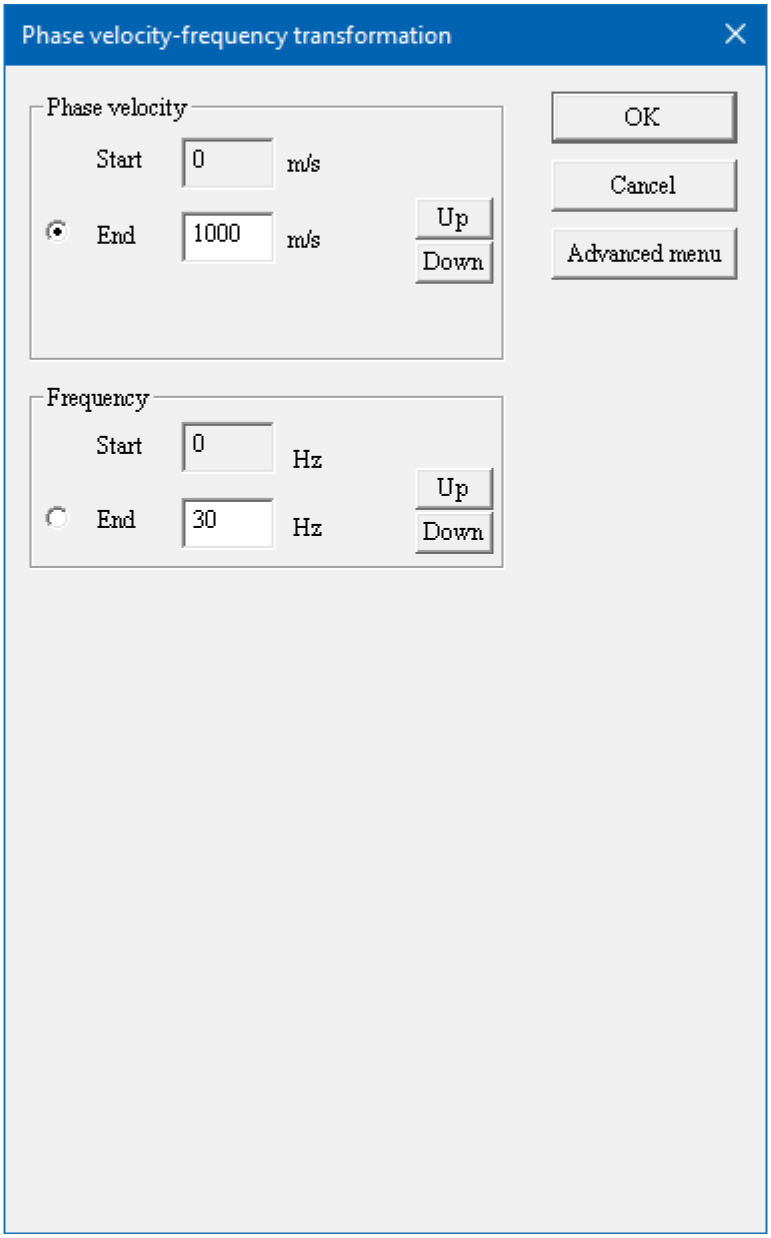
6.3.1 Phase Velocity-Frequency Transformation [CTRL+D]



To transform one MASW shot record or CMP cross-correlation gather from the time to frequency domain and to calculate the phase velocity for each frequency, select *Phase velocity-frequency transformation*.

For a MAM dataset, the same function is used to generate a phase velocity-frequency plot, but first the dataset must be processed by the *2D Spatial Autocorrelation* function. Refer to Section 6.3.6, Page 276, for a complete explanation.

Once selected, set the boundaries for the phase velocity calculation in the **Phase velocity-frequency transformation** dialog box. The radio buttons can be ignored as they only apply when using the software on a seismograph with integrated PC.

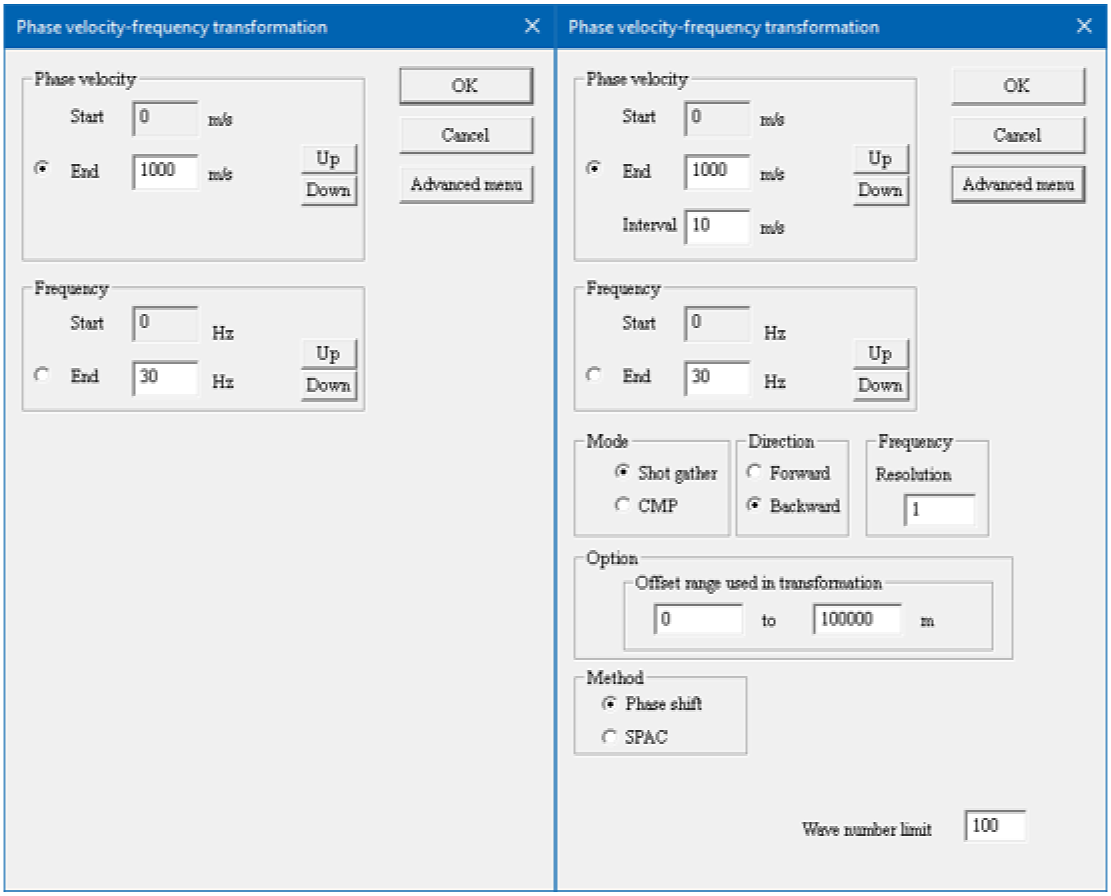


The *Start Phase Velocity* and *Start Frequency* are set fixed at 0.

For *End Phase Velocity*, enter the approximate maximum velocity expected for the site. If you find that the end velocity in the calculated phase velocity-frequency plot is too low or too high, the calculation can simply be re-run.

For *End Frequency*, adjust the default value to capture the bandwidth of fundamental mode surface wave signal. The default value of 30 Hz is suitable for most cases. Again, it is simple to adjust this value and re-run the calculation if you want to experiment with this setting.

The default dialog box format hides the **Advanced** menu. Pressing on *Advanced menu* reveals the rest of the parameters with default values for active source (shown on left) and passive source (shown on right) processing. These parameters are automatically updated by the software depending on the type of data being processed. Typically, none of the settings need to be changed.



The *Phase Velocity Interval* defines the resolution at which the calculation steps through the range of velocities indicated. Increasing this value reduces the resolution. During the picking stage, if the phase velocity-frequency plot lacks resolution, the resolution can be improved by reducing this value.

Mode of *Shot gather* or *CMP gather* applies to 2D MASW processing where shot gather traces are assembled into CMP gathers. This parameter is automatically updated by the software depending on the type of data being processed.

Direction of *Forward* means that the shot coordinate is less than the coordinate of the first geophone. *Backward* means the shot coordinate is greater than the coordinate of the first geophone. The software assumes that the same gain was used on all traces and automatically attempts to determine the direction. This is done by comparison of the amplitudes of the first and last traces. If the last trace amplitude is smaller, the software assumes a *Forward* direction and vice-versa for *Backward*. If you have recorded with individual gain settings, you may want to check that the software correctly determined the direction.

The *Frequency resolution* controls how finely phase velocity is calculated. If this value is increased, the resolution will be reduced. This value cannot be less than 1 and must be an integer.

The *Offset range used in transformation* sets the range of traces used in the transformation. This is a difference, not actual coordinates. *Offset* is the distance from the shot to any given receiver. This is mainly used for muting out near-source effects in 2D MASW data processing and is not applicable for 1D MASW.

Method indicates what procedure will be used. This parameter is automatically updated by the software depending on the type of data being processed. For active source data processing, the *Method* is *Phase shift*. For passive source data processing, the *Method* is *SPAC* by *2D*. The *Wave number limit* is the high frequency limit used to avoid aliasing when fitting Bessel functions in the SPAC process. The default value of 100 is relatively large and suitable for most cases.

Upon completion of the transformation, a phase velocity-frequency plot is displayed. A trend of peak "amplitudes", which corresponds to the degree of fit for each frequency, should be obvious. It is typical for the widths of the peaks to broaden as the frequency decreases because the signal-to-noise ratio tends to decrease with frequency.

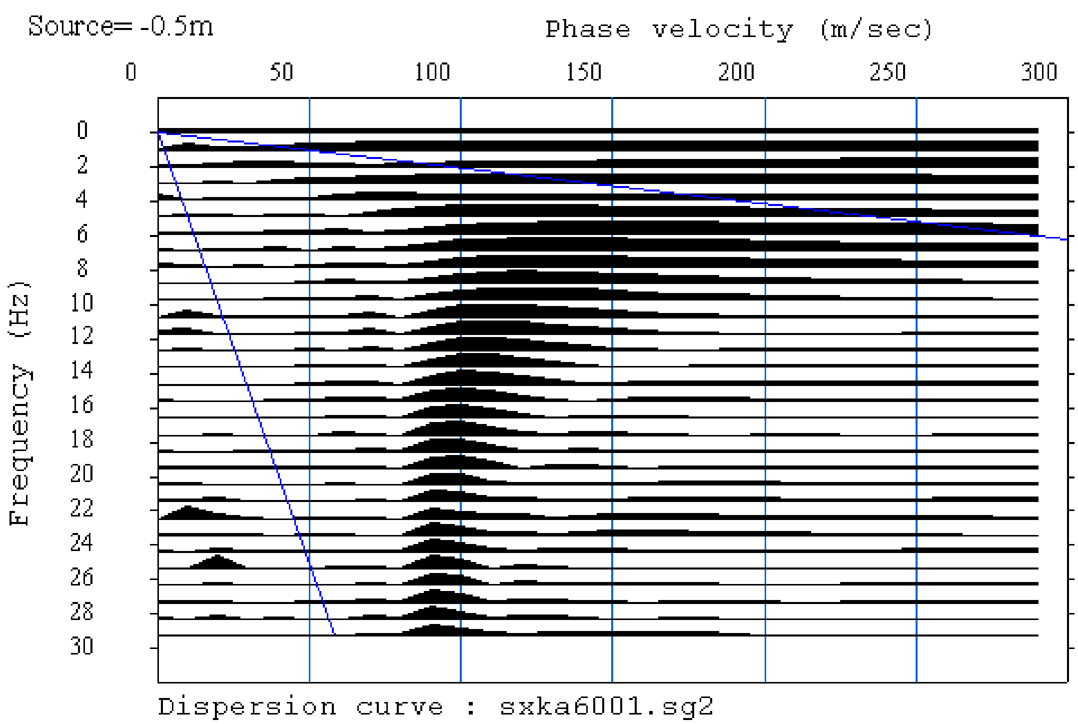
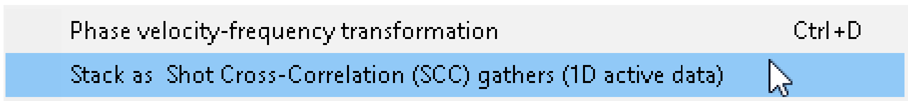


Figure 118: Phase velocity-frequency plot.

6.3.2 STACK AS SHOT CROSS-CORRELATION (SCC) GATHERS (1D ACTIVE DATA)



In 1D MASW processing, shots having different shot locations cannot be stacked in the time domain. For example, two opposite end-shots, as shown below, cannot processed together as raw data. SeisImager first must calculate Shot Cross-correlation (SCC) gathers and then stack the SCC gathers. The phase velocity image can then be calculated from the stacked SCC gathers.

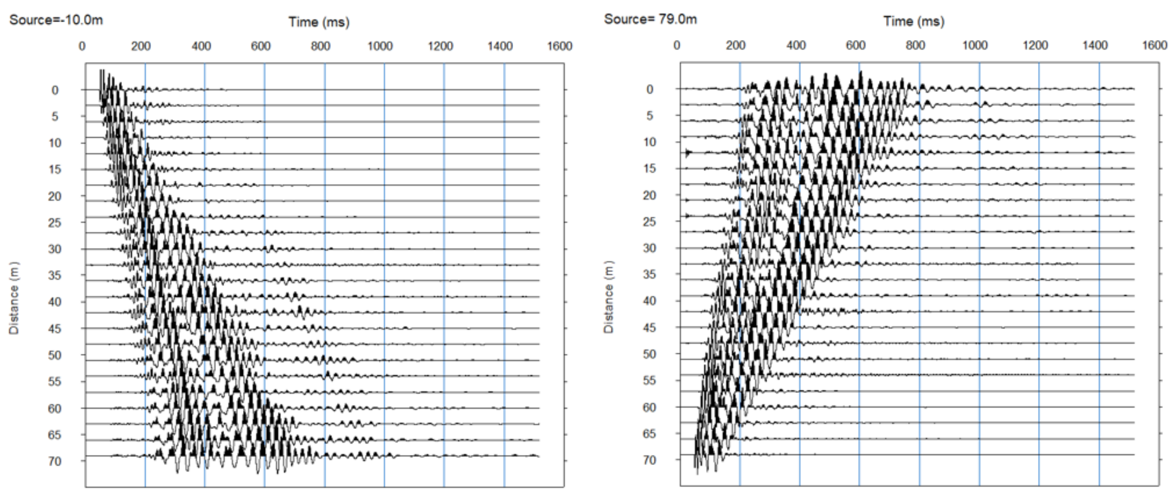


Figure 119: Shot cross-correlation gathers.

The concept of an SCC is illustrated below:

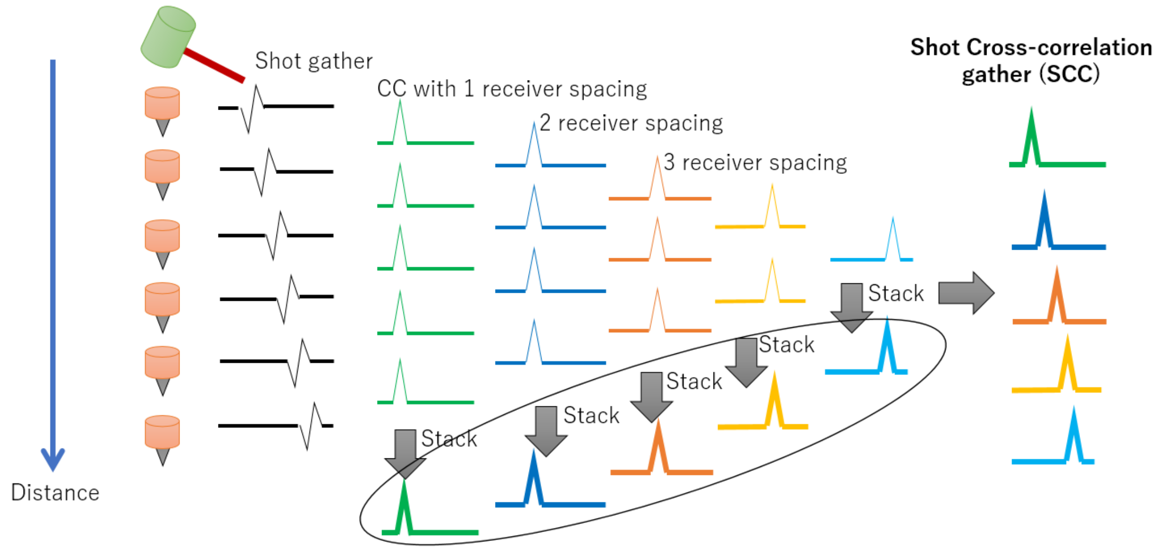


Figure 120: The Shot Cross-Correlation Gather (SCC).

The above schematic is summarized below using two shot gathers:

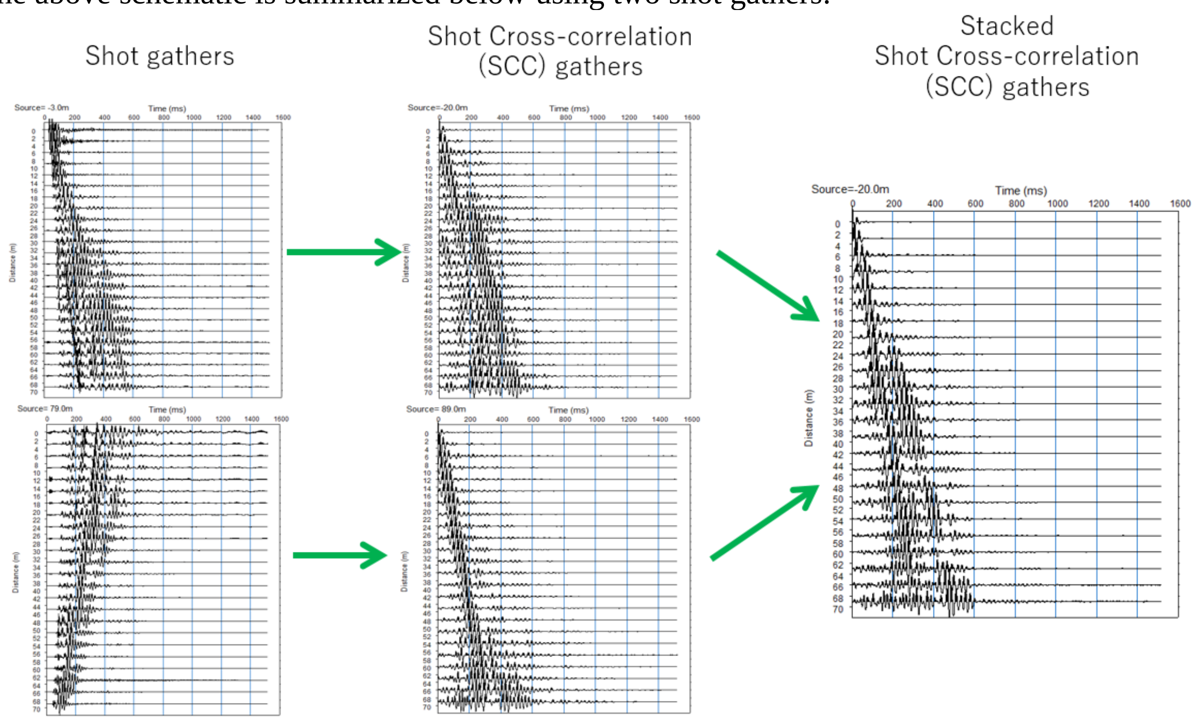


Figure 121: Stacked SCC from two shot gathers.

The processing flow is shown in Figure 122.

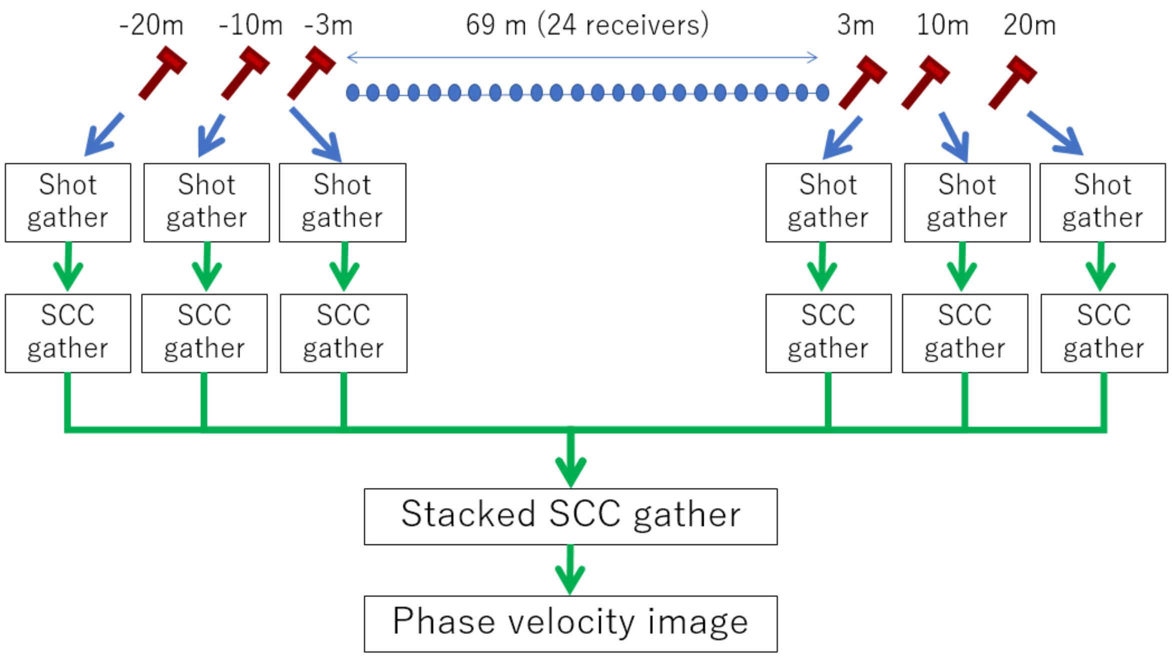
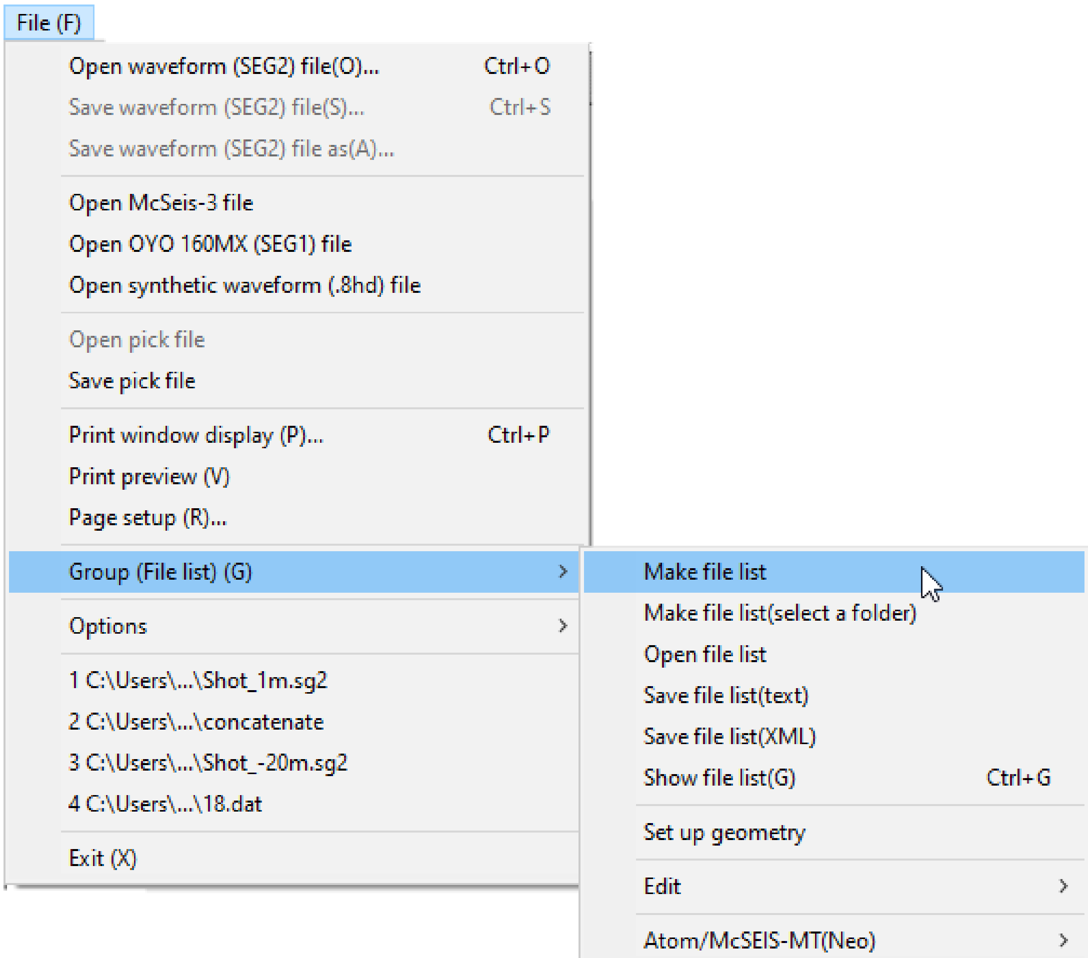
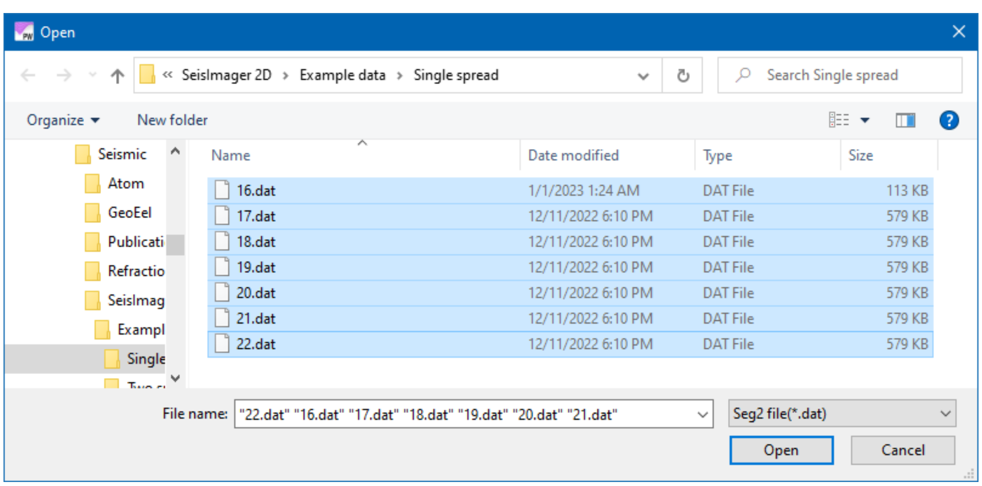


Figure 122: Processing flow from raw shot gathers to phase velocity image using stacked shot-correlation gathers.

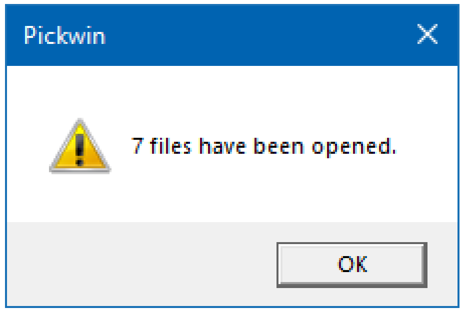
To calculate and stack the SCCs, use the following procedure:

1. Make a list file of raw shot gathers:

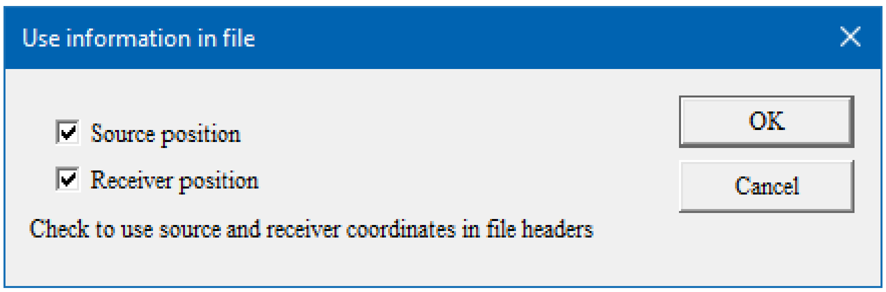




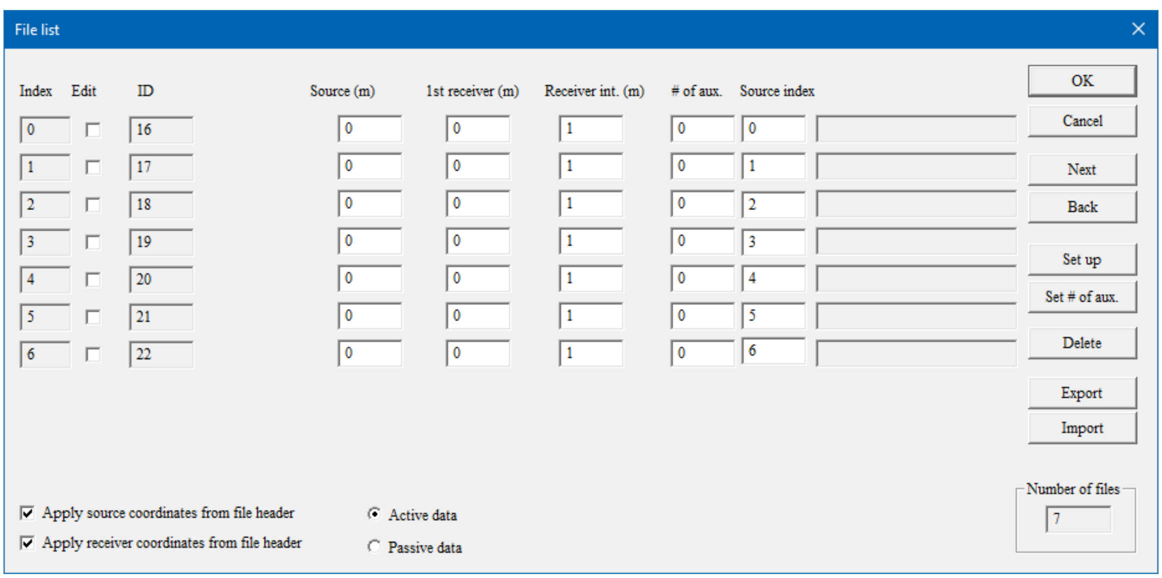
2. Confirm the number of files:



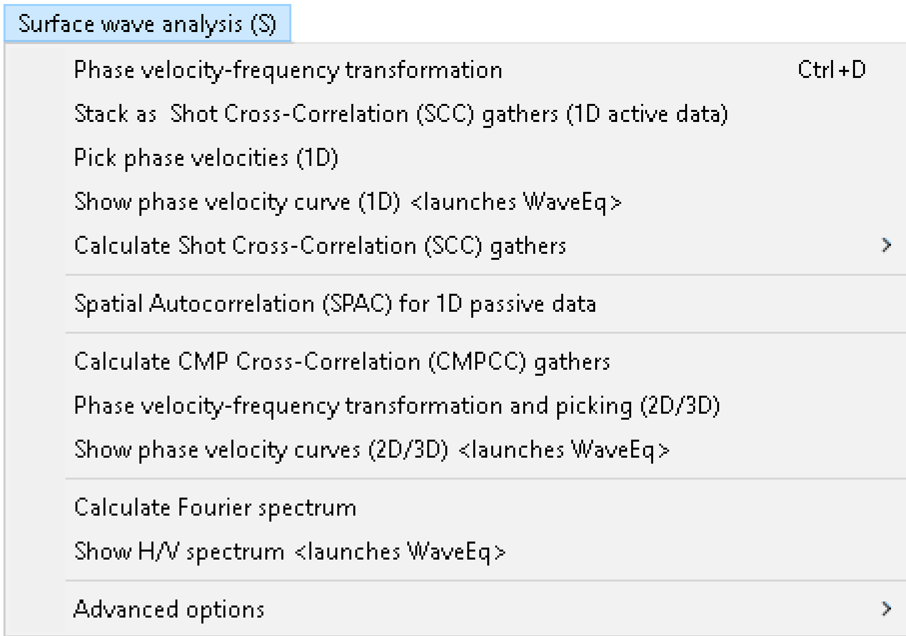
3. Check the source and receiver position boxes (assuming they are correct in the header):



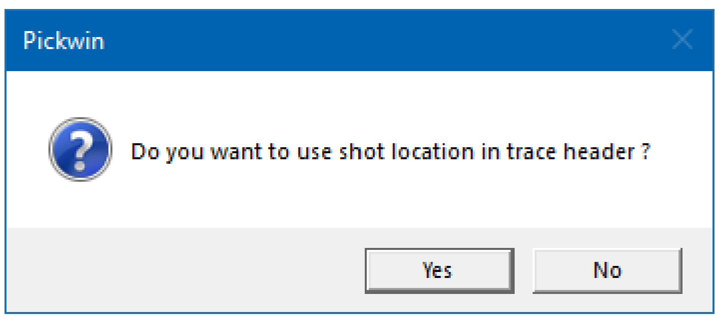
4. Confirm the file IDs and update the source and receiver locations if necessary:



5. In the **Surface wave analysis** menu, select *Stack as Shot Cross-correlation (SCC) gathers (1D active data):*



6. If each file contains the correct shot location, press *Yes*. If not, choose *No* and the program will infer the shot locations based on trace amplitude.



The calculated SCC gathers will appear. Make sure there is no time-shift among files (traces).

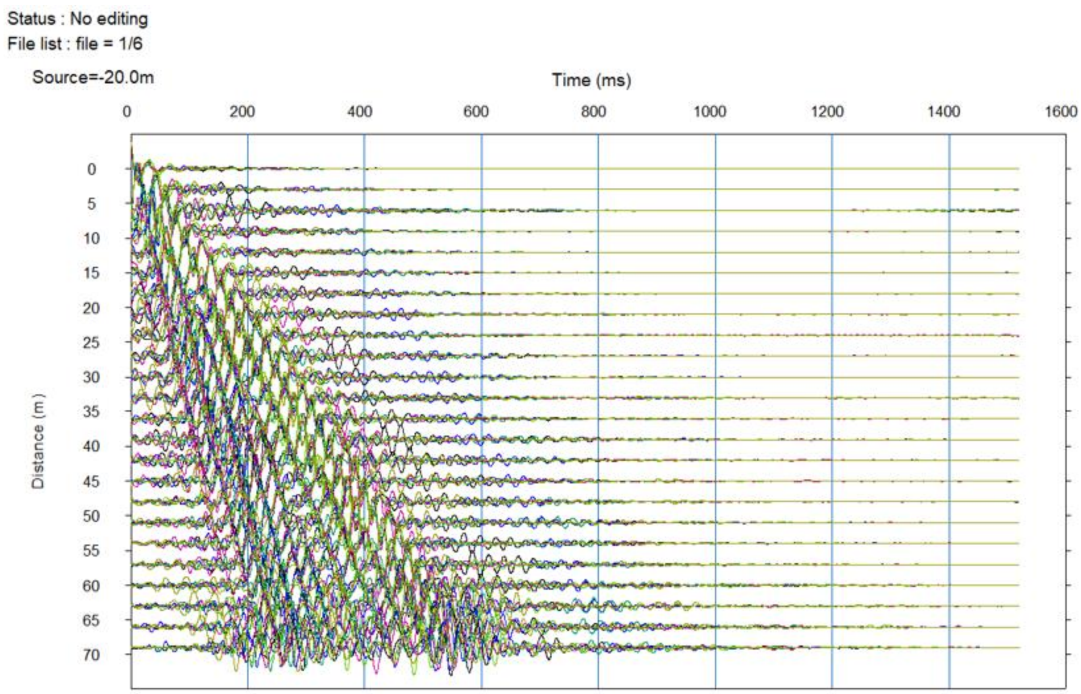
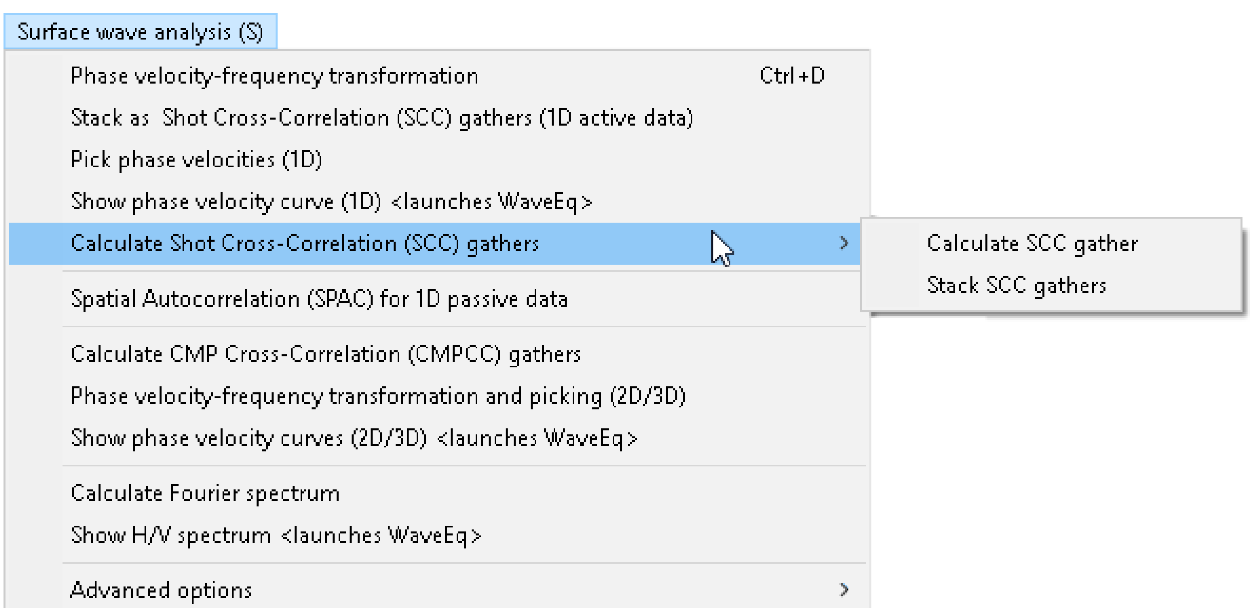


Figure 123: Calculated SCC gathers.

Now you must stack the SCC gathers.

7. In the **Surface wave analysis** menu, select *Calculate Shot Cross-correlation (SCC) gathers* **|** *Stack SCC gathers:*



The stacked SCC gather will appear:

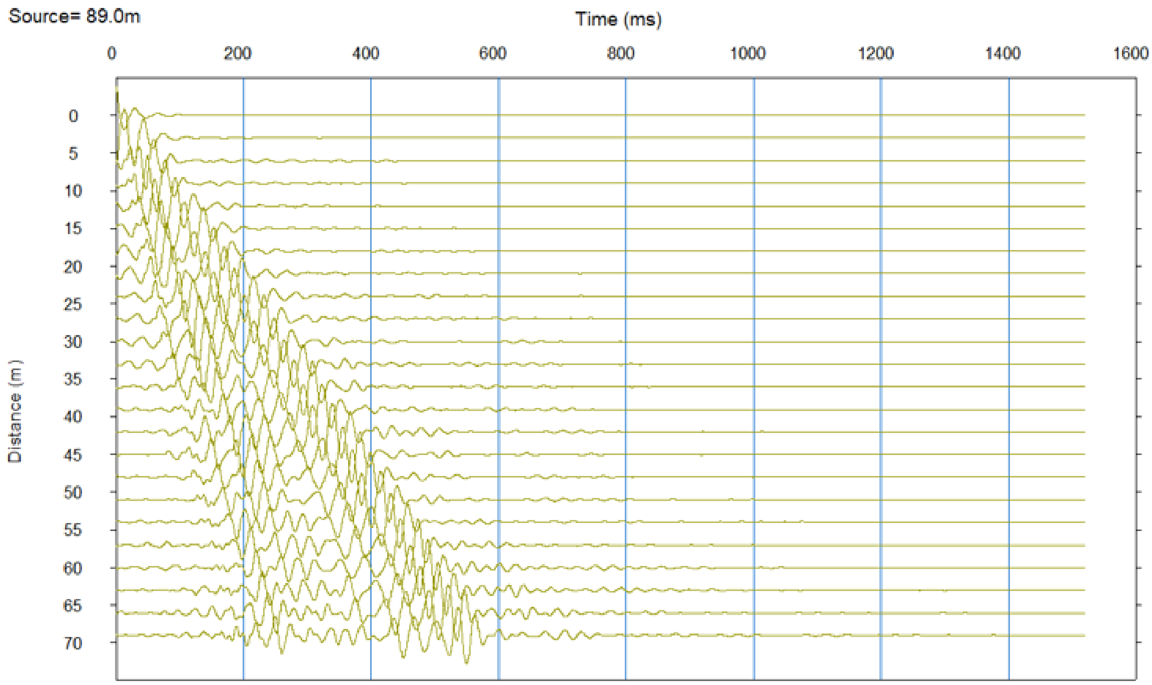
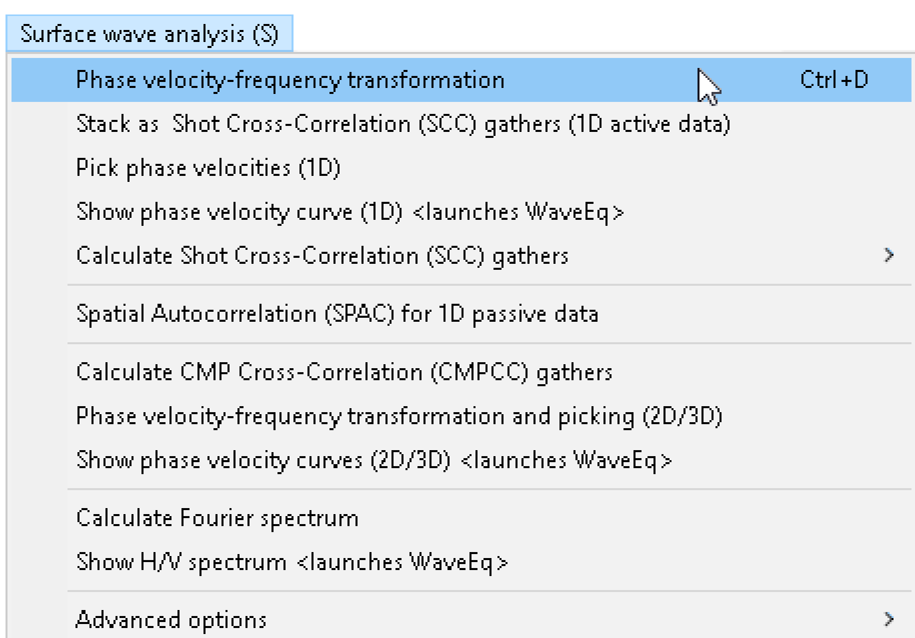


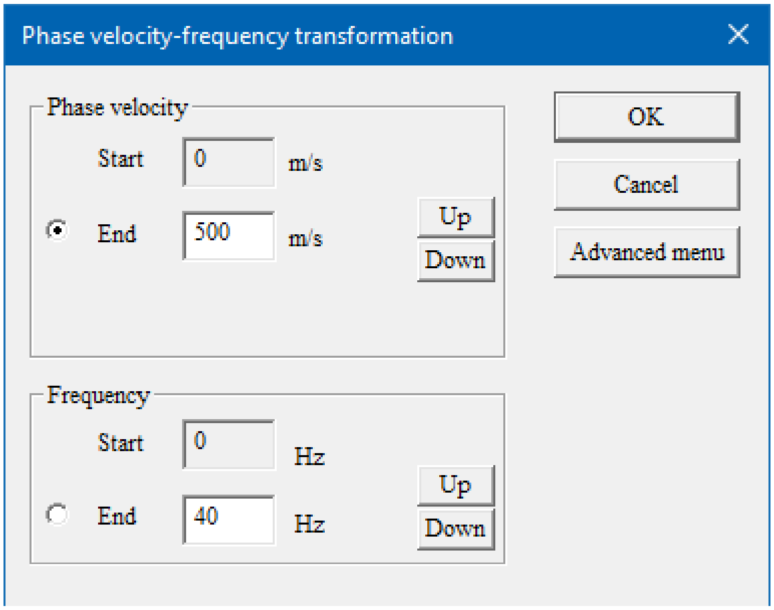
Figure 124: Stacked SCC gather.

You are now ready to calculate the phase velocity image.

8. In the **Surface wave analysis** menu, select *Phase velocity-frequency transformation*:



9. Set up the display parameters and press OK:



The phase velocity image will appear:

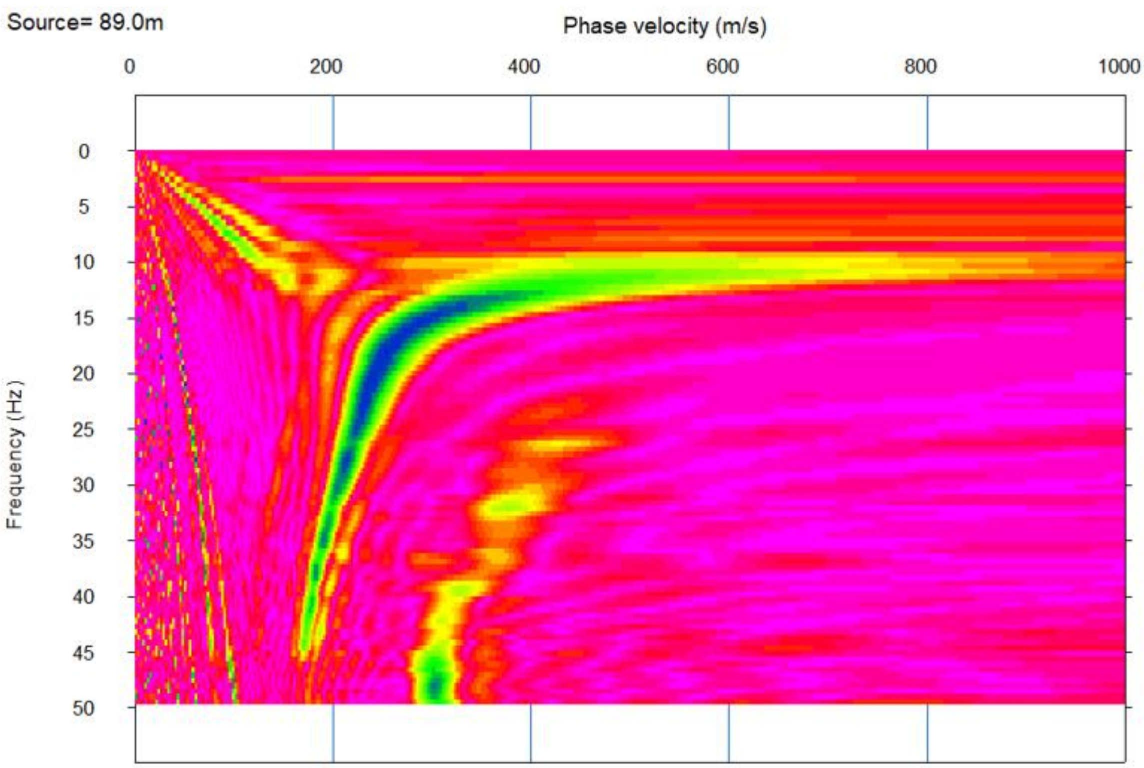
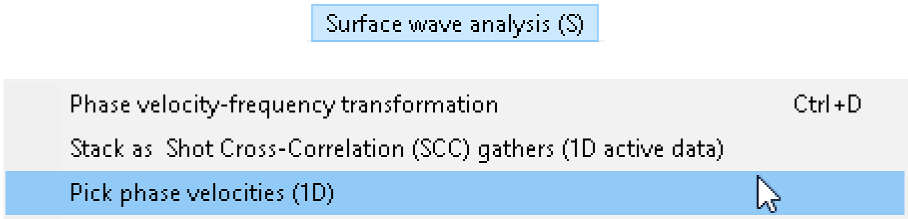


Figure 125: Phase velocity-frequency plot.

6.3.3 PICK PHASE VELOCITIES (1D)

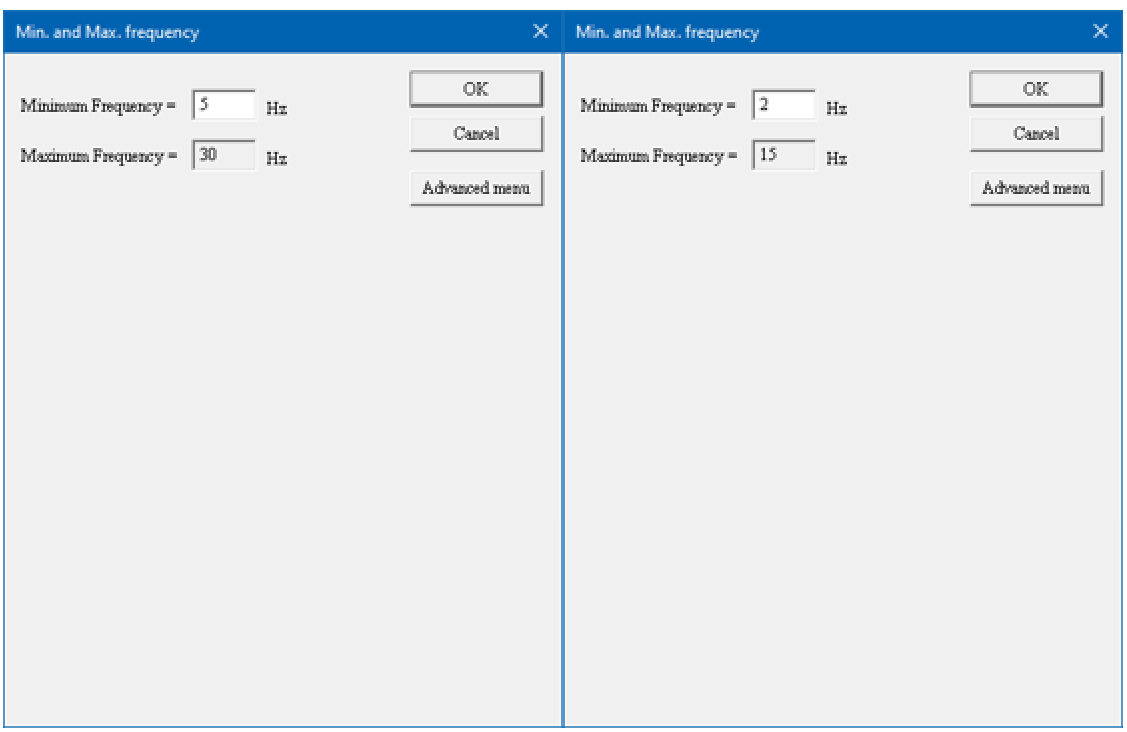


To automatically pick the maximum amplitudes on the phase velocity-frequency plot which define the dispersion curve, select *Pick Phase Velocity (1D)*.

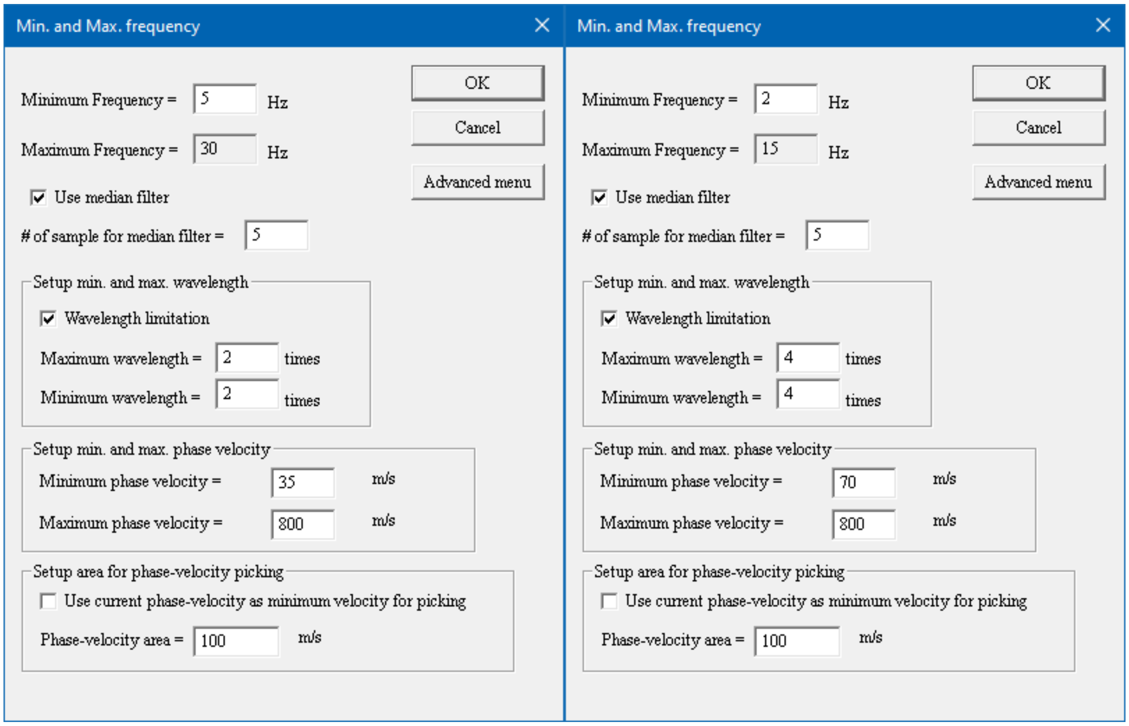
Set the frequency bounds for automatic picking in the **Min. and Max. Frequency** dialog box. For active source data processing (shown on left), the *Minimum Frequency* default value is 5 assuming that 4.5 Hz geophones were used.

For passive source data processing (shown on right), the *Minimum Frequency* default value is 2 assuming that 2 Hz seismometers were used. If the dataset was acquired with 4.5 Hz geophones, the *Minimum Frequency* can be increased to 5 if desired; however, there may be signal below 5 Hz and any spurious picks made between 2 and 5 Hz can easily be deleted manually. It is not crucial that this value be precisely correct.

The value shown for the *Maximum Frequency* reflects in Fourier space the value closest to that set in the **Phase velocity-frequency transformation** dialog box.



The default dialog box format hides the **Advanced** menu. Pressing on *Advanced menu* reveals the rest of the parameters with default values for active source (shown on left) and passive source (shown on right) processing. These parameters are automatically updated by the software depending on the type of data being processed. Typically, none of the settings need to be changed.



After the dispersion curve is automatically picked, if *Use Median filter* is checked, a median filter is applied to remove noisy picks. The median filter is a moving window filter sized by the *number of samples for the median filter*. For high tolerance of noisy picks, a large number would be set for the number of samples. The default value of 5 is suitable for most cases.

The *Wavelength limitation* defines the wavelength (phase velocity divided by frequency) boundaries for picking. If this option is checked, the limits as defined will be used for picking. The *Maximum wavelength* limit is calculated by the total offset or array length multiplied by the scalar value entered. The *Minimum wavelength* limit is calculated by the geophone interval multiplied by the scalar value entered. For active source processing, the default value is 2 and for passive source processing the default value is 4.

On the phase velocity-frequency plot, the *Maximum wavelength* setting controls the slope (x/y) of the upper blue line (nearly parallel to the x-axis) and the *Minimum wavelength* controls the slope of the lower blue line (nearly parallel to the y-axis). To widen the limits of picking, that is, the separation between the blue lines, enter a value greater than 4 for the *Maximum wavelength* and a value less than 4 for the *Minimum wavelength*. Refer to Page B-8 for more information on the *Maximum wavelength* and *Minimum wavelength*.

The *Minimum phase velocity* is the lowest phase velocity for which a pick will be made. For active source data, depending on whether the units are set to *meters* or *feet*, the default value is 35 m/s or 150 ft/s, respectively. For passive source data, it is 70 m/s or 70 ft/s. The *Maximum phase velocity* is the highest phase velocity for which a pick will be made. For all types of data and regardless of units, the default value is 1000 m/s or ft/s.

On the phase velocity-frequency plot, a trend of peak amplitudes should be obvious. If it appears that there is only noise below a particular phase velocity on the lower frequency end, that velocity should be entered for the *Minimum phase velocity* to focus the picks to the velocity range of the amplitudes associated with the dispersion curve. Otherwise, noise with amplitudes larger than those for signal will be picked. On the higher frequency end, if there is a higher mode(s), the velocity between it and the fundamental mode can be entered for the *Maximum phase velocity* to help prevent the amplitudes associated with the higher mode from being picked (even with these limits set, further editing of the dispersion curve will likely be required in WaveEq).

Upon completion of picking, the phase velocity-frequency plot with dispersion curve picks (red points) is displayed.

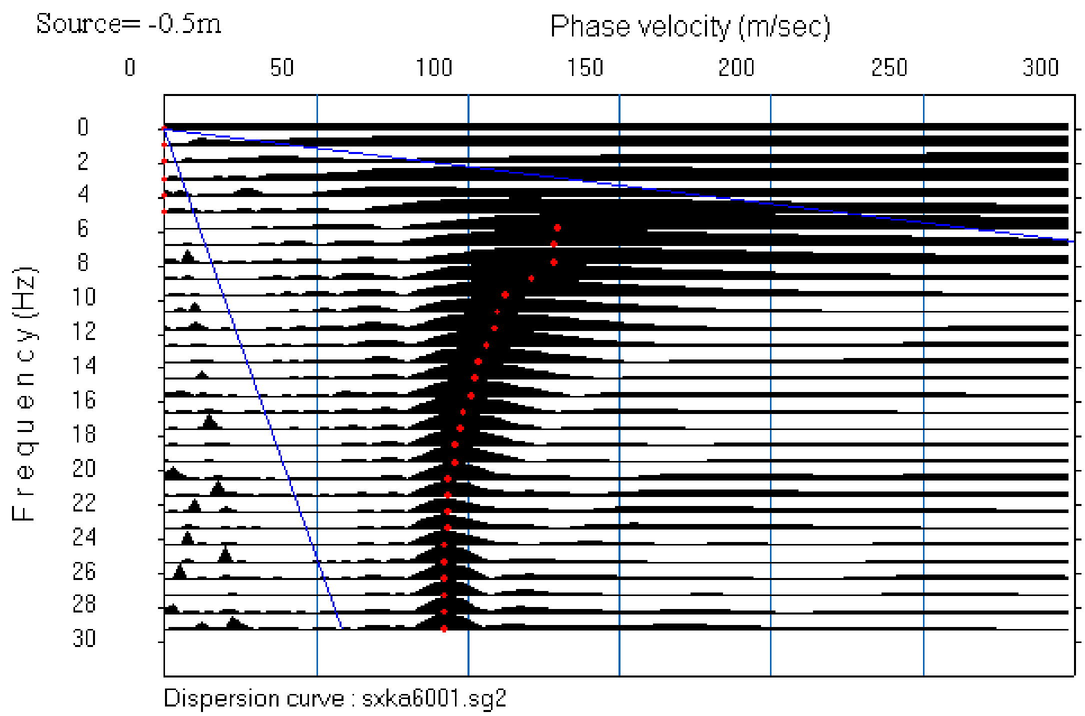
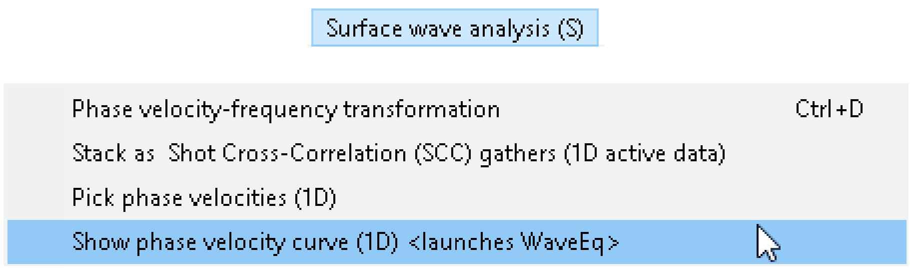


Figure 126: Phase velocity-frequency plot with peak frequency picks.

Picks are automatically made at the mathematical maximum amplitude for each frequency. The x and y-pairs of phase velocity and frequency define the dispersion curve. The automatic picks can be manually edited with the mouse by individually clicking on a new point or by dragging the mouse over a range of frequencies to set a range of new picks. Manual picking is facilitated using the *Fine color contour* button to switch to a color plot and the *Waveform amplitude*, *Horizontal scale*, and *Vertical scale* buttons to optimize the gain and scale. (These functions are common with SeisImager/2D; refer to the SeisImager/2D manual for a complete explanation.) To help identify maxima, as you drag the mouse over the plot the amplitude values can be read on the bottom bar 12:amp.=0.87285, where the value preceding the colon is the frequency and the value following is the amplitude.

Any picks lying on the y-axis have a phase velocity value of zero and are automatically excluded from further analysis.

6.3.4 SHOW PHASE VELOCITY CURVE (1D)



Once the dispersion curve is picked in Pickwin, the picks are held in memory for import to WaveEq. WaveEq is used for detailed editing, inversion, and additional analysis. WaveEq can be opened separately and a *.pvs* file read in, but this single step is the easiest way to automatically launch WaveEq and import a dispersion curve just picked in Pickwin.

To automatically launch WaveEq and import the dispersion curve from Pickwin, select *Show phase velocity curve (1D)*.

WaveEq is launched and the dispersion curve plot is displayed. The unit labels set in Pickwin carry over. Note that in WaveEq, *Phase velocity* is plotted on the vertical axis and *Frequency* is plotted on the horizontal axis. Refer to Section 7.3.2, Page 344, for a complete explanation of this plot.

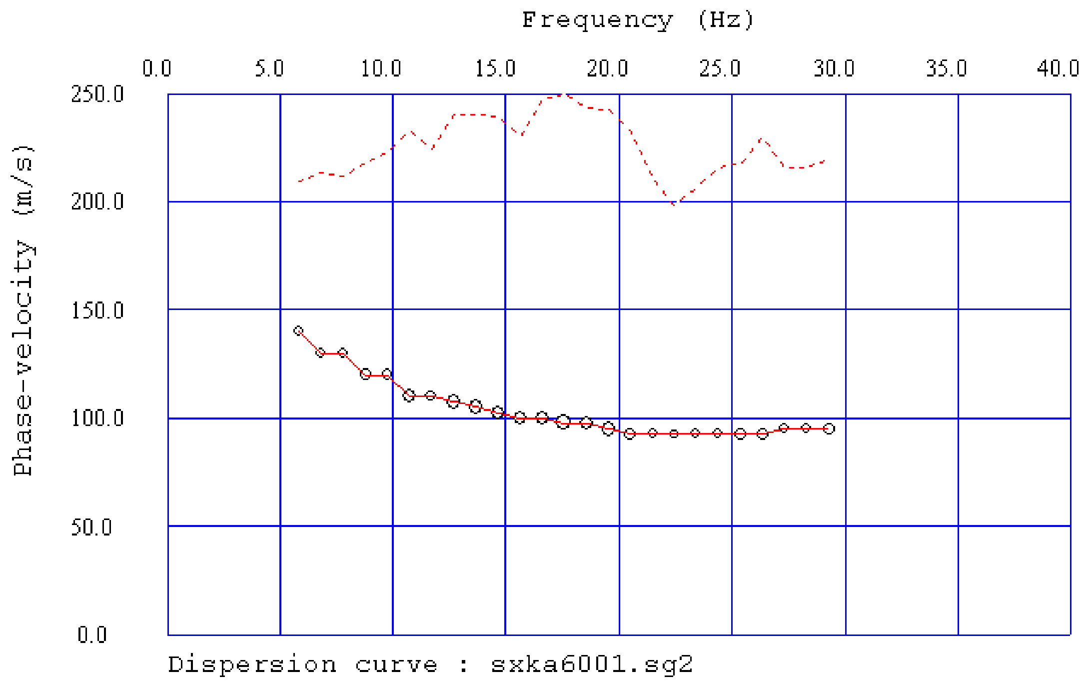
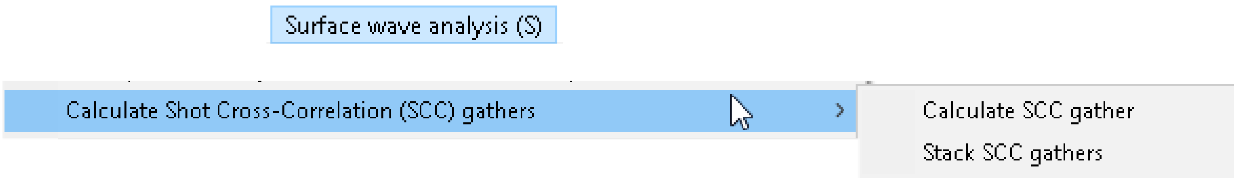


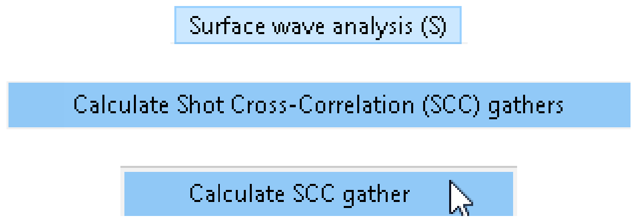
Figure 127: Dispersion curve. Includes quality plot.

6.3.5 CALCULATE SHOT CROSS-CORRELATION (SCC) GATHERS



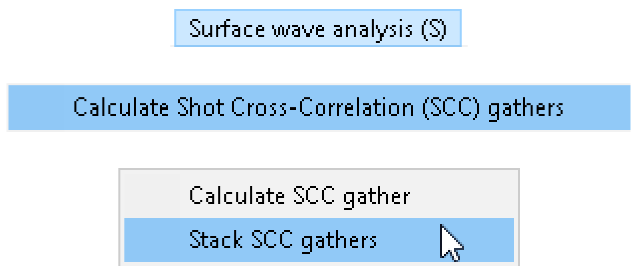
The functions in this menu are identical to those described in Section 6.3.2 above below. The only difference is that in this menu, the functions work on individual shot gathers, whereas the menu item described in Section 6.3.2 works on file *lists*. However, the process is the same. In general, it is uncommon to apply these functions to individual shot gathers, and the items in this menu are rarely used.

6.3.5.1 Calculate SCC Gather



See Section 6.3.2 above below.

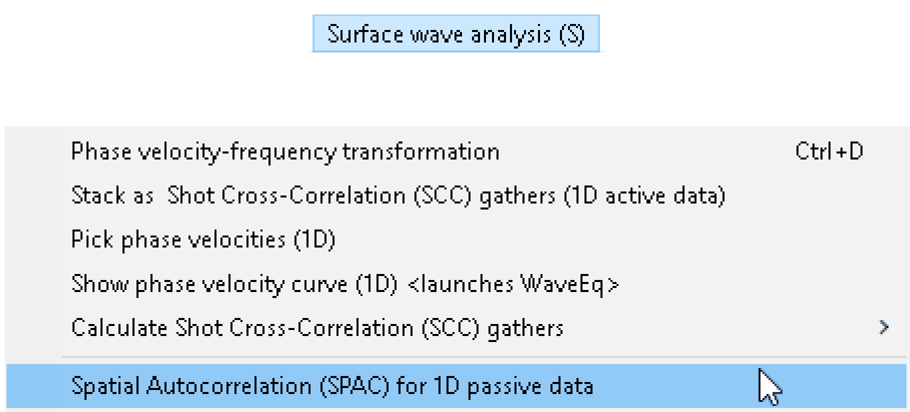
6.3.5.2 Stack SCC Gathers



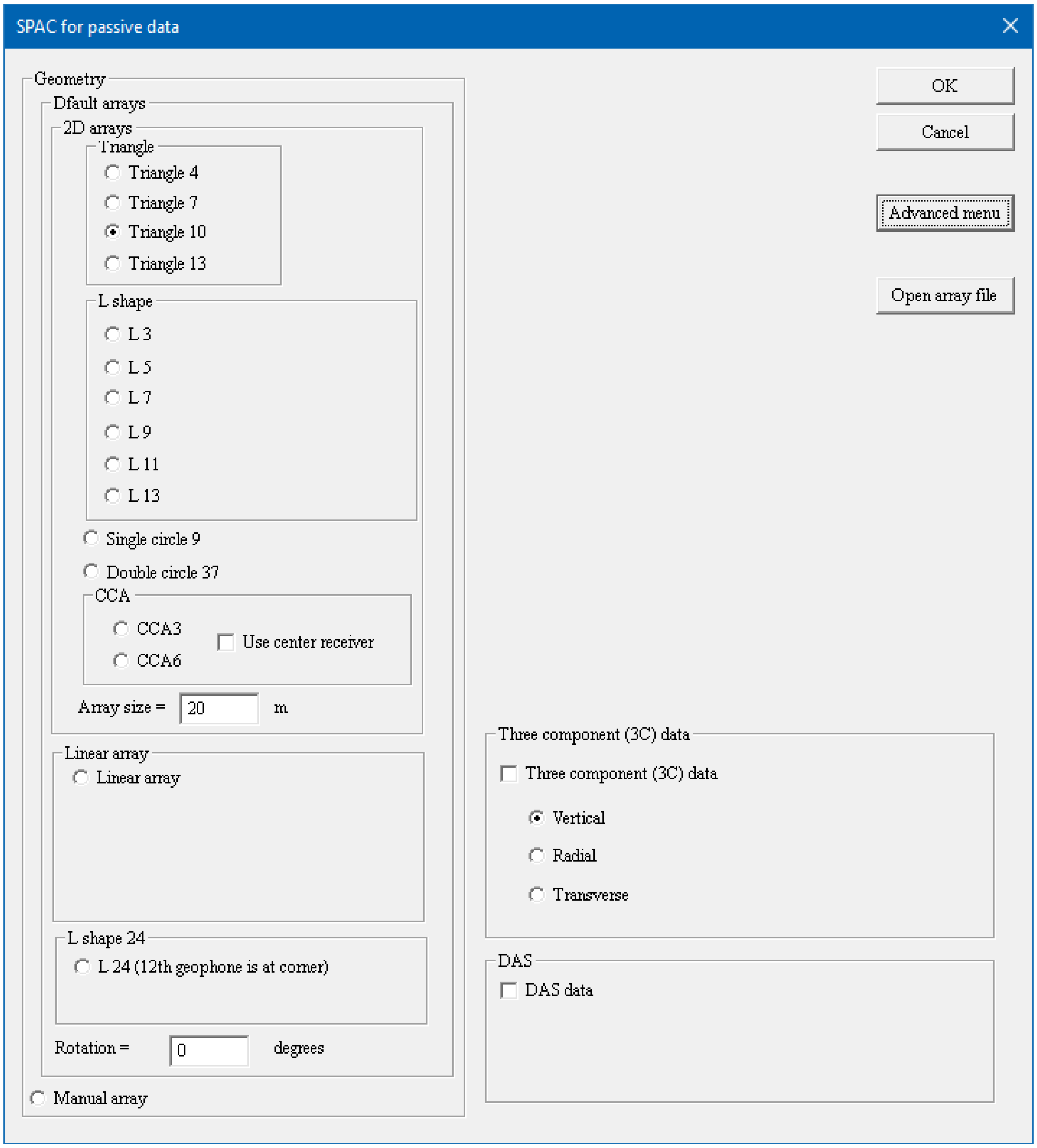
See Section 6.3.2 above below.

6.3.6 Spatial Autocorrelation (SPAC) For 1D Passive Data

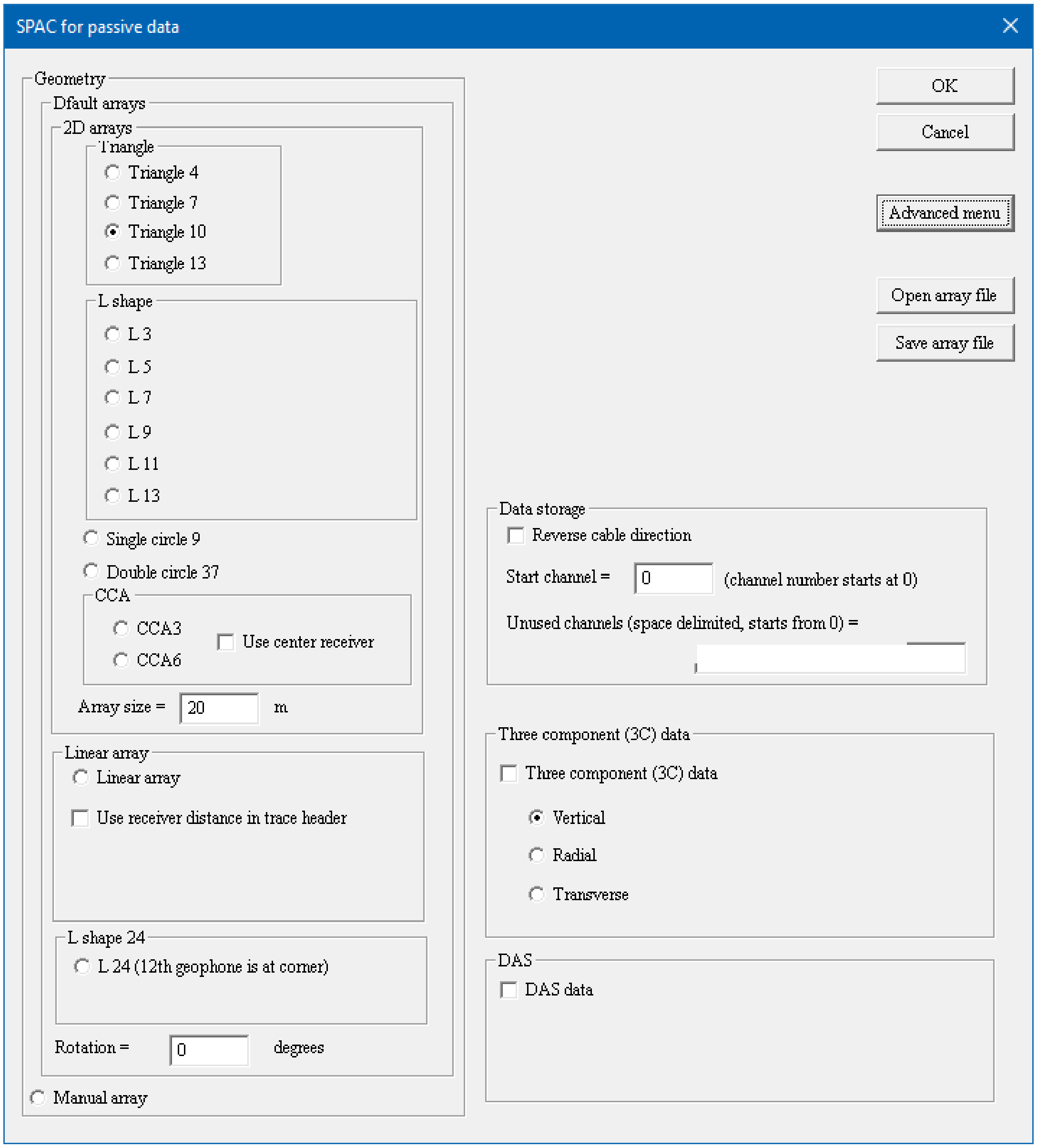
For MAM datasets, the function *2D Spatial autocorrelation* uses the SPAC method to analyze the signal coherency between multiple observation points in a receiver array (independent of source location). Once the signal coherency spectrum is known, phase velocity can be determined by finding the best fit between theoretical and observed coherency. A tutorial on using the SPAC method in SeisImager/SW method can be found here.



Once selected, set the geometry of the passive source array in the **2D SPAC** dialog box. Refer to Section 3.2 , Page 26, for an explanation of the different array types and *Array size*.

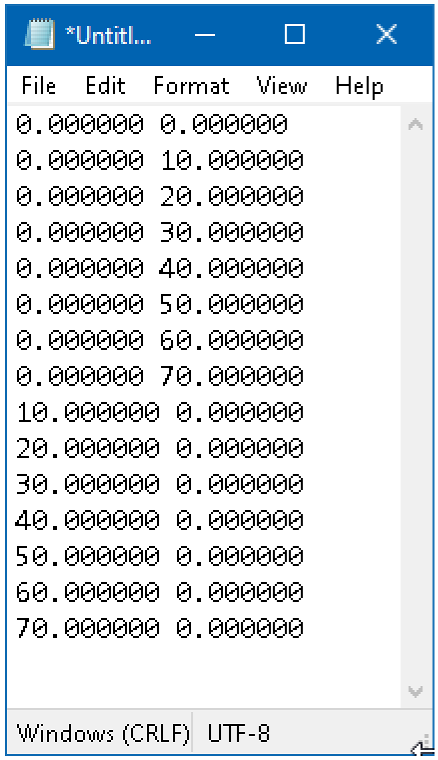


The default dialog box format hides the **Advanced** menu. Pressing *Advanced menu* reveals options to define a *Manual array*, *Open array file*, *Save array file*, and to set *Data storage* parameters.

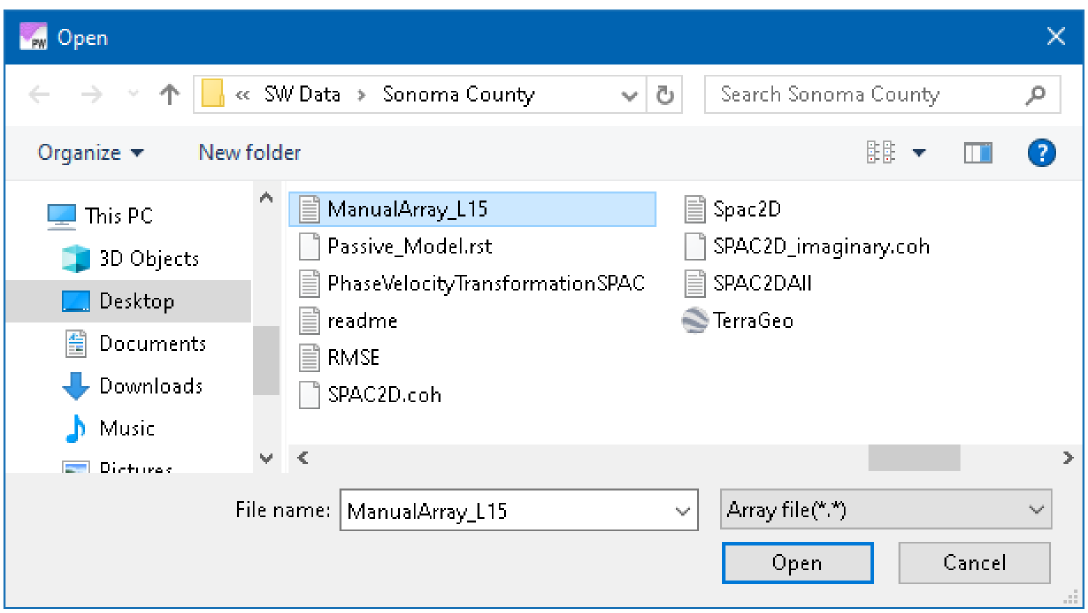


Data storage allows a particular array geometry to be applied to other data. *Reverse cable direction* will flip the channel order, *Start channel* sets the new start channel number, and *Unused channels* allows dead or unused channels to be deleted.

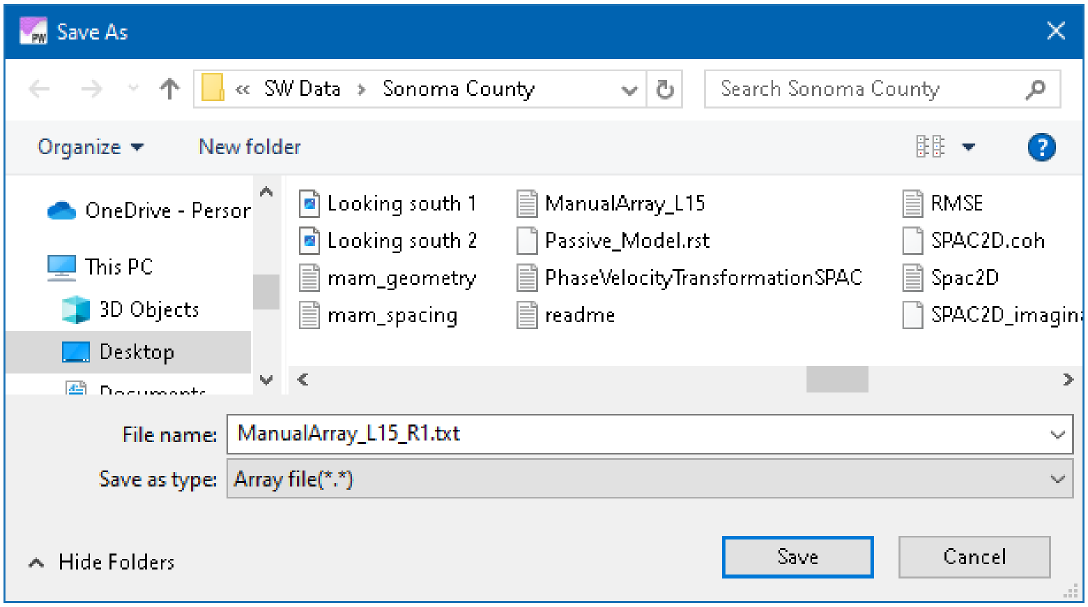
If your array does not conform to one of the standard geometries, a *Manual array* can be defined in a simple space-delimited text file where each row is a pair of x- and y-coordinates.



Once the *Array file* is prepared, press *Open array file*, highlight the file, and press *Open*.



If changes are made to an existing *Array file*, press *Save array file* to revise the file or to save a new file with a different name.



Once the *2D Spatial autocorrelation* process is complete, a signal coherency plot is displayed.

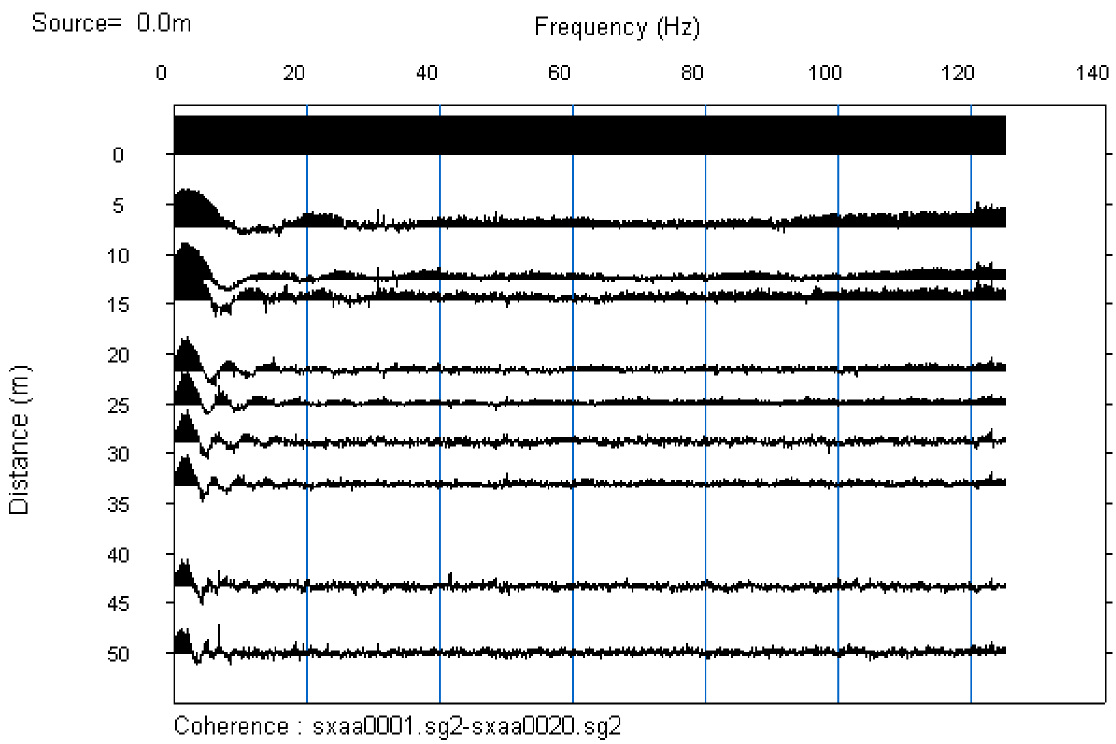


Figure 128: Signal coherency plot.

Coherence is the similarity between all possible pairs of geophones, in this case in a triangle array with 10 geophones, with an array size of 50 m. The separation between each geophone pair is plotted on the y-axis as *Distance* and the coherence between each of those two traces is plotted as a function of *Frequency* on the x-axis.

Consider the geophone separation of zero, the coherence is 1 shown by a bar, or horizontal line shaded black, across all frequencies. At a distance of zero, a trace is compared with itself and there is 100% similarity or coherence of 1. Generally, as geophone separation increases, coherence decreases. Coherence also tends to be higher at lower frequencies and decreases with higher frequencies.

The shape of a coherency curve by nature is a Cosine function with 1D arrays and a Bessel function (decaying Cosine function) with 2D arrays (shown above). The coherency curve for each separation is well shaped (calculated from what is considered an ideal dataset). Compare this with the coherency plot for a 60-foot *L11* array that shows poor coherence for all separations greater than zero (shown below).

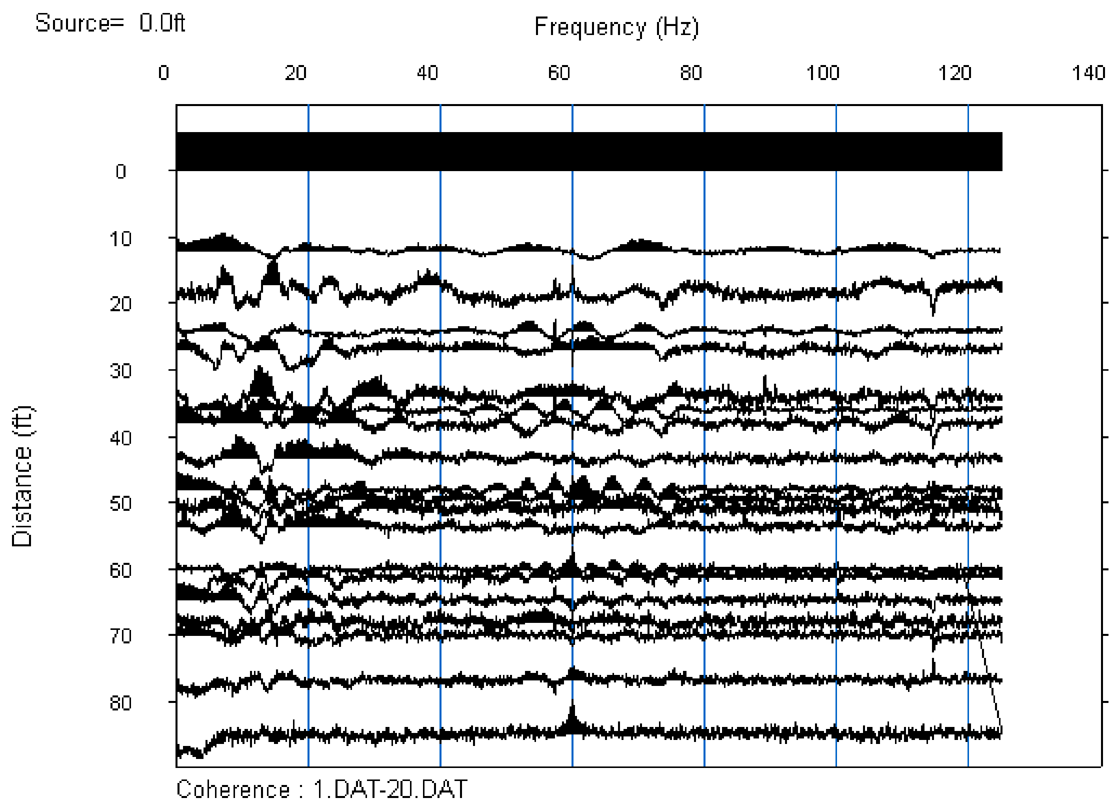
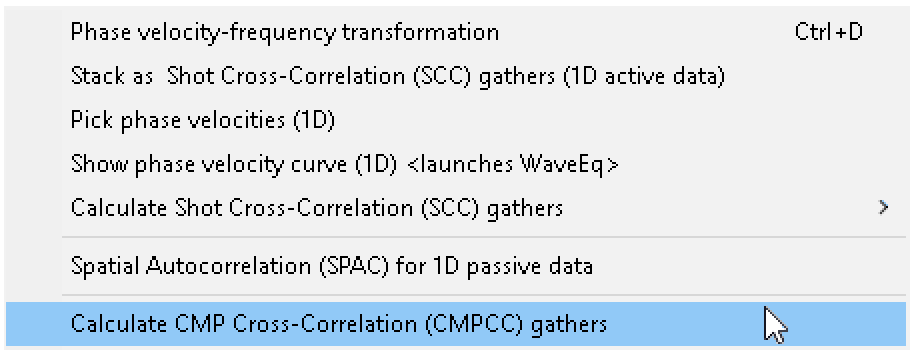


Figure 129: Coherency plot showing poor coherence for non-zero separations.

In the field, coherence is a quick calculation and can be readily performed to confirm that MAM datasets will yield good results.

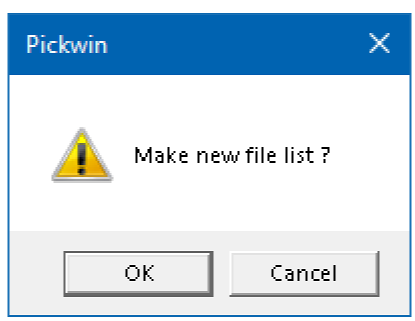
6.3.7 CALCULATE CMP CROSS-CORRELATION (CMPCC) GATHERS



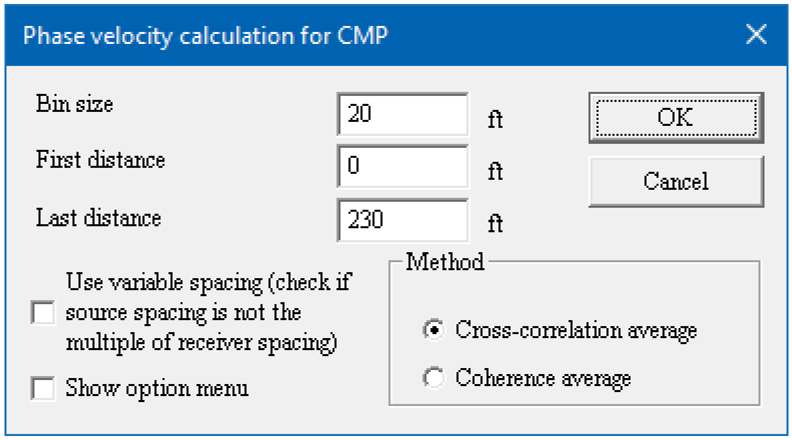
Once a 2D MASW dataset has a file list and its geometry has been assigned, the traces can be assembled into CMP cross-correlation gathers. The steps include calculation of cross-correlations between every pair of traces in each shot record, gathering of correlation traces by CMPs, and time domain stacking of correlation traces having equal spacing. The effect is to improve the lateral resolution and accuracy over what is normally achieved with conventional 2D MASW. Refer to Hayashi and Suzuki (2004) for a complete explanation of the process.

First, a file list with assigned geometry is opened using the **Group (File List)** menu, *Open File List* or *Make File List* and *Set up Geometry*, as applicable. Once opened, select *Surface Wave Analysis* | *Calculate CMP Cross-correlation (CMPCC) Gathers.*

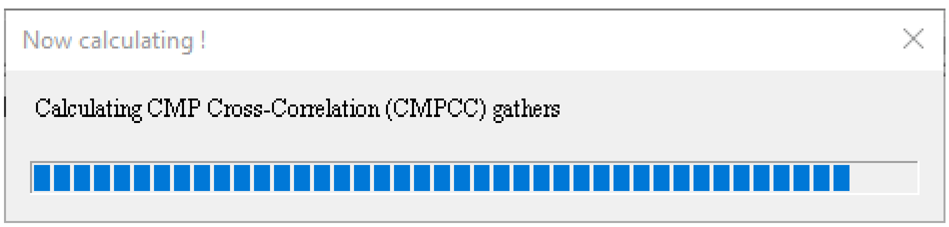
You will be prompted to make a new (and different) file list. The new file list is built using the existing file list held in memory; the original file list itself is not overwritten. For the new file list, the source and receiver locations in the existing file list are replaced with CMP locations and CMP cross-correlation gather names. Press *OK*.



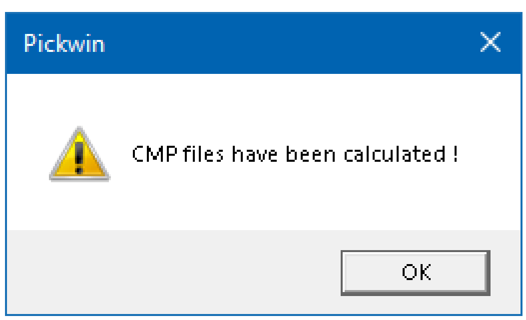
Next, set the parameters for organizing the CMPs for the phase velocity calculation. The *Bin size* is automatically calculated as two times the receiver interval. In this application, a bin is a discrete length that divides the survey line. Within one bin, traces are sorted based on mid-point locations and then stacked to obtain one output trace with increased signal-to-noise ratio. The effect of increasing the *Bin size* is to reduce the resolution of the final V_S cross-section. The default value for *Bin size* is suitable for most cases. The *First distance* and *Last distance* are taken from the first and last coordinates of the receiver spread in the file list. Press *OK.*



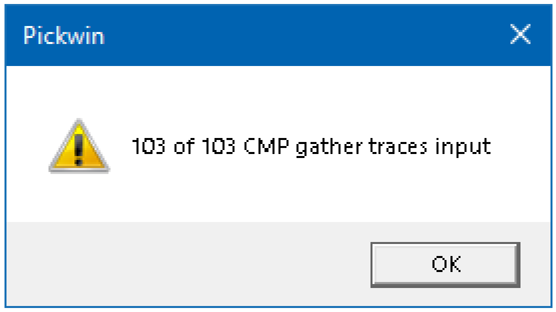
CMP cross-correlation traces are calculated, and CMP cross-correlation gathers are assembled. A new set of CMP cross-correlation gather SEG-2 files are written to the dataset directory with the name *cmp_XXXXX.sg2* where the X values are the CMP locations.



Confirmation that the CMP cross-correlation gathers are calculated and assembled is displayed; press *OK.*



The number of CMP gathers is reported; press *OK.*



Once calculation of the CMP cross-correlation gathers is complete, a plot of the CMP cross-correlation gather geometry is displayed. Refer to Table 5 in Section 6.1.5.7, Page 233, for explanation of the geometry plot attributes and display functionality.

The horizontal axis, *Spacing*, is the separation or spatial distribution of the cross-correlation traces. The vertical axis, *CMPCC Gather No.*, is the number of the CMP cross-correlation gather.

This example shows the highest fold occurs for the center shots which have the most traces.

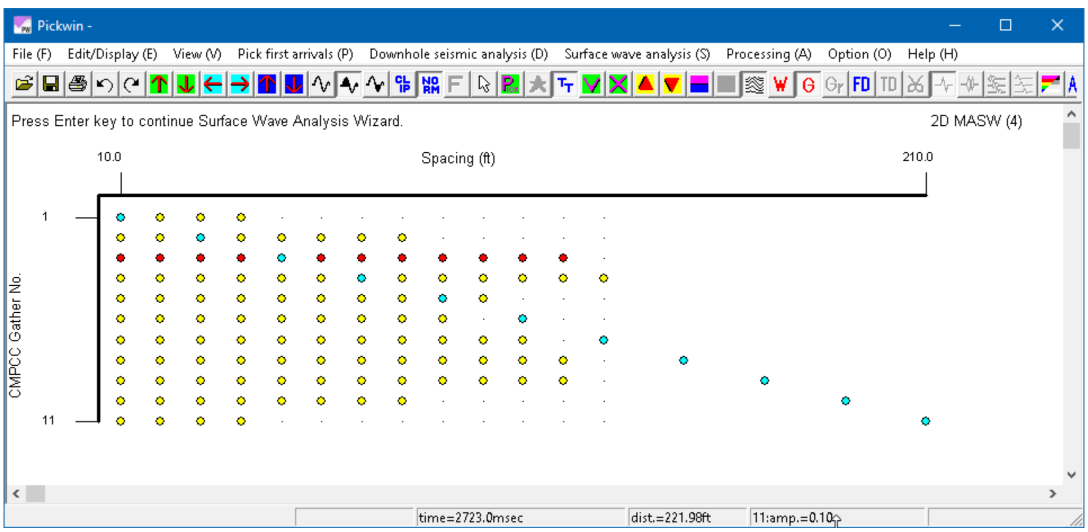
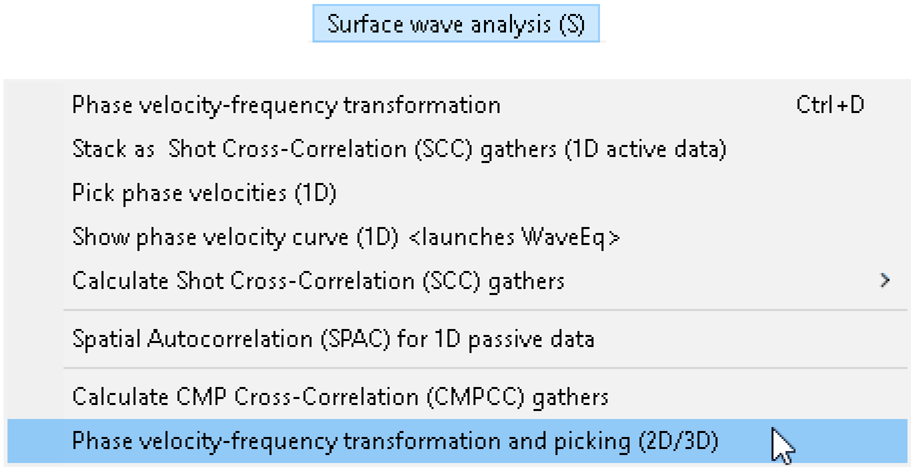


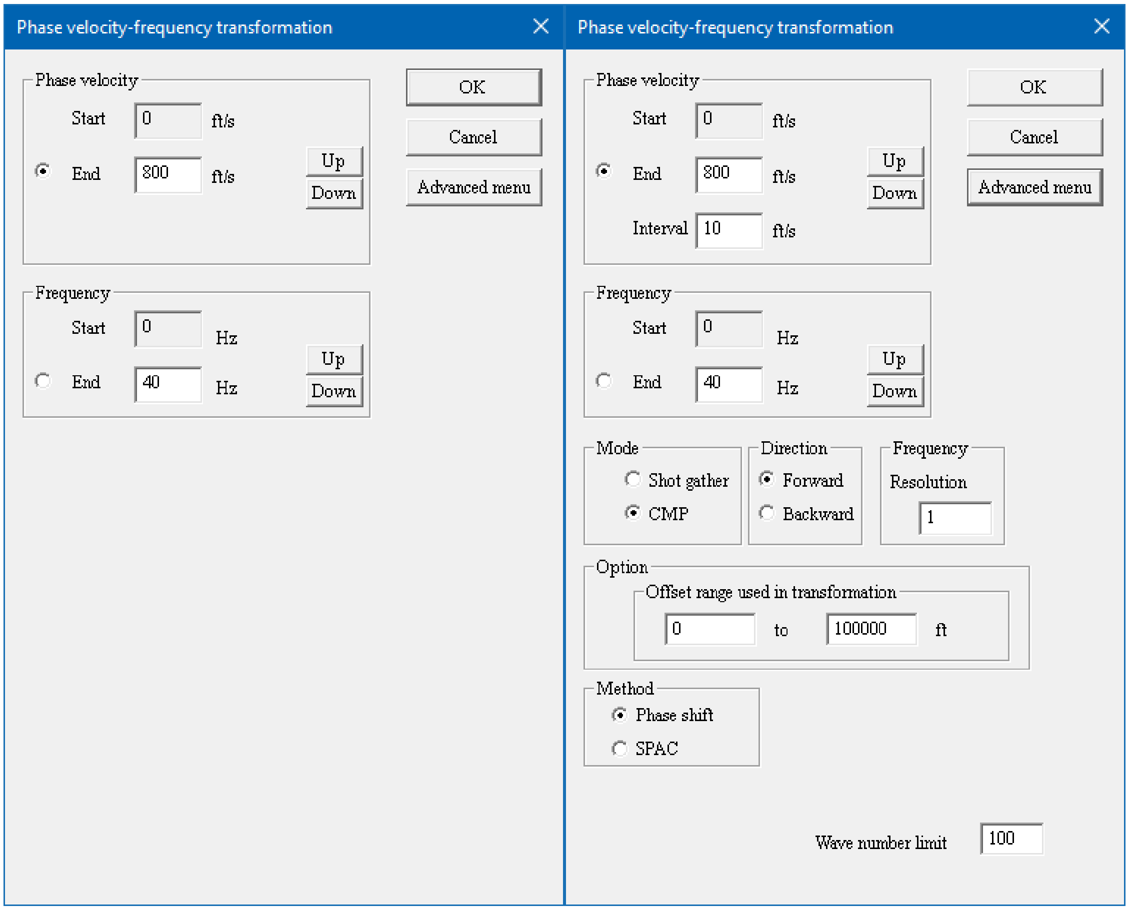
Figure 130: CMP cross-correlation gather geometry. Highest fold occurs in center shots where trace counts are the highest.

6.3.8 PHASE VELOCITY-FREQUENCY TRANSFORMATION AND PICKING (2D/3D)

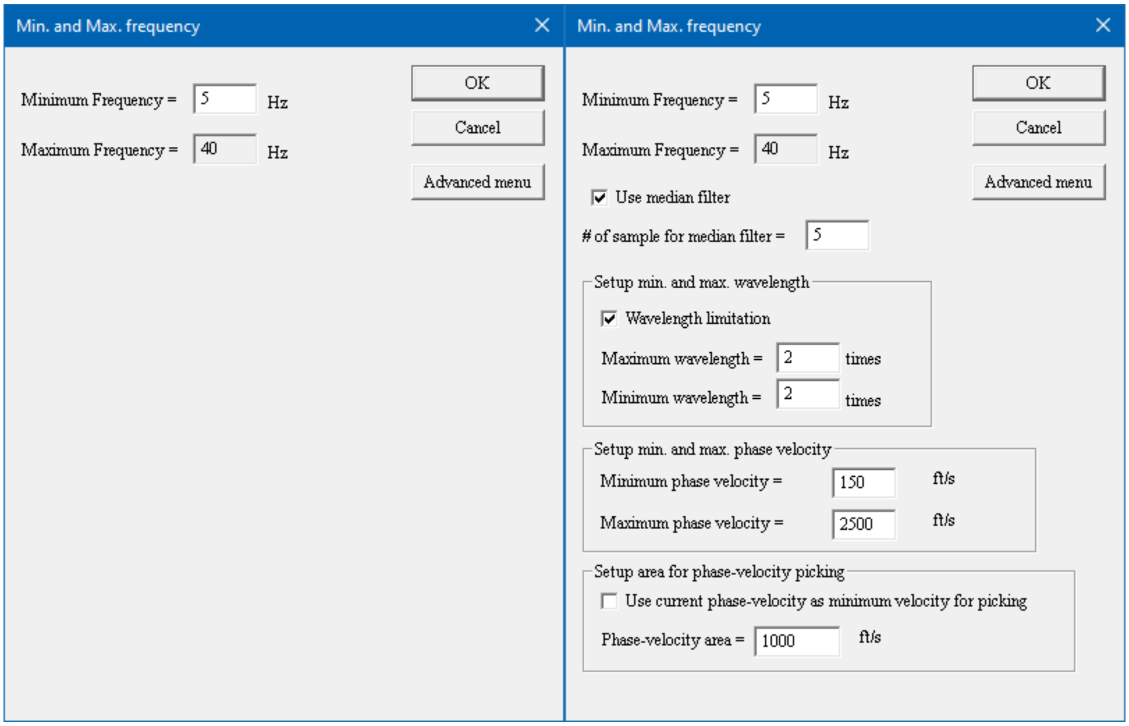


Once CMP cross-correlation gathers are assembled, select *Phase velocity-frequency transformation and picking (2D/3D)* to transform the time domain gathers to the frequency domain, to calculate the phase velocity for each frequency, and to pick the maximum amplitudes which define the dispersion curves. For 2D MASW, the transformation and picking are combined into this one function.

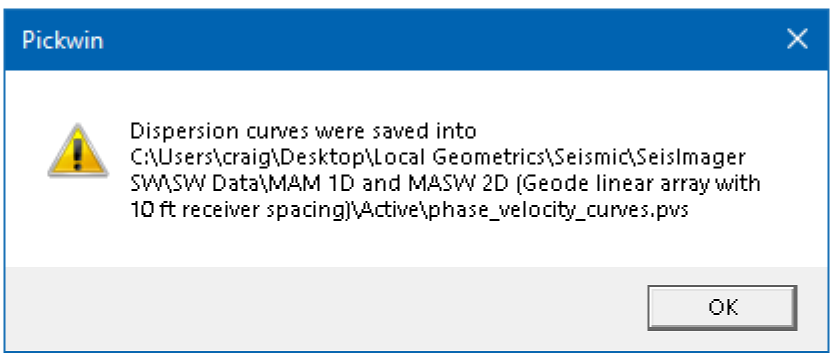
The **Phase velocity-frequency transformation** dialog box (shown on left and **Advanced** menu shown on right) is the same as that explained in Section 6.3.1 on Page 258. Press *OK* when done.



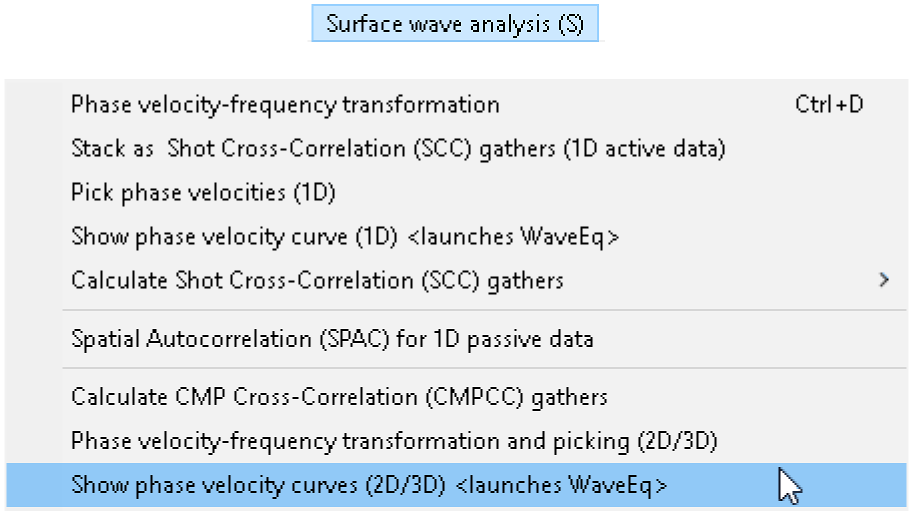
Next, the **Min. and Max. Frequency** dialog box (shown on left and **Advanced** menu shown on right) is automatically displayed so the amplitude maxima for each curve can be automatically picked. The **Min. and Max. Frequency** dialog box is the same as that explained in Section 6.3.3 on Page 271. Press *OK* when done. Advanced features are rarely altered and can generally be left to the default settings. Contact support@seisimager.com for assistance if necessary.



Upon completion of picking, because 2D MASW datasets include many files, all the individual dispersion curves are not shown in Pickwin. The picks are automatically saved as a *.pvs* file in the dataset directory and held in memory for import to WaveEq.



6.3.9 Show Phase Velocity Curves (2D/3D) <Launches WaveEQ>



Once the dispersion curves are picked in Pickwin, the curves are held in memory for import to WaveEq. WaveEq is used for detailed editing, inversion, and additional analysis. WaveEq can be opened separately and a *.pvs* file read in, but this single step is the easiest way to automatically launch WaveEq and import dispersion curves just picked in Pickwin.

Select *Show phase velocity curves (2D/3D)* to automatically launch WaveEq and import the dispersion curves from Pickwin.

WaveEq is launched and the dispersion curve plot is displayed. The unit labels set in Pickwin carry over. Note that in WaveEq, *Phase velocity* is plotted on the vertical axis and *Frequency* is plotted on the horizontal axis. Refer to Section 7.5, starting on Page 433, for a complete explanation of this plot.

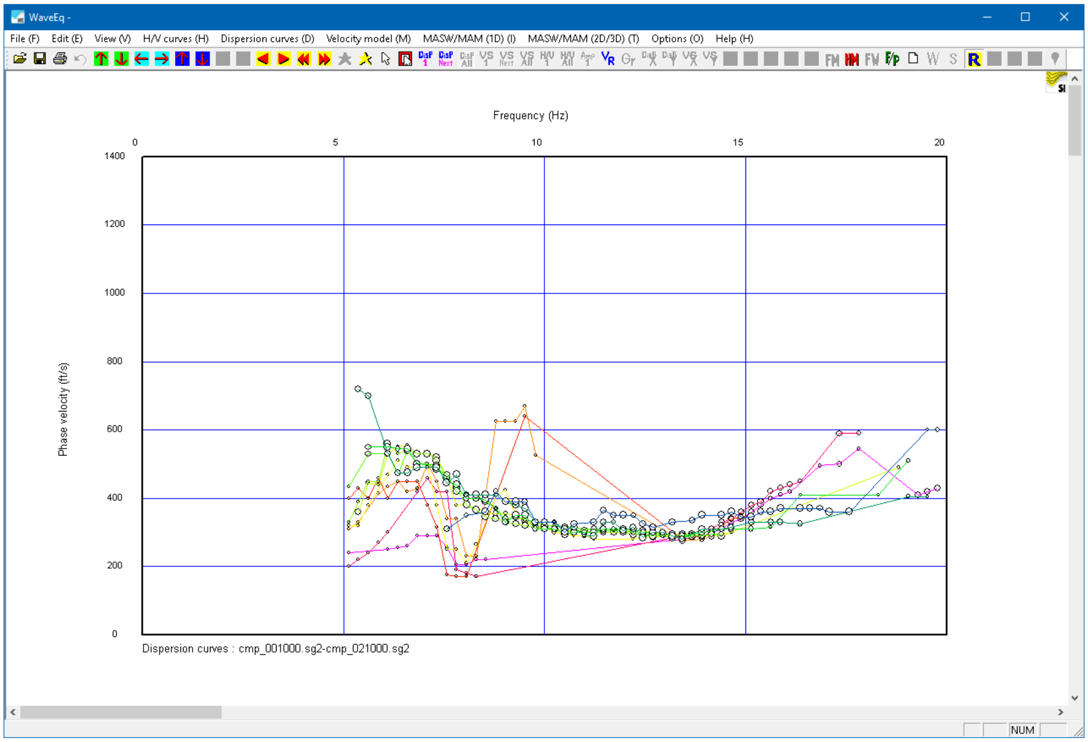
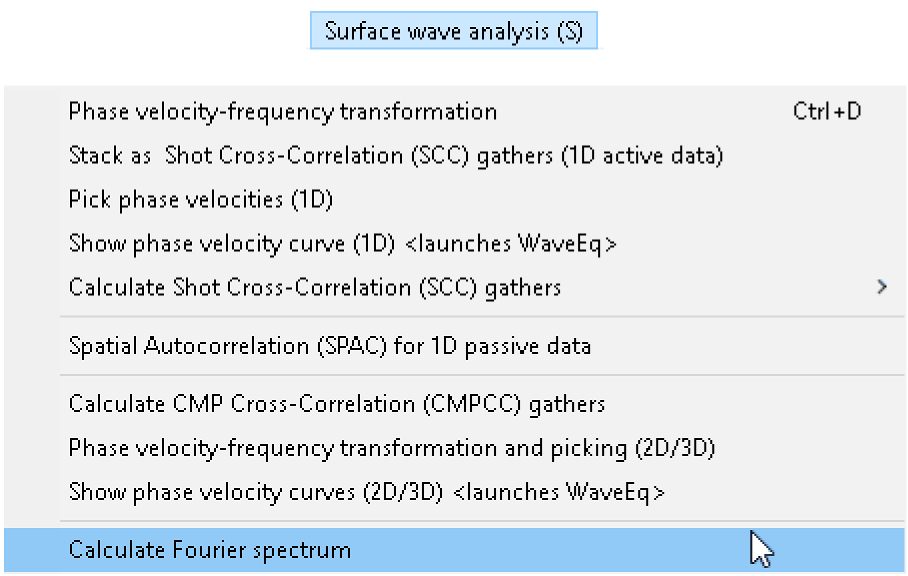
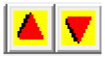


Figure 131: Dispersion curves.

6.3.10 CALCULATE FOURIER SPECTRUM



To transform your data into the frequency domain (prior to calculating the H/V spectrum, for example, see next section), first create a file list by selecting *File* | *Group (File list)* | *Make file list* and choosing the time domain waveform files to be transformed. Alternatively, if the folder **only** contains the waveform files you wish to transform, select *File* | *Group (File list)* | *Make file* *list (select a folder).* All of the waveform files will be automatically read in (Section 6.1.5.2, Page 227).

The first of your waveform files will be displayed; you may scroll through them using the  buttons on the tool bar.

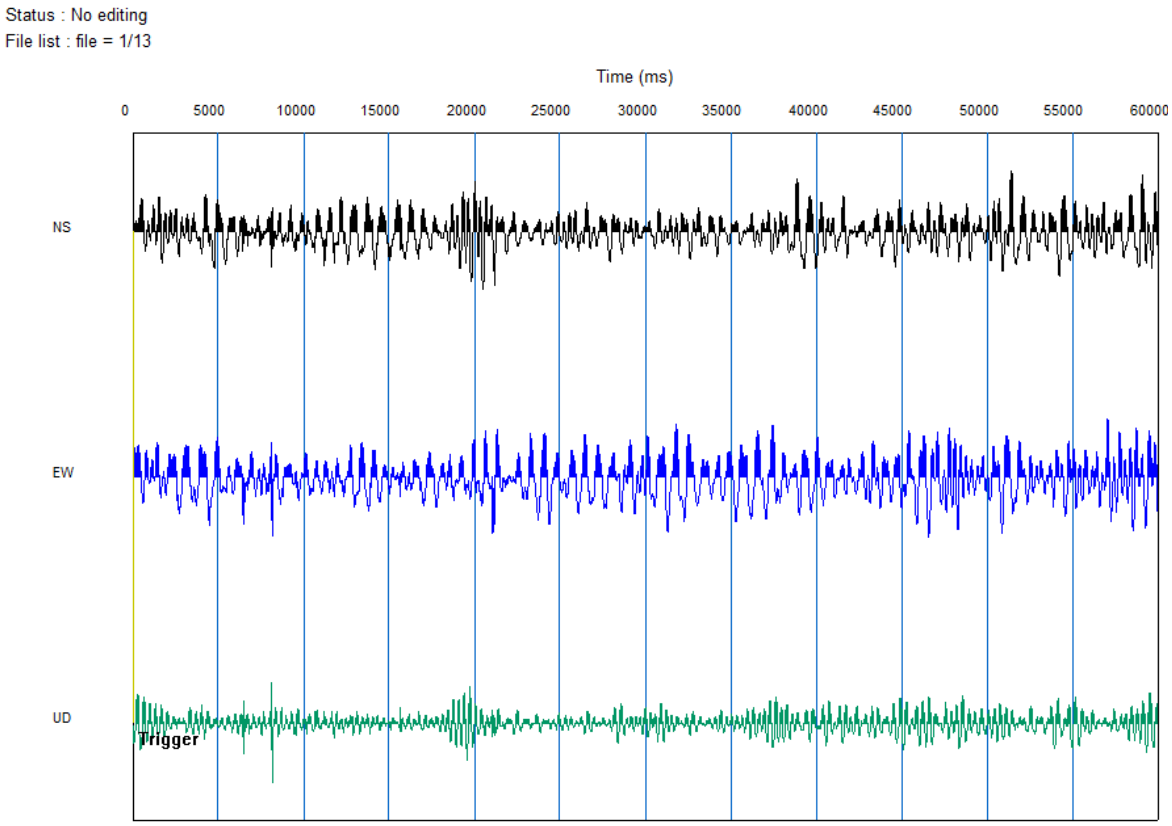


Figure 132: 3-componenet time domain plot.

In this example, we have 13 three-component files (only one file is shown above); two horizontal and one vertical. Each trace is one minute long.

Now would be a good time to save your file list for later use. XML is the most convenient format. Select *File* | *Group (File list)* | *Save file list (XML).* You will be prompted for a file name.

Next, select *Surface wave analysis* | *Calculate Fourier spectrum:*

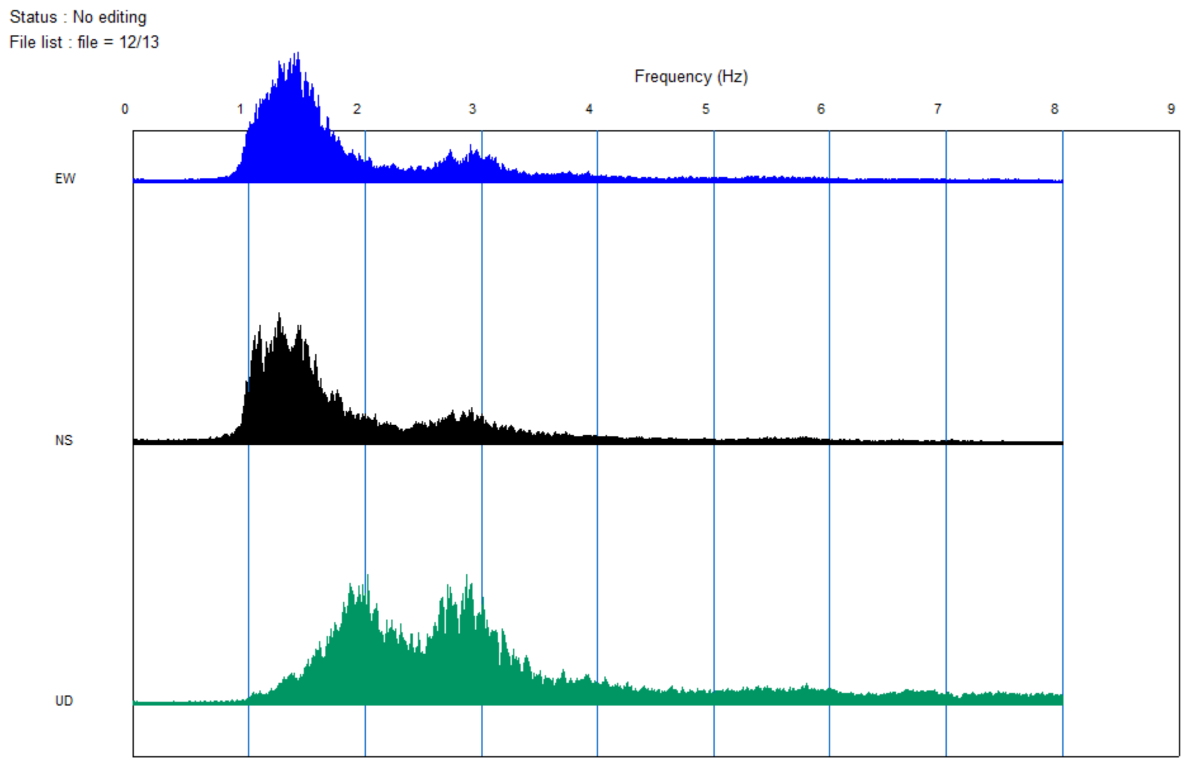
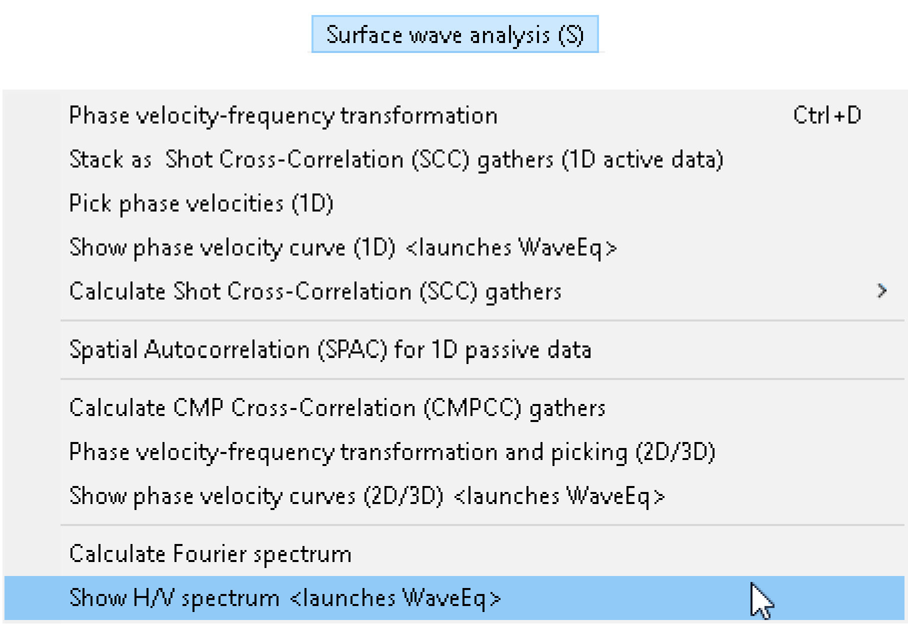


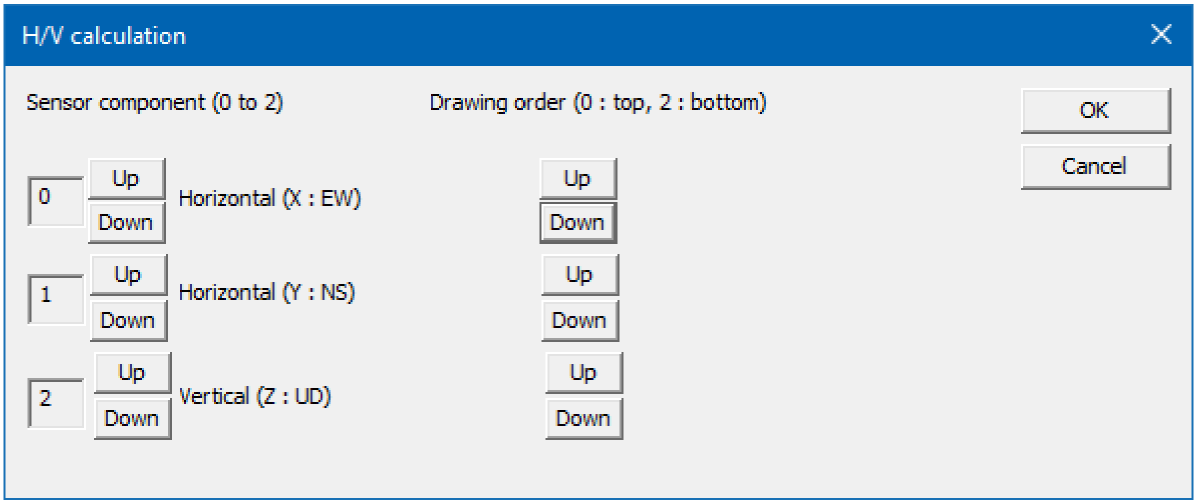
Figure 133: Three-component passive data displayed in the frequency domain.

The data has been transformed into the frequency domain.

6.3.11 SHOW H/V SPECTRUM



To view the H/V spectrum, select *Surface wave analysis* | *Show H/V spectrum.* This will automatically launch WaveEQ.



Edit the component numbers and drawing order if necessary, and press *OK*:

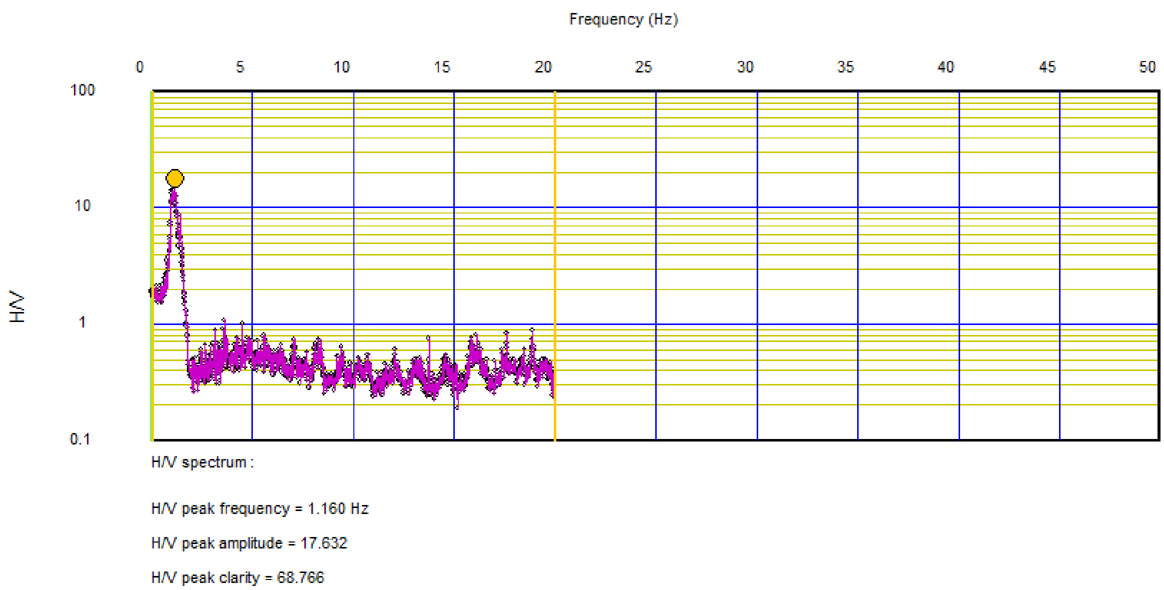
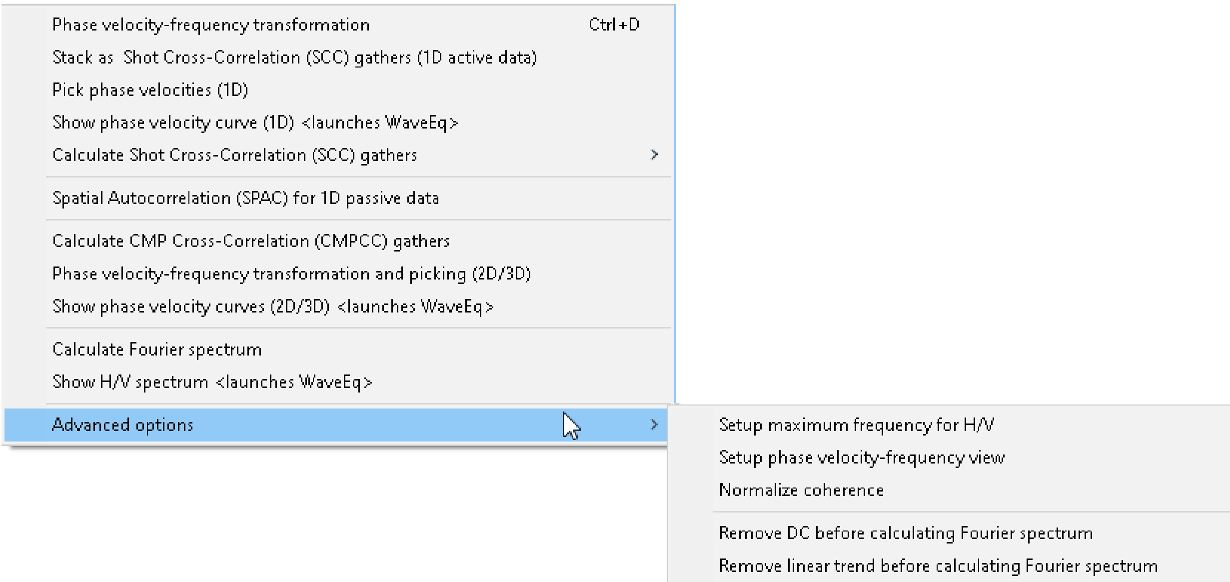


Figure 134: H/V spectrum.

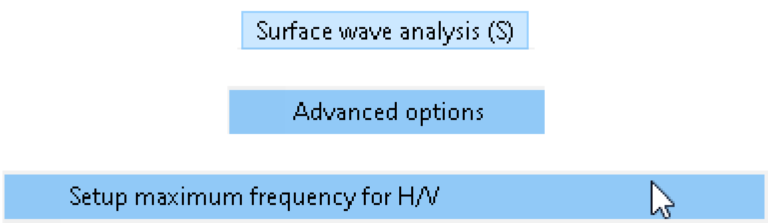
The H/V spectrum will be displayed.

6.3.12 ADVANCED OPTIONS



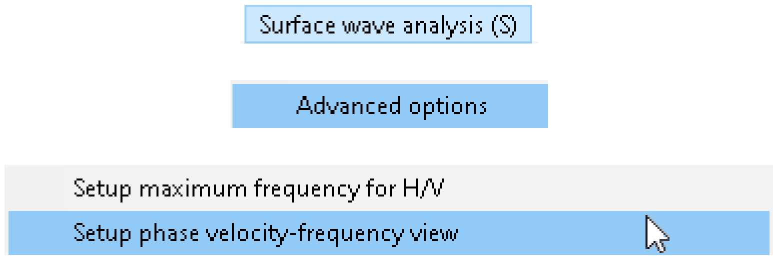
Continue.

6.3.12.1 SETUP MAXIMUM FREQUENCY FOR H/V



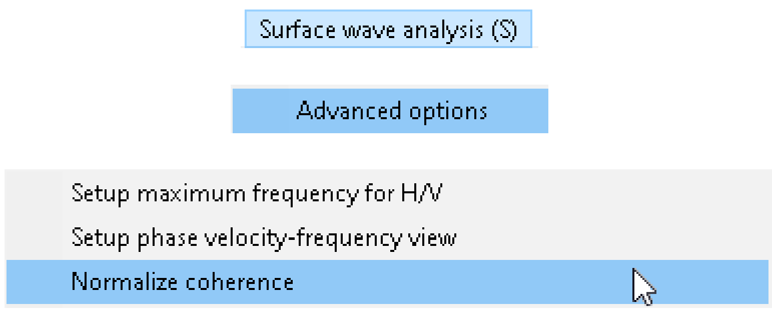
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

6.3.12.2 Setup Phase Velocity-Frequency View



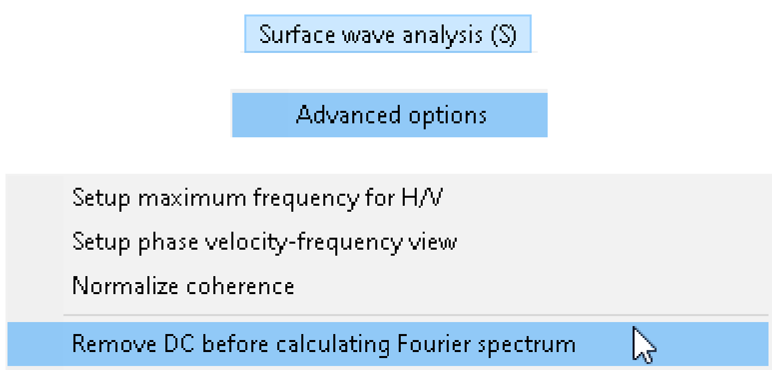
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

6.3.12.3 Normalize Coherence



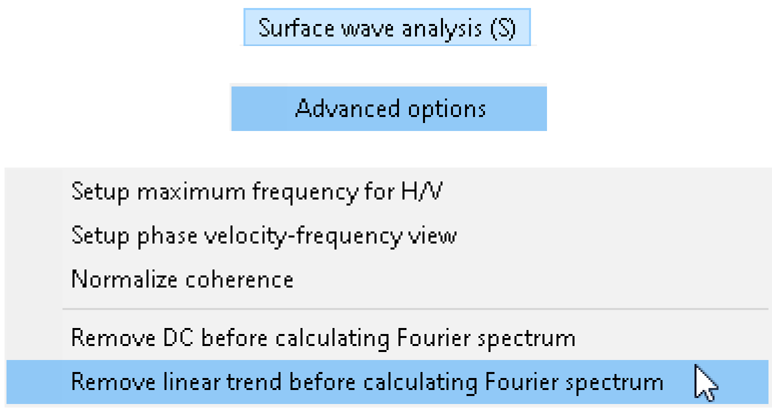
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

6.3.12.4 Remove DC Before Calculating Fourier Spectrum



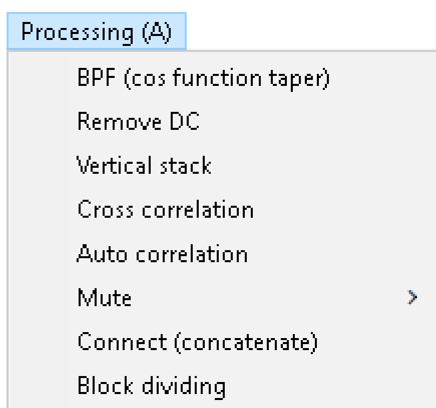
This is a toggle switch; enable it if you wish to remove any DC component in your data prior to calculation the Fourier spectrum.

6.3.12.5 Remove Linear Trend Before Calculating Fourier Spectrum



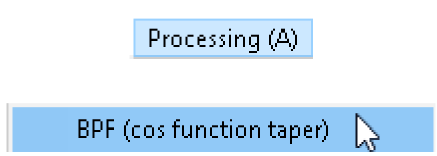
This is a toggle switch; enable it if you wish to remove any linear trend in your data prior to calculation the Fourier spectrum.

6.4 Processing Menu

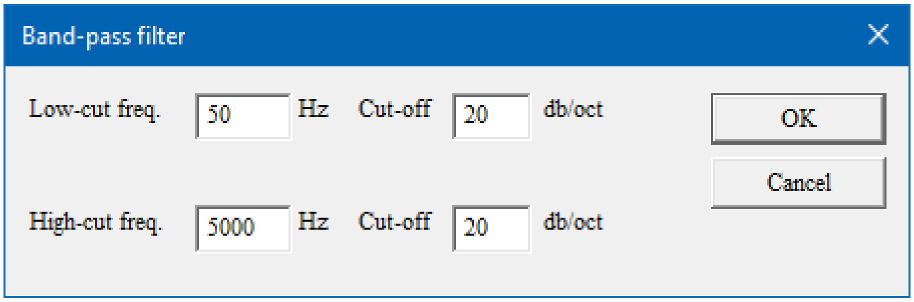


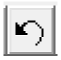
The **Processing** menu includes various data processing tools that can be useful for both refraction and surface wave data.

6.4.1 BPF (Cos Function Taper)



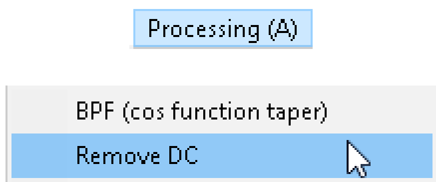
This is a bandpass filter for which you can set the specific filtering parameters:



You must filter each waveform file individually. To disable the bandpass filter, press the *Undo*  button.

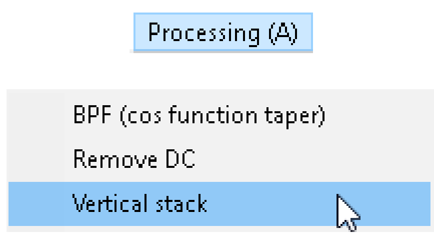
Note: *If you filter your data and save it, it will be saved in a filtered state.*

6.4.2 REMOVE DC



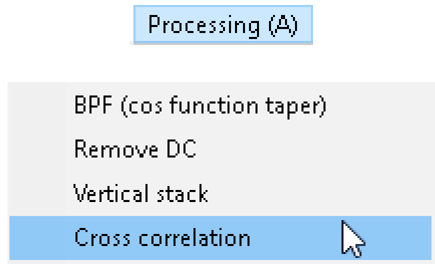
This feature removes any DC offset that might be present in your traces.

6.4.3 VERTICAL STACK



You may vertically stack (sum) two or more records together. This is handy if stacking was not done in the field. Simply append (Section 6.1.5.9 , Page 245) two or more files together, then select *Processing* | *Vertical Stack*.

6.4.4 CROSS-CORRELATION



You may cross-correlate all the traces against any one trace. To do so, you must select an operator by pressing the  button and clicking on the desired trace:

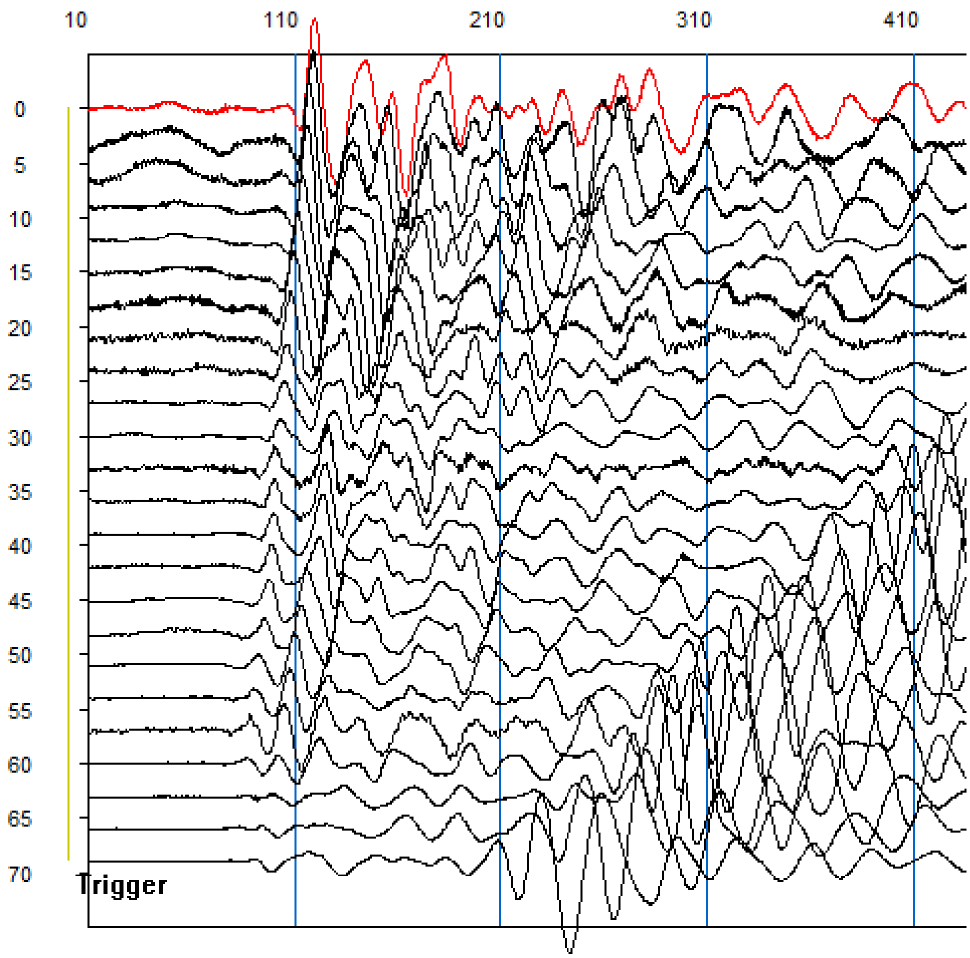
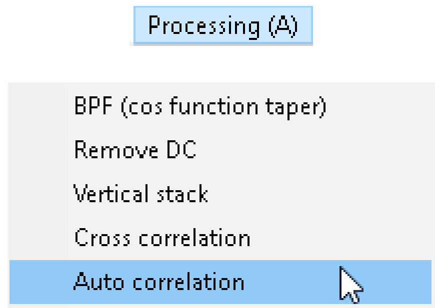


Figure 135: Operator (red) selected for cross-correlation.

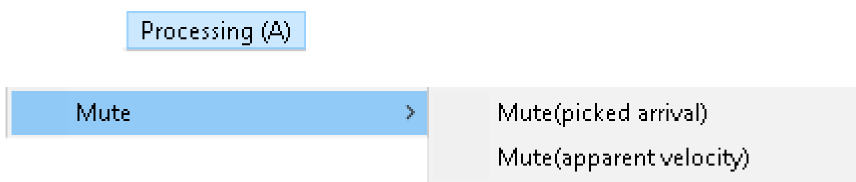
The selected trace will turn red; this is your operator. Now select *Cross correlation*, and all of the traces in the record will be cross correlated with the operator.

6.4.5 AUTO-CORRELATION



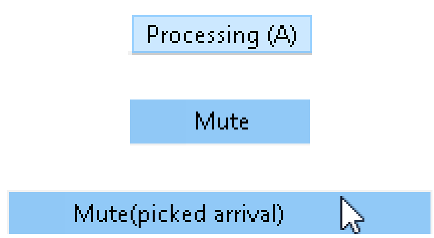
This feature auto correlates each trace with itself.

6.4.6 MUTE



You may mute the record on the basis of picked arrivals or velocity.

6.4.6.1 MUTE (PICKED ARRIVAL)



To mute based on first arrivals, pick the arrivals and then select Mute (picked *arrivals)*.

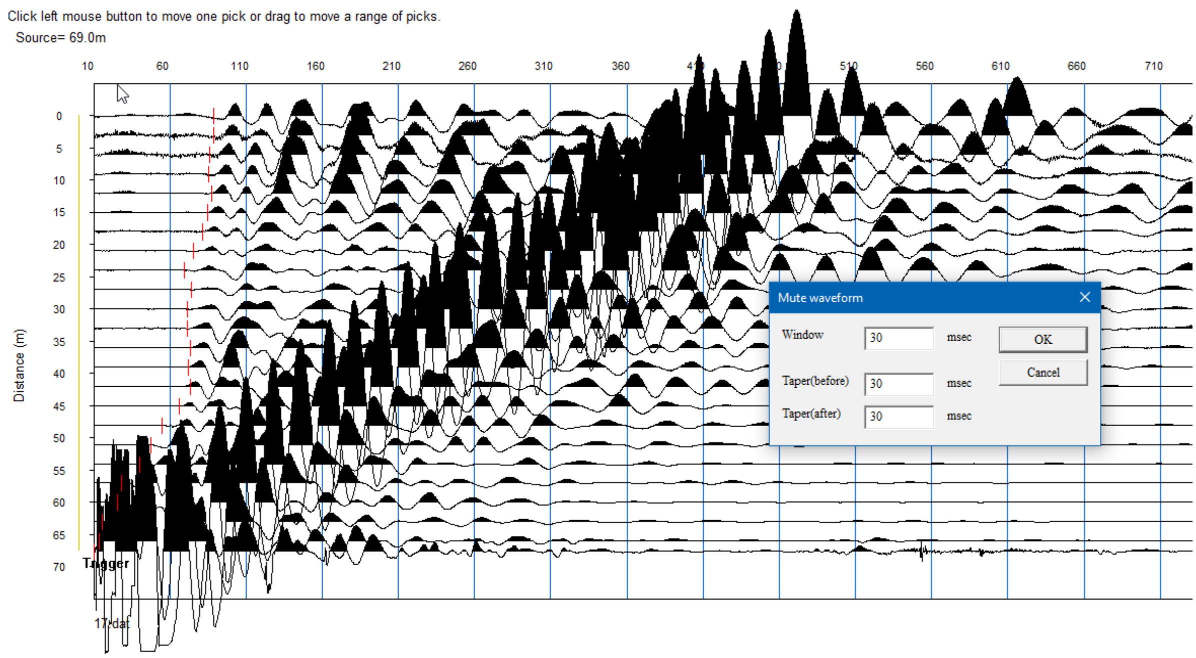


Figure 136: MASW record with first arrival picks.

Set your mute parameters (see above) and press *OK.* Your record will be muted according to these parameters. In this example, we chose to mute the traces before and after the first breaks:

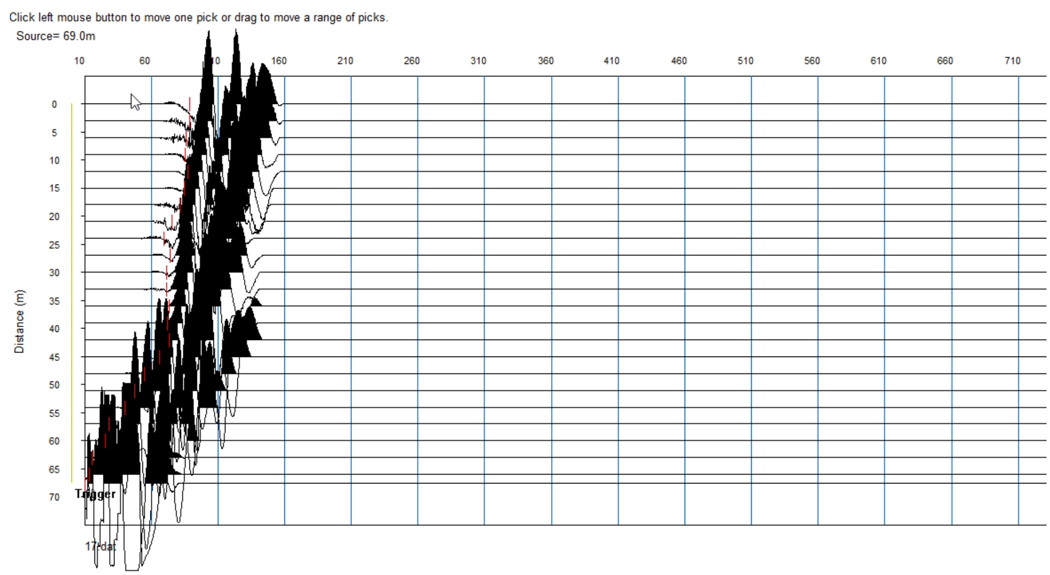
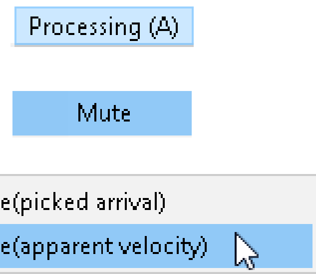


Figure 137: Refraction record muted on basis of the first arrivals.

6.4.6.2 MUTE (APPARENT VELOCITY)



You may also mute traces based on apparent velocity. This is most useful when working in the frequency domain (such as surface wave analysis) but can be applied to refraction data as well. Enter the range of velocities you wish to preserve:

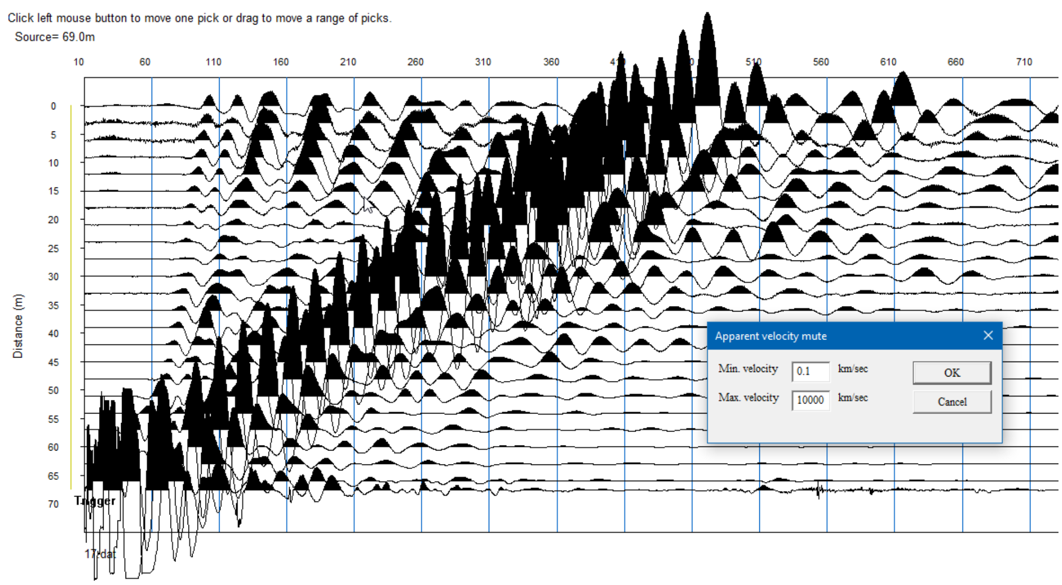


Figure 138: Unmuted refraction record.

Press *OK*.

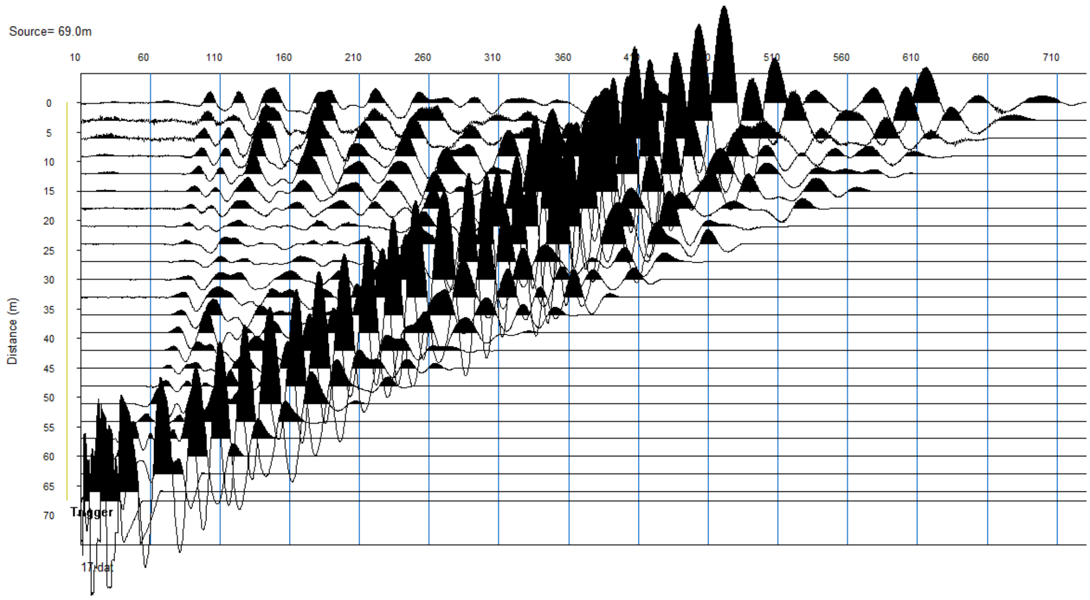
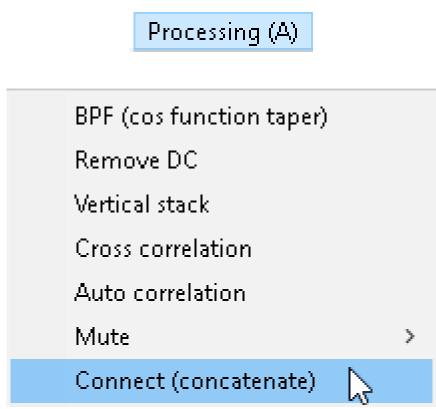


Figure 139: Refraction record muted on basis of velocity.

In general, muting is rarely applied to refraction data.

6.4.7 CONNECT (CONCATENATE)

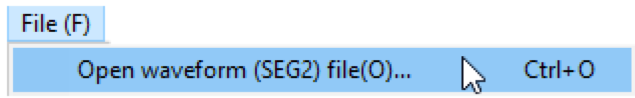


You may concatenate files together end-to-end in time using the “concatenate” feature. This can be useful if your data is broken up into many small files, perhaps from numerous shot records with a common shot point. The process is as follows:

1) Open a waveform file.
2) Open a second waveform file and choose *Append to present data* instead of *New*.
3) Repeat #2 up to eight more times – you may append up to 10 files together in a single step.
4) Select *Processing* | *Connect (concatenate)*
5) You will be prompted for a file name for the concatenated file.

This is best illustrated by an example.

Open a waveform file:



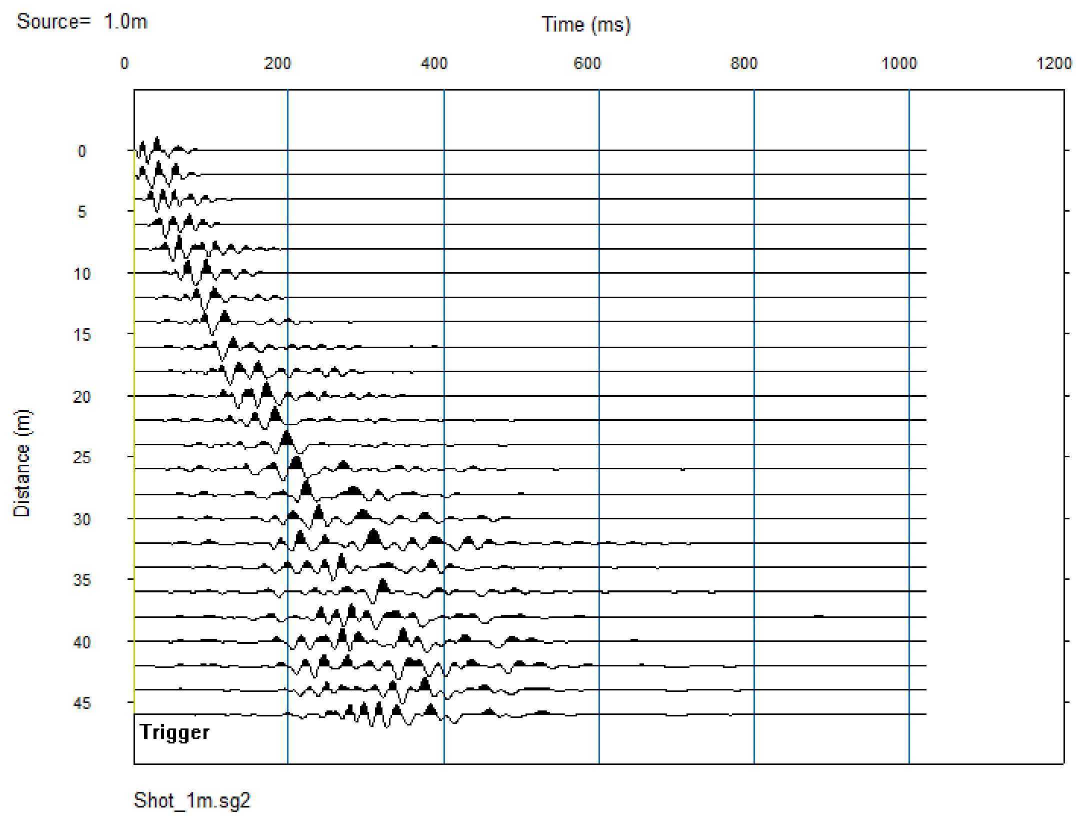
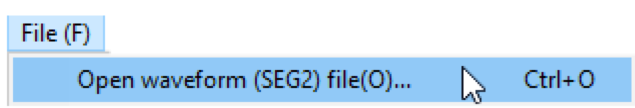


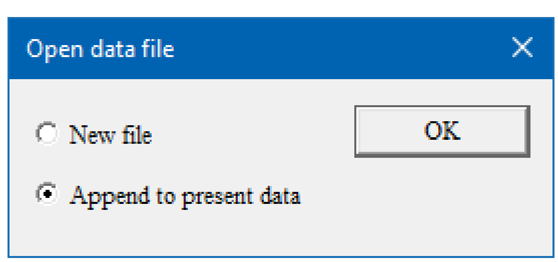
Figure 140: Waveform file.

We have a typical single-shot 24-channel MASW file, with 1024 samples/trace.

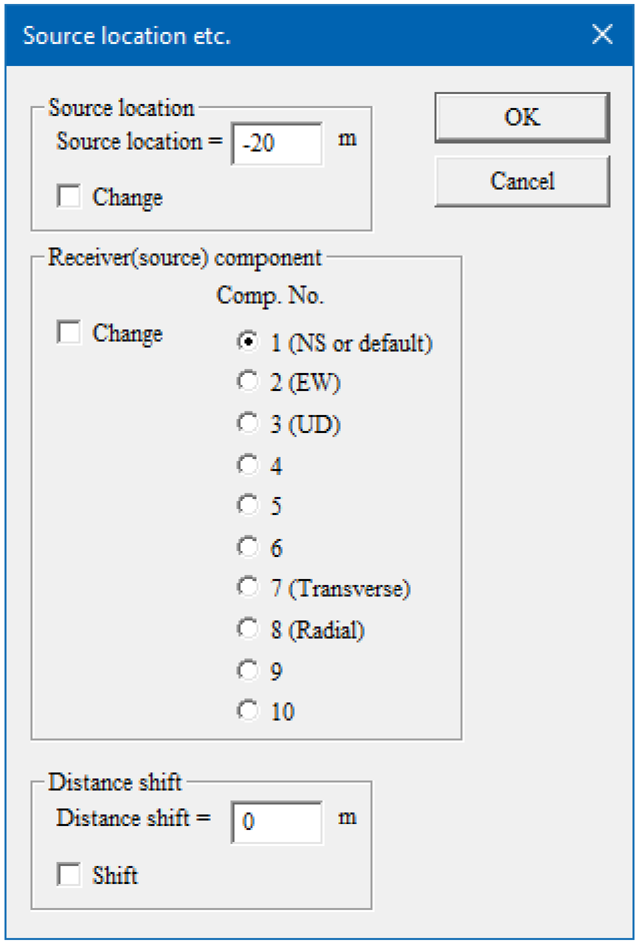
Open a second waveform file:



Append it to the first:



Make any necessary adjustments:



Press *OK*.

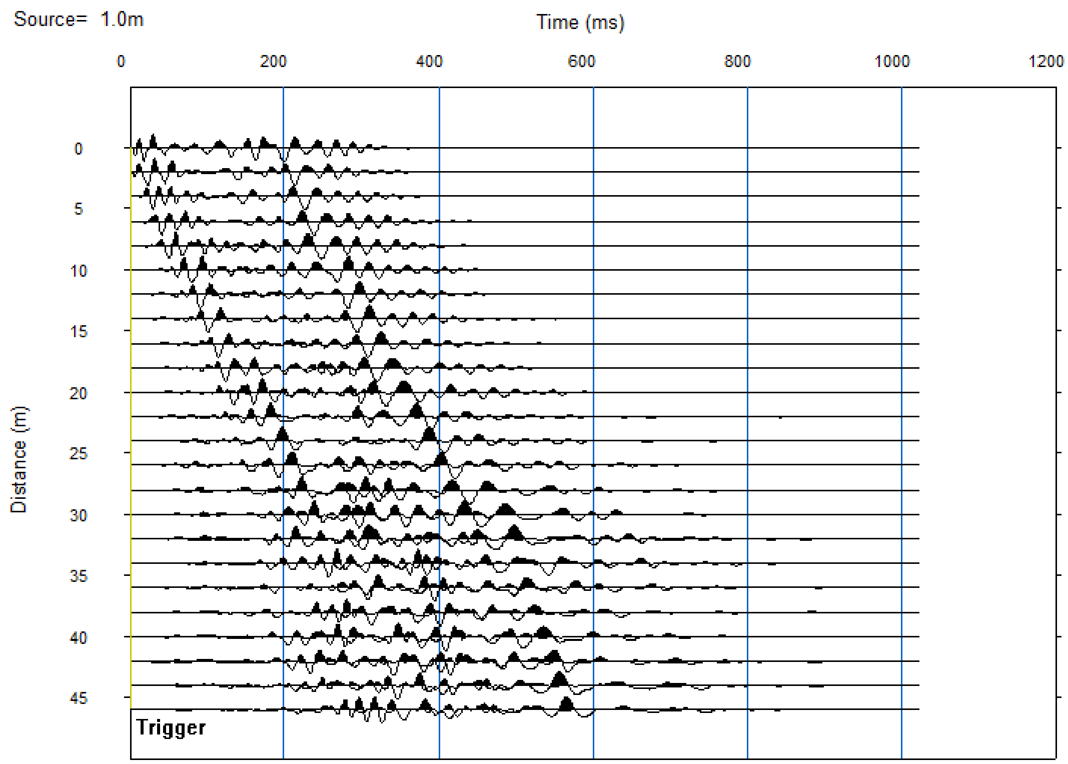
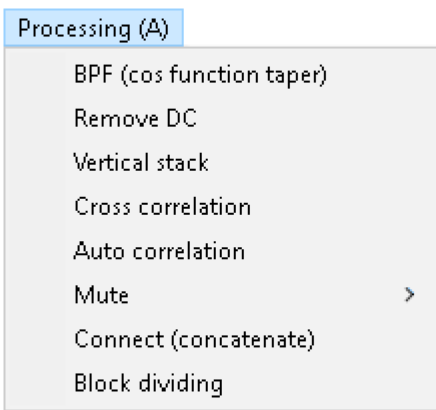


Figure 141: Two waveform files appended together.

The two files have been appended together.

Repeat as necessary until all files to be concatenated have been appended together.

Select *Processing* | *Connect (concatenate)*:



Provide a file name for the concatenated file when prompted.

Now the appended files have been concatenated together in time. Each trace is 2048 samples.

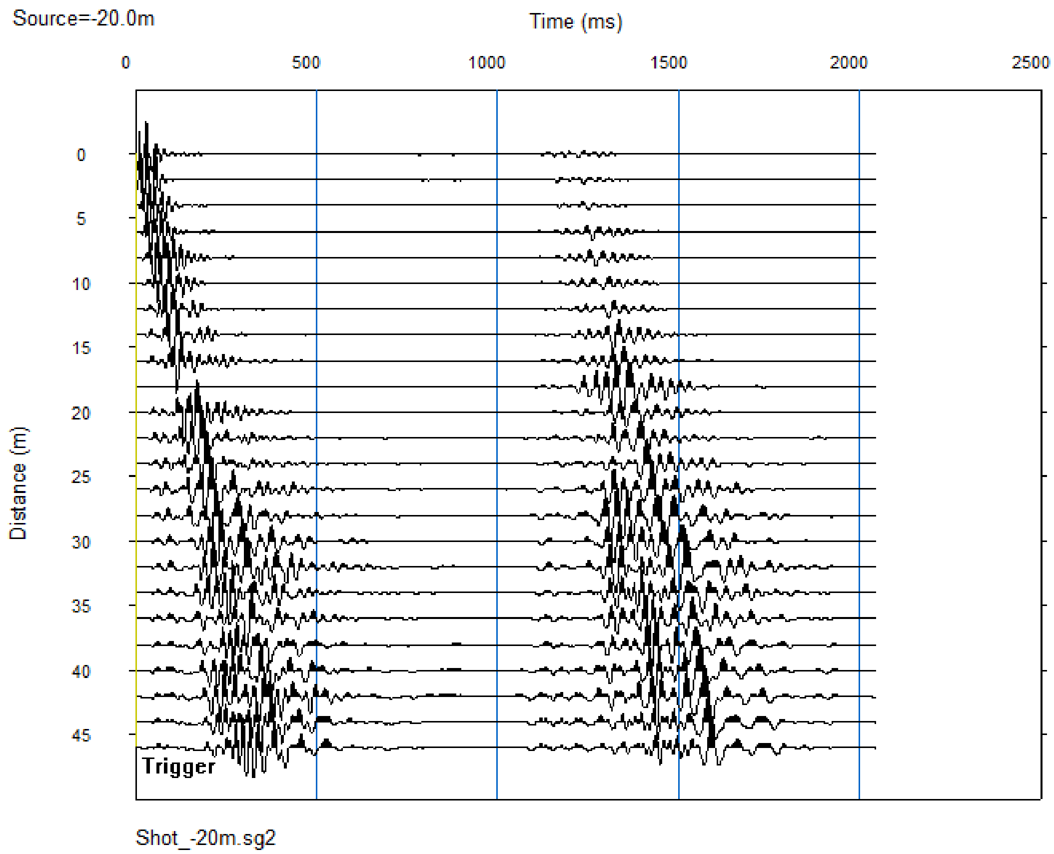
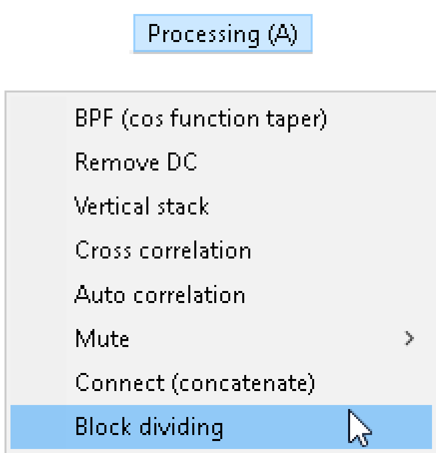


Figure 142: Concatenated waveform files.

Note: *If you have more than 10 files to append/concatenate, see Section 6.1.5.9, Page 245.*

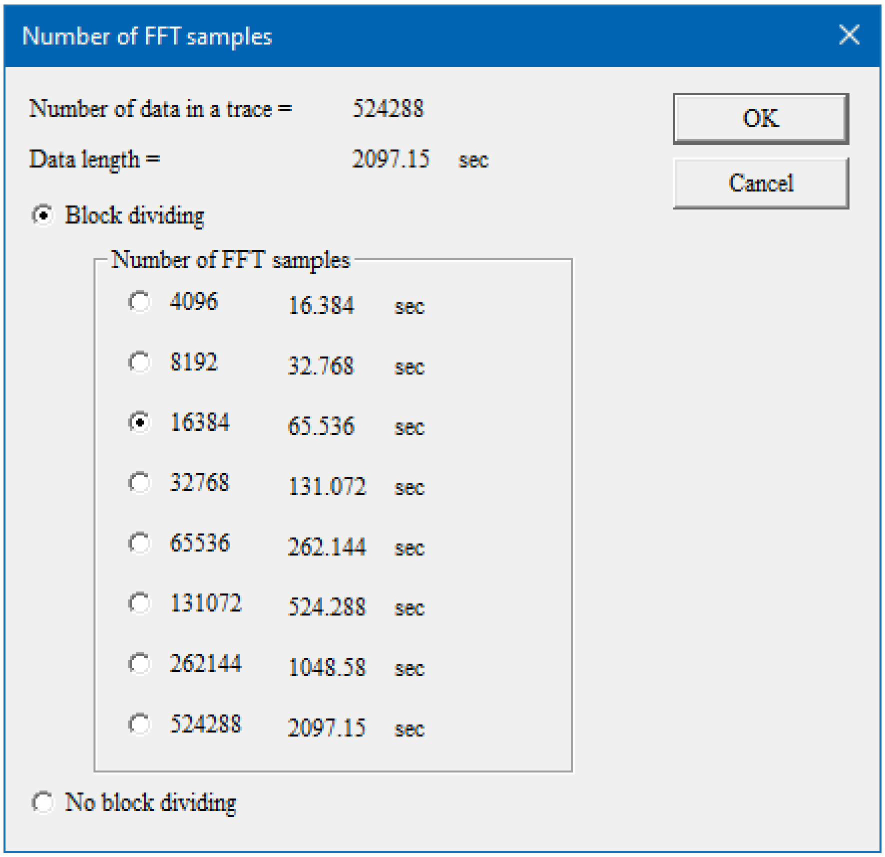
6.4.8 BLOCK DIVIDING



This feature is the opposite of concatenation and is useful if your files are too long to be manageable. This is very common when using Atom or McSeis MT Neo seismographs, particularly when recording passive surface wave data.

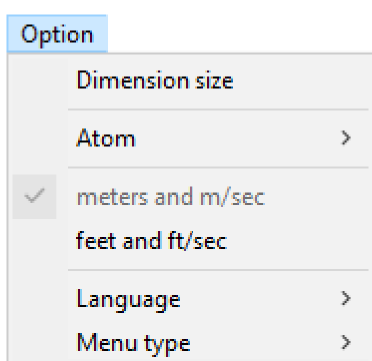
This is best illustrated by an example. The next dialog box allows you to enable/disable “block dividing” and to set the length of each “sub” trace. In general, it is desirable to work with traces of 16k or 32k samples (or less); at the standard passive data sample interval of 4 msec, this works out to 1 or 2 minutes.

Select a trace length and press *OK*.

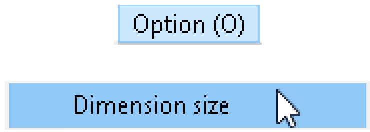


6.5 OPTION MENU

The **Option** menu includes program controls and display settings.

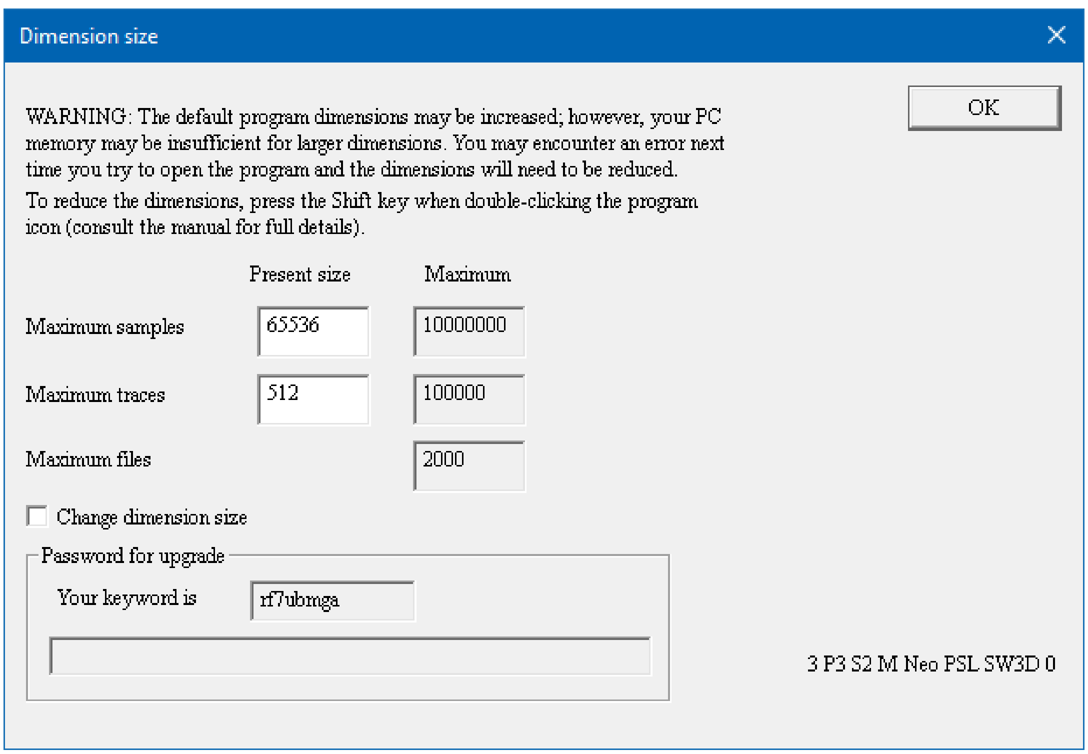


6.5.1 DIMENSION SIZE

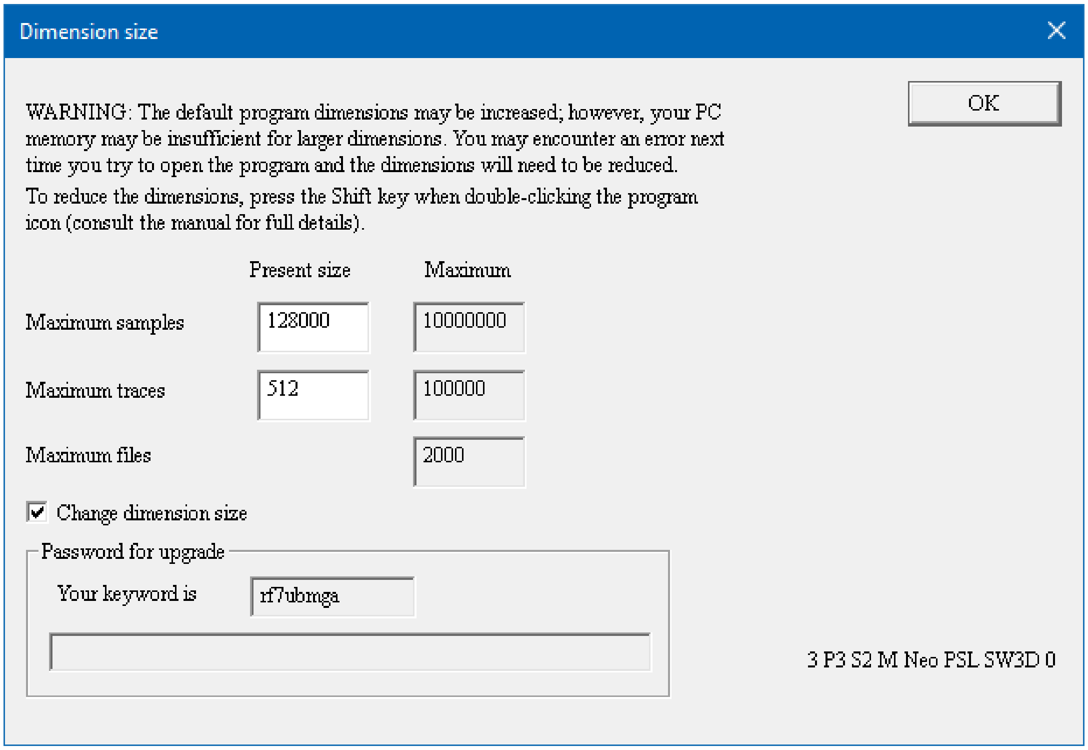


To view or change the program data input allowances, select *Dimension size*.

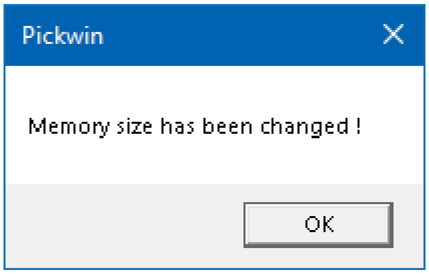
Present size reflects the current dimensions for *Maximum samples* and *Maximum traces* and *Maximum* shows the largest possible dimensions. Typically, it is unnecessary to change the number of *Maximum samples*. It can be useful to change the number of *Maximum traces* to 64 from 128 to speed up processing, but this will also reduce the resolution of the phase velocity plot. The number of *Maximum traces* may need to be increased if you are processing a passive source dataset with a large number of traces, for example, greater than 48.



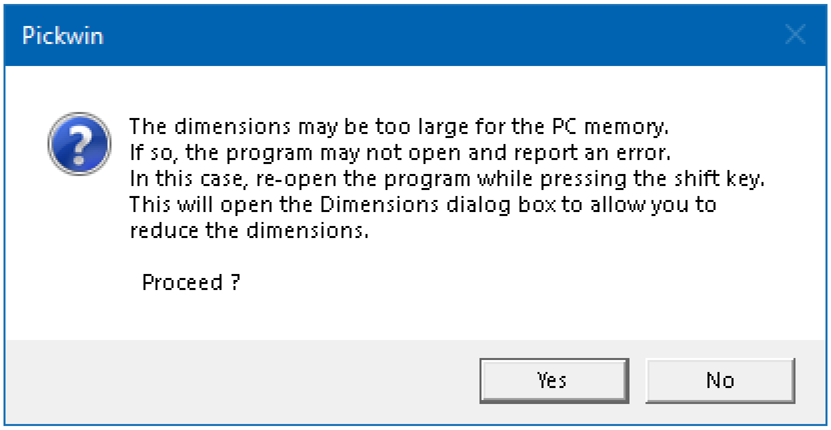
To change the dimensions, enter the new value(s), check *Change dimension size*, and press *OK*.



Press *OK* and restart the program.



If a very large value is entered, such as 1024 for *Maximum traces*, a warning message will appear before you are allowed to restart the program. It is recommended that you do not proceed; select *No* and reduce the dimensions.



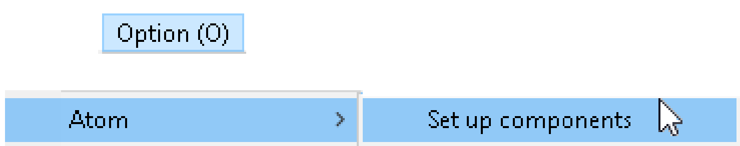
If you proceed and indeed the PC has insufficient memory, the program will no longer be able to open. To lower the values and recover the program, open the **Dimension size** dialog box directly by pressing the *Shift* key while double-clicking the program icon.

Note: *Sometimes the program will simply crash rather than post the above message. If that happens, use the procedure outlined on Page 3 to restore the system defaults.*

The wizard automatically defaults to standard dimensions to run efficiently. To use non-standard dimensions, you will need to process data manually.

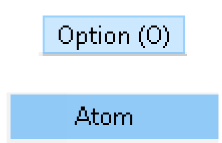
If a program upgrade is purchased, the new registration password can be directly entered in the **Dimension size** dialog box in the *Password for upgrade* field; however, it is strongly recommended to upgrade via the SeisImager Registration program instead.

6.5.2 Atom



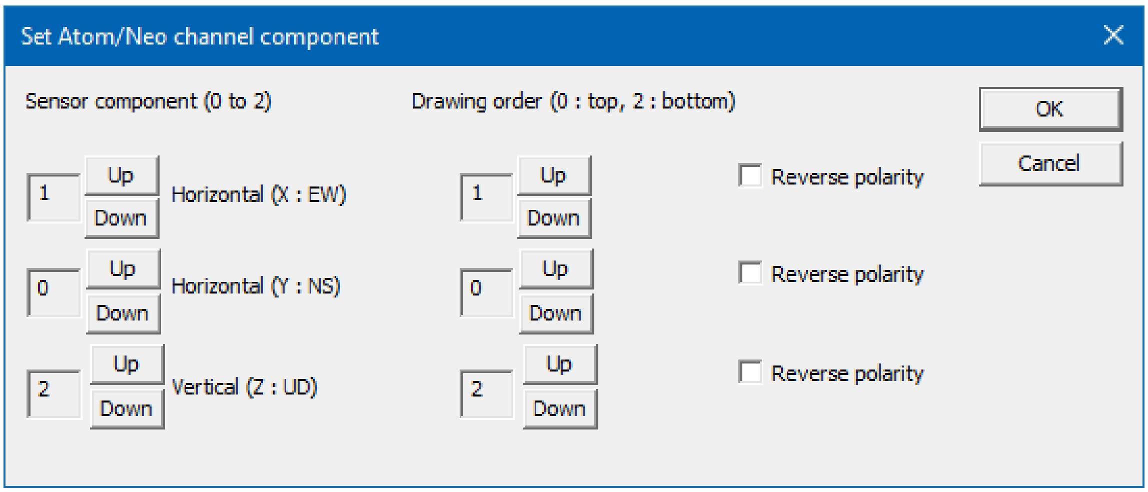
Continue.

6.5.2.1 Set Up Components

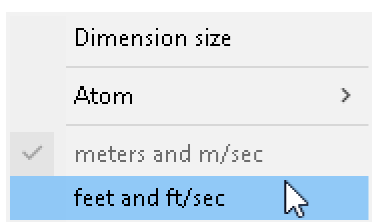


The Atom and McSeis Neo include three-component modules to work with three-component geophones. There are many makes and models of 3C geophones, all of which are wired differently. For this reason, it is necessary to define which component is EW, which is NS, and which is vertical.

The default values are for the make and model sold by Geometrics (as of this writing), which is the Sunfull™ PS-2B 3C geophone. If you use a different geophone, you will need to get the component and polarity information from the manufacturer.

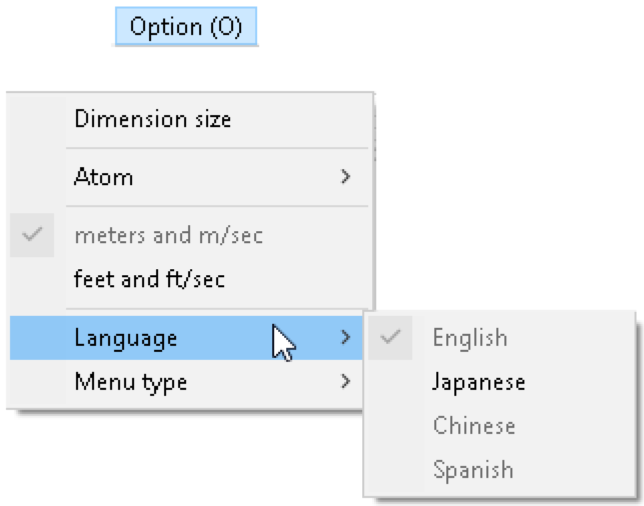


6.5.3 METERS AND M/SEC AND FEET AND FT/SEC



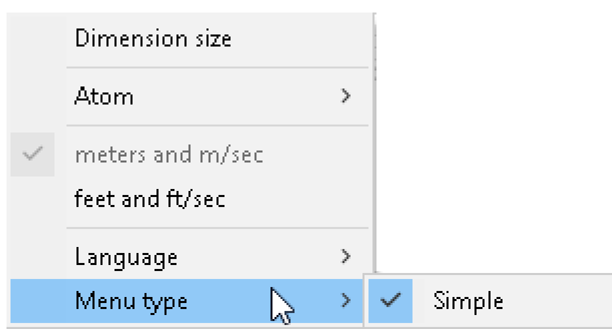
Select the desired unit labels by choosing *meters and m/sec* or *feet and ft/sec*. The setting is reflected in the display labels, dialog box labels, and default values where applicable.

6.5.4 LANGUAGE

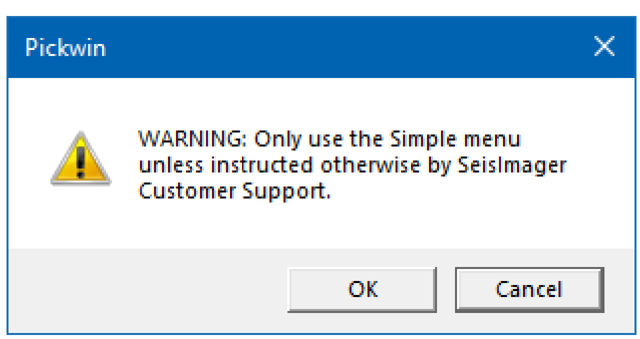


Choose your preferred language. At the time of this writing (July 2024), Chinese and Spanish were in development.

6.5.5 MENU TYPE



SeisImager includes advanced options for very special applications that are only available if *Simple* is unchecked. These are undocumented and should only be used under supervision from Geometrics. If *Simple* is unchecked, you will see the following warning:

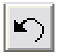
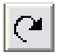


Pressing *OK* above will give you access to these features (mainly processing). Contact support@seisimager.com for assistance. To return to the **Simple** menu, select *Option* | *etc.* | *Menu type* | *Simple*.

6.6 Tool Buttons

Figure 143: Pickwin Tool Buttons

The button bar functions essential or uniquely used for surface wave data processing are covered in this section. For a complete description of the button bar functions common to SeisImager/SW and SeisImager/2D, please refer to the separate SeisImager/2D manual.

6.6.1 Undo  and Redo 

After the phase velocity-frequency transformation has been calculated for a given waveform file or dataset, press the *Undo* button to cancel the phase velocity plot.

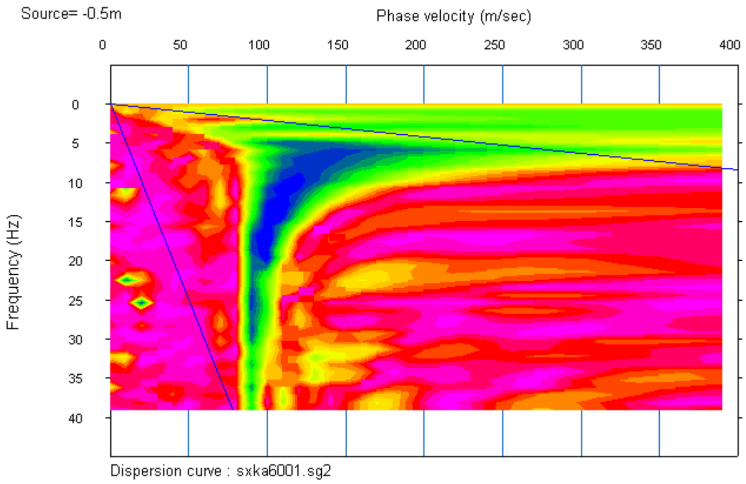


Figure 144: Phase velocity-frequency plot.

For a single file (shot or CMP cross-correlation gather), after pressing the *Undo* button, the waveform file will appear.

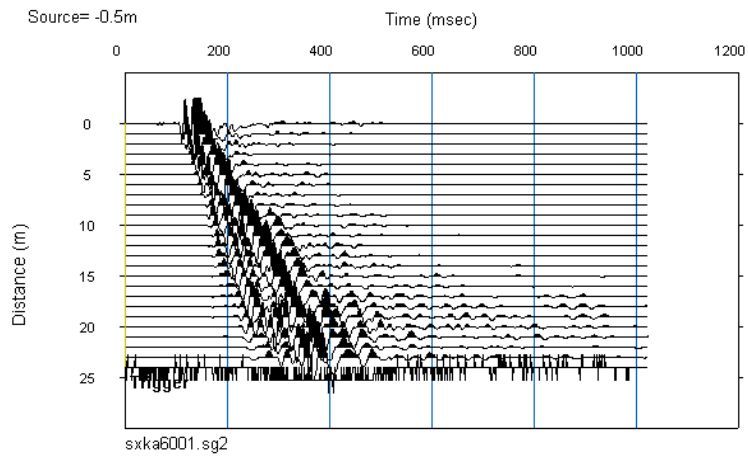


Figure 145: Waveform file after pressing ***Undo*** *button.*

For a passive source dataset, after pressing the *Undo* button, the coherency plot will appear.

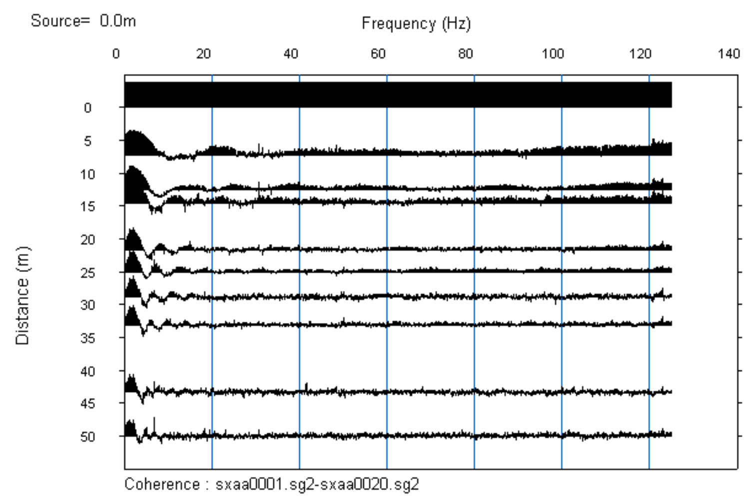


Figure 146: Coherency plot after pressing ***Undo*** *button.*

To return to the phase velocity plot in either case, press the *Redo* button. Note that the *Undo* and *Redo* functions run only one cycle, so if *Undo* is pressed again, the waveform and coherency files will not be found, and it will be necessary to restart the program.

The *Undo* button is very useful when the optimal analysis parameters are not yet known, and iterative testing is required.

6.6.2 NORMALIZE 

When traces are normalized, the maximum amplitude of each trace will be equalized. Lower amplitude traces (those farther from the source) will be “turned up” so that their maximum amplitude is equal to that of higher-amplitude traces. This has the effect of equalizing the appearance of all the traces across the record and allows viewing of the active source surface wave train.

With *Normalize* off, the signals on traces distant from the source are not visible.

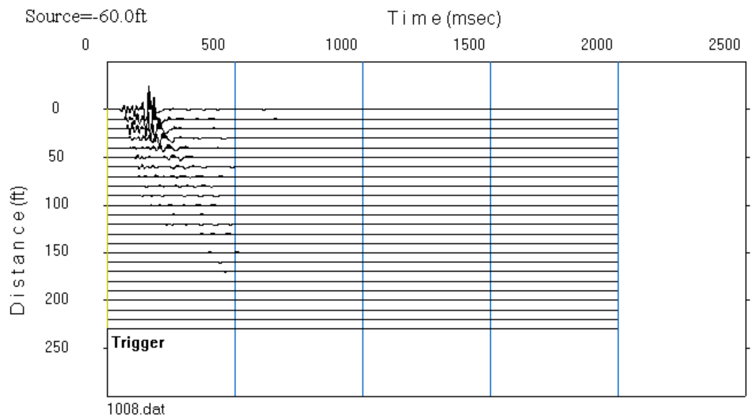


*Figure 147: Waveform file with **Normalize** disabled.*

With *Normalize* on, signals on traces at all distances are visible.

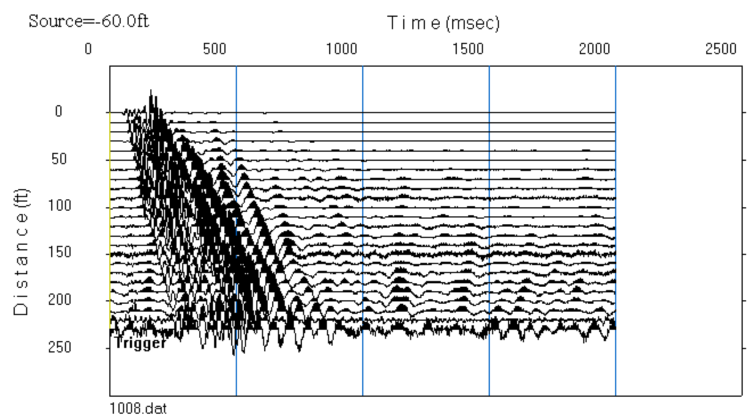


*Figure 148: Waveform file with **Normalize** enabled.*

To observe trace-to-trace variations with passive source surface wave data, *Normalize* should be turned off. With *Normalize* on, note the appearance of traces 4 through 7.

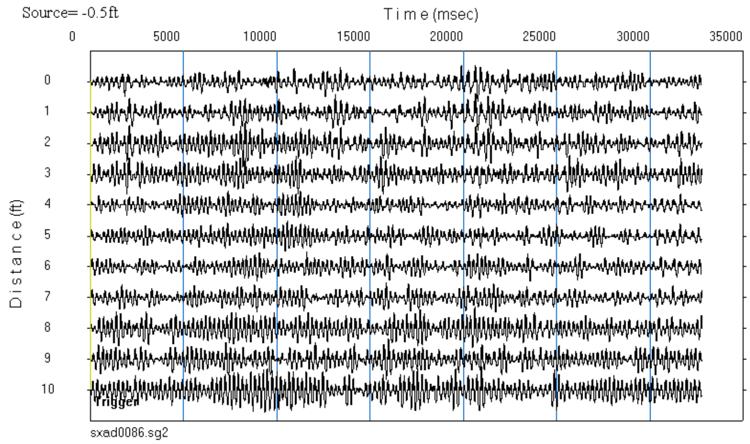


*Figure 149: MAM record with **Normalize** enabled.*

With *Normalize* off, traces 4 through 7 are slightly higher amplitude.

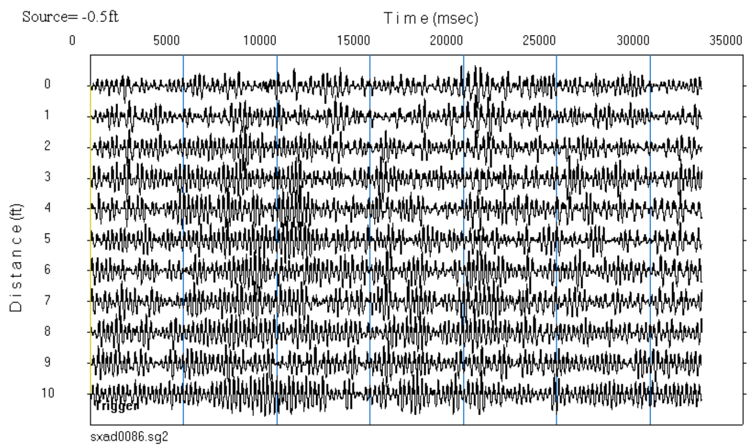
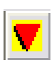
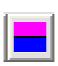


*Figure 150: MAM record with **Normalize** disabled.*

6.6.3 SHOW PREVIOUS WAVEFORM FILE  AND SHOW NEXT WAVEFORM FILE 

When more than one waveform file (shot or CMP cross-correlation gather) is input, the files can be scrolled through using the *Show previous waveform file* and *Show next waveform file* buttons.

6.6.4 COARSE CONTOUR COLOR 

The phase velocity-frequency plot display is enhanced with color gradients. To apply a coarse contour color scale, press the *Coarse contour color* button.

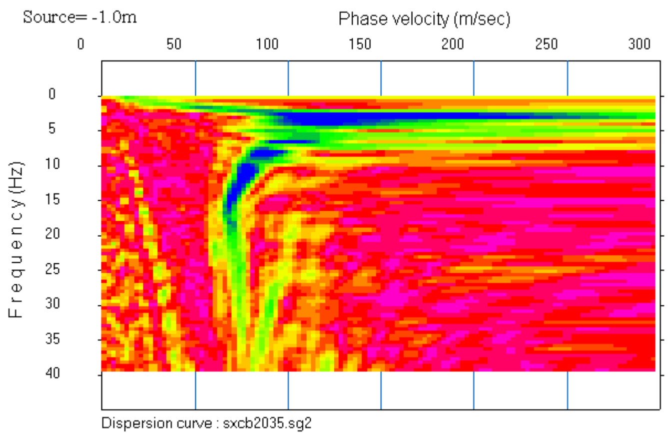


Figure 151: Phase velocity-frequency plot with coarse color contours.

6.6.5 FINE CONTOUR COLOR 

The phase velocity-frequency plot display is enhanced with color gradients. To apply a fine contour color scale, press the *Fine contour color* button. The fine setting takes slightly longer to paint on the screen, but gives a smoother gradient compared to *Coarse contour color*.

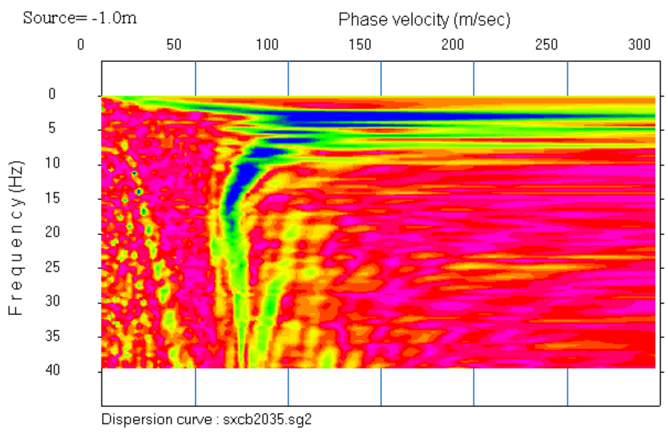
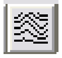


Figure 152: Phase velocity-frequency plot with fine color contours.

6.6.6 WIGGLE LINE  AND SHADED BLACK 

The default trace display for the phase velocity-frequency plot is a black line with the positive side shaded corresponding to the *Wiggle line* and *Shaded black* buttons, respectively.

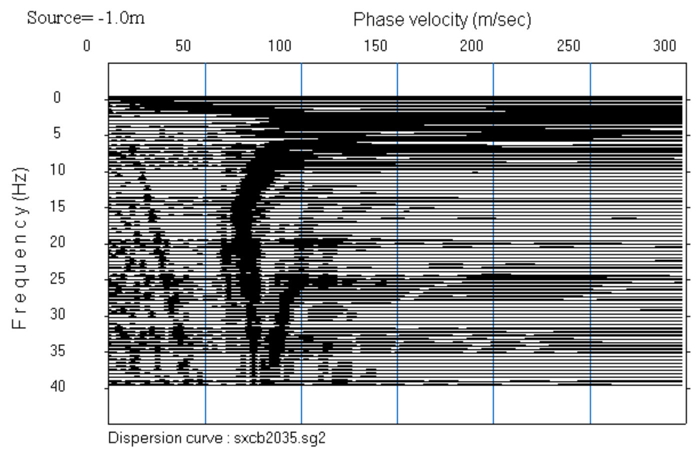


*Figure 153: Waveform plot displayed with **Wiggle trace** and **Shaded black** enabled.*

6.6.7 Show Waveforms  and Show Geometry 

After the geometry has been calculated and applied to a given dataset, the *Show waveforms* button and the *Show geometry* button are activated and allow toggling between the two views. In the *Show geometry* view, the *Show previous waveform file* and *Show next waveform file* buttons allow selection of a shot or CMP cross-correlation gather's geometry.

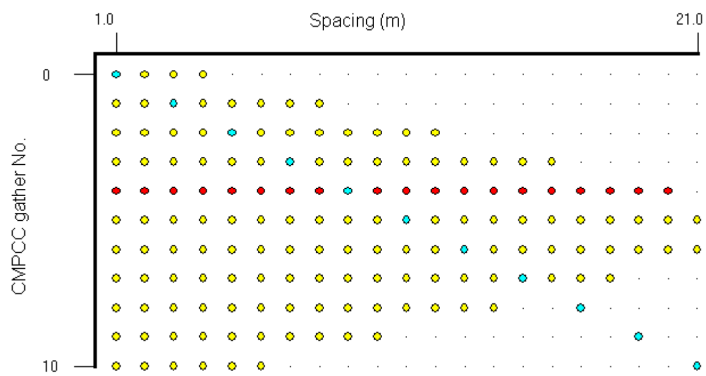


Figure 154: Geometry plot.

Press the *Show waveforms* button to display the gather associated with the selected geometry.

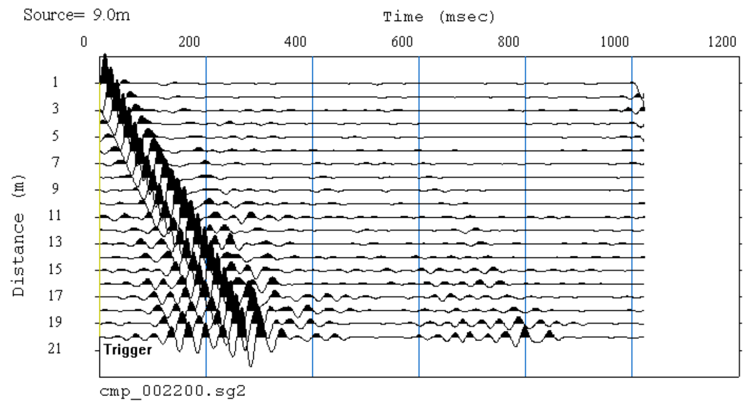


Figure 155: Waveform plot.

6.6.8 FREQUENCY DOMAIN

The *Frequency domain* button transforms a time domain waveform file to the frequency domain. Pressing the *Frequency domain* button will change the view from the waveform record to a plot of the frequency content or spectrum for each trace. It will be necessary to press the right *Horizontal scale* button or the *right-arrow* key to expand the frequency scale and zoom in on the lower end.

Unlike most active source data, it is usually difficult to evaluate the quality of passive source data by viewing the waveform record in the time domain. Similar frequency content from trace-to-trace indicates higher-quality data.

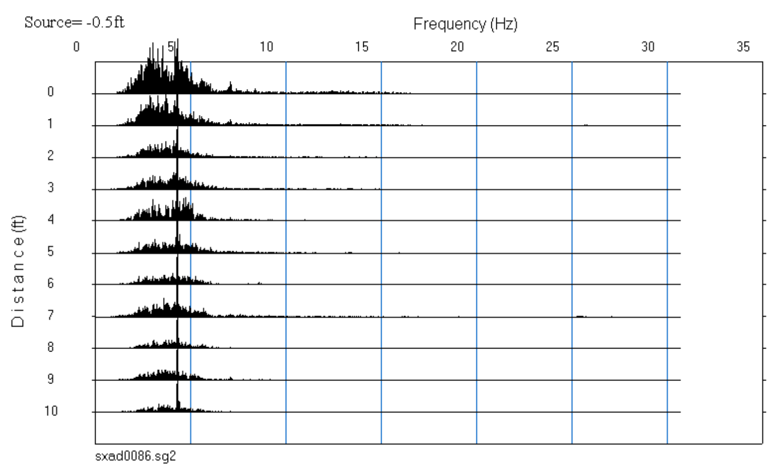


Figure 156: Coherency plot.

Uneven frequency content from trace-to-trace indicates lower-quality data.

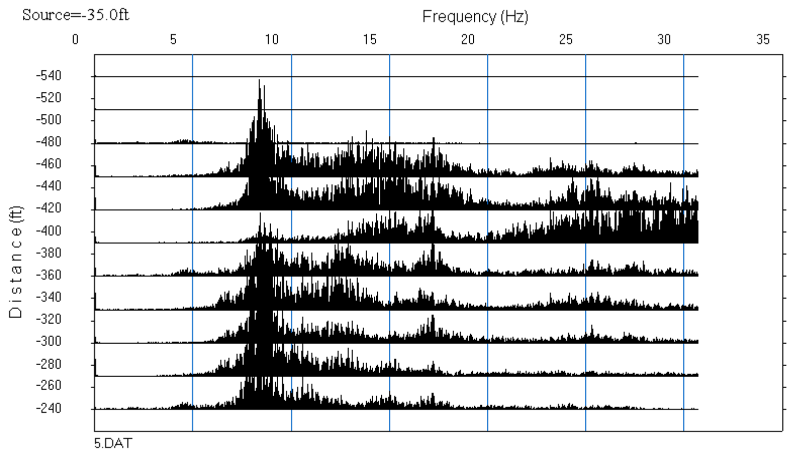


Figure 157: Coherency plot of Figure 156 stretched horizontally.

6.6.9 Time Domain

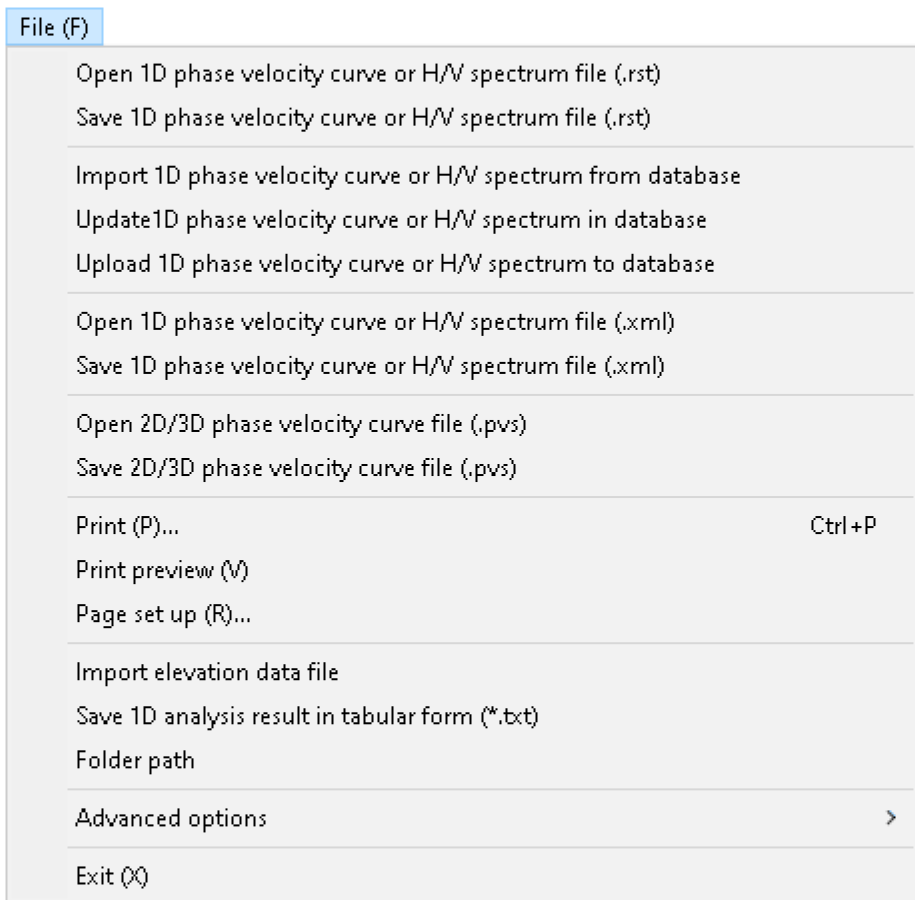
The *Time Domain* button toggles out of the *Frequency domain* view.

7 THE WAVEEQ MODULE FUNCTIONS

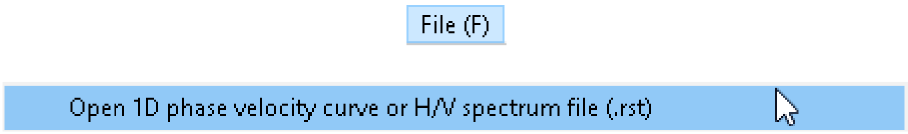
Continue.

7.1 FILE MENU

The **File** menu includes functions for opening WaveEq result files, importing and exporting various files, and printing.

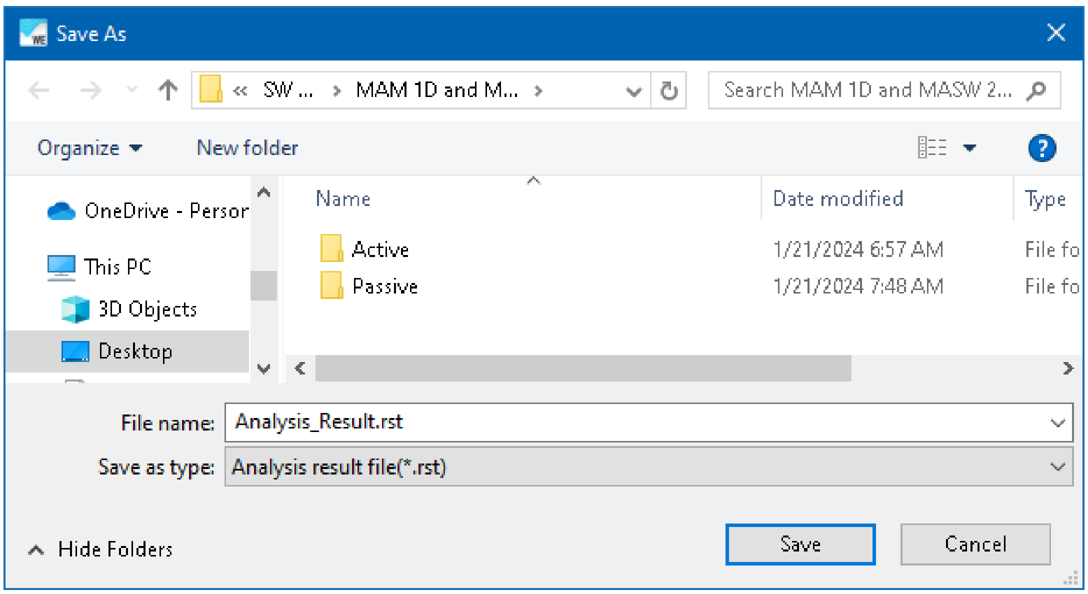


7.1.1 Open 1D Phase Velocity Curve or H/V Spectrum File (.rst)

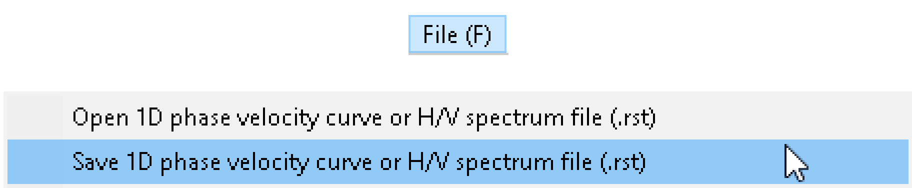


To open a single dispersion curve, V_S curve, or H/V spectrum file previously saved with the extension *.rst*, select *Open 1D phase velocity curve or H/V spectrum file (.rst)*.

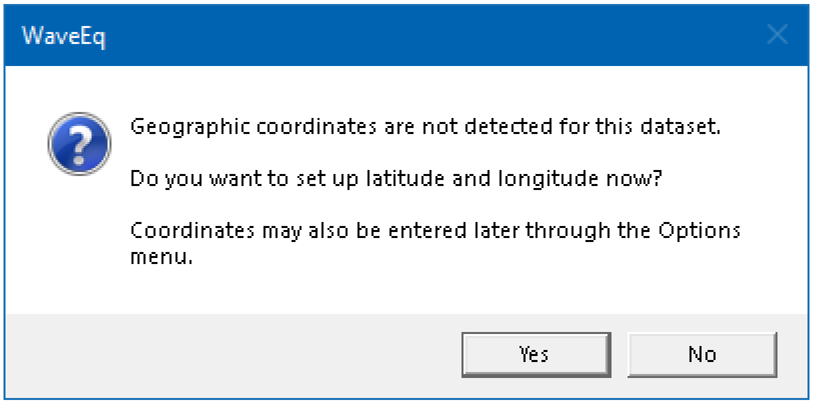
Highlight the file and press *Open*.



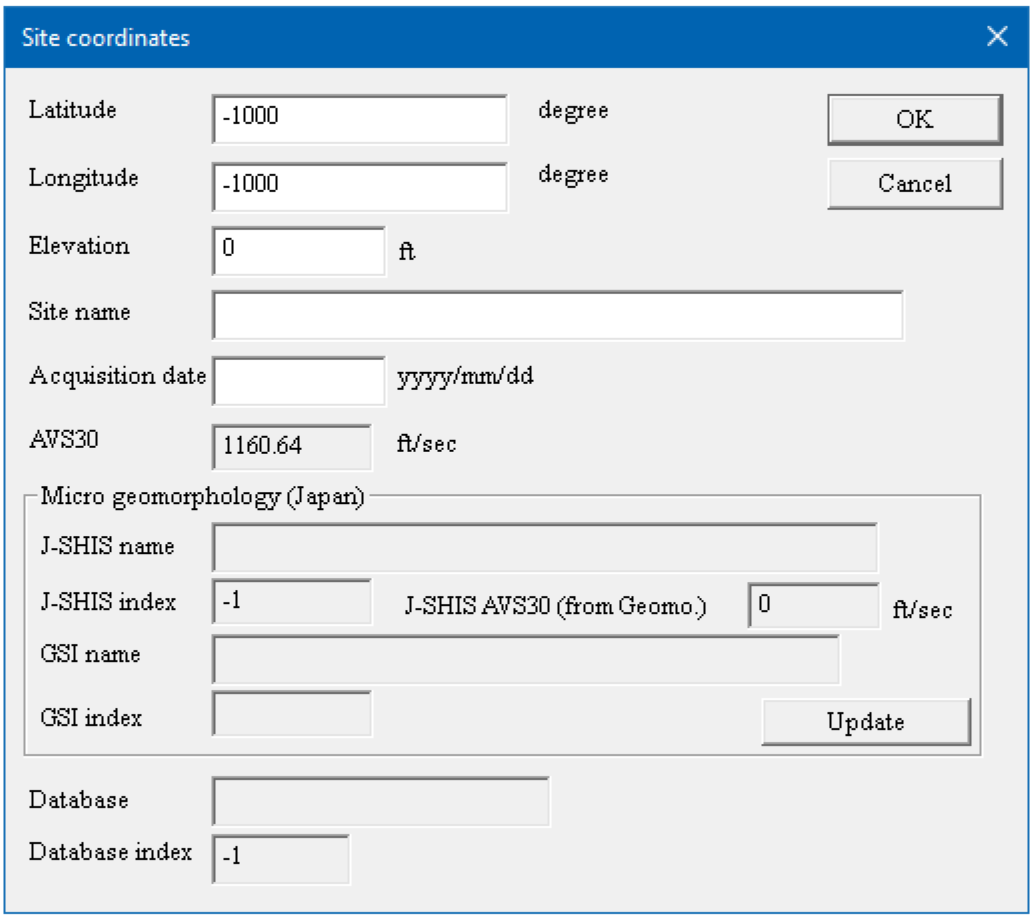
7.1.2 Save 1D Phase Velocity Curve or H/V Spectrum File (.rst)



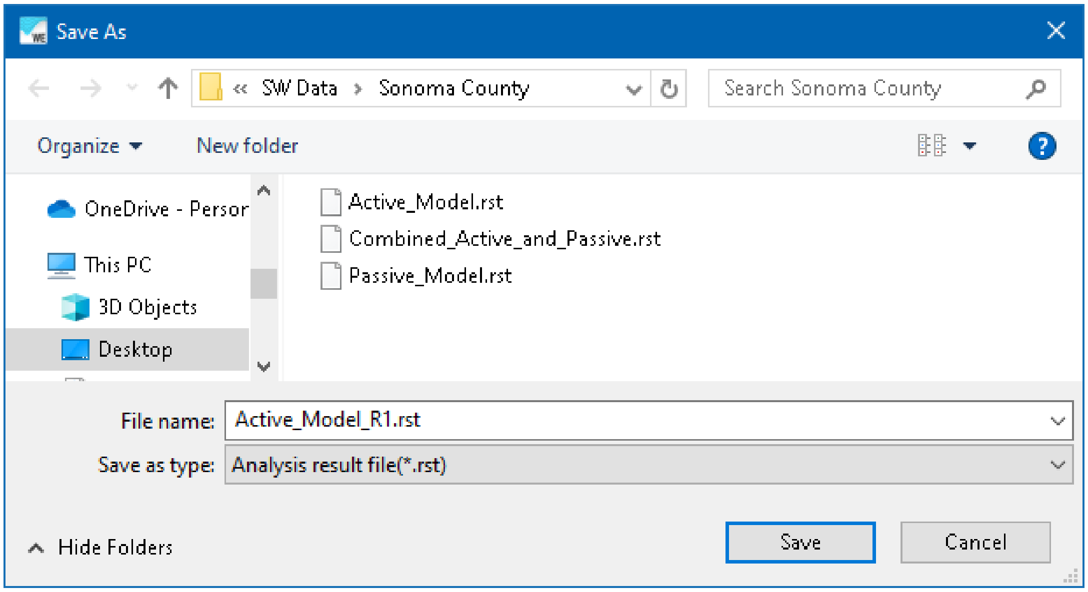
To save a single dispersion curve, V_S curve, or H/V spectrum file, select *Save 1D phase velocity curve or H/V spectrum file (.rst)*. A curve file can be saved at any time in the processing flow and will reflect the extent of results at the time of save. If you have not yet entered latitude and longitude, you may do so here by answering yes:



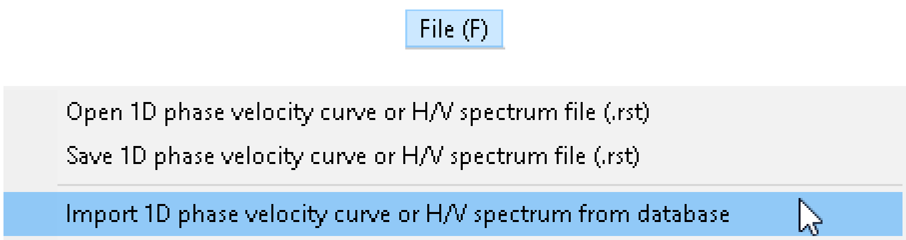
The following dialog will appear. The parameters should be self-evident.



Assign a file name with the extension *.rst* and press *Save*.

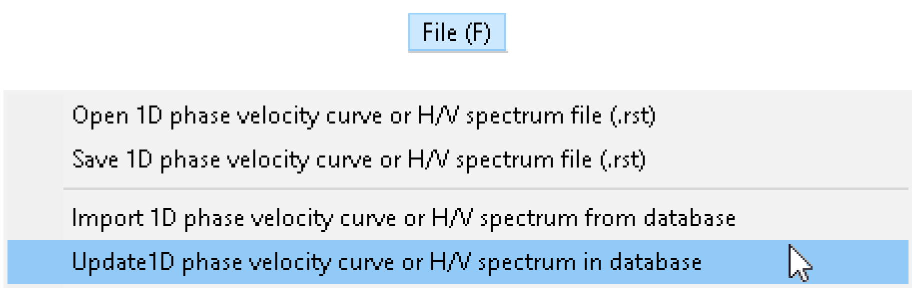


7.1.3 Import 1D Phase Velocity Curve or H/V Spectrum From Database



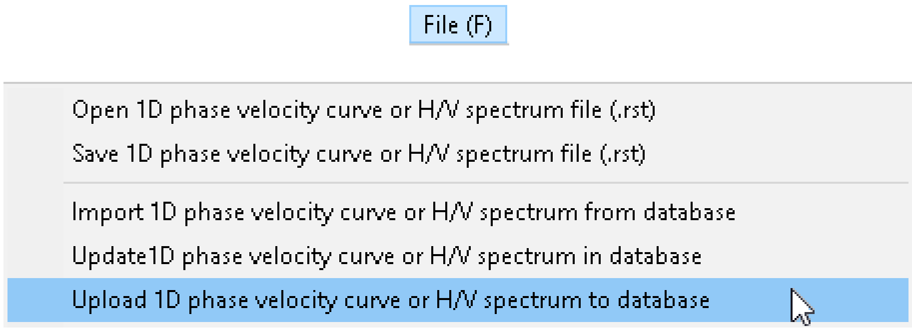
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.1.4 Update 1D Phase Velocity Curve or H/V Spectrum in Database



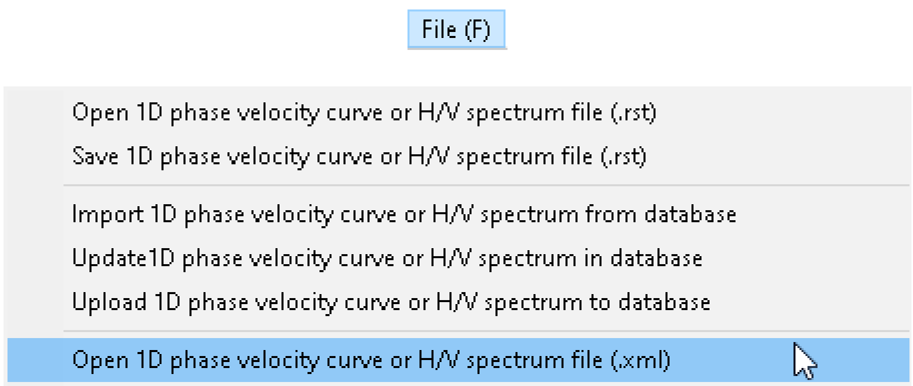
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.1.5 UPLOAD 1D PHASE VELOCITY CURVE OR H/V SPECTRUM TO DATABASE



This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

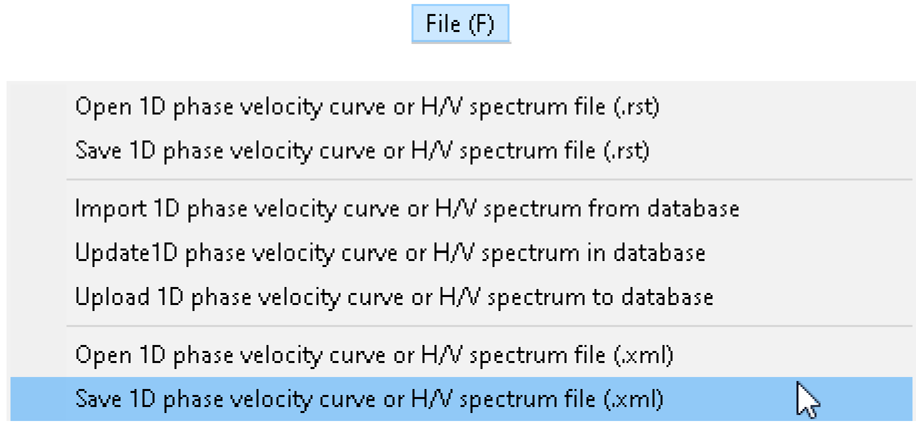
7.1.6 OPEN 1D PHASE VELOCITY CURVE OR H/V SPECTRUM FILE (.XML)



To open a single dispersion curve, V_S curve, or H/V spectrum file previously saved with the extension *.xml*, select *Open 1D phase velocity curve or H/V spectrum file (.xml)*.

Highlight the file and press *Open*.

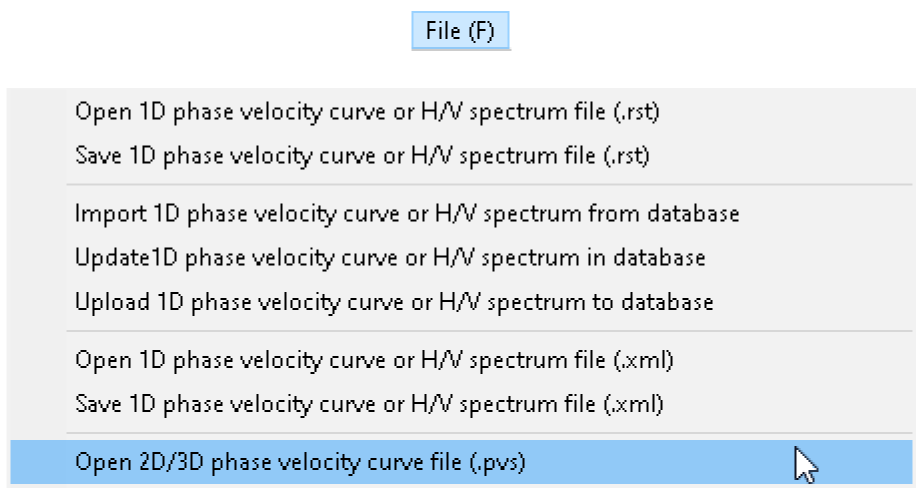
7.1.7 SAVE 1D PHASE VELOCITY CURVE OR H/V SPECTRUM FILE (.XML)



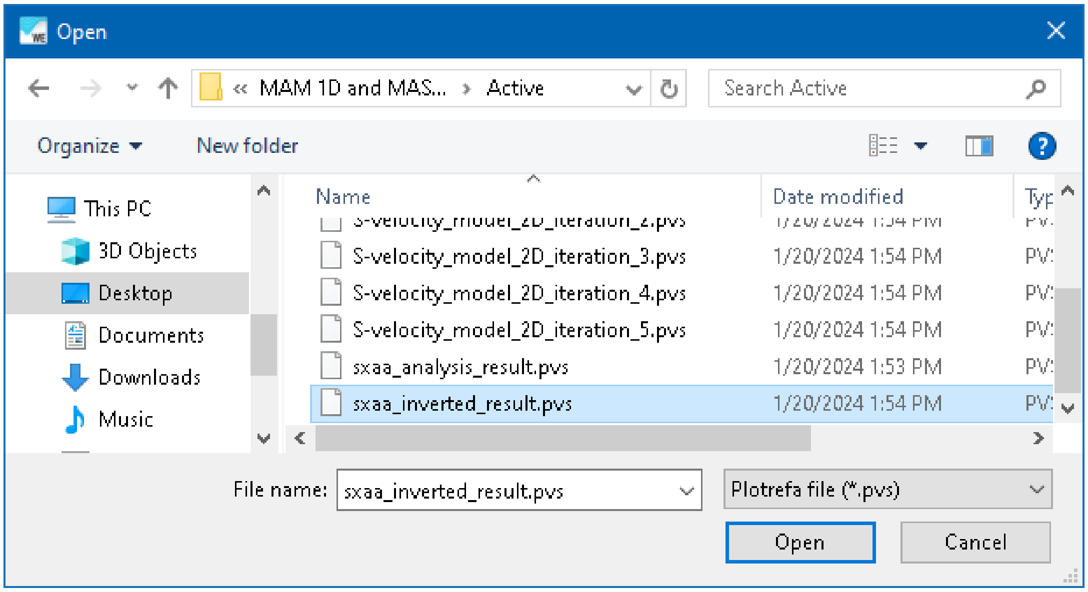
To save a single dispersion curve, V_S curve, or H/V spectrum file in xml format, select *Save 1D phase velocity curve or H/V spectrum file (.xml).* A curve file can be saved at any time in the processing flow and will reflect the extent of results at the time of save.

Assign a file name with the extension *.xml* and press *Save*.

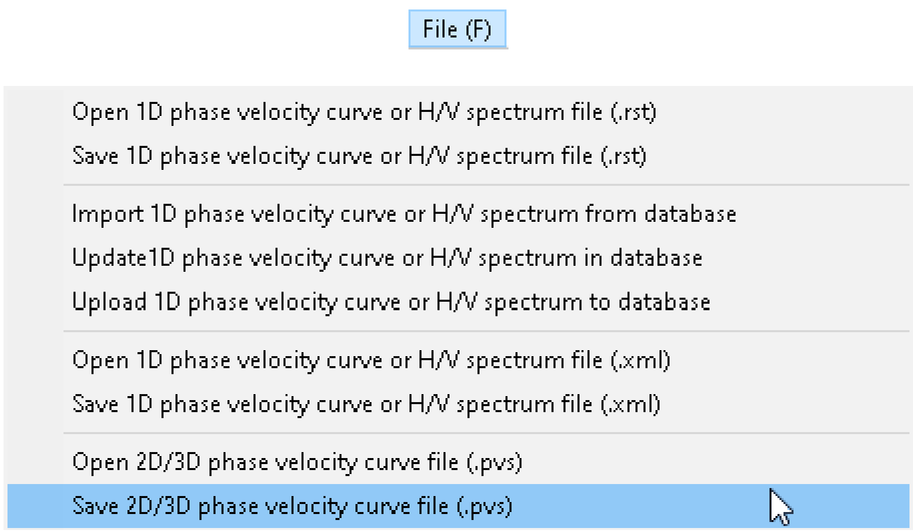
7.1.8 OPEN 2D/3D PHASE VELOCITY CURVE FILE (.PVS) 



To open a set of dispersion curves previously saved with the extension *.pvs*, select *Open 2D Phase Velocity Curve File (.pvs)*. Highlight the file and press *Open*.

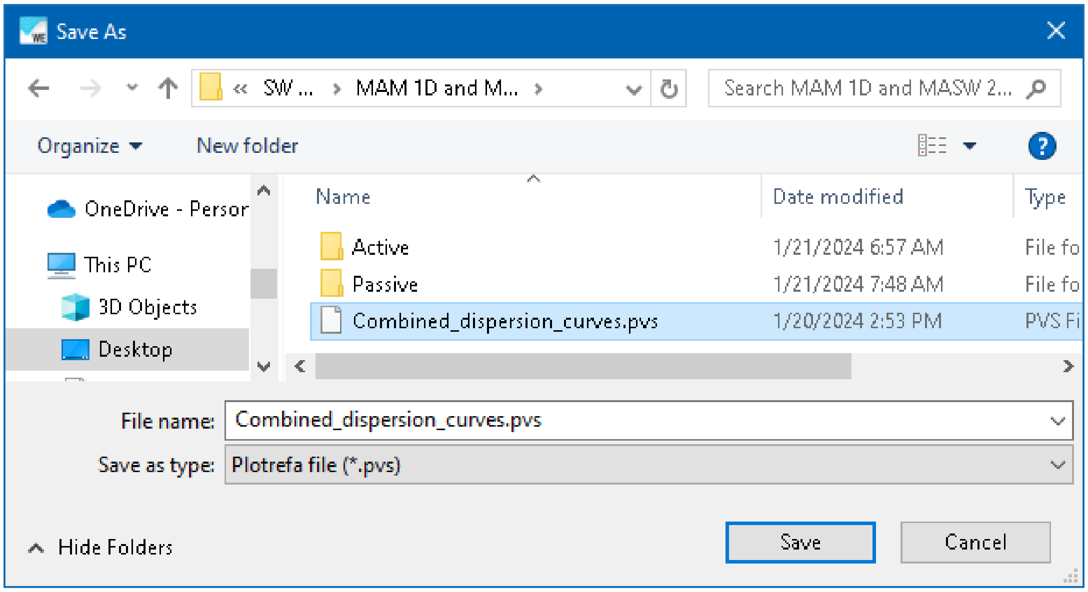


7.1.9 SAVE 2D/3D PHASE VELOCITY CURVE FILE (.PVS)

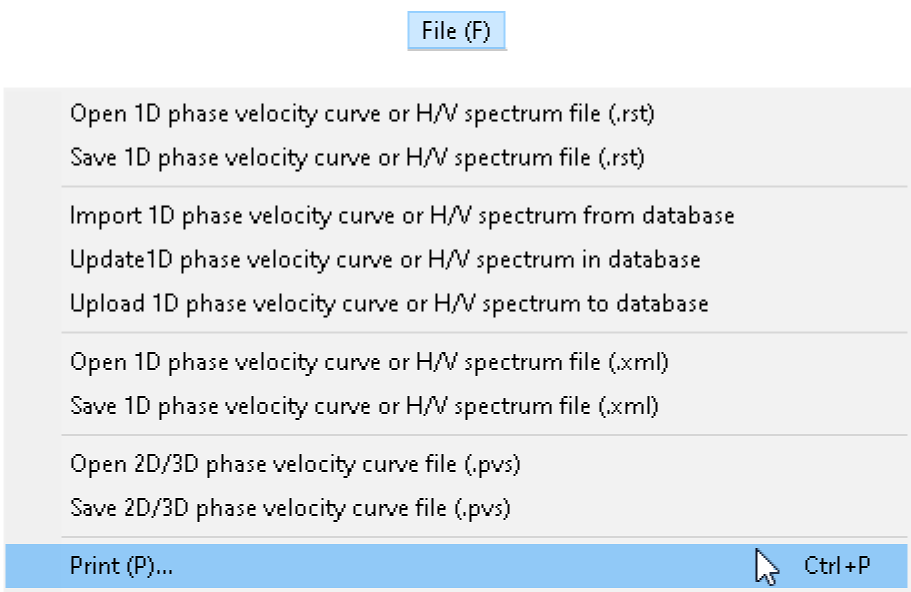


To save a set of dispersion curves, select *Save 2D Phase Velocity Curve File (.pvs)*. A curve file can be saved at any time in the processing flow and will reflect the extent of results at the time of save.

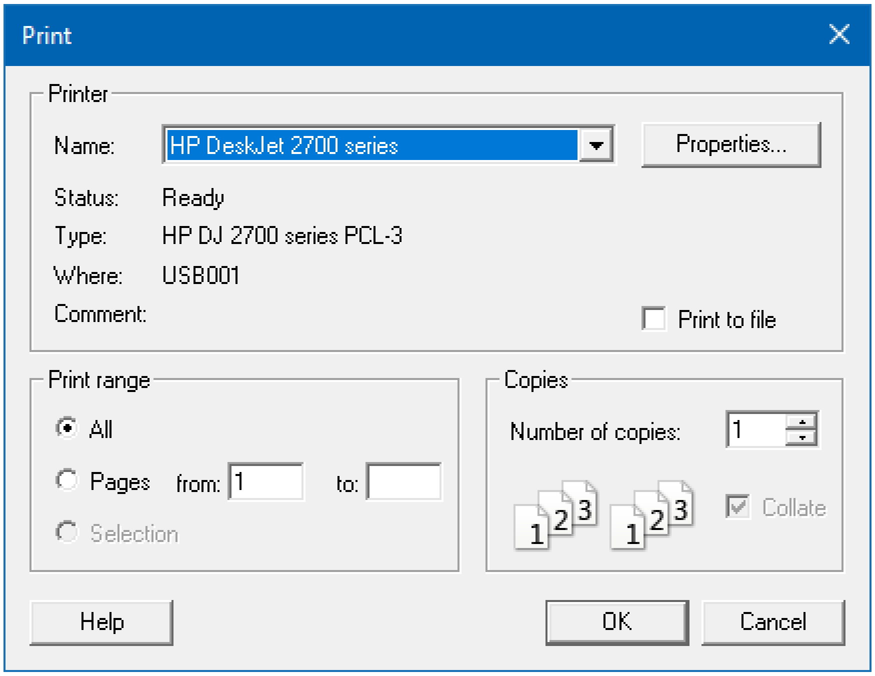
Assign a file name with the extension *.pvs* and press *Save*.



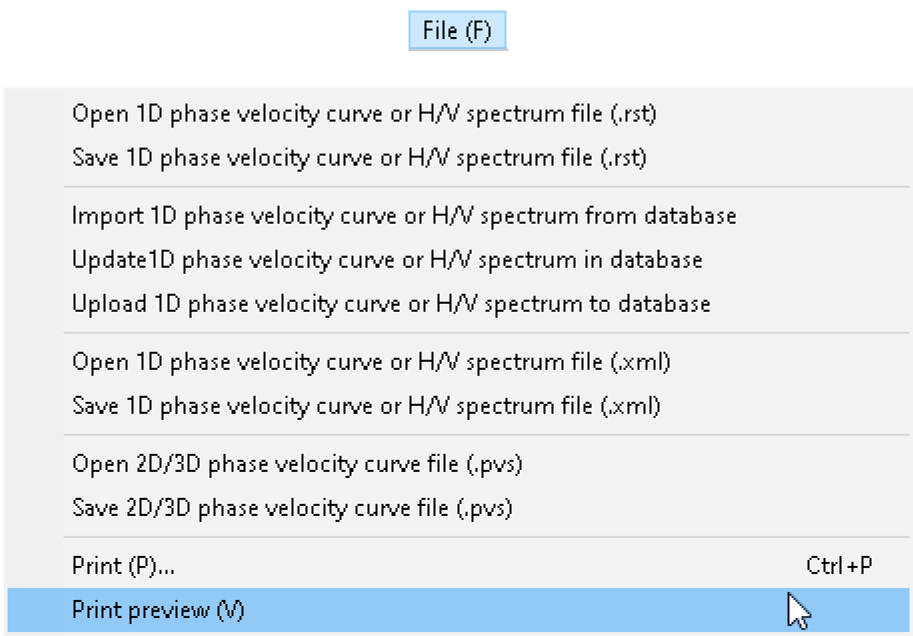
7.1.10 PRINT [CTRL+P]



To print the current WaveEq display, choose *Print*, press *Ctrl+P*, or press the *Print* button.



7.1.11 PRINT PREVIEW



To preview the WaveEq display before printing, select *Print preview (V)*.

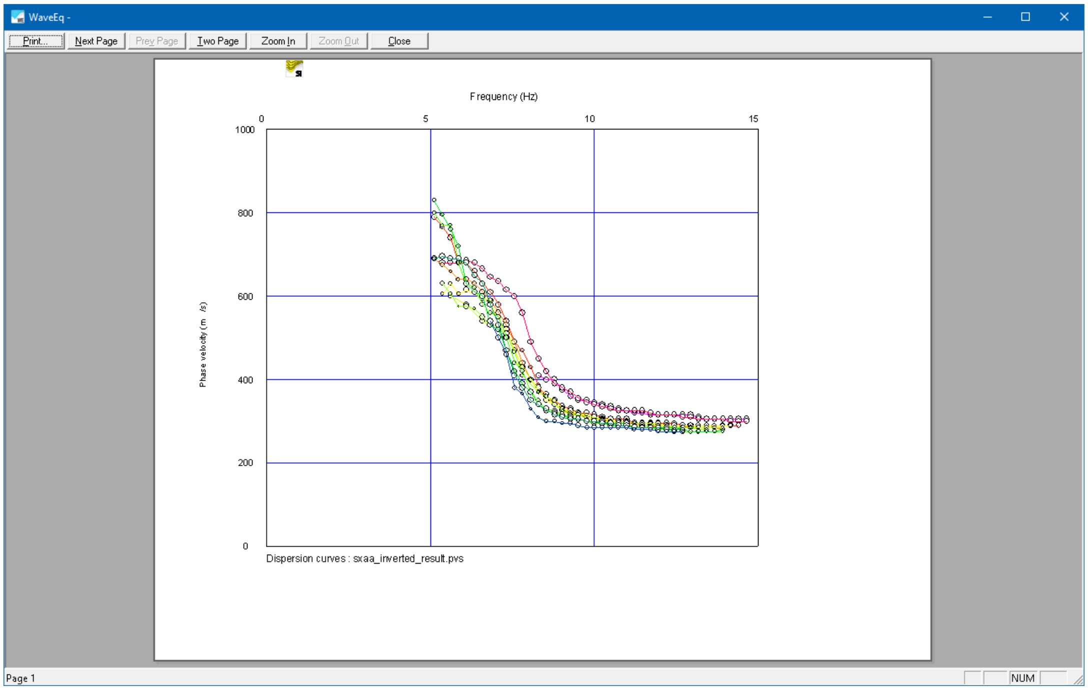
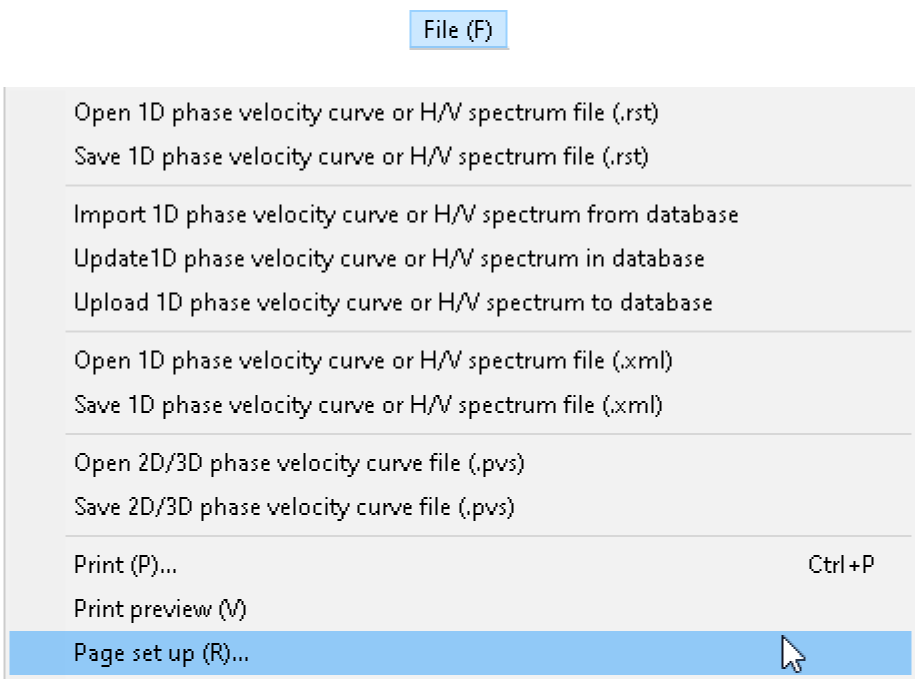


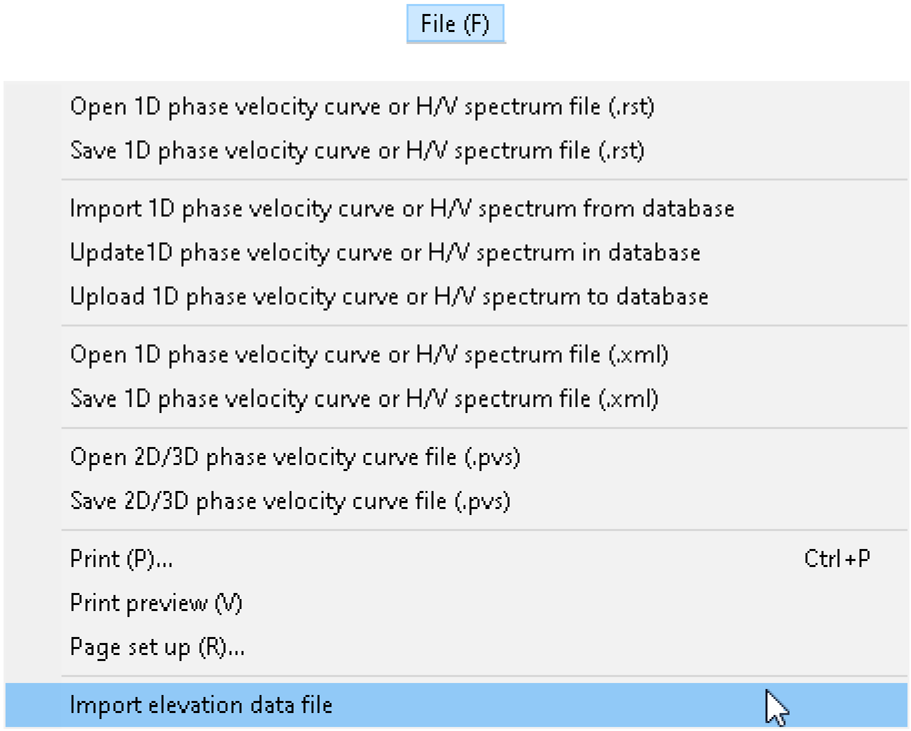
Figure 158: WaveEQ display, read for printing.

7.1.12 PAGE SETUP



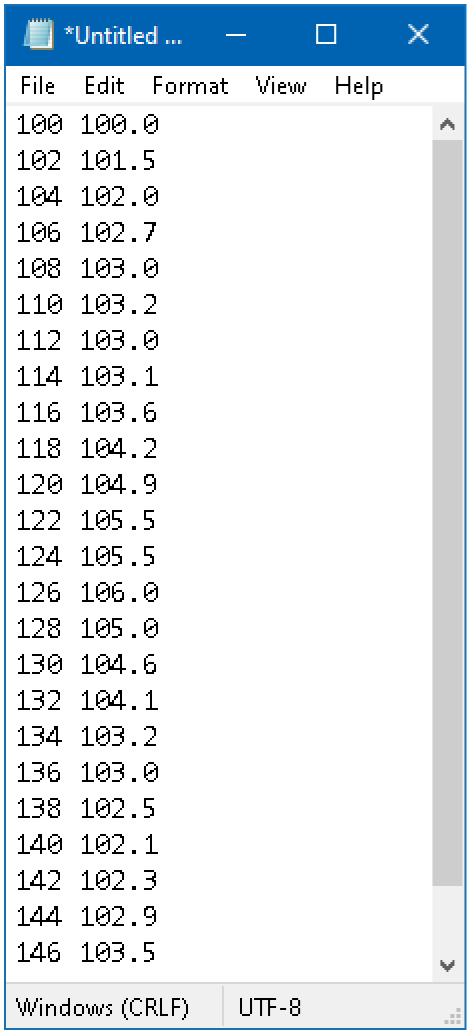
To set up a page for printing, select *Page set up*.

7.1.13 IMPORT ELEVATION DATA FILE

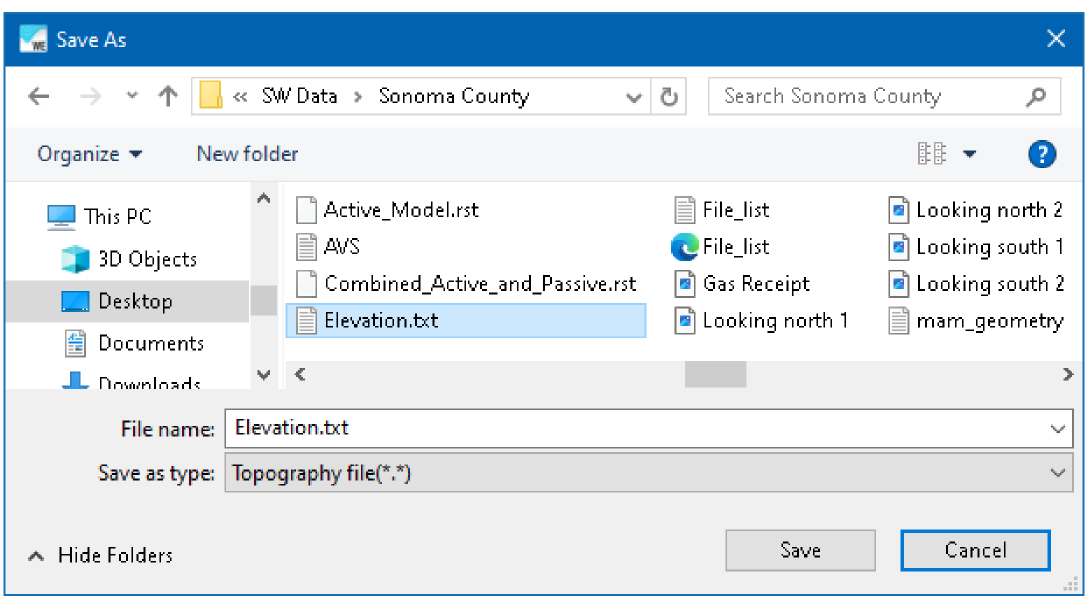


Survey line elevations can be imported and plotted on 2D MASW initial and final cross-sections. Note that elevations are not incorporated into the data analysis, they are only used for plotting. For this reason, it is recommended that surveys be conducted on generally flat ground. Some variation in elevation can be tolerated and would be averaged, especially for the passive source surveys, but flat ground is best.

Create an elevation file as a simple space-delimited text file where each row is a pair of x- and z-coordinates. At a minimum, two coordinates are required; the values in between will be interpolated. The coordinates need not exactly match the geophone and shot locations and can extend off the ends of the survey line.

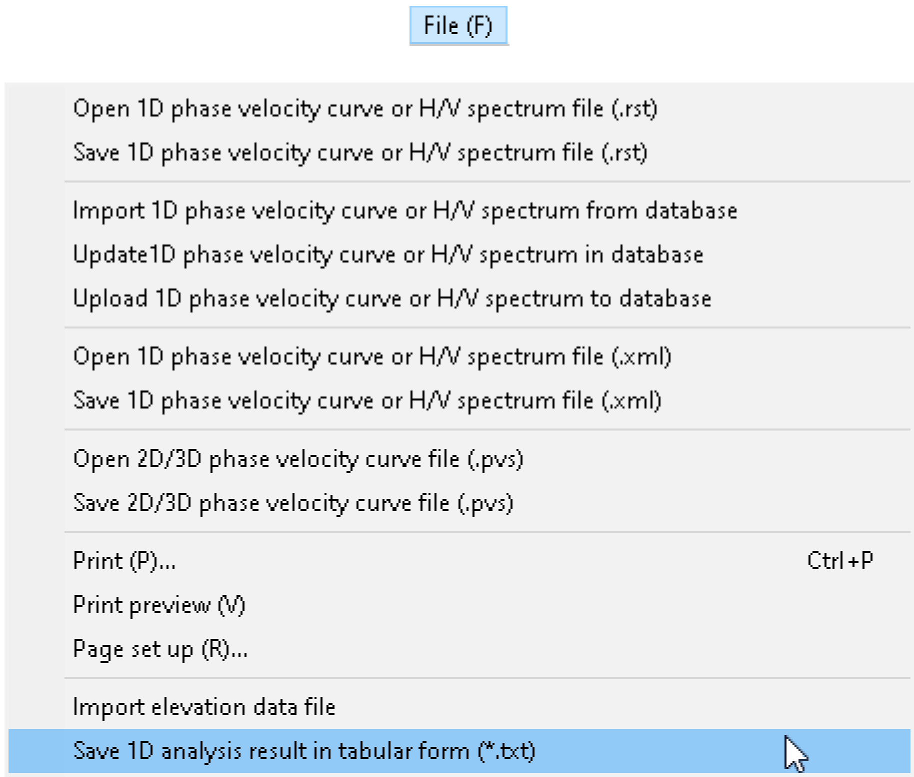


To open an elevation file, select *Import elevation data file*, highlight the file, and press *Open*.



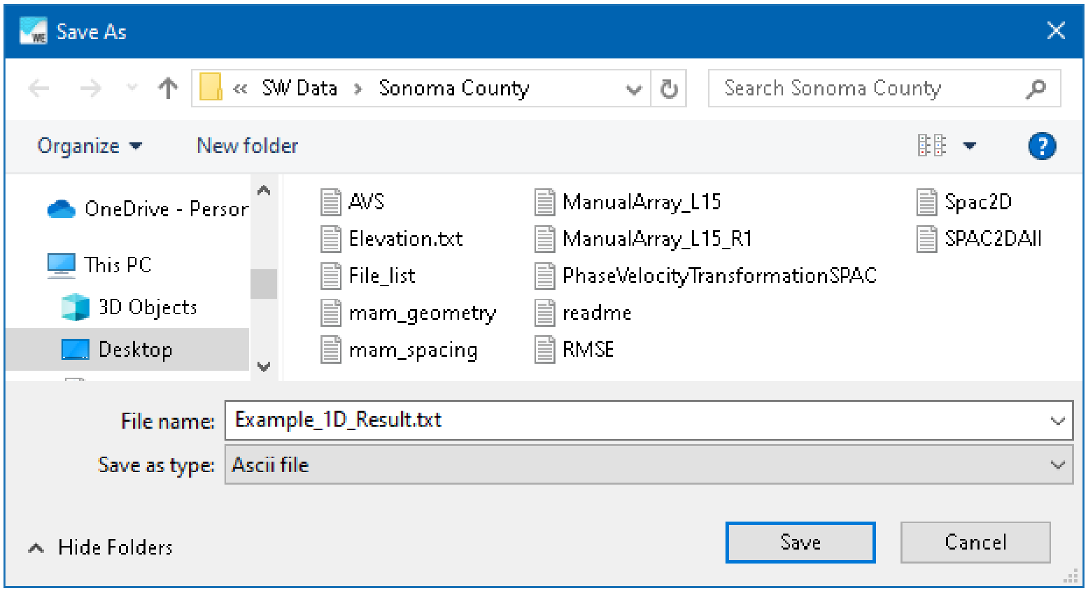
If not imported here, elevation data can also be imported into GeoPlot by opening the **File** menu and selecting *Open topography data file*.

7.1.14 SAVE 1D ANALYSIS RESULT IN TABULAR FORM (.TXT)



To save the final results of a 1D MASW or MAM dataset analysis in tabular form, select *Save 1D analysis result in tabular form (.txt)*.

Assign a file name with the extension *.txt* and press *Save*.



The file is a simple text file with *Depth*, *S-wave velocity*, *p-wave velocity*, *Density*, and *N* (blow counts). Refer to Section 7.6.13.1, Page 464, for more information on the relationships used for calculating the equivalent *p-wave velocity*, *Density*, and *N*.

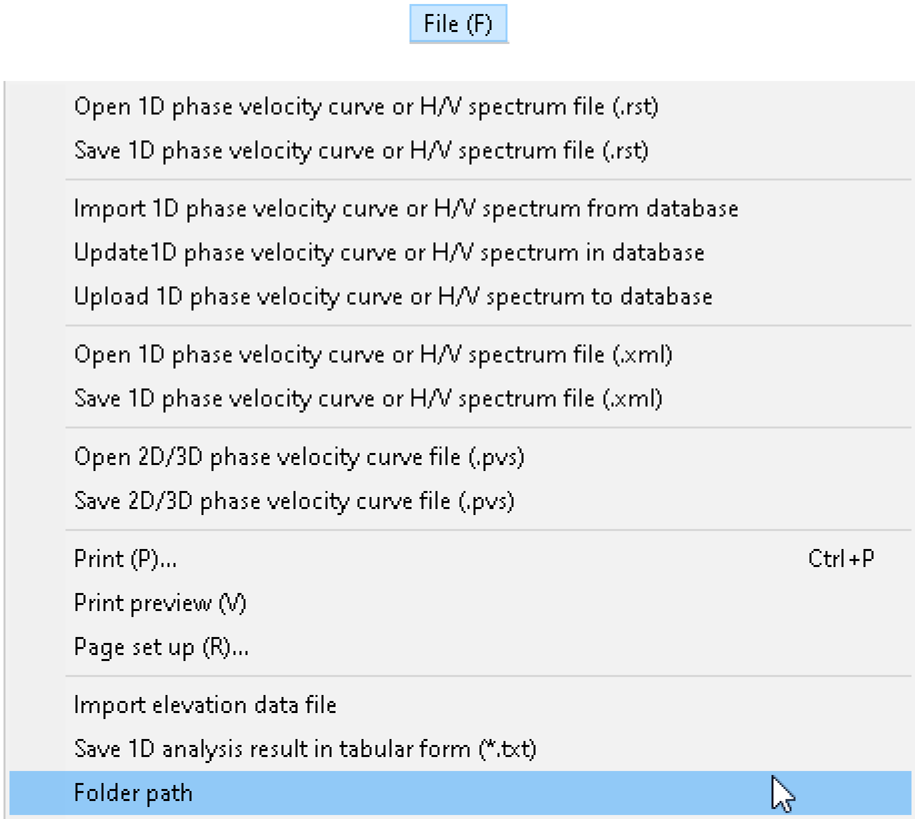
Example_1D_Result - Notepad

Depth(f)	S-wave velocity(f/s)	P-wave velocity(f/s)	Density(g/cc)	N
0.000000	673.011482	4979.325771	1.793592	10.861207
3.571429	665.467322	4970.952034	1.792775	10.478198
7.692308	665.672004	4971.179008	1.792797	10.488462
12.362638	687.886178	4995.836735	1.795204	11.644319
17.582420	800.911427	5121.294975	1.807405	18.902597
23.351650	1037.152052	5383.522034	1.832662	43.055725
29.670332	1109.184980	5463.478565	1.840297	53.321451
36.538464	1466.292024	5859.867096	1.877692	129.700541
43.956043	1527.904987	5928.257942	1.884067	147.867036
51.923077	1568.261027	5973.052979	1.888230	160.667706
60.439560	1588.407040	5995.414734	1.890305	167.333531
69.505501	1594.092011	6001.725197	1.890890	169.248307
79.120880	1592.697024	6000.176907	1.890746	168.777049
89.285706	1588.899016	5995.961189	1.890356	167.498636
121.428566	1594.092011	6001.725197	1.890890	169.248307

Ln 1, Col 1 100% Windows (CRLF) UTF-8

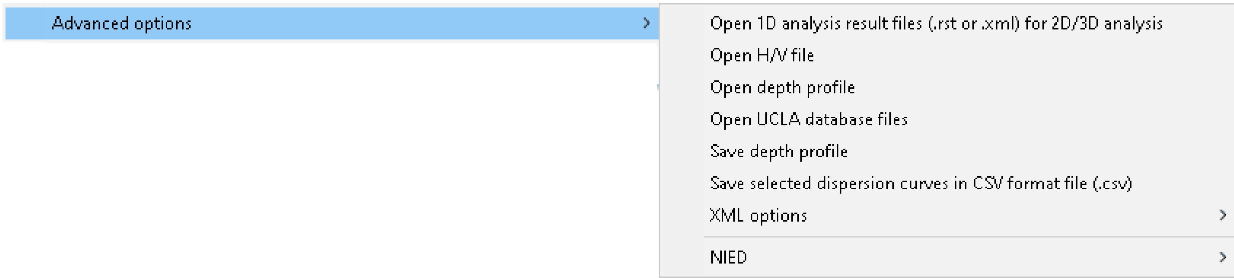
Table 12: 1D results file.

7.1.15 FOLDER PATH



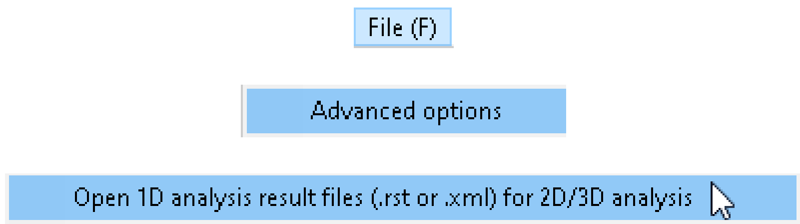
WaveEQ generates some files automatically while producing a velocity model. In most cases, you will never refer to these files. The path for these automatically generated files defaults to the folder from which you read the original data. If you would like to avoid clutter in the data file, create (outside of WaveEQ) and separate folder, select *Folder Path*, and then choose the new folder as the path for automatically generated files.

7.1.16 Advanced Options



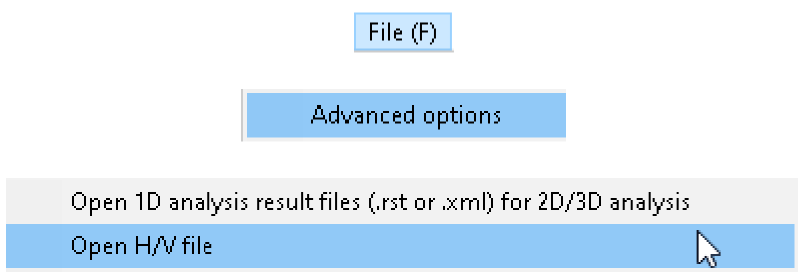
Some of the items in the following sub-menus are subject to change and are undocumented. They are rarely used, and when they are, support from Geometrics is generally required.

7.1.16.1 Open 1D Analysis Result Files (.rst or .xml) for 2D/3D Analysis



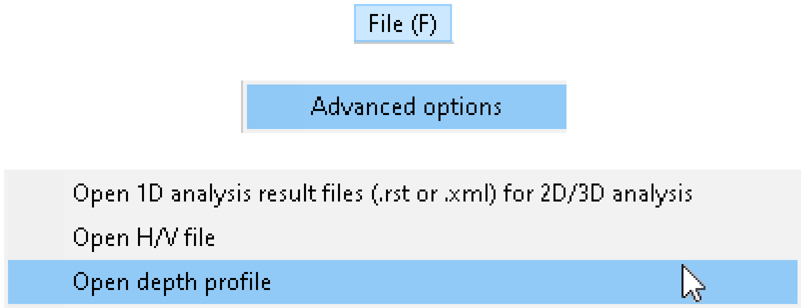
If you have a series of 1D V_S profiles, you may open all of them at once to conduct a 2D or 3D analysis.

7.1.16.2 Open H/V File



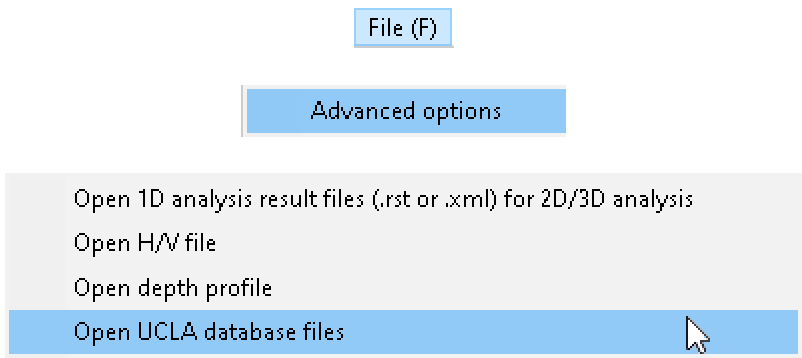
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.1.16.3 Open Depth Profile



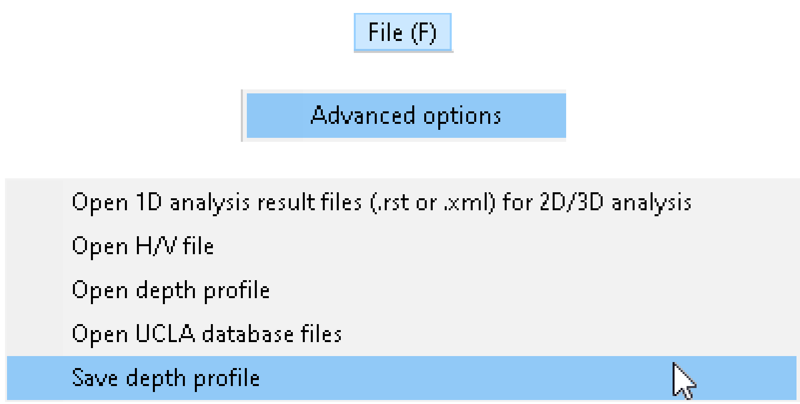
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.1.16.4 Open UCLA Database Files



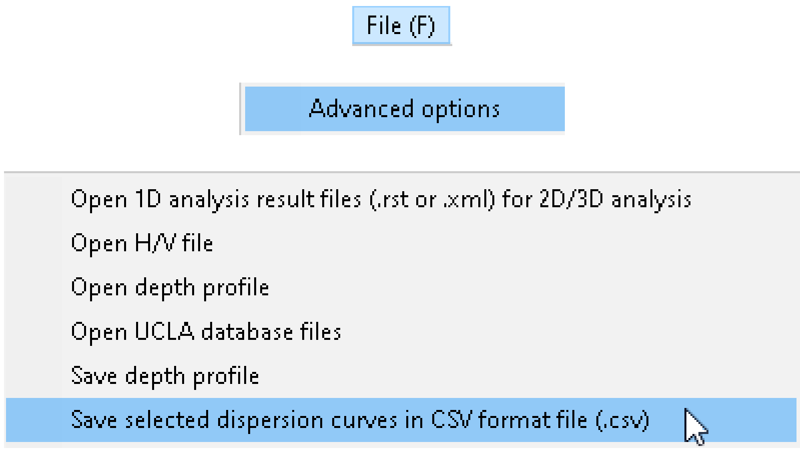
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

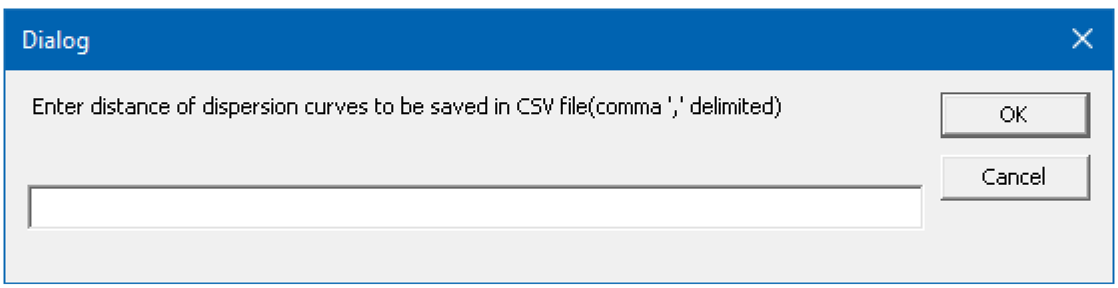
7.1.16.5 Save Depth Profile



This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

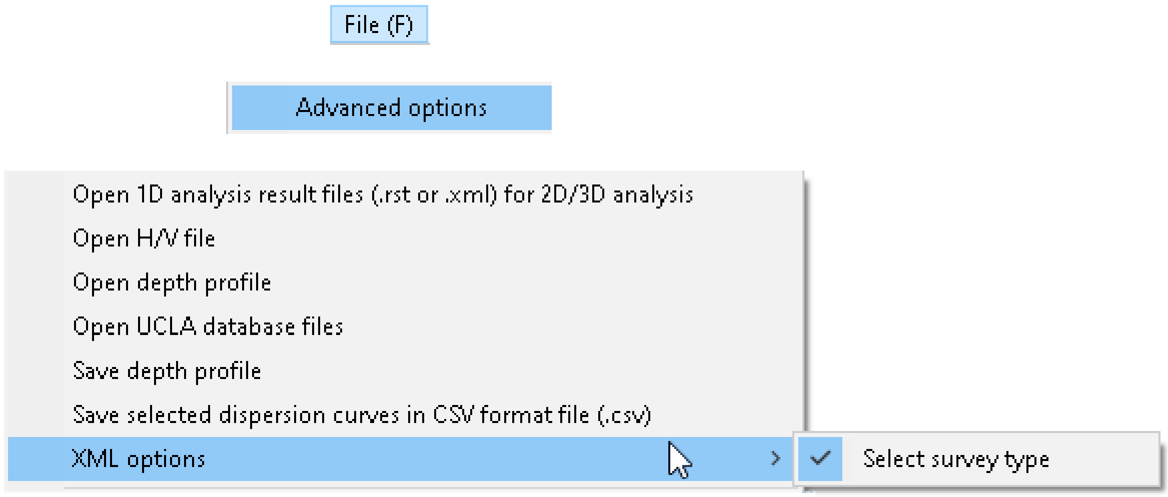
7.1.16.6 Save Selected Dispersion Curves in CSV Format File (.csv)





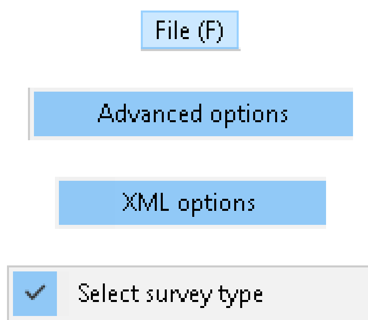
This function lets you save individual dispersion curves into separate CSV files for import into Excel® or other third-party software.

7.1.16.7 XML OPTIONS



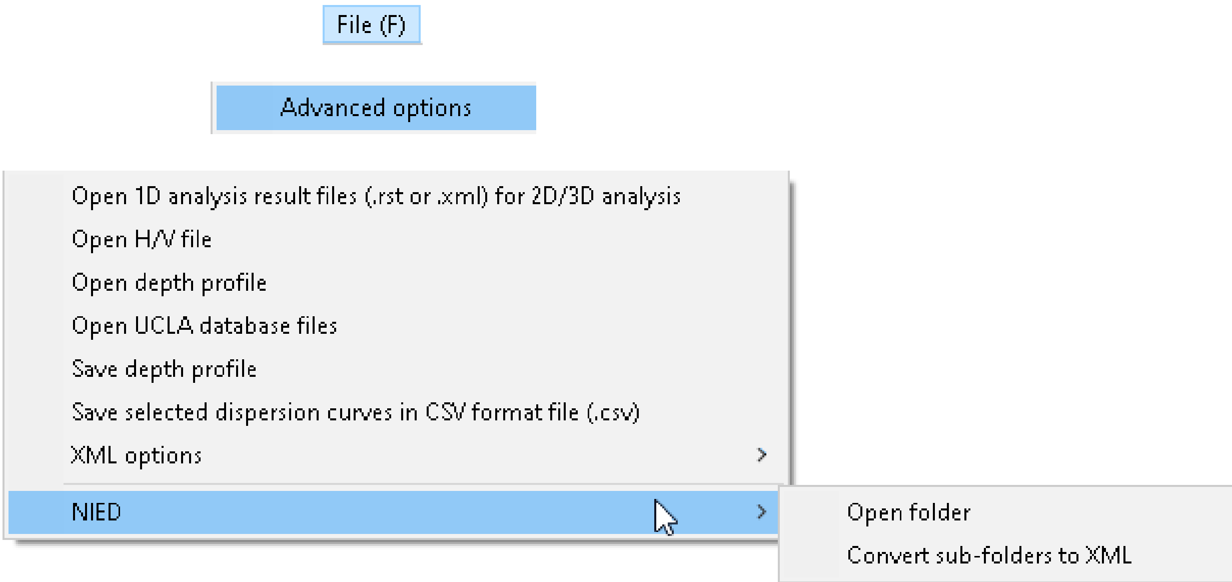
Continue.

7.1.16.7.1 SELECT SURVEY TYPE



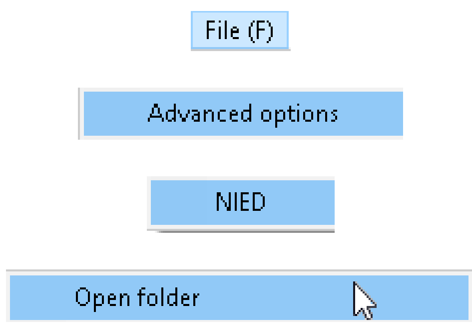
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.1.16.8 NIED



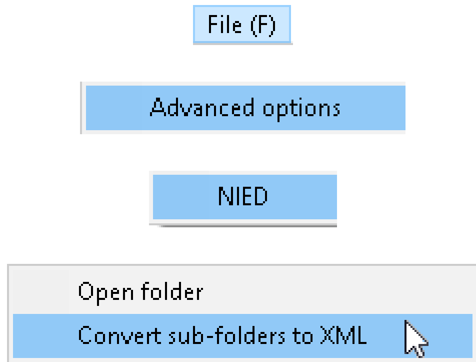
Continue.

7.1.16.8.1 Open Folder



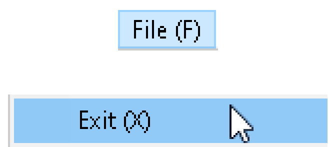
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.1.16.8.2 CONVERT SUB-FOLDERS TO XML

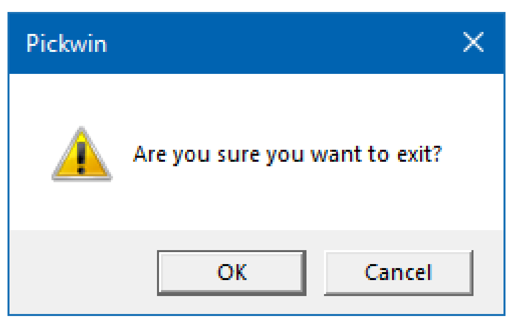


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.1.17 EXIT



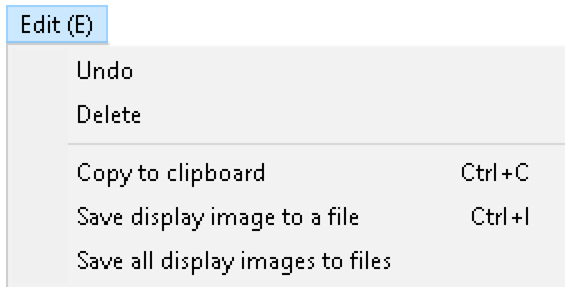
To exit the WaveEQ module, choose *Exit.* You will see the following dialog box:

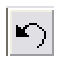


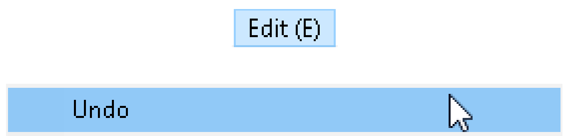
Press *OK* to exit WaveEQ or press *Cancel* to continue using WaveEQ.

7.2 Edit Menu

The **Edit** menu contains functions for making and reversing edits and copying graphical displays to the clipboard.

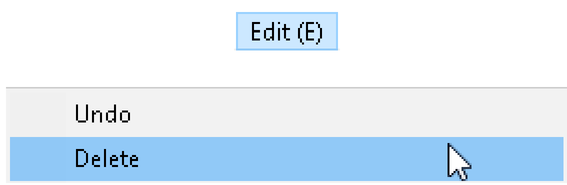


7.2.1 Undo 



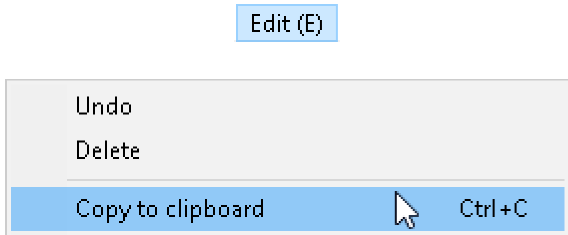
The *Undo* function can be used to reverse the deletion or repositioning of a point on a dispersion curve using the *Select dispersion curve*  or *Correct dispersion curve*  buttons, respectively. *Undo* does not apply to all functions.

7.2.2 Delete



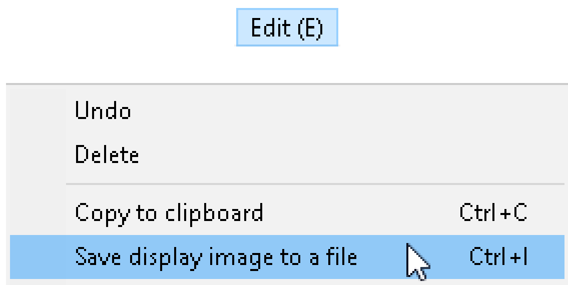
The *Delete* function or *Delete* key becomes active when a point on the dispersion curve has been selected using the *Select dispersion curve*  button. To delete a point on a dispersion curve, activate editing with the *Select dispersion curve* button, then use the mouse to select the point(s) on the dispersion curve to be deleted. The selected points are highlighted in red. Select *Delete* or press the *Delete* key to remove the selected points.

7.2.3 Copy to Clipboard [CTRL+C]



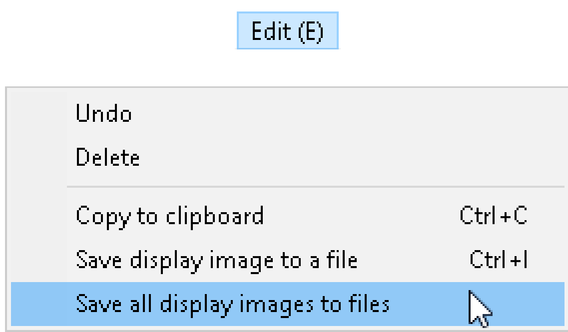
To copy the current display to the clipboard for pasting into Microsoft Word or other application, select *Copy to clipboard*.

7.2.4 Save Display Image to a File [CTRL+I]



This feature saves whatever is on the screen to a PNG, JPG, BMP, or GIF file.

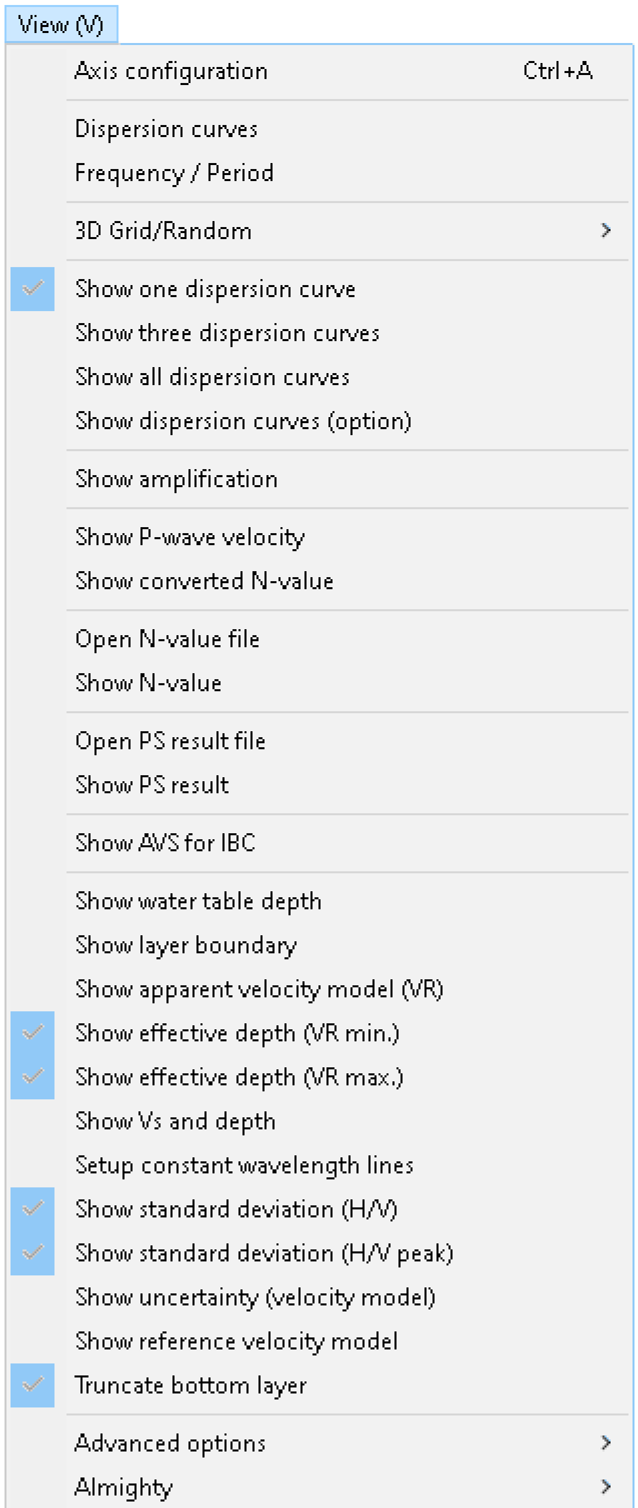
7.2.5 Save All Display Images to Files



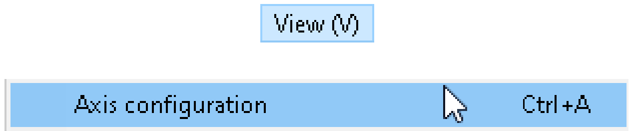
If you are working with a file list, this feature saves all shot gathers (or phase velocity images) in the file list to a PNG, JPG, BMP, or GIF file.

7.3 VIEW MENU

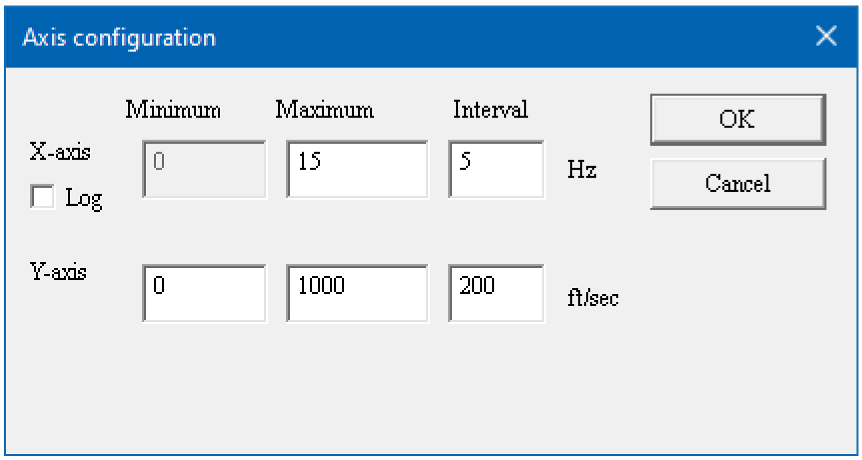
The **View** menu includes functions to configure scales, alter displays, and overlay or import other types of data.



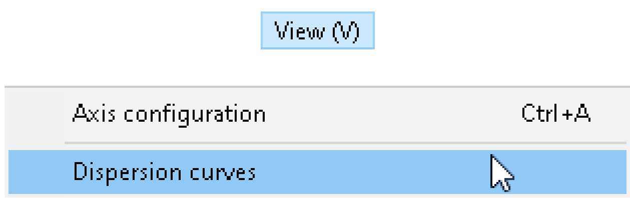
7.3.1 Axis Configuration [CTRL+A]



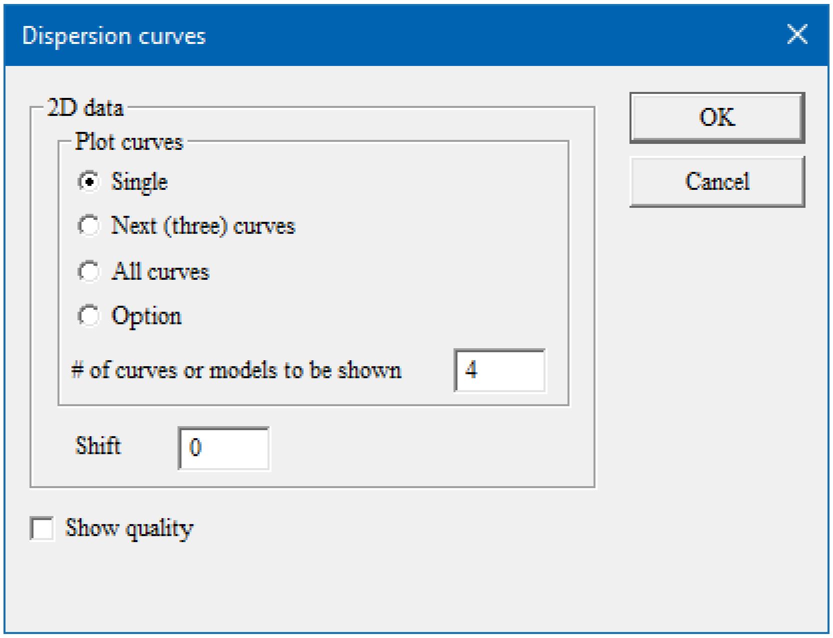
To configure the axis scales on a dispersion curve(s) or velocity curve(s) plot, select *Axis configuration*. The *Minimum* values for the *X-axis* and *Y-axis* are fixed at zero. The *Maximum* values set the outer limits. The *Interval* is the size of the sub-divisions.



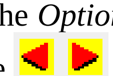
7.3.2 Dispersion Curves



The **Dispersion curves** dialog box controls how dispersion curves are displayed. The *Plot curve* options allow *Single*, *Next (three) curves*, or *All curves* to be displayed. These settings correspond to the *Show one dispersion curve* , *Show next dispersion curve* , and *Show all dispersion curves* buttons, respectively.



The *Single* and the *Show one dispersion curve* buttons display one dispersion curve in red. *Next (three) curves* and the *Show next dispersion curve* button display one curve in red with the down-line adjacent curve in green and the up-line adjacent curve in blue for a total of three curves. The *All curves* and the *Show all dispersion curves* buttons display all curves starting with red, blue, and green, with the rest unique in color but undefined. They are undefined since with all curves displayed, it is the overall trend that is meant to be discerned, not the individual curves.

You may also set a customized number of curves by checking the *Option* radio button and entering a number. You may scroll through the curves using the  buttons.

Shift allows the curves to be bulk shifted by the value entered.

If *Show quality* is checked (the default), a dashed quality curve is displayed with each dispersion curve. The quality curve is a relative indicator of the quality of the data points that define a dispersion curve and corresponds with data point circle size as shown below. If all data points are high quality (large circles), the curve is predominantly flat. However, due to variation in the signal-to-noise ratio, the quality curve will have peaks and valleys correlating with the relatively higher and lower quality data points (smaller circles), respectively.

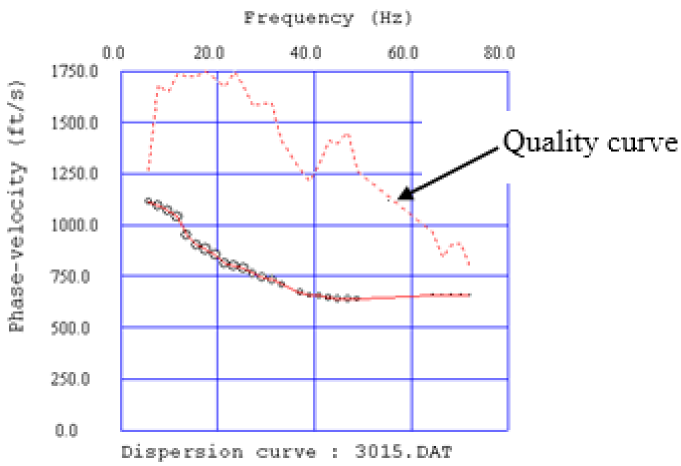
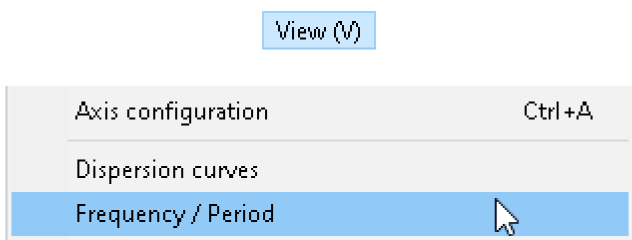


Figure 159: Phase velocity plot with quality curve.

For display of a *Single*, *Next (three) curves*, or *All curves*, the quality curve has the same colors as the associated dispersion curves. Refer to Sections 7.5.8 and 7.5.10 starting on Page 444 for more information on quality.

7.3.3 FREQUENCY/PERIOD 



The function *Frequency/period* and the *Frequency/period*  button allow toggling the view of the dispersion curve between frequency (cycles per second) and period (seconds), the inverse of frequency.

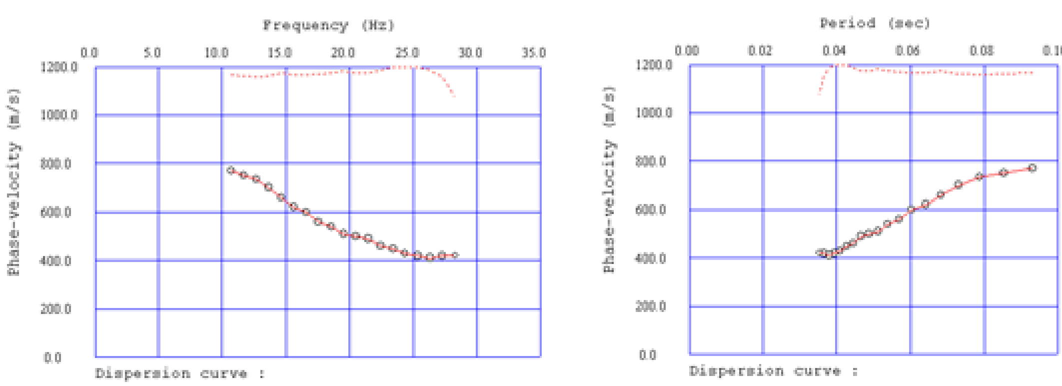
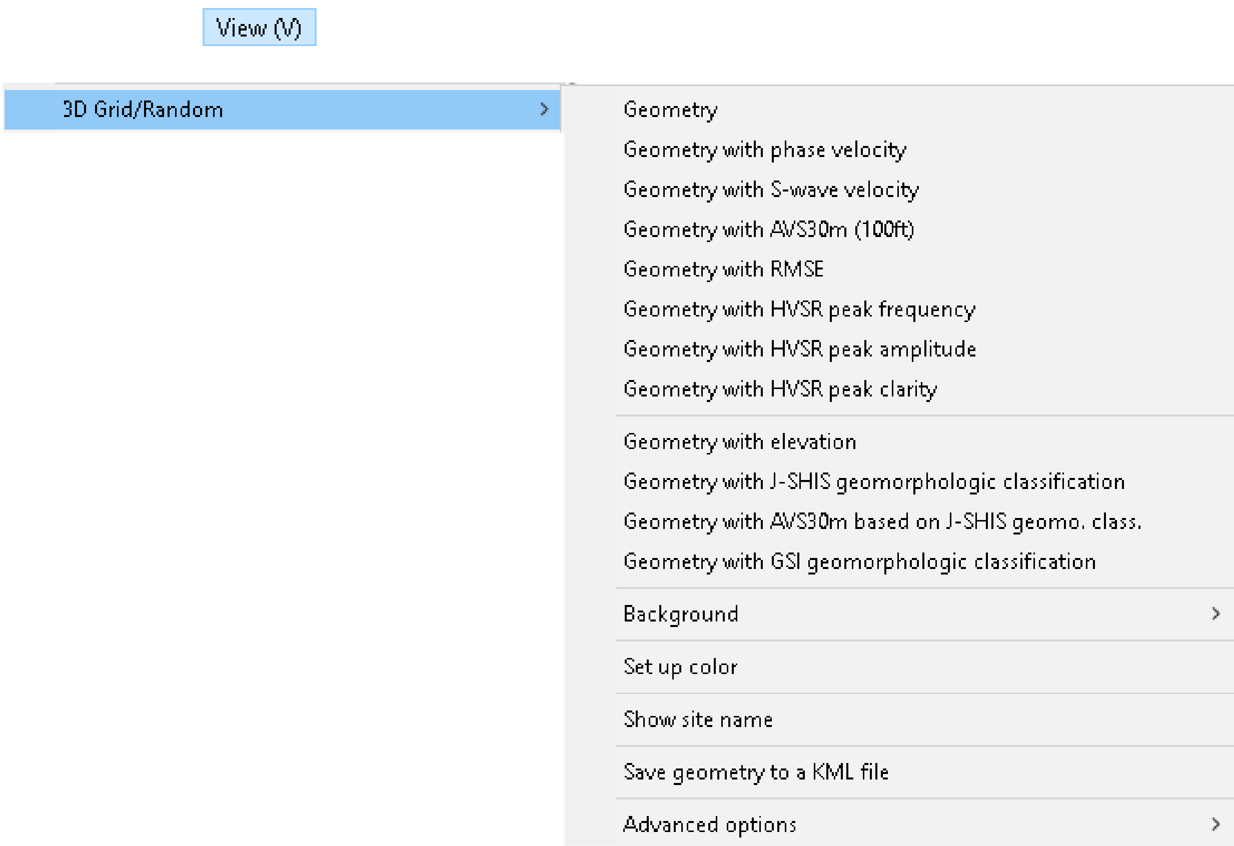


Figure 160: Phase velocity vs. frequency (left) and phase velocity vs. period (right).

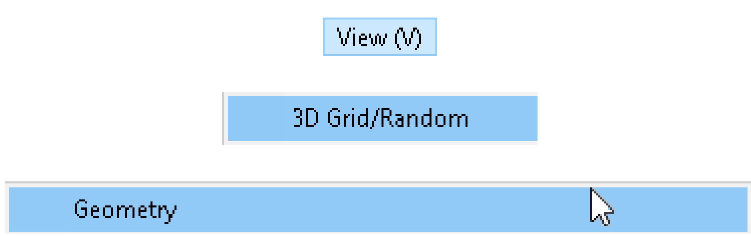
It may be more intuitive to think in terms of seconds, which directly relates to the natural period of buildings, etc.

7.3.4 3D Grid/Random



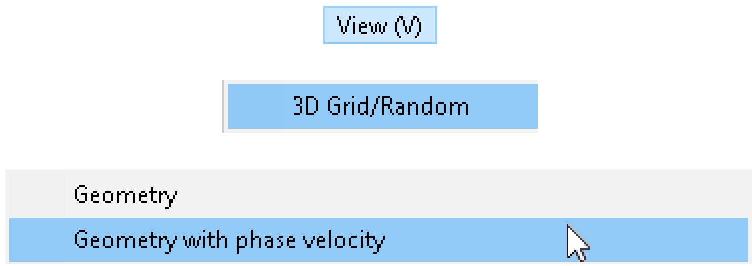
Items in this menu are covered in this tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.1 Geometry



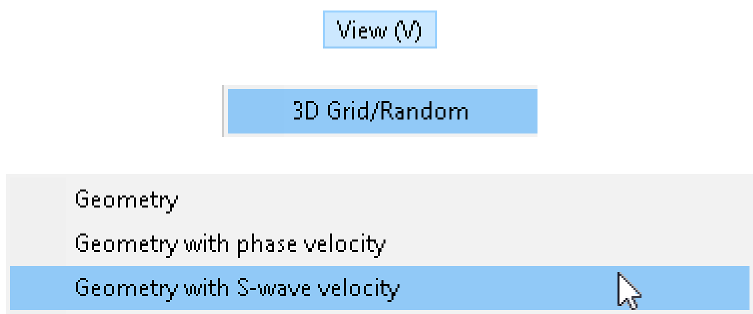
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.2 Geometry With Phase Velocity



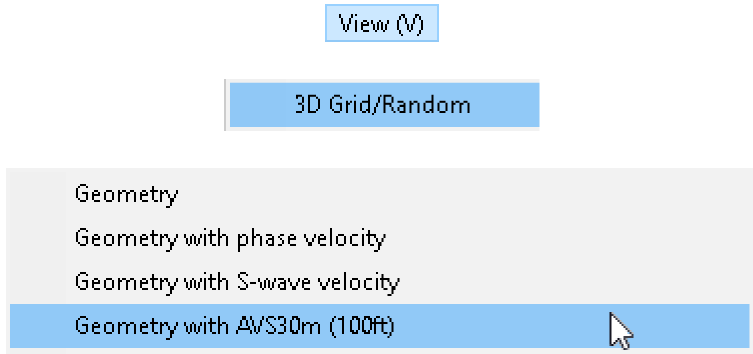
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.3 Geometry With S-wave Velocity



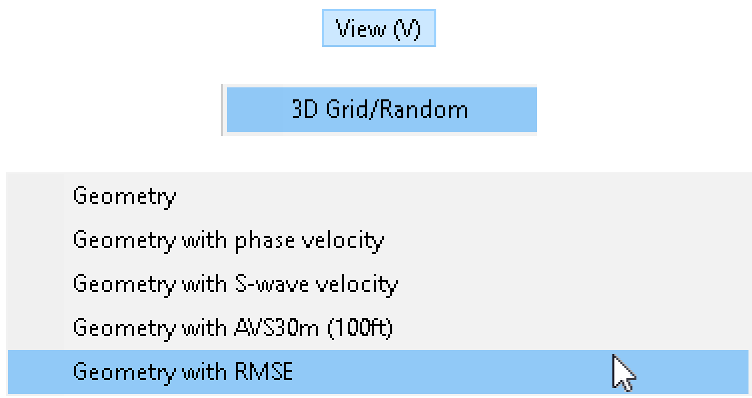
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.4 Geometry With AVS30m (100 ft)



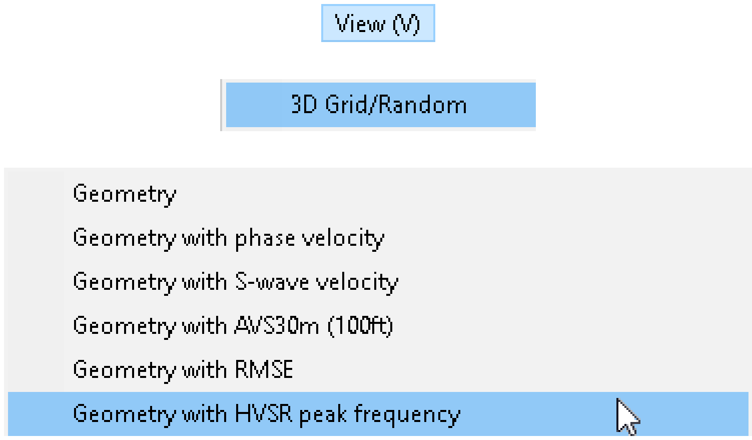
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.5 Geometry With RMSE



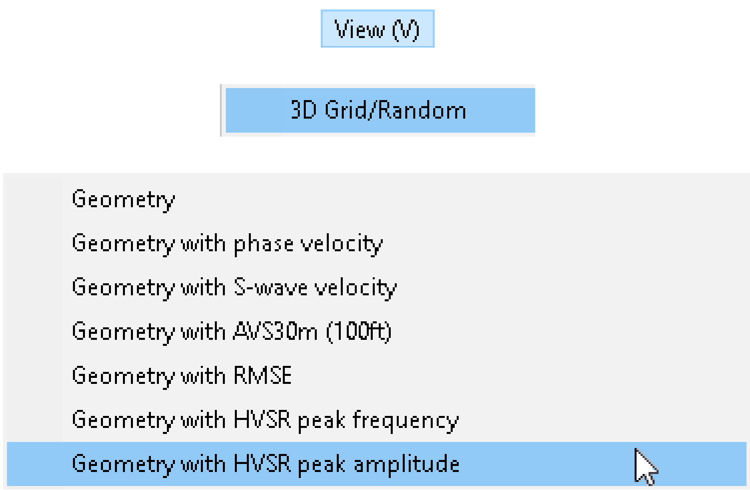
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.6 Geometry With HVSR Peak Frequency



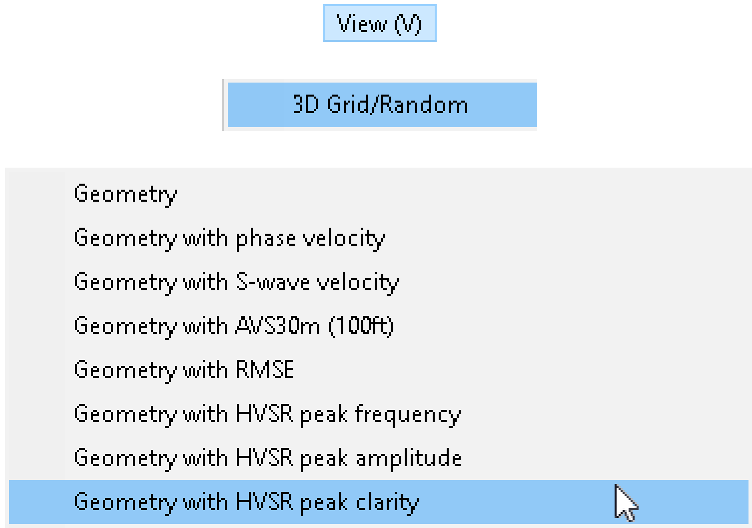
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.7 Geometry With HVSR Peak Amplitude



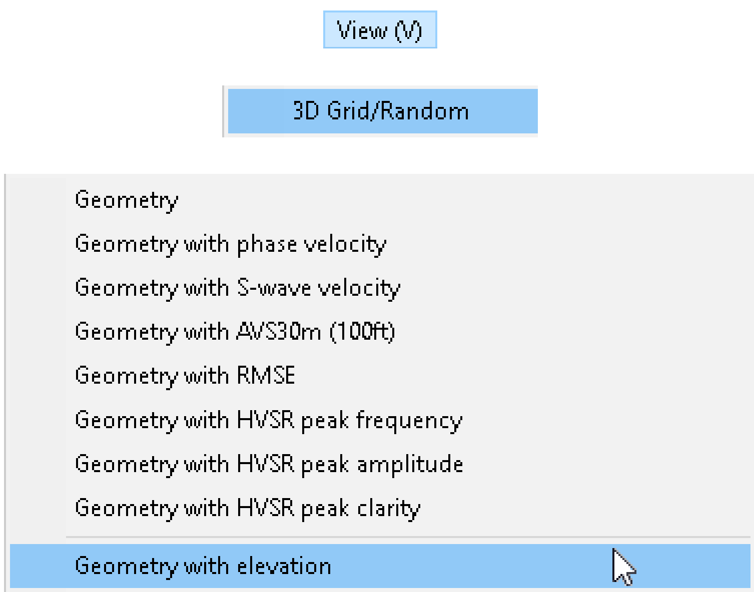
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.8 Geometry With HVSR Peak Clarity



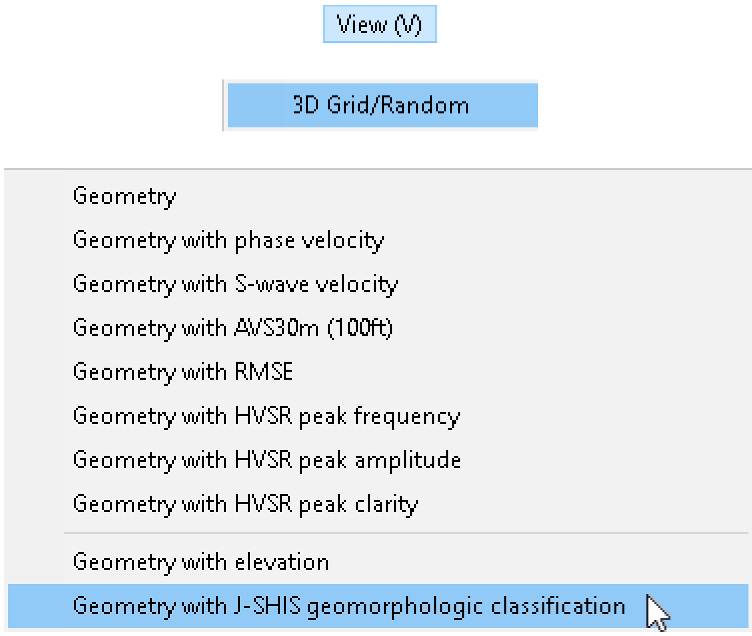
See [tutorial](). If your question is not covered in the tutorial, please contact us at [support@seisimager.com]().

7.3.4.9 Geometry With Elevation



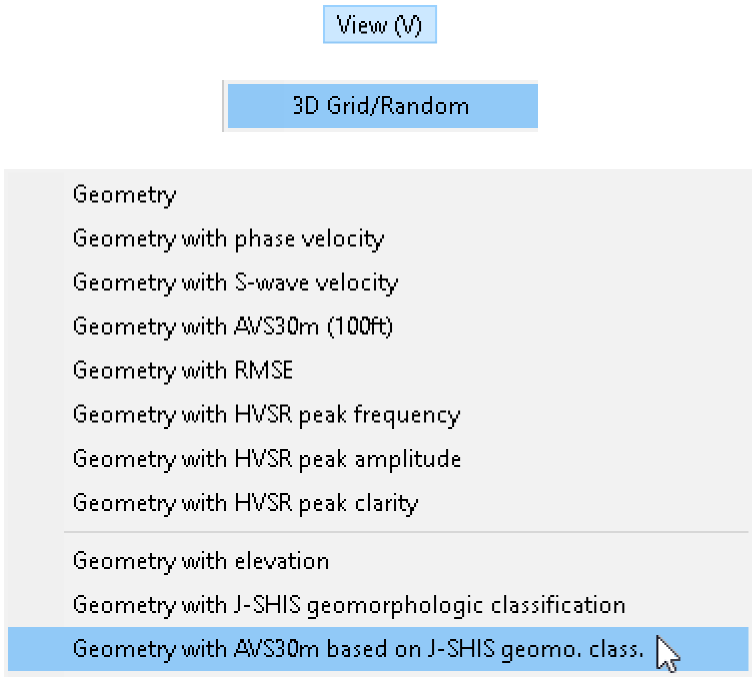
See [tutorial](). If your question is not covered in the tutorial, please contact us at [support@seisimager.com]().

7.3.4.10 GEOMETRY WITH J-SHIS GEOMORPHOLOGIC CLASSIFICATION



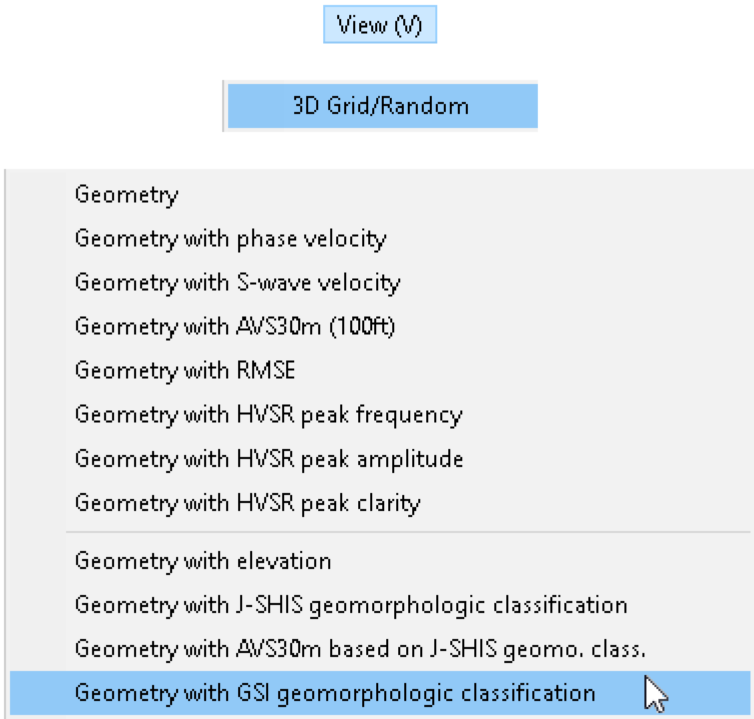
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.11 Geometry with AVS30m Based on J-SHIS Geomorphologic Classification



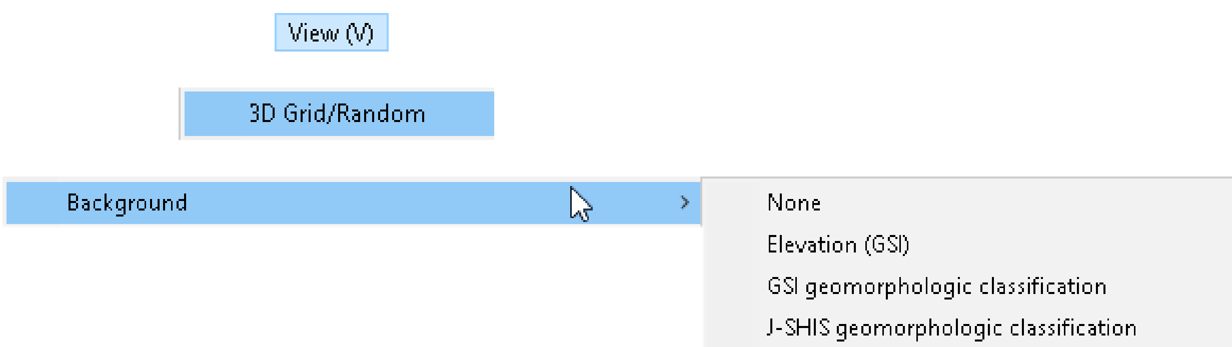
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.12 Geometry with GSI Geomorphic Classification



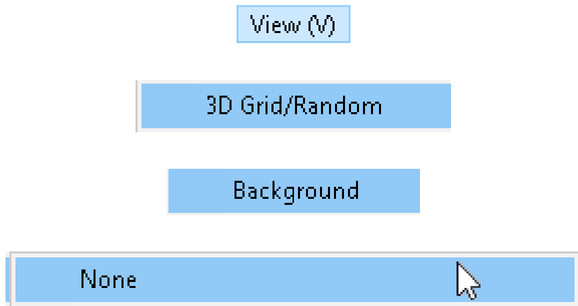
See [tutorial](). If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.13 Background



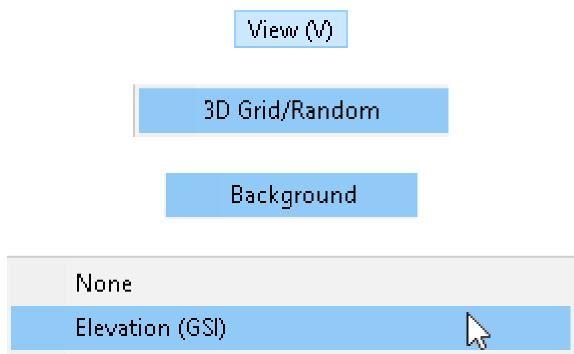
Continue.

7.3.4.13.1 None



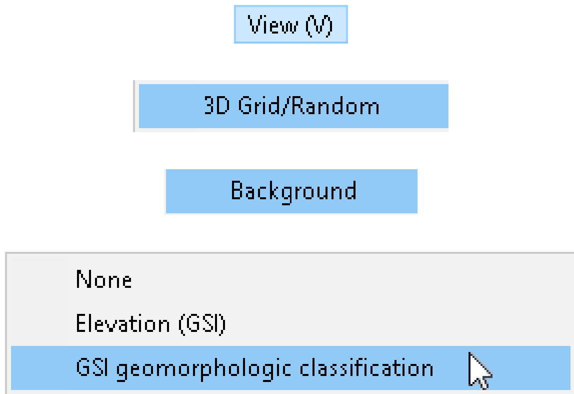
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.13.2 Elevation (GSI)



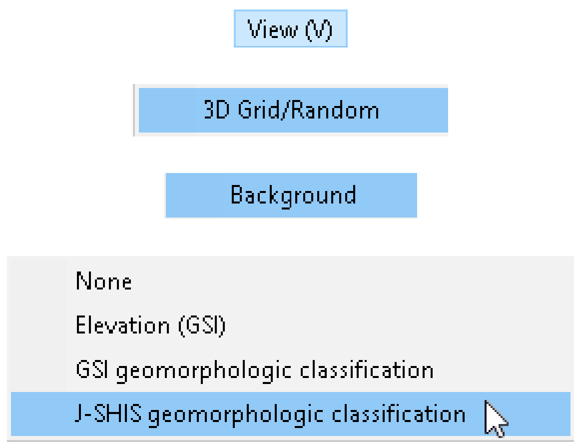
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.13.3 GSI Geomorphologic Classification



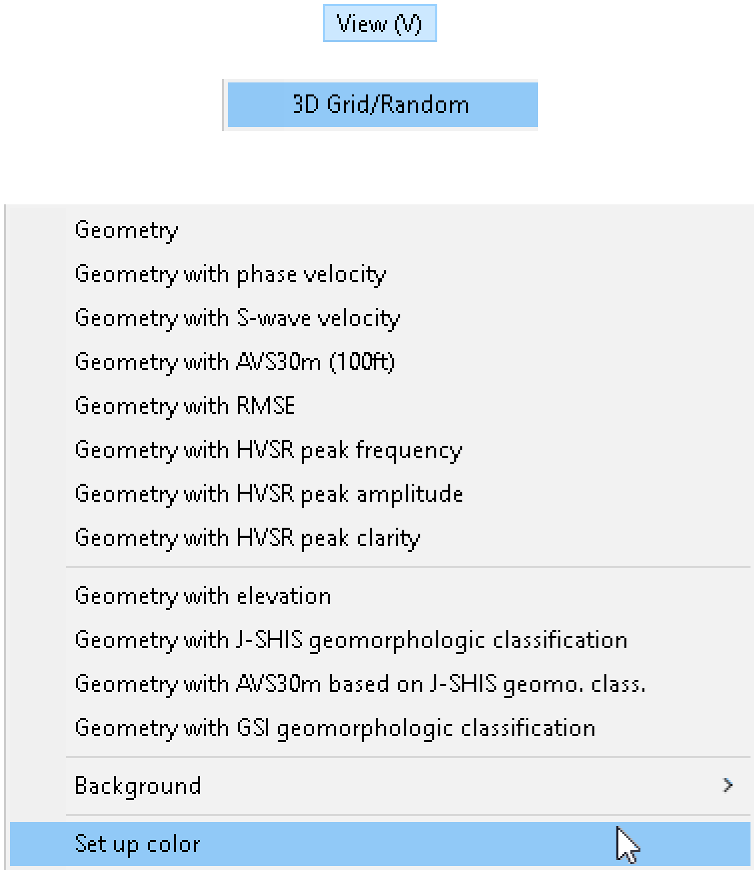
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.13.4 J-SHIS Geomorphologic Classification



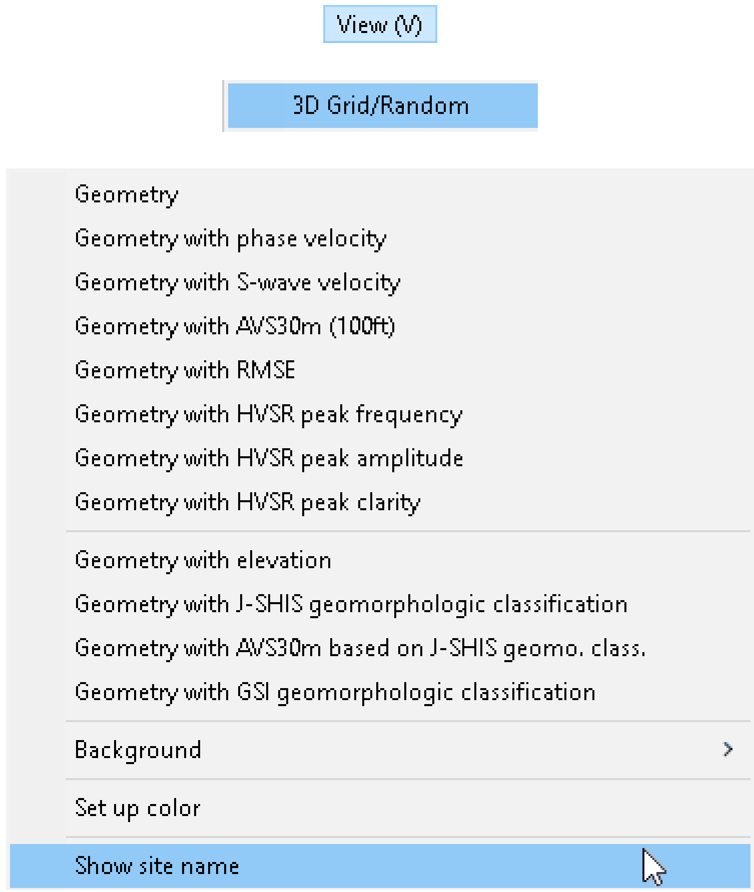
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.14 Set Up Color



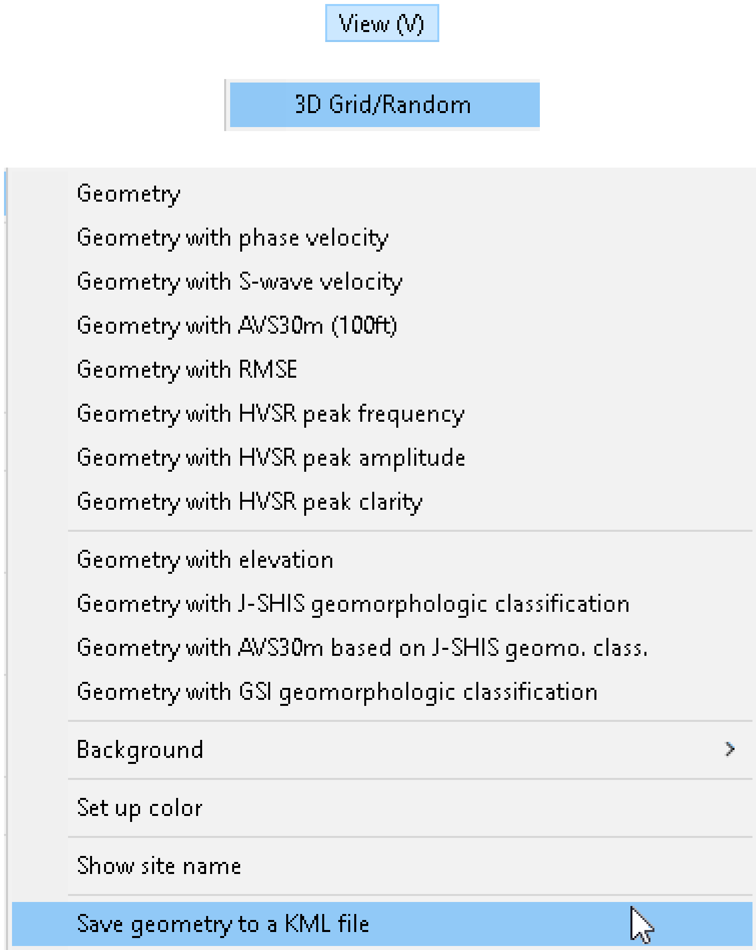
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.15 Show Site Name



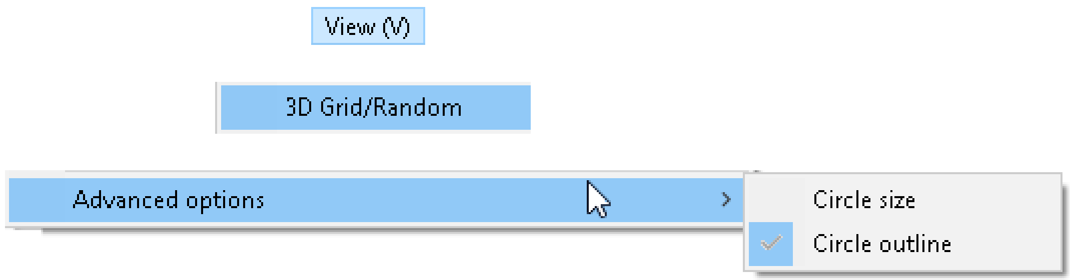
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.16 Save Geometry to a KML File



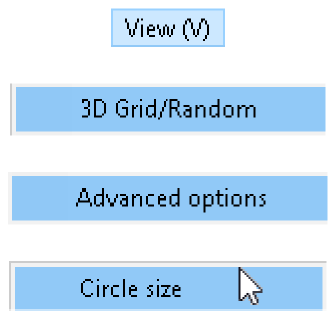
See tutorial. If your question is not covered in the tutorial, please contact us at support@seisimager.com.

7.3.4.17 Advanced Options



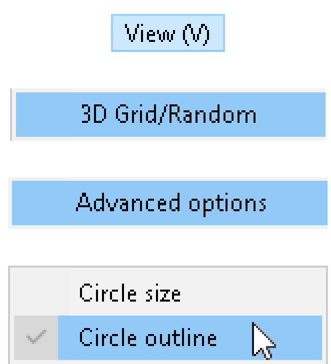
Continue.

7.3.4.17.1 Circle Size



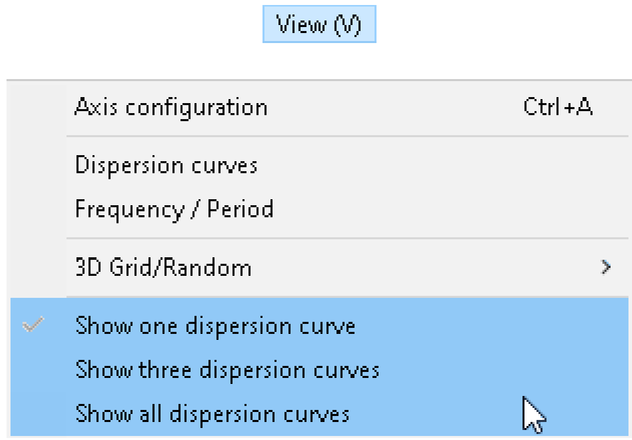
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.4.17.2 Circle Outline



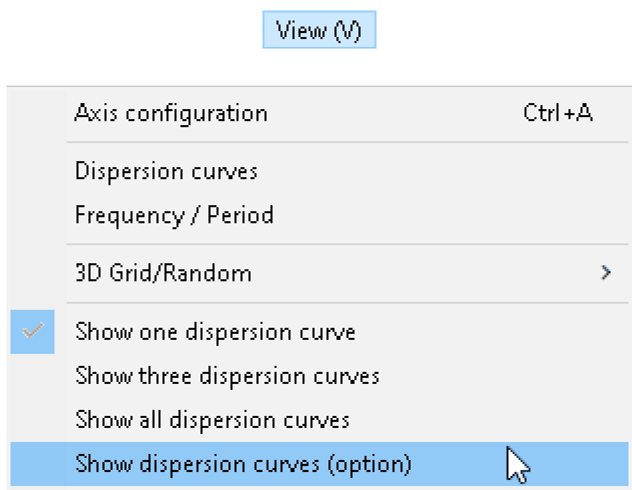
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.5 SHOW ONE , NEXT , AND ALL  DISPERSION CURVES



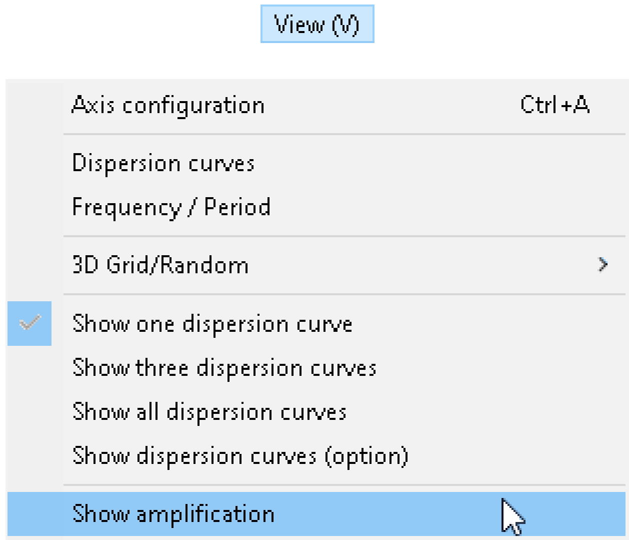
Show one dispersion curve, *Show Next (three) dispersion curves*, and *Show all dispersion curves* are the menu items associated with the button bar functions described in Section 7.3.2, Page 344. Choosing these menu items overrides the settings in the menu described in Section 7.3.2.

7.3.6 SHOW DISPERSION CURVES (OPTION)



If you set a custom number of dispersion curves to be displayed (see Section 7.3.2, Page 344), choose *Show Dispersion Curves (Option)* to display the custom number of curves.

7.3.7 SHOW AMPLIFICATION 



When displaying the H/V curve, you may show the ground amplification curve by choosing *View | Show Amplification* or by pressing the  button:

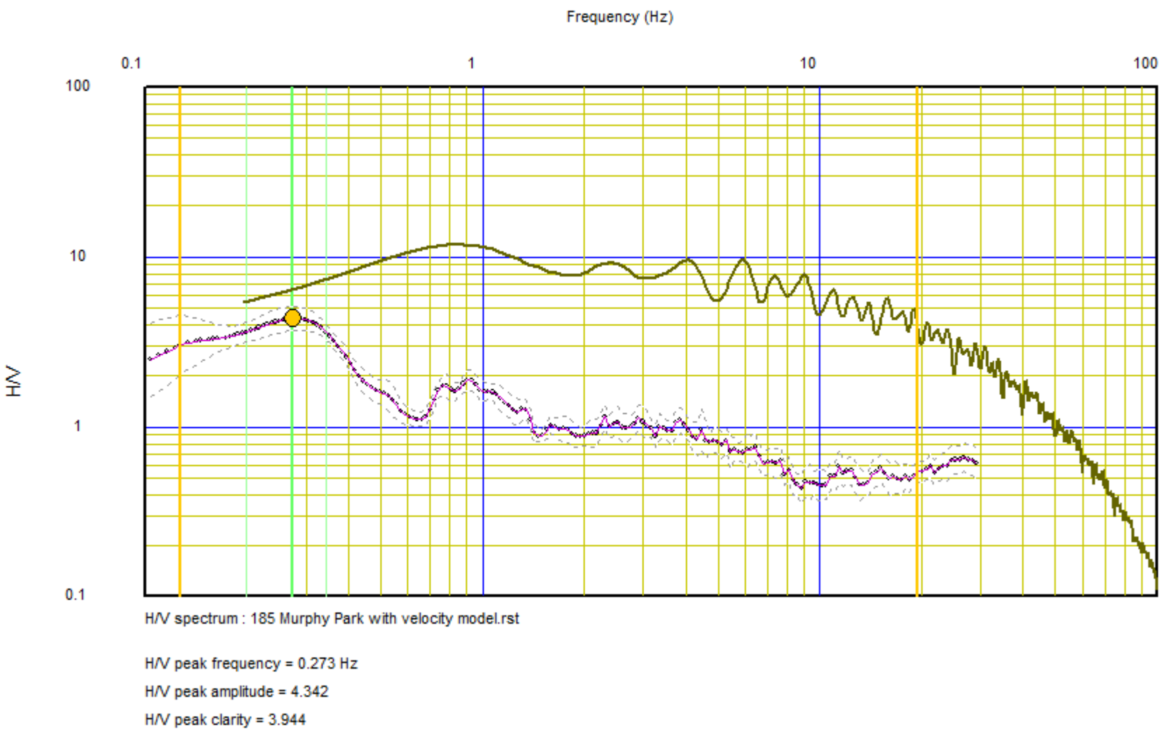
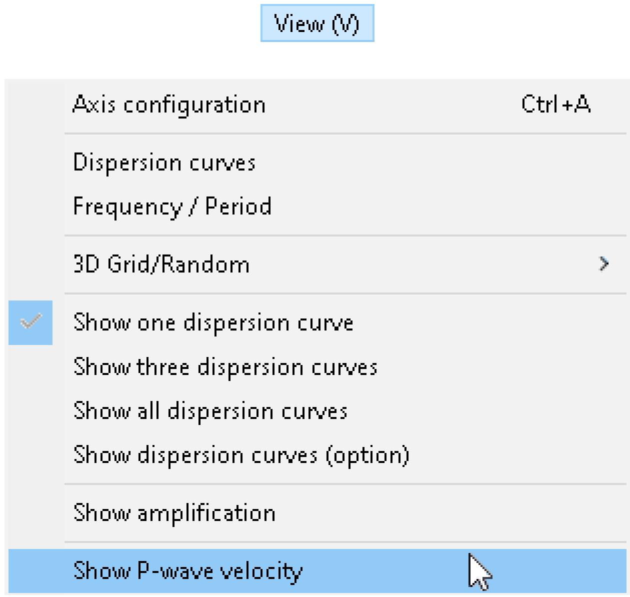


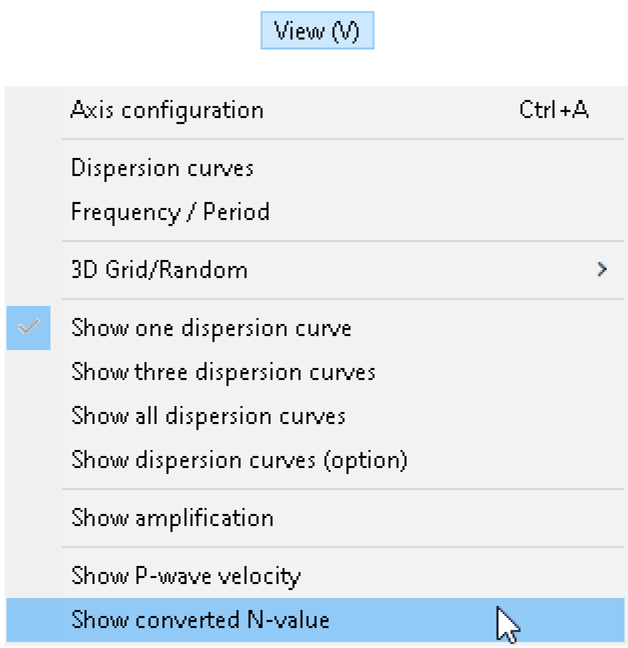
Figure 161: H/V curve (purple) with ground amplification plot (dark green).

7.3.8 Show p-wave Velocity



This toggle switch enables the display of the p-wave velocity profile. A green curve is displayed for V_p and the horizontal axis will include a second scale corresponding to the V_p values.

7.3.9 Show Converted N-Value



To display the converted N-value, click on *Show converted N-value*. A red curve is displayed for the N-values and the horizontal axis will include a third scale corresponding to the N-values.

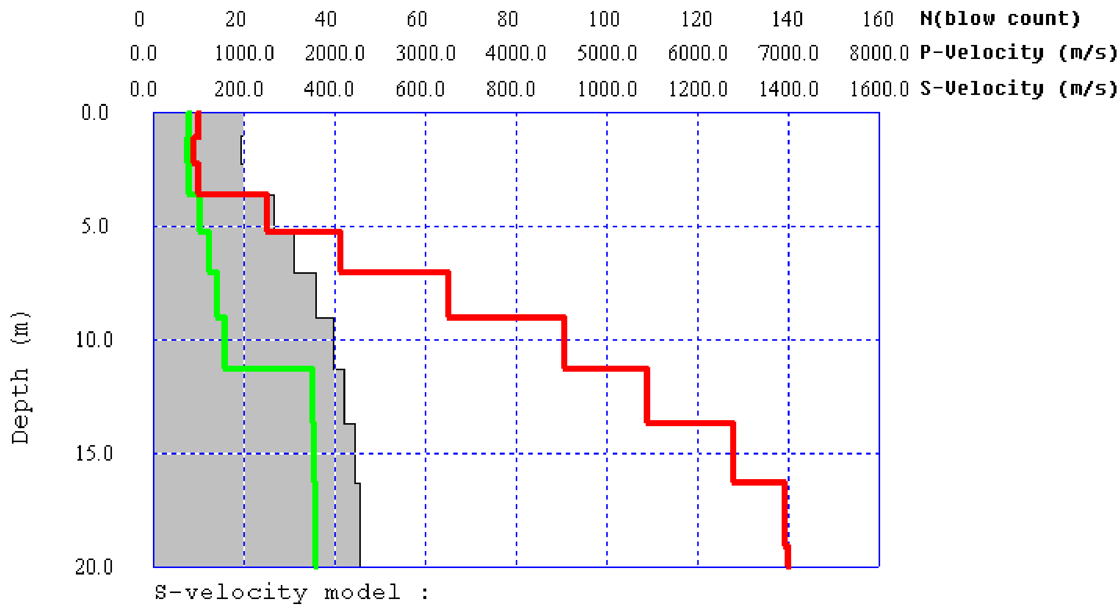
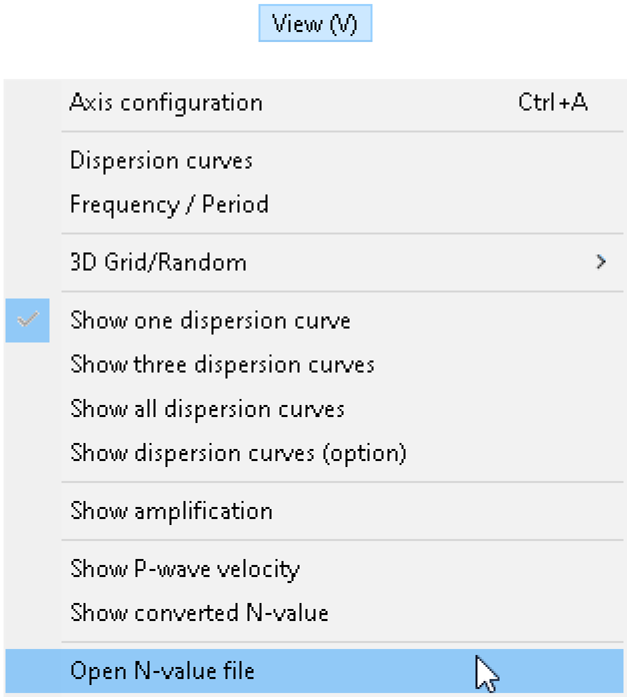


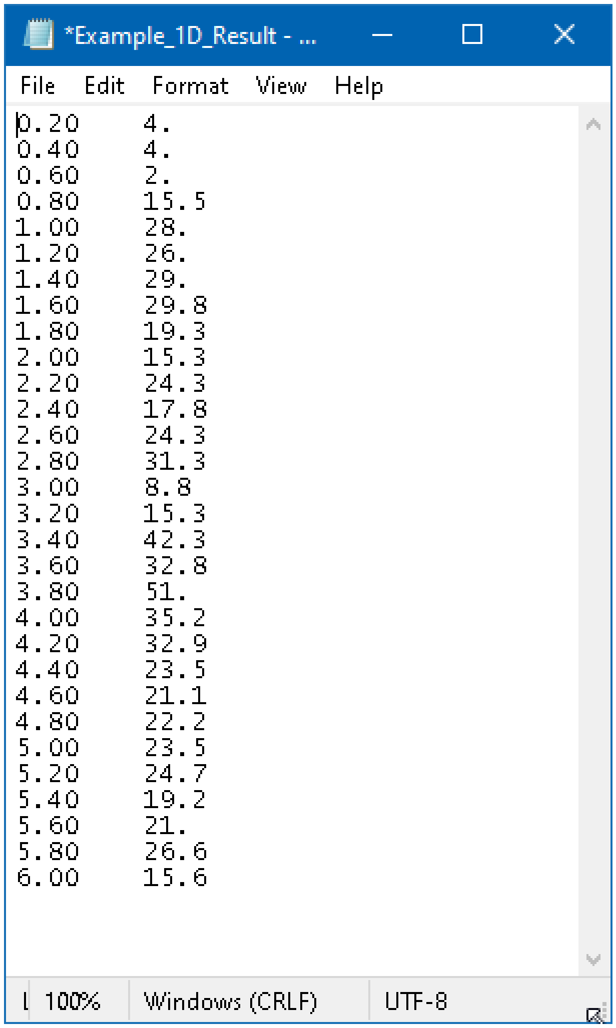
Figure 162: Vs curve with p-wave velocity (green) and blow count overlain.

The V_p values and N-values are calculated using the equations defined in the **Velocity model** menu, under *Advanced options* | *V_p and V_S relationship* and *Advanced options* | *N and V_S relationship*. Refer to Section 7.6.13.2 on Page 465 for more information.

7.3.10 OPEN N-VALUE FILE



Measured N-values can be used to define the initial V_S model used for inversion. The values are formatted in a space- or tab-delimited text file with a depth and corresponding N-value in each row. The file can have the extension *.n* or *.txt*.

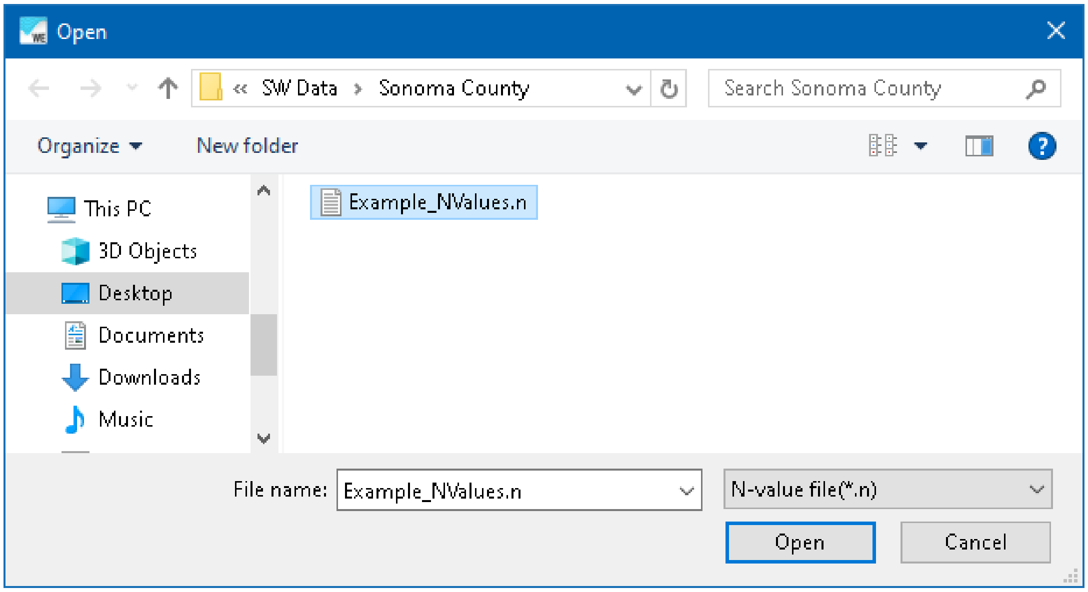

*Example_1D_Result - ...

File Edit Format View Help

0.20	4.
0.40	4.
0.60	2.
0.80	15.5
1.00	28.
1.20	26.
1.40	29.
1.60	29.8
1.80	19.3
2.00	15.3
2.20	24.3
2.40	17.8
2.60	24.3
2.80	31.3
3.00	8.8
3.20	15.3
3.40	42.3
3.60	32.8
3.80	51.
4.00	35.2
4.20	32.9
4.40	23.5
4.60	21.1
4.80	22.2
5.00	23.5
5.20	24.7
5.40	19.2
5.60	21.
5.80	26.6
6.00	15.6

100% Windows (CRLF) UTF-8

Once the file is prepared, select *Open N-value file*, highlight the file, and press *Open*. If it has the extension *.txt*, you will need to choose *All files* under *Files of type*, so it is shown in the list.



The N-values are stored in memory until the initial V_S model is created, at which time the initial model will be displayed with the N-values. When an N-value file has been opened, by default the initial model will be based on the N-values. Refer to Section 7.7.1, Page 479, for more information.

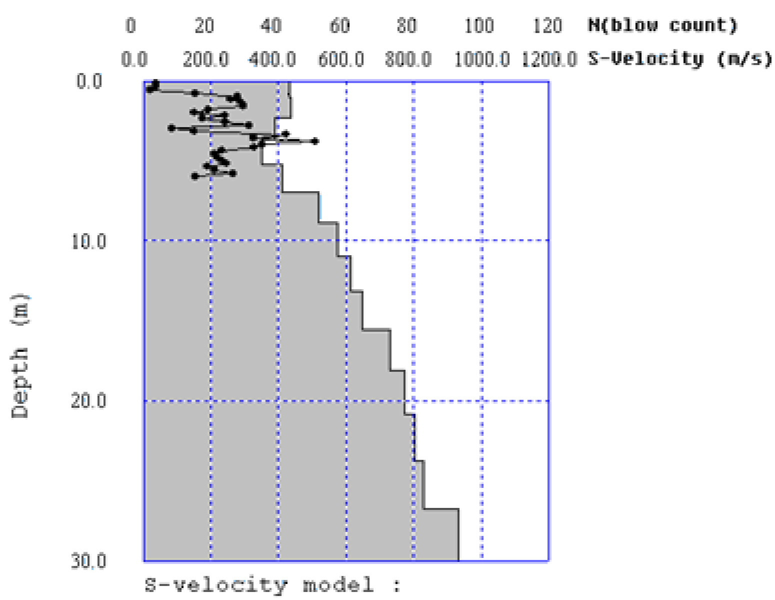
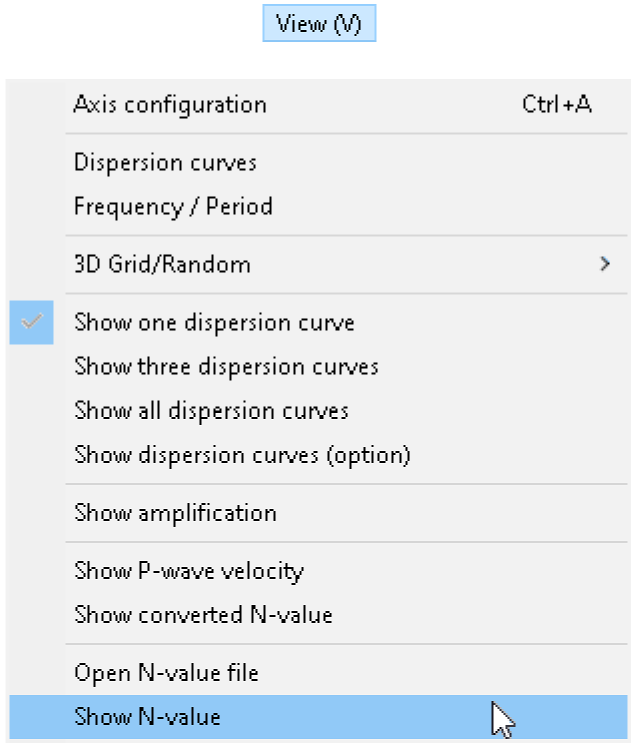


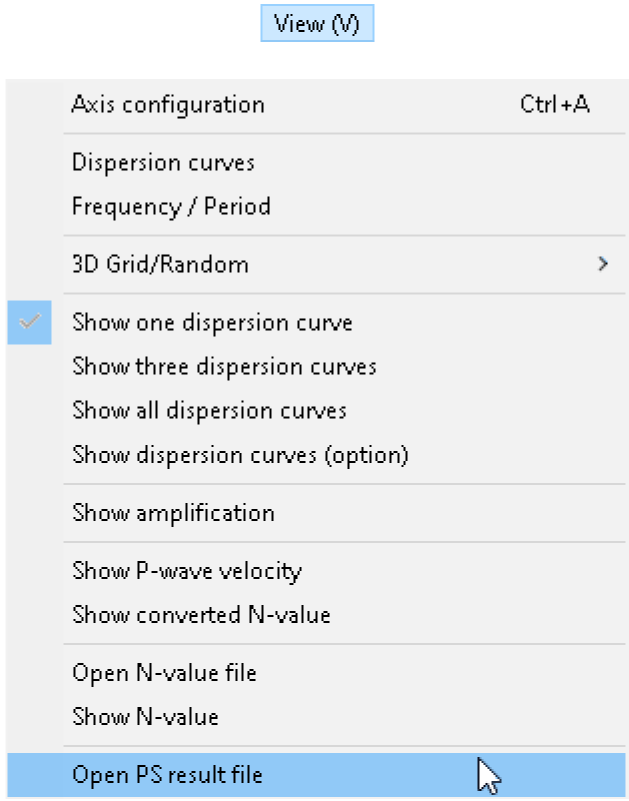
Figure 163: Initial V_S model with N-values.

7.3.11 Show N-Value



To toggle between viewing the V_S curve with and without N-values, select *Show N-value*.

7.3.12 OPEN PS RESULT FILE



Once a velocity model exists, measured V_p and V_S values can be input for comparison or to refine the model. The values need to be formatted in a space- or tab-delimited text file with a depth and corresponding V_p and V_S values in each row. The file can have any extension.

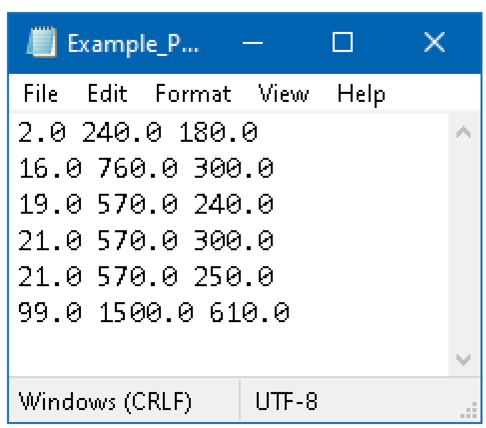
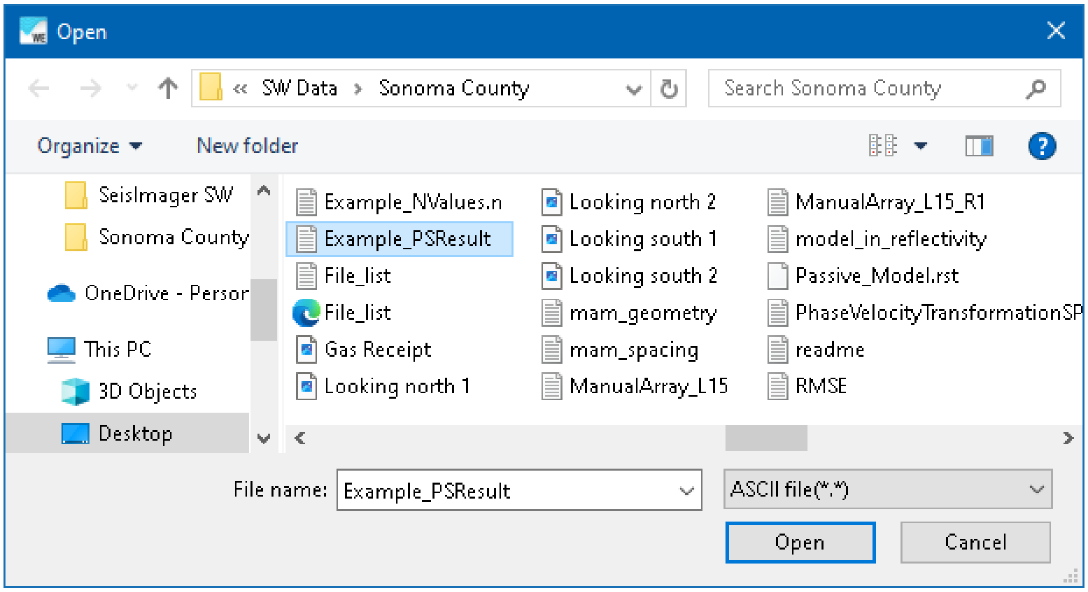
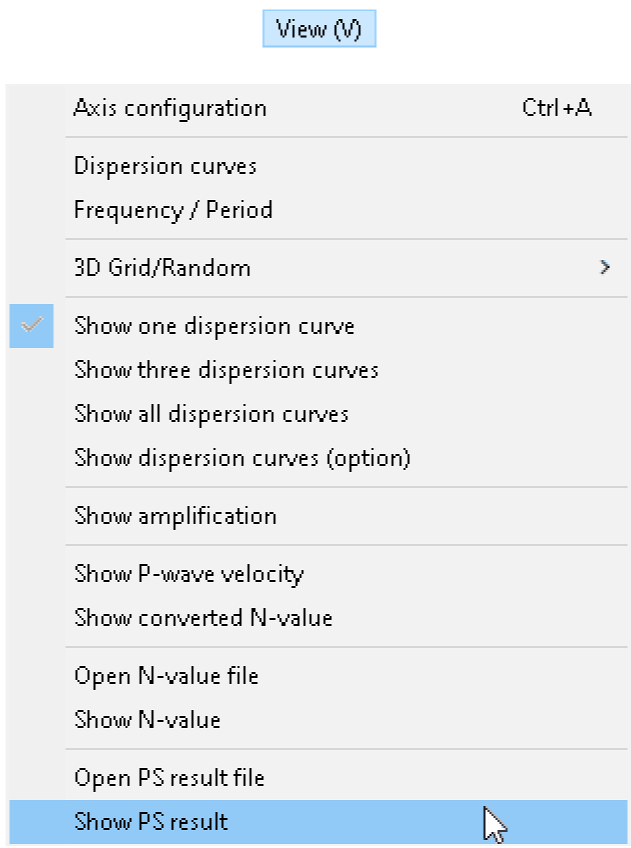


Table 13: PS result file.

Once the file is prepared, select *Open PS result file*, highlight the file, and press *Open*.

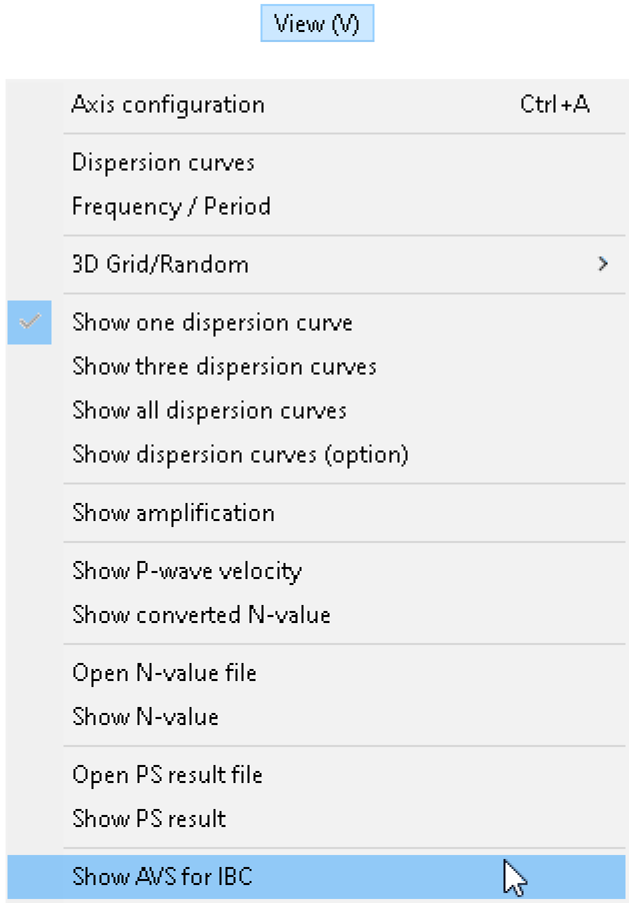


7.3.13 SHOW PS RESULT



To toggle between viewing the model with and without the measured V_P and V_S data, select *Show PS result*.

7.3.14 Show AVS for IBC



To calculate the average V_S as defined by the 2000 and 2003 International Building Code (IBC) in Section 1615.1.5, Equations 16-22 and 16-44, respectively, select *Show AVS for IBC*. The calculated average V_S is shown at the bottom of the velocity model in the applicable units.

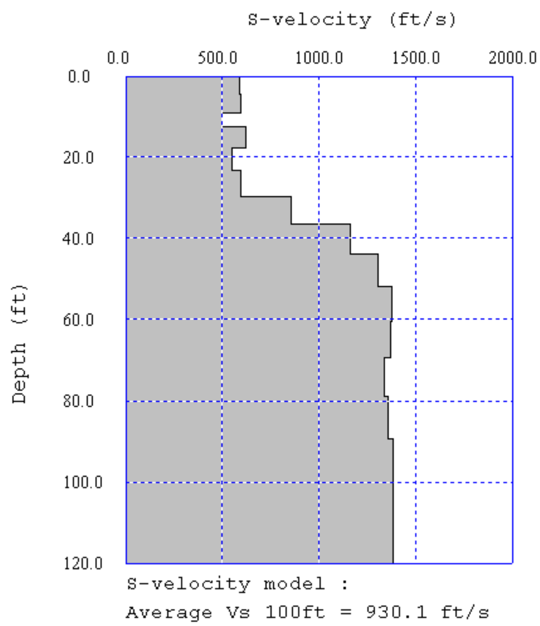


Figure 164: V_S model with AVS shown at bottom.

The result is saved to a text file with the name AVS.txt in the dataset directory. The first row reports the applicable units and maximum depth used for the calculation. Following are six columns of data, one row for each layer. The columns from left to right are: layer number (No.), shear-wave velocity (V_S), slowness (sl) (the inverse of velocity), layer thickness (d), layer thickness divided by V_S (Tot. V_S), and total thickness (Tot. d). The last row reports the IBC V_S100/UBC V_S30 value. In this example, the second layer (No. 1) is 3.132-feet thick (d) with a layer thickness-to-V_S ratio of 13.024 seconds (Tot. V_S), and the total depth at the base of this layer is 7.692 feet (Tot. d).

```
AVS.txt - Notepad
File Edit Format View Help
0/15 0.673011 1.485859 0.003571
1/15 0.665467 1.502703 0.007692
2/15 0.665672 1.502241 0.012363
3/15 0.687886 1.453729 0.017582
4/15 0.800911 1.248578 0.023352
5/15 1.037152 0.964179 0.029670
6/15 1.109185 0.901563 0.036538
7/15 1.466292 0.681992 0.043956
8/15 1.527905 0.654491 0.051923
9/15 1.568261 0.637649 0.060440
10/15 1.588407 0.629562 0.069505
11/15 1.594092 0.627316 0.079121
12/15 1.592697 0.627866 0.089286
13/15 1.588899 0.629367 0.121429
14/15 1.594092 0.627316 99.121429
Unit=f Depth=100.000001 # of layers=14
No.     Vs      Sl      d       Tot. Vs Tot. d
0       0.673   1.486   3.571   5.307   3.571
h=3.571429 v=673.011475
1       0.665   1.503   4.121   11.499  7.692
h=4.120879 v=665.467346
2       0.666   1.502   4.670   18.515  12.363
h=4.670331 v=665.671997
3       0.688   1.454   5.220   26.103  17.582
h=5.219782 v=687.886169
4       0.801   1.249   5.769   33.307  23.352
h=5.769230 v=800.911438
5       1.037   0.964   6.319   39.399  29.670
h=6.318681 v=1037.152100
6       1.109   0.902   6.868   45.591  36.538
h=6.868132 v=1109.184937
7       1.466   0.682   7.418   50.650  43.956
h=7.417582 v=1466.291992
8       1.528   0.654   7.967   55.864  51.923
h=7.967032 v=1527.905029
9       1.568   0.638   8.516   61.295  60.440
h=8.516483 v=1568.260986
10      1.588   0.630   9.066   67.002  69.505
h=9.065937 v=1588.406982
11      1.594   0.627   9.615   73.034  79.121
h=9.615384 v=1594.092041
12      1.593   0.628   10.165  79.416  89.286
h=10.164827 v=1592.697021
13      1.589   0.629   10.714  86.159  100.000
AVS100 = 1160.6 f/s
Ln 1, Col 1   100%   Windows (CRLF)   UTF-8
```

Table 14: AVS.txt.

The average N as defined by the 2000 and 2003 International Building Code (IBC) in Section 1615.1.5, Equations 16-23 and 16-45, respectively, will also be calculated if you have opened an N-value file.

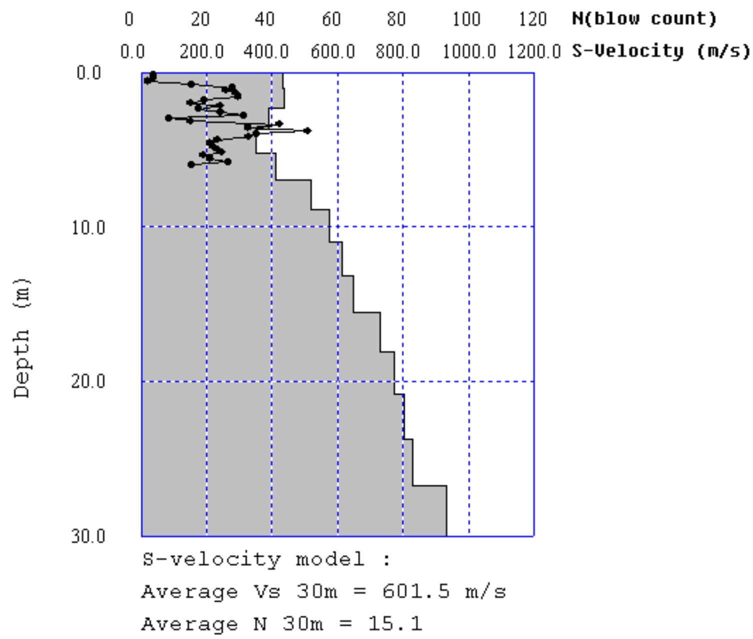


Figure 165: V_S model with N-values.

The result is saved to a text file with the name AN.txt in the dataset directory. There are five columns of data, one row for each layer. The columns from left to right are: layer number (No.), the N-value (N), layer thickness (d), total thickness (Tot. d), and layer thickness divided by the N-value (Tot. d/n). The last row reports the IBC N100/UBC N30 value. In this example, the second layer (No. 1) is 0.2 meters thick (d) with a layer thickness-to-N ratio of 0.1 (Tot. d/n), and the total depth at the base of this layer is 0.4 meters (Tot. d).

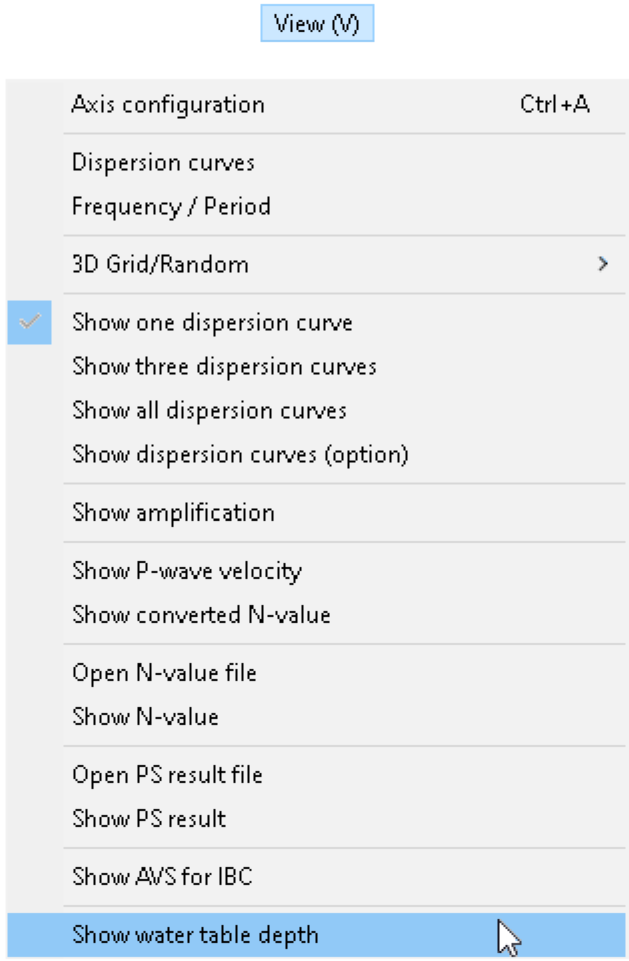
No.	N	d	Tot. d	Tot. d/n
0	4.000	0.200	0.200	0.050
1	4.000	0.200	0.400	0.100
2	2.000	0.200	0.600	0.200
3	15.500	0.200	0.800	0.213
4	28.000	0.200	1.000	0.220
5	26.000	0.200	1.200	0.228
6	29.000	0.200	1.400	0.235
7	29.800	0.200	1.600	0.241
8	19.300	0.200	1.800	0.252
9	15.300	0.200	2.000	0.265
10	24.300	0.200	2.200	0.273
11	17.800	0.200	2.400	0.284
12	24.300	0.200	2.600	0.292
13	31.300	0.200	2.800	0.299
14	8.800	0.200	3.000	0.322
15	15.300	0.200	3.200	0.335
16	42.300	0.200	3.400	0.339
17	32.800	0.200	3.600	0.345
18	51.000	0.200	3.800	0.349
19	35.200	0.200	4.000	0.355
20	32.900	0.200	4.200	0.361
21	23.500	0.200	4.400	0.370
22	21.100	0.200	4.600	0.379
23	22.200	0.200	4.800	0.388
24	23.500	0.200	5.000	0.397
25	24.700	0.200	5.200	0.405
26	19.200	0.200	5.400	0.415
27	21.000	0.200	5.600	0.425
28	26.600	0.200	5.800	0.432
29	15.600	24.200	30.000	1.984

AN30 = 15.1

Table 15: AN.txt.

If the average V_S and N are to be calculated, it is recommended that there be reliable information to 30 m or 100 ft. Although the V_S model may extend to 30 m or 100 ft depth, the recorded surface waves may not have actually sampled to that depth. Refer to Section 7.3.15 on how to estimate the depth of penetration.

7.3.15 Show Water Table Depth



To show the depth of the water table on a velocity model, select *Show water table depth.* A blue line with the standard water table symbol will appear as shown below. If there is no water table depth established, the line will plot at a depth of zero. The depth of the water table is set in a separate menu explained in Section 7.6.8, Page 454.

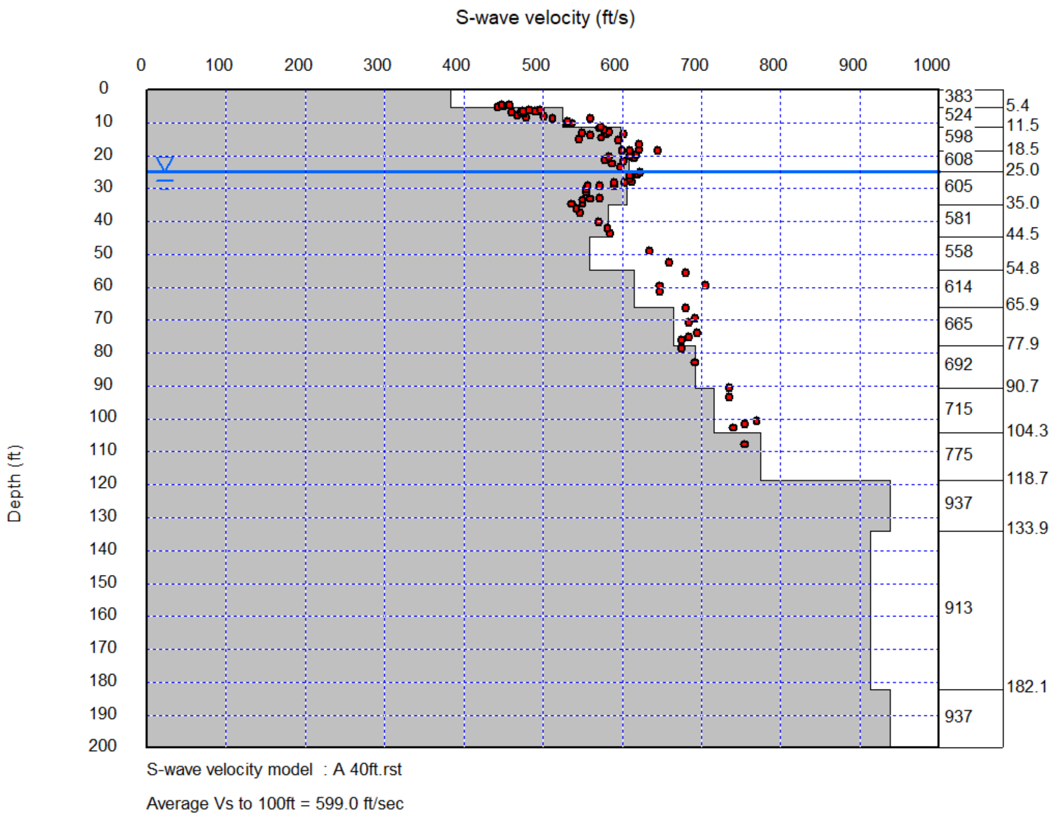
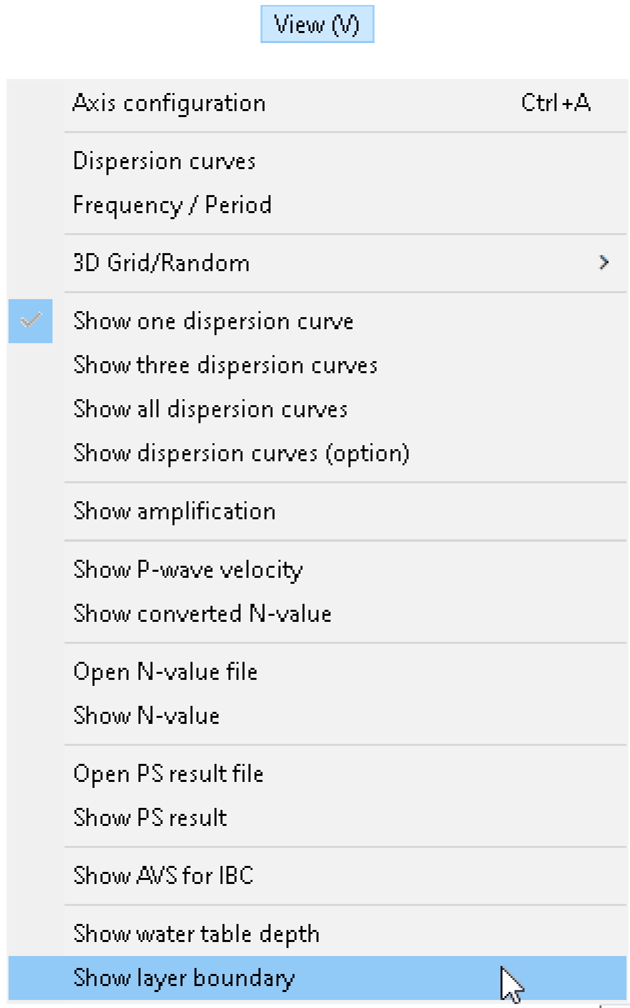


Figure 166: Velocity model showing water table.

7.3.16 Show Layer Boundary



Selecting *Show layer boundary* or pressing the *Correct velocity model* button will outline the layers in the profile with horizontal black lines. Using the mouse, the vertical edge of any of the layers can be dragged to a new position to modify the V_S curve. In the dispersion curve view, the dispersion curve calculated for the altered model can be viewed by pressing on the *Comparison* button. The V_S curve can be manually fitted to the observed data in this manner.

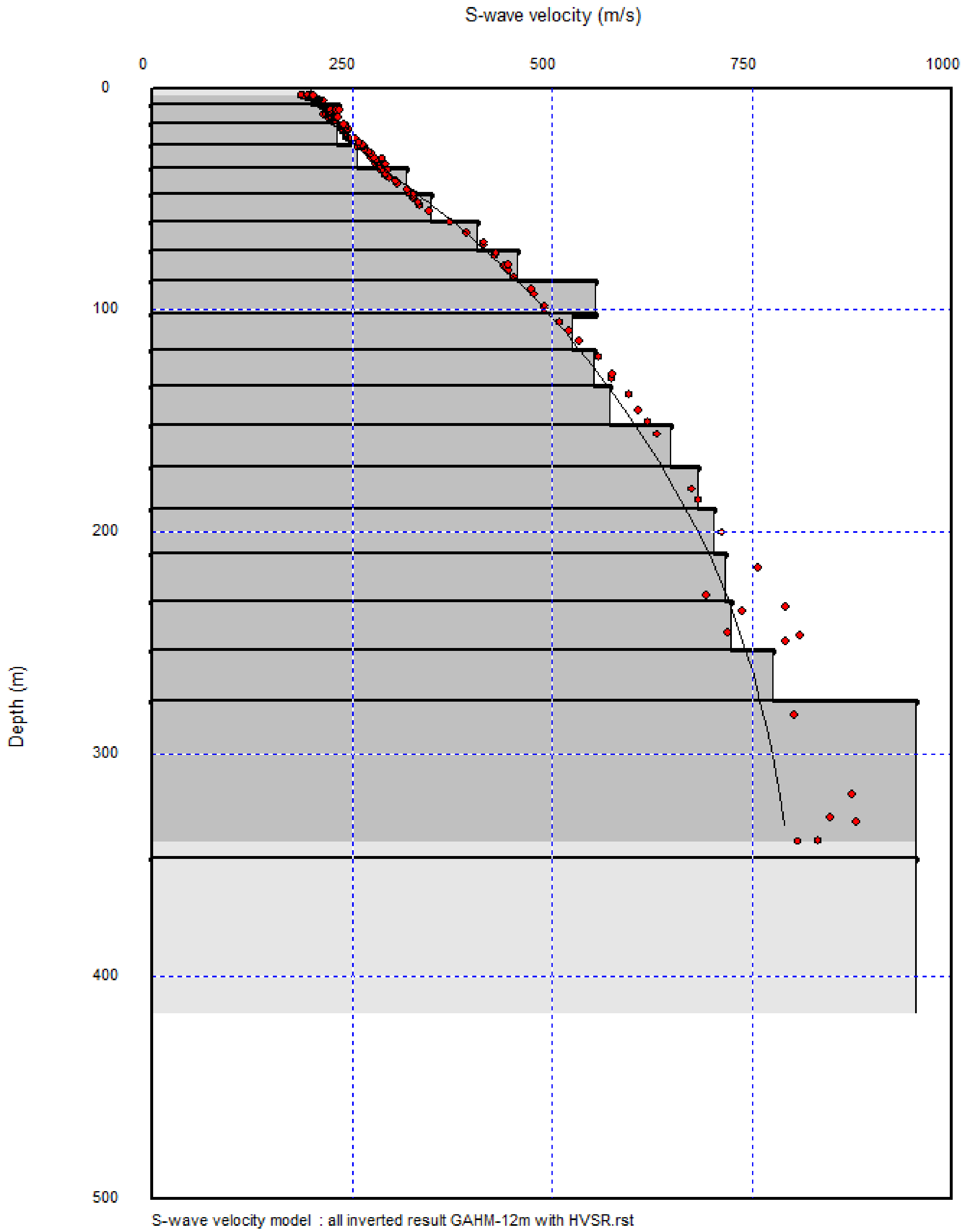
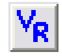
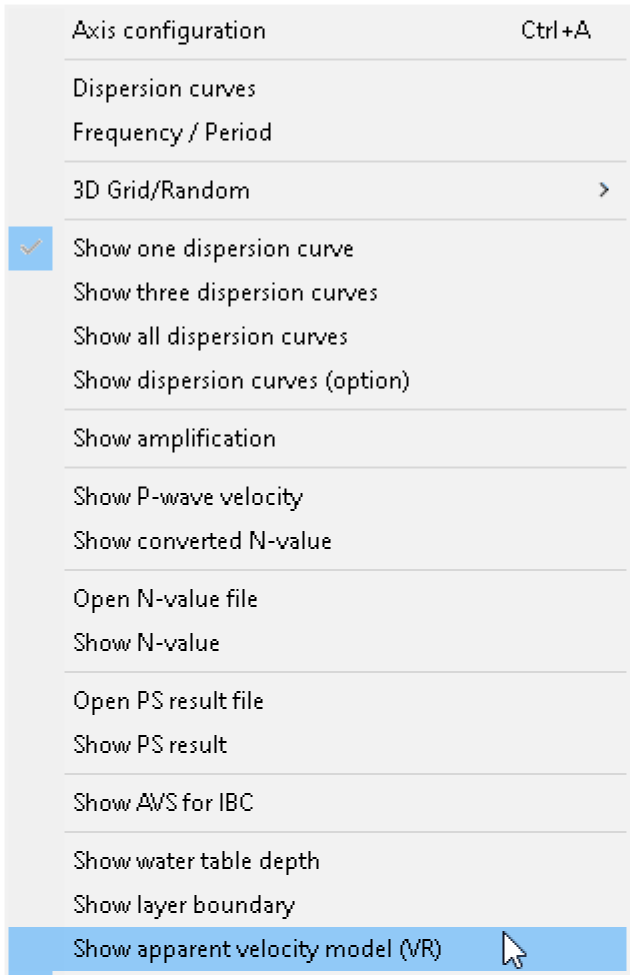
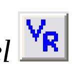


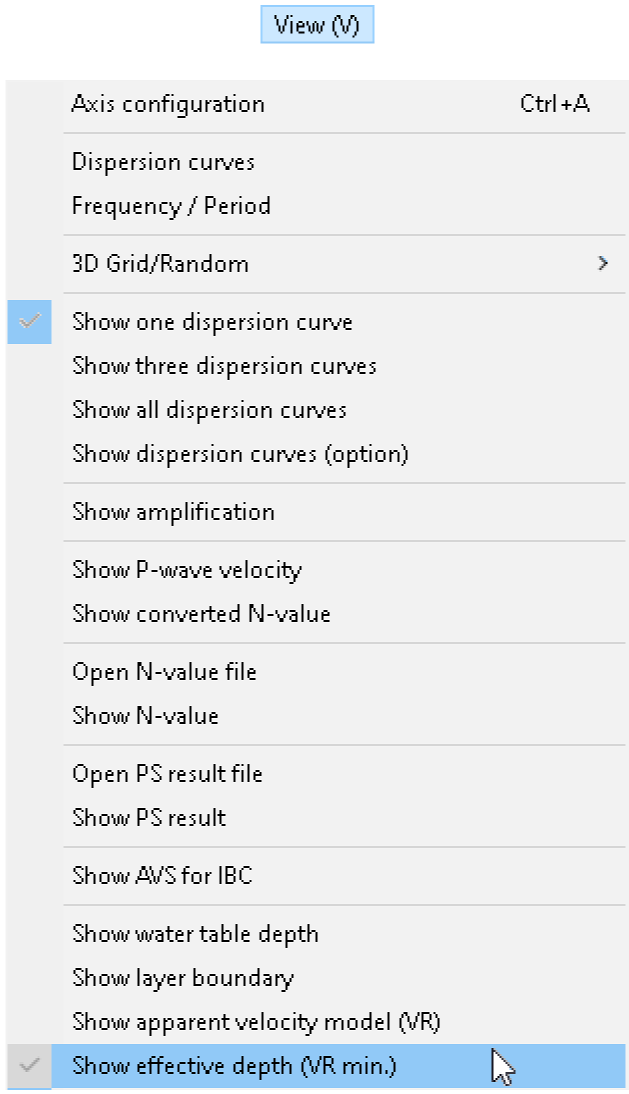
Figure 167: Vs model with layer boundaries highlighted for editing.

7.3.17 Show Apparent Velocity Model (V_R) 



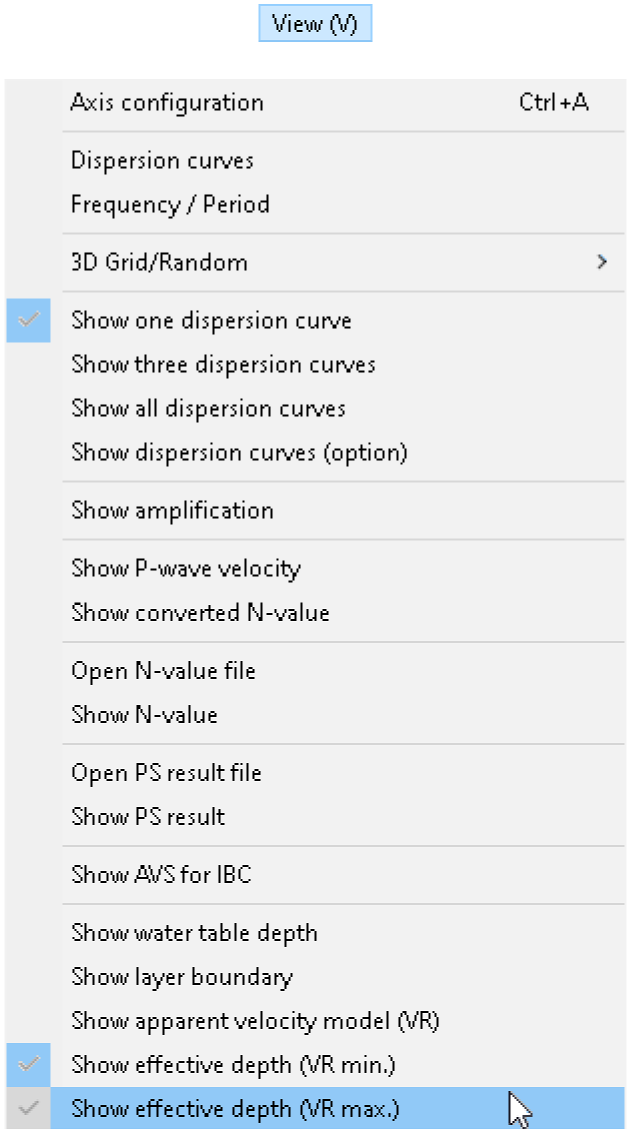
Selecting *Show apparent velocity model (V_R)* or pressing the *Apparent velocity model*  button will plot in red points the one-third-wavelength approximation. Using each set of dispersion curve points (phase velocity, frequency), the wavelength is calculated (phase velocity divided by frequency), and then multiplied by one-third from the empirically determined estimate of depth of penetration. At that calculated depth, the associated phase velocity is plotted. This approximation is the best indicator of actual depth range of penetration.

7.3.18 SHOW EFFECTIVE DEPTH (V_R MIN.)



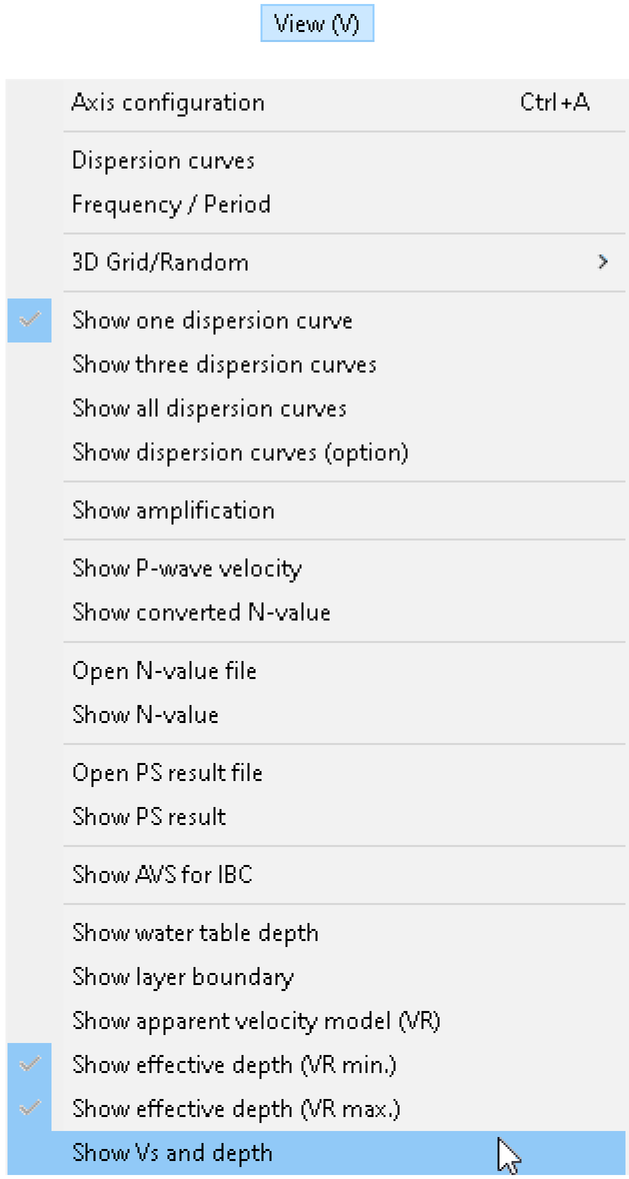
Show effective depth (V_R min) shades the profile light grey from the surface down to the shallowest red point. This setting is on by default to call attention to the limits of the data.

7.3.19 SHOW EFFECTIVE DEPTH (V_R MAX.)



Show effective depth (V_R max) shades the profile light grey from the deepest red point downward.

7.3.20 SHOW V_S AND DEPTH



Show V_S and depth overlays the layer information used to calculate the IBC V_S100/UBC V_S30 value.

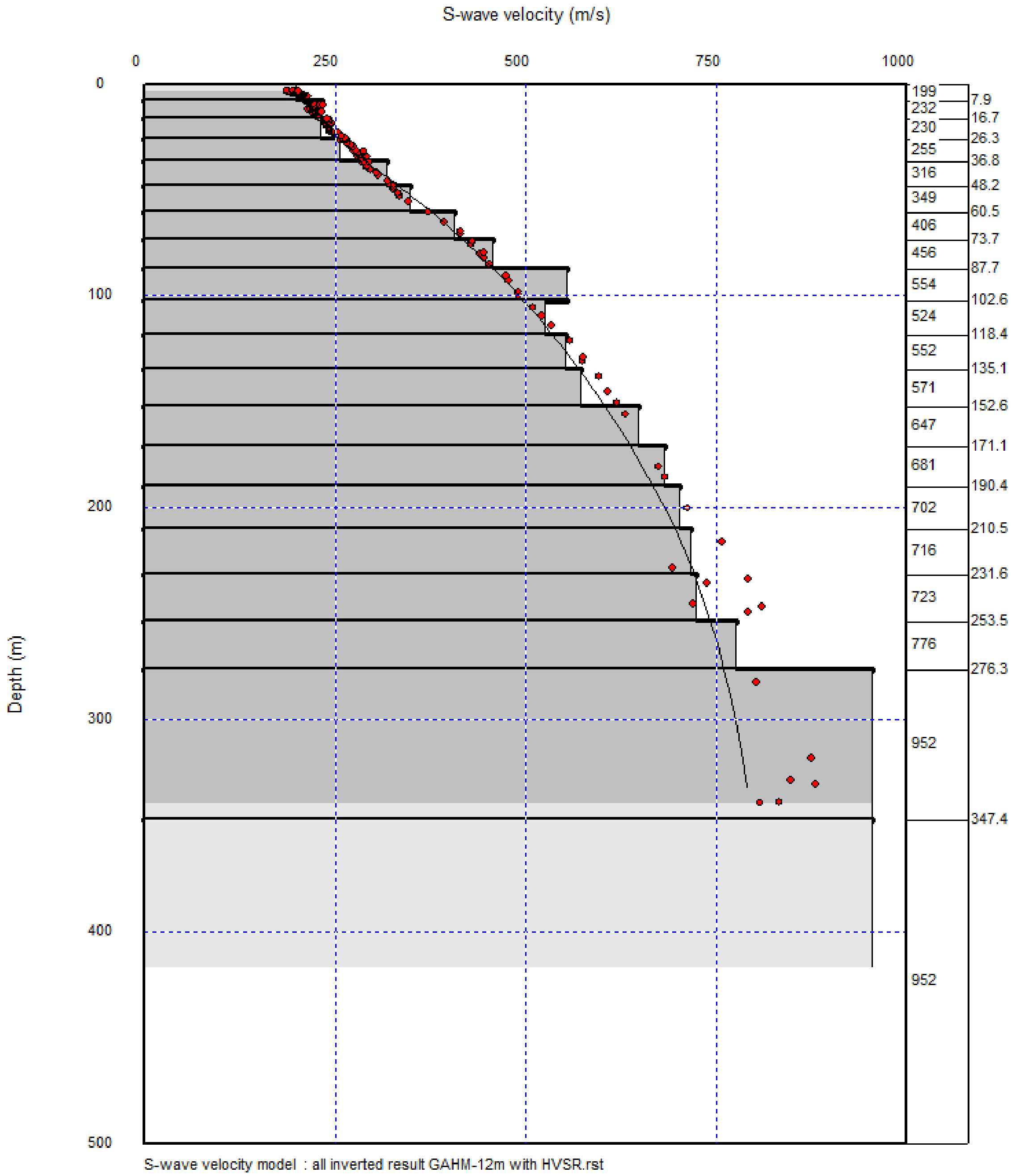
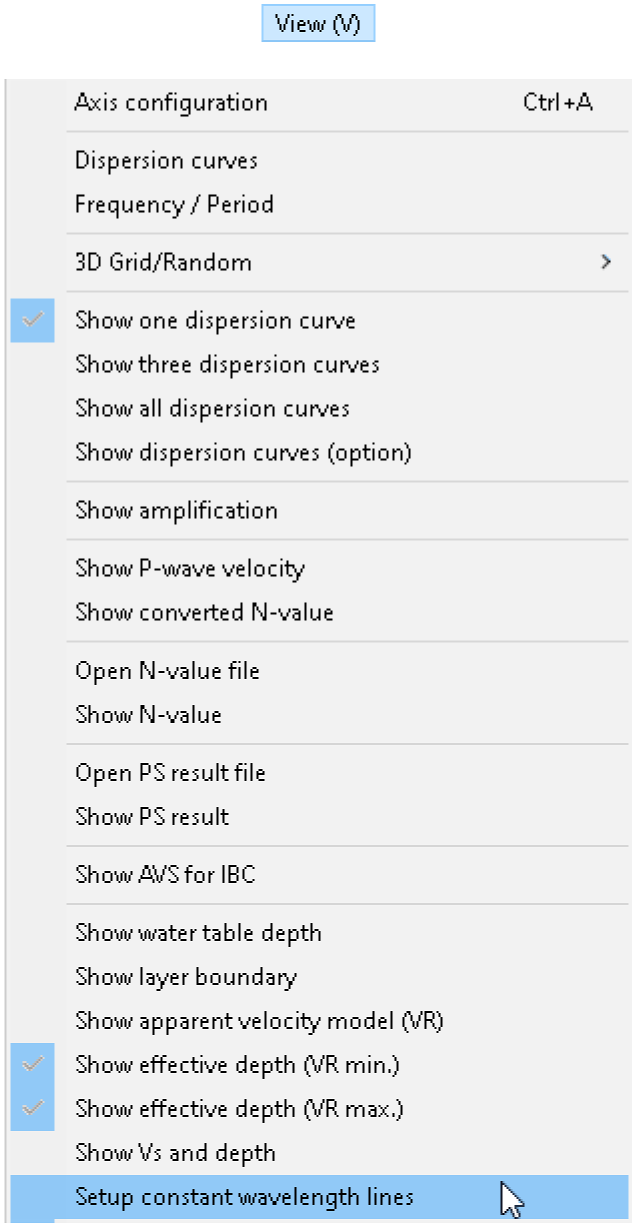
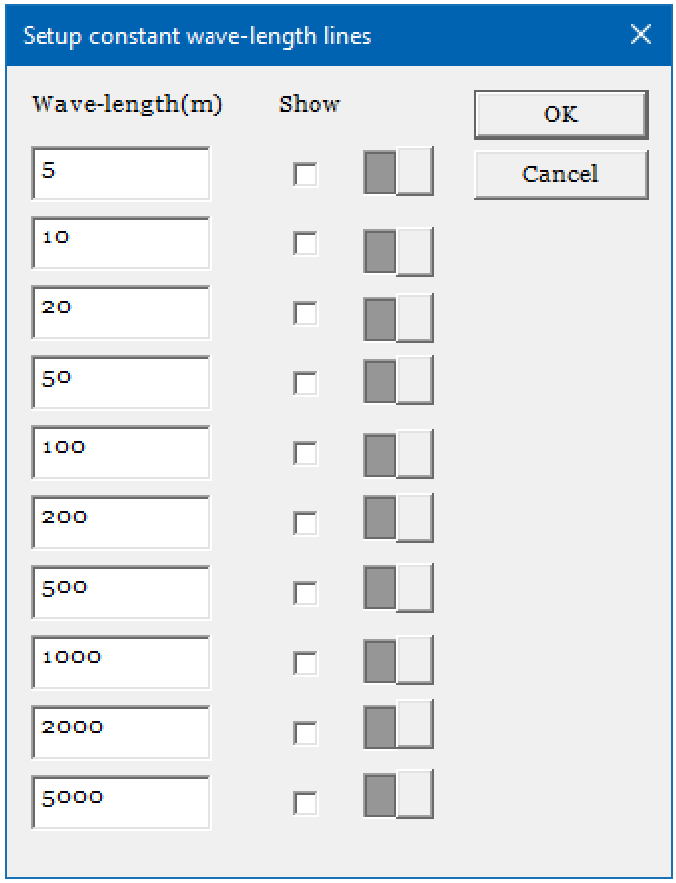


Figure 168: Vs model of Figure 167 with layer information shown along right axis.

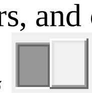
7.3.21 Set up Constant Wavelength Lines

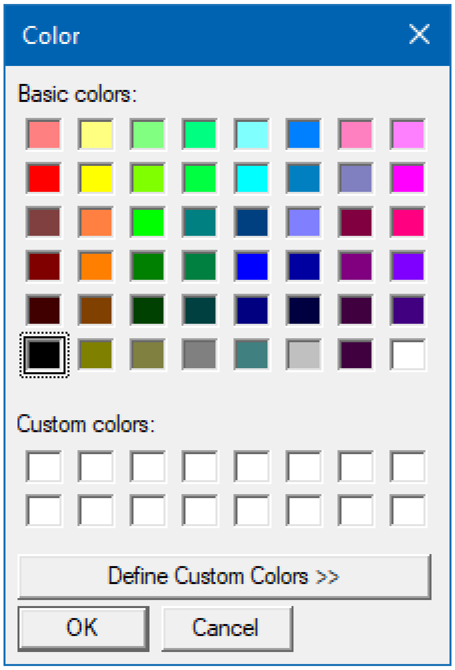


If you would like to show lines of constant wavelength on the dispersion curve plot, open the **View** menu and select *Setup constant wavelength lines*. You will be presented with the following dialog:



Use the defaults or type in the desired wavelengths in meters, and check the appropriate boxes.

To set the color of a particular line, press the corresponding  button to display the color pallette:



Once you are finished setting it up, the lines of constant wavelength will appear on the dispersion curve plot:

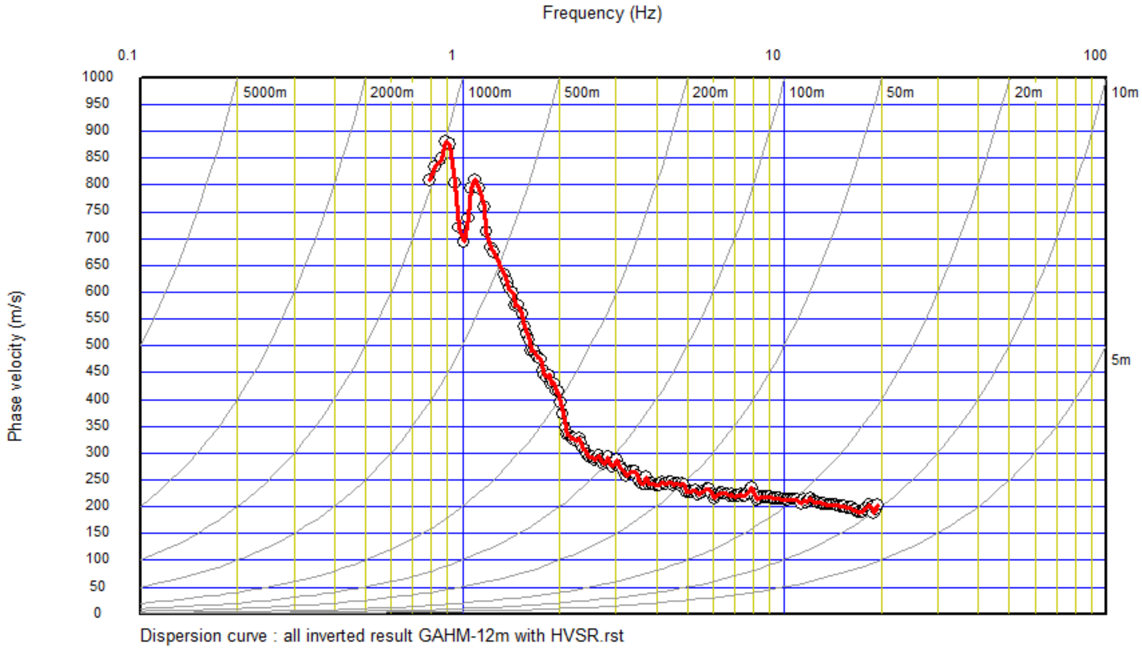
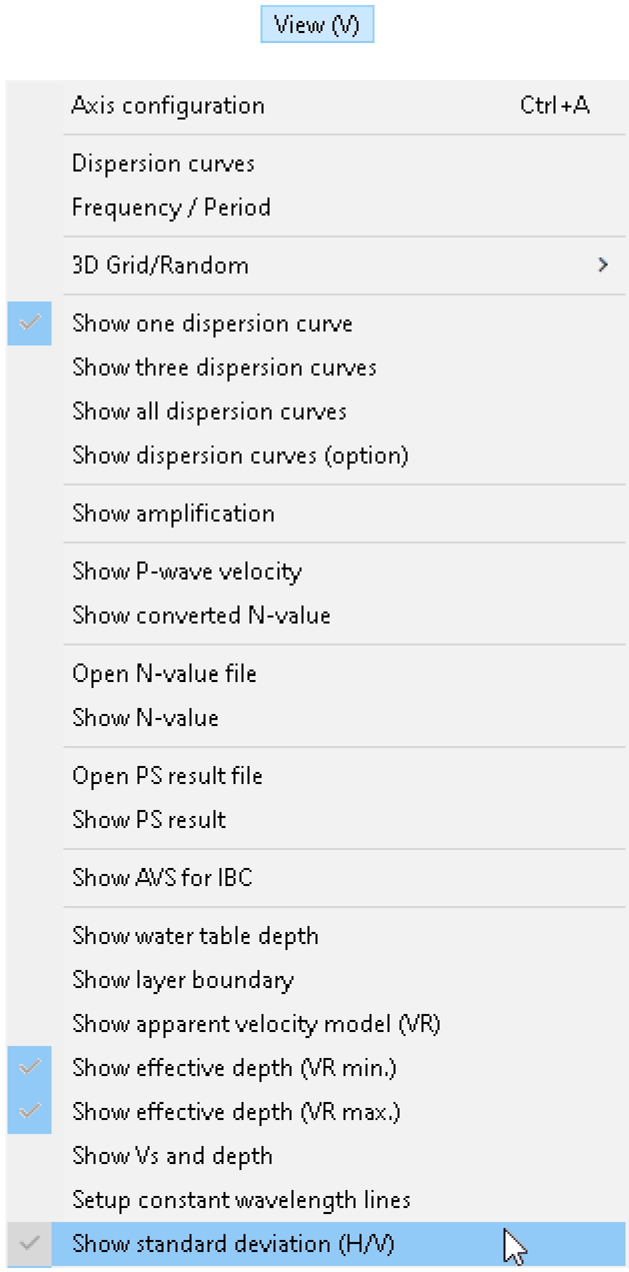


Figure 169: Dispersion curve showing lines of constant wavelength.

7.3.22 Show Standard Deviation (H/V)



To display the standard deviation of the H/V curve, select *View* | *Show Standard Deviation (H/V)*:

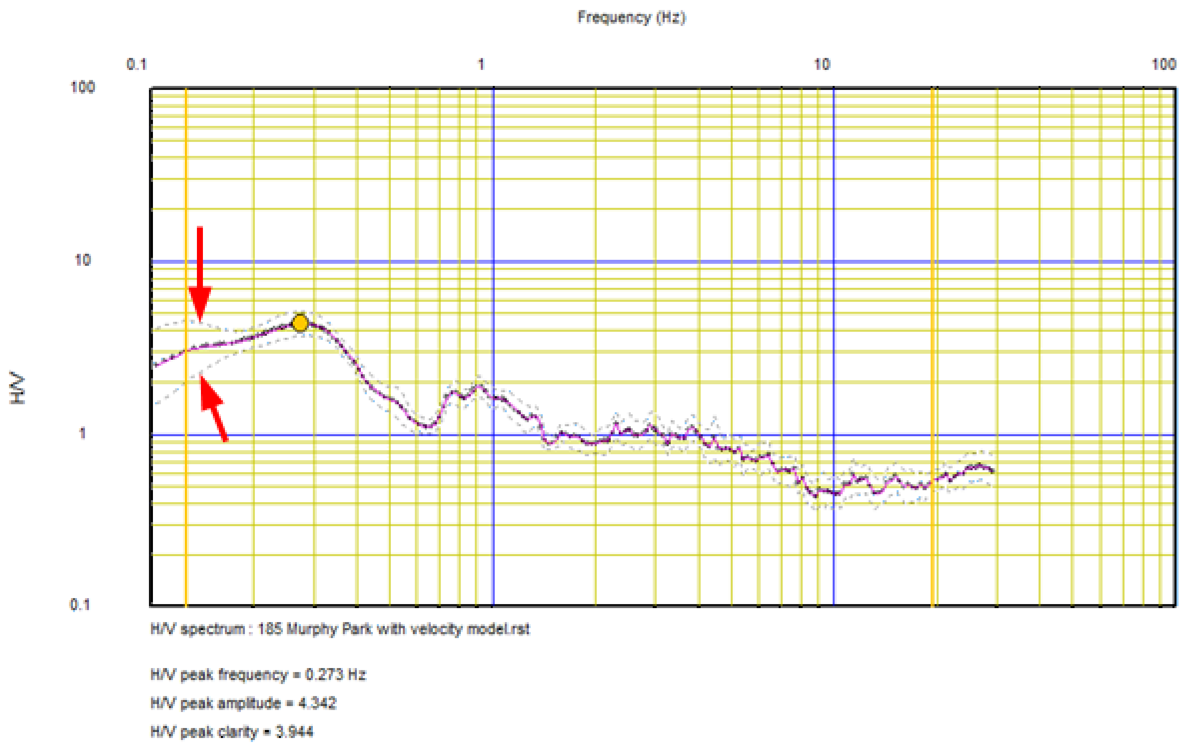
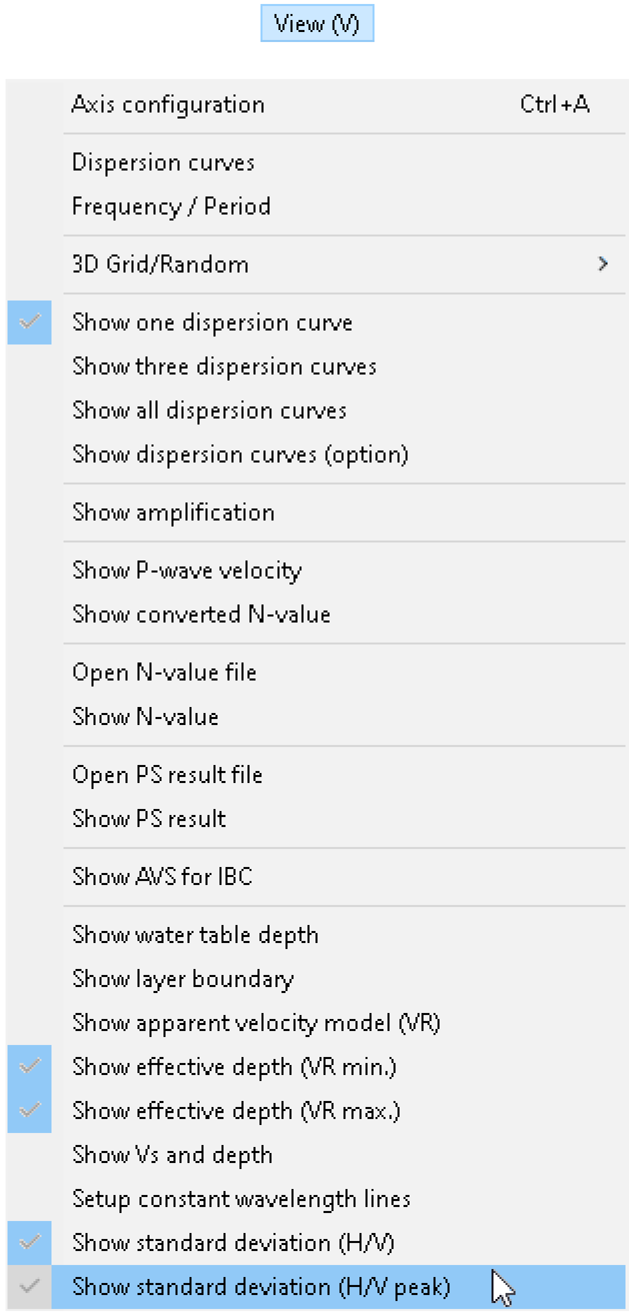


Figure 170: H/V plot with standard deviation lines included.

The standard deviation is represented by the grey dotted line above and below the H/V curve.

7.3.23 Show Standard Deviation (H/V Peak)



You may display the standard deviation of the H/V peak in a similar fashion:

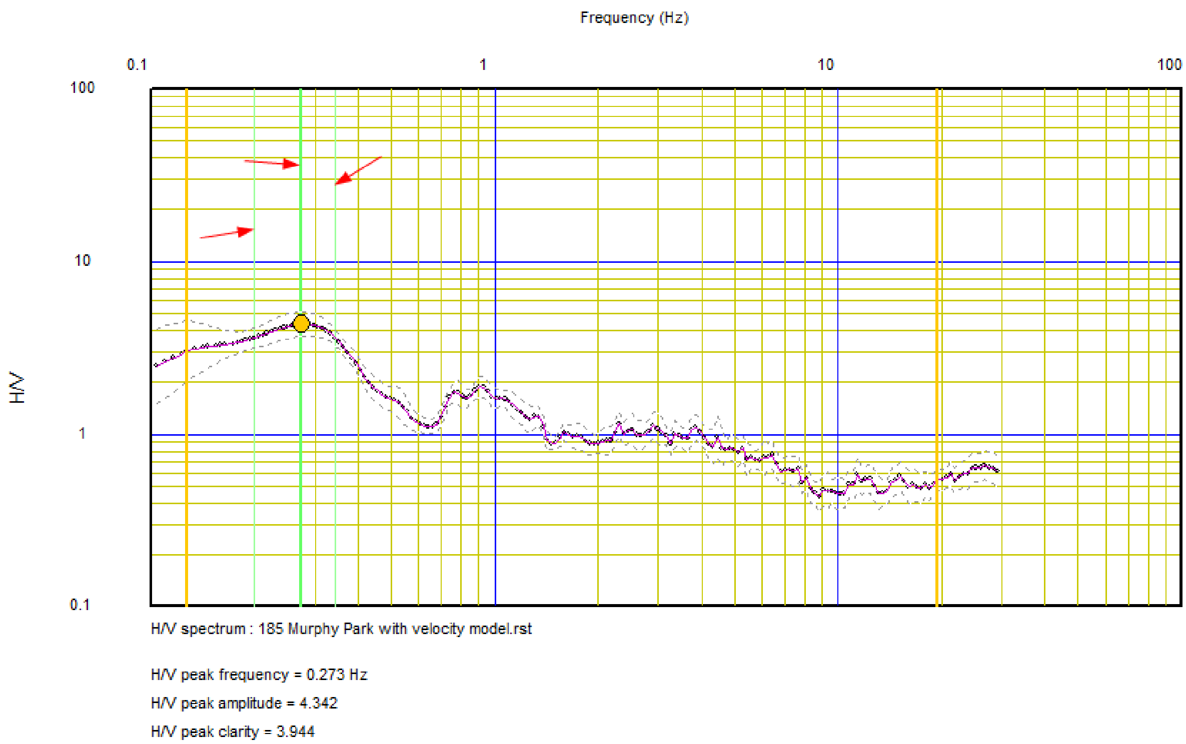
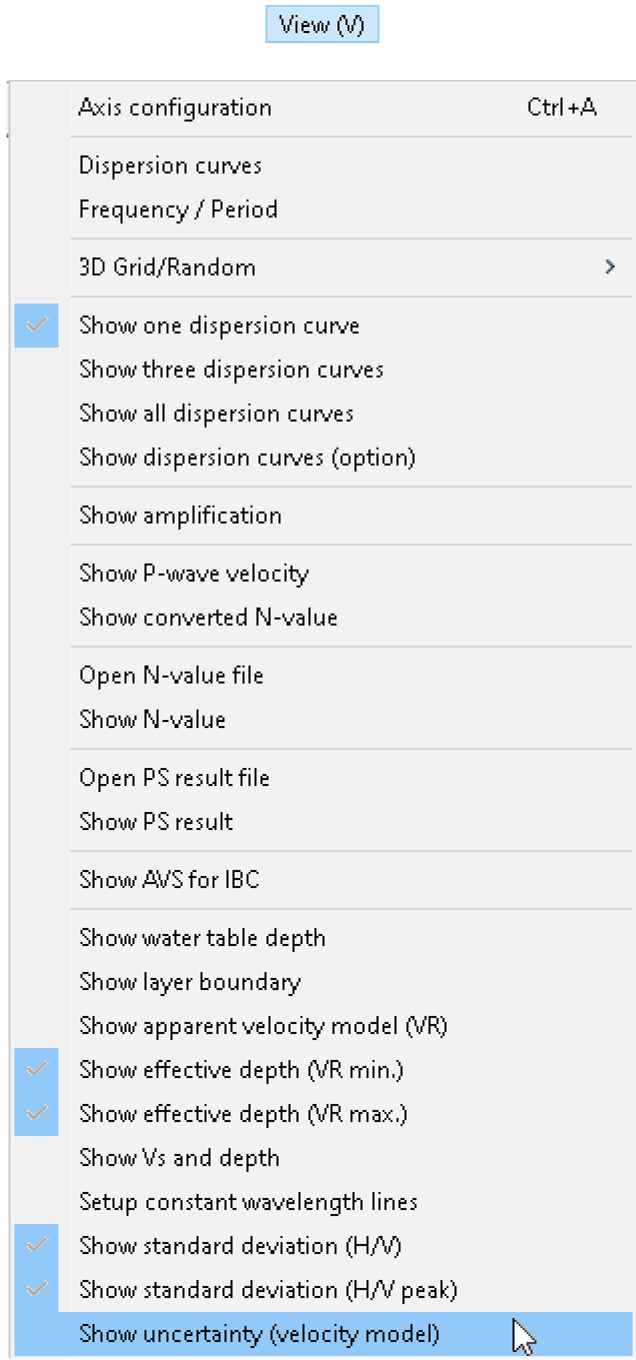


Figure 171: Standard deviation of H/V peak.

Refer to the red arrows in the above figure. The peak of the H/V curve is represented by the thick green line. The standard deviation is represented by the thin green lines on either side.

7.3.24 SHOW UNCERTAINTY (VELOCITY MODEL)



If you have used a Genetic Algorithm to create your model, you may show the uncertainty in the VS profile with this feature, as shown below.

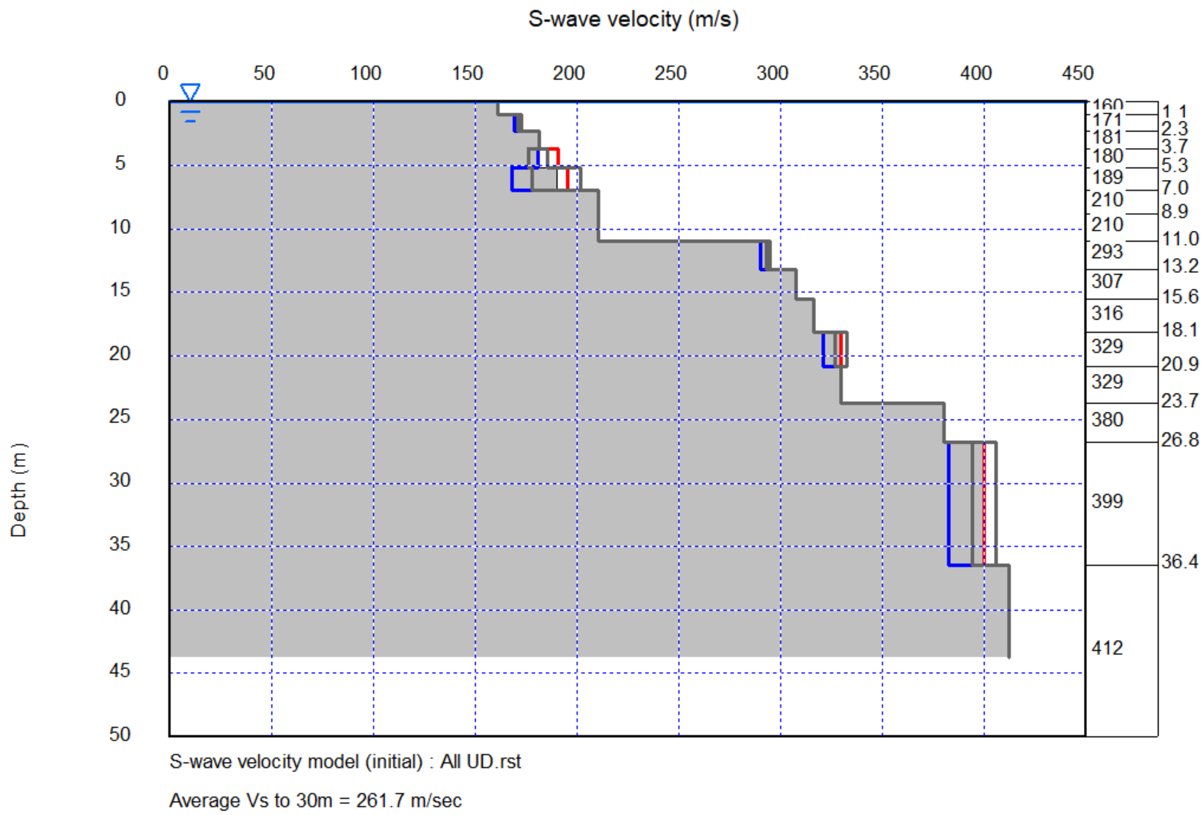
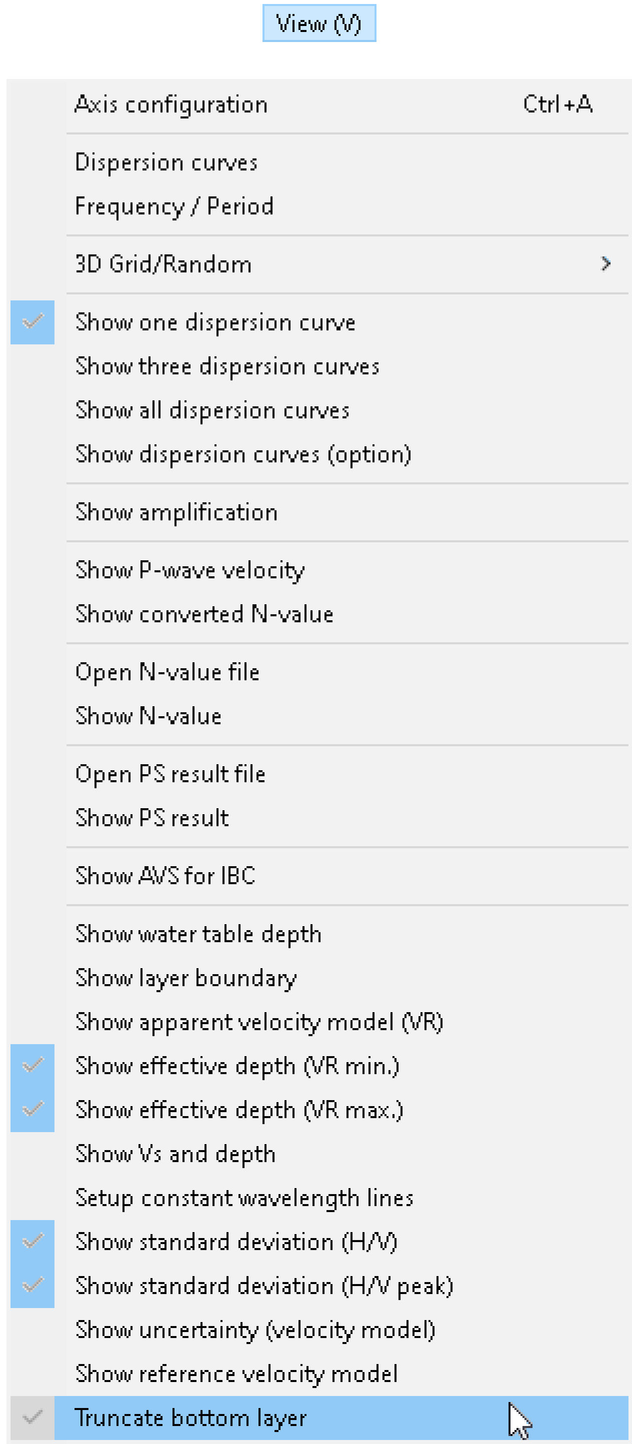


Figure 172: V_S model showing uncertainty in velocities.

7.3.25 SHOW REFERENCE VELOCITY MODEL

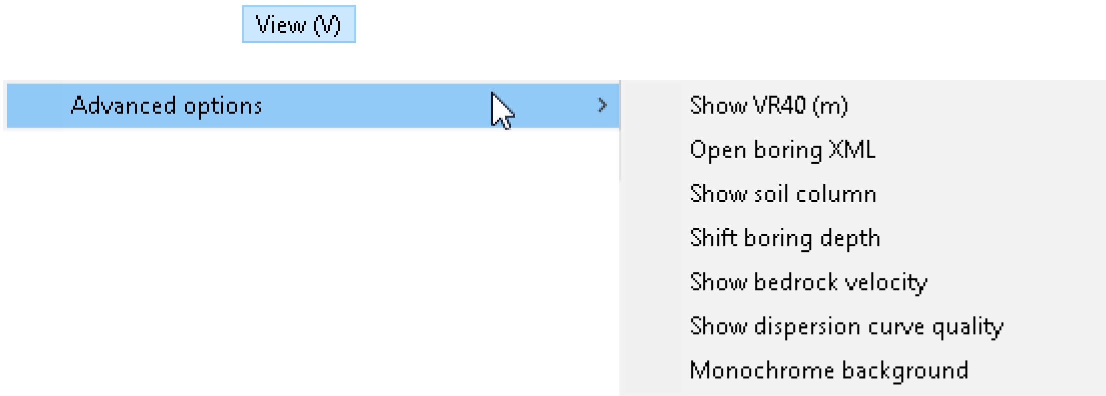
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.26 Truncate Bottom Layer



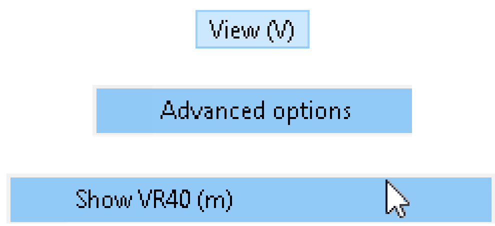
Oftentimes, the bottom layer of the velocity model is much thicker than necessary. Choosing the option will reduce the thickness to a more reasonable value.

7.3.27 Advanced Options



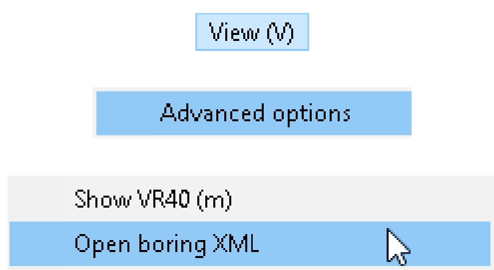
Many of the items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.3.27.1 Show VR40 (m)



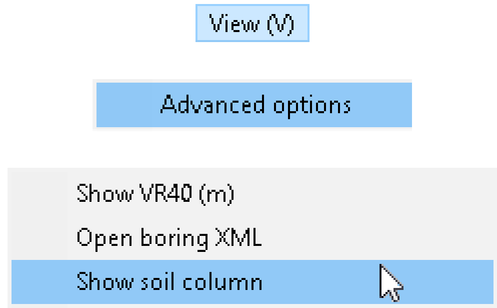
VR40 is an approximation of VS30 but is based on wavelength rather than depth in meters.

7.3.27.2 Open Boring XML



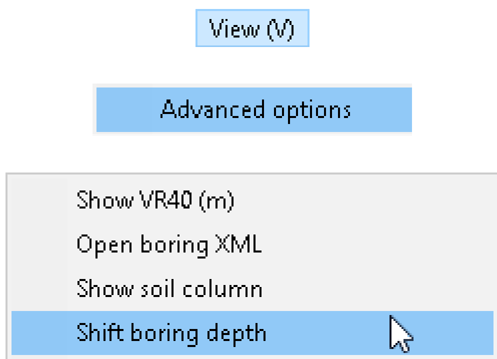
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.27.3 Show Soil Column



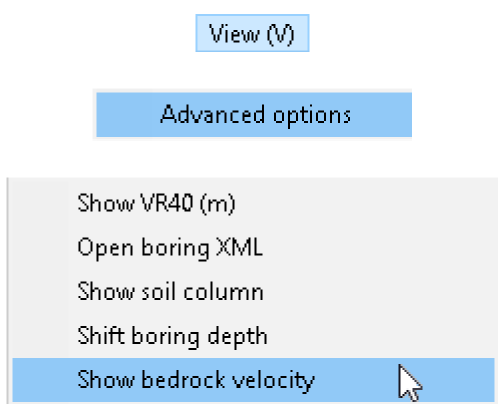
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.27.4 Shift Boring Depth



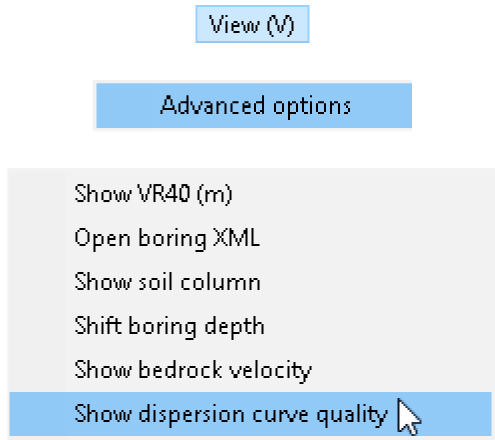
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.27.5 Show Bedrock Velocity



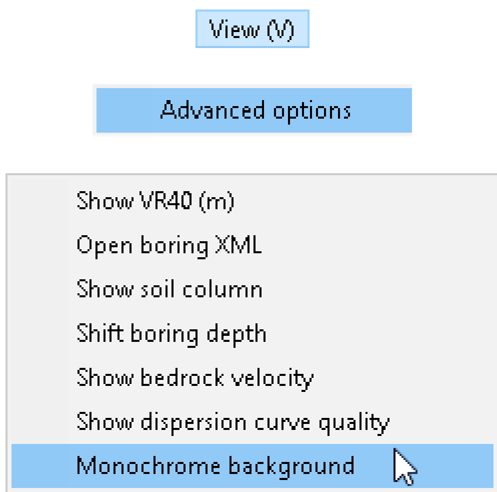
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.27.6 Show Dispersion Curve Quality



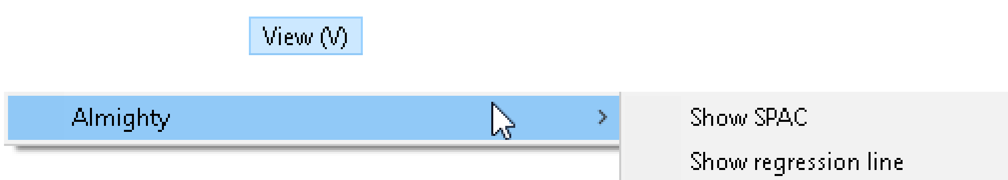
This is the same as described in Section [7.3.2]() on Page 344. See [Figure 159](): Phase velocity plot with quality curve.

7.3.27.7 Monochrome Background



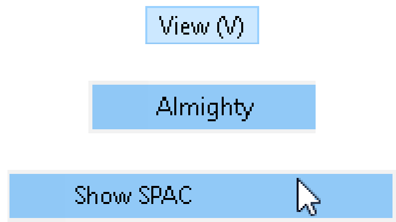
This feature is highly specialized and rarely used. Please contact [support@seisimager.com]() for assistance.

7.3.28 Almighty



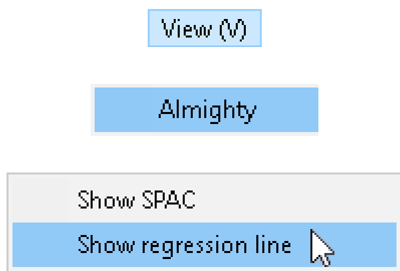
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.3.28.1 Show SPAC



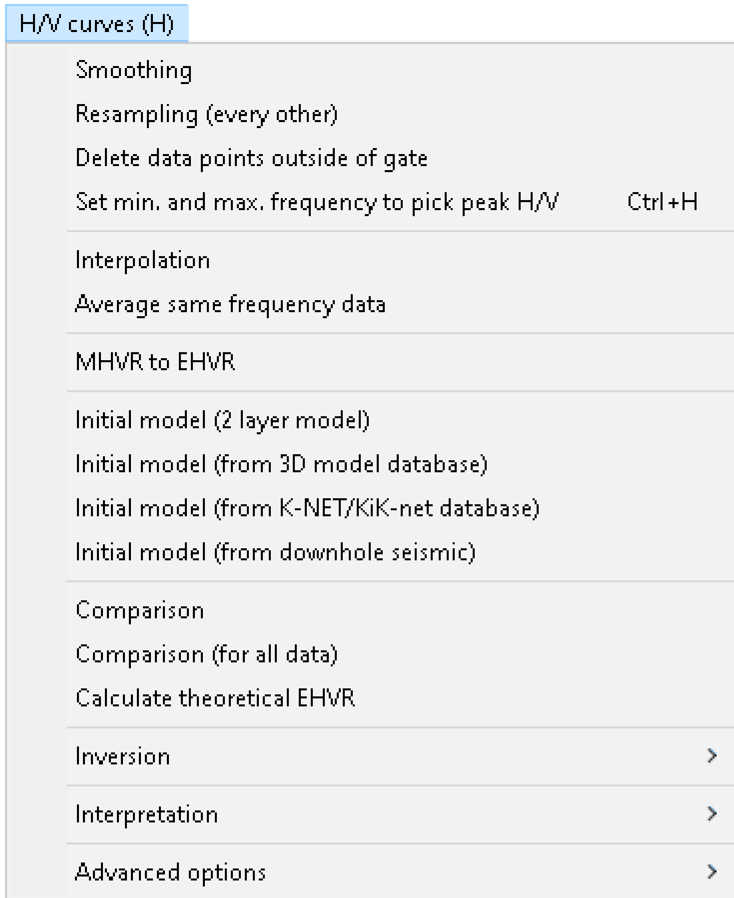
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.3.28.2 Show Regression Line

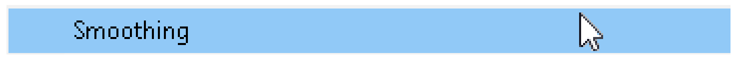


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.4 H/V CURVES MENU



7.4.1 SMOOTHING



The theoretical H/V curve is generally smooth. Observed data is, however, noisy and, as such, it is often difficult to define a peak frequency of H/V. Smoothing can help to define a stable peak frequency. WaveEq can apply a Parzen window to smooth the observed H/V curve. Select *Smoothing* to apply the Parzen window. Set the window band for the Parzen window. A larger window band yields a smoother H/V curve. The default value is suitable for most cases.

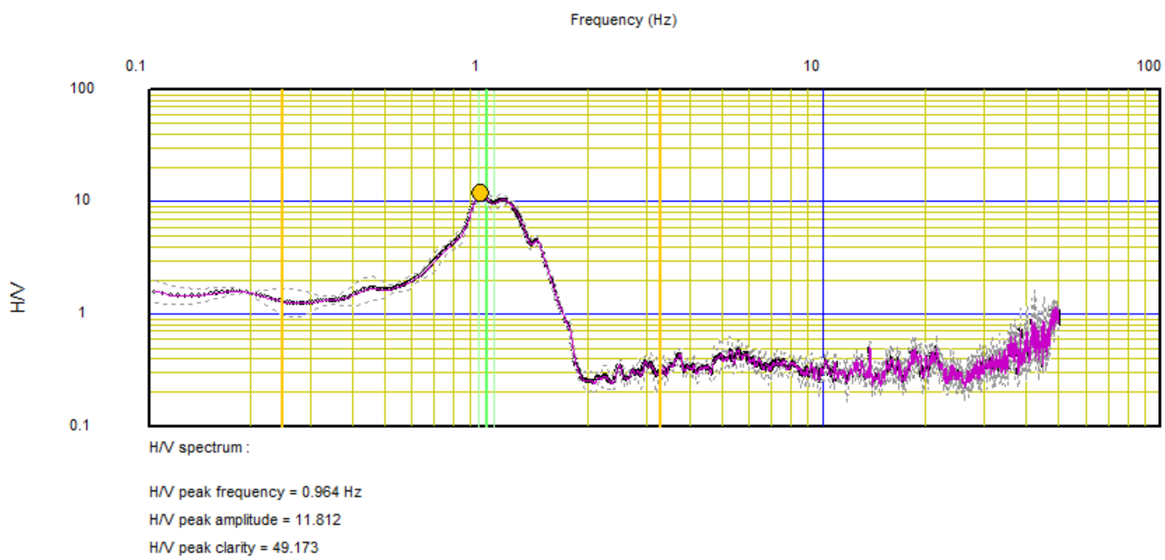
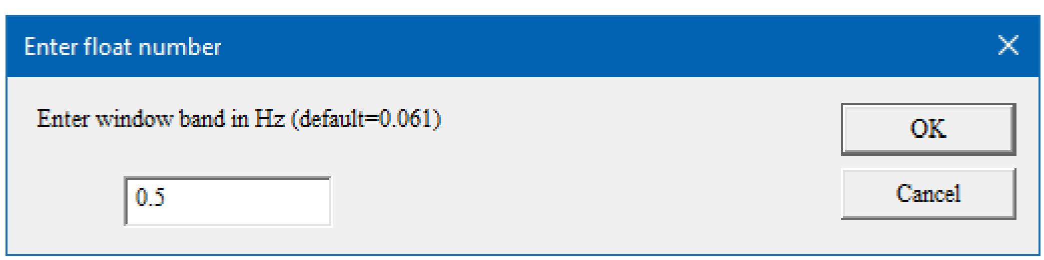


Figure 173: Raw H/V data.



Below is an example of H/V curve using a Parzen window with a bandwidth of 0.5 Hz.

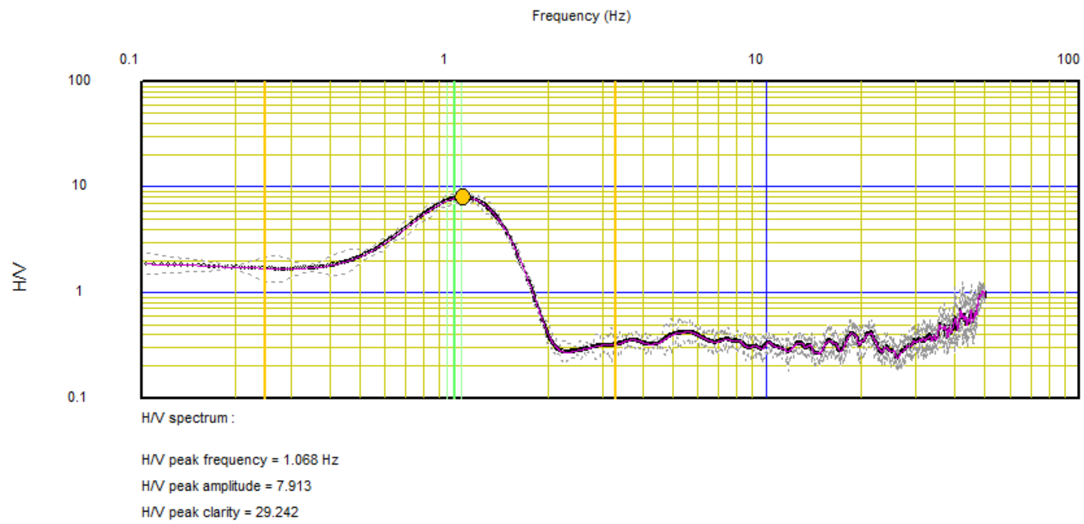
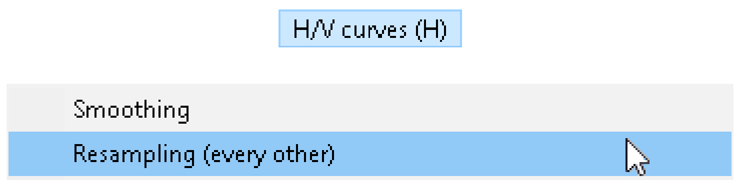


Figure 174: Smoothed H/V data.

7.4.2 RESAMPLING (EVERY OTHER)



Use this function when an inversion of H/V will be done. The frequency interval (Δf) of H/V data is defined by the length of the time domain waveform data used for calculation of the FFT. The equation is:

$$\Delta f = \frac{1}{T},$$

where T is the length of the FFT calculation (in seconds) and is the same as the data length of one file (discontinuously recorded data as a SEG2 file) or one block (continuously recorded data).

The number of H/V data points is half of the number of data samples of one file or one block.

The number of observed data is generally more than several hundred and is too large to apply an inversion. You must therefore resample the data before applying the inversion. Keep the number of samples to less than 100 if an inversion will be applied.

To resample the H/V data, select *Resampling (every other)*. You may do this several times. Below is an example of resampled data after being resampled several times:

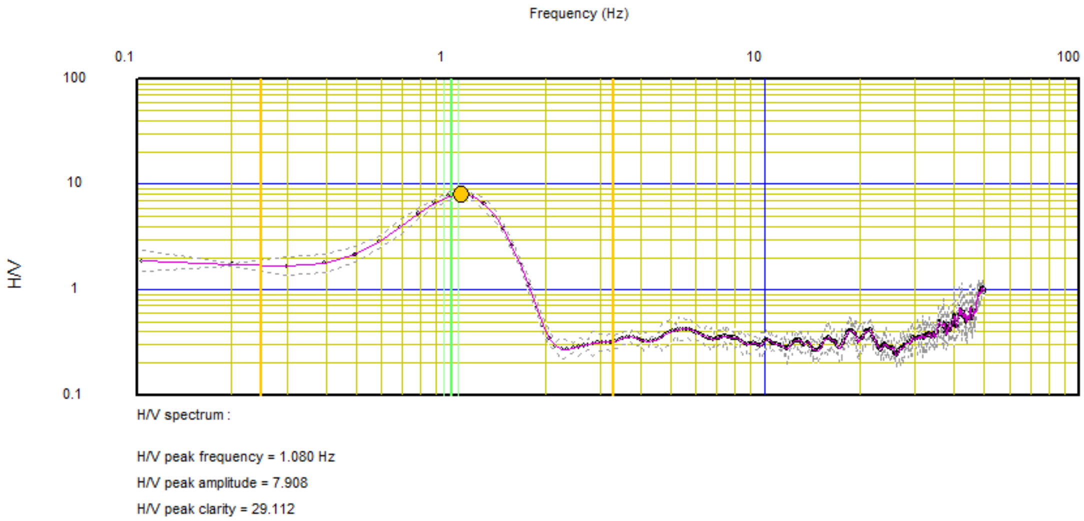
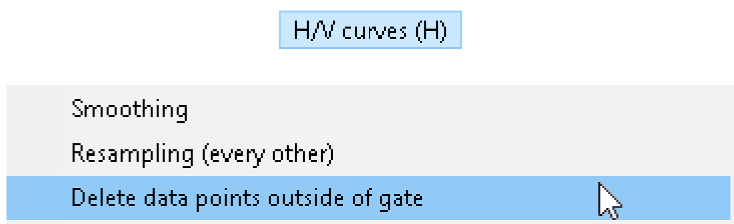


Figure 175: Resampled H/V curve.

7.4.3 DELETE DATA POINTS OUTSIDE OF GATE



H/V data outside of the frequency of interest is meaningless and it is better to remove it. To remove the unwanted H/V data, select *Delete data points outside of gates* or press *Ctrl+X*.

Follow the instructions in the upper left-hand corner of the window. The red gate is the active gate.

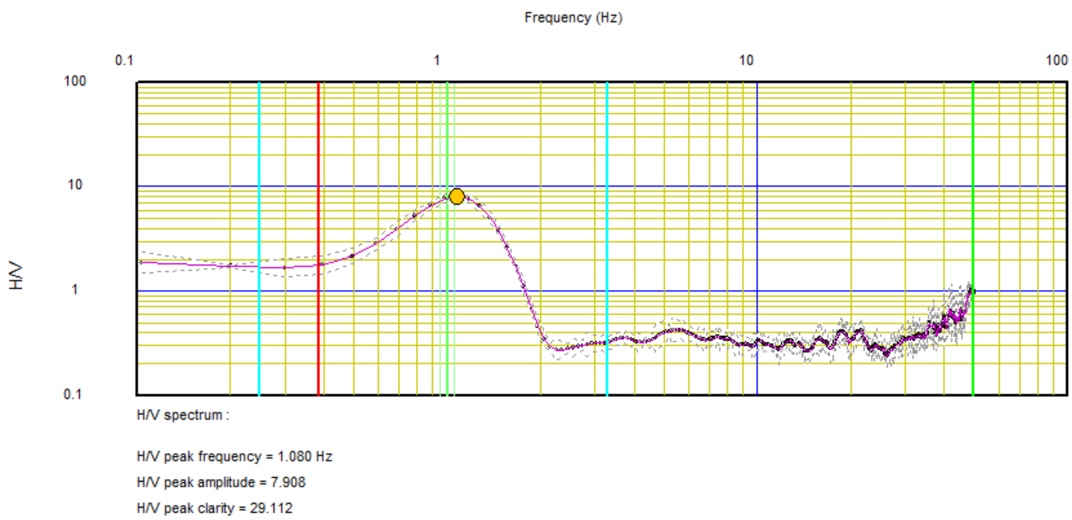


Figure 176: Using gate to trim H/V curve.

Use the *right*- and *left-arrow* key to position the left-hand gate at the frequency below which you wish to delete data. Then press the *Enter* key to activate the right-hand gate and position it the same way using the *arrow* keys.

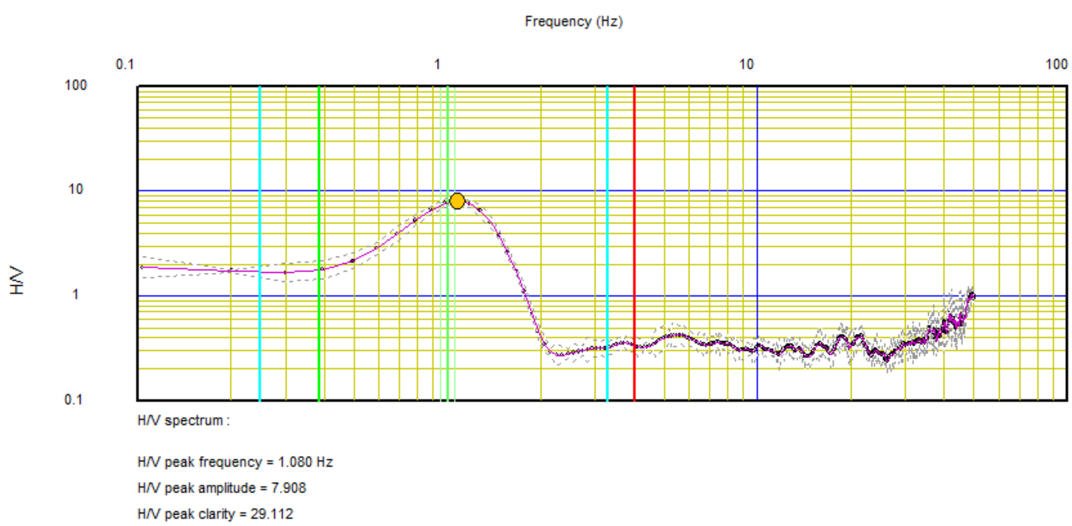


Figure 177: Using gate to trim H/V curve.

Press the *Enter* key to delete the data.

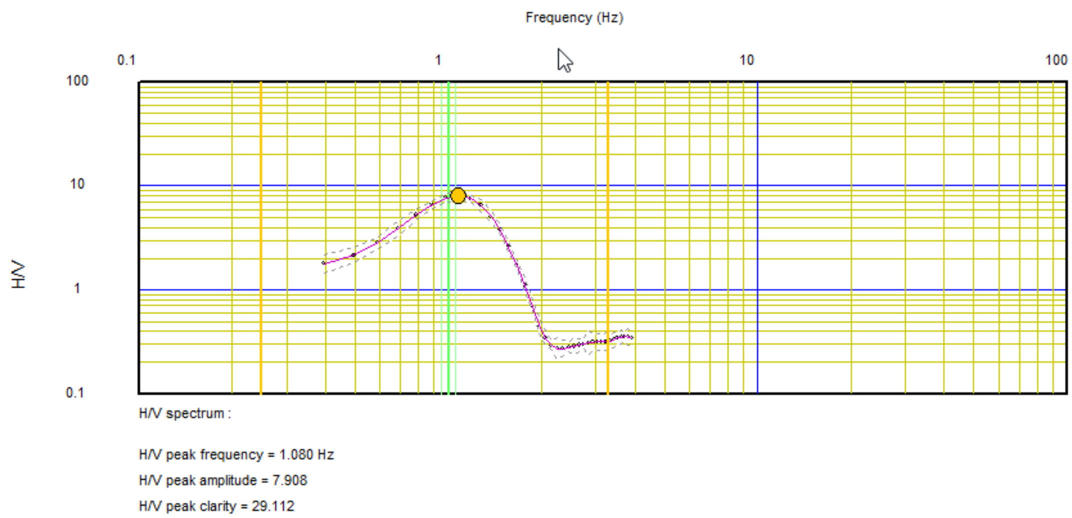
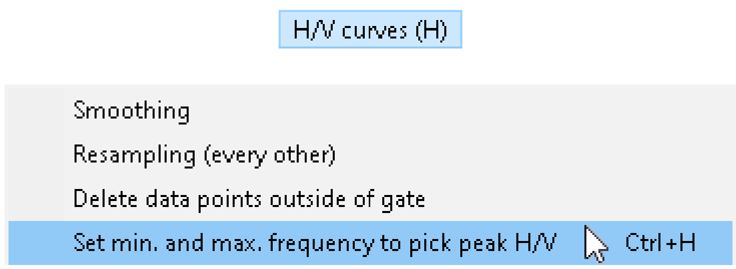


Figure 178: Trimmed H/V curve.

7.4.4 SET MIN. AND MAX. FREQUENCY TO PICK PEAK H/V [CTRL+H]



This defines the frequency range in which the H/V peak frequency will be picked. Set the gate as described above for deleting data. The frequency range will be indicated by two orange vertical lines:

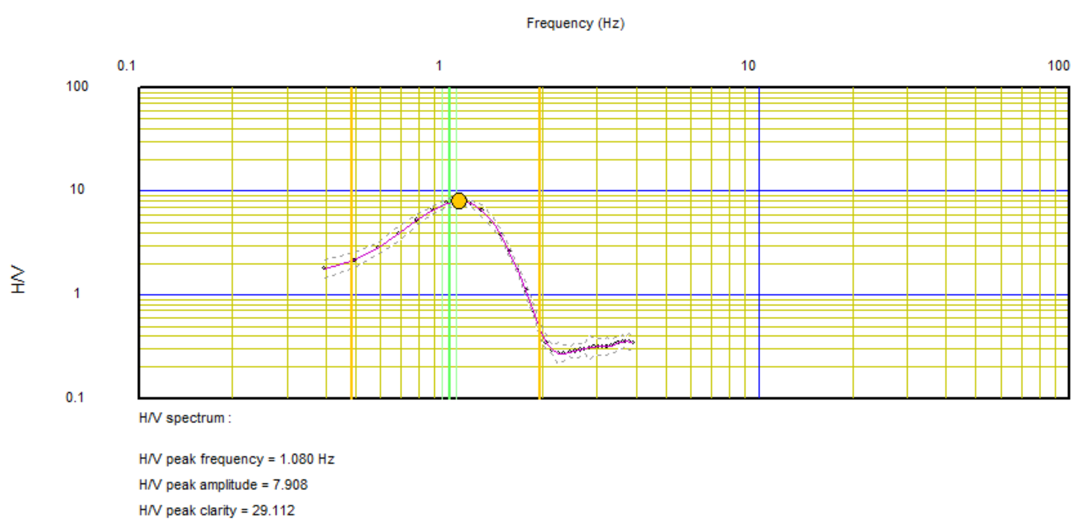
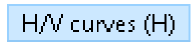
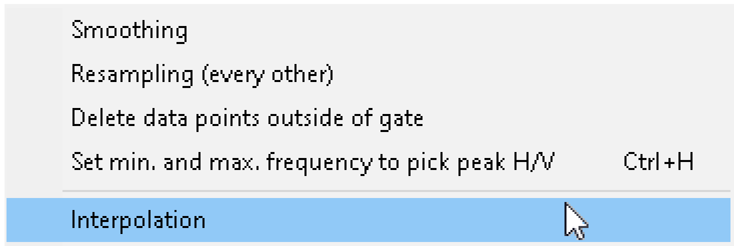


Figure 179: Defining frequency range of H/V peak.

7.4.5 INTERPOLATION





Interpolation is just another way of reducing the number of data points making up the H/V curve. Unlike resampling (described above), interpolation does *not* preserve the original frequency content. Generally, this is not important, but some practitioners prefer to do so. Either way is acceptable in most cases.

When you choose *Interpolation*, you will be asked for an integer. This is the number of data points that will be left in the H/V curve after interpolating.

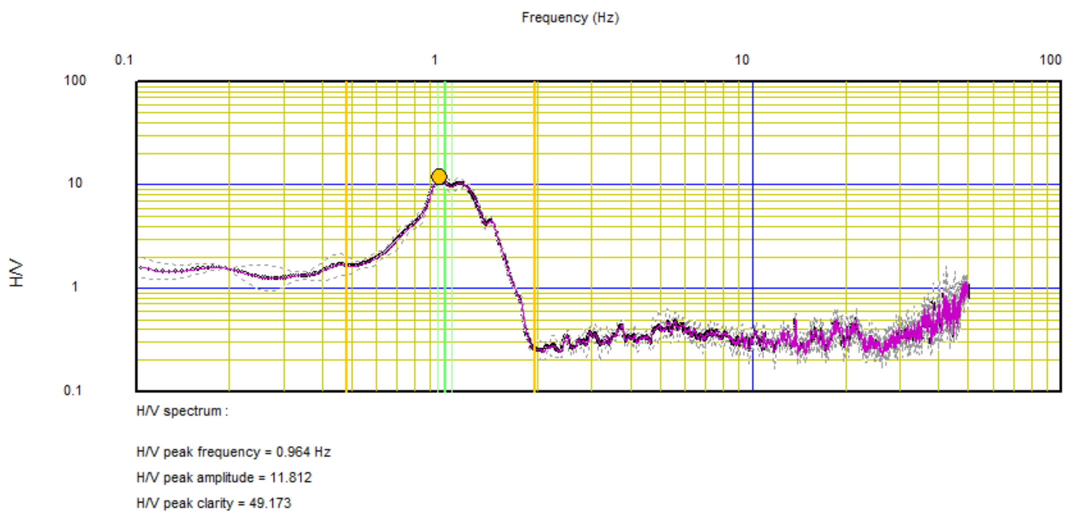
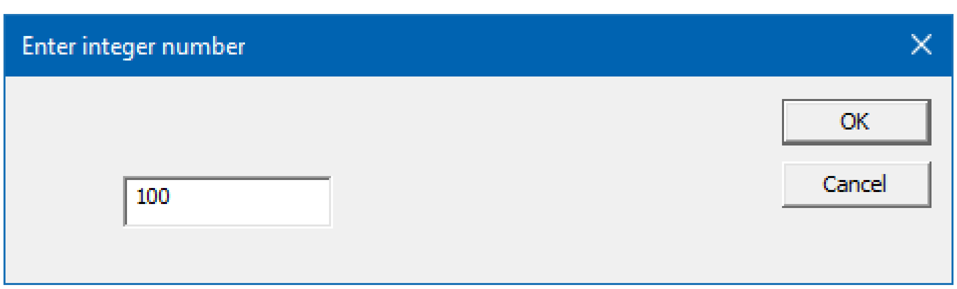


Figure 180: Raw, un-interpolated H/V curve.



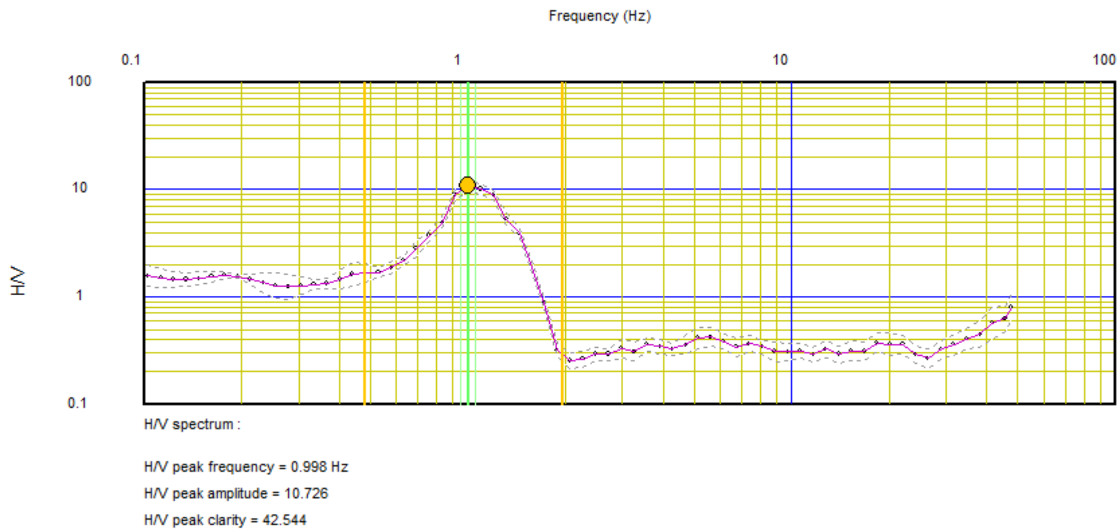
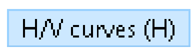
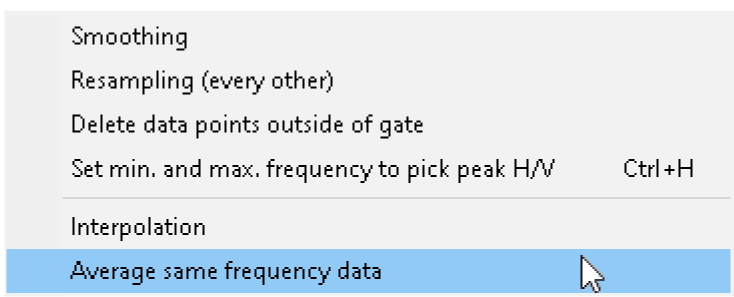


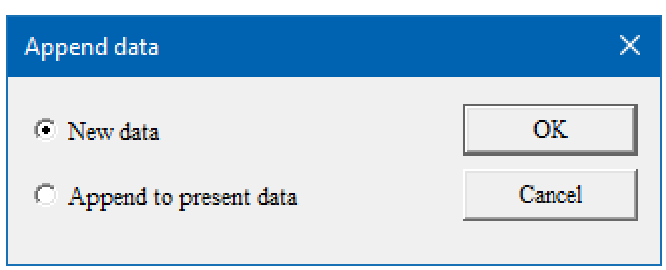
Figure 181: Interpolated H/V curve.

7.4.6 AVERAGE SAME FREQUENCY DATA





When doing a site assessment, it is not uncommon to conduct multiple soundings. It is sometimes desirable to take the average of all those soundings, particularly if they are relatively close to each other. To do so, read in the first H/V curve. When prompted, select *New data*:



Next, read in the rest of the curves that you would like to average together, but select *Append to present data* for each one. The various H/V curves will be displayed together on the same plot:

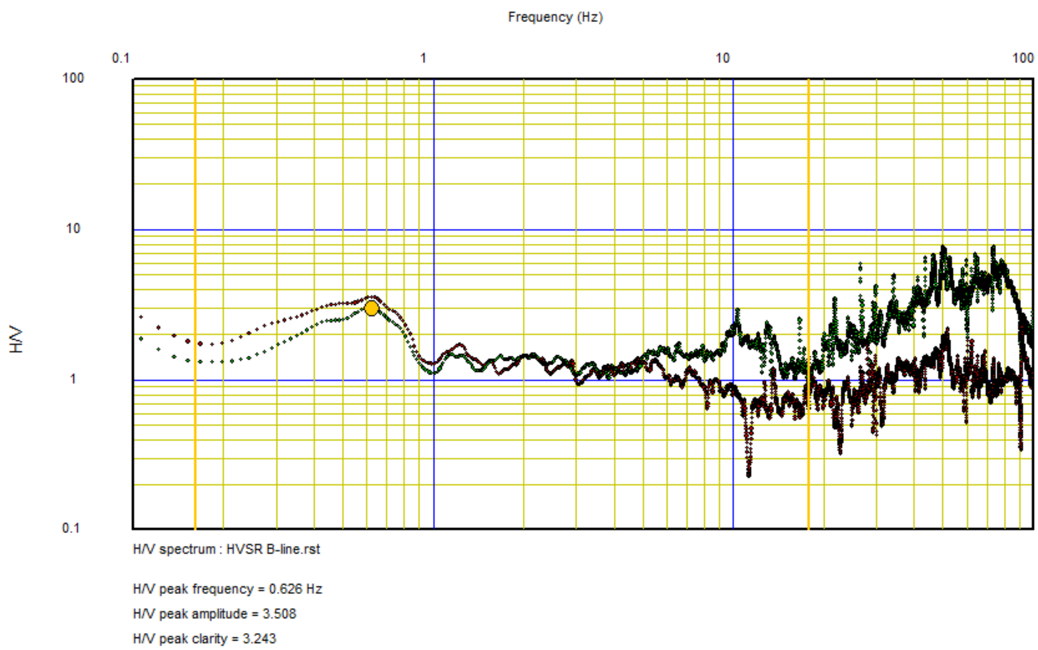


Figure 182: Two H/V curves plotted together.

In the above plot, two H/V curves have been read in. To average them, select *H/V curves | Average same frequency data*. The various curves will be averaged, and the average curve will be displayed:

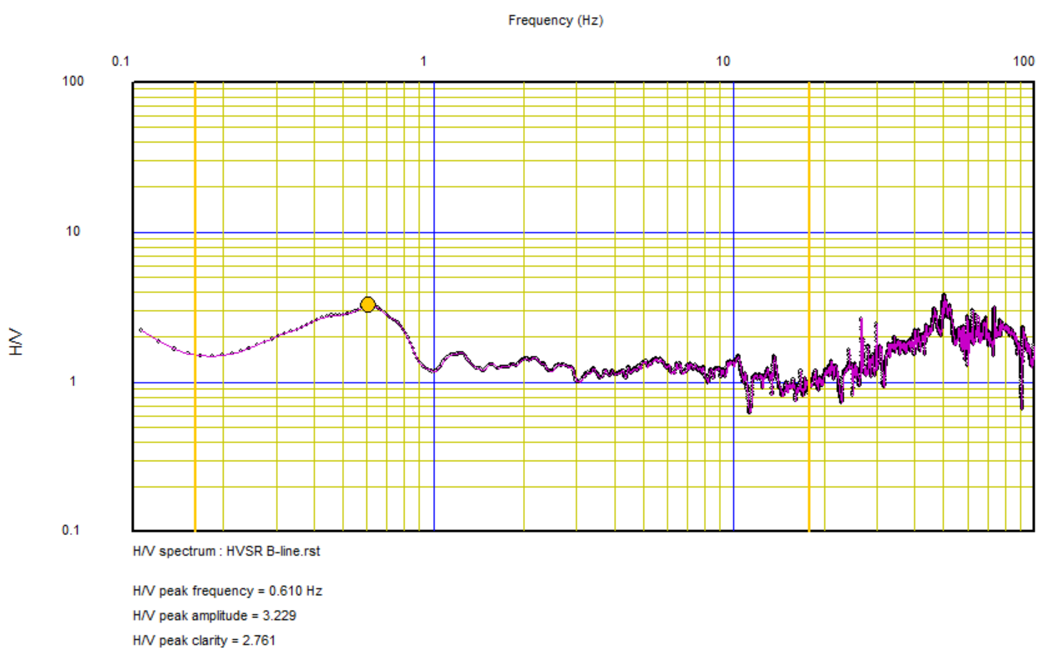
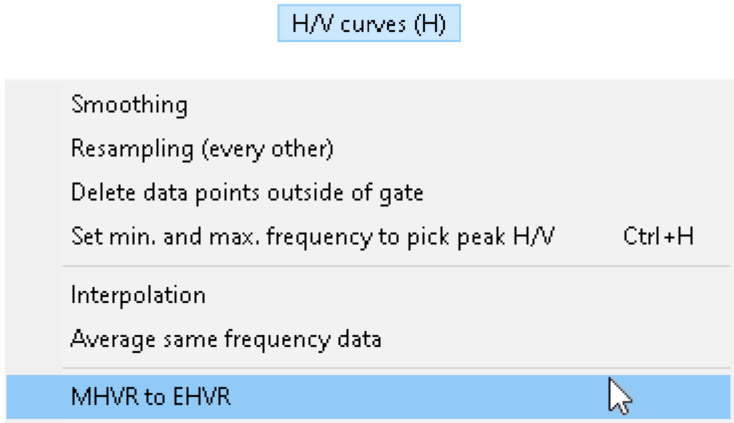


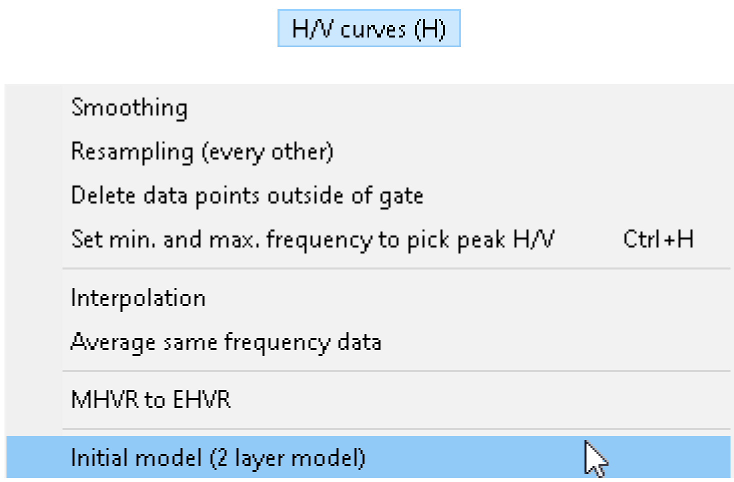
Figure 183: Average of H/V curves shown in Figure 182.

7.4.7 MHVR TO EHVR

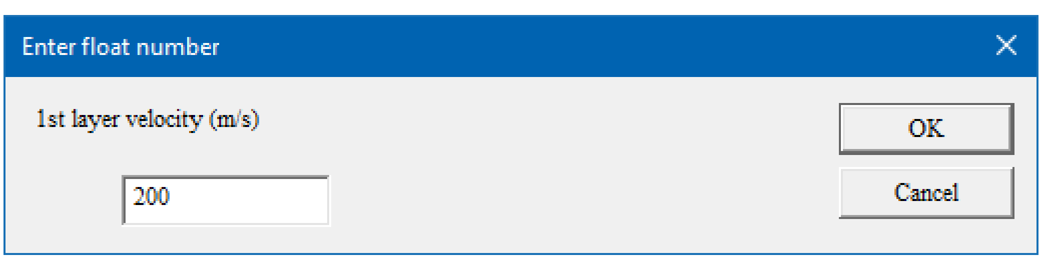


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.4.8 INITIAL MODEL (2 LAYER MODEL)



To make an initial velocity model for the H/V analysis, select *H/V Curves | Initial model (2 Layer Model)*. The initial model is a two-layer velocity model. Set the S-wave velocity for the first layer (V_{S1}).



Depth to a second layer (D_2) is calculated with a peak frequency of H/V (f) as follows:

$$D_2 = Vs_1 \div f \div 4.$$

The S-wave velocity for the second layer (V_{S2}) is automatically set to triple that of V_{S1}. Press OK and the initial S-wave velocity model is displayed.

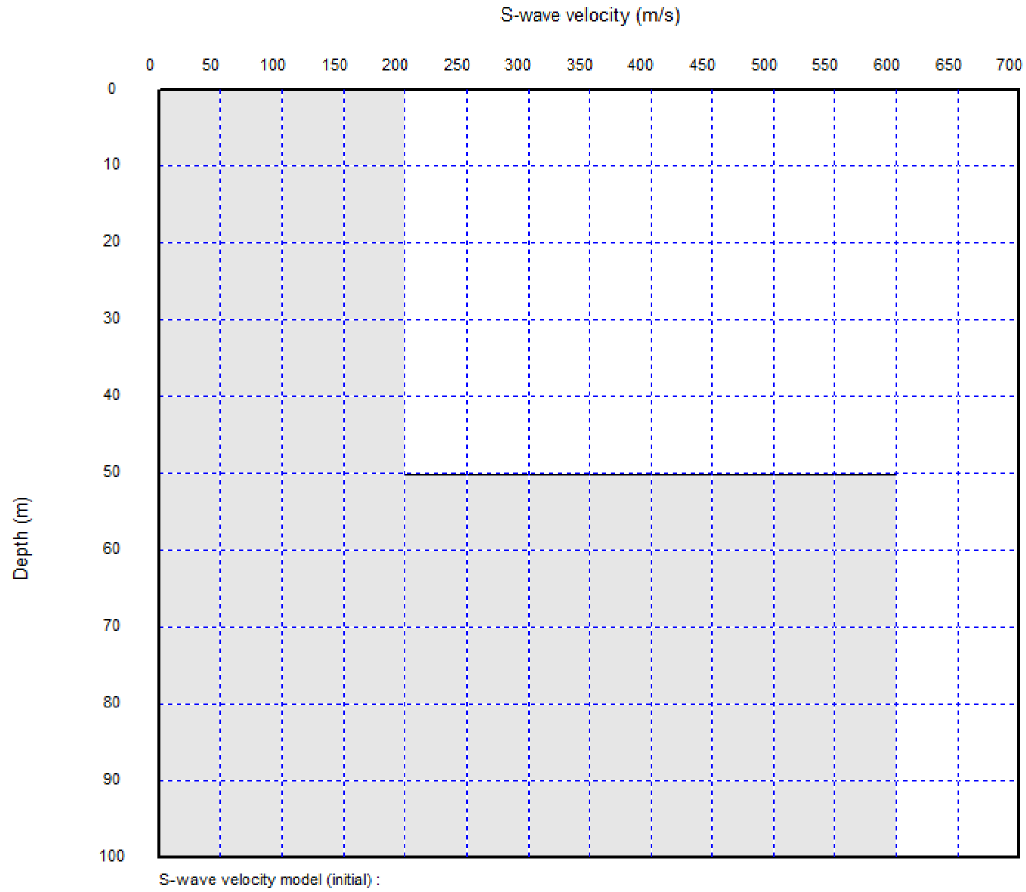
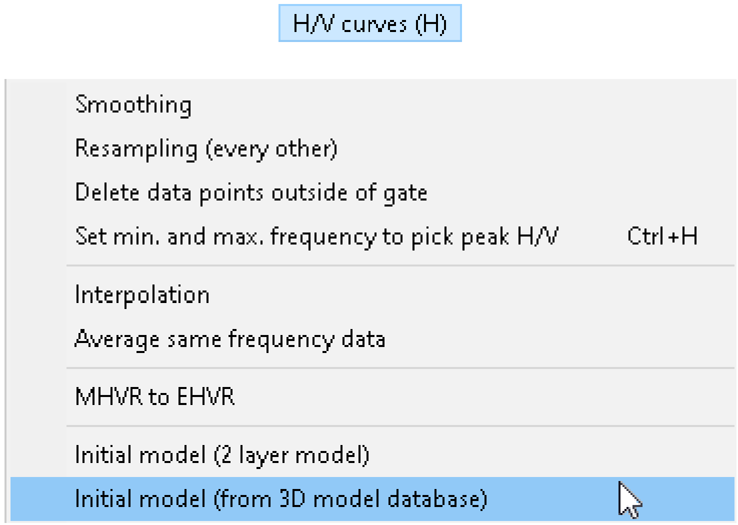


Figure 184: Initial S-wave velocity model.

Note: *If you only see a single layer, you may need to adjust the vertical axis. Click on* ***View | Axis configuration*** *and increase the Y-axis maximum.*

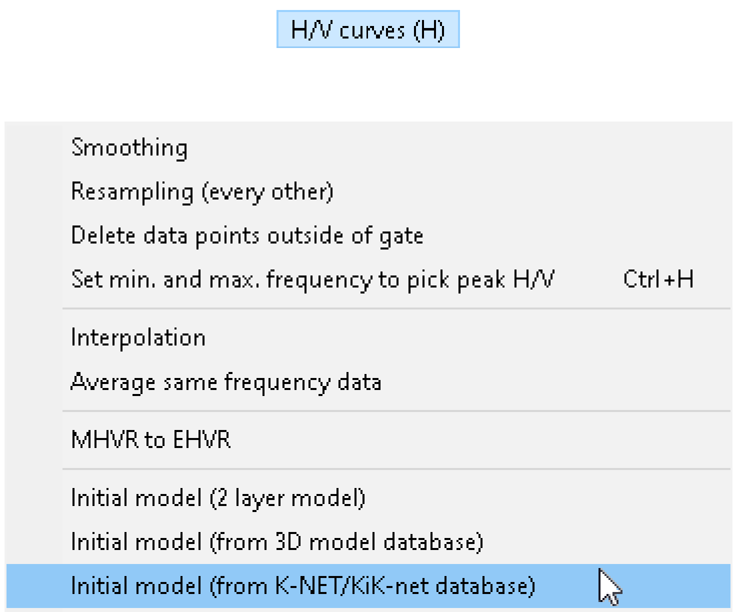
Note that an inversion using only H/V data is essentially non-unique and unstable. Do not rely on the inversion of H/V data alone; we recommend incorporating other information, such as phase velocity data, drilling logs, and geological information.

7.4.9 INITIAL MODEL (FROM 3D MODEL DATABASE)



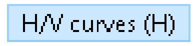
This creates an initial model based on the 3D community velocity models. It is only available in Japan and in the San Francisco Bay and Los Angeles areas of the United States. Contact support@seisimager.com for assistance.

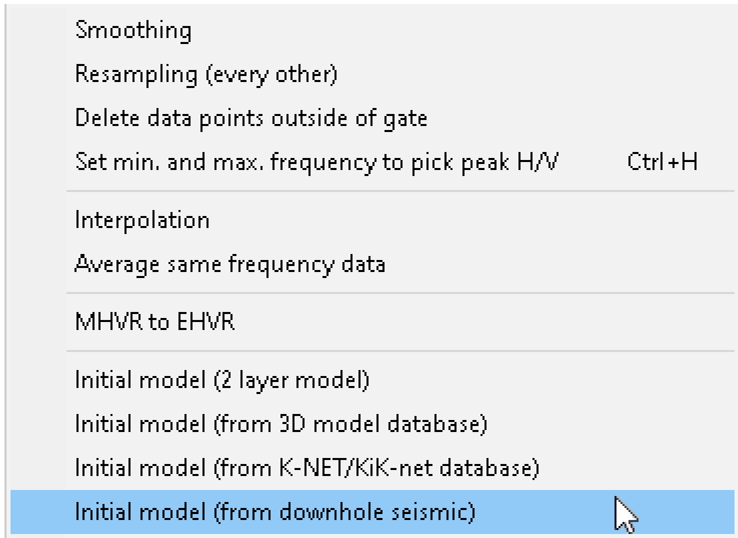
7.4.10 INITIAL MODEL (FROM K-NET/KIK-NET DATABASE)



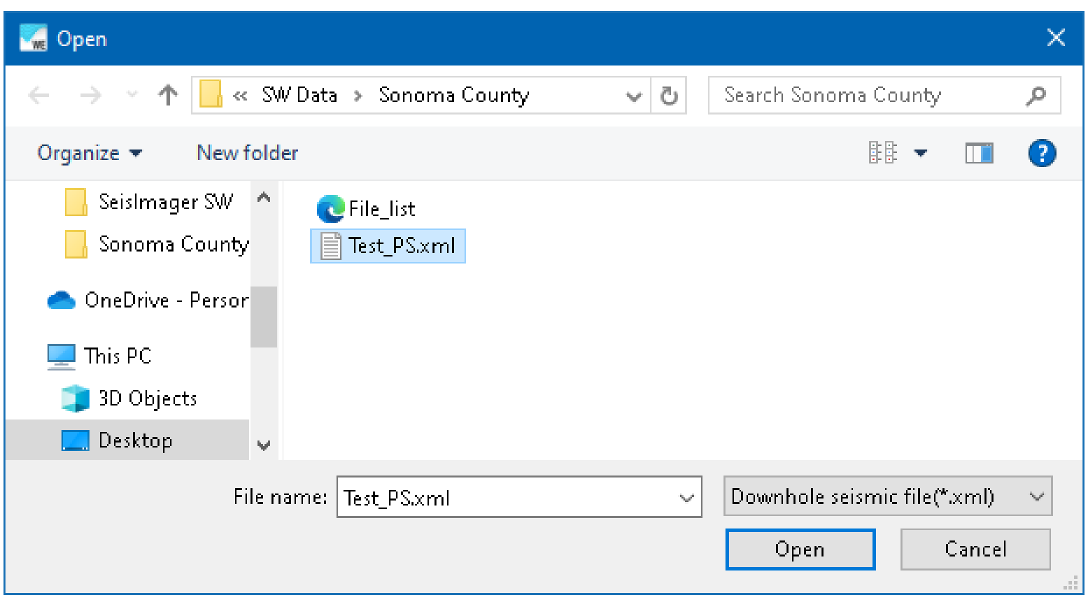
This creates an initial model based on K-Net/KiK-net Database developed by Kyoto University. Contact support@seisimager.com for assistance.

7.4.11 INITIAL MODEL (FROM DOWNHOLE SEISMIC)

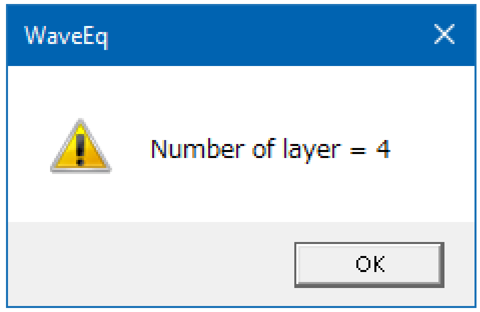




To make an initial velocity model for H/V analysis based on seismic logging, *select H/V Curves | Initial model (from downhole seismic)*. An XML file saved by SeisImager/DH (PSLog) can be used as a velocity model. Highlight the file and press *Open*.



The number of layers in the model will be displayed. Press *OK* to confirm.



The velocity model will be displayed.

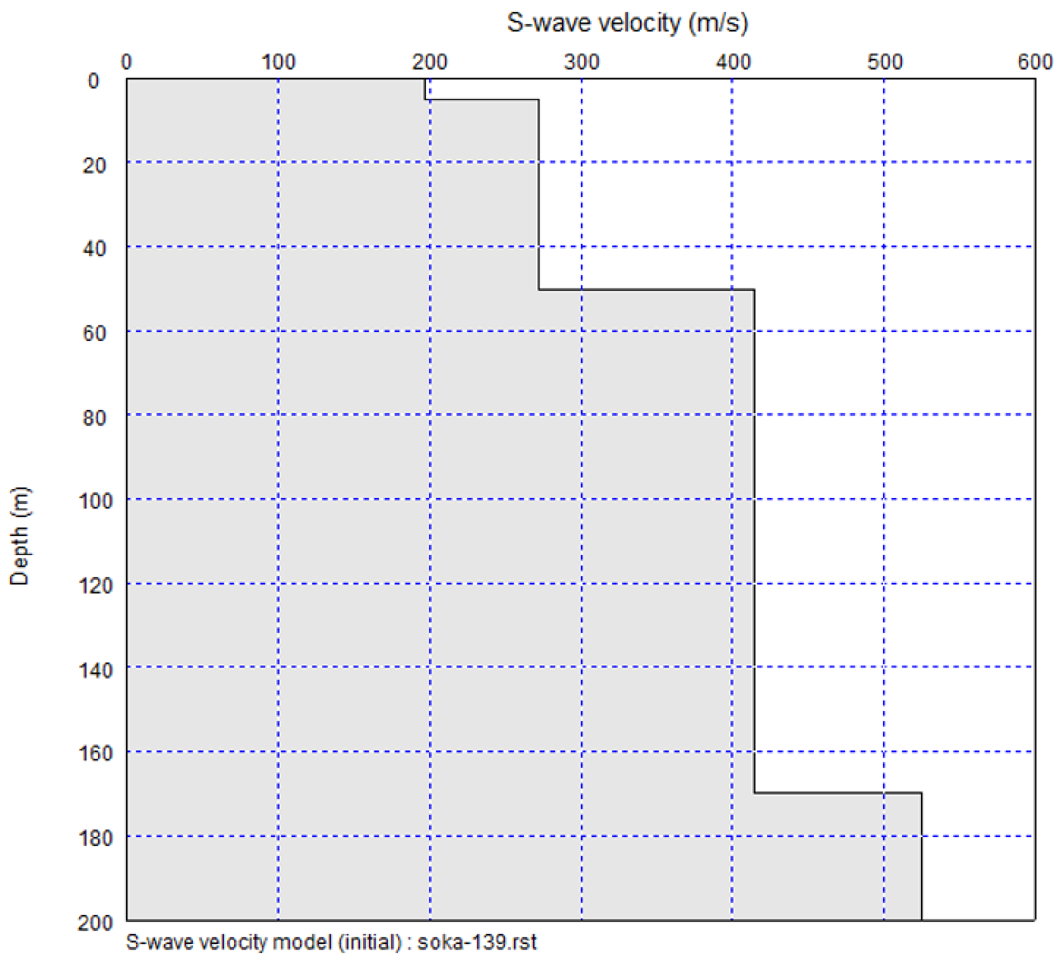
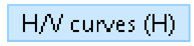
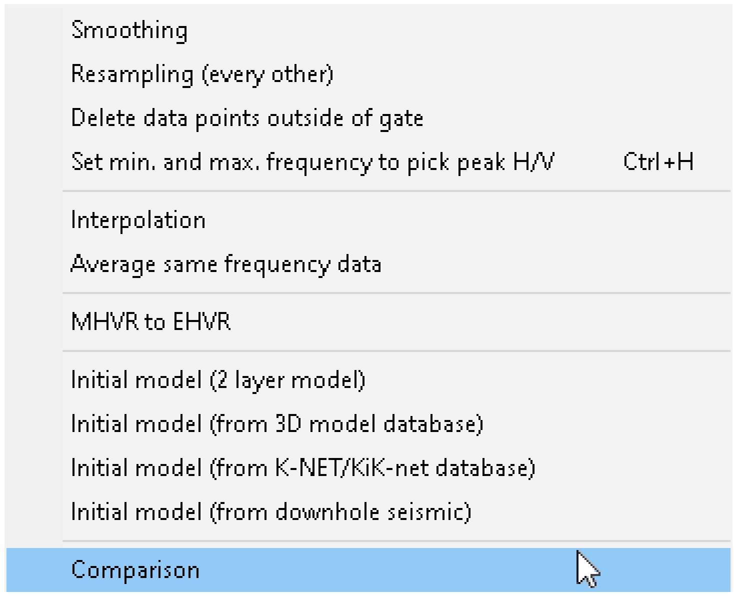


Figure 185: Initial velocity model from downhole survey.

7.4.12 COMPARISON





To calculate and overlay a theoretical H/V curve over an observed H/V curve, select *H/V Curves* | *Comparison* or press the *Calculate theoretical dispersion curves*  button. The calculated curve is shown as a black line. To remove the calculated H/V curve from the display, press the *Calculate theoretical dispersion curves* button again.

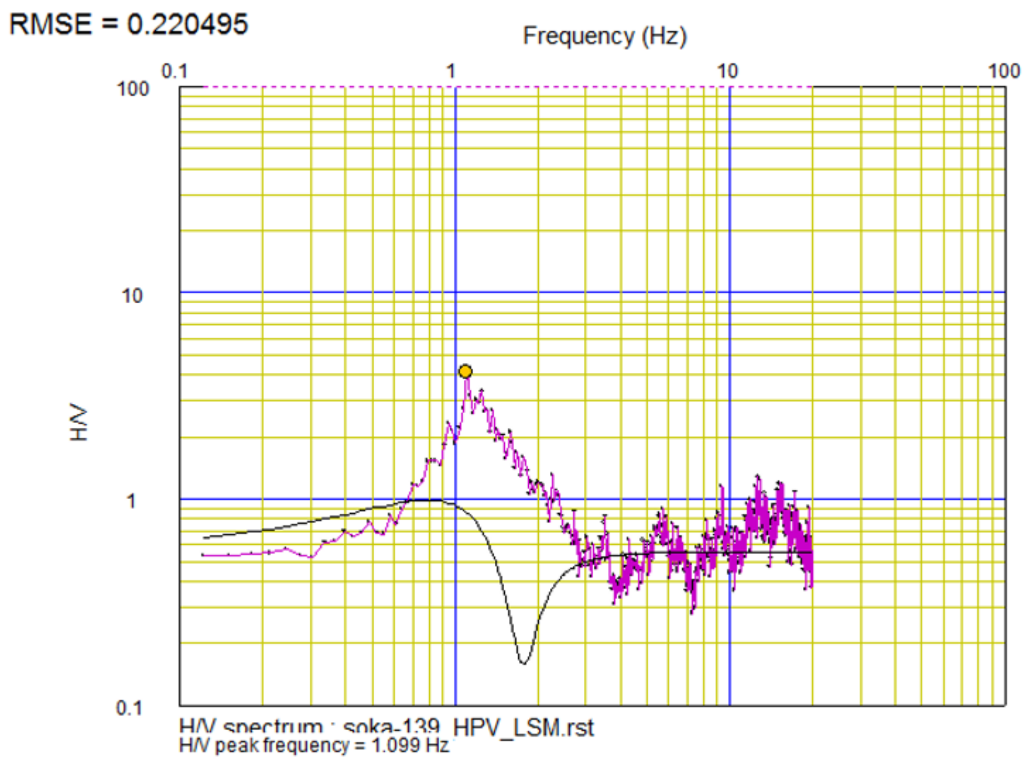
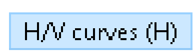
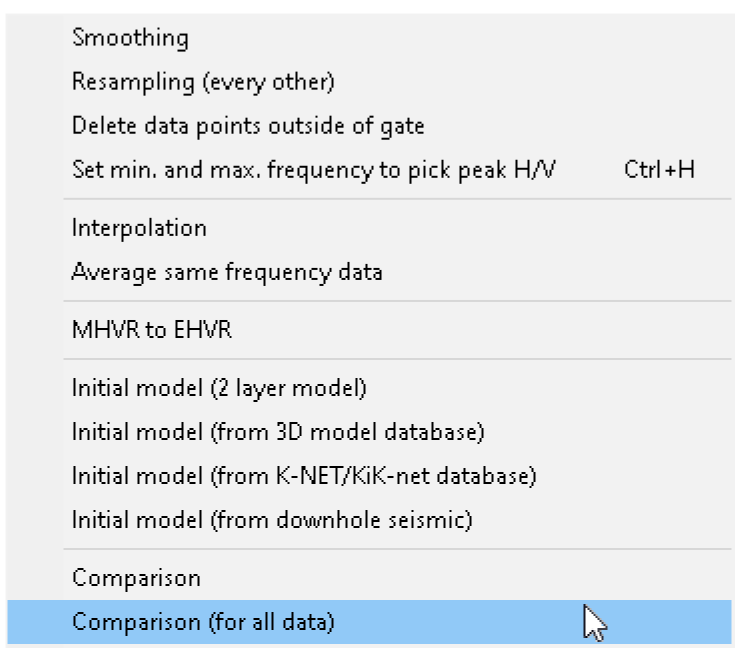


Figure 186: Theoretical (black) vs observed H/V curve.

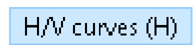
7.4.13 COMPARISON (FOR ALL DATA)

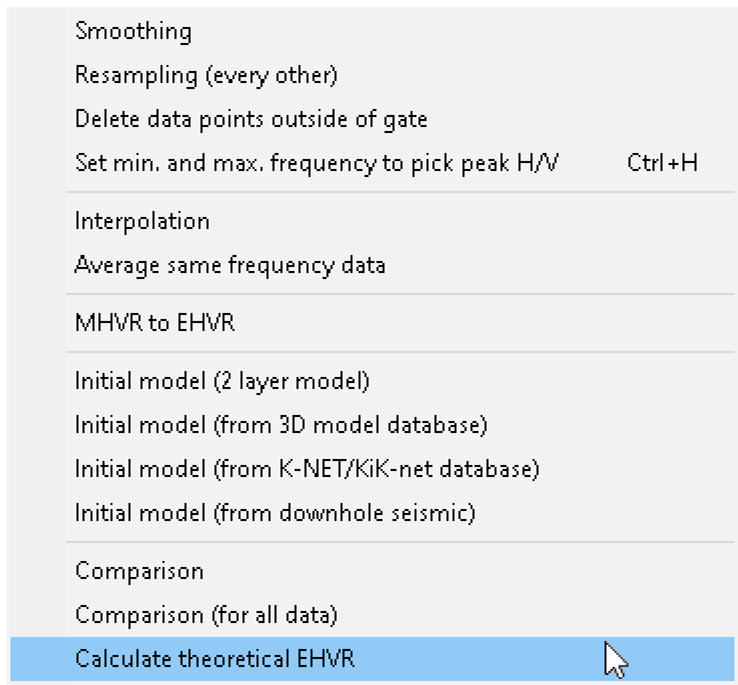




This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

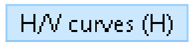
7.4.14 CALCULATE THEORETICAL EHVR

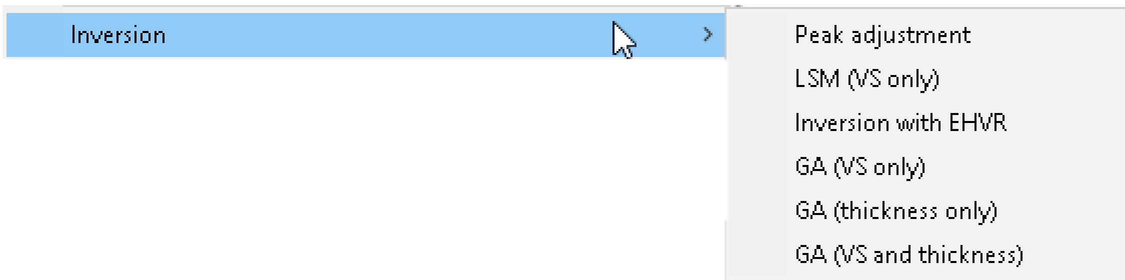




This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.4.15 INVERSION





H/V Curves | Inversion includes functions for the inversion of H/V data. There are several different inversion methods to choose from. Use an appropriate method depending on observed data, site conditions, and investigation purposes. Remember, the inversion of H/V data is unstable compared to the inversion of dispersion curve data. We suggest using a small number of iterations and checking the validity of the results carefully.
All inversion functions may be carried out with data from the fundamental mode only or the fundamental and higher mode H/V curves. Inversions use only the fundamental mode when the 

button is selected and use both fundamental and higher modes when the 

button is selected.

Joint inversions of a dispersion curve and an H/V spectrum may be performed if the user has phase velocity and H/V measurements. Use functions in *MASW (1D) | Advanced inversion* to perform the joint inversion functions.

An example of observed and theoretical H/V data (left) and initial velocity model (right) will be used in the following discussion. The initial model (Model A) is a six-layer model. The theoretical H/V data is calculated for the initial model.

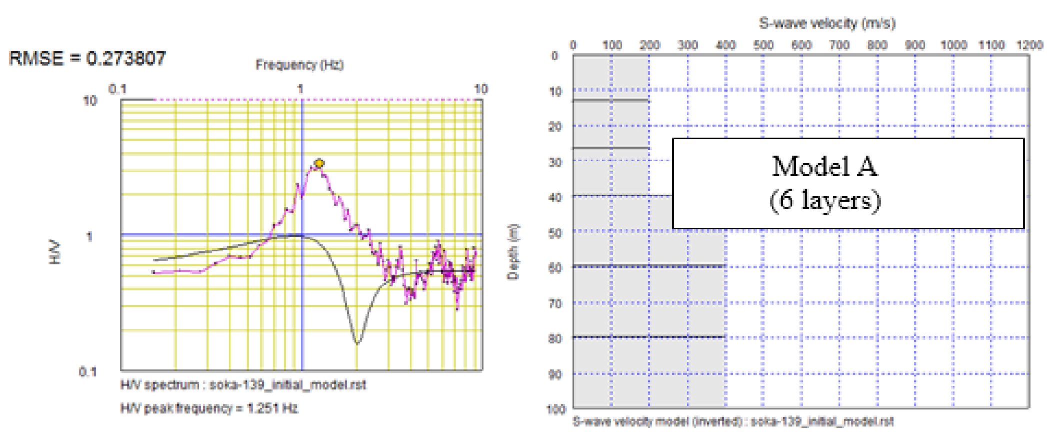


Figure 187: Observed and calculated H/V curve (left) and initial velocity model.

7.4.15.1 Peak Adjustment

You may fine-tune the V_S model by adjusting it so that the calculated H/V peak is equal to the observed peak. To do so, read in the H/V curve. Press  to display the velocity model:

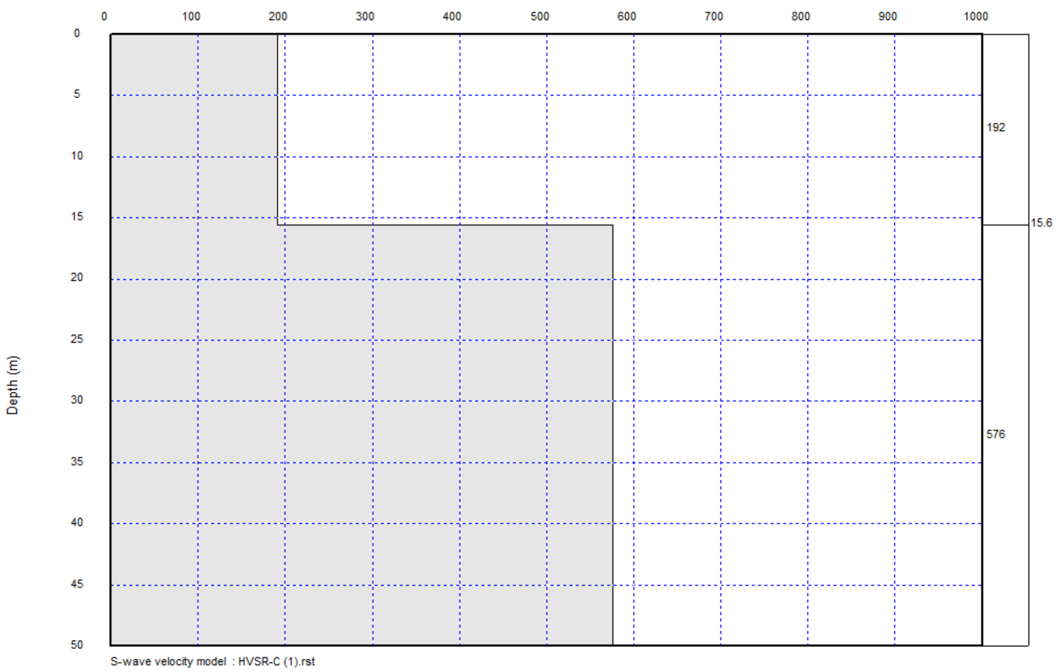


Figure 188: V_S model.

Note that in this case the layer boundary before adjustment is at 15.6 meters. Now, press  to display the measured H/V curve:

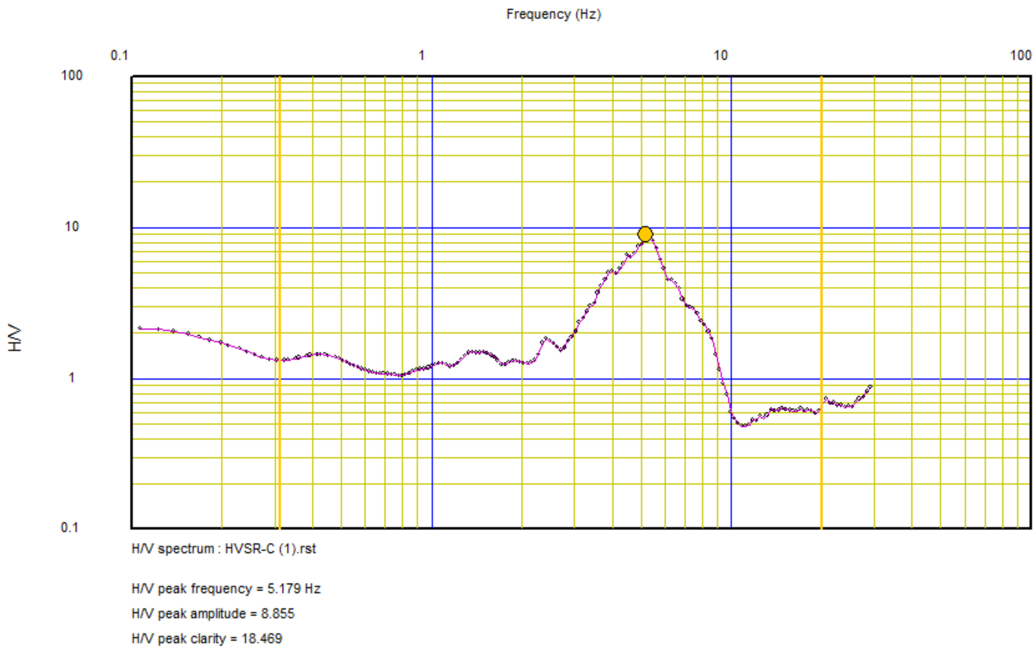


Figure 189: H/V curve for velocity model shown in Figure 188.

Next, press  to display the theoretical H/V curve:

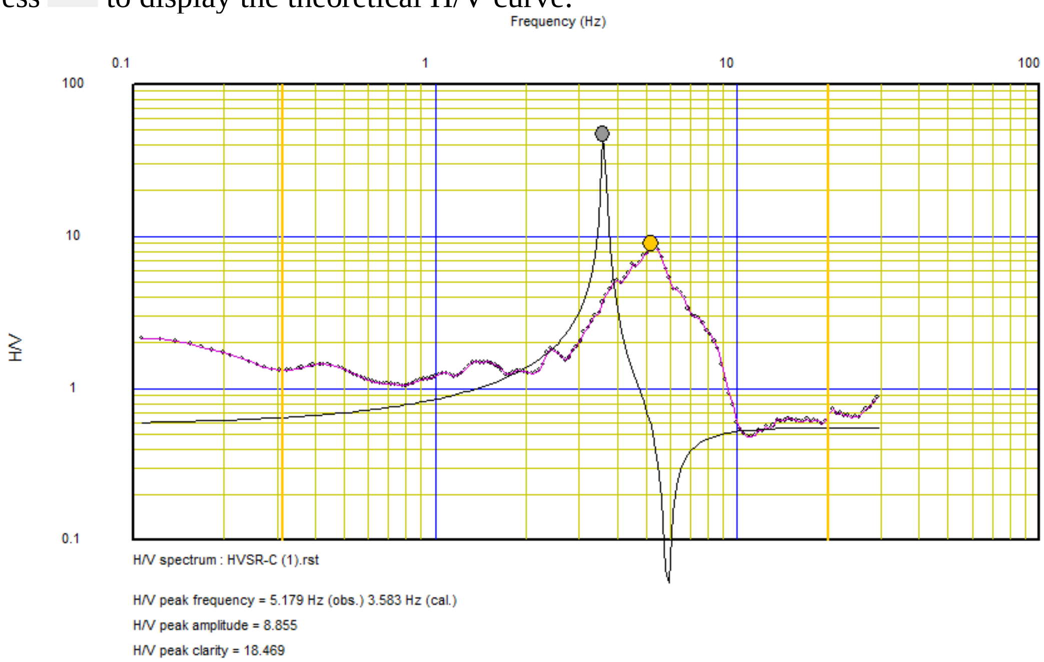
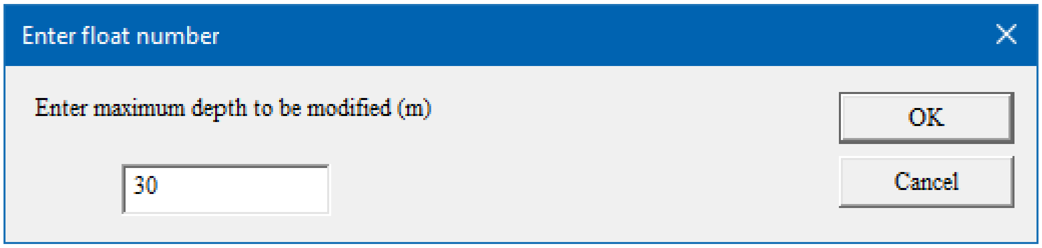


Figure 190: Measured and calculated H/V peaks.

Note the frequency offset between the calculated and measured peaks. Now, select *H/V Curves | Inversion | Peak adjustment.* You will be presented with the following dialog:



While this number may range from ~20-40 meters, the default value of 30 meters will be sufficient for 90% of cases. Contact support@seisimager.com if you need assistance with this parameter.

Press *OK* and the V_S model will be modified such that the calculated H/V peak matches the measured H/V peak:

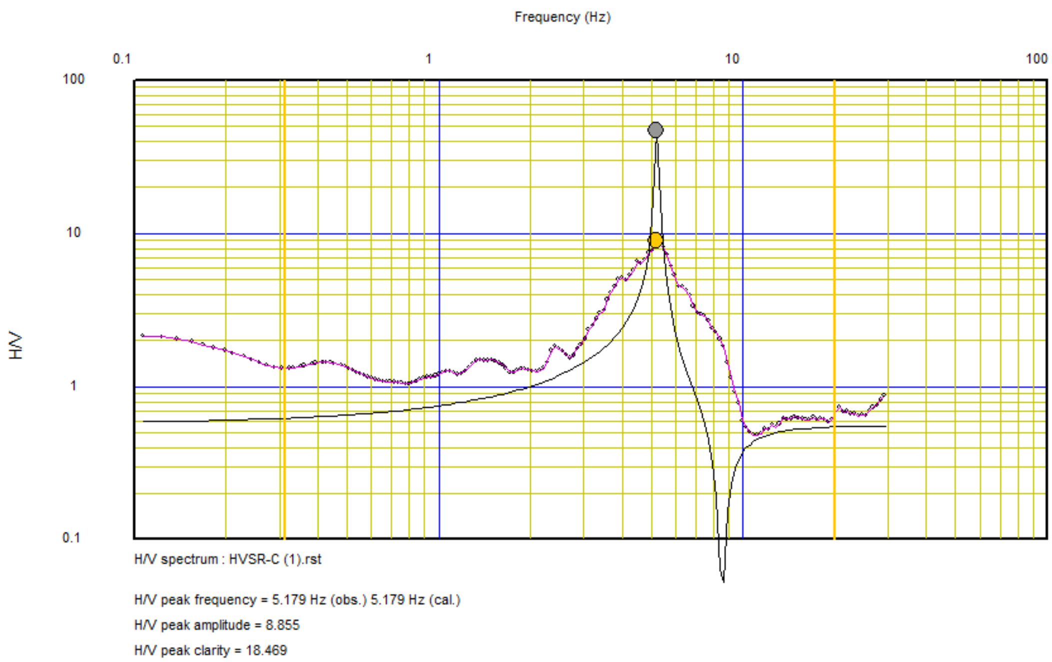


Figure 191: Adjusted H/V curves.

The adjusted V_S model is displayed below. Compare to the original above.

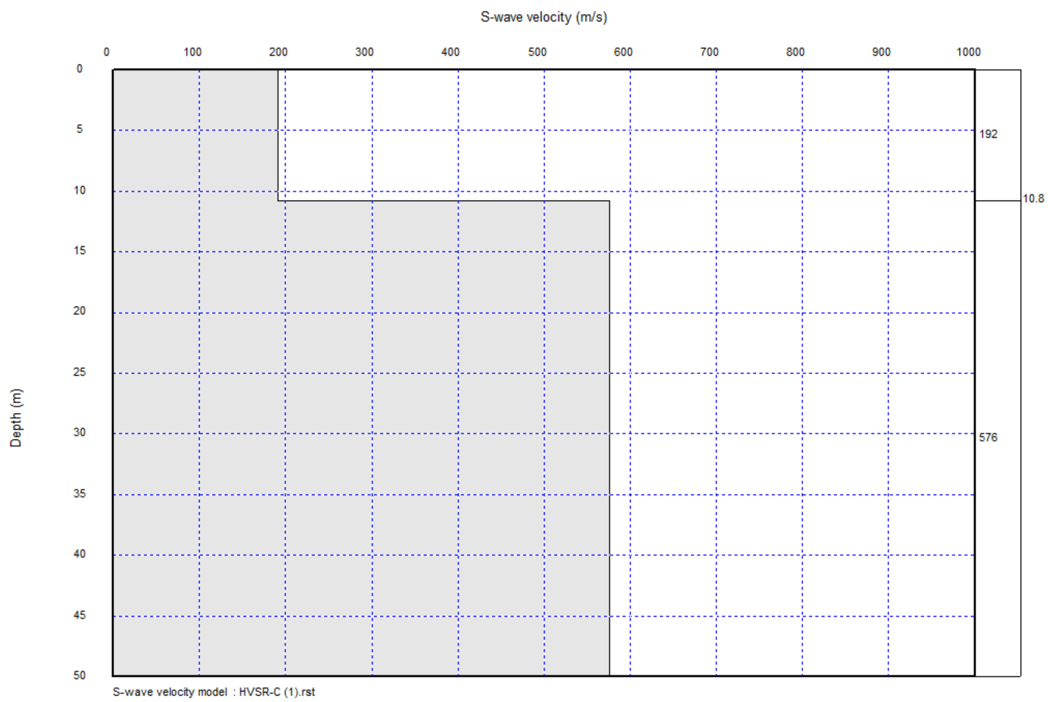
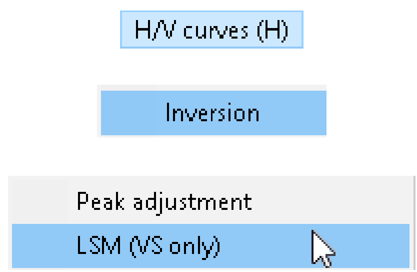


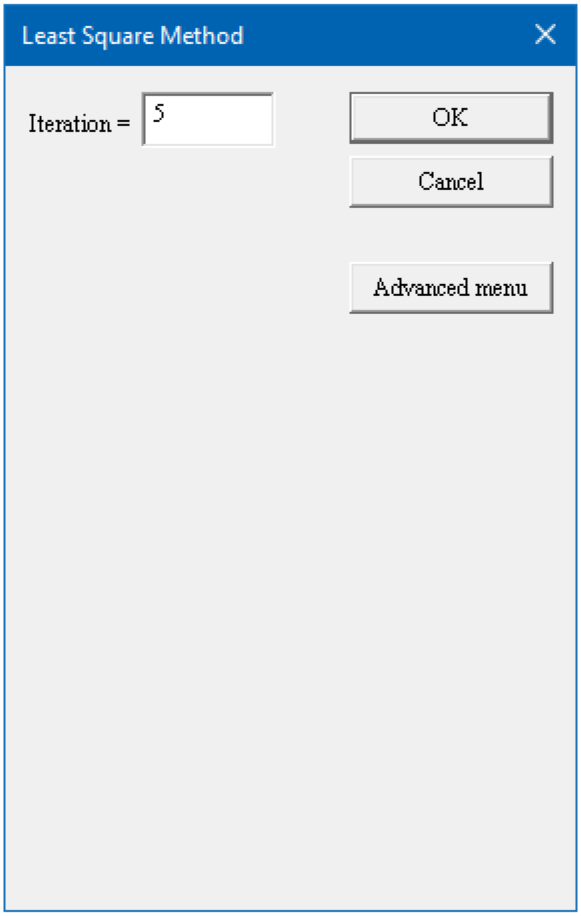
Figure 192: Adjusted velocity model.

7.4.15.2 LSM (VS ONLY)



An S-wave velocity model is estimated by non-linear least square methods, and layer thickness is held constant under this inversion process. Observed data in the inversion is H/V data, and unknown parameters in the inversion are S-wave velocity of each layer.

Set the number of iterations for the inversion. The default value of 5 for *Iteration* is suitable for most cases.



An example of an inverted result is shown below. Error between observed and thoretical H/V is smaller than for the initial model (Model A, Page 417).

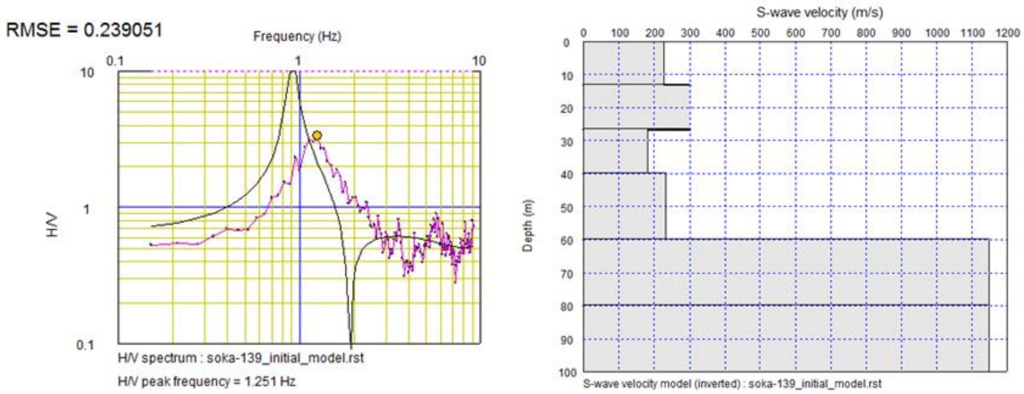
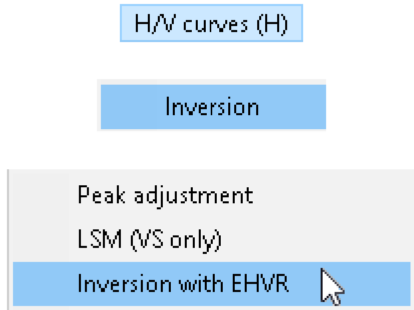


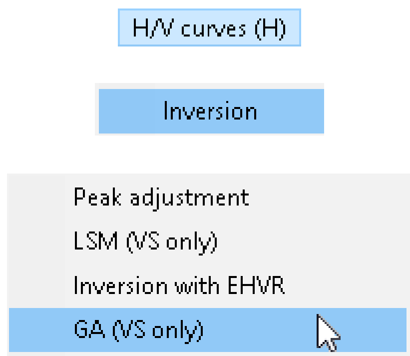
Figure 193: Measured and calculated H/V peak (left) and Vs model (right).

7.4.15.3 INVERSION WITH EHVR



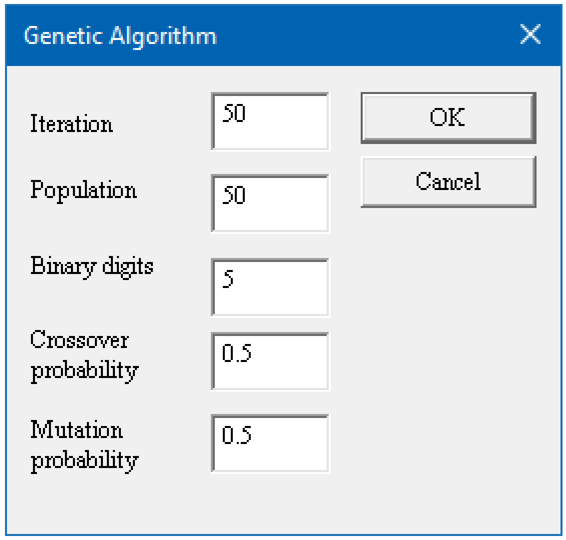
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.4.15.4 GA (VS ONLY)

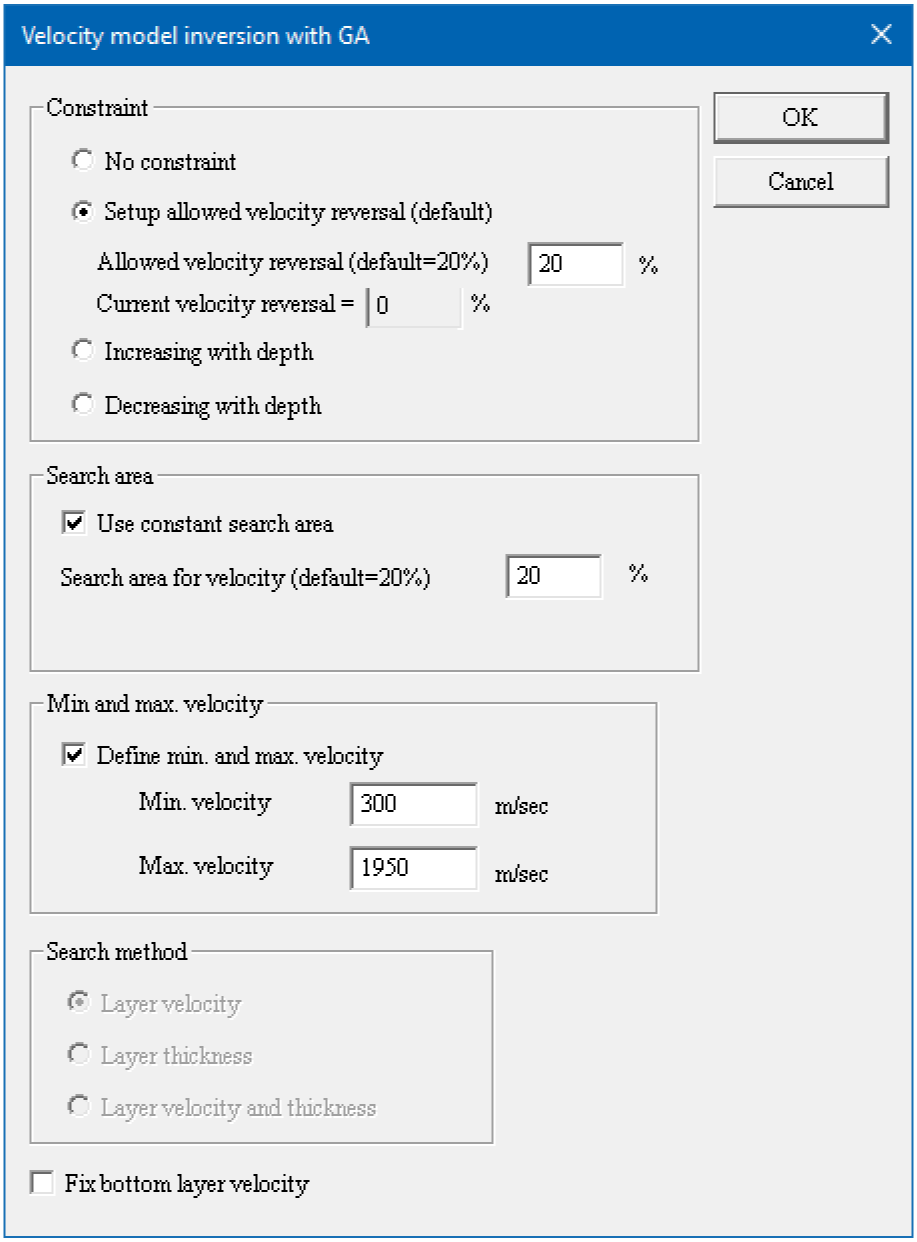


In this case, the S-wave velocity model is estimated by a Genetic Algorithm (See Sections 5.2.1.4 through 5.2.1.6 starting on Page 201 for a deeper discuss of GA.) Observed data in the inversion are absolute H/V values and peak frequency of H/V spectrum. Unknown parameters in the inversion are the S-wave velocity of each layer.

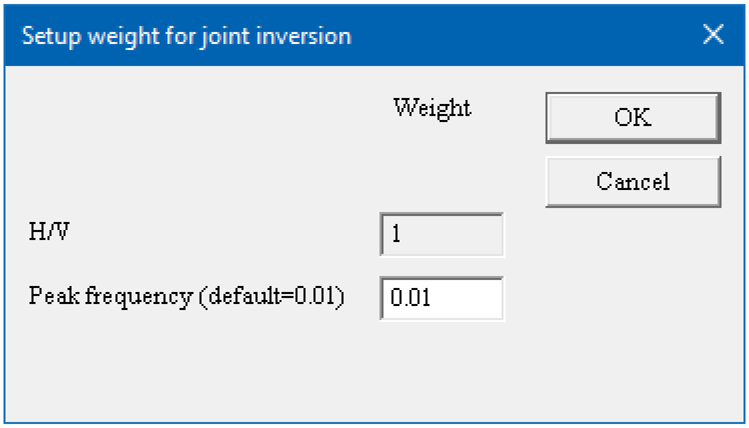
Set the parameters for the Genetic Algorithm. The default values (Iteration=50, Population=50, Binary digits=5, Crossover probability=0.5, Mutation probability=0.5) are suitable for most cases. Press the *OK* button to proceed.



Set the parameters for constraints depending on the site conditions. (Contact support@seisimager.com for assistance.) Press the *OK* button to proceed.



Set the weight for observed data. The default value of 0.01 for *Peak frequency* is suitable for most cases. Press *OK* to start the inversion.



An example of the inverted the result is shown below. The error between observed and thoretical H/V is smaller than the initial model (Model A, Page 417).

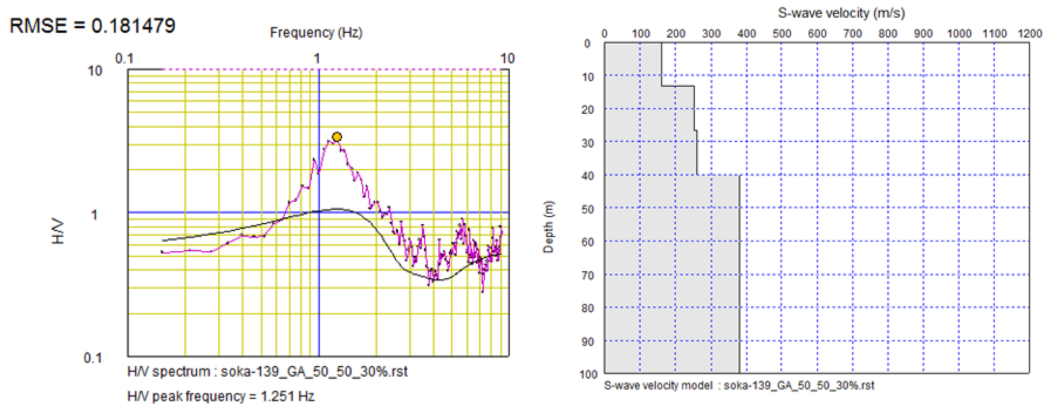
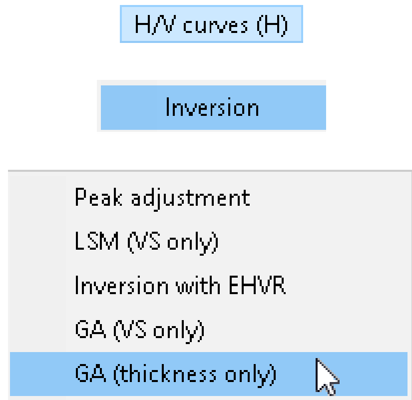


Figure 190: Measured and calculated H/V peak (left) and Vs model (right).

7.4.15.5 GA (Thickness Only)



Here, the S-wave velocity model is estimated by a Genetic Algorithm. Algorithm (See Sections 5.2.1.4 through 5.2.1.6 starting on Page 201 for a deeper discuss of GA.) Observed data in the inversion are absolute H/V values and peak frequency of the H/V spectrum. Unknown parameters in the inversion are thickness of each layer. Thickness of layer is difficult to estimate compared with S-wave velocity. Keep the number of layers as small as possible. A two-layer model is used as the initial model (Model B).

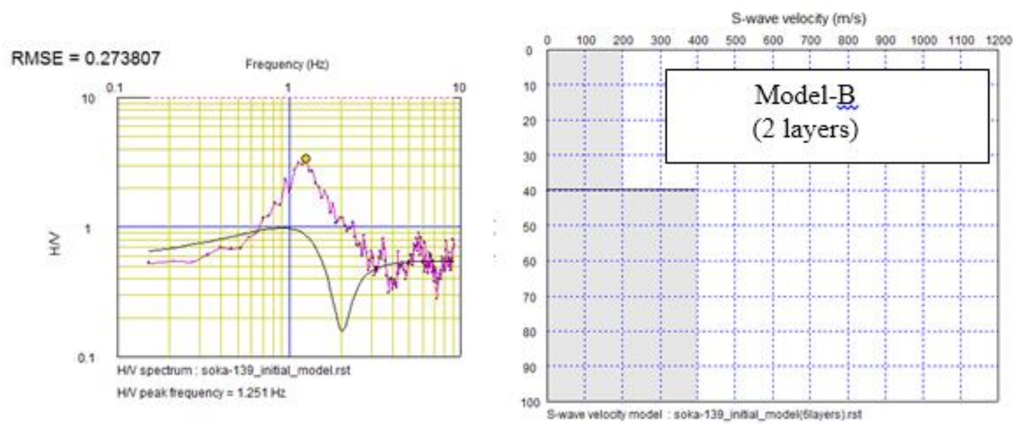
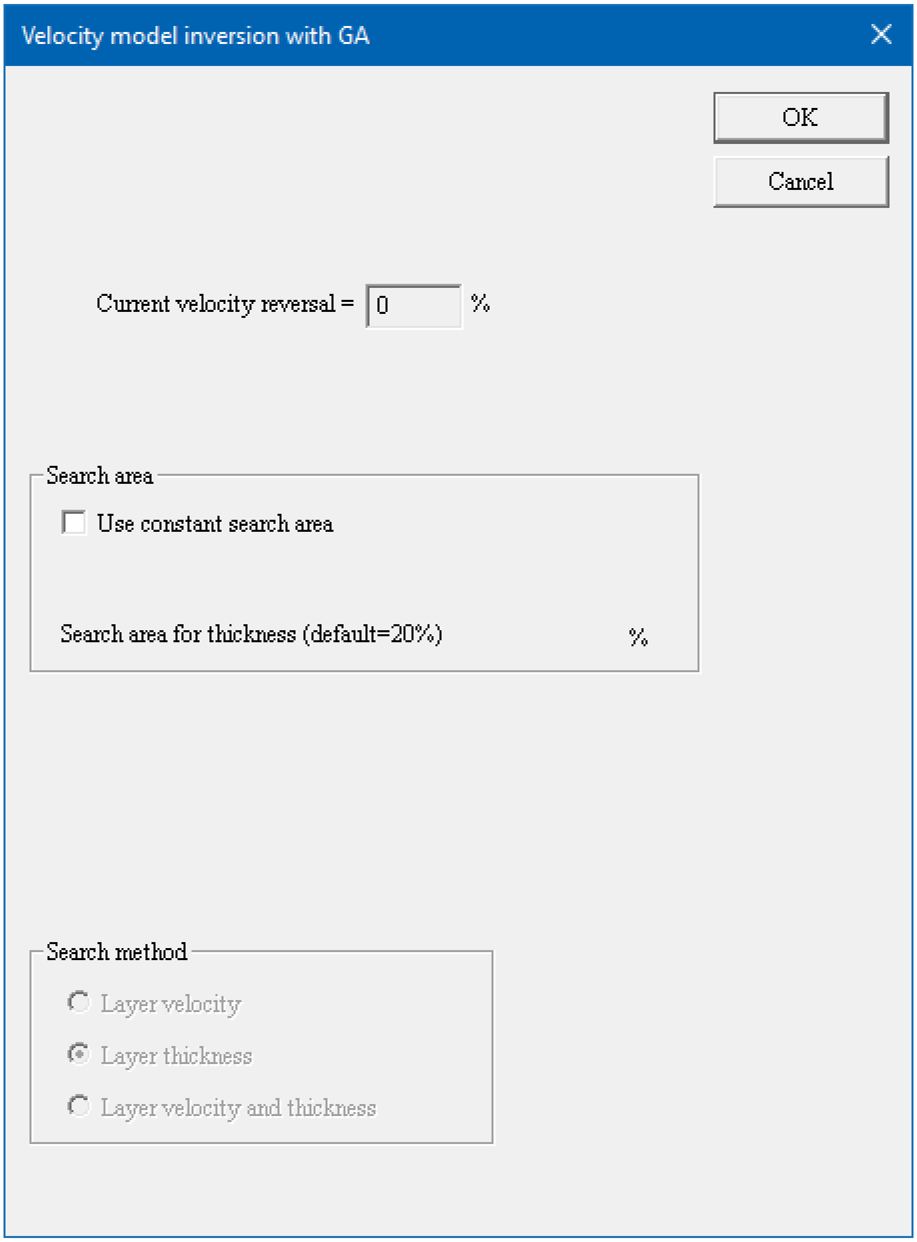


Figure 194: Measured and calculated H/V peak (left) and Vs model (right).

Set the parameters for constraints depending on the site conditions. Press the *OK* button to proceed. (Contact support@seisimager.com for assistance).



An example of the inverted result is shown below. Error between observed and thoretical H/V is smaller than the initial model (Model B).

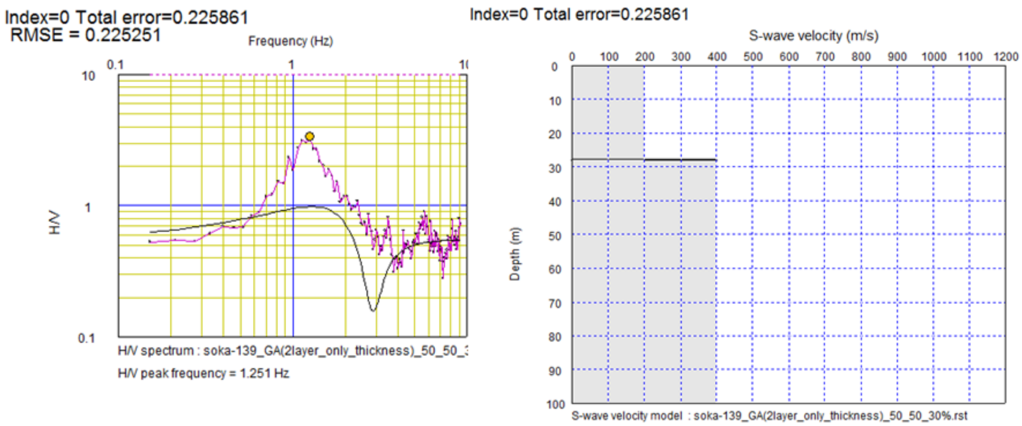
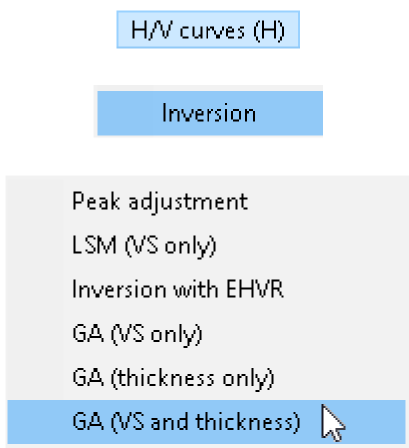
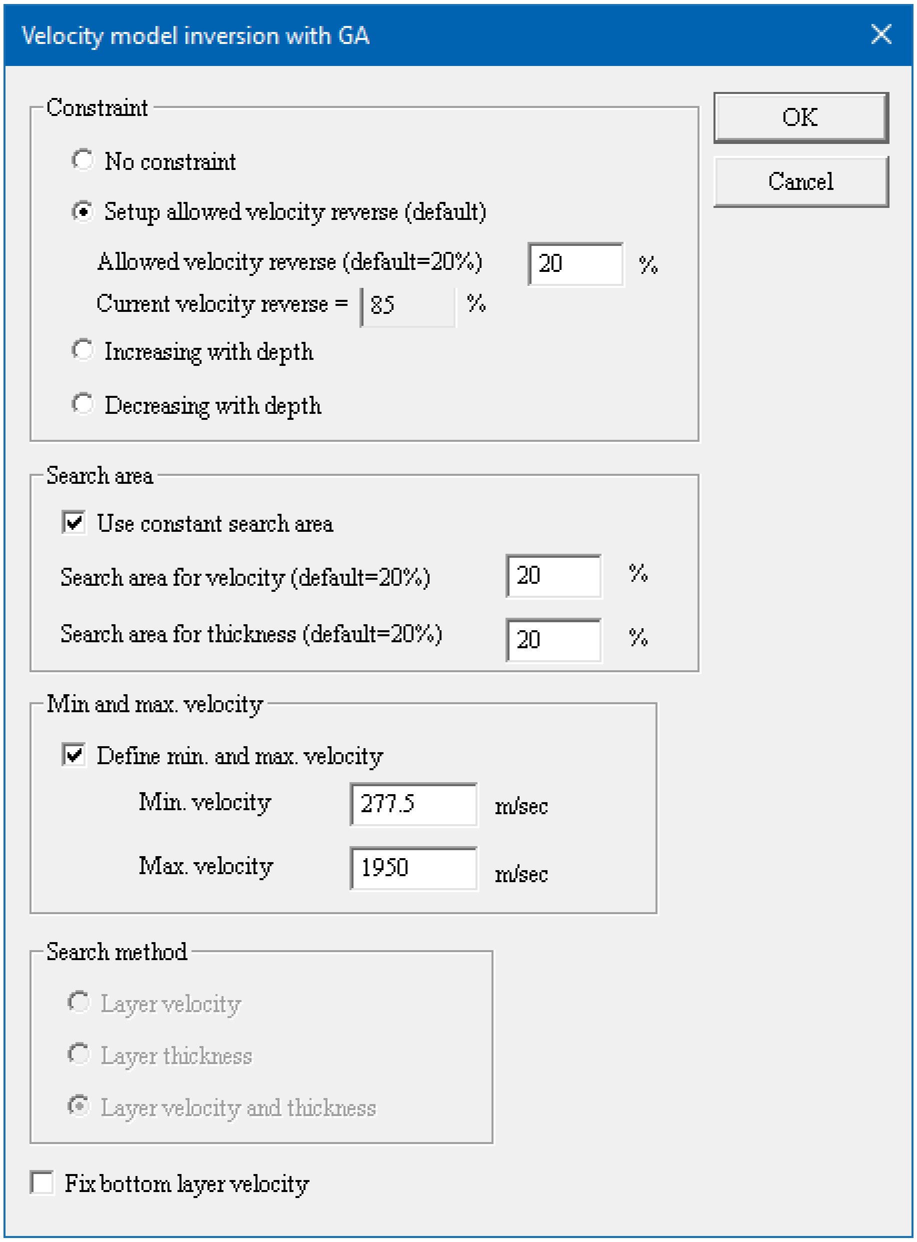


Figure 195: Measured and calculated H/V peak (left) and Vs model (right).

7.4.15.6 GA (VS AND THICKNESS)



The S-wave velocity model is estimated by a Genetic Algorithm. Algorithm (See Sections 5.2.1.4 through 5.2.1.6 starting on Page 201 for a deeper discuss of GA.) Observed data in the inversion are absolute H/V values and peak frequency of the H/V spectrum. Unknown parameters in the inversion are thickness and S-wave velocity of each layer. Estimating thickness and S-wave velocities simultaneously is difficult compared with the inversion estimating S-wave velocity only. Keep the number of layers as small as possible. The two-layer model (Model B) mentioned in the previous section is used as an initial model.



An example of the inverted result is shown below. Error between observed and thoretical H/V is smaller than the initial model (Model B).

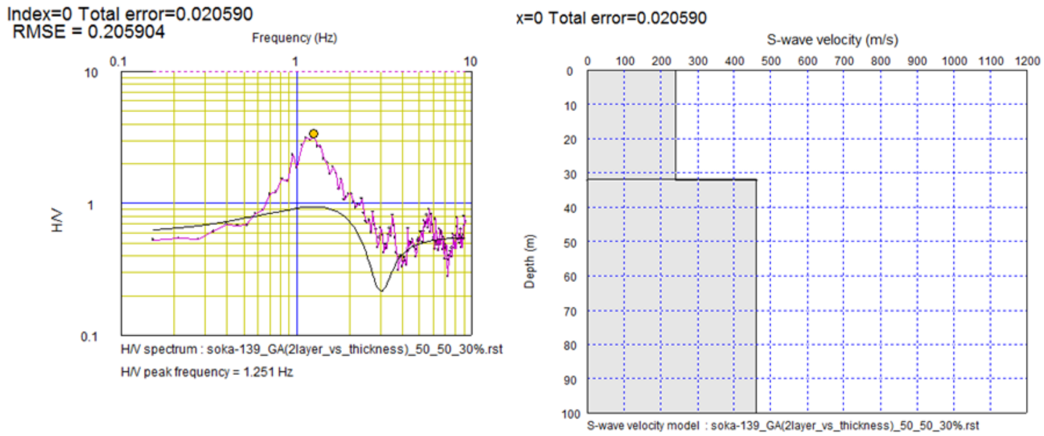
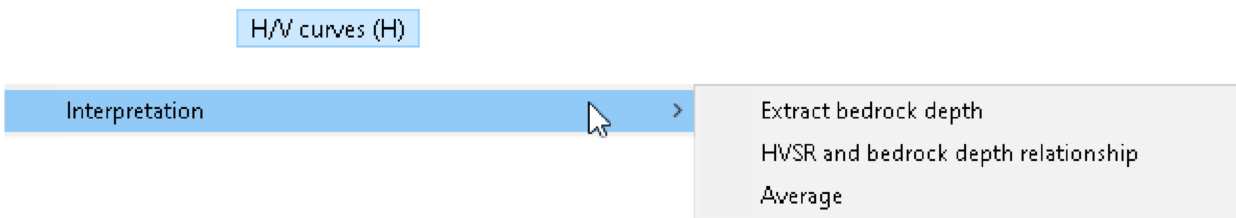


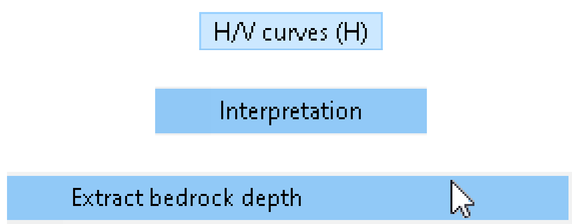
Figure 196: Measured and calculated H/V peak (left) and Vs model (right).

7.4.16 INTERPRETATION



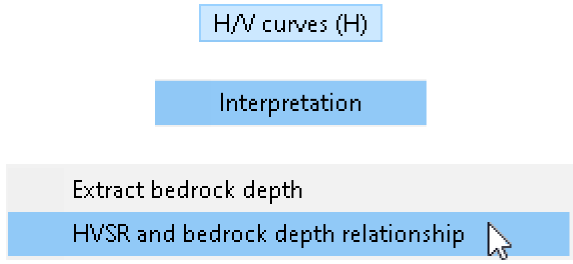
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.4.16.1 EXTRACT BEDROCK DEPTH



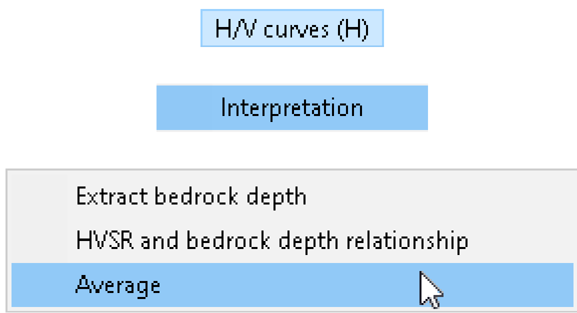
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.4.16.2 HVSR and Bedrock Depth Relationship



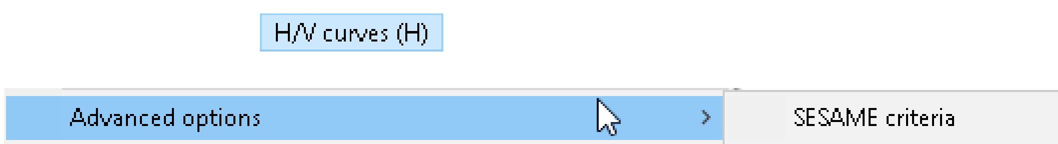
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.4.16.3 Average



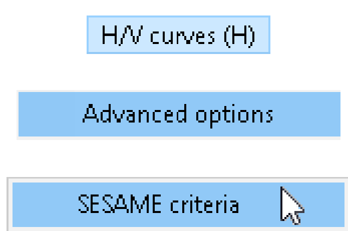
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.4.17 Advanced Options



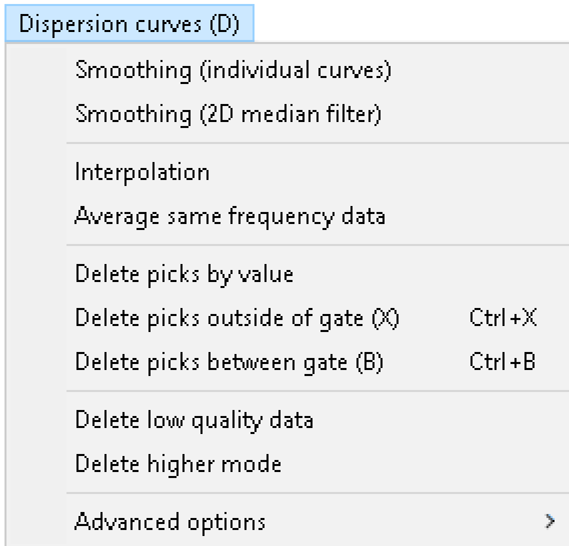
The item in the following sub-menu is rarely used, and when it is, support from Geometrics is generally required.

7.4.17.1 SESAME Criteria



This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.5 DISPERSION CURVES MENU



The **Dispersion curves** menu allows various editing of dispersion curves, including data point deletion and curve smoothing. Editing can be particularly important to remove outlying data points, noisy jitter, higher modes, etc. Relatively small-scale anomalies on dispersion curves cannot be resolved by the surface wave method, and they can cause instabilities in the inversion and/or unrealistic aspects in the final results. The overall trend of the dispersion curve(s) should be preserved in the editing process.

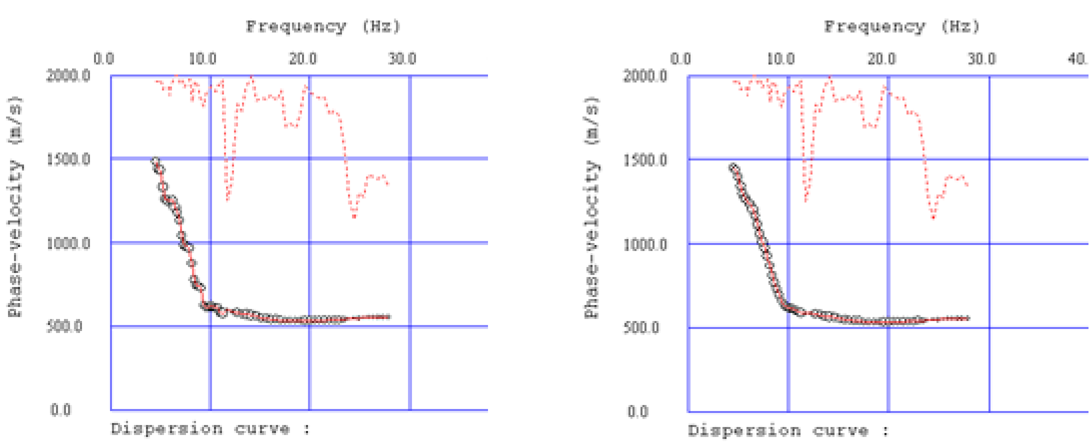


Figure 197: Raw dispersion curve (left) and smoothed dispersion curve (right).

7.5.1 SMOOTHING (INDIVIDUAL CURVES)

To smooth one dispersion curve, select *Smoothing (individual curves)*. The process recalculates one individual dispersion curve using the average of three adjacent data points in the direction of frequency. The original dispersion curve (shown on left) is converted to a smoother curve with less noisy jitter and the data points evenly distributed (shown on right).

When applied to a 2D dataset with multiple dispersion curves, the process acts on each individual curve. All the original curves (shown on left) are converted to smoother curves with less noisy jitter and the data points evenly distributed (shown on right).

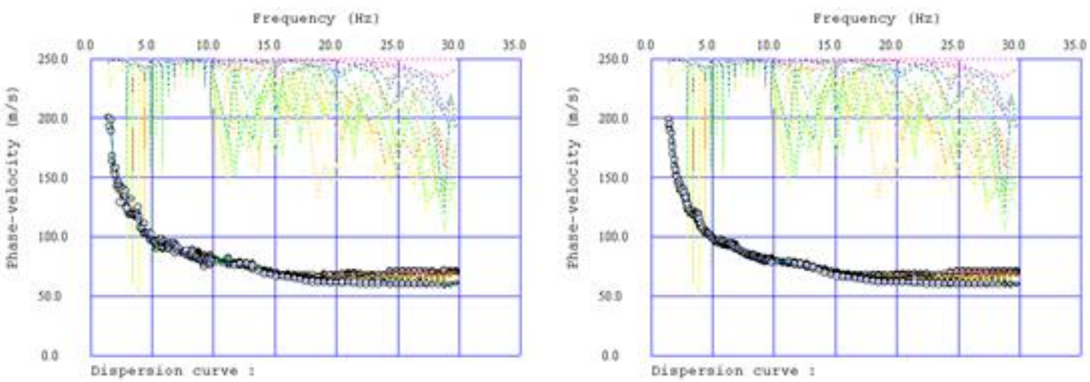
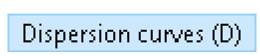
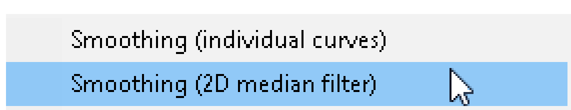


Figure 198: Raw dispersion curves (left) and smoothed dispersion curves (right).

Since *Smoothing (individual curves)* is applied in the direction of frequency, you may find that for some 2D datasets, a smoothing function applied from curve to curve yields preferable results.

7.5.2 SMOOTHING (2D MEDIAN FILTER)





To smooth between dispersion curves in a 2D dataset, select *Smoothing (2D median filter)*. This process recalculates the set of dispersion curves using the median of five adjacent data points from curve to curve. The original dispersion curves (shown on left) are converted to smoother curves with fewer outlying data points and the relative difference between individual curves preserved (shown on right).

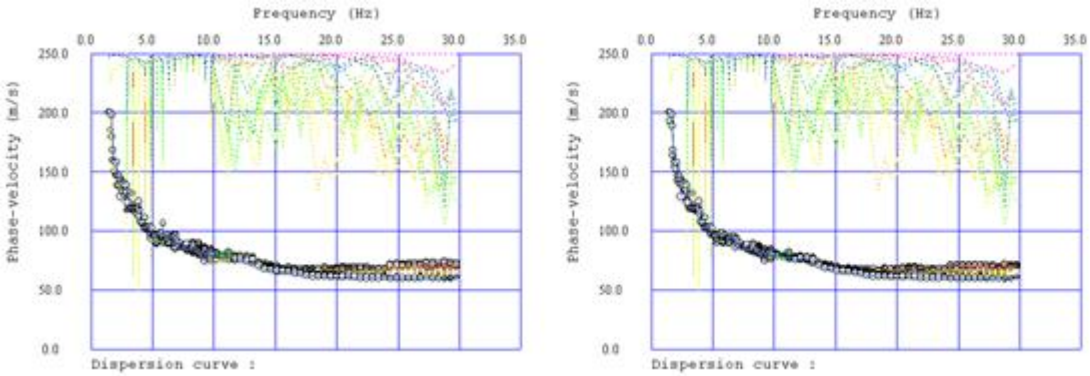
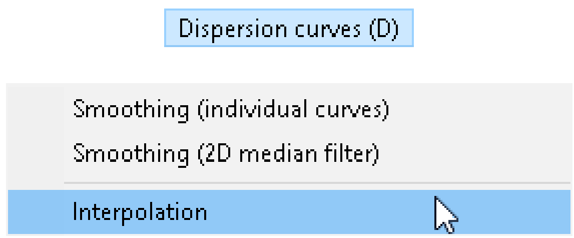


Figure 199: Raw dispersion curves (left) and filtered dispersion curves (right).

7.5.3 INTERPOLATION



If the dispersion curve is oversampled, resulting in a large number of phase velocities, the inversion can take a long time. It is sometimes advantageous to resample and interpolate the dispersion curve prior to doing the inversion. To do so, read in the dispersion curve.

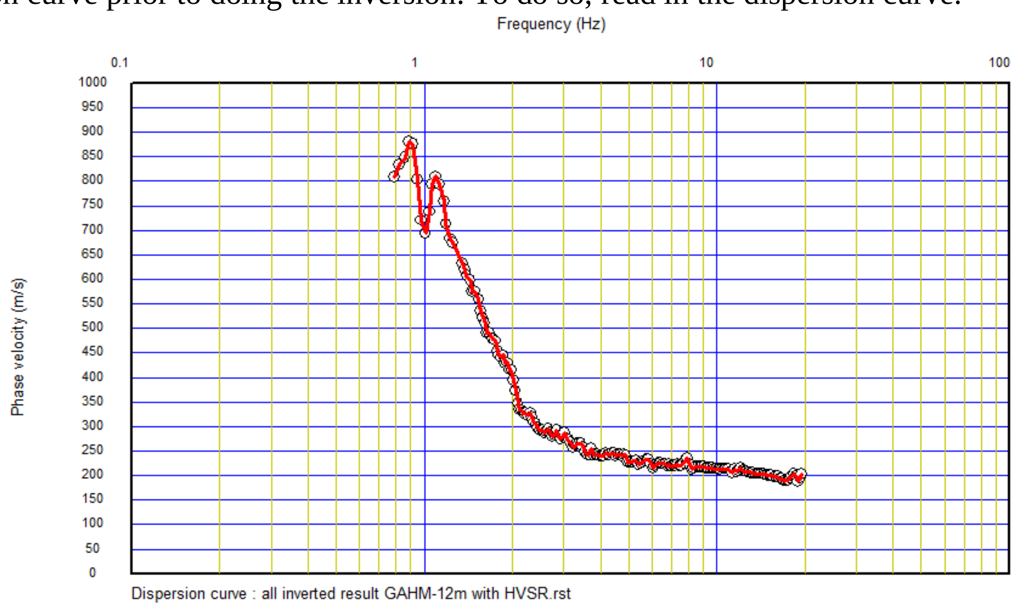
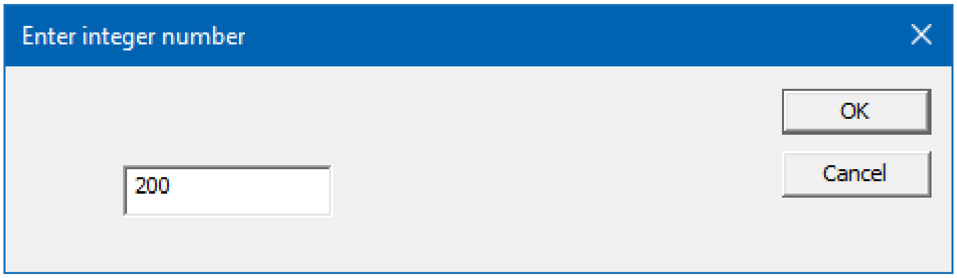


Figure 200: Raw dispersion curve.

Select *Dispersion curves* | *Interpolation*. You will be presented with the following dialog:



The smaller the number, the fewer the points in the resampled curve. For instance, in this case, to reduce the number of points by ½, enter 100. The resampled dispersion curve is shown below.

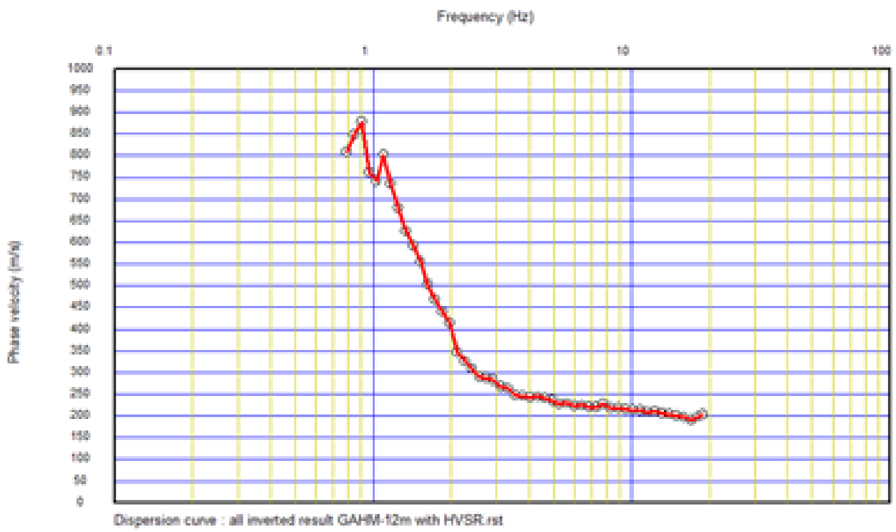
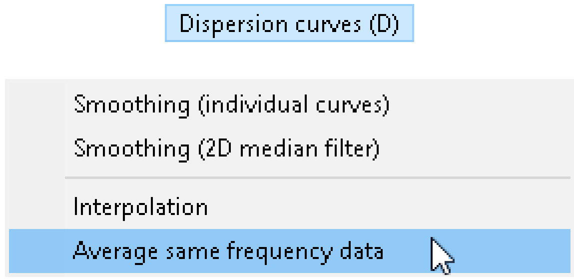
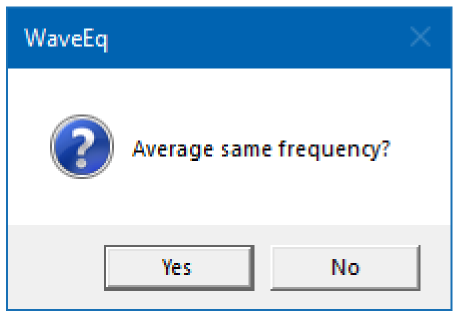


Figure 201: Interpolated dispersion curve.

7.5.4 AVERAGE SAME FREQUENCY DATA



You may average dispersion curves together using the following procedure. Read in and display a dispersion curve. Next, read in and *append* the rest of the curves you wish to average together. With each appended curve, you will be prompted to average them:



If you know that you do not want to edit the curves before averaging them, press *Yes*. On the other hand, if you wish to view and/or edit the curves prior to averaging them, press *No*.

In this example, we have read in two dispersion curves, as shown below.

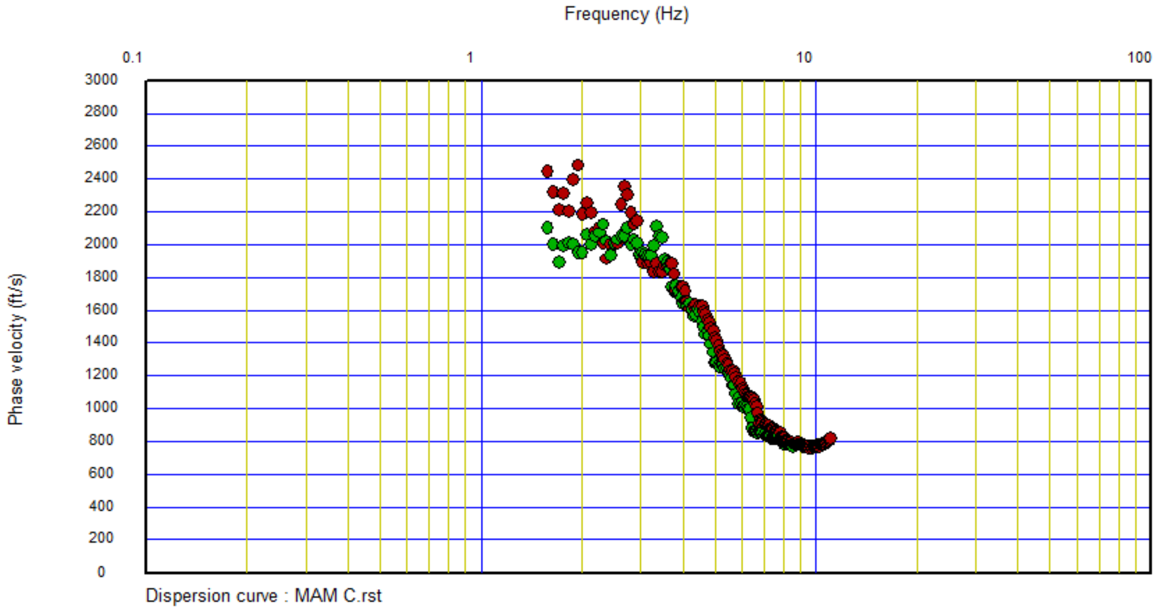


Figure 202: Two dispersion curves to be averaged together.

When asked if we wanted to average them, we chose *No*. Now we have a chance to edit them if necessary. When we are ready to average them together, we select *Dispersion curves* | *Average same frequency data* and the two curves will be averaged and displayed:

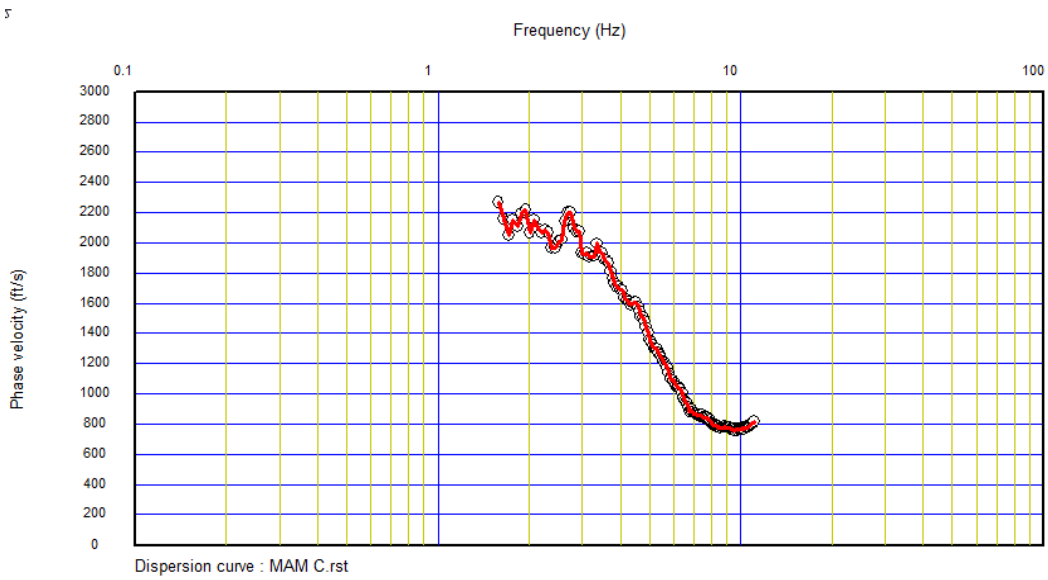
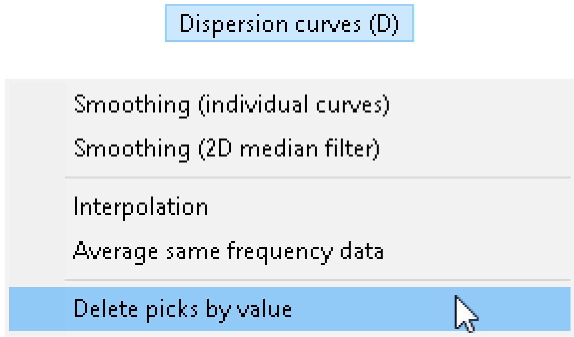
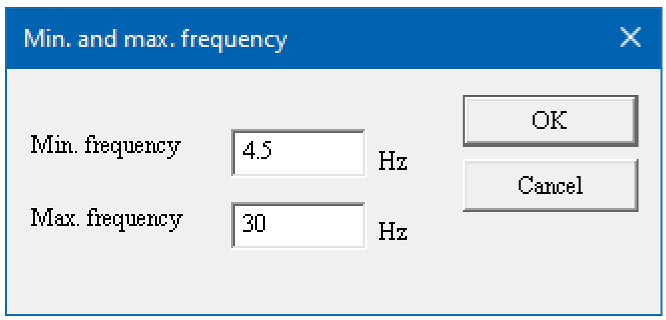


Figure 203: Frequency-averaged dispersion curves of Figure 202.

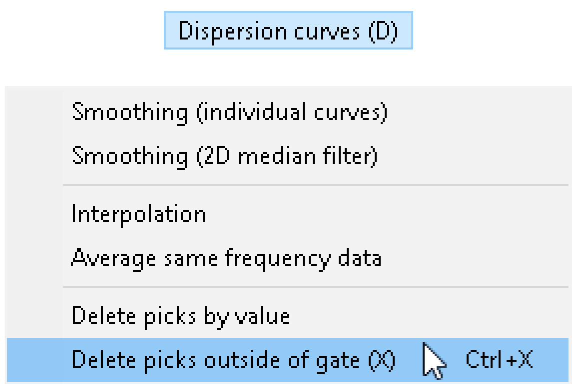
7.5.5 DELETE PICKS BY VALUE



To set the minimum and maximum gate frequencies by entering specific values, select *Delete picks by value*.



7.5.6 DELETE PICKS OUTSIDE OF GATE [CTRL+X]



As an alternative, the frequency range can be set visually. Select *Delete picks outside of gate* and two gates will appear on the dispersion curve plot (shown on left in Figure 204). If needed, press the *Esc* key to exit.

Red indicates which gate is active and green indicates which gate is inactive. Use the *right*- and *left-arrow* keys to move the red gate to the new minimum frequency (shown on right in Figure 204).

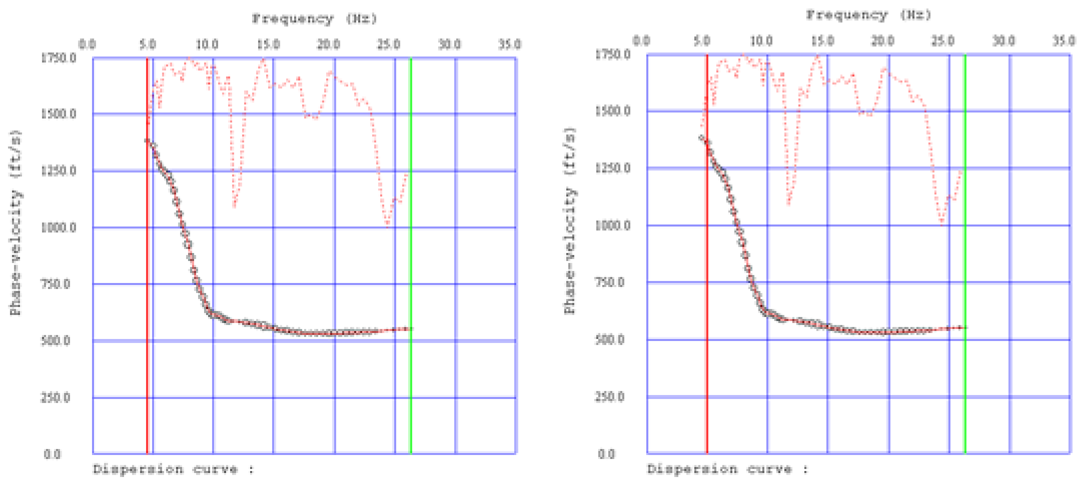


Figure 204: Using gate to trim ends of dispersion curve.

After the first gate is positioned, press the *Enter* key and the next gate will become active. Use the *arrow* keys to move the gate to the new maximum frequency (shown on left in Figure 205). Press the *Enter* key when done and the trimmed dispersion curve is displayed (shown on right in Figure 205).

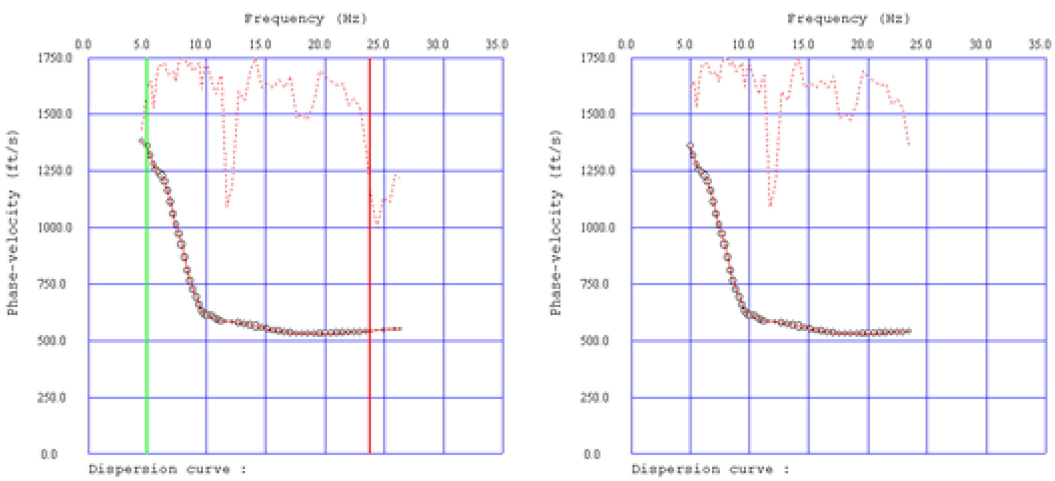


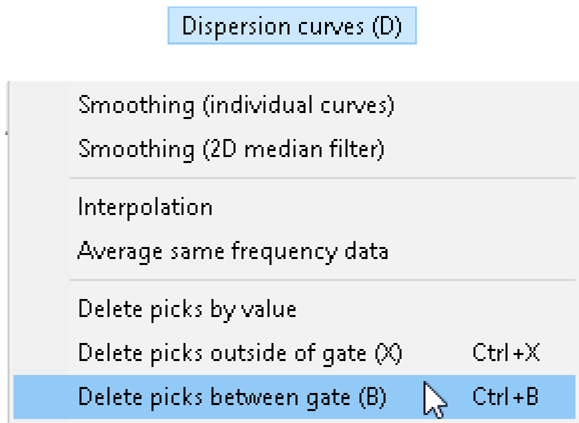
Figure 205: Trimmed dispersion curve (right).

In setting the gates, exclude only the points that are poor quality or spurious. Commonly, on the low frequency end, the phase velocity will begin to decrease, and the dispersion curve will slope downward (when phase velocity is plotted on the y-axis). This decrease in phase velocity is usually an artifact of difficult picking because the peak amplitudes at low frequencies become less distinct.

Note: *Hold down the Shift key to fine tune the gate settings.*

To determine where to set the new maximum frequency on the high frequency end, the quality line can be used to assess where the quality starts to decrease (usually due to weak amplitudes at higher frequencies). In addition to quality, if the phase velocity starts to increase, that is likely related to higher mode energy and those points should be deleted.

7.5.7 Delete Picks Between Gate [CTRL+B]



To remove points within a gate, select *Delete picks between gate*. The gates are positioned as described for *Delete picks outside of gate*, except that the inactive gate is indicated by teal blue.

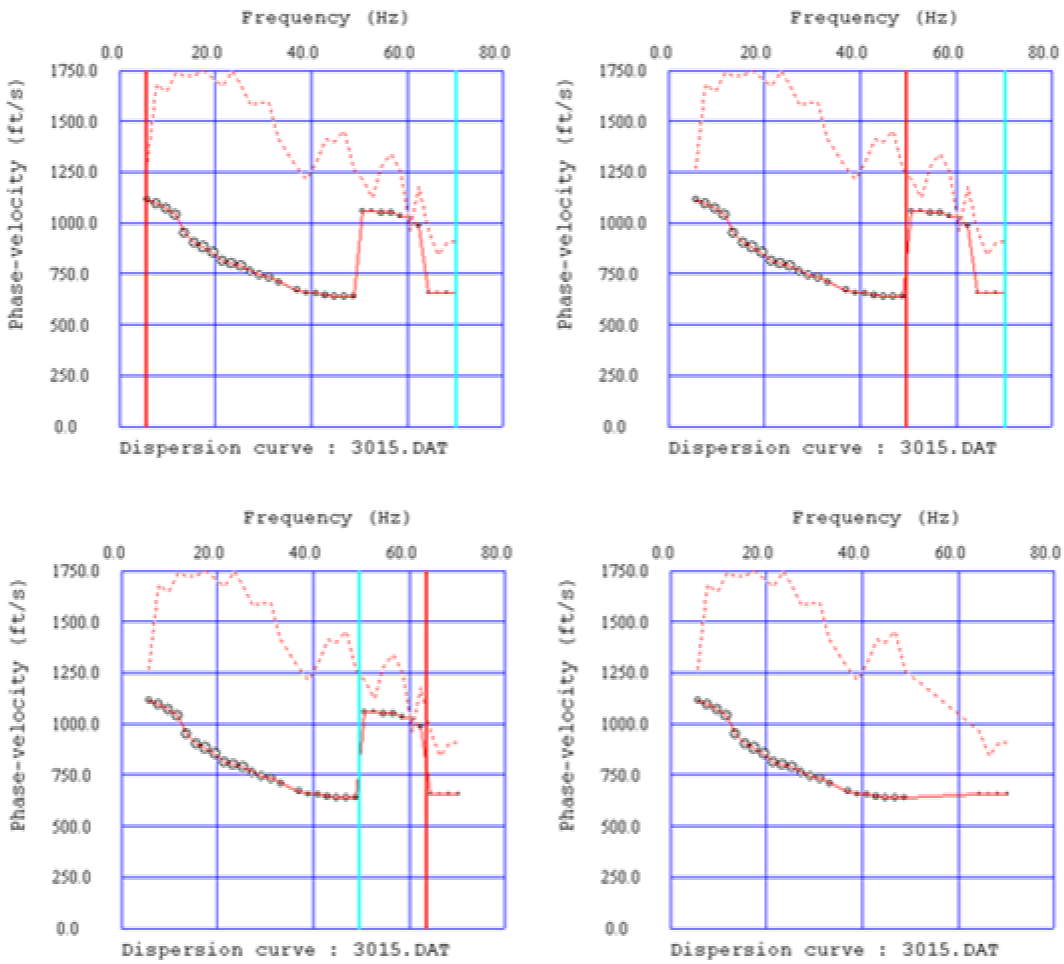
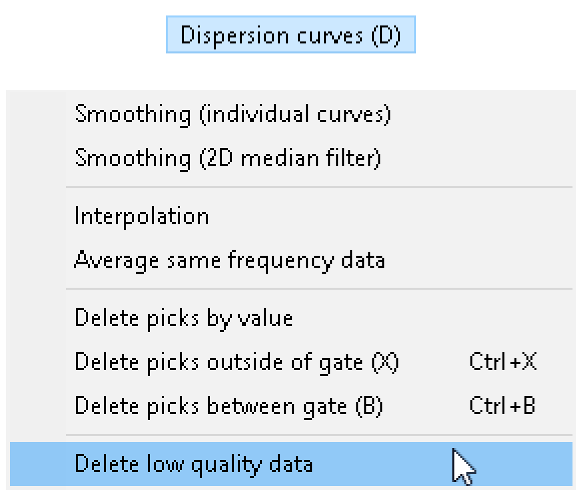
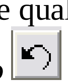


Figure 206: Removing spurious data (in this case, higher mode) from dispersion curve.

7.5.8 DELETE LOW QUALITY DATA



To automatically delete low-quality picks, select *Delete low quality data*. Low quality tolerance is set under *Advanced options | Setup low quality limit*. Refer to Section 7.5.10, Page 444, on how to adjust the quality tolerance.

Upon selection, all the points that fall below the quality limit will be deleted (shown on right below). To reverse the changes, press the *Undo*  button.

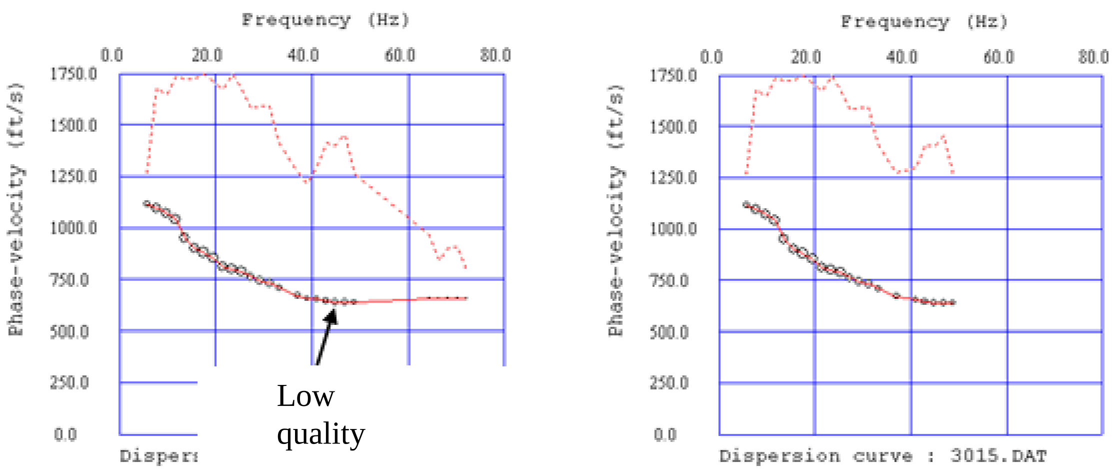
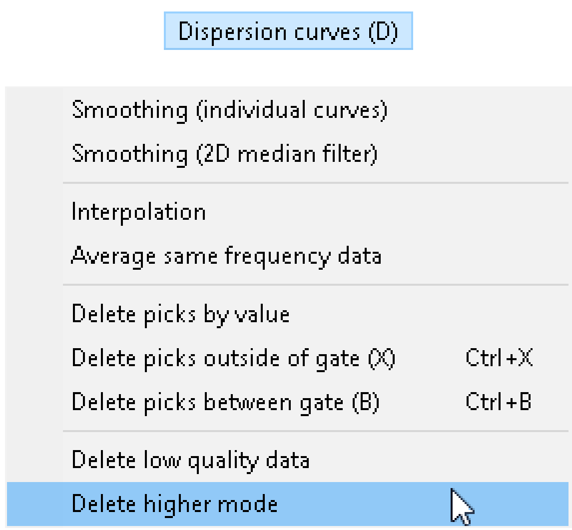


Figure 207: Removing low-quality data from dispersion curve.

7.5.9 Delete Higher Mode



If higher mode picks appear in the dispersion curve (shown on left below), select *Delete higher mode* to automatically delete the picks (shown on right below). Higher mode tolerance is set under *Advanced options* | *Setup higher mode selection*. Refer to Section 7.5.10, Page 444, on how to adjust the higher mode tolerance.

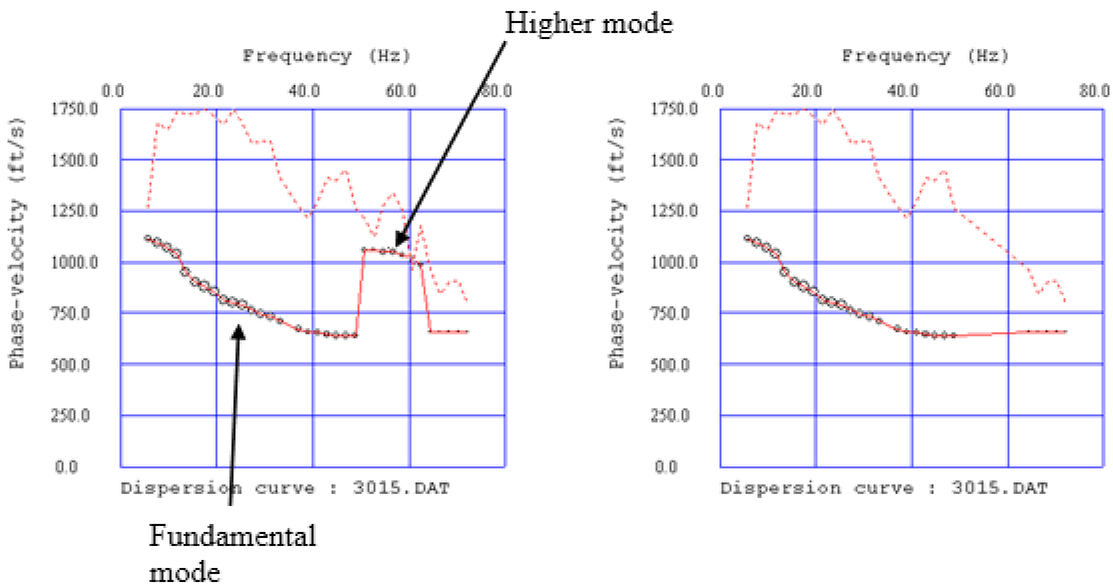
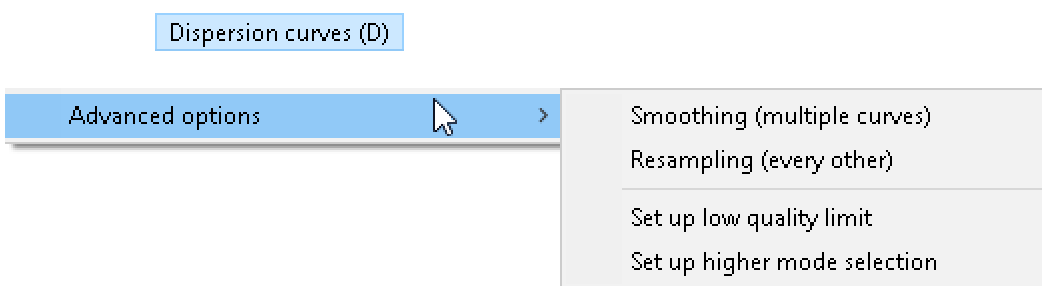


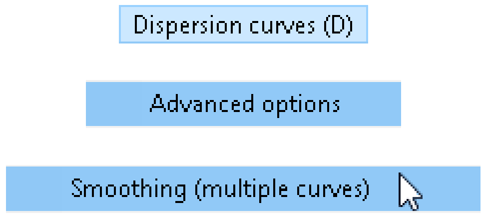
Figure 208: Removing higher mode points from dispersion curve.

7.5.10 Advanced Options



Continue.

7.5.11 SMOOTHING (MULTIPLE CURVES)



To smooth between dispersion curves in a 2D dataset, select *Smoothing (multiple curves)*. The process is similar to *Smoothing (2D median filter)* (Section 7.5.2, Page 434), except that the average of five adjacent data points is used instead of the median. The original dispersion curves (shown on left below) are converted to smoother curves with fewer outlying data points but the relative difference between the individual curves is minimized (shown on right below).

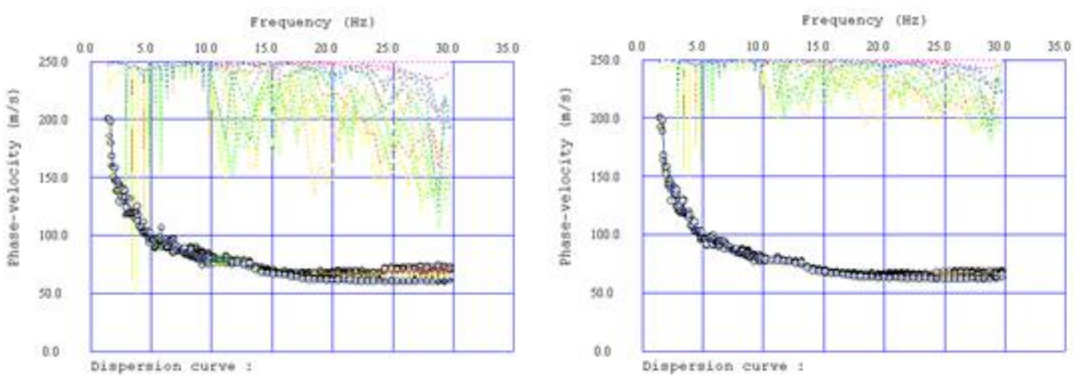
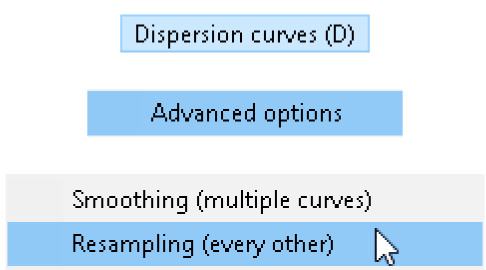


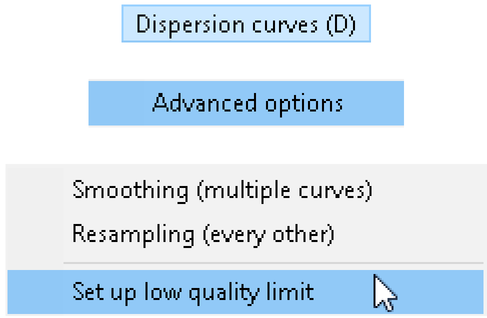
Figure 209: Smoothing dispersion curves.

7.5.12 RESAMPLING (EVERY OTHER)

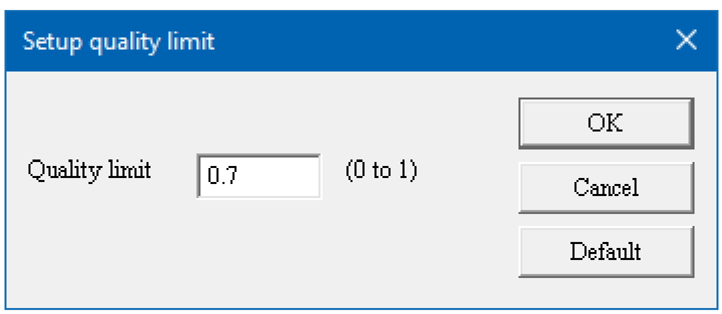


Resampling (every other) is used to speed up processing by decimating the dataset (removes every other sample).

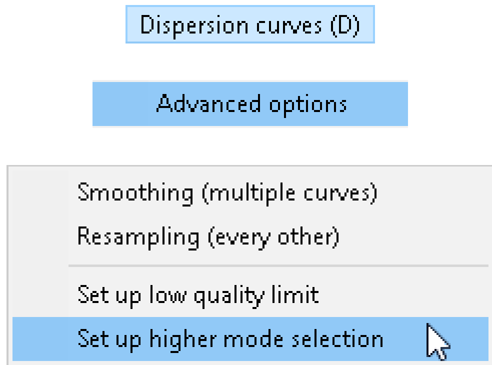
7.5.13 SET UP LOW QUALITY LIMIT



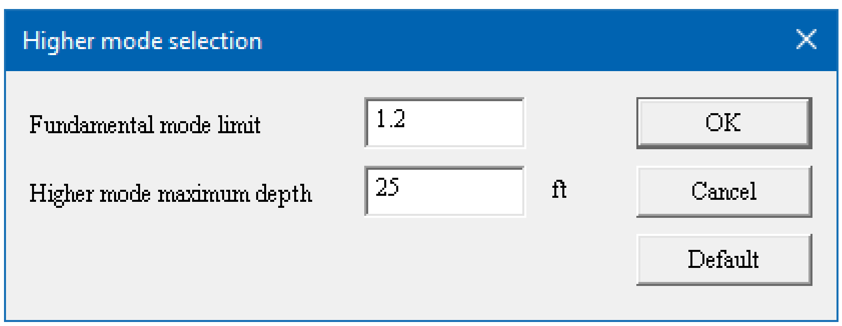
Setup low quality limit allows the filter limit that is used when the function *Delete low quality data* is selected to be set. Quality is a relative measurement normalized against the highest signal for each dataset. Quality is indicated by the quality line and the data point circle size on the dispersion curve plot. The largest circle size possible is equal to 1.0 and the smallest circle size possible is a dot, which equals zero. The default *Quality limit* value is 0.7, meaning that where the quality line goes below 70% of the relative scale, the associated data points will be deleted. The default *Quality limit* value is suitable for most cases.



7.5.14 SETUP HIGHER MODE SELECTION

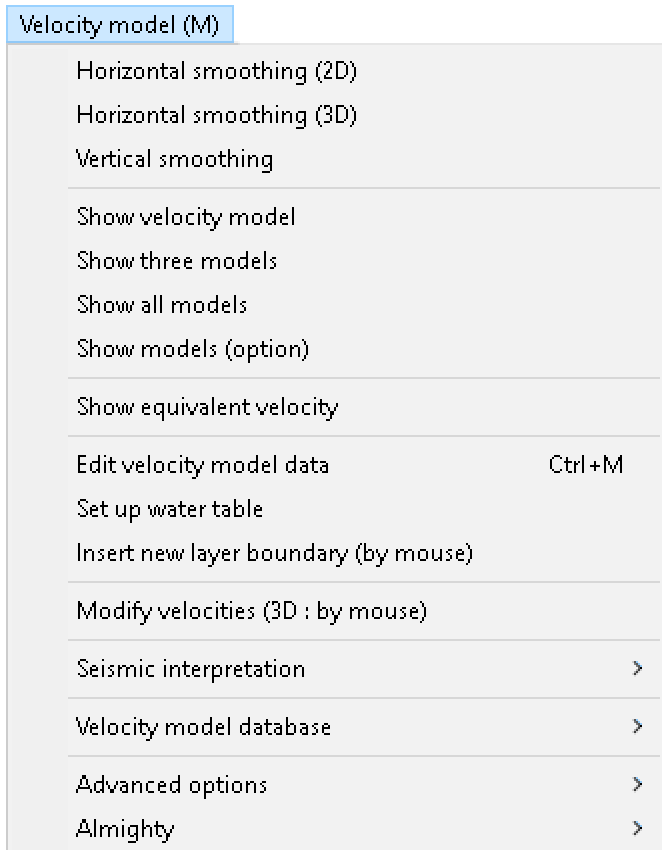


Setup higher mode selection allows the filter limits used when the function *Delete higher mode* is selected to be set. The default *Fundamental mode limit* value is 1.2, meaning that where the value of any data point is 20% more than adjacent values, those points are deleted. This value can be set between 1.0 and 5.0. The *Higher mode maximum depth* is the depth as determined from the one-third-wavelength approximation, below which the associated data points will not be allowed.

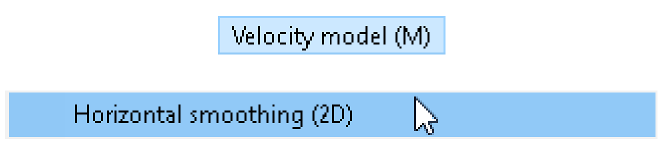


7.6 VELOCITY MODEL MENU

The **Velocity model** menu allows editing and setting of parameters for calculation of velocity models. In addition, it includes display controls and some analyses for interpretation.

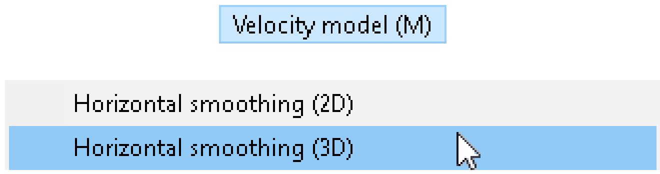


7.6.1 HORIZONTAL SMOOTHING (2D)



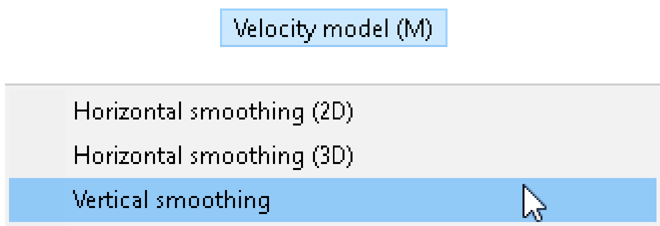
To horizontally smooth between individual velocity models in a 2D dataset, select *Horizontal smoothing (2D)*. The process recalculates the set of velocity models using the average of three adjacent data points from model to model. Any sharp lateral velocity gradients between the original velocity models are smoothed.

7.6.2 Horizontal Smoothing (3D)

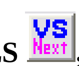


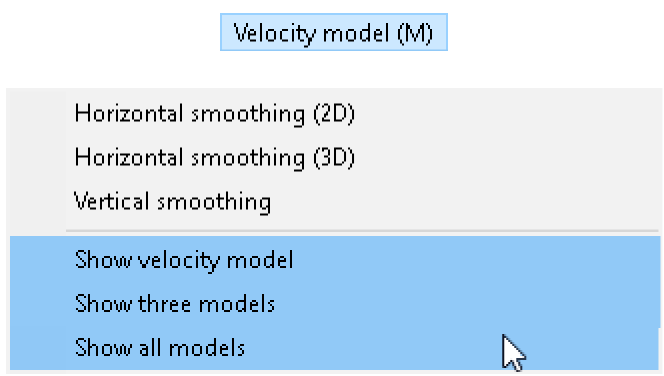
Horizontal smoothing (3D) is a highly specialized and rarely used feature. Please contact support@seisimager.com for assistance.

7.6.3 Vertical Smoothing



To vertically smooth individual velocity models in a 2D dataset, select *Vertical smoothing*. The process recalculates individual velocity models using the average of three adjacent data points in the direction of depth. Any sharp vertical velocity gradients in the original velocity model are smoothed.

7.6.4 Show Velocity Model , Show Three Models , Show All Models 

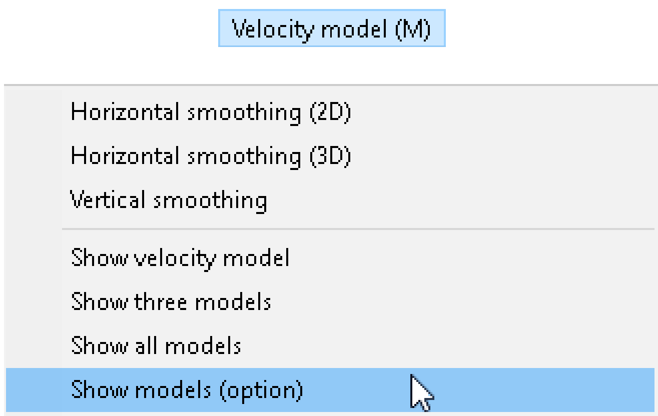


Once a velocity model exists, *Show velocity model* , *Show three models* , and *Show all models*  are used to control the display.

Show velocity model and the associated button display one velocity model in black with grey shading. *Show three models* and the associated button display one model in red with the down-line adjacent model in green and the up-line adjacent model in blue for a total of three models. *Show all models* and the associated button display all models starting with red, blue, green, and with the rest of the colors unique but undefined. They are undefined since with all models displayed, it is the overall trend that is meant to be discerned, not the individual models.

The *Show velocity model* button is useful for toggling from the dispersion curve to velocity model view.

7.6.5 SHOW MODELS (OPTION)



Section 7.3.2 (Page 344) describes how you may customize the number of dispersion curves that are shown at any one time by selecting *Option* and entering the number of curves. This applies to the number of velocity models as well. For instance, if you choose to display five dispersion

curves, then selecting *Velocity model* | *Show models (option)* will display only the models

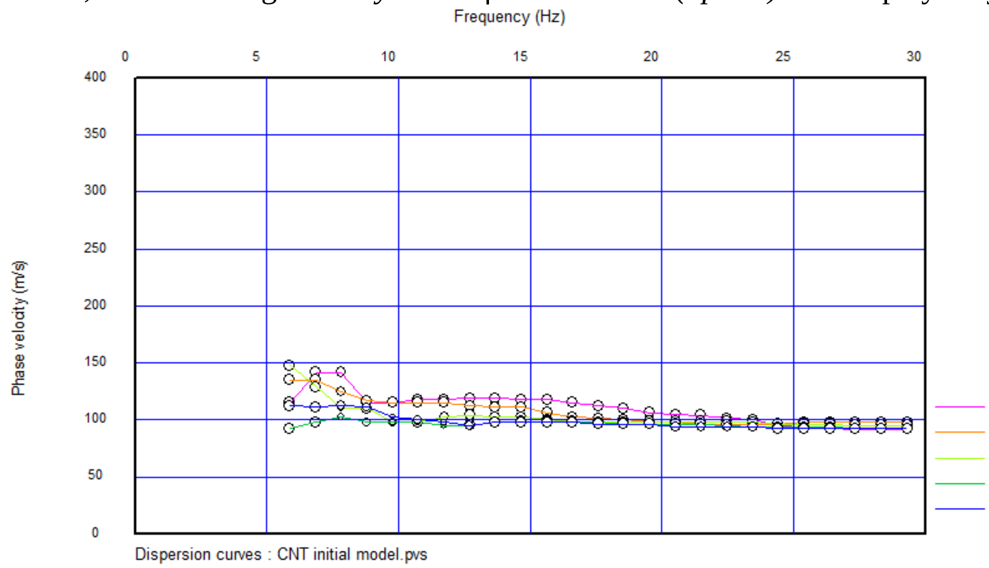


Figure 210: Dispersion curves.

for the displayed dispersion curves:

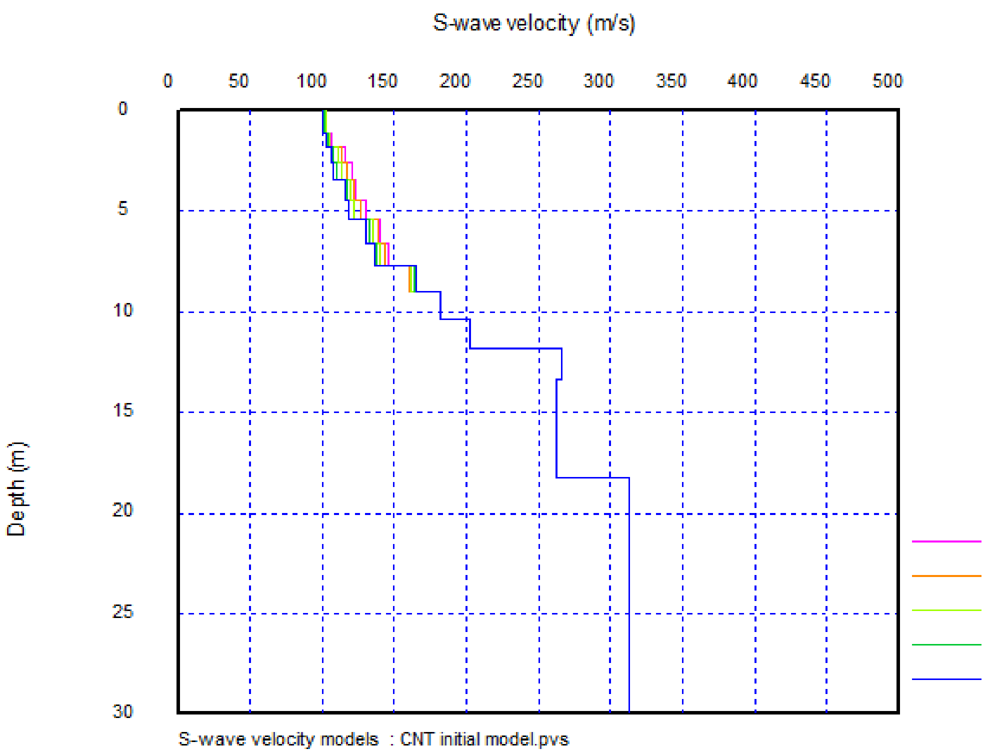
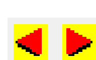
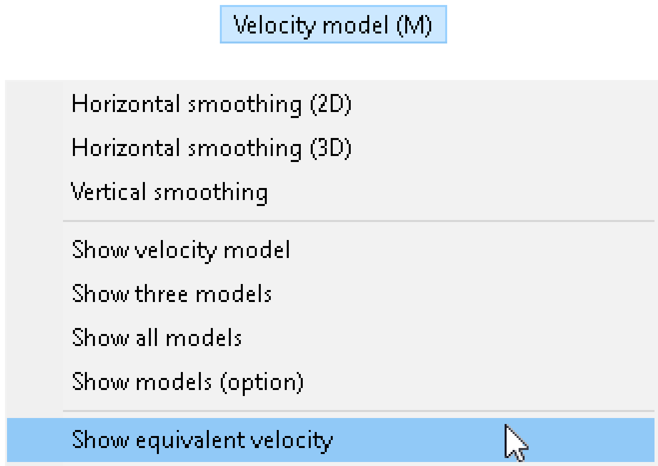


Figure 211: Velocity models corresponding to dispersion curves shown in Figure 210.

You may then scroll through the models using the  buttons, the same way you can scroll through the dispersion curves.

7.6.6 Show Equivalent Velocity



You may display the “Equivalent” (average) velocity by toggling this option:

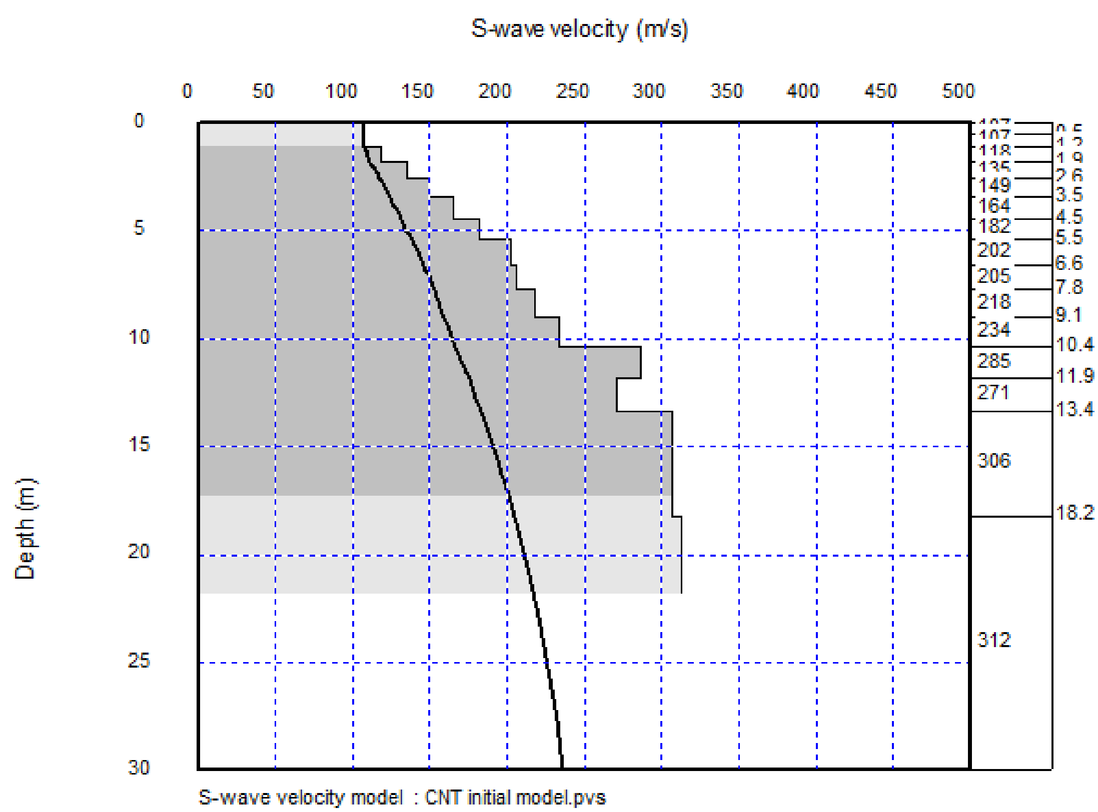
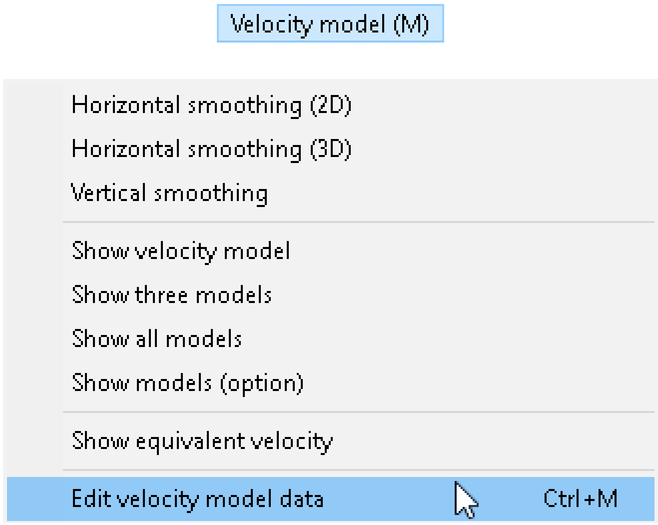
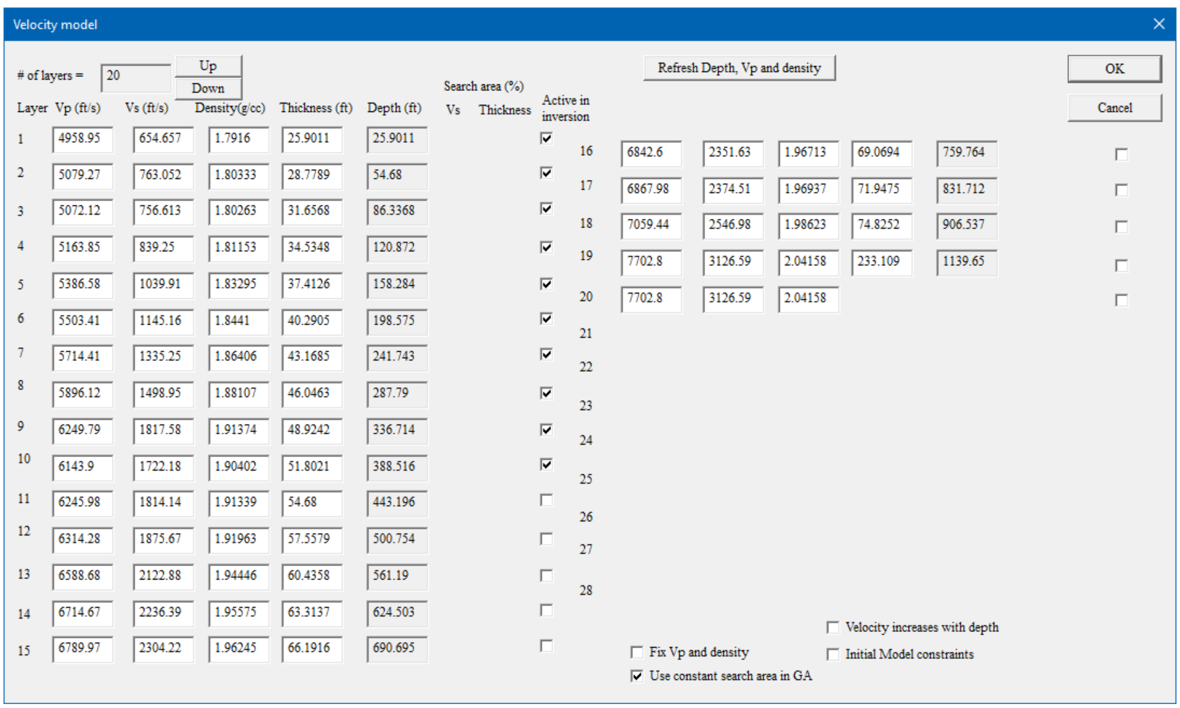


Figure 212: Velocity model with average velocity curve.

7.6.7 Edit Velocity Model Data [CTRL+M]



If necessary, you may manually edit the velocity model data. Select *Velocity model | Edit velocity model data*:



Press *Refresh depth, V_p and density* to update V_S and density using the V_S-V_p and V_p-density relationships.

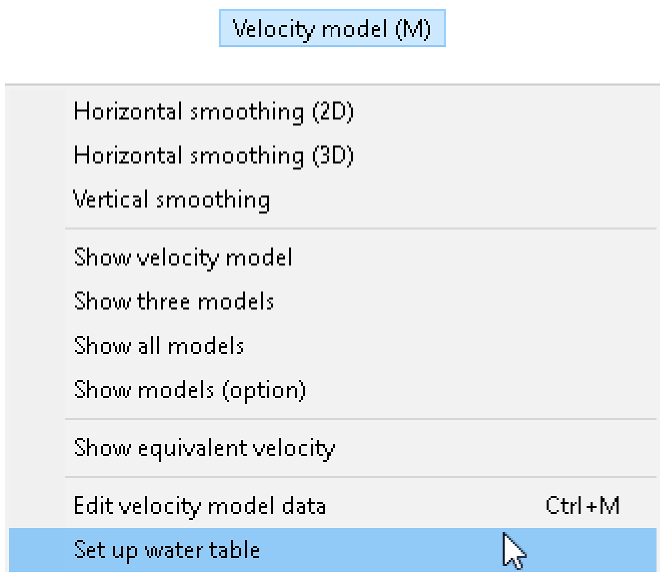
Check *Fix V_p and density* to keep V_p and density to the values shown in the dialog. If you uncheck this box, V_p and density will be automatically calculated from V_S.

Uncheck *Use constant search area in GA* if you would like to be able to set the Genetic Algorithm search radii individually. This feature is rarely used; contact support@seisimager.com for assistance.

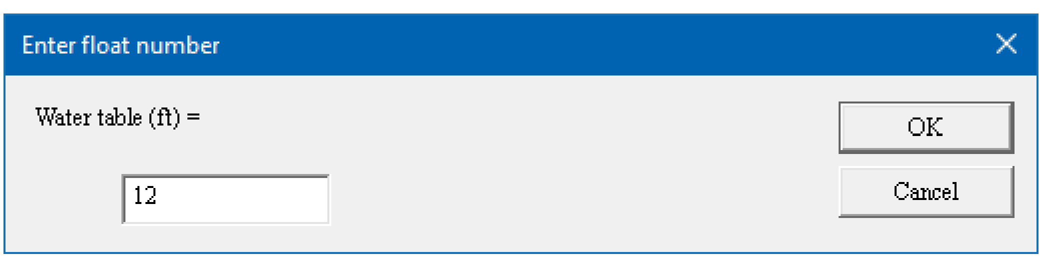
Check *Velocity increases with depth* to force velocities to increase with depth.

Check *Initial Model constraints* to set the area (+/- 30%) of V_S changed in the inversion.

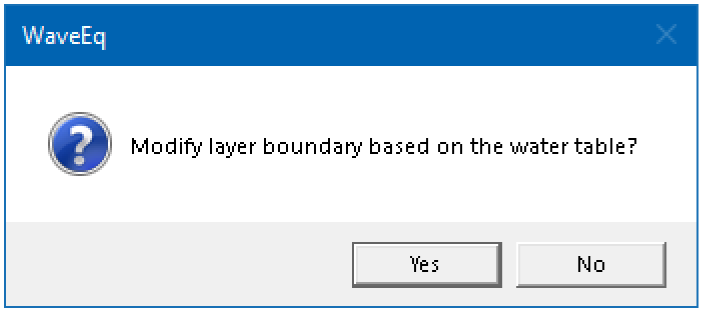
7.6.8 SET UP WATER TABLE



Once a velocity model exists, the depth of the water table can be set with *Setup water table*. The default *Water table* value is zero; enter the applicable value and press *OK*.

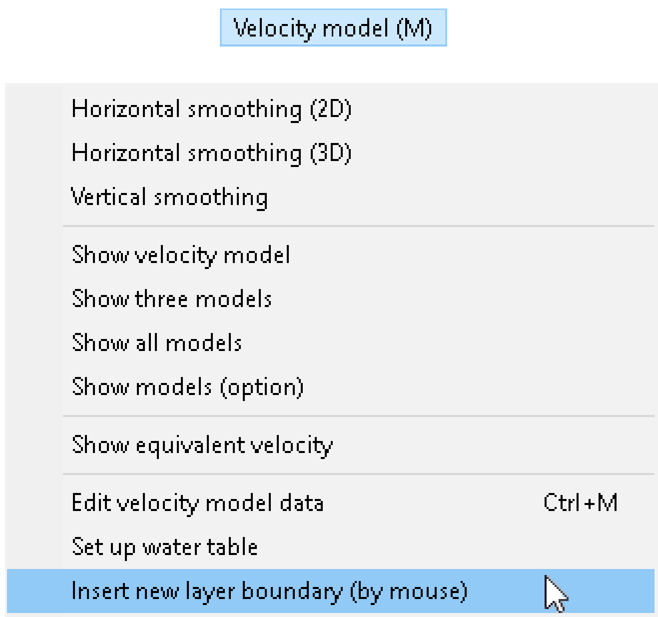


The model layer boundaries will be adjusted to place a boundary at the water table depth. Press *Yes* to confirm the change.



The water table is now set. Open the **View** menu and select *Show water table depth* to display the water table as a blue line with the standard water table symbol on the velocity model.

7.6.9 Insert New Layer Boundary (By Mouse)



To insert a new layer, select *Velocity* | *Insert new layer boundary (by mouse)*, and then click on the depth at which to insert the layer. Below is an unedited velocity model:

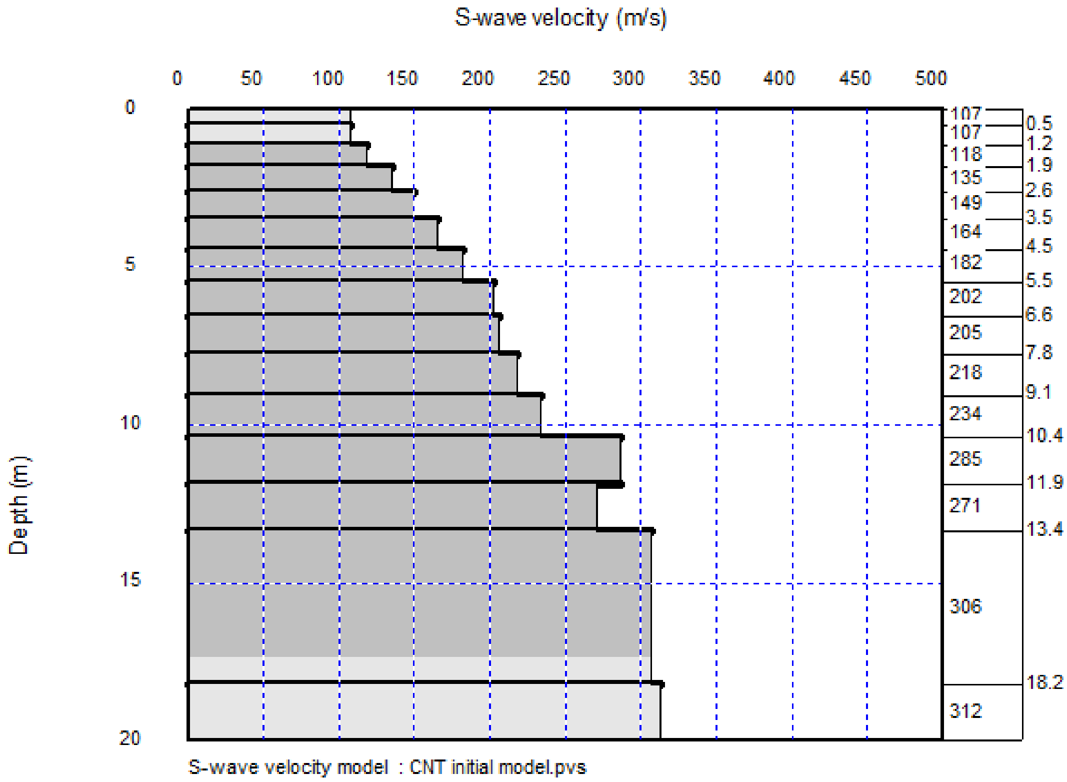


Figure 213: V_S model.

Next is the same model, with a new layer inserted at 14.6 meters:

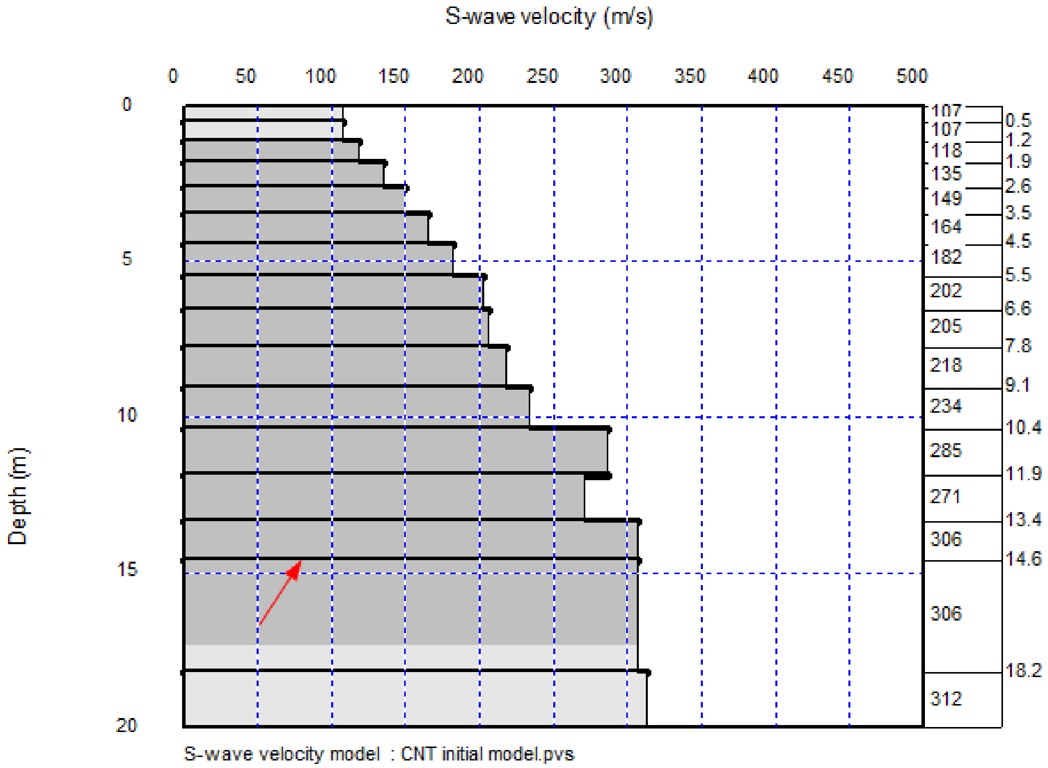
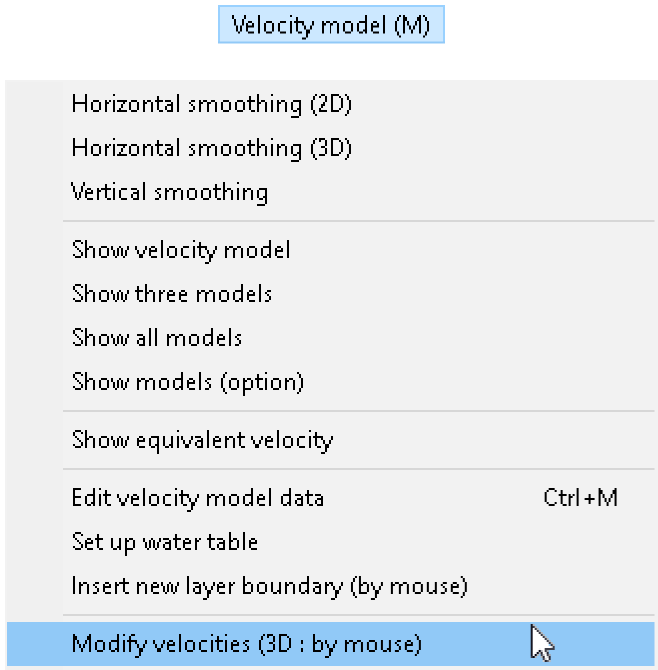


Figure 214: Velocity model of Figure 213 with new layer inserted.

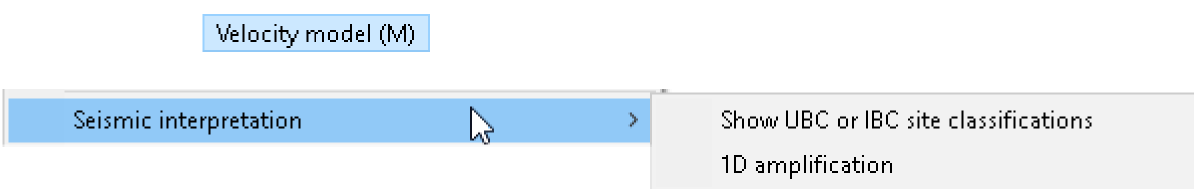
See Section 7.6.7, Page 453, to update the velocity of the new layer.

7.6.10 Modify Velocities (3D: By Mouse)



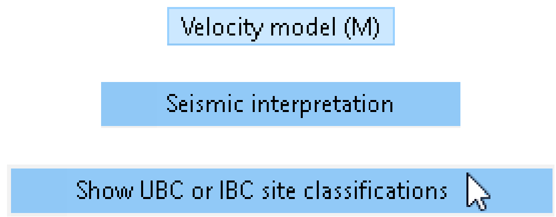
This feature allows you to modify velocities in a 3D model. This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.11 Seismic Interpretation



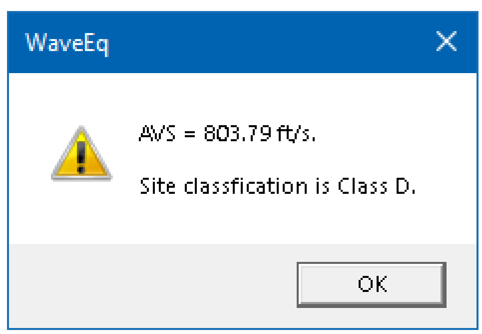
Site classification and ground amplification can be displayed for any given velocity model, as shown in the following two sections.

7.6.11.1 SHOW UBC OR IBC SITE CLASSIFICATIONS



In addition to calculating the average V_S as described in Section 7.3.14, Page 371, the associated site class can also be determined by selecting *Show UBC or IBC site classifications*. [The UBC is the Uniform Building Code (1997) which uses metric units. The IBC (2000, 2003) is based on the UBC but uses English units. Refer to Building Seismic Safety Council (1997), International Code Council (2000, 2003), and Underwood and Hayashi (2005) for more information.]

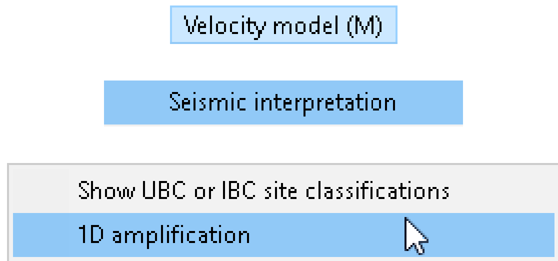
Once *Show UBC or IBC site classifications* is selected, the average V_S is calculated and displayed with the associated site class (Table 16).

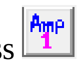


Site class	Soil type	UBC V_s30	IBC V_s100
Class A	hard rock	$V_s30 > 1{,}500$ m/s	$V_s100 > 5{,}000$ ft/s
Class B	rock	$760 < V_s30 \leq 1500$ m/s	$2{,}500 < V_s100 \leq 5{,}000$ ft/s
Class C	very dense soil, soft rock	$360 < V_s30 \leq 760$ m/s	$1{,}200 < V_s100 \leq 2{,}500$ ft/s
Class D	stiff soil	$180 < V_s30 \leq 360$ m/s	$600 < V_s100 \leq 1{,}200$ ft/s
Class E	soft soil	$V_s30 < 180$ m/s	$V_s100 < 600$ ft/s
Class F	soils requiring site specific evaluation	Non-applicable	Non-applicable

Table 16: UBC/IBC Site Classifications.

7.6.11.2 1D Amplification



Select *Velocity Model* | *Seismic Interpretation* | *1D amplification* or press  to calculate the amplification of SH waves based on multiple reflections.

An example of amplification for Model B (Page 44) is Model BModel Bshown below. Amplification is shown as a thick ocher line on the H/V spectrum display.

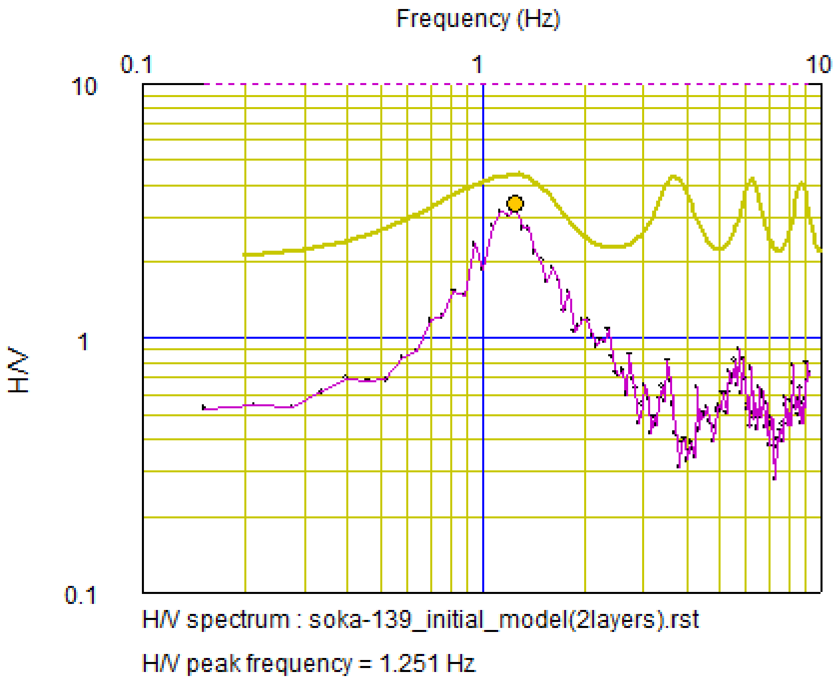
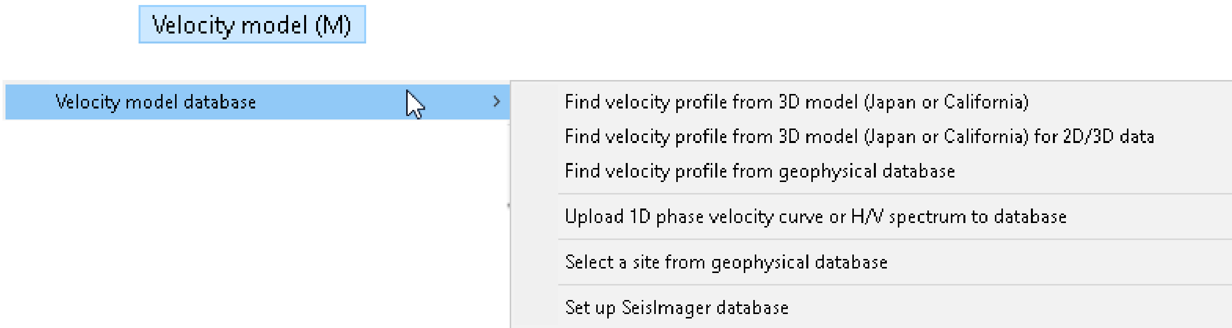


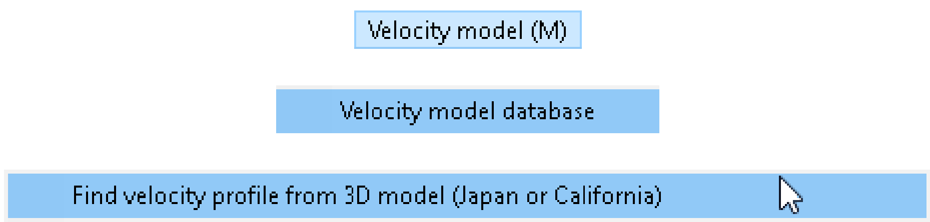
Figure 215: H/V curve and corresponding amplification curve.

7.6.12 Velocity Model Database



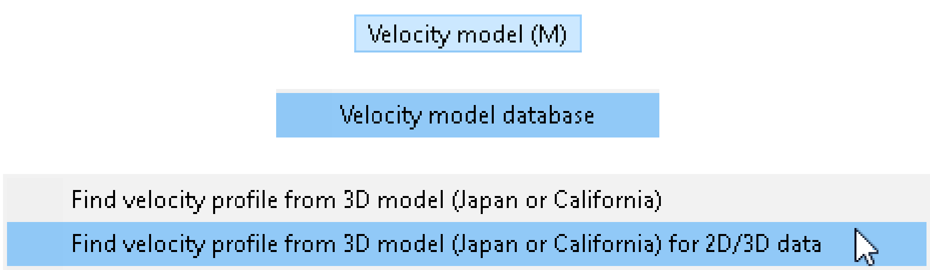
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.6.12.1 Find Velocity Profile From 3D Model (Japan or California)



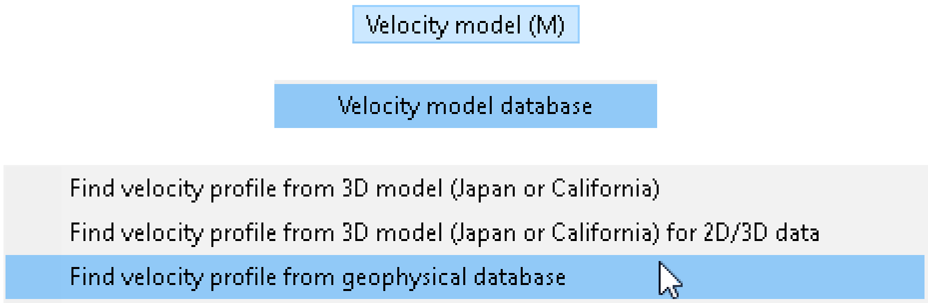
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.12.2 Find Velocity Profile From 3D Model (Japan or California) For 2D/3D Data



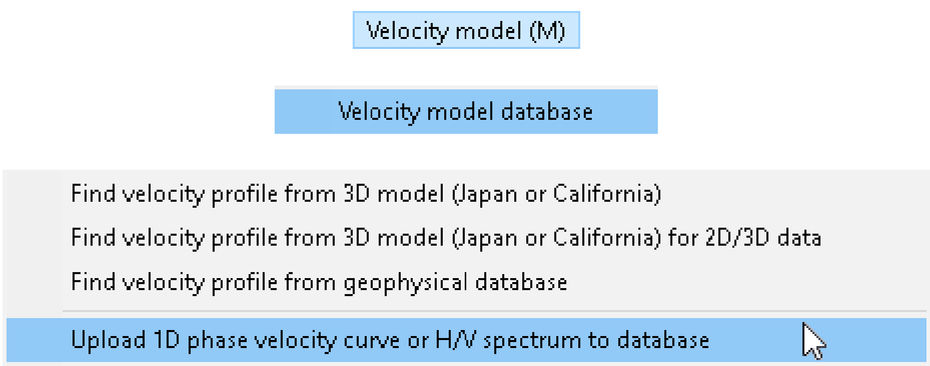
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.12.3 Find Velocity Profile From Geophysical Database



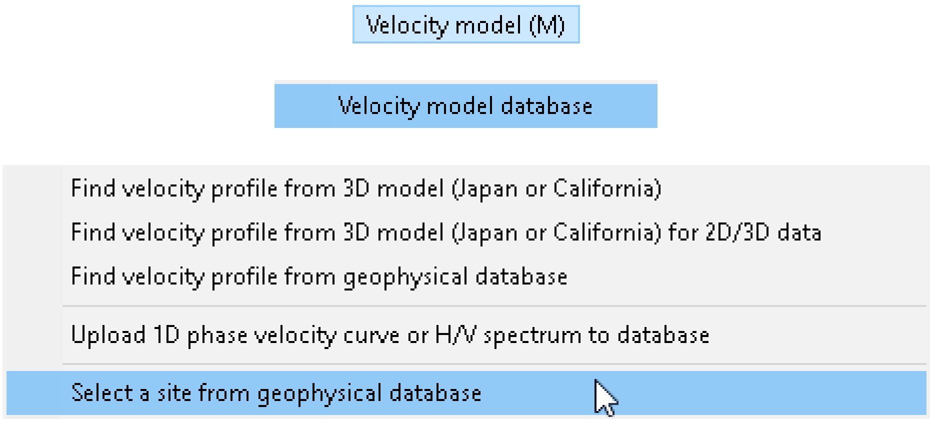
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.12.4 Upload 1D Phase Velocity Curve or H/V Spectrum to Database



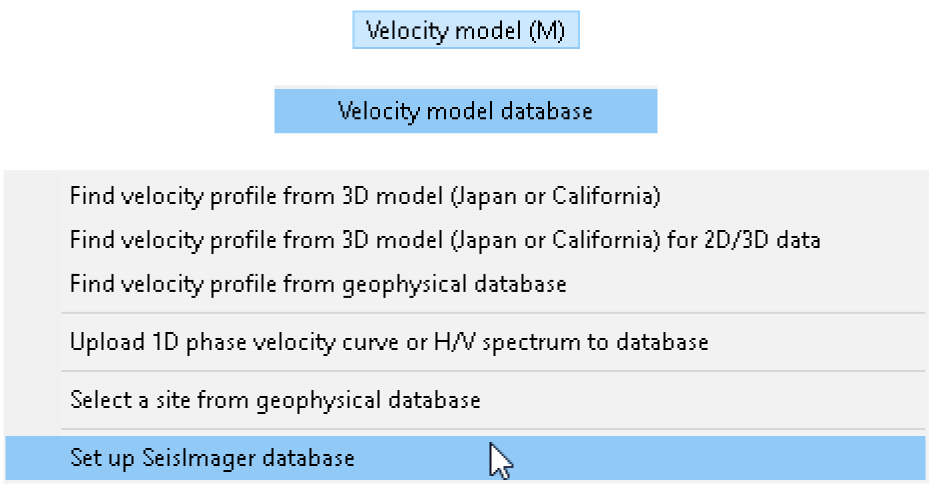
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.12.5 Select a Site From Geophysical Database



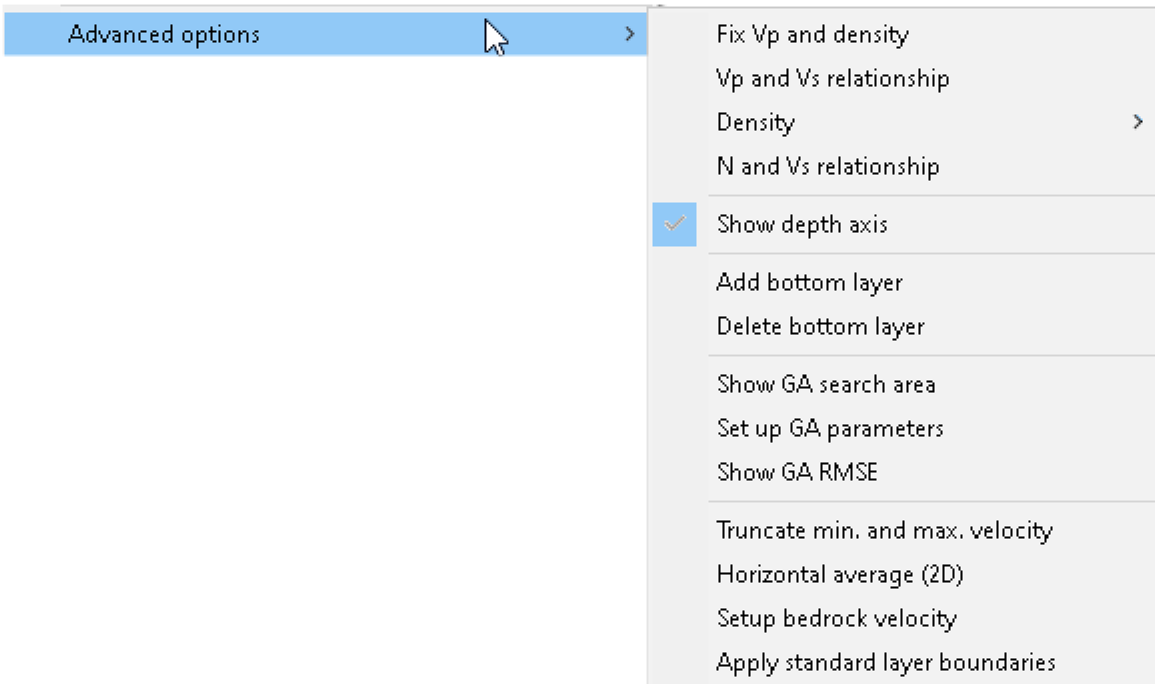
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.12.6 Set Up SeisImager Database

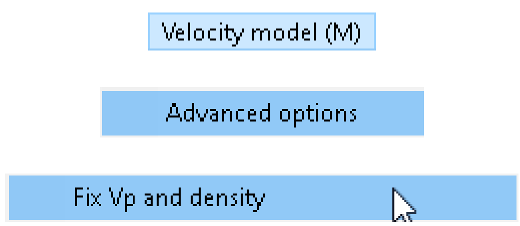


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13 Advanced Options

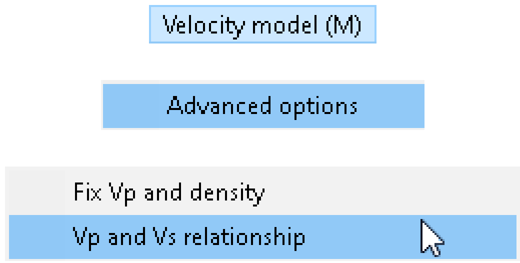


7.6.13.1 Fix V_P and Density



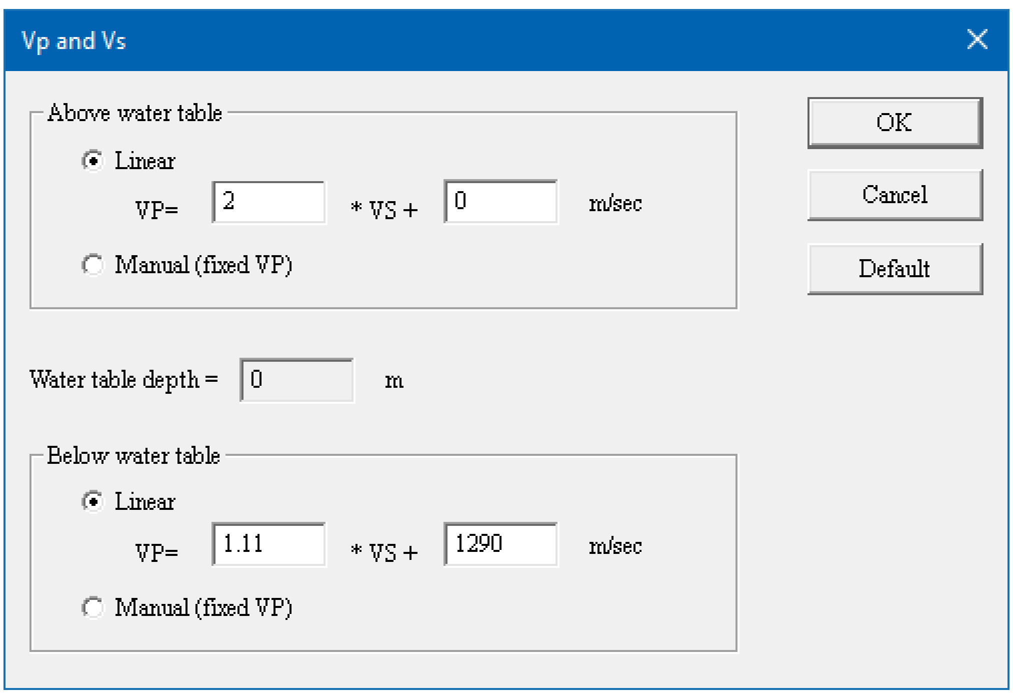
Fix V_p *and Density* is rarely used, and when it is, support from Geometrics is generally required. Please contact support@seisimager.com for assistance with this function. The same is true for the *Density* option.

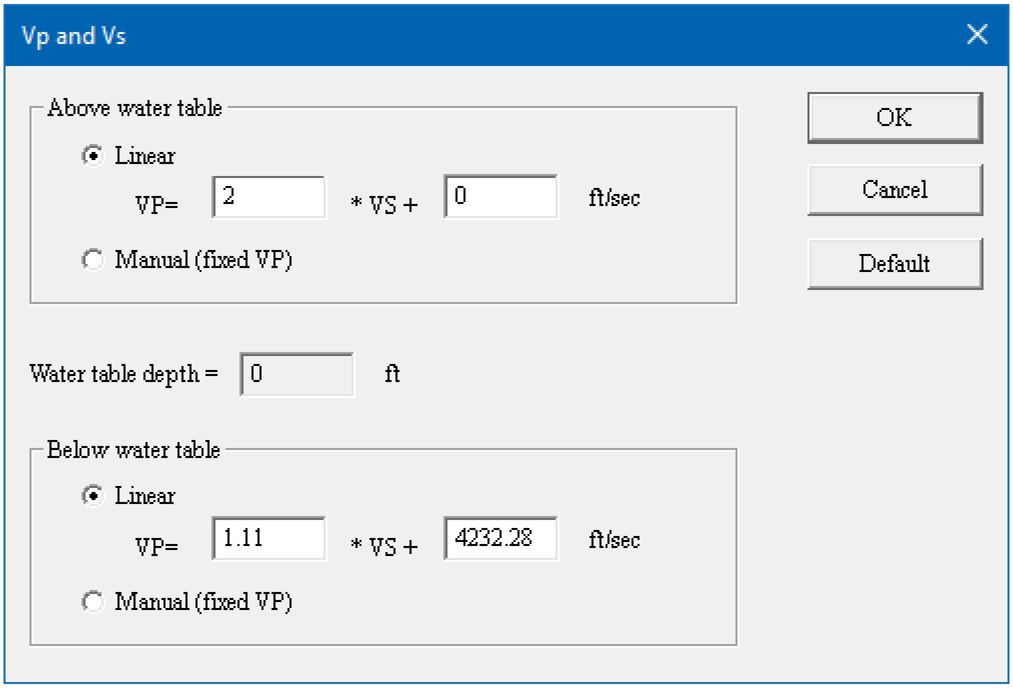
7.6.13.2 V_P AND V_S RELATIONSHIP



The **V_p and V_S relationship** dialog box allows the equations used for calculating V_p from V_S to be customized.

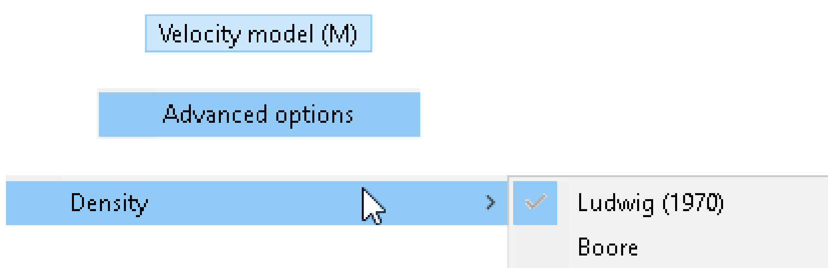
To modify the default equations for calculating V_p from V_S, select *V_p and V_S relationship* (dialog box with metric units selected shown on top, with English units selected shown on bottom). An equation may be defined for above and below the water table, with the water table depth set in the **Velocity model** menu in the **Setup water table** dialog box (Section 7.6.8, Page 454). The default equation for above the water table is simply $2V_S$. The default equation for below the water table is from Kitsunezaki (1990). The effect of V_p on phase velocity is typically minimal; these relationships are suitable for most models.





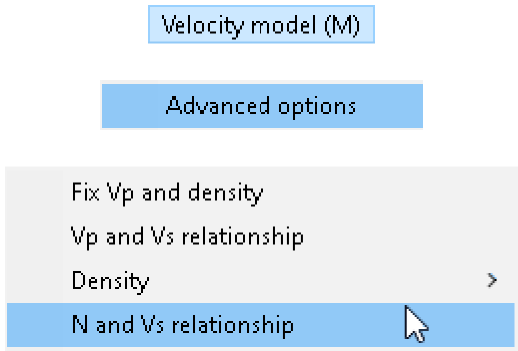
Relationships can also be manually set by selecting *Manual* and inputting V_p values through the **View** menu under *Open PS result file*.

7.6.13.3 DENSITY



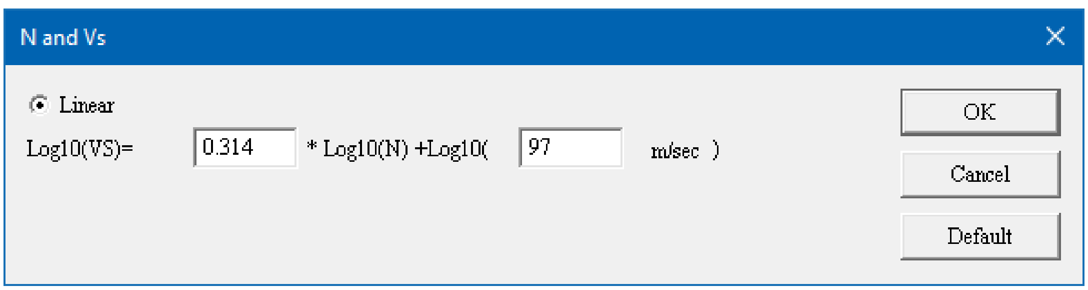
This feature defaults to Ludwig (1970) and is rarely changed. Please contact support@seisimager.com for assistance.

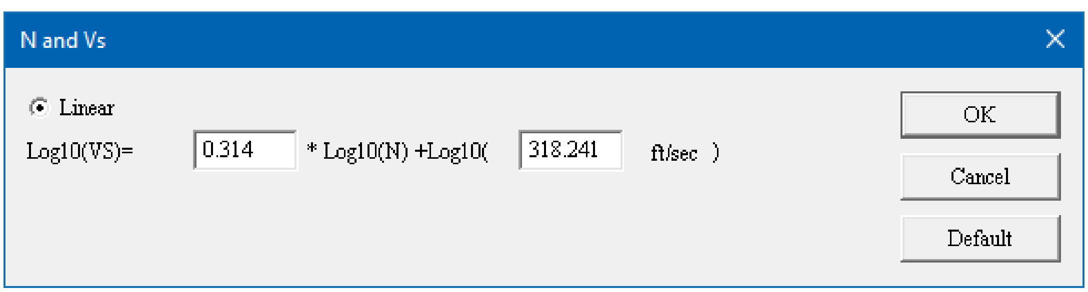
7.6.13.4 N and V_S Relationship



The **N and V_S relationship** dialog box allows the equations used for calculating N from V_S to be customized.

To modify the default equations for calculating N from V_S, select *N and V_S relationship* (dialog box with metric units selected shown on top, with English units selected shown on bottom). The default equations are from Imai and Tonouchi (1982). This relationship is suitable for most models.



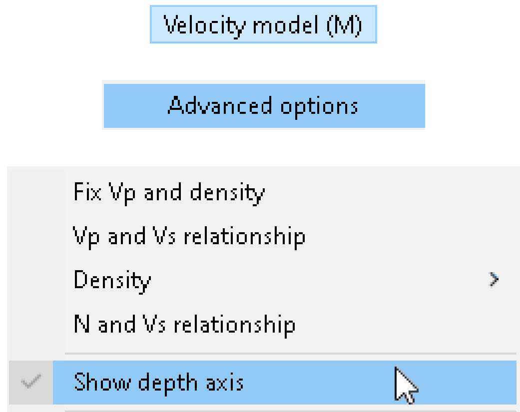


Where applicable, the equation used for calculating density is as follows [from Ludwig *et al.* (1970)].

$$\rho = 1.2475 + 0.399V_p - 0.026V_p^2$$

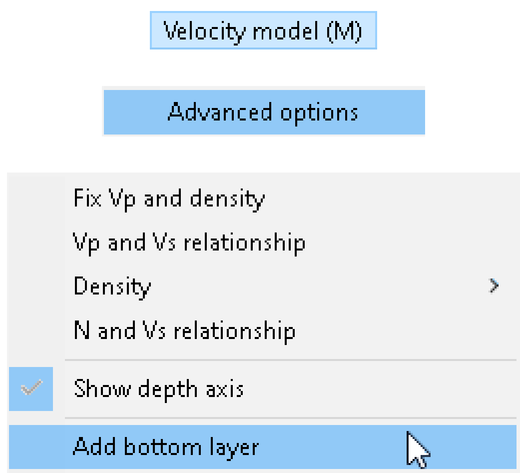
To revert to the default values, press *Default*.

7.6.13.5 Show Depth Axis



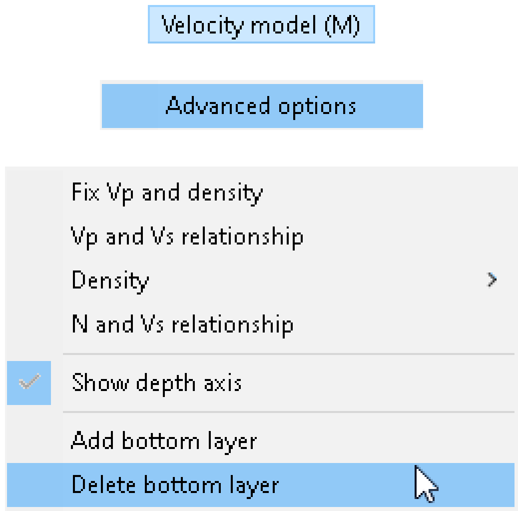
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13.6 Add Bottom Layer



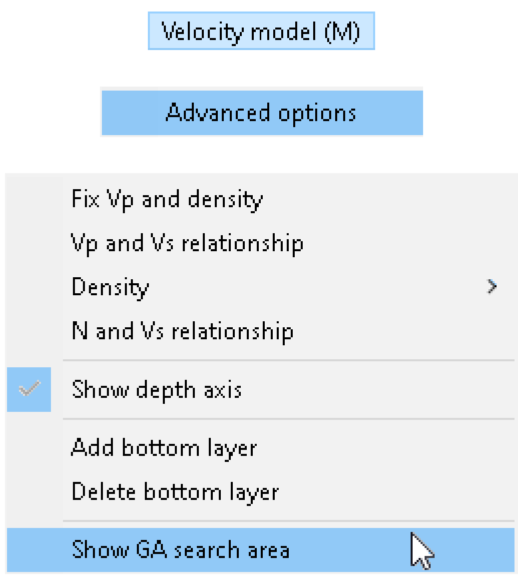
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13.7 Delete Bottom Layer



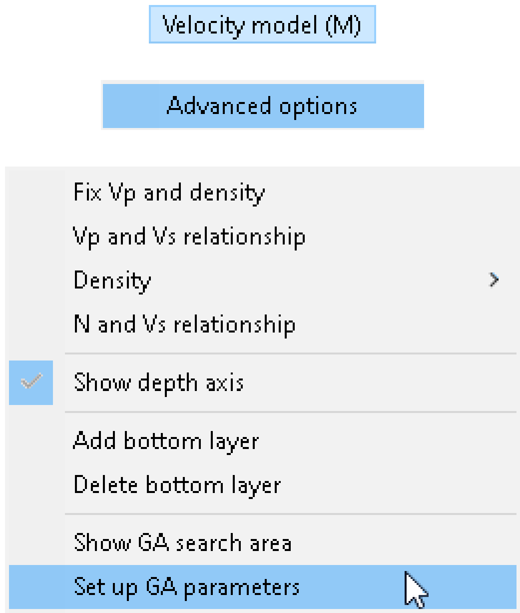
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13.8 Show GA Search Area



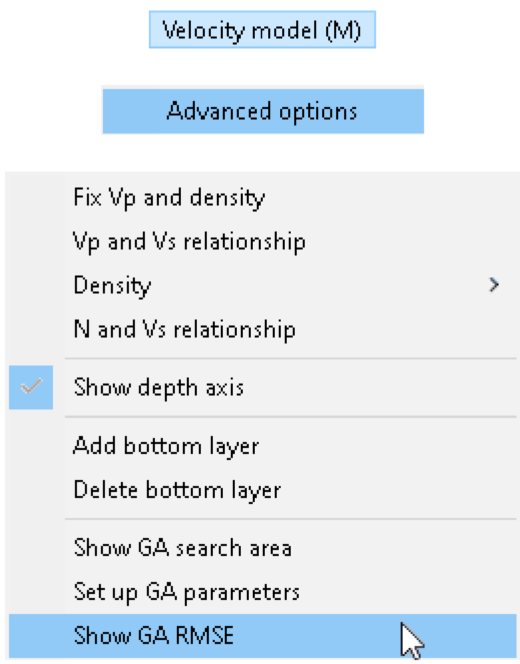
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13.9 Set Up GA Parameters



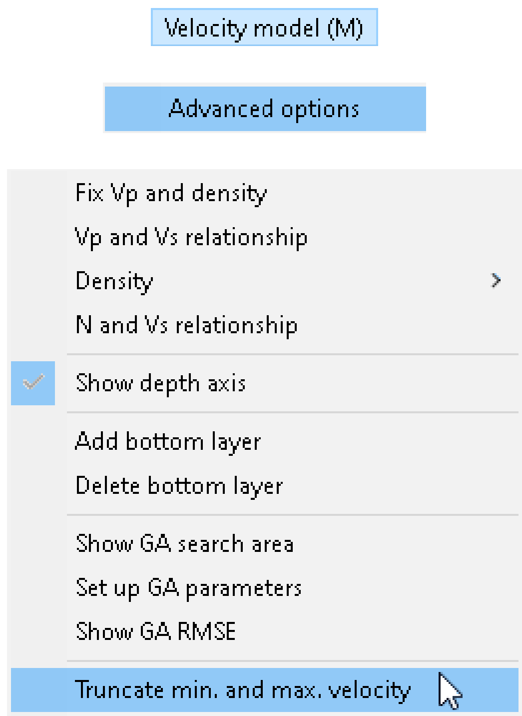
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13.10 Show GA RMSE

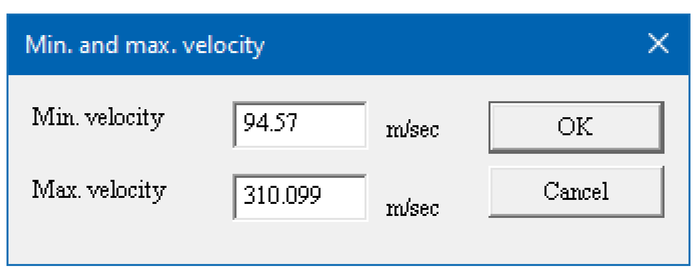


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13.11 Truncate Min. and Max. Velocity



To set a minimum and maximum velocity for a given velocity model, select *Truncate min. and max. velocity* to reveal the following dialog box.



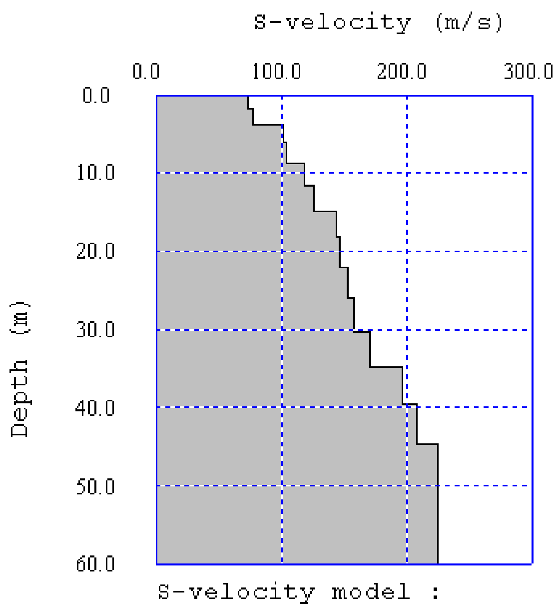
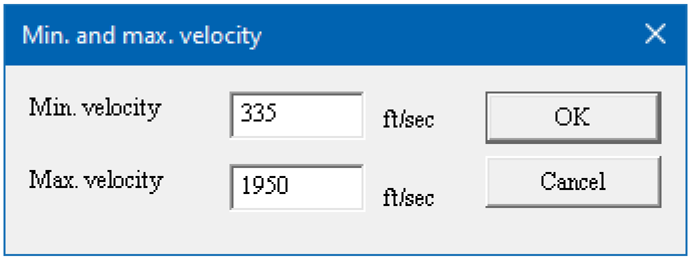


Figure 216: V_S model.

To set new boundaries, enter new values as desired and press *OK*. Note that the value entered for *Max. velocity* will be retained for the WaveEq session unless changed again or a new WaveEq instance is opened.



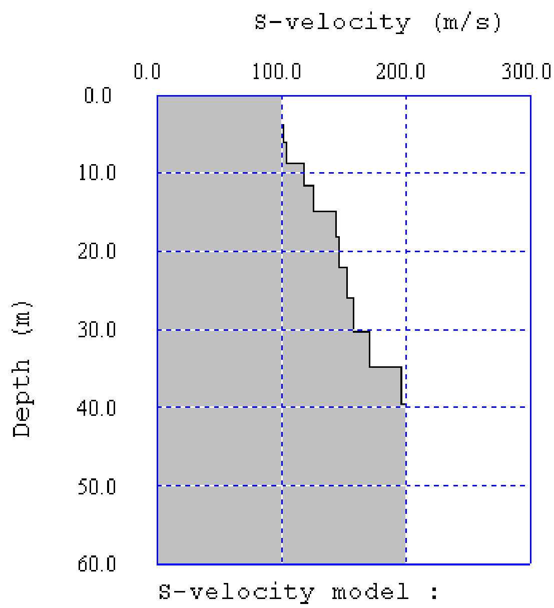
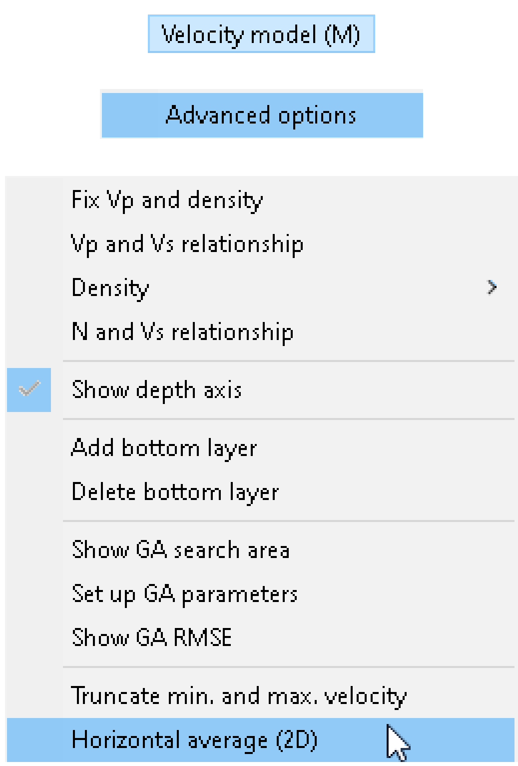


Figure 217: Truncated version of velocity model shown in Figure 216.

Typically, *Truncate min. and max. velocity* is used when building an initial model from scratch.

7.6.13.12 Horizontal Average (2D)



To make a cross-sectional velocity model uniform in the direction of distance, select *Horizontal average (2D)*. The process recalculates the velocity model using the average value at each depth. The original model (shown on left below) with horizontal variation is converted to a simplified, horizontally uniform model (shown on right below).

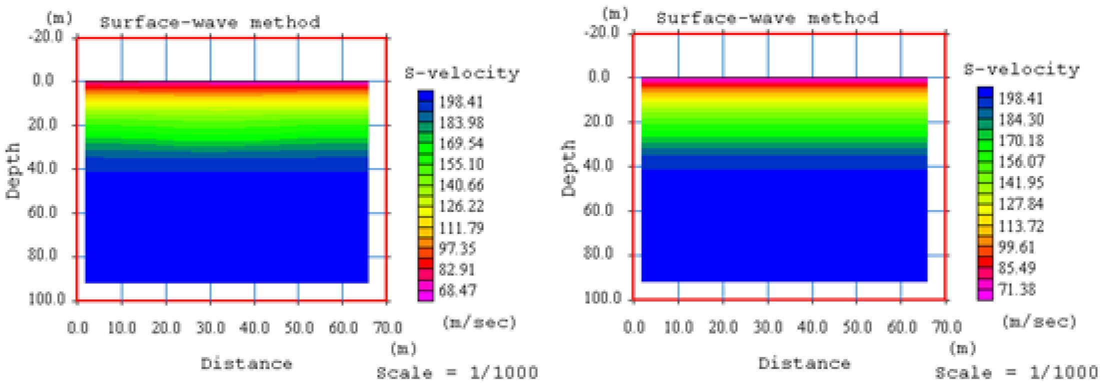
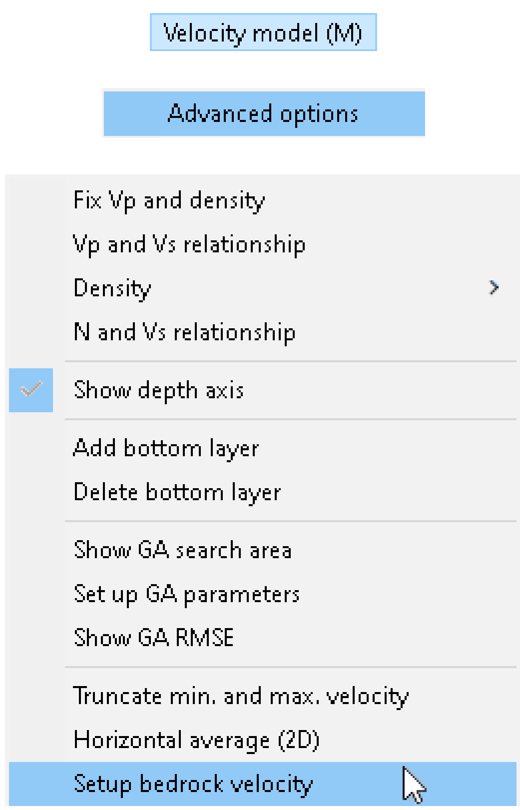


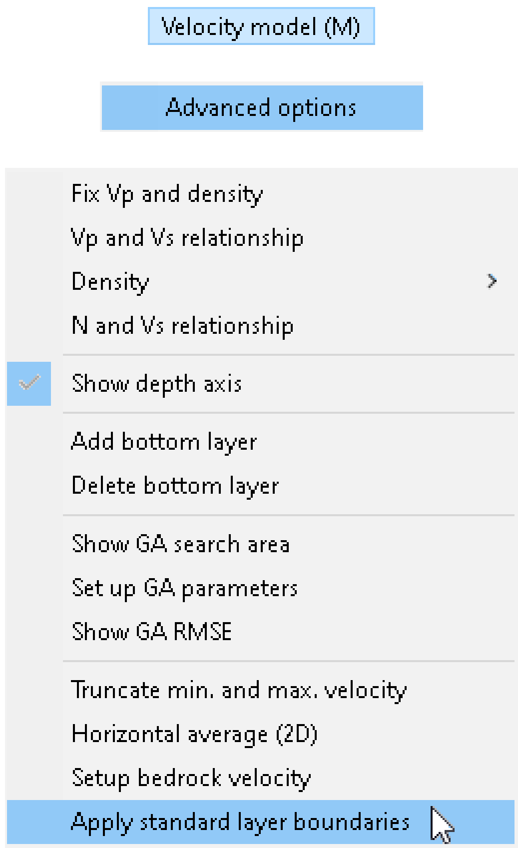
Figure 218: Original velocity model (left) and horizontally averaged model (right).

7.6.13.13 SET UP BEDROCK VELOCITY



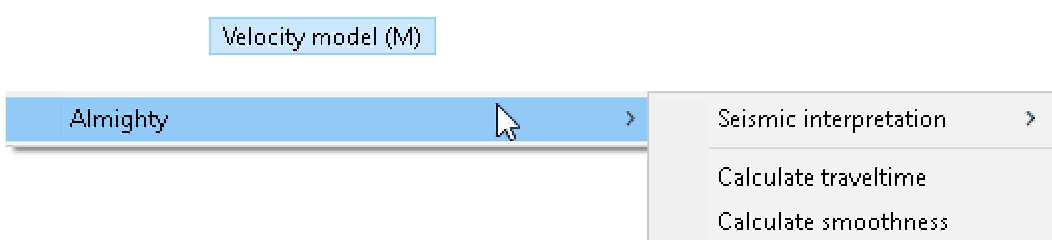
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.13.14 Apply Standard Layer Boundaries



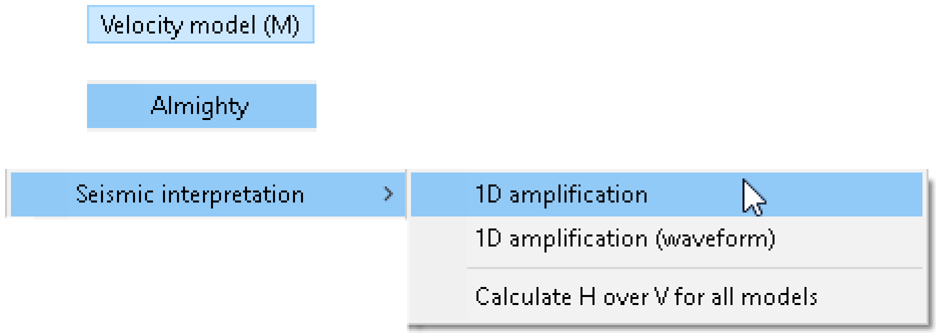
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.14 Almighty



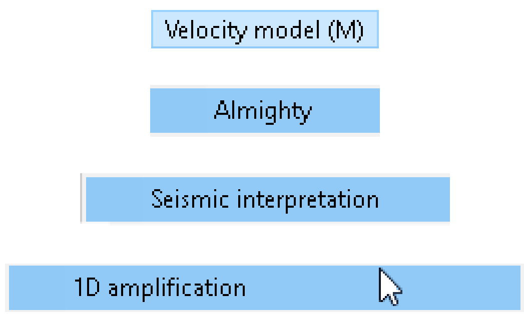
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.6.14.1 Seismic Interpretation



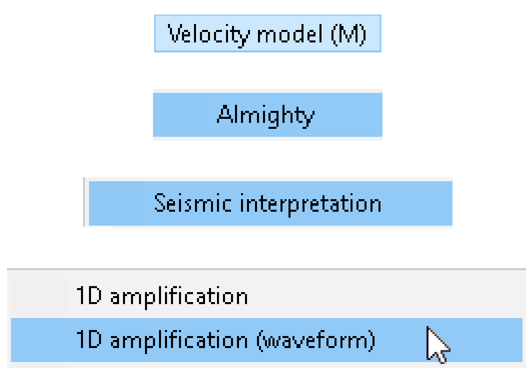
Continue.

7.6.14.1.1 1D Amplification



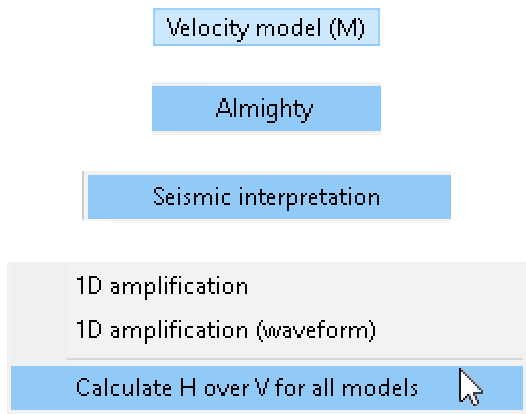
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.14.1.2 1D Amplification (Waveform)



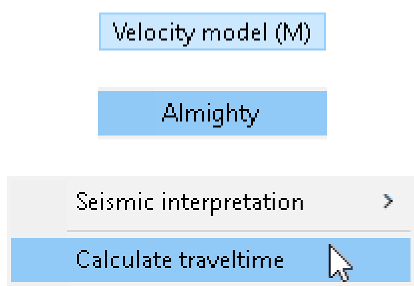
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.14.1.3 Calculate H Over V For All Models



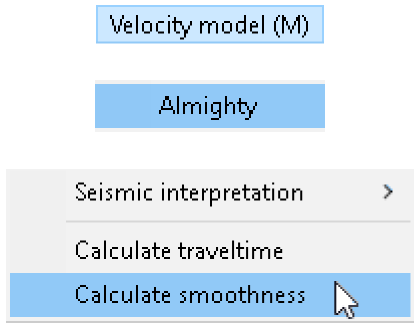
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.6.14.2 Calculate Travel Time



This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

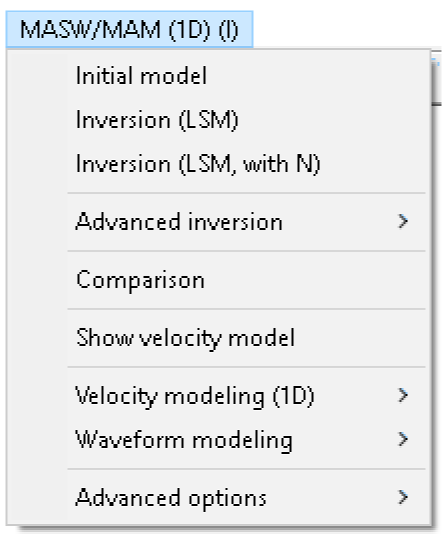
7.6.14.3 CALCULATE SMOOTHNESS



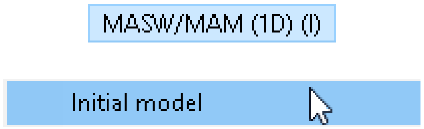
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7 MASW/MAM (1D) MENU

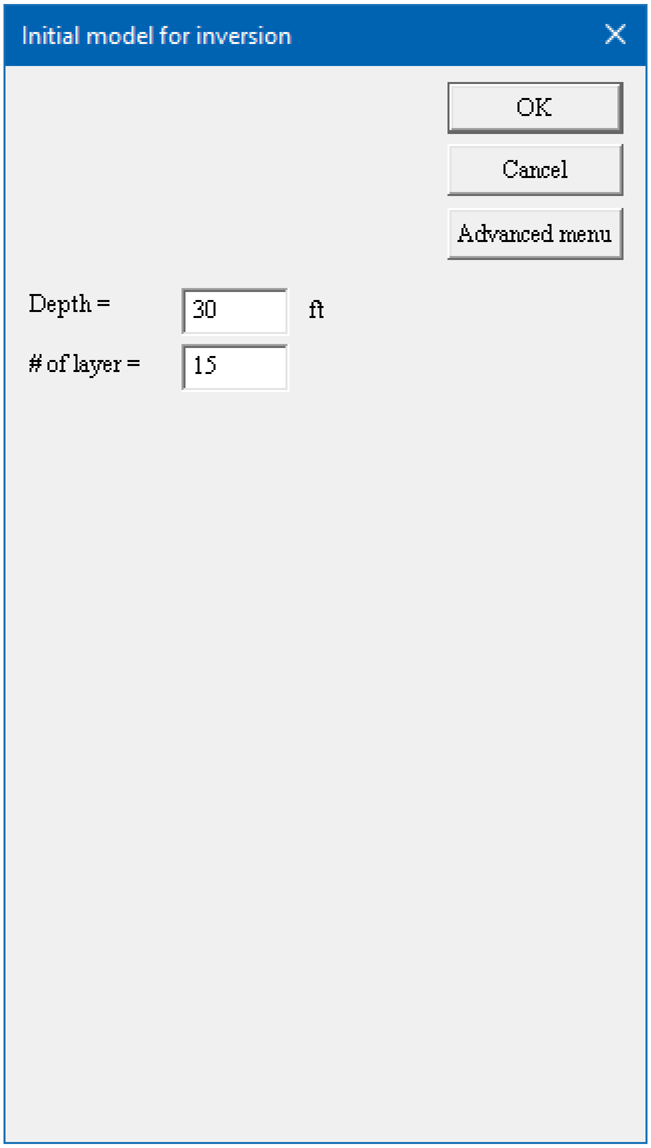
The **MASW/MAM (1D)** menu primarily includes functions for calculating an initial model for a 1D dataset and running the inversion to find the best fit of the modified initial model data with the observed data. Other modeling functions are also included. Although the term MASW refers to active source surveys, the same functions apply for analysis of MAM datasets.



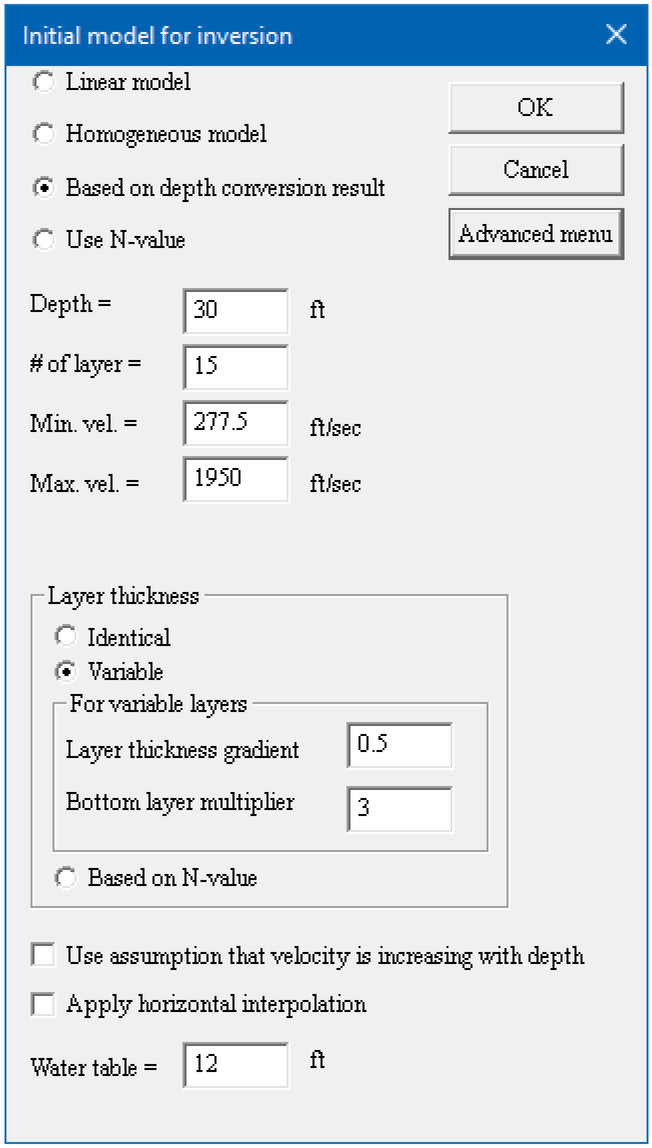
7.7.1 INITIAL MODEL



The initial V_S model is the starting point for the inversion. To generate an initial model for a single dispersion curve, select *Initial model*. The **Initial model for inversion** dialog box shows only the *Depth* and *Number of layers* by default. In most cases, only the maximum *Depth* of the model needs to be entered and the default value of 15 for the *Number of layers* is suitable.



Pressing on *Advanced menu* reveals the rest of the parameters with default values. Typically, none of these settings need to be changed. For help with these parameters, contact support@seisimager.com.



Initial models are calculated using *Based on depth conversion result* by default. This method uses 1.1 times the phase velocity for an estimate of V_S and the one-third-wavelength approximation for an estimate of depth. The *Minimum* (phase) *velocity* and *Maximum* (phase) *velocity* are automatically assigned, corresponding directly to the low and high values observed on the dispersion curve. The *Maximum velocity* is automatically assigned to the deepest layer.

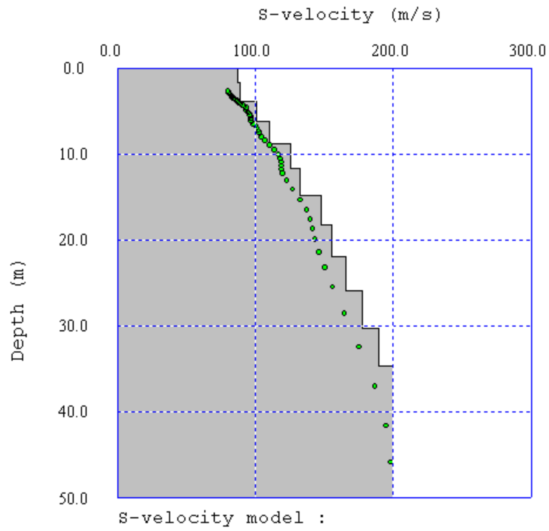
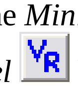


Figure 219: Initial V_S model.

Alternatively, initial models can be constructed using a *Linear model*, *Homogeneous model*, or using N-values via *Use N-value*. A *Linear model* (shown on left below) is constructed following a straight line starting at the *Minimum velocity* and ending at approximately the *Maximum velocity* (the model may not extend to exactly the *Maximum velocity* depending on the number and configuration of layers). A *Homogeneous model* (shown on right below) has no velocity variation with depth; the *Minimum* and *Maximum velocity* have the same value. The *Show apparent velocity model*  button provides a visual comparison of the *Based on depth conversion result* model with the *Linear model* and the *Homogeneous model*.

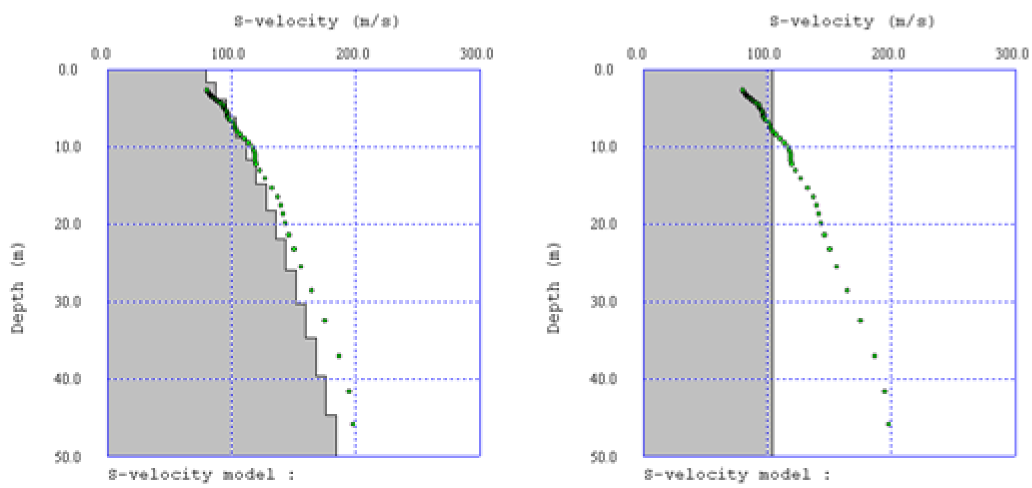
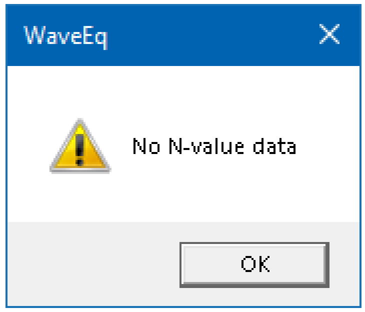


Figure 220: Linear initial model (left) and homogeneous initial model (right).

To base the initial model on N-values, select *Use N-value*. The model *Depth* will be automatically set to the deepest N-value. Note that the N-value file must already be open through the **View** menu under *Open N-value* file. If it is not open, you will be notified. Press *OK*, open the N-value file, and then come back to *Initial model*.



Layer thickness applies to all models. Selecting *Identical* sets all layers to equal thickness. By default, the layer thickness is set to *Variable*, and thus, layer thickness increases with depth. The *Layer thickness gradient* controls how the thickness increases with depth. A value of 1 means there is no gradient and layer thicknesses are identical. A value less than 1 thickens the layers with depth and as the value decreases, the gradient of thickening increases. The default value of 0.5 is suitable for most models.

The *Bottom layer multiplier* controls the thickness of the bottom layer relative to overlying layers. The thickness of the bottom layer, or layer just above the model half-space, can have a large impact on the calculated dispersion curve. Setting it thicker than the overlying layers stabilizes the inversion, hence the *Variable* default setting. After the *Layer thickness gradient* is applied, the thickness of the bottom layer is multiplied by the multiplier value. The multiplier default value is 3 and is suitable for most models.

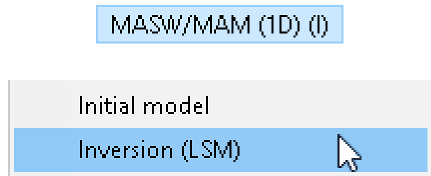
To set layer thickness based on N-values, select *Based on N-value*. As noted above, the N-value file must already be open through the **View** menu under *Open N-value* file.

To disallow velocity inversions in the final V_S model, check *Use assumption that velocity is increasing with depth*. It is common to see small velocity inversions near the surface (especially at paved sites), and at the water table due to an increase in pore pressure, and thus, it is suggested to leave this setting unchecked. This setting can be useful when you detect higher modes and want to suppress their influence on the final result.

For initial cross-sectional models, *Apply horizontal interpolation* is checked by default to allow construction by interpolation between a series of velocity curves.

The **Initial model for inversion** dialog box settings revert to the default values each time the dialog box is opened.

7.7.2 INVERSION (LSM)



To calculate the V_S curve that best matches the observed data, select *Inversion (LSM)*. The mathematical process is based on the Least-Squares Method and simply stated, iteratively modifies the initial model data to minimize the difference from the observed data. After running through several iterations, the modified initial model is output as the final model. Refer to Hayashi (2003) for a complete explanation.

The following dispersion curve, H/V spectrum, and initial model are used as an example. The inversion performed by this menu only changes the S-wave velocity of each layer, and the number of layers in the initial model must be large (10 to 20).

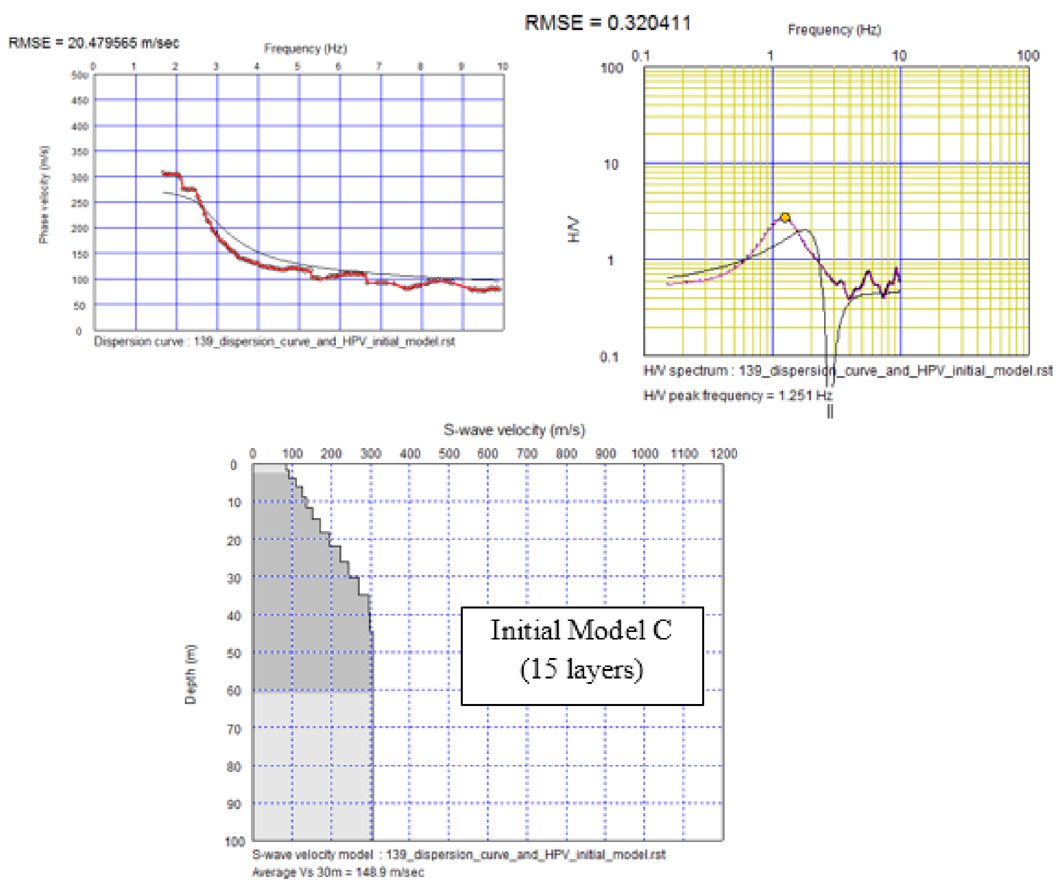
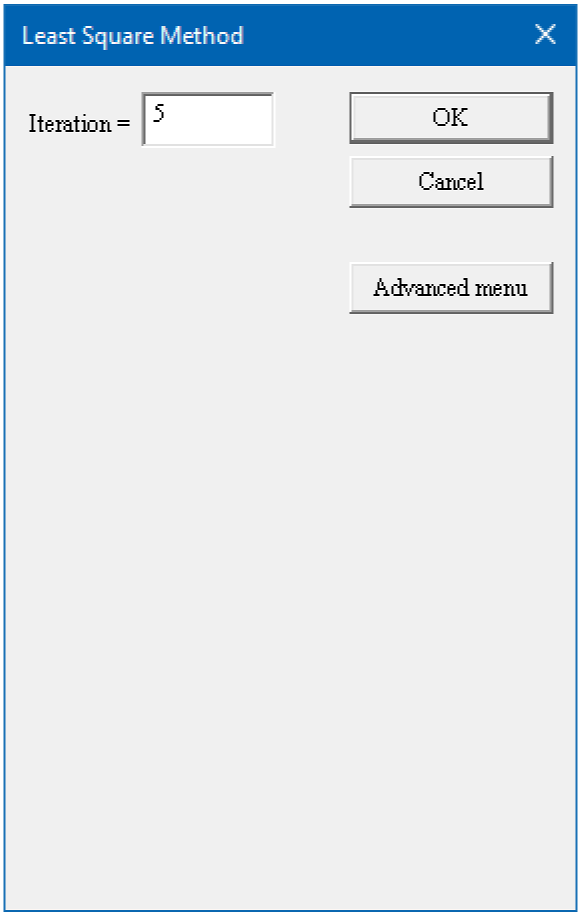


Figure 221: Example dispersion curve, H/V spectrum, and initial model.

Upon selecting *Inversion (LSM)*, the **Least Squares Method** dialog box shows the *Iteration* parameter with a default value of 5.



Iteration is the number of times the initial model data will be compared and modified to converge on the best match with the observed data. In between iterations, the improved model is used as the new starting point, so the error or mismatch should decrease. The iteration concept is conveyed by the flow chart below.

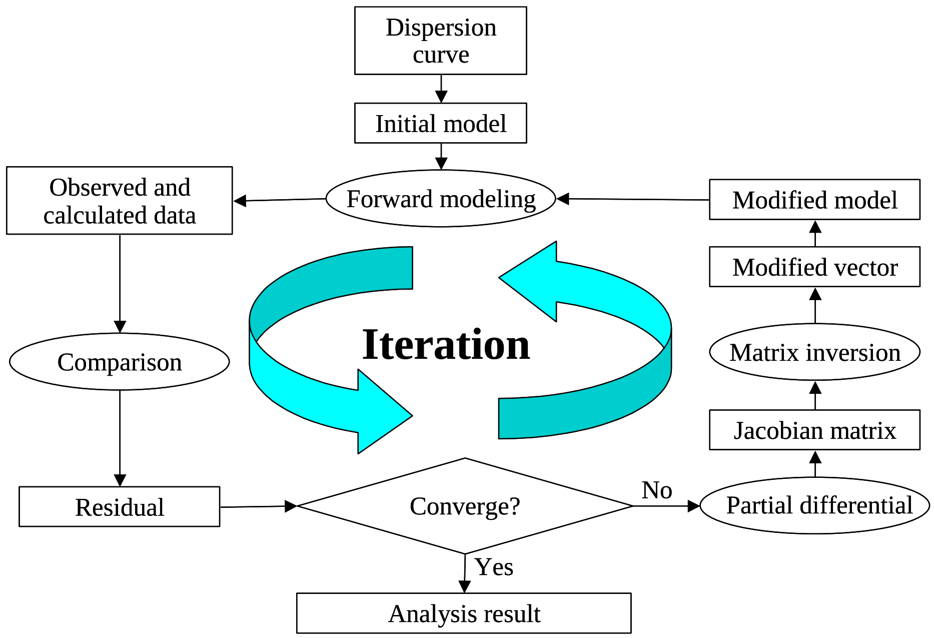
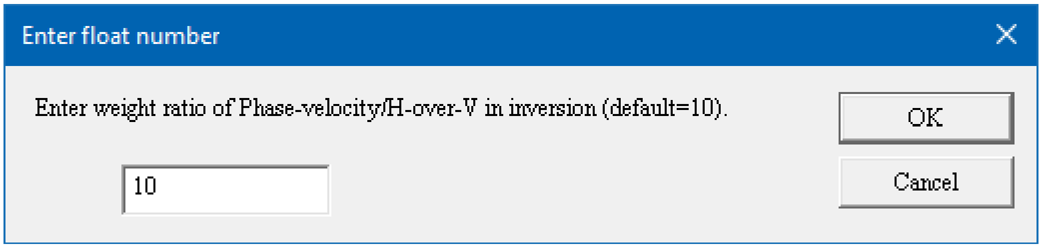


Figure 222: Iteration flow chart.

The default *Iteration* value of 5 is suitable for most cases. Increasing the *Iteration* value may occasionally be necessary; this will allow the process additional attempts to minimize the mismatch between the modified initial model data and the observed data.

Set the weight ratio of Phase velocity and H/V in the inversion. Larger values give greater weight to dispersion curve data. The default value is 10, and this is suitable for most cases.



Upon pressing *OK*, the inversion process begins and the error in velocity (m/s or ft/s) and percentage (%) is displayed. The error should decrease after each iteration and the final error should be less than about 5%, but this will depend on the dataset.

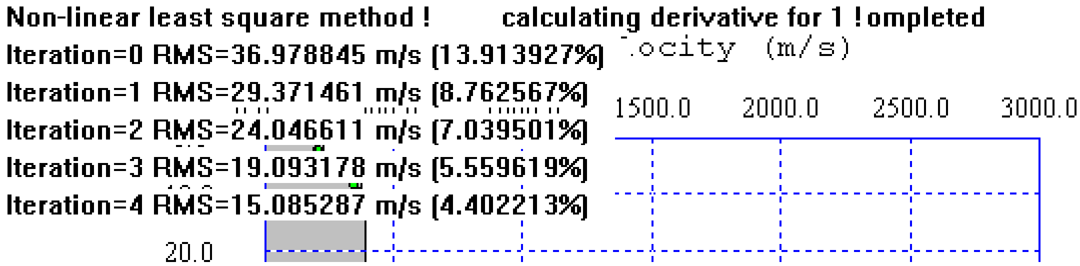
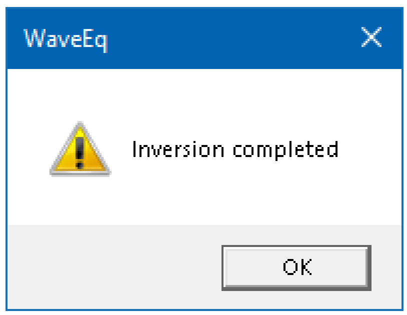


Figure 223: Iteration process displayed on screen during Least Squares analysis.

Once the inversion is complete, press *OK*.



The final error value is saved to a file called *RMSE.txt* in the dataset directory.

If the error ever increases during the inversion, the process will terminate. The initial model settings, inversion parameters, and units selected in the **Option** menu should be checked and modified, if necessary, before running the process again.

An example of the inverted result is shown below. Error between observed and theoretical phase velocities and H/V is smaller than that in the initial model (Model C, Page 493).

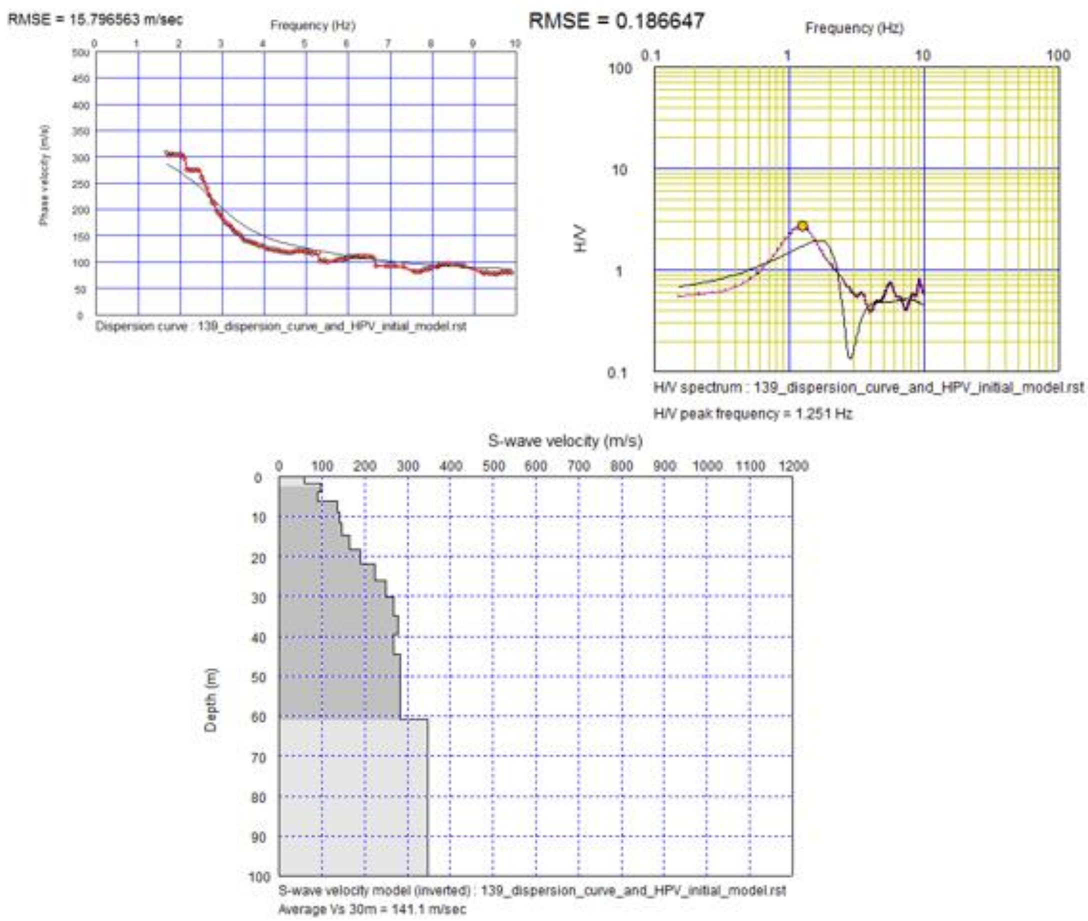
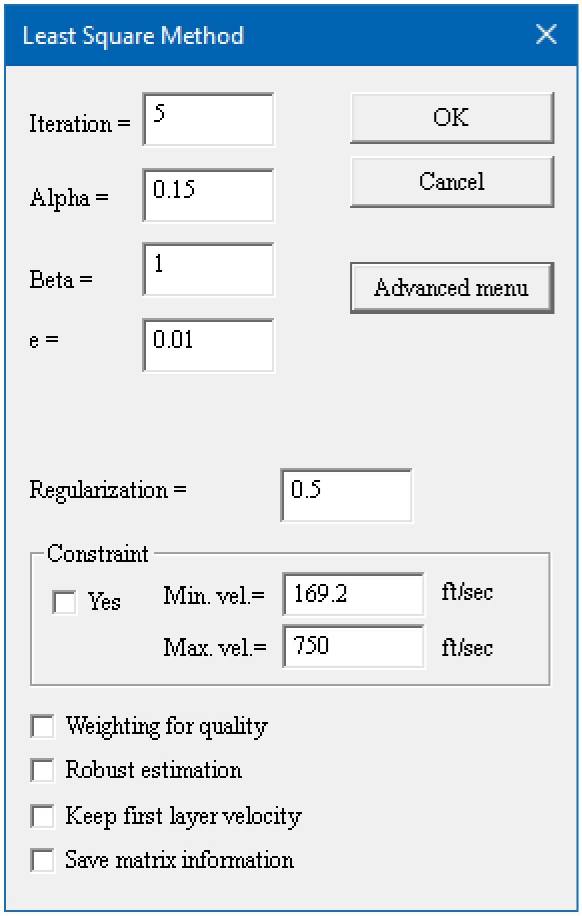


Figure 224: Inverted result.

Pressing on *Advanced menu* reveals the rest of the parameters with default values. Typically, none of these settings need to be changed.



The *Alpha* and *Beta* settings optimize the matrix inversion through deceleration and acceleration, respectively. An *Alpha* multiplier of the maximum logical value of 1 provides the least stabilization. Values less than 1 provide increasing stability but are more computationally intensive, and thus, cause the process to run more slowly. A value of zero cancels this factor.

Alpha is so named because it is used in the first iteration to stabilize the inversion. As the process stabilizes, *Alpha* is multiplied by *Beta* to increase the inversion speed. A *Beta* value of 1 causes no acceleration; values greater than 1 are used for acceleration.

e is a dumping parameter also with the effect of stabilization. *e* would be increased to increase stability.

Regularization is a type of matrix smoothing, working to control large velocity gradients across each depth layer. For a higher degree of smoothing and lower tolerance of lateral velocity gradients, a lower value would be used. A value of 1 equals no smoothing. All the layers would be artificially similar if excessive smoothing was applied.

The values for *Alpha*, *Beta*, *e*, and *Regularization* rarely need to be changed. Illogical values for these parameters will cause erroneous results.

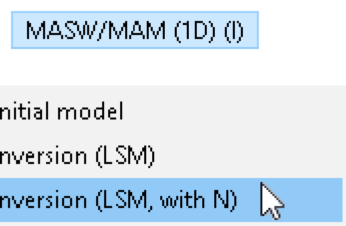
Saying *Yes* to *Constraint* will use the indicated *Minimum* (phase) *velocity* and *Maximum* (phase) *velocity* to limit the lower and upper bounds of the inversion. This can be useful if you have accurate knowledge of velocity, otherwise the default values are automatically assigned corresponding directly to the low and high values observed on the dispersion curve.

Weighting for quality incorporates dispersion curve pick quality into the inversion. *Robust estimation* puts less weight on data with large errors. *Keep first layer velocity* prevents the velocity of the shallowest layer from changing. This is useful if the first layer has a high known velocity, like pavement.

If *Save matrix information* is checked, the Jacobian matrix from each iteration is saved to a file called *Matrix.txt* in the dataset directory.

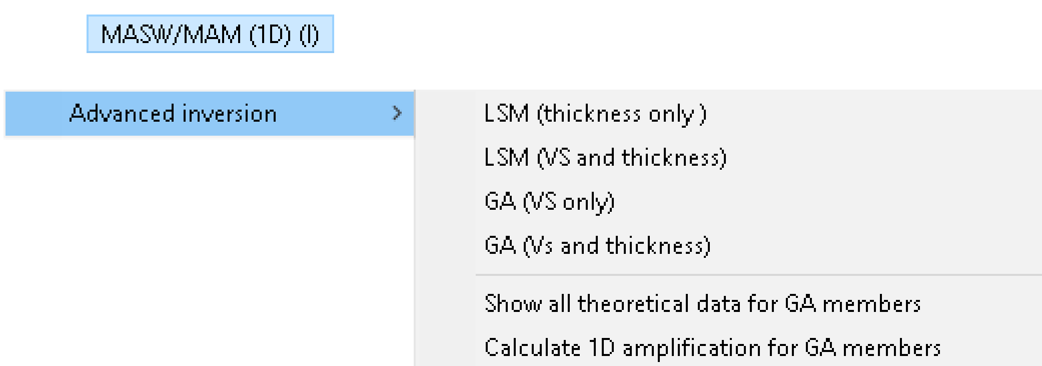
Note that the **Least Squares Method** dialog box parameters revert to the default values each time WaveEq is opened.

7.7.3 Inversion (LSM, with N)



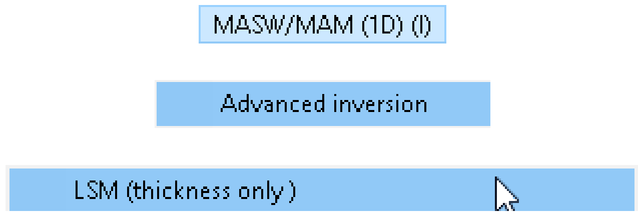
If N-values are used to construct the initial model, select *Inversion with N* instead of *Inversion*. The **Least Squares Method** dialog box settings are the same as those explained in Section 7.7.2, Page 483, except that the default value for *e* equals 0.1 and *Regularization* equals 0.5.

7.7.4 Advanced Inversion



There are many inversion options available. These are illustrated below.

7.7.4.1 LSM (Thickness Only)



Select *MASW/MAM (1D)* | *Advanced Inversion* | *LSM (thickness only)* to perform an inversion in which the thickness of each layer is changed. The following dispersion curve and an initial model (Model D) are used as an example. The inversion performed by this menu only changes the thickness of each layer and it is better to keep the number of layers small (3 to 7).

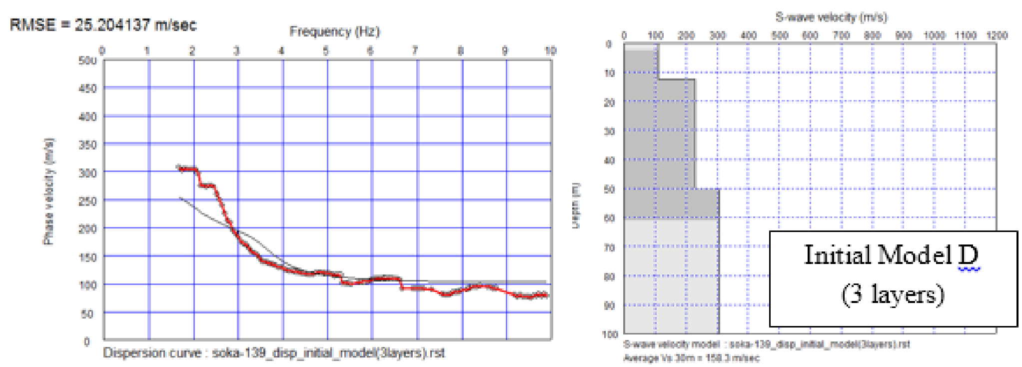
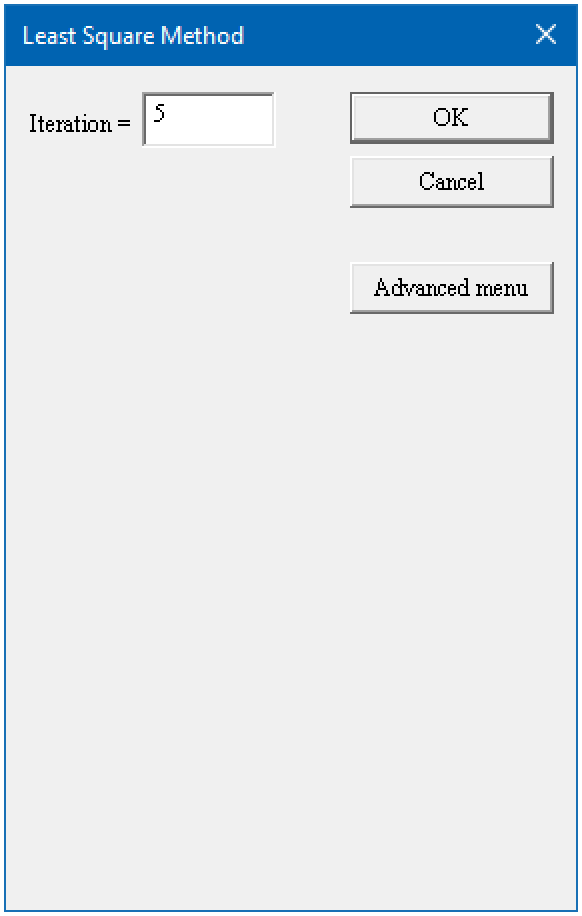


Figure 225: Example velocity model and dispersion curve.

Set the number of iterations for the inversion. The default value of 5 for *Iteration* is suitable for most cases.



An example of the inverted result is shown below. The error between observed and theoretical phase velocities is smaller than that in the initial model (Model D).

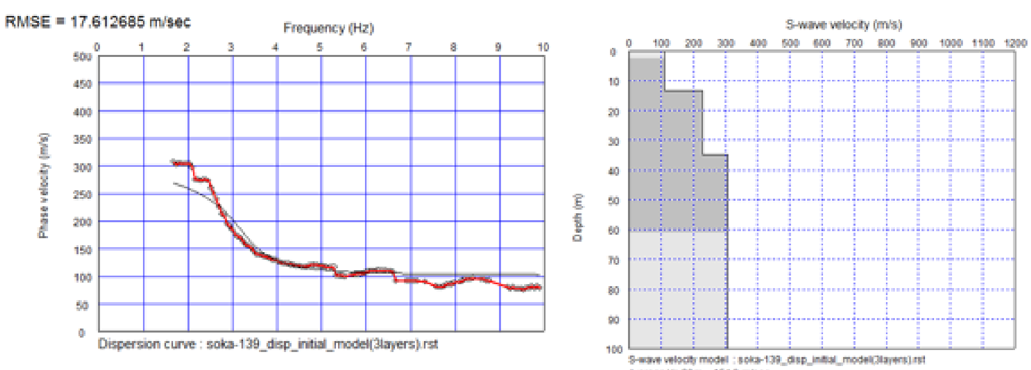
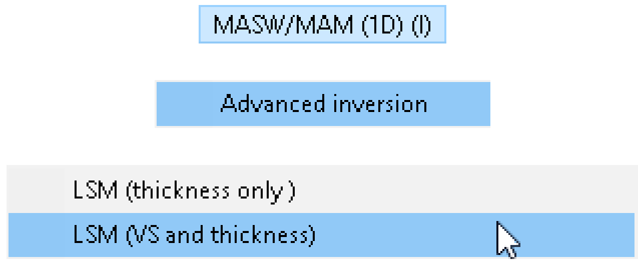


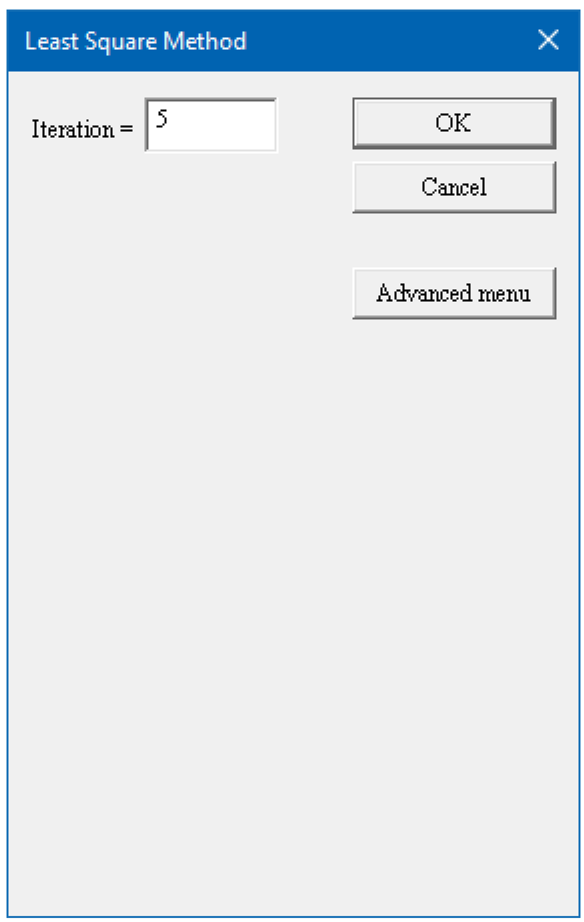
Figure 226: Inverted result.

7.7.4.2 LSM (VS and Thickness)



Select *MASW/MAM (1D)* | *Advanced inversion* | *LSM (VS and thickness)* to perform an inversion in which both S-wave velocity and thickness of each layer are changed. The inversion performed by this menu changes both S-wave velocity and thickness of each layer and it is better to keep the number of layers small (3 to 7). The Initial Model D is used as an example.

Set the number of iterations for the inversion. The default value of 5 for *Iteration* is suitable for most cases.



An example of the inverted result is shown below. The error between observed and theoretical phase velocities is smaller than that in the initial model (Model D).

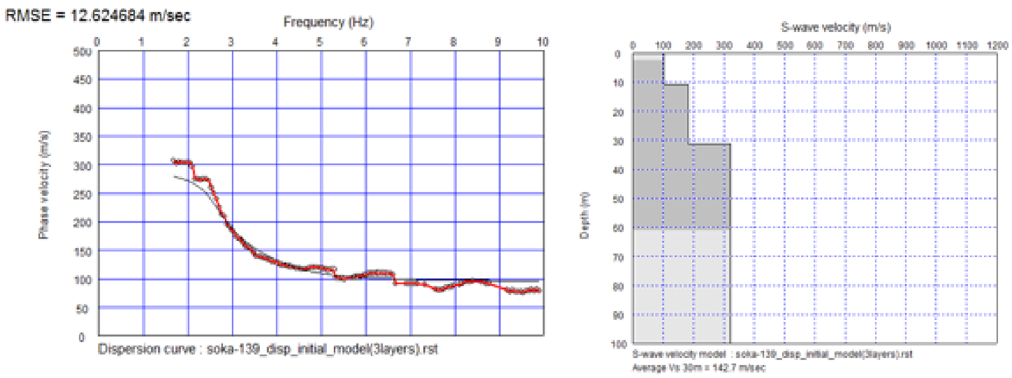
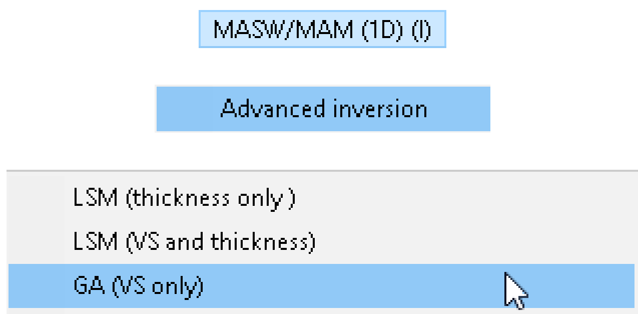


Figure 227: Inverted result.

7.7.4.3 GA (VS ONLY)



Select *MASW/MAM (1D)* | *Advanced inversion* | *GA (VS only)* to perform an inversion in which only the S-wave velocity is changed. An inversion that only uses a dispersion curve and a joint inversion that uses both a dispersion curve and an H/V spectrum can be performed by this menu. The inversion applied by this menu changes the S-wave velocity of each layer, and the number of layers in the initial model must be large (10 to 20). Model C is used as an example.

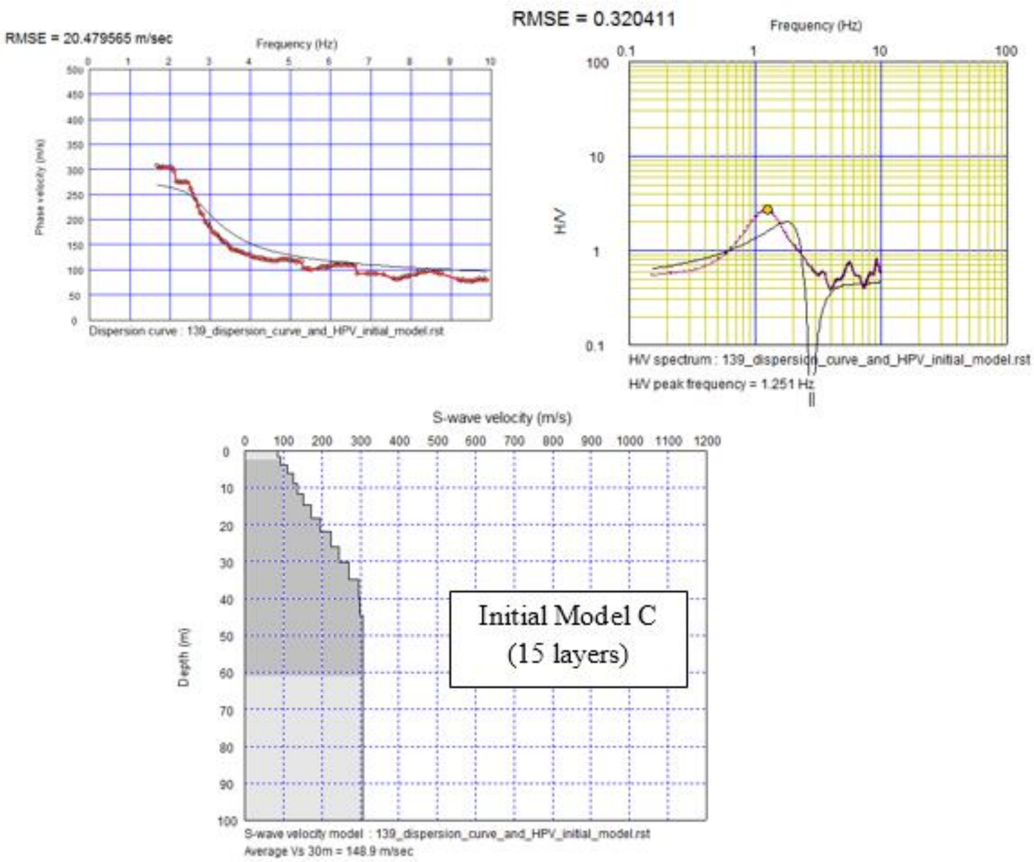
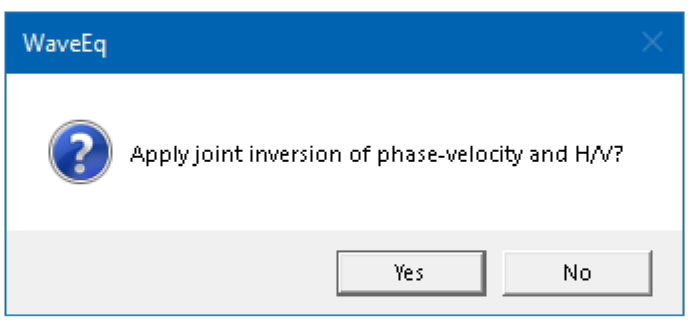
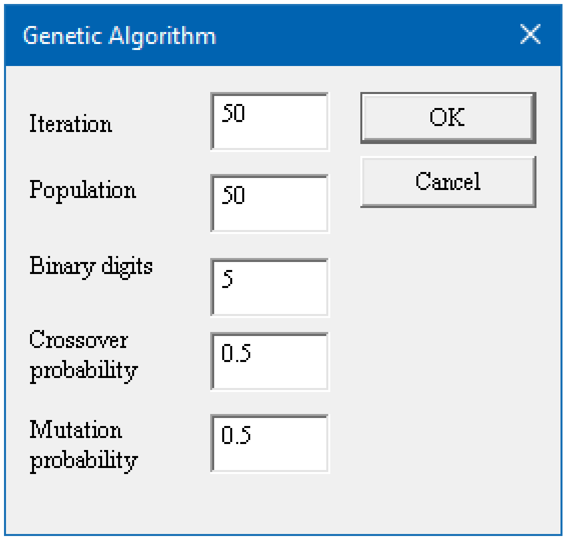


Figure 228: Example dispersion curve, H/V curve, and V_S model.

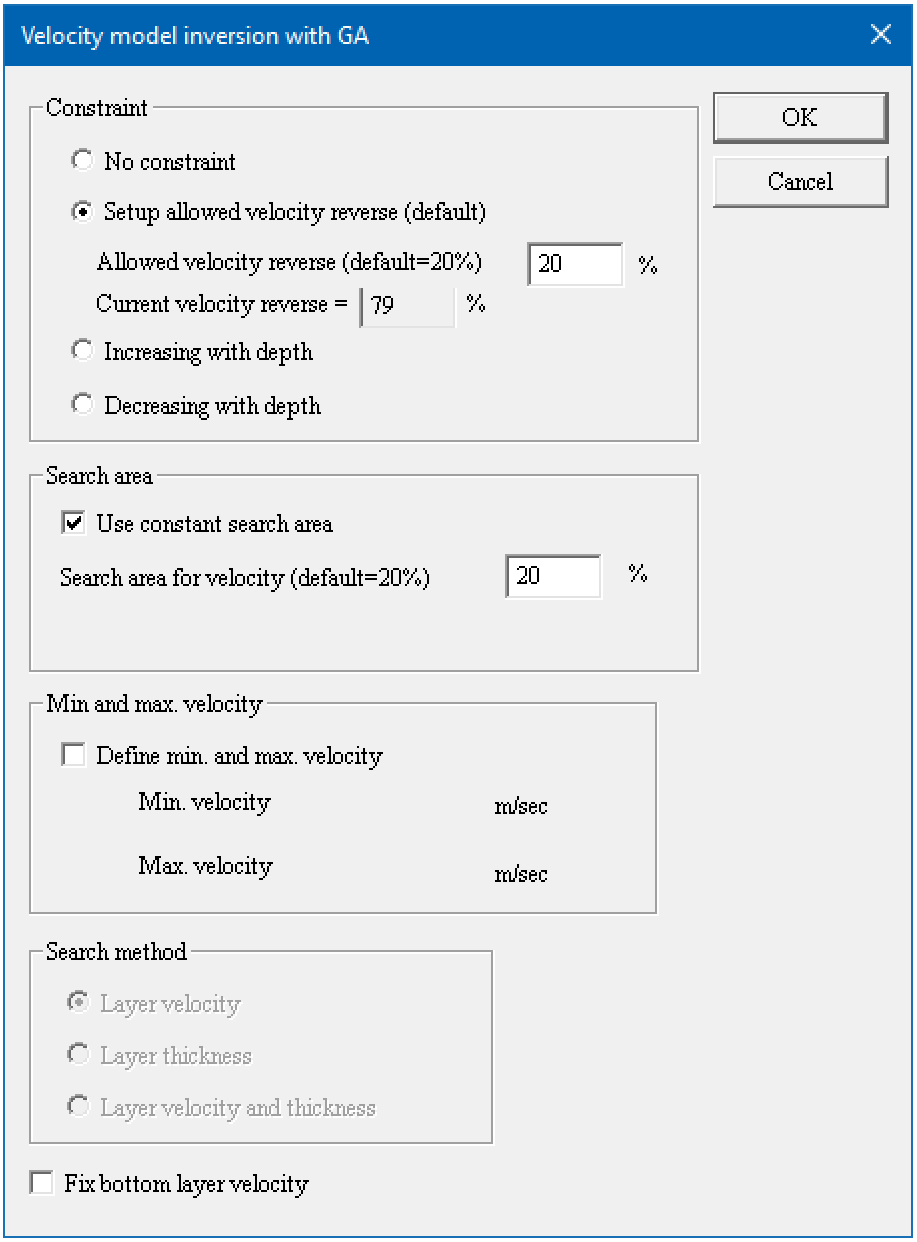
The dialog box shown below will appear when the data contains both phase velocity and H/V data. Press *Yes* if you intend to apply the joint inversion of phase velocity and H/V data. Press *No* to apply only the inversion of phase velocity data.



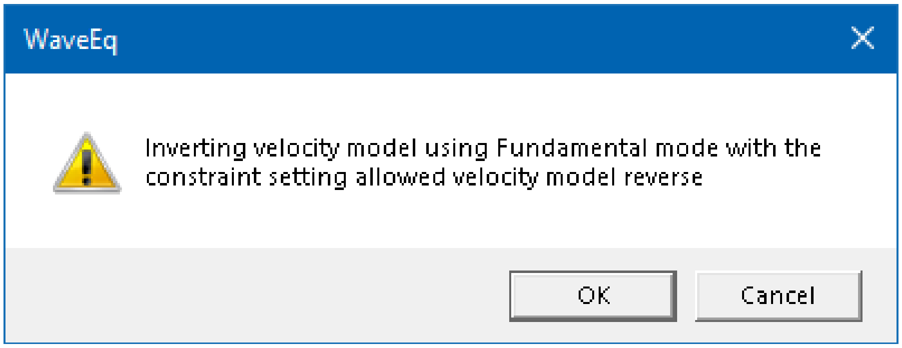
Set the parameters for the Genetic Algorithm. The default values (Iteration=50, Population=50, Binary digits=5, Crossover probability=0.5, Mutation probability=0.5) are suitable for most cases. Press the *OK* button to proceed.


Genetic Algorithm
Iteration
50
Population
50
Binary digits
5
Crossover probability
0.5
Mutation probability
0.5
OK
Cancel

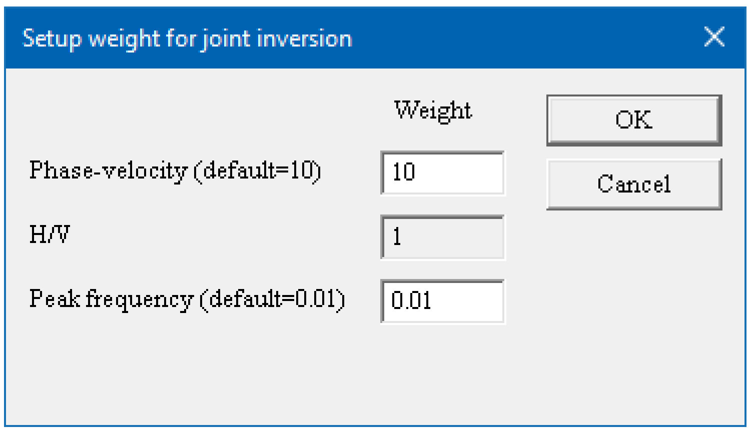
Set the parameter for constraint based on site conditions. Press the *OK* button to proceed.



Confirm the setup for the inversion. Press OK to continue.



Set the weight ratio of Phase velocity, H/V and peak frequency of H/V in the inversion. A larger value gives more weight to the dispersion curve data. The default values (10 and 0.01) are suitable for most cases.



An example of the inverted result is shown below. The error between observed and theoretical phase velocities is smaller than that in the initial model (Model C, Page 44).

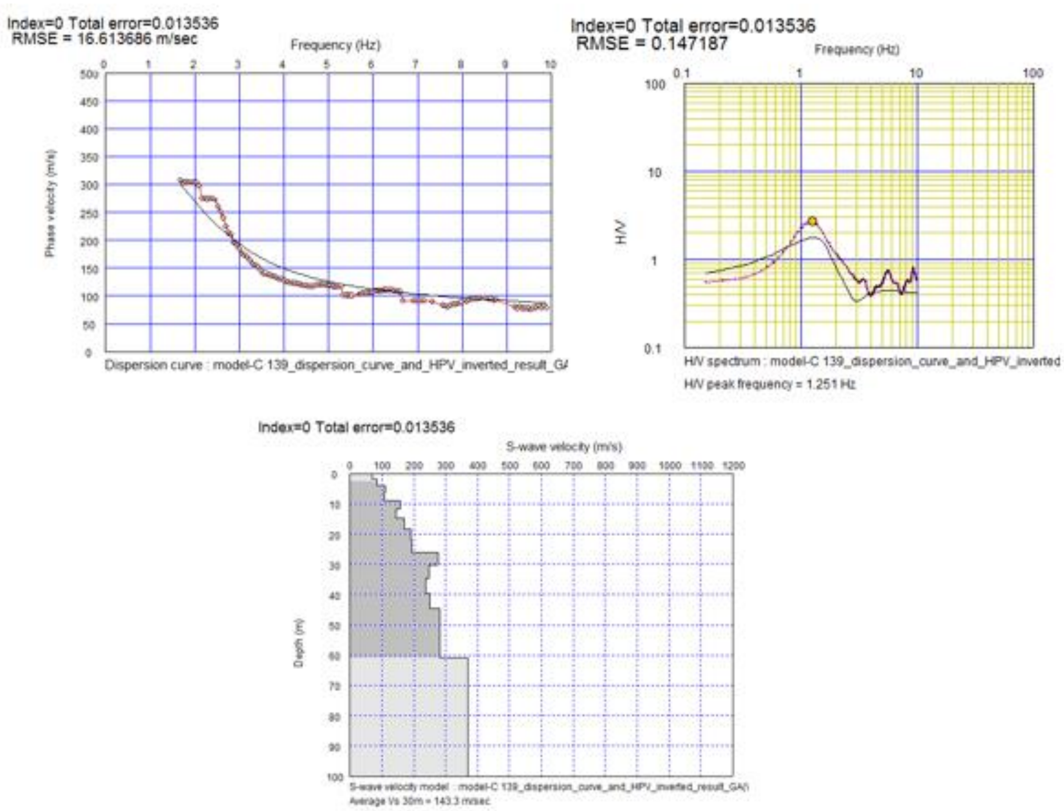
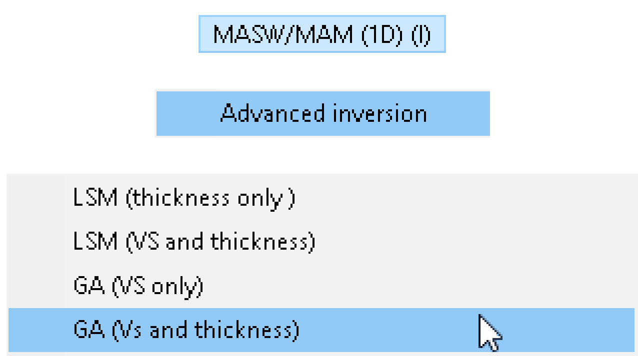


Figure 229: Inverted result.

7.7.4.4 GA (VS and Thickness)



Select *MASW/MAM (1D)* | *Advanced inversion* | *GA (VS and thickness)* to perform an inversion in which both S-wave velocity and thickness of each layer are changed. An inversion that only uses a dispersion curve and a joint inversion that uses both a dispersion curve and an H/V spectrum can be performed through this menu. The inversion performed through this menu changes both S-wave velocity and thickness of each layer, and it is better to keep the number of layers small (3 to 7).

A) Example using the Fundamental Mode

The Initial Model D is used for an example.

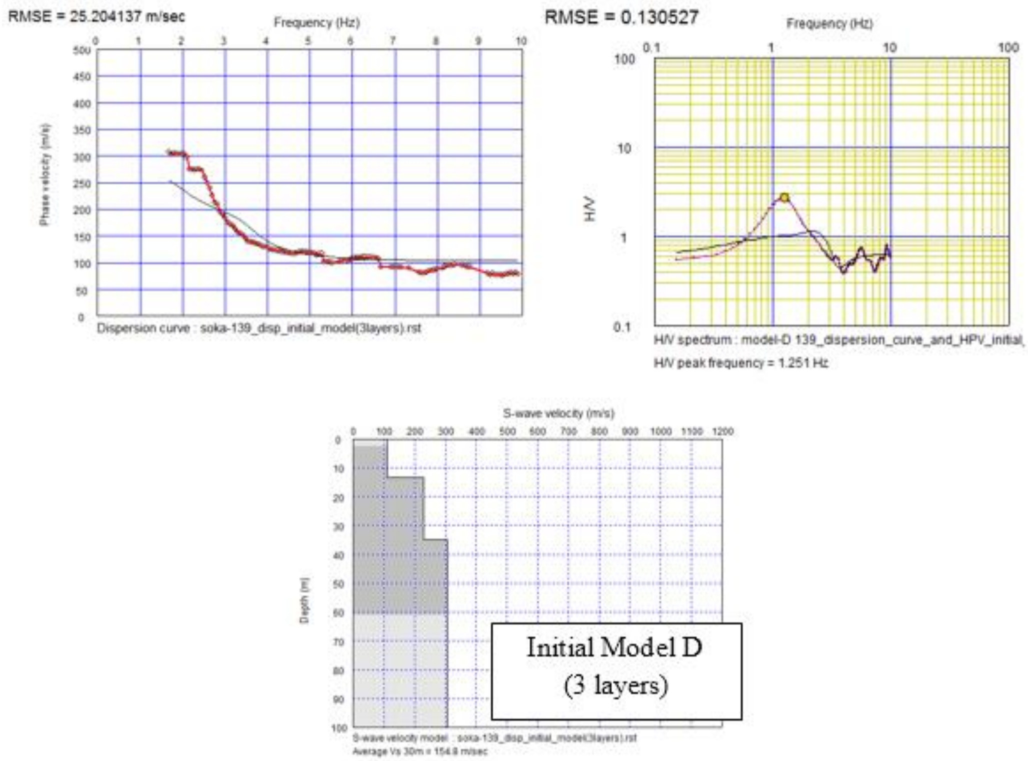
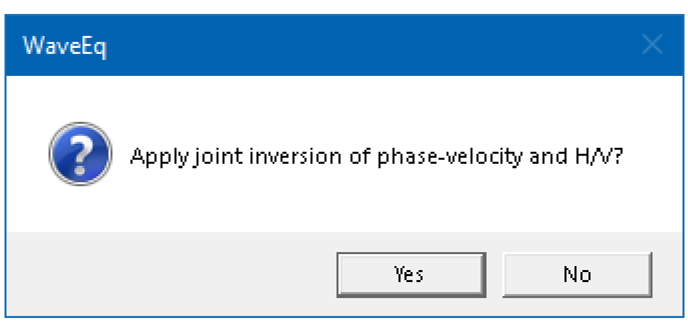
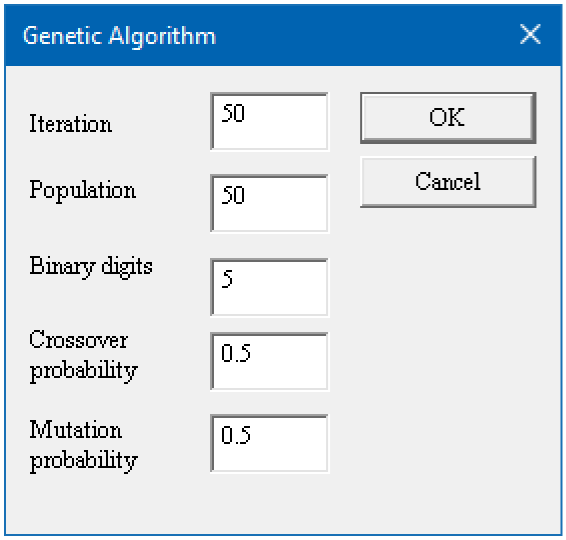


Figure 230: Example dispersion curve, H/V curve, and V_S model.

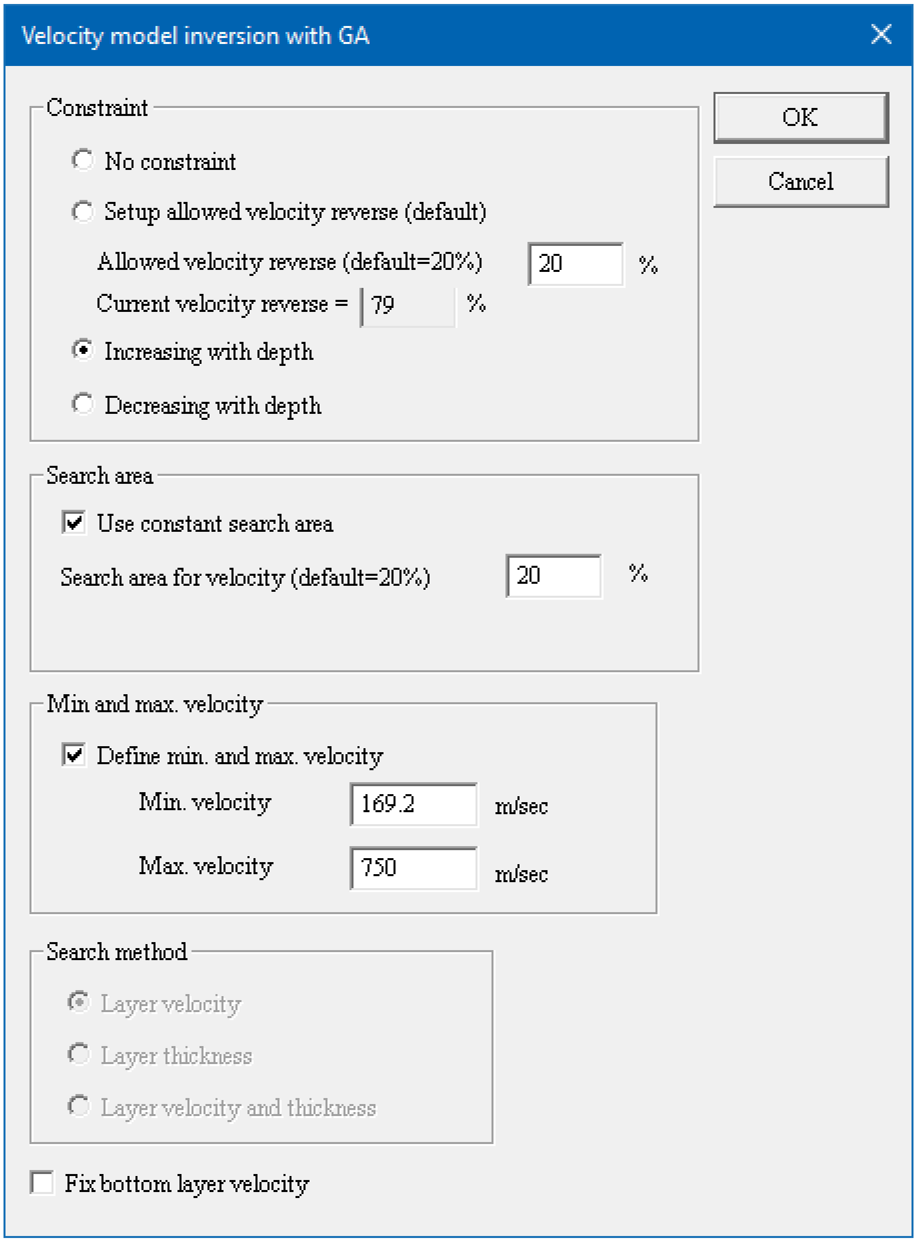
The dialog box shown below will appear when the data contains both phase velocity and H/V data. Press *Yes* if you intend to apply the joint inversion of phase velocity and H/V data. Press *No* to apply only the inversion of phase velocity data.



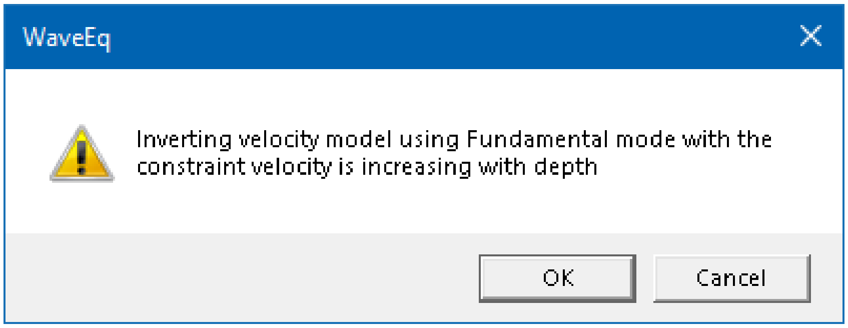
Set the parameters for the Genetic Algorithm. The default values (Iteration=50, Population=50, Binary digits=5, Crossover probability=0.5, Mutation probability=0.5) are suitable for most cases. Press the *OK* button to proceed.



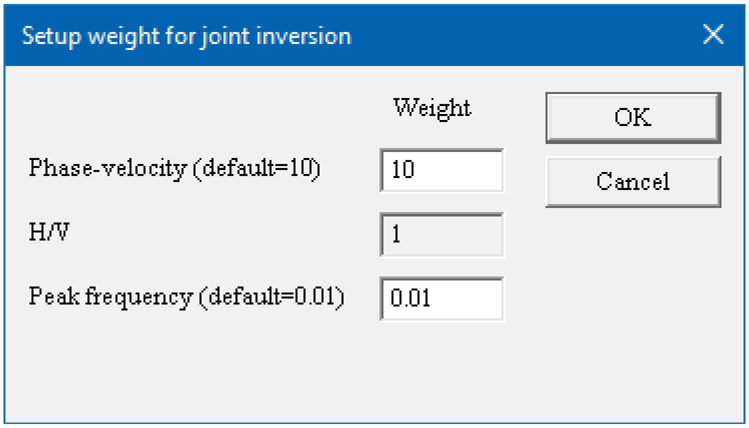
Set the parameters for constraints based on site conditions. (Contact support@seisimager.com for assistance.) Press the *OK* button to proceed.


Velocity model inversion with GA
Constraint
No constraint
Setup allowed velocity reverse (default)
Allowed velocity reverse (default=20%)
20
%
Current velocity reverse =
79
%
Increasing with depth
Decreasing with depth
OK
Cancel
Search area
Use constant search area
Search area for velocity (default=20%)
20
%
Min and max. velocity
Define min. and max. velocity
Min. velocity
169.2
m/sec
Max. velocity
750
m/sec
Search method
Layer velocity
Layer thickness
Layer velocity and thickness
Fix bottom layer velocity

Confirm the setup for the inversion. Press *OK* to continue.



Set the weight ratio of Phase velocity and Peak frequency of H/V in the inversion. A larger value gives more weight to dispersion curve data. The default values (10 and 0.01) are suitable for most cases.



An example of an inverted result is shown below. The error between observed and theoretical phase velocities is smaller than that in the initial model (Model D, Page 499).

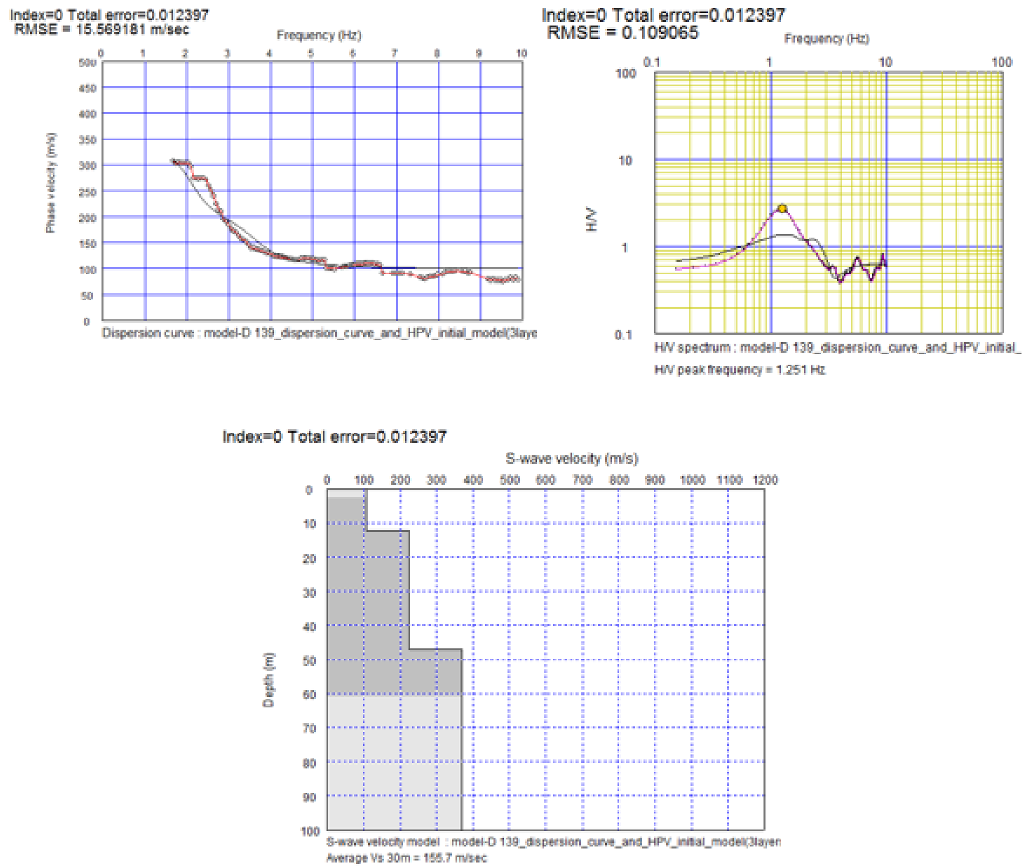


Figure 231: Inverted result.

B) An example using higher modes.

Press the  button to apply the inversion using higher modes. The Initial Model D is used as an example. Press the  button and the theoretical dispersion curves (or H/V) of fundamental and higher modes will appear together with averaged (effective mode) or maximum phase velocities (or H/V). The inversion takes into account higher modes when the  button is pressed.

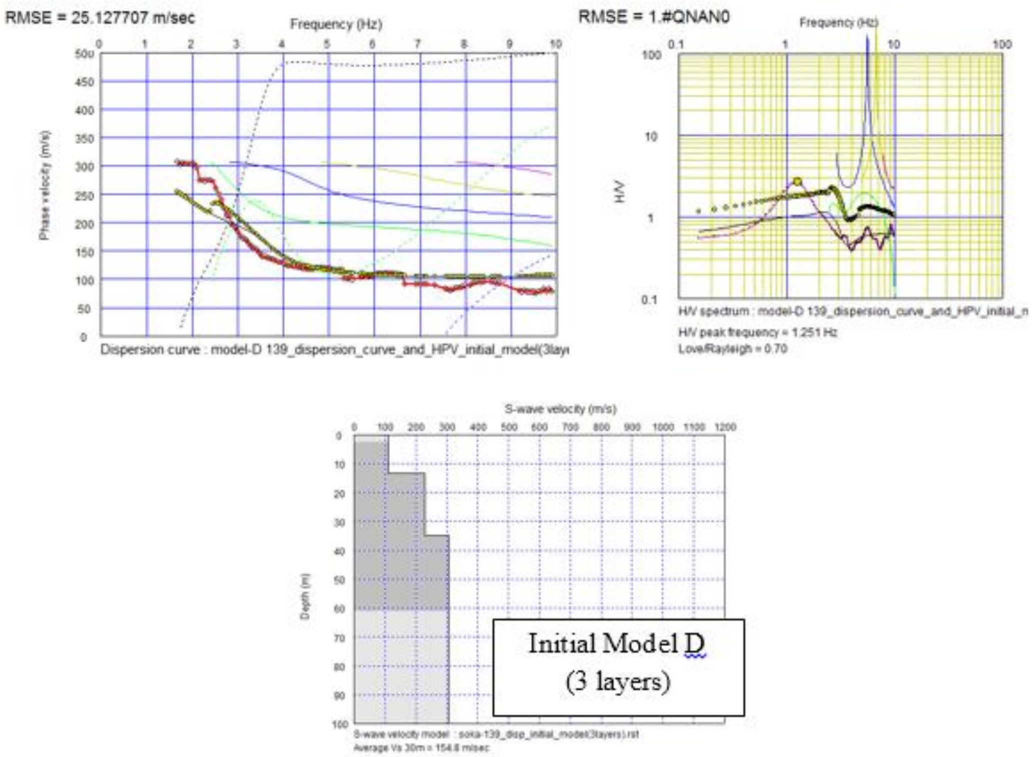
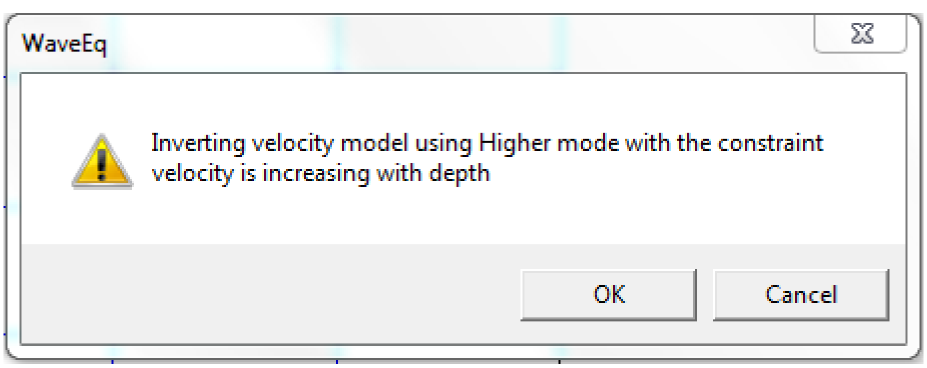


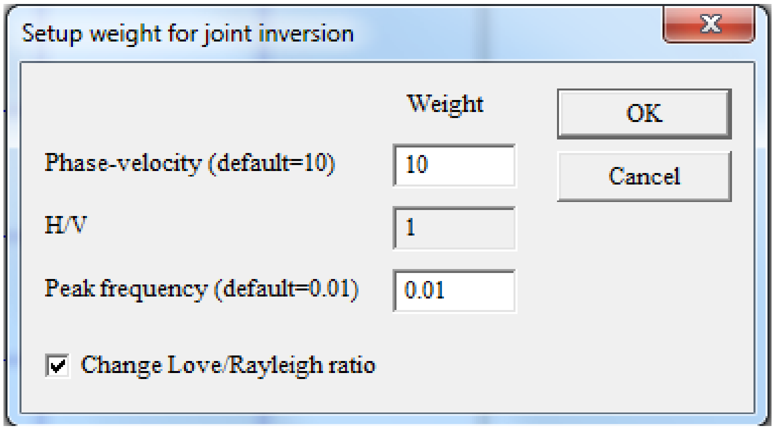
Figure 232: Example dispersion curve, H/V curve, and V_S model.

The inversion procedure is exactly the same as the inversion using the fundamental mode.

Make sure it uses higher modes in the dialog box shown below.



You can change the Love/Rayleigh ratio automatically during the inversion.



An example of the inverted result is shown below. The error between observed and theoretical phase velocities is smaller than that in the initial model (Model D, Page 499).

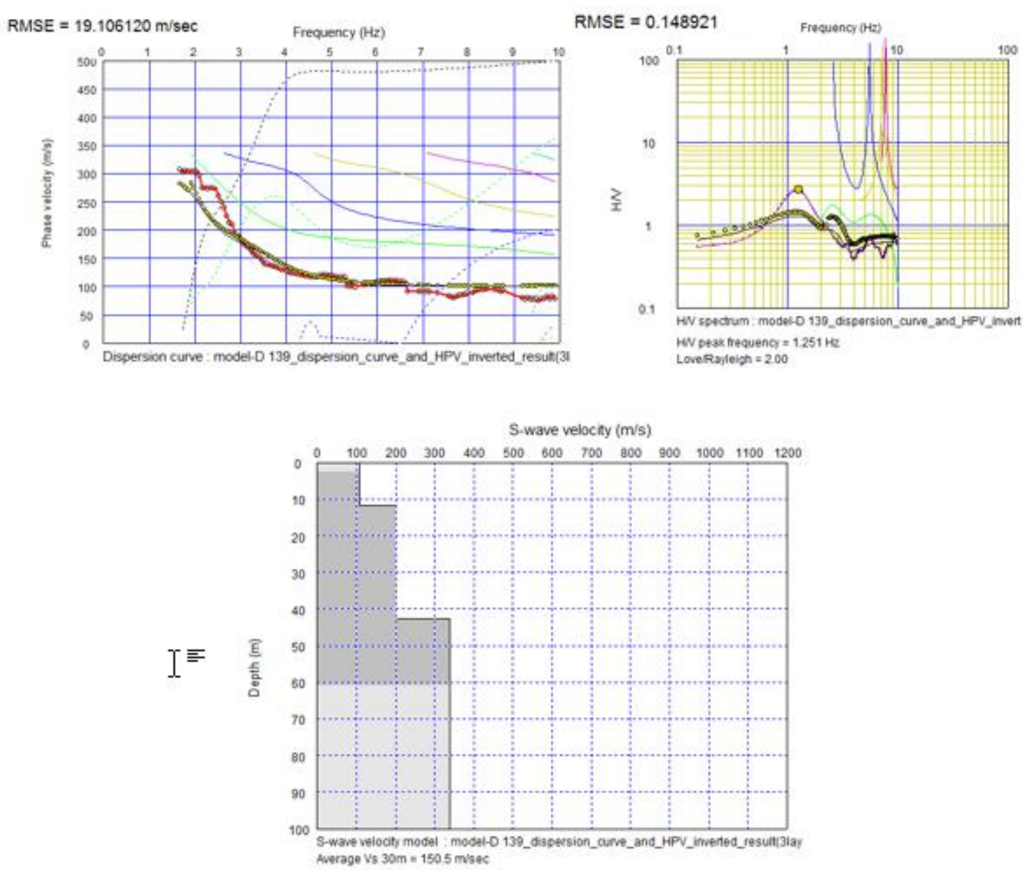
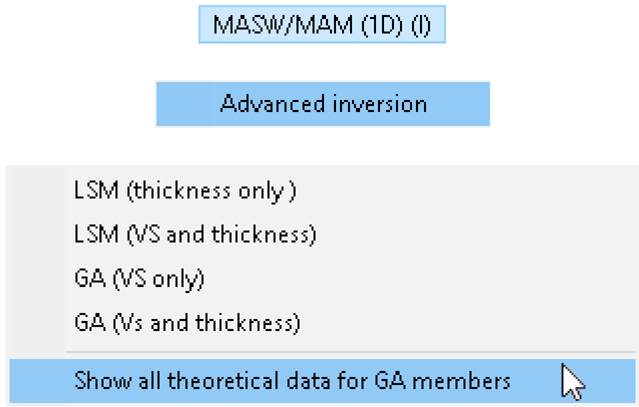


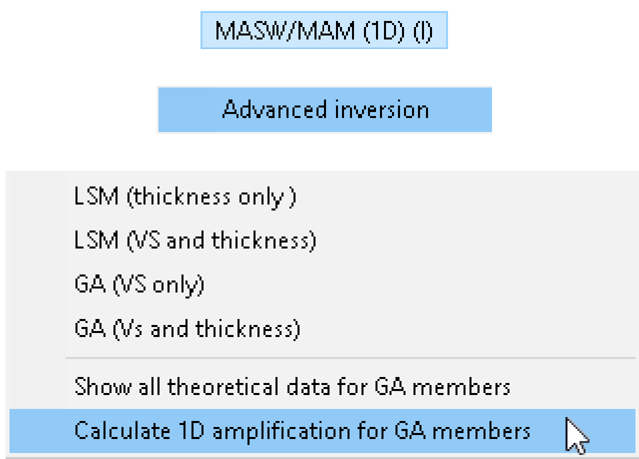
Figure 233: Inverted result.

7.7.4.5 Show All Theoretical Data For GA Members



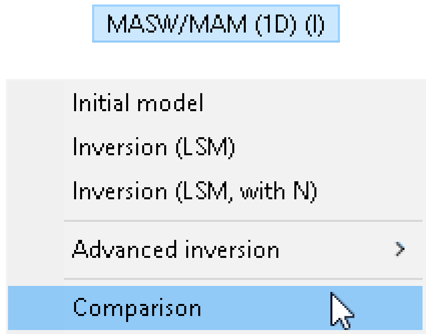
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.4.6 Calculate 1D Amplification For GA Members



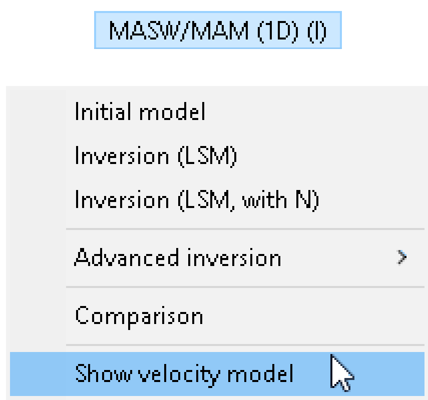
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.5 COMPARISON

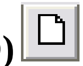


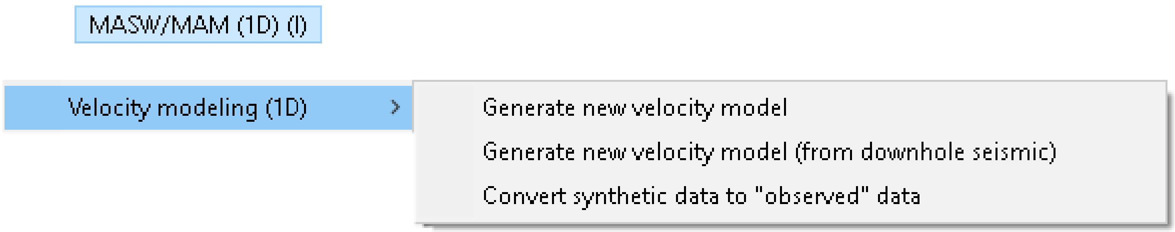
To calculate and overlay a theoretical dispersion curve on an observed dispersion curve, select *Comparison* or press the *Calculate theoretical dispersion curves* button. The calculated curve is shown as a black line. To remove the calculated dispersion curve from the display, press the *Calculate theoretical dispersion curves* button again.

7.7.6 SHOW VELOCITY MODEL



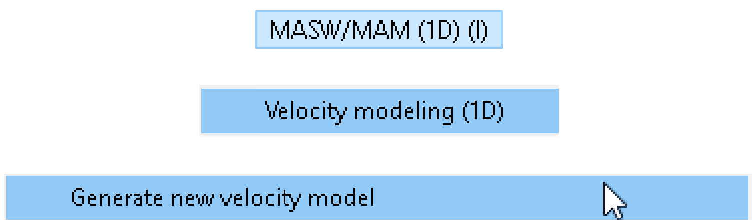
To toggle to the velocity model display from the dispersion curve display, select *Show velocity model* or press the *Show velocity model* button.

7.7.7 VELOCITY MODELING (1D) 

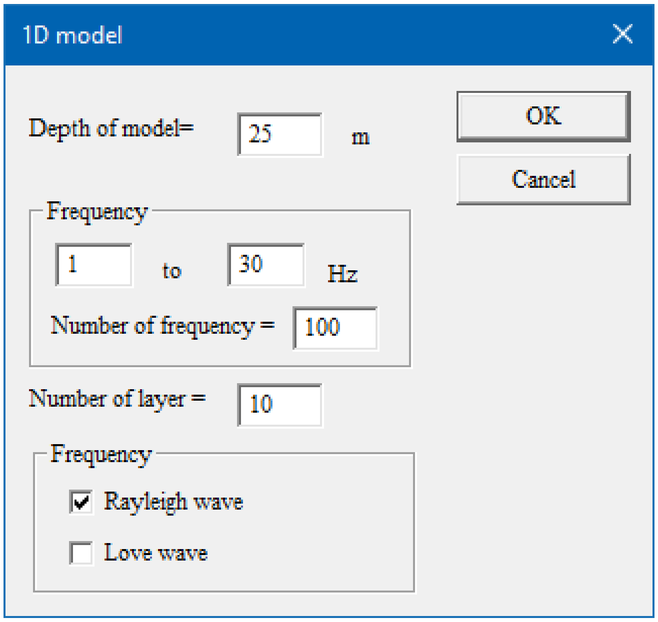


Continue.

7.7.7.1 GENERATE NEW VELOCITY MODEL



A synthetic velocity model can easily be created independent of a waveform file. Modeling can be useful for planning a survey, modeling borehole data, or testing and comparing various results. To set the parameters for a velocity model, select *Modeling (1D)* or press the *Creating a new velocity model for modeling*  button.



Depth of model is used to indicate the maximum depth of the model. The default *Frequency* range is suitable to simulate depth of penetration from an active source. If the *Depth of model* is greater than 30 m or 100 ft, correspondingly, the lower-end frequency should be set to 0.2 Hz to simulate a greater sampling depth.

The frequency range is divided by the *Number of frequency* and sets the resolution of the dispersion curve. The *Number of frequency* default value of 60 is suitable for the default frequency range. If the frequency range is widened significantly, the *Number of frequency* should also be scaled up accordingly. If you would like to use Love waves in the analysis, check *Love wave*.

Note: *Love waves are rarely used in surface wave methods.*

Upon pressing *OK*, the following homogeneous model appears; the associated dispersion curve does not yet exist.

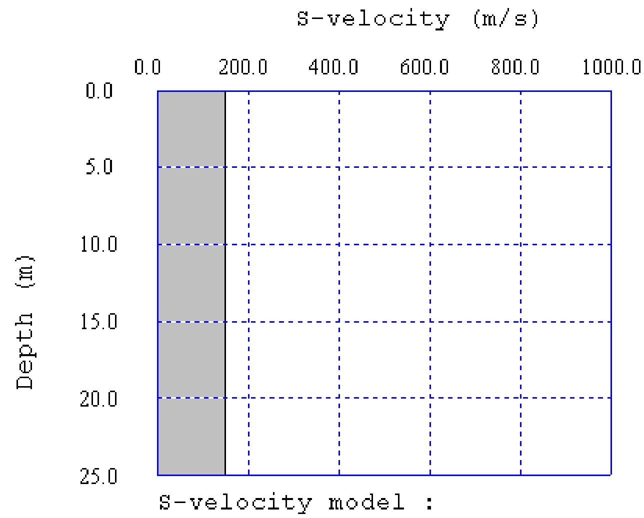


Figure 234: Homogeneous model.

To modify the velocity model, press the *Correct velocity model* button. Horizontal black lines defining the model layers appear. Use the mouse to click on the vertical edge of a layer and the selected layer edge will turn red. Drag the edge to the desired velocity.

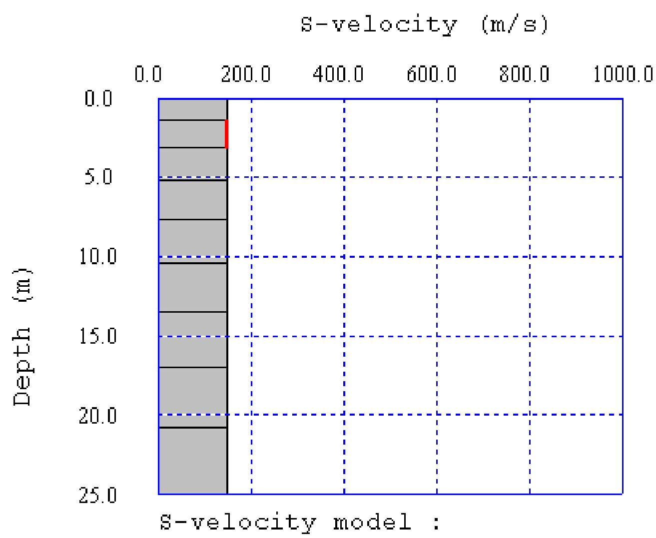


Figure 235: Homogeneous model with layers inserted.

Position the rest of the layers and set the water table if desired.

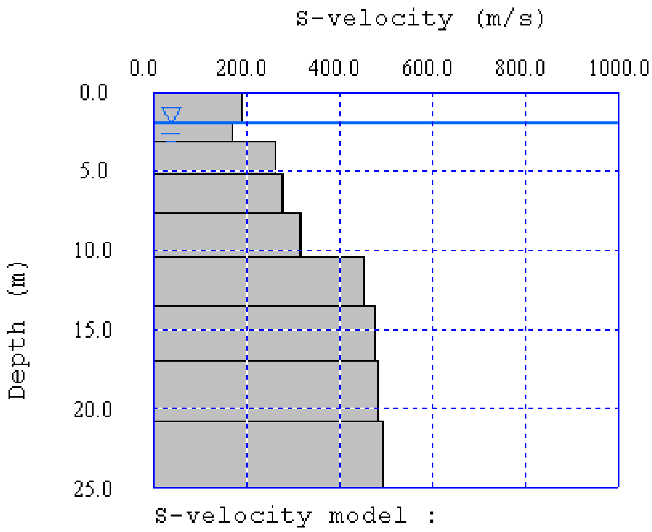
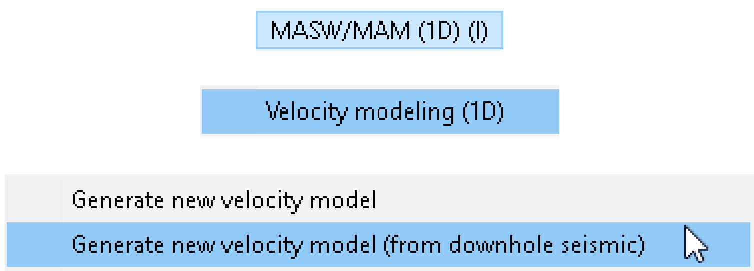


Figure 236: Final model including water table.

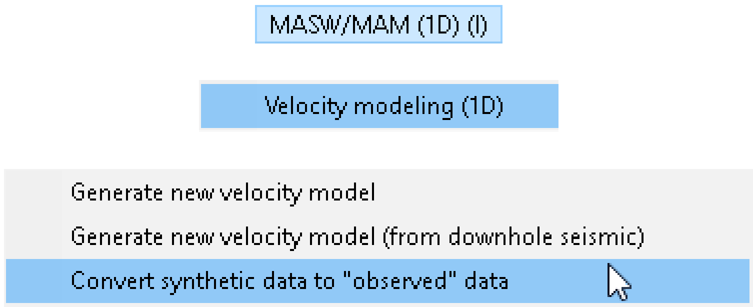
Refer to Section 7.7.9, Page 521, to continue modeling by simulating a survey and generating a dispersion curve.

7.7.7.2 Generate New Velocity Model (From Downhole Seismic)



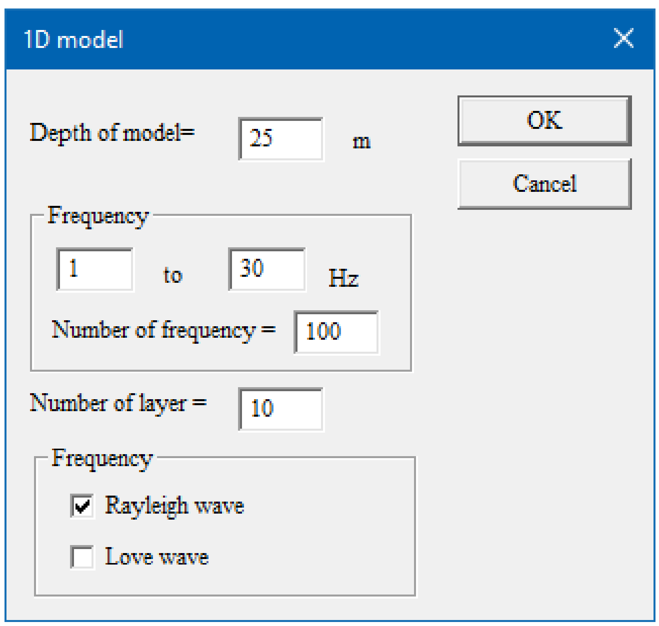
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.7.3 CONVERT SYNTHETIC DATA TO "OBSERVED" DATA



You may convert synthetic data to "observed" data by the following procedure.

Select *MASW/MAM (1D)* | *Velocity Modeling (1D)* | *Generate New Velocity Model*. You will see the following dialog box:



Set the model parameters as desired and press *OK*. If necessary, modify the model by adding layers (Section 7.6.9, Page 455) and modifying their velocities (Section 7.6.7, Page 453). Once the model has been created (see below), press the button and then the button. The synthetic phase velocity curve will be displayed:

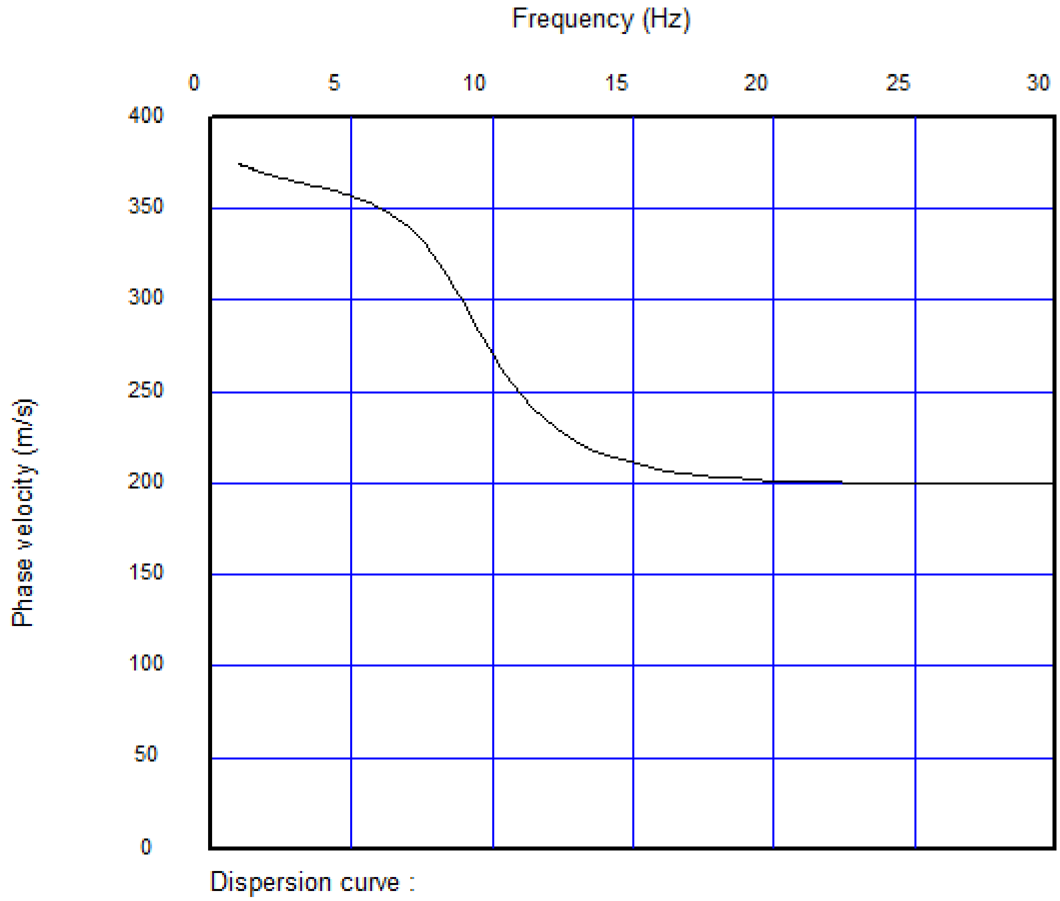


Figure 237: Synthetic dispersion curve.

To convert to "observed" data, select *MASW/MAM (1D)* | *Velocity Modeling (1D)* | *Convert synthetic data to "observed" data.*

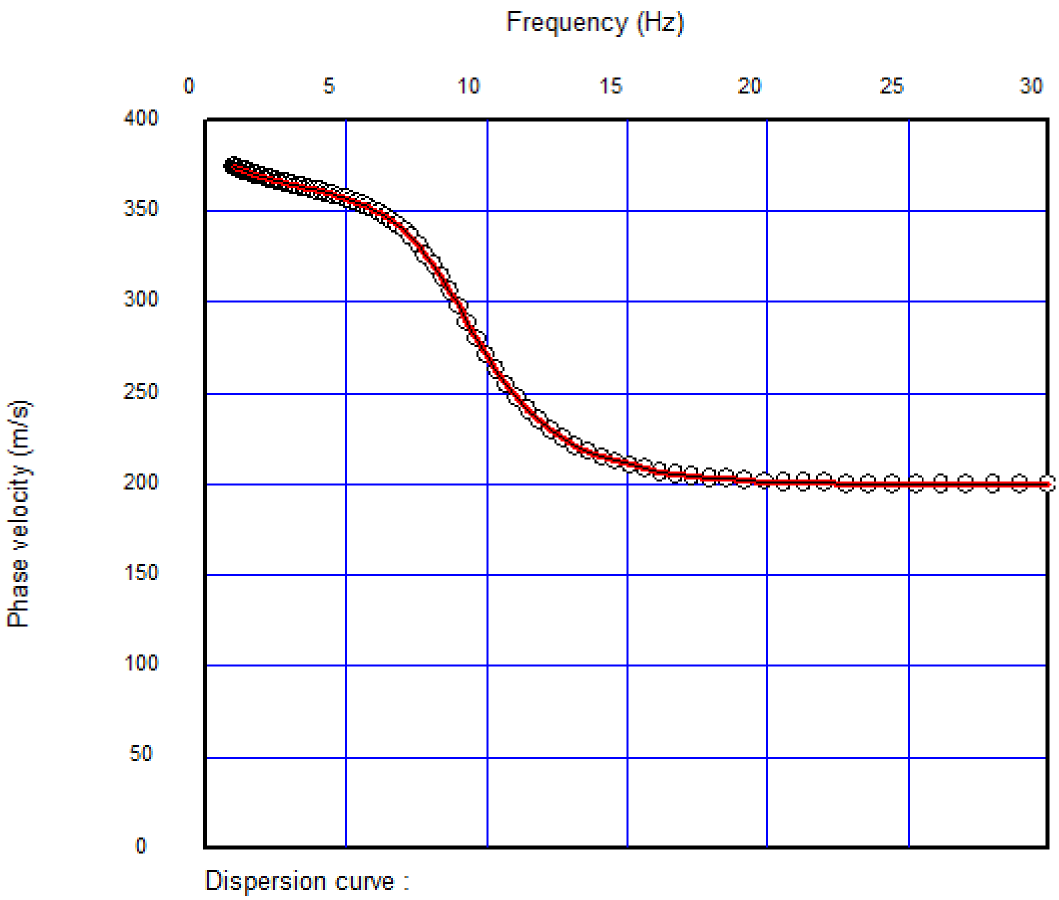


Figure 238: "Observed" dispersion curve.

The data will now be recognized by the application as "real" or "observed" data and can treated as such.

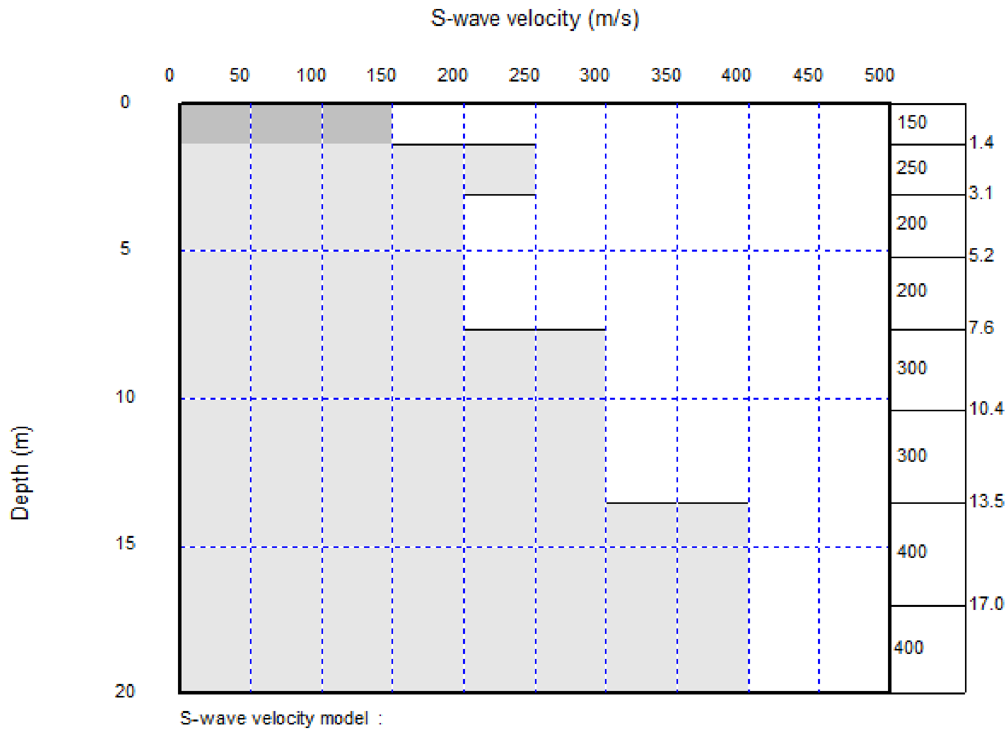
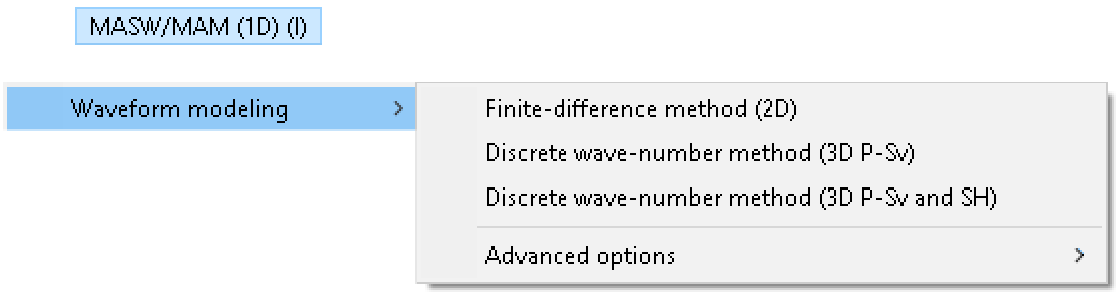


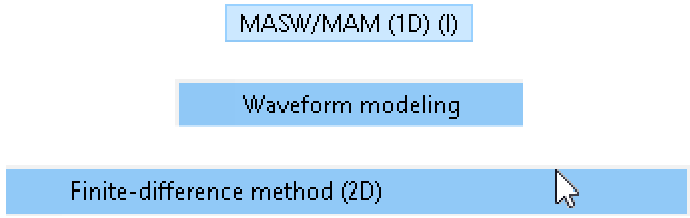
Figure 239: "Observed" velocity model.

7.7.8 WAVEFORM MODELING



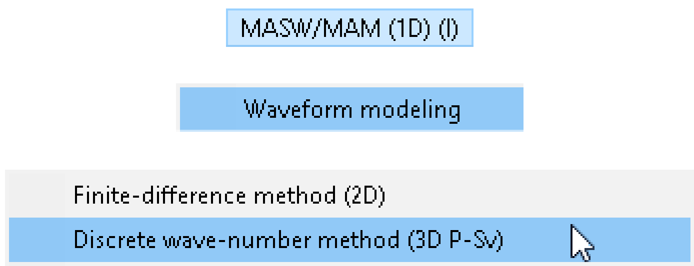
Continue.

7.7.8.1 Finite-difference Method (2D)

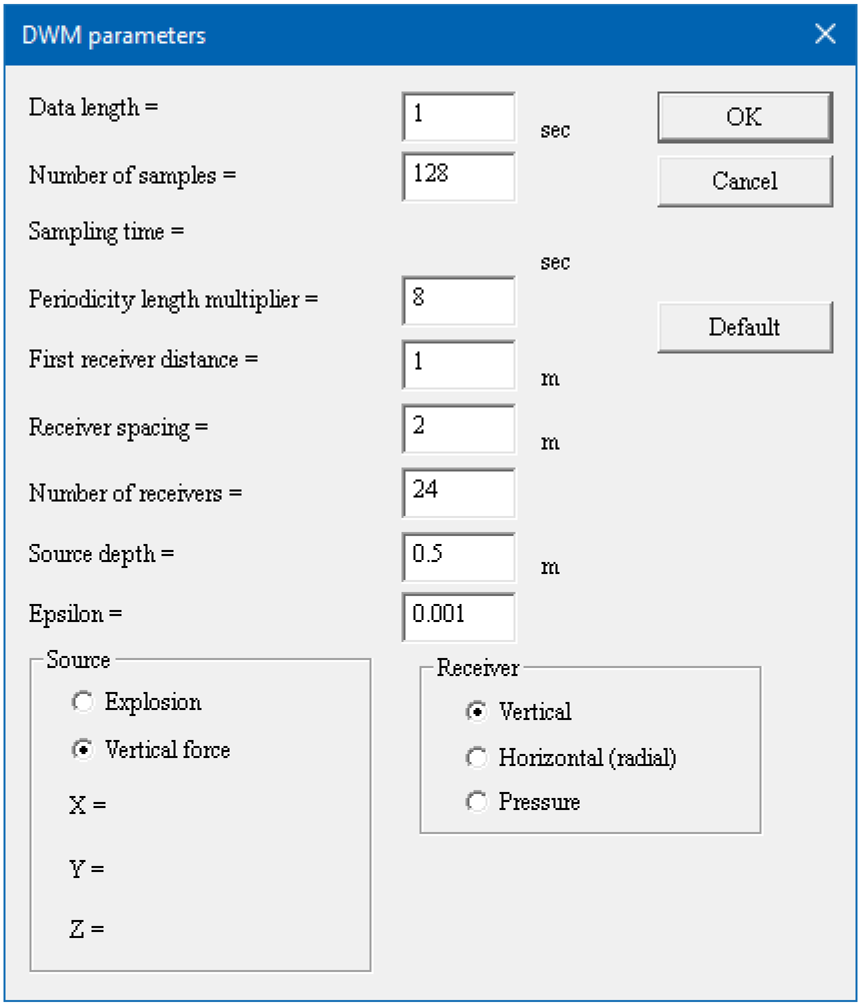


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.8.2 Discrete Wave-number Method (3D P-S_V)



Once a synthetic velocity model exists, a synthetic waveform file must be generated to calculate the dispersion curve. Only active source waveform files can be simulated. To generate the waveform file, select *Waveform Modeling | Discrete wave-number method (3D P-S_V)*. The **DWM parameters** dialog box settings determine how the waveform record is calculated:



The *Data length* is the record length in time. *Number of samples* relates to the sample interval used in field acquisition; 1 second divided by 128 samples equals a sample interval of 7.8 milliseconds. Although this is much larger than what is commonly used in the field for a 1D MASW survey, a value of 128 is sufficient and makes the calculation less computationally intensive.

The *Periodicity length multiplier* defines the size of the calculation, and the default value is suitable for most cases. *First receiver distance* is the near offset, the *Receiver spacing* is simply the geophone interval, and the *Number of receivers* is the number of channels. Refer to Section 3.1, Page 11, for values similar to what would be used in the field for a 1D MASW survey. The *Source depth* is the depth below surface of the source; for a surface source, enter zero. *Epsilon* controls the accuracy of the calculation, and the default value is suitable for most cases.

To revert to the default values, press *Default*.

Press *OK* and the corresponding waveform file is calculated and automatically displayed in Pickwin.

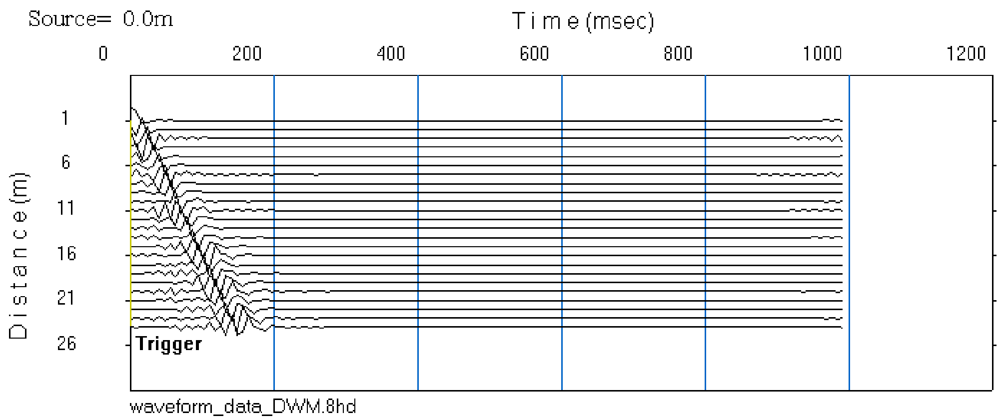


Figure 240: Synthetic waveform file.

The waveform file is automatically saved to the current directory with the file name *waveform_data_DWM.8hd*.

Proceed with calculating phase velocity and picking the dispersion curve as if the synthetic waveform file was a field record.

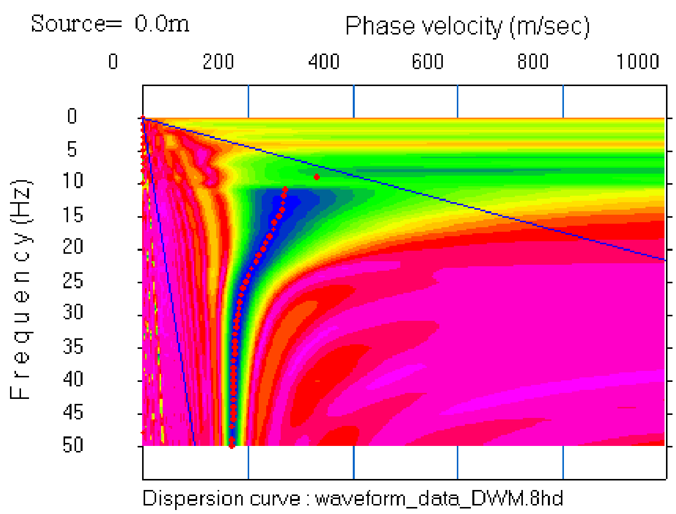
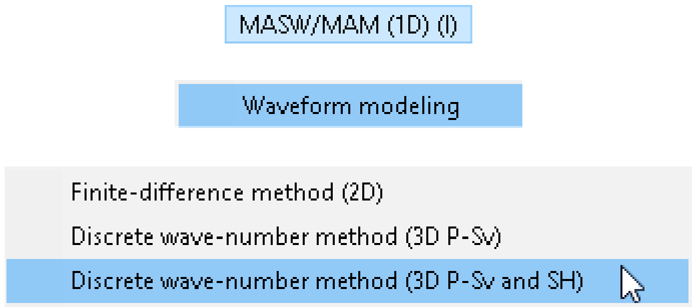


Figure 241: Phase velocity-frequency plot corresponding to synthetic waveform file in Figure 240.

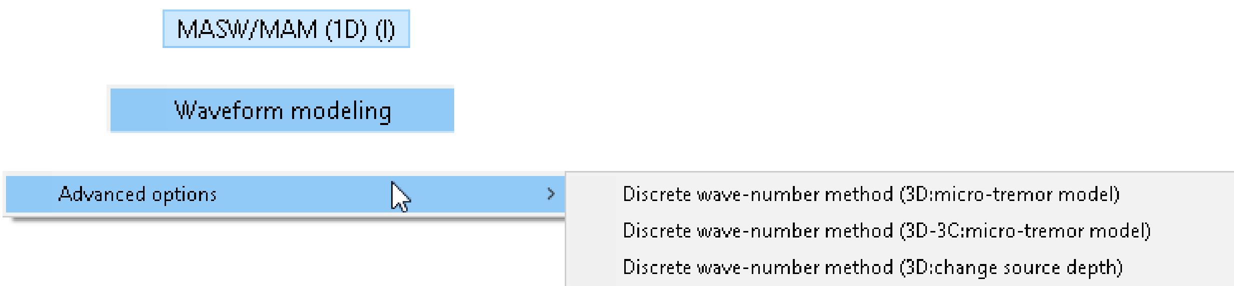
Import the dispersion curve picks into WaveEq, set up an initial model, and run the inversion. Refer to Section 7.11.7, Page 593, for explanation of additional modeling functions.

7.7.8.3 Discrete Wave-number Method (3D P-S_V and SH)



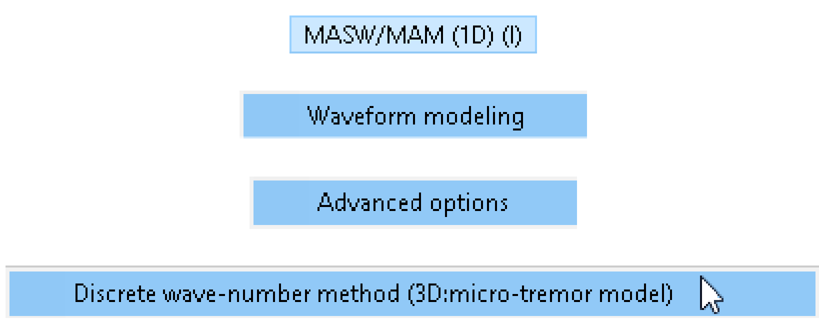
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.8.4 Advanced Options



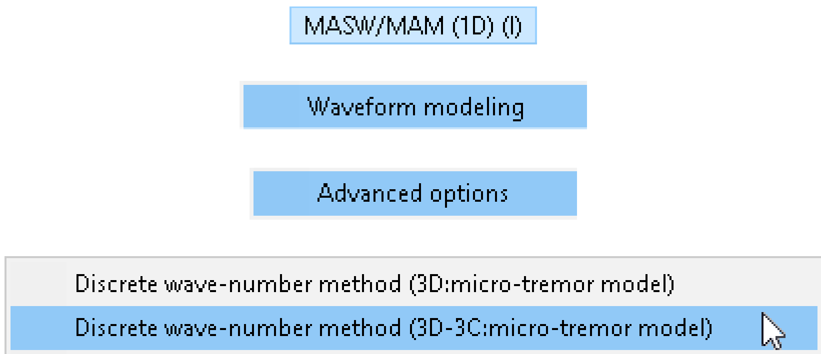
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.7.8.4.1 Discrete Wave-number method (3D: Microtremor Model)



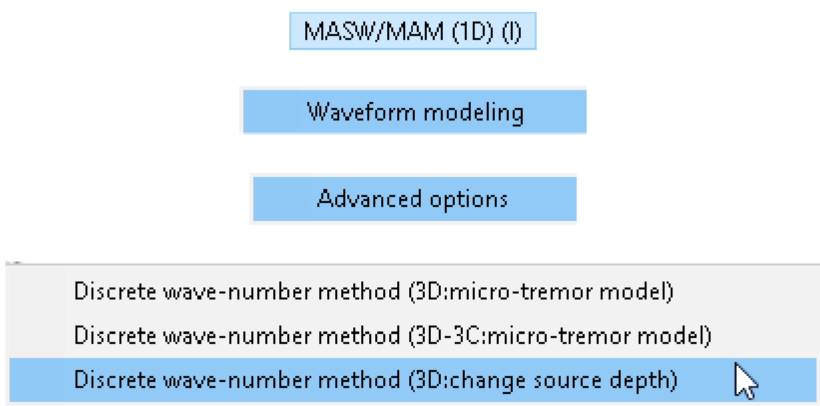
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.8.4.2 Discrete Wave-number method (3D-3C: Microtremor Model)



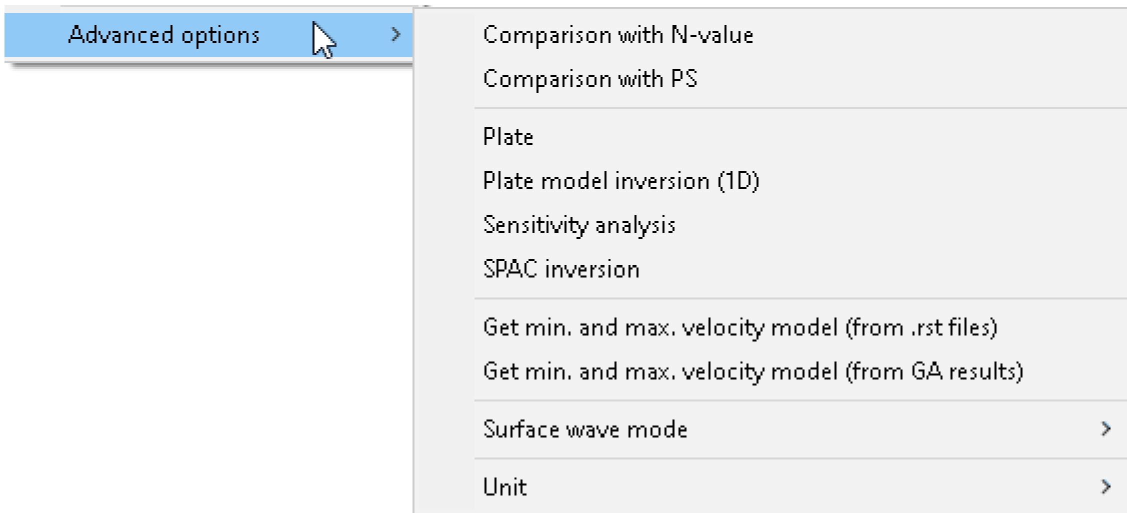
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.8.4.3 Discrete Wave-number method (3D: Change Source depth)



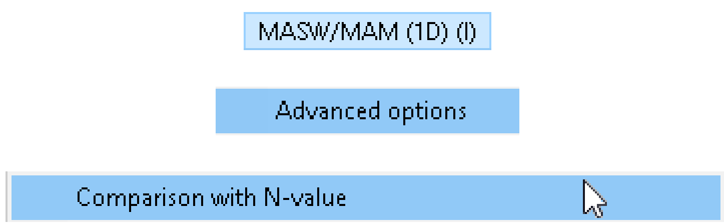
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9 ADVANCED OPTIONS



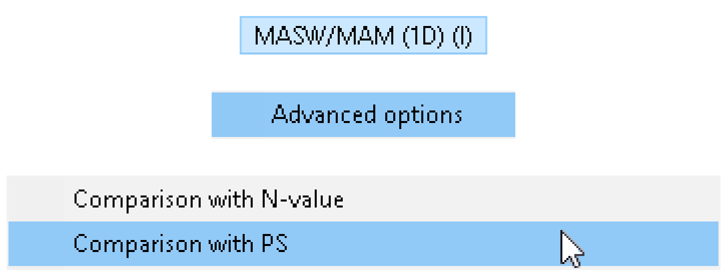
The features in the following sub-menus are highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.1 COMPARISON WITH N-VALUE



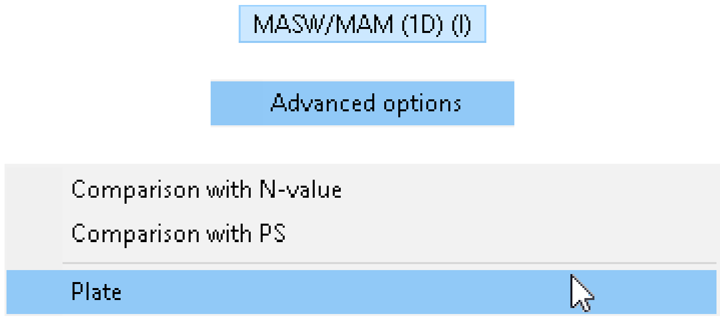
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.2 COMPARISON WITH PS



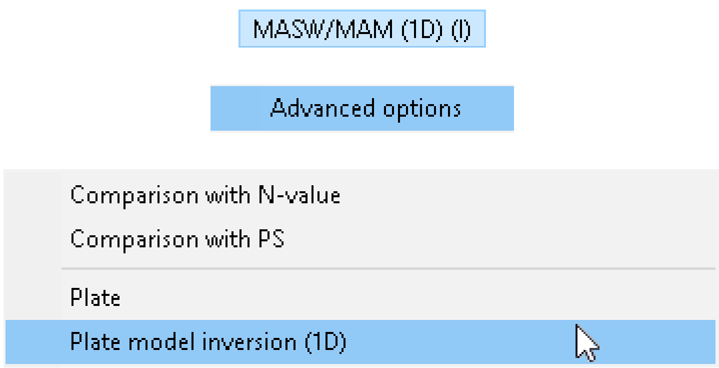
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.3 Plate



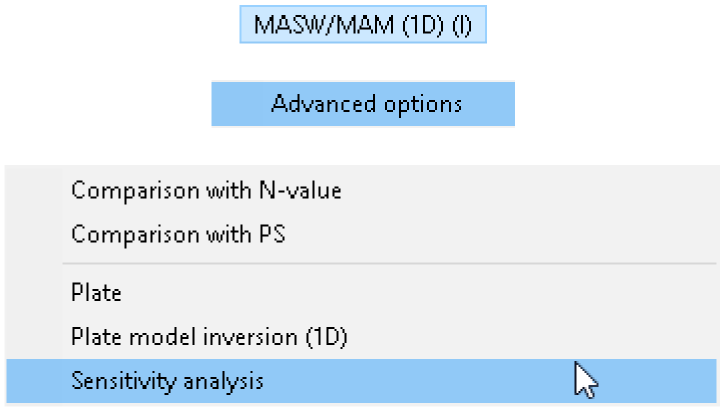
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.4 Plate Model Inversion (1D)



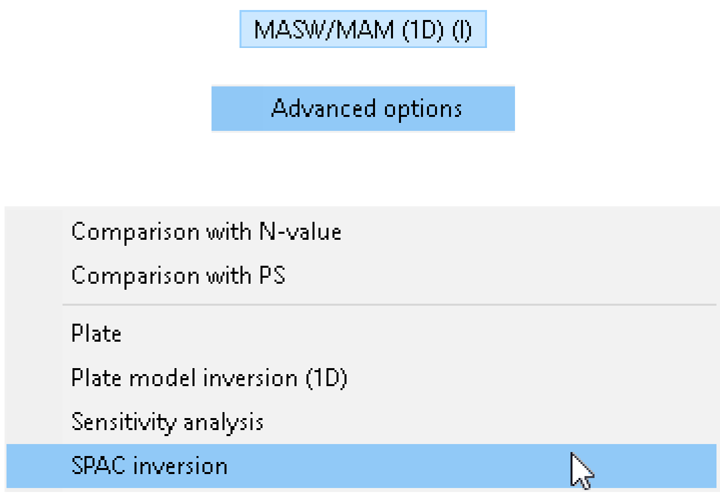
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.5 Sensitivity Analysis



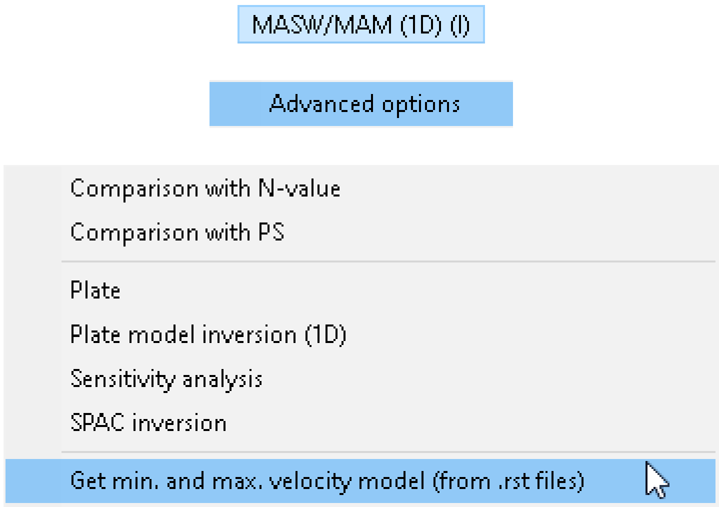
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.6 SPAC Inversion



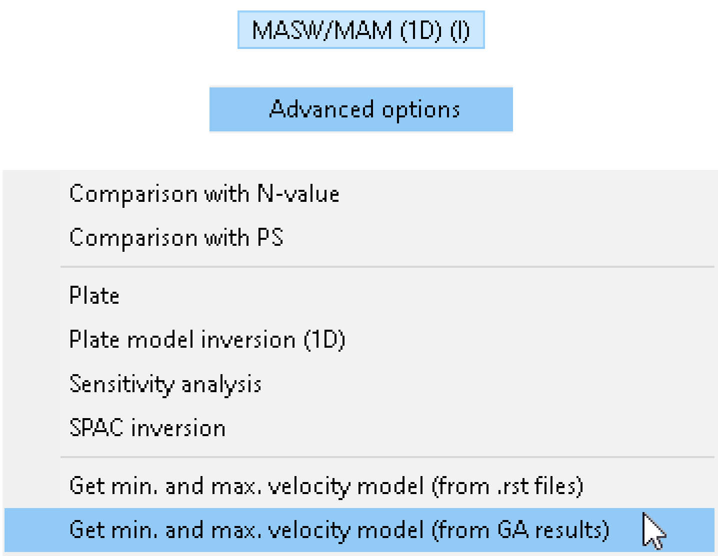
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance. At tutorial on SPAC inversion can be found here.

7.7.9.7 Get Min. and Max. Velocity Model (From .rst files)



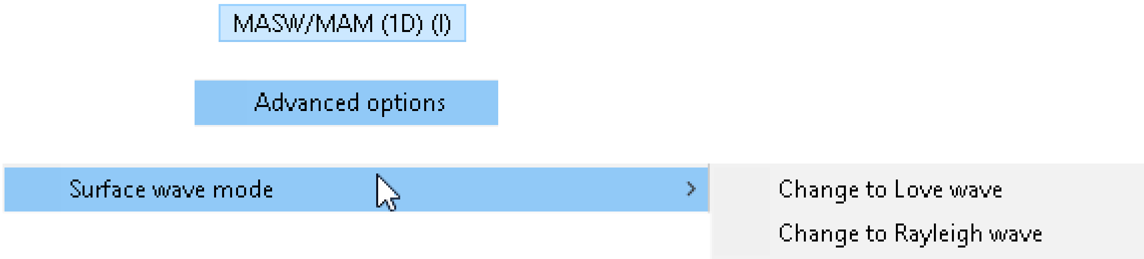
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.8 Get Min. and Max. Velocity Model (From GA Results)



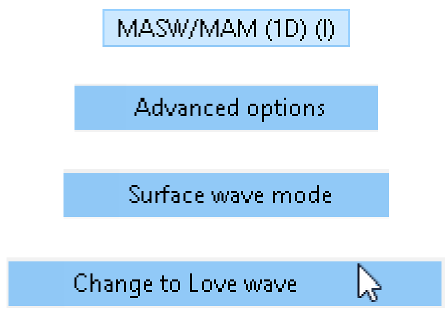
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.9 Surface Wave Mode



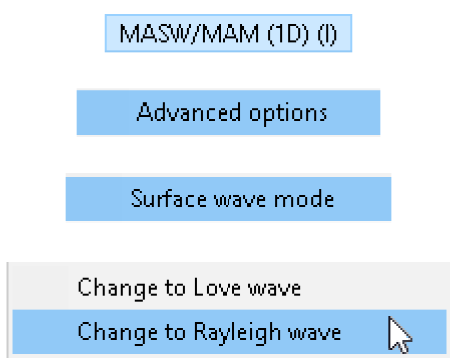
Continue.

7.7.9.9.1 Change to Love Wave



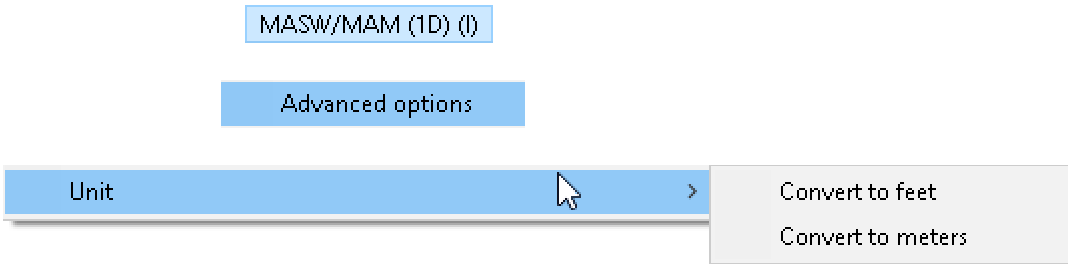
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.9.2 Change to Rayleigh Wave



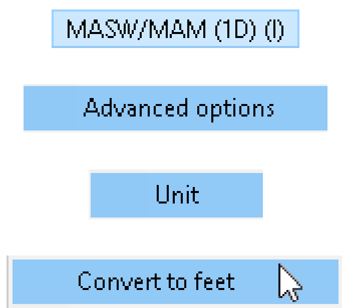
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.7.9.10 UNIT



You may change the units between meters and feet using the next two sub-menus.

7.7.9.10.1 CONVERT TO FEET



You may convert the units of your model from ft and ft/sec to m and m/sec and vice-versa. Compare the following displays of the same dispersion curve and model. The first pair is in m and m/sec; the second pair is in ft and ft/sec.

Note: *You will most likely need to adjust the axis limits [Ctrl+A] when converting between units.*

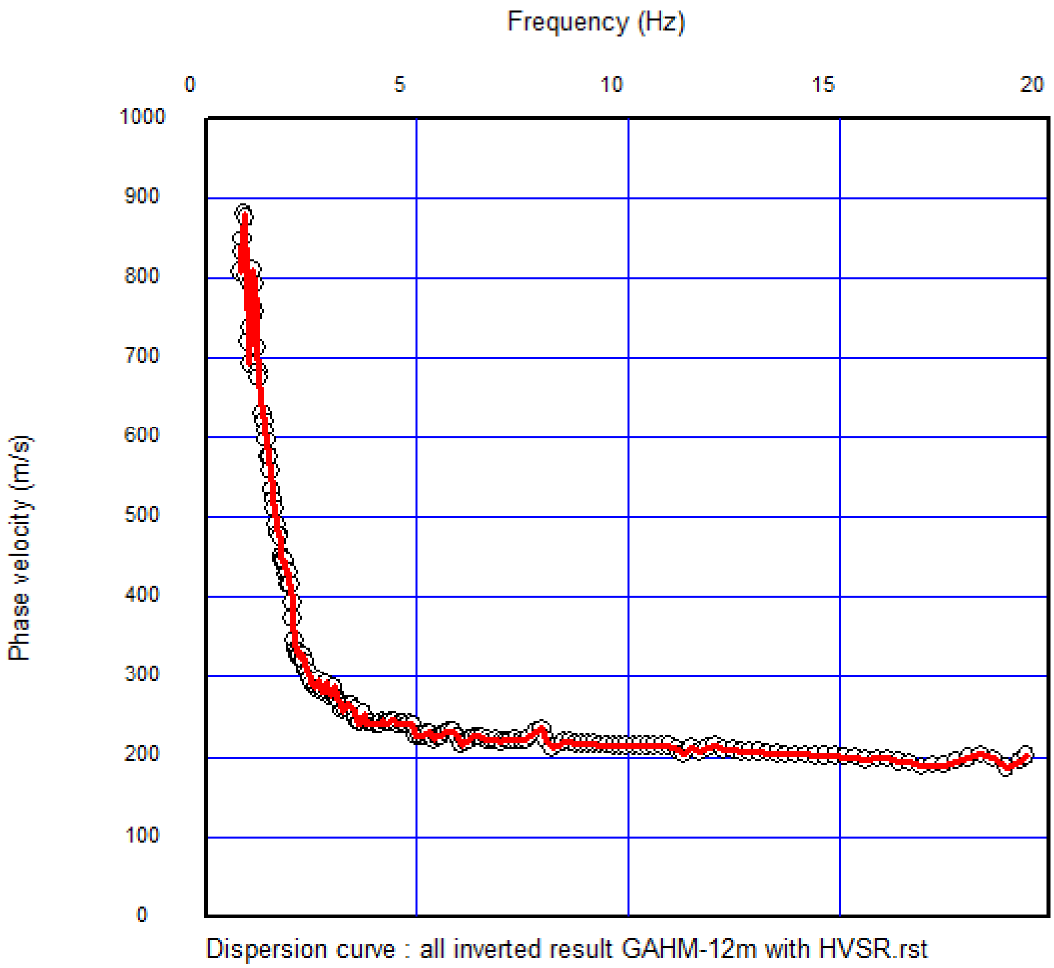


Figure 242: Dispersion curve displayed in m/sec.

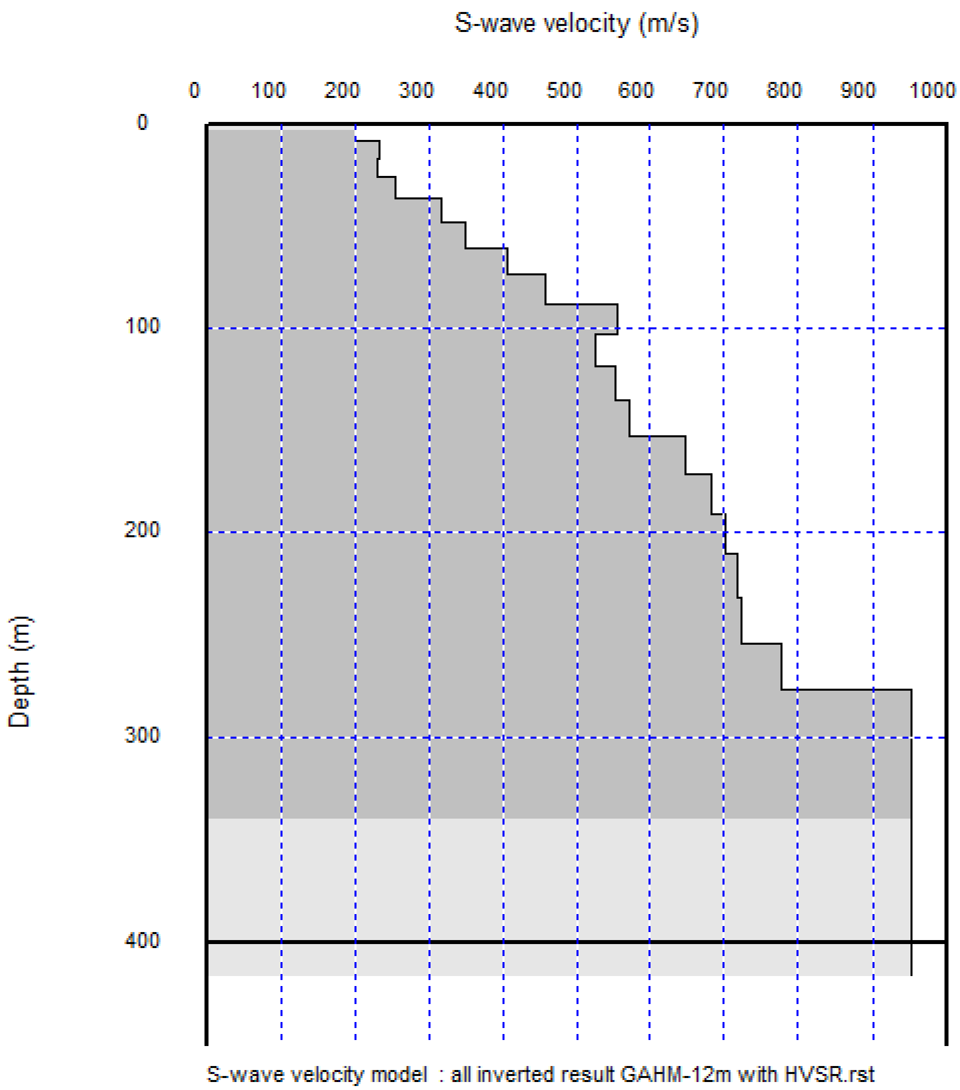


Figure 243: Velocity model displayed in m and m/sec.

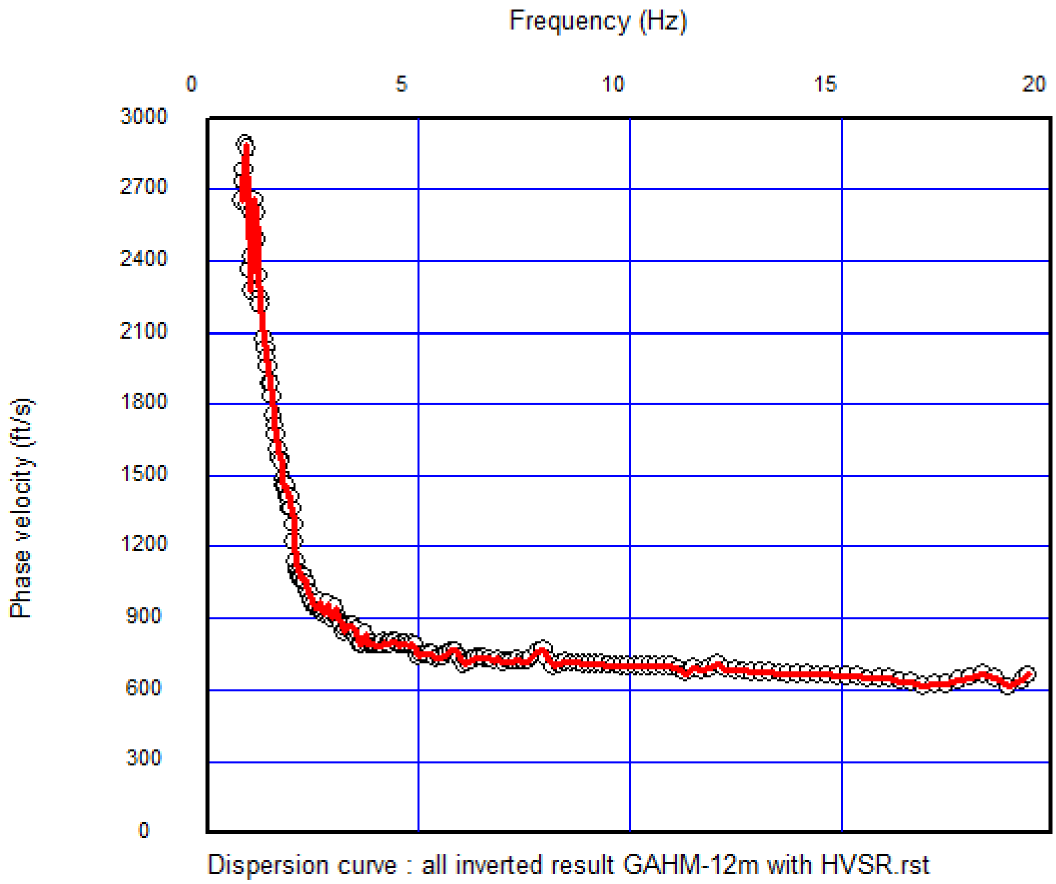


Figure 244: Dispersion curve from Figure 242 displayed in ft/sec.

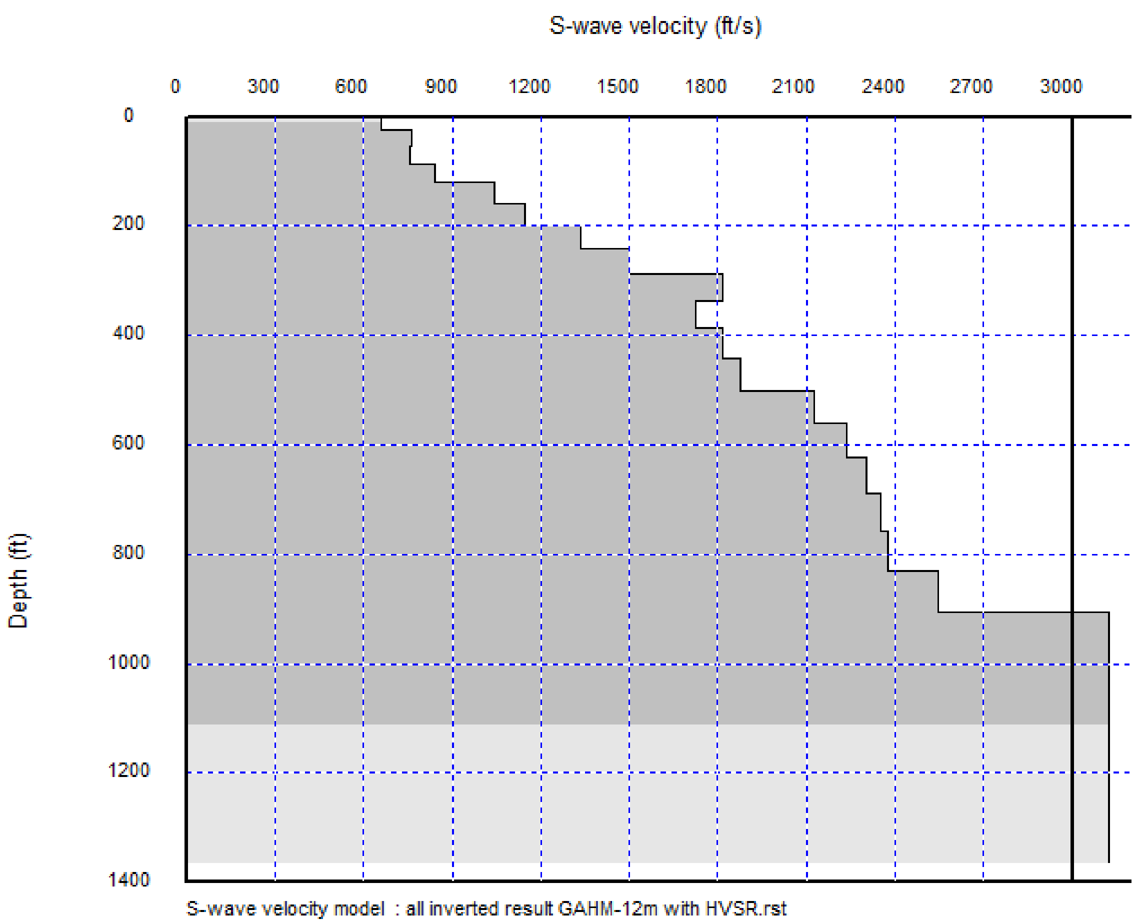
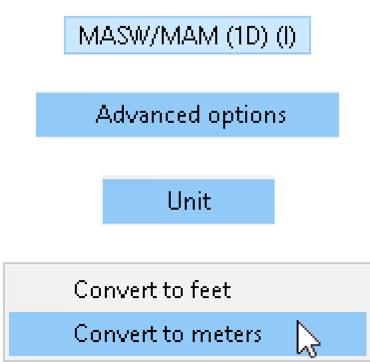


Figure 245: Velocity model from Figure 243 displayed in ft and ft/sec.

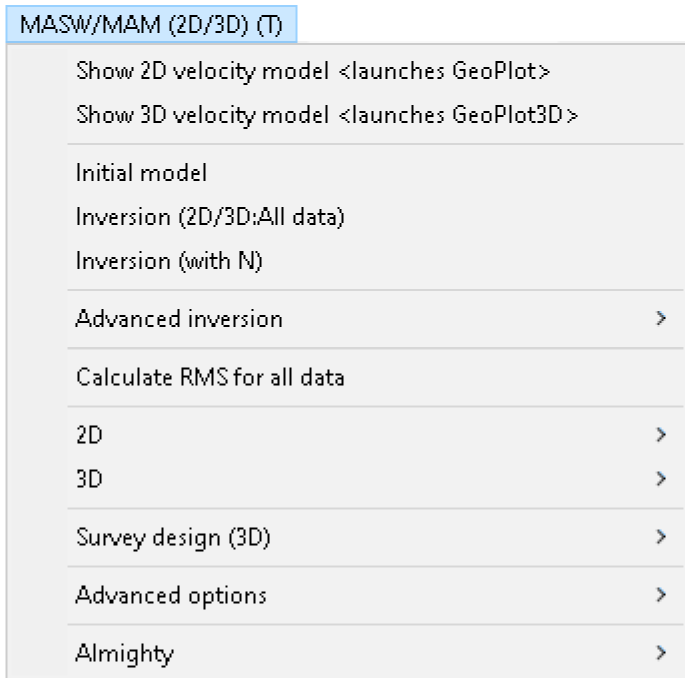
7.7.9.10.2 CONVERT TO METERS



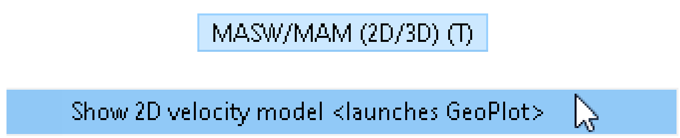
This is just the reverse of that described in the previous section.

7.8 MASW/MAM (2D/3D) MENU

The **MASW/MAM (2D/3D)** menu includes functions for calculating an initial model for a 2D dataset and running the inversion to find the best fit of the modified initial model data with the observed data. For purchasers of SeisImager/SW-1D, this menu is not active.

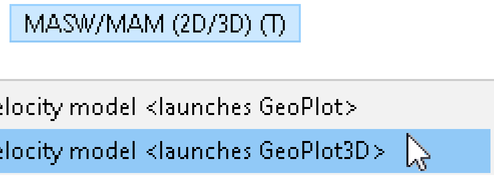


7.8.1 SHOW 2D VELOCITY MODEL <LAUNCHES GEOPLOT>



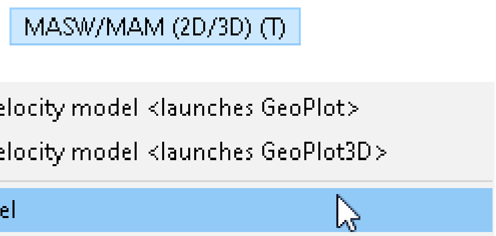
Once initial or final models exist for a series of CMP cross-correlation gathers, the applicable cross-sectional model can be viewed in GeoPlot by selecting *Show 2D velocity model*. The unit labels set in WaveEq carry over. Refer to Section 4.1.3, Page 90, for more information on setting display parameters in GeoPlot.

7.8.2 Show 3D Velocity Model <Launches GeoPlot3D>



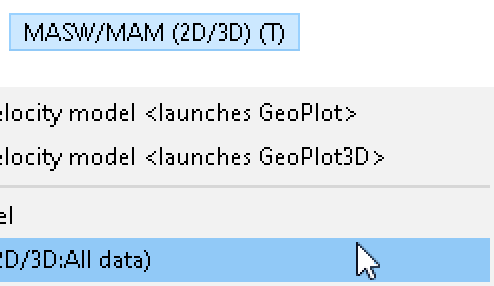
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance. You might find it useful to look at this tutorial. If you would like to work through it, an example dataset can be found here.

7.8.3 Initial Model



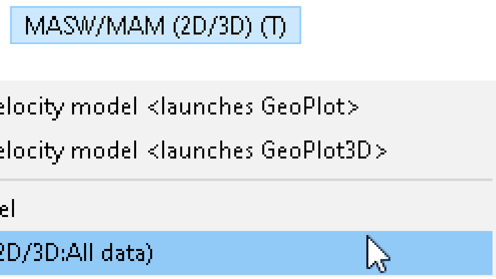
The initial cross-sectional V_S model is the starting point for the inversion. For 2D MASW, the initial cross-sectional model is interpolated from individual 1D initial models for a set of CMP cross-correlation gathers. To generate an initial cross-sectional model from the set of gathers, select *Initial model*. The **Initial model for inversion** dialog box settings are the same as those explained in Section 7.7.1, (Page 479) except that *Apply horizontal interpolation* is checked by default to allow the cross-sectional model to be constructed by interpolation between the series of 1D models.

7.8.4 Inversion (2D/3D: All Data)



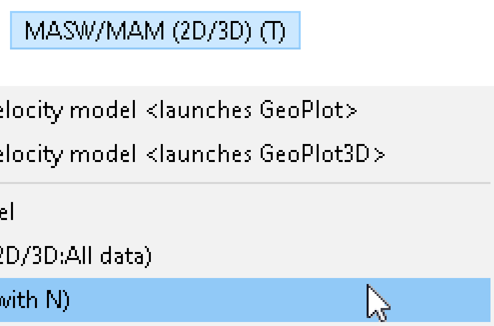
The *Inversion (2D/3D: All Data)* and *Inversion (with N)* processes can be computationally intensive, and may take some time to complete, depending on the size of the dataset. Also, the higher the *Iteration* value, the longer the process will take. In the Windows Task Manager, WaveEq may report as “Not Responding”, but if the memory usage is dynamically changing, this indicates the process is running properly.

7.8.5 INVERSION (2D/3D: ALL DATA)



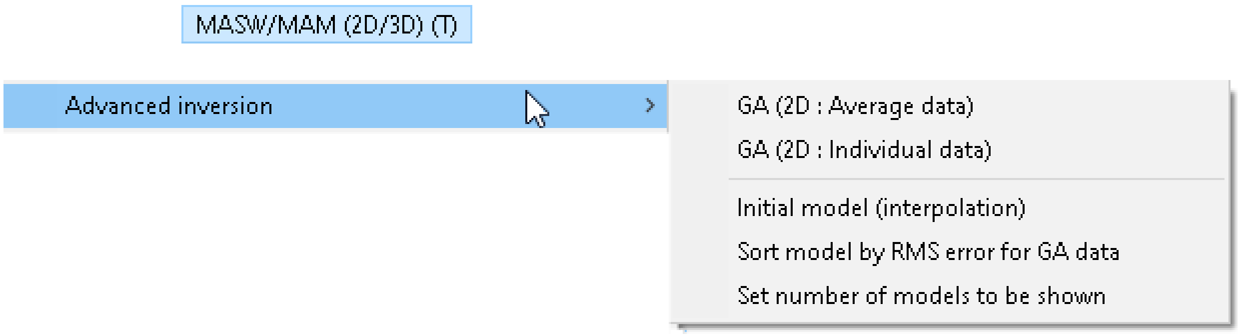
To calculate the V_S cross-section that best matches the observed data, select *Inversion (2D/3D:All Data)*. The **Least Squares Method** dialog box settings are the same as those explained in Section 7.7.2 (Page 483), except that the default value for *e* equals 0.1 and for *Regularization* equals 0.5.

7.8.6 INVERSION (WITH N)



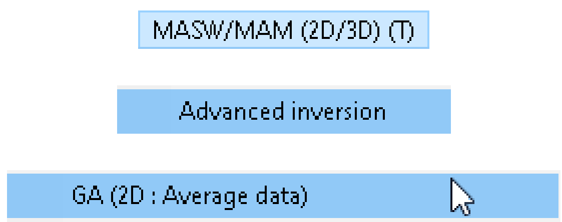
If N-values are used to construct the initial model, select *Inversion (with N)* instead of *Inversion (2D/3D:All Data)*. The **Least Squares Method** dialog box settings are the same as those explained in Section 7.7.2 (Page 483), except that the default value for *e* equals 0.1 and for *Regularization* equals 0.5.

7.8.7 Advanced Inversion



SeisImager includes several advanced inversion tools. Many of the items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.7.1 GA (2D: Average Data)



Select *MASW/MAM (2D/3D)* | *Advanced inversion* | *GA (2D: Average data)* to apply the inversion to two-dimensional data using the Genetic Algorithm (GA).

A 2D velocity section of the initial model, example of 1D dispersion curve, and velocity model are shown below.

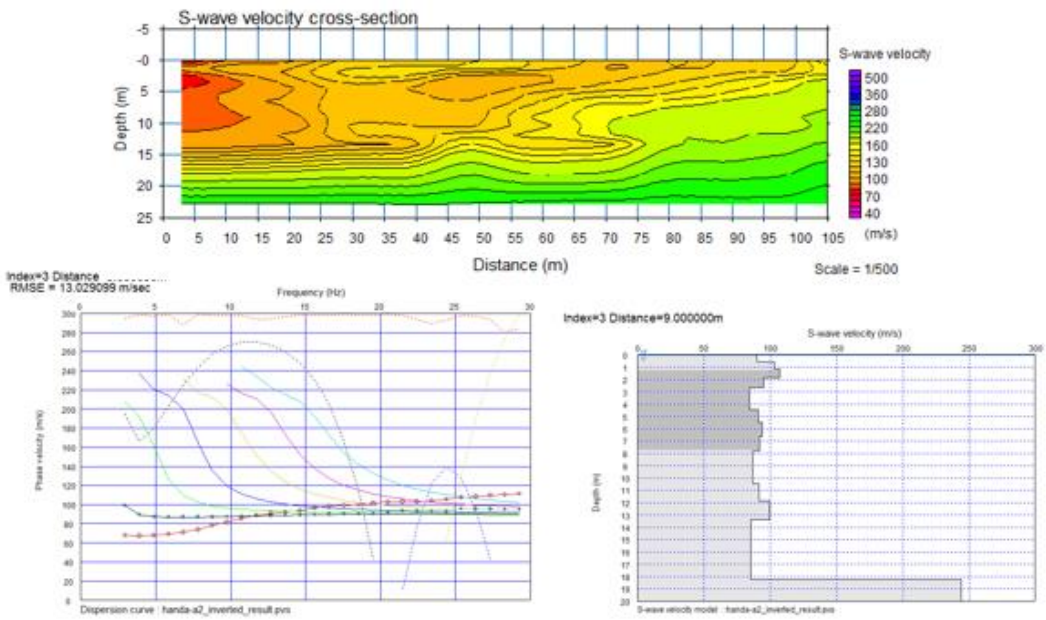
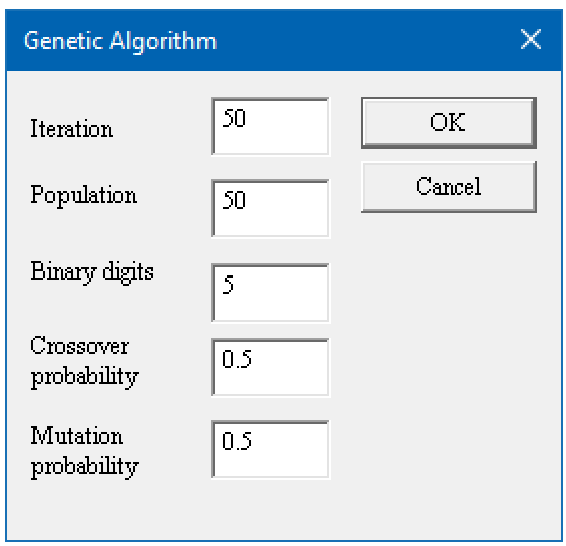
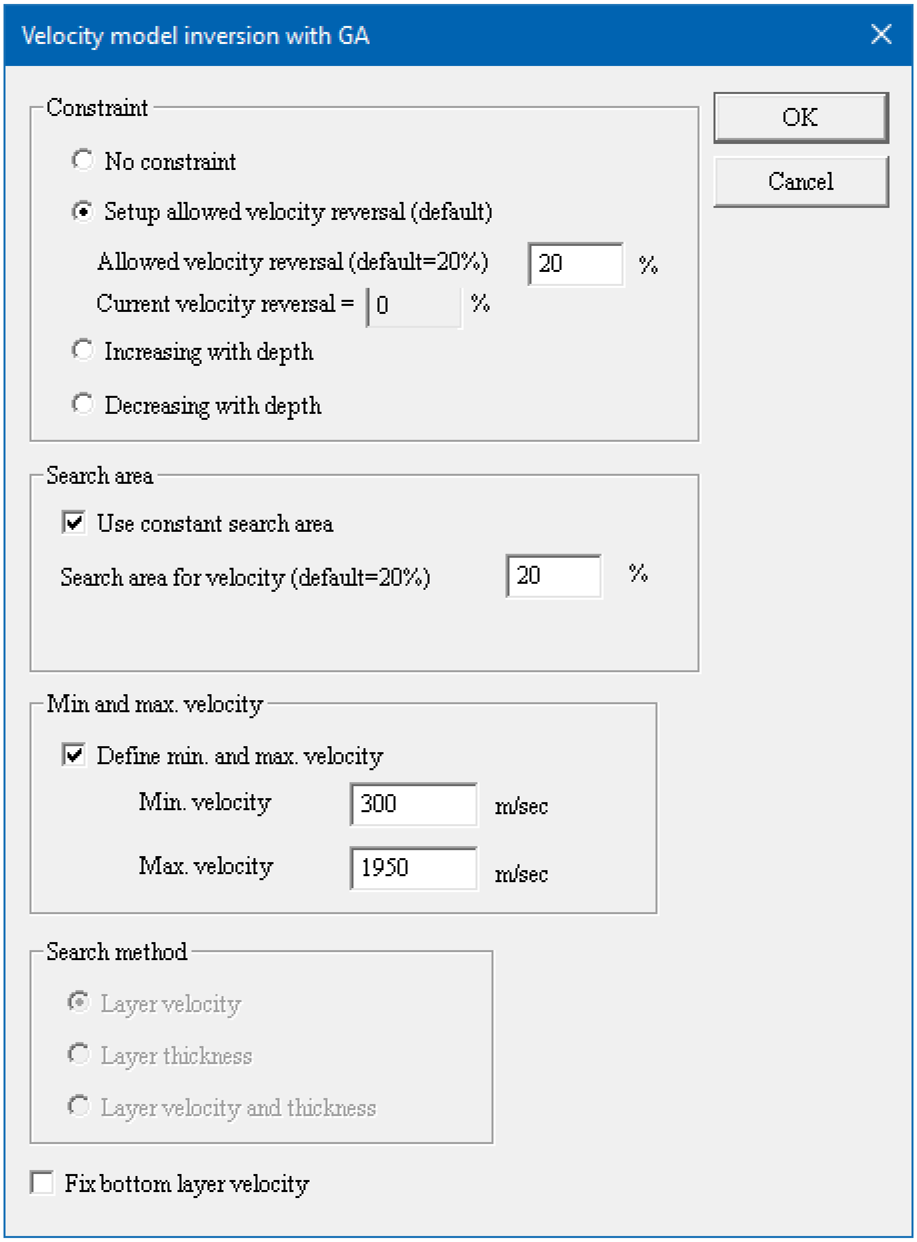


Figure 246: Example 2D velocity section, 1D dispersion curve, and1D V_S model.

Set the parameters for the Genetic Algorithm. The default values (Iteration=50, Population=50, Binary digits=5, Crossover probability=0.5, Mutation probability=0.5) are suitable for most cases. Press the *OK* button to proceed.



Set the parameters for constraints based on site conditions. (Contact support@seisimager.com for assistance.) Press the *OK* button to proceed.


Velocity model inversion with GA
Constraint
No constraint
Setup allowed velocity reversal (default)
Allowed velocity reversal (default=20%)
20
%
Current velocity reversal =
0
%
Increasing with depth
Decreasing with depth
OK
Cancel
Search area
Use constant search area
Search area for velocity (default=20%)
20
%
Min and max. velocity
Define min. and max. velocity
Min. velocity
300
m/sec
Max. velocity
1950
m/sec
Search method
Layer velocity
Layer thickness
Layer velocity and thickness
Fix bottom layer velocity

An example of an inverted result is shown below. The error between observed and theoretical phase velocities is smaller than that for the initial model.

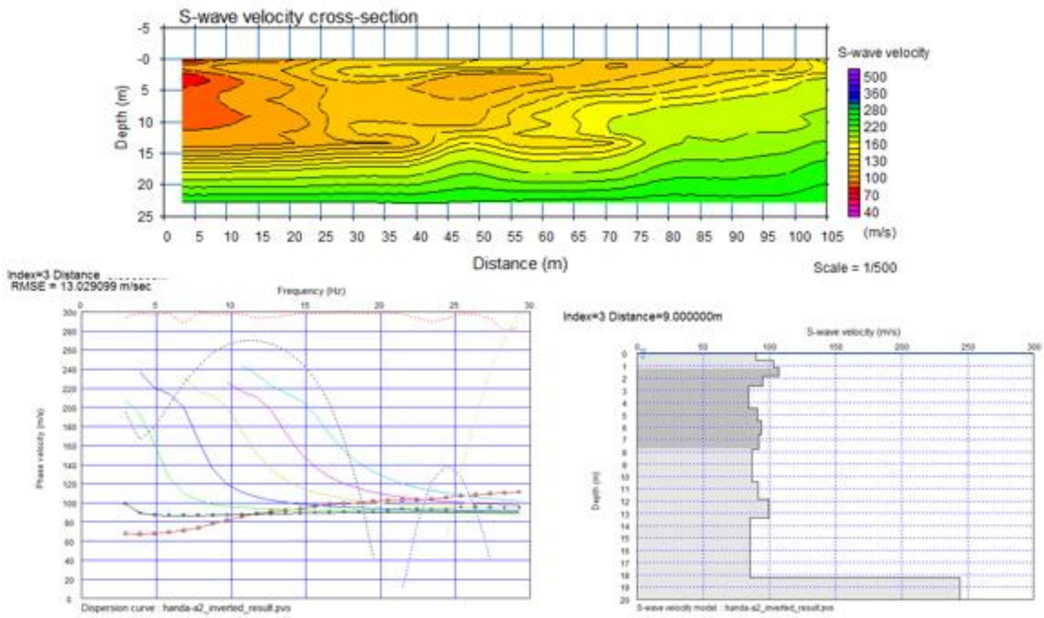
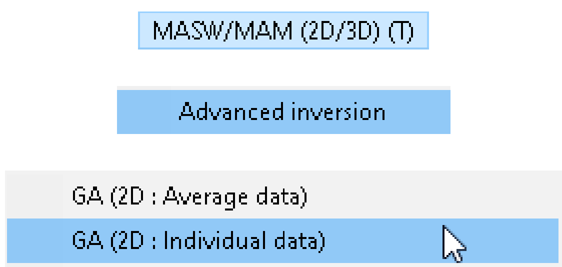


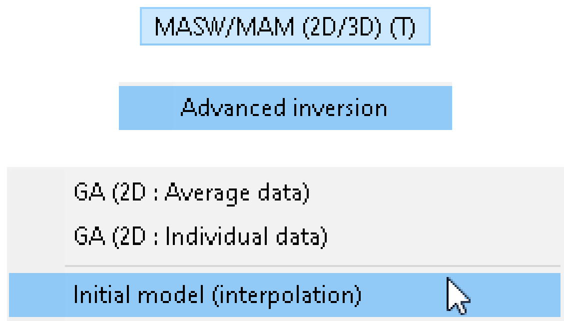
Figure 247: Inverted result.

7.8.7.2 GA (2D: Individual Data)



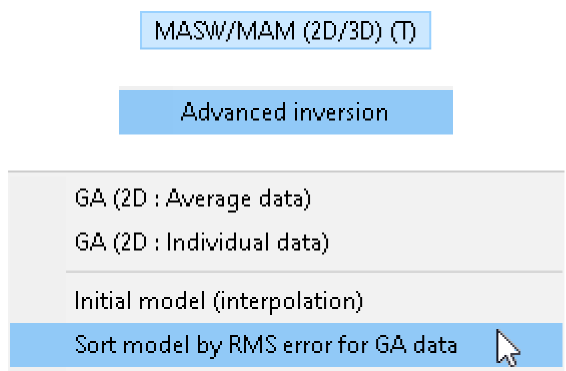
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.7.3 INITIAL MODEL (INTERPOLATION)



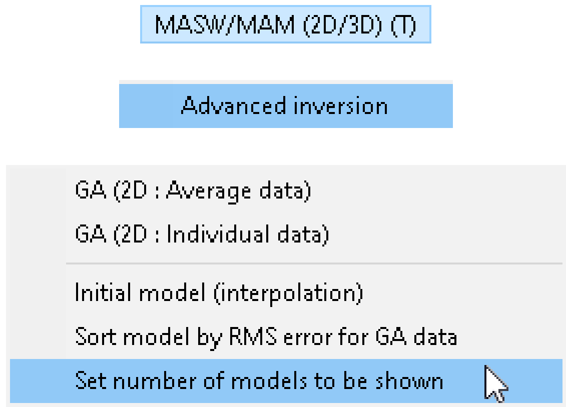
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.7.4 SORT MODEL BY RMS ERROR FOR GA DATA



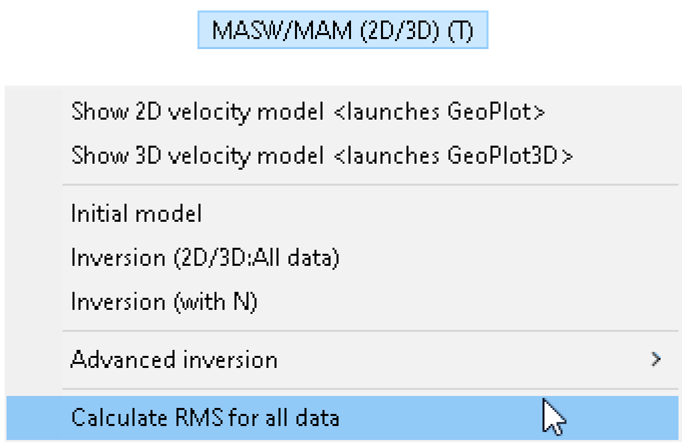
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.7.5 SET NUMBER OF MODELS TO BE SHOWN

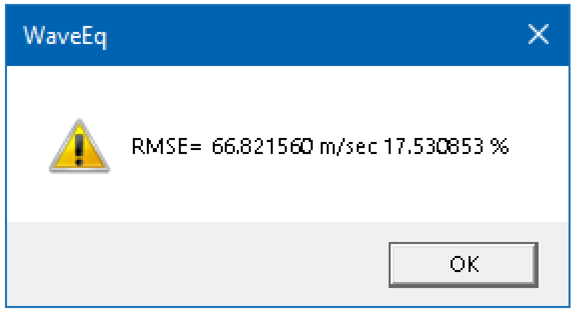


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

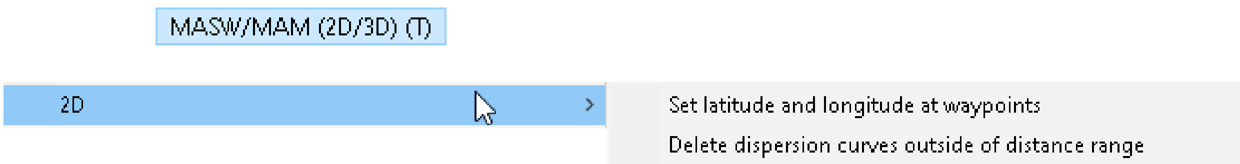
7.8.8 CALCULATE RMS FOR ALL DATA



To calculate the RMS error for an inversion, select *Calculate RMS for all data*. The RMS error is reported as a velocity (m/s or ft/s) and a percentage (%). It is preferable for the error to be less than about 5%, but it will depend on the dataset.

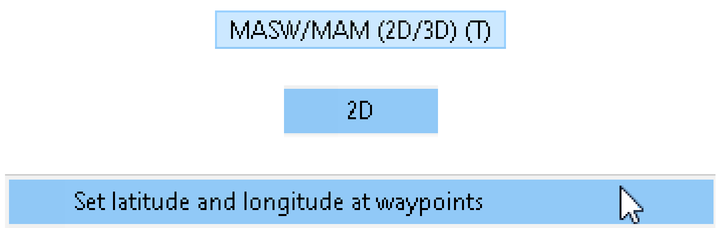


7.8.9 2D



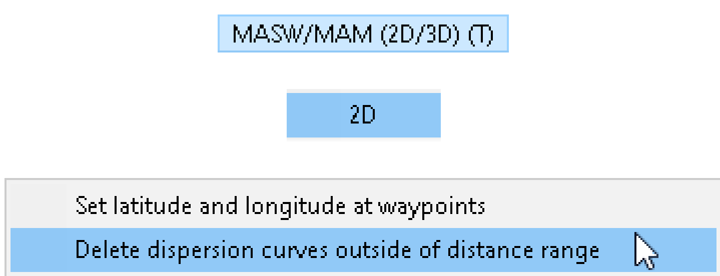
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.9.1 Set Latitude and Longitude at Waypoints



This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.9.2 Delete Dispersion Curves Outside of Distance Range

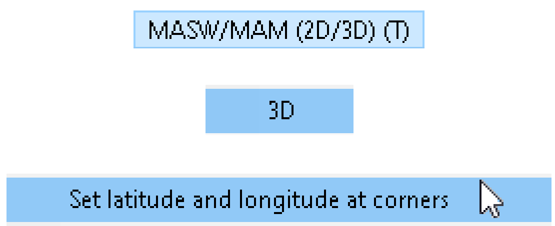


This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.10 3D

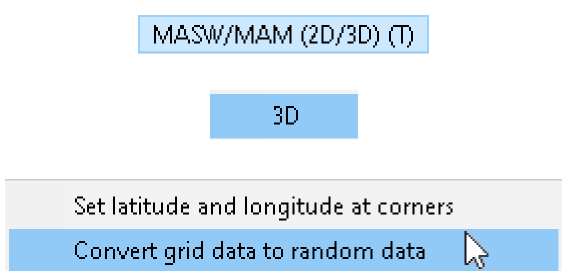
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.10.1 Set Latitude and Longitude at Corners



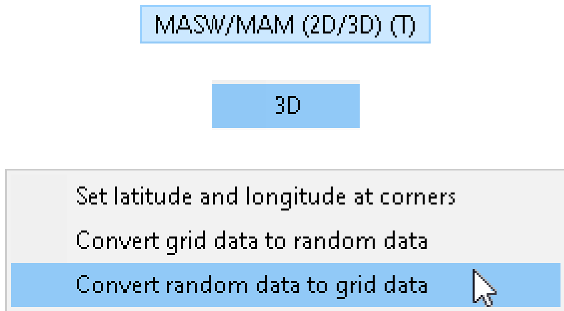
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.10.2 Convert Grid Data to Random Data



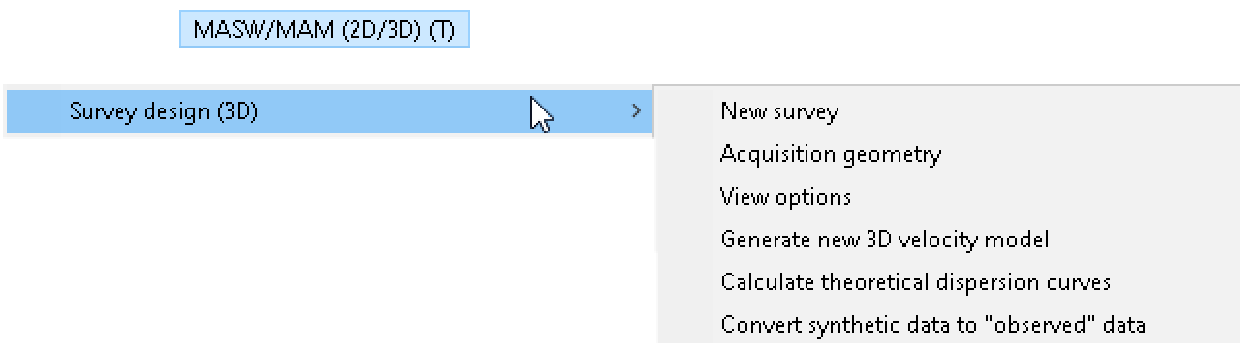
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.10.3 CONVERT RANDOM DATA TO GRID DATA



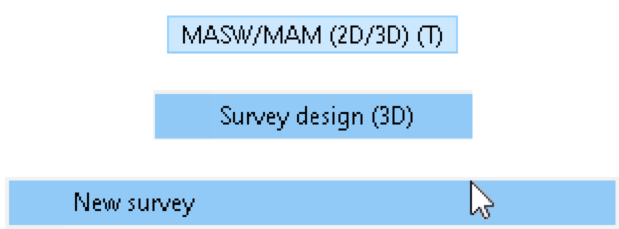
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.11 SURVEY DESIGN (3D)



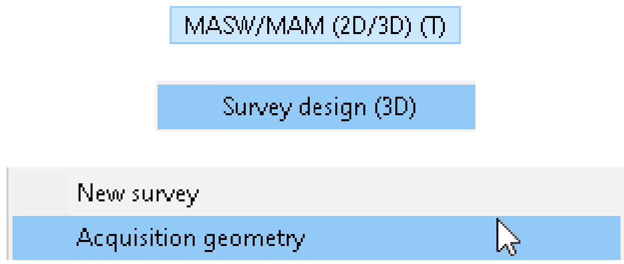
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.11.1 NEW SURVEY



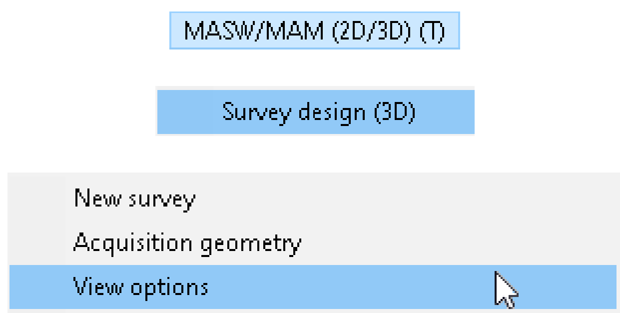
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.11.2 Acquisition Geometry



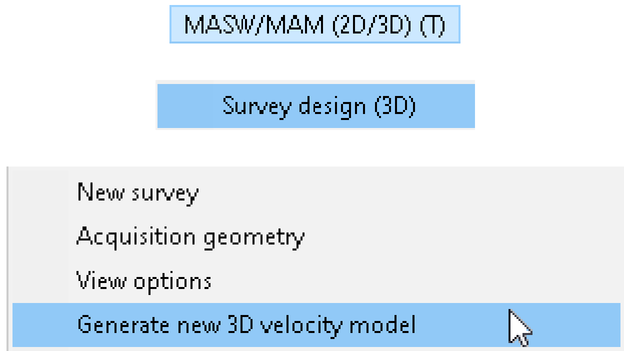
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.11.3 View Options



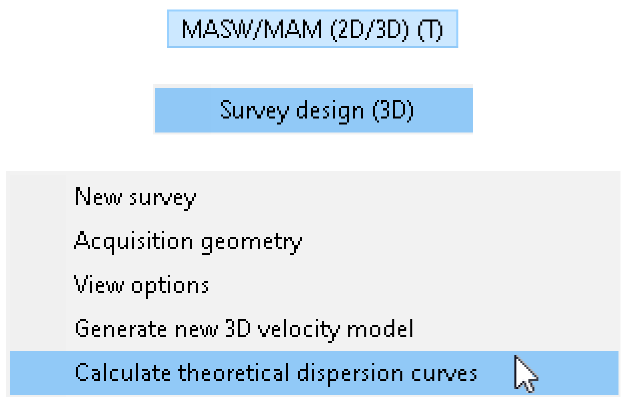
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.11.4 Generate New 3D Velocity Model



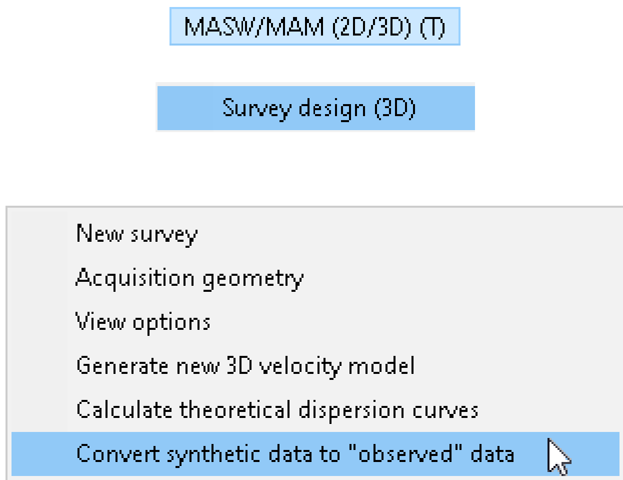
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.11.5 Calculate Theoretical Dispersion Curves



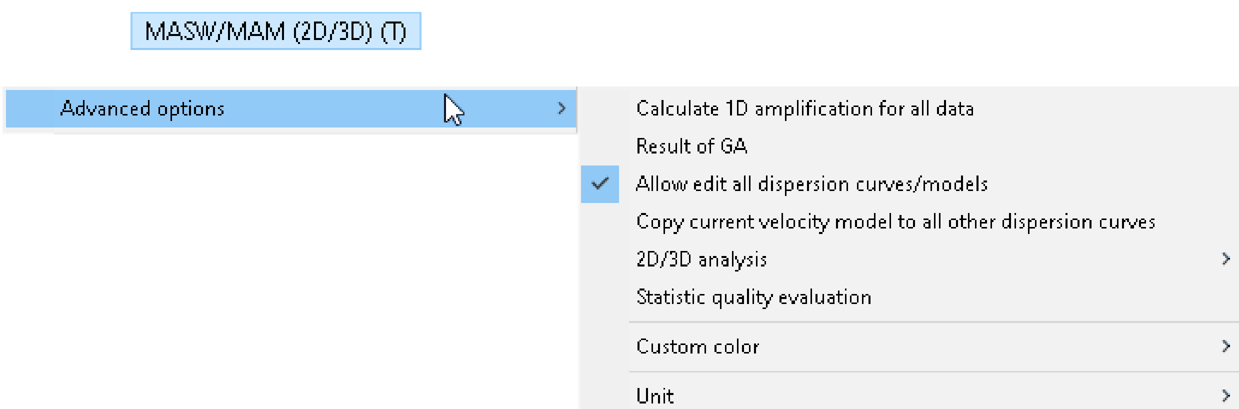
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.11.6 CONVERT SYNTHETIC DATA TO "OBSERVED" DATA



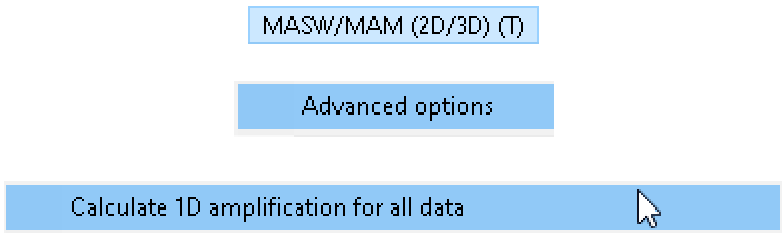
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12 ADVANCED OPTIONS



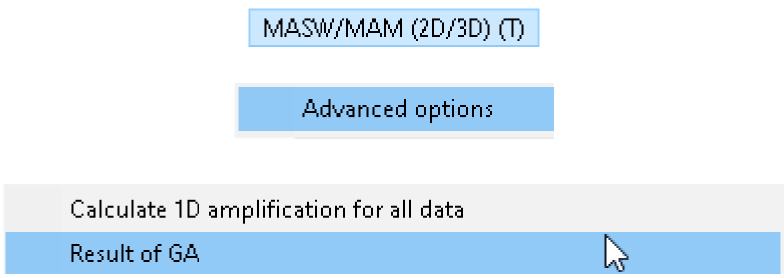
Many of the items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.12.1 CALCULATE 1D AMPLIFICATION FOR ALL DATA



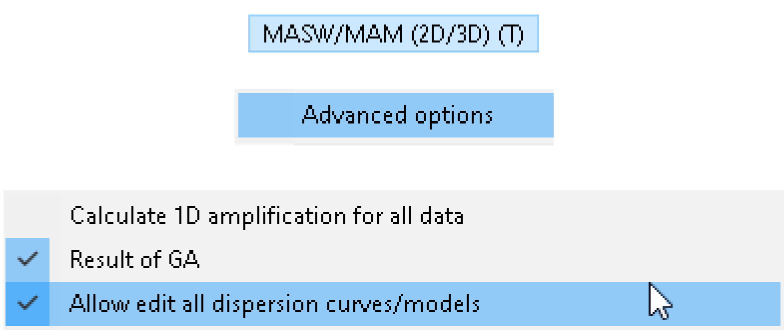
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.2 RESULT OF GA



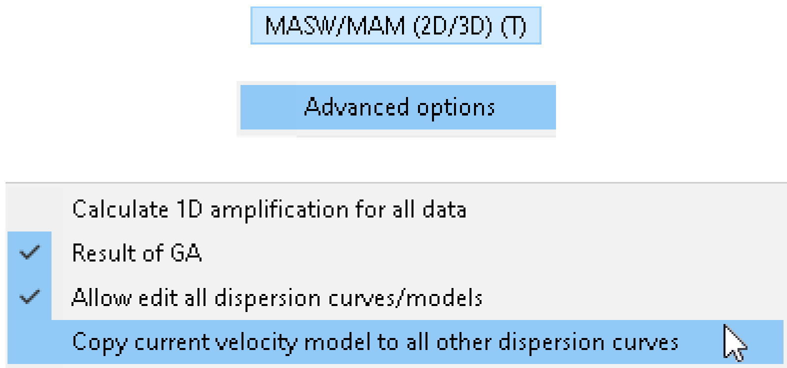
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.3 ALLOW EDIT ALL DISPERSION CURVES/MODELS



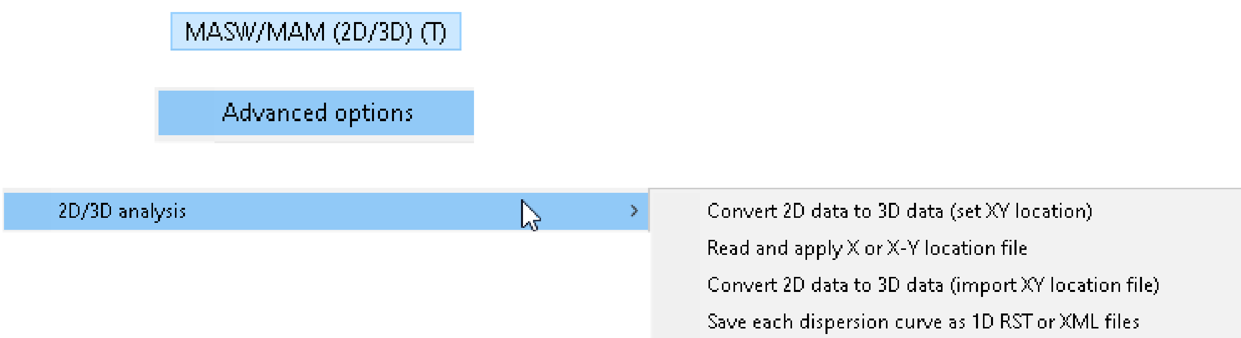
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.4 Copy Current Velocity Model to All Other Dispersion Curves



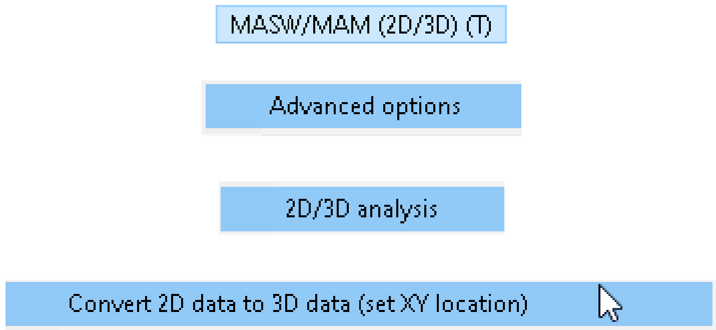
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.5 2D/3D Analysis



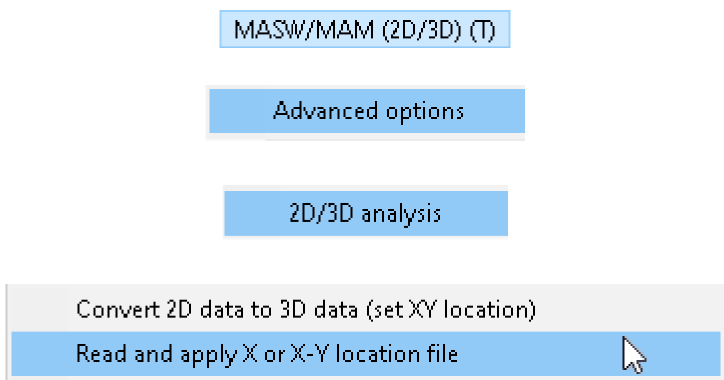
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.12.5.1 Convert 2D Data to 3D Data (Set XY Location)



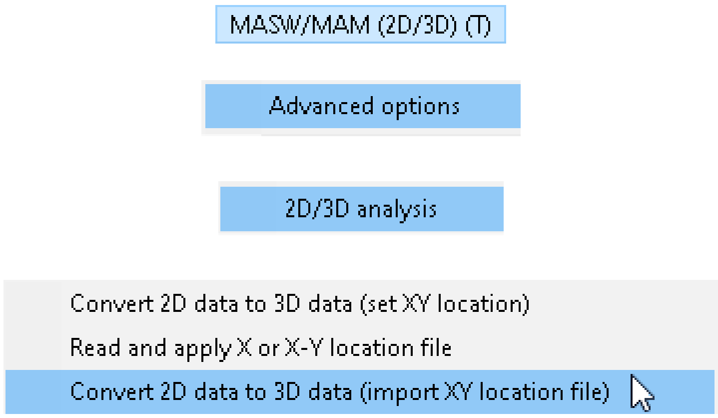
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.5.2 Read and Apply X or XY Location File



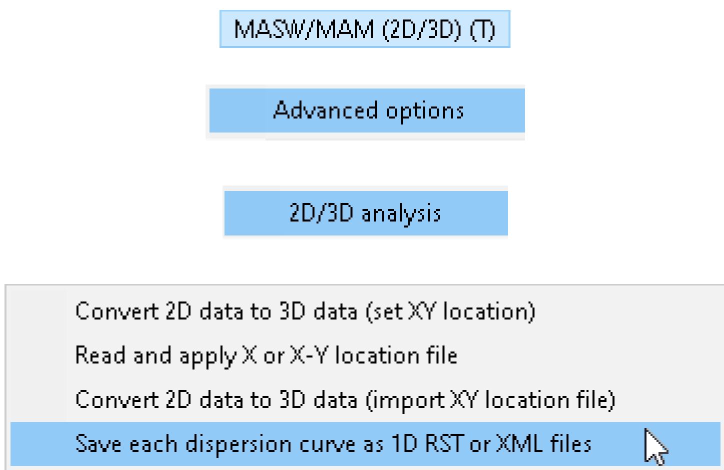
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.5.3 Convert 2D Data to 3D Data (Import XY Location File)



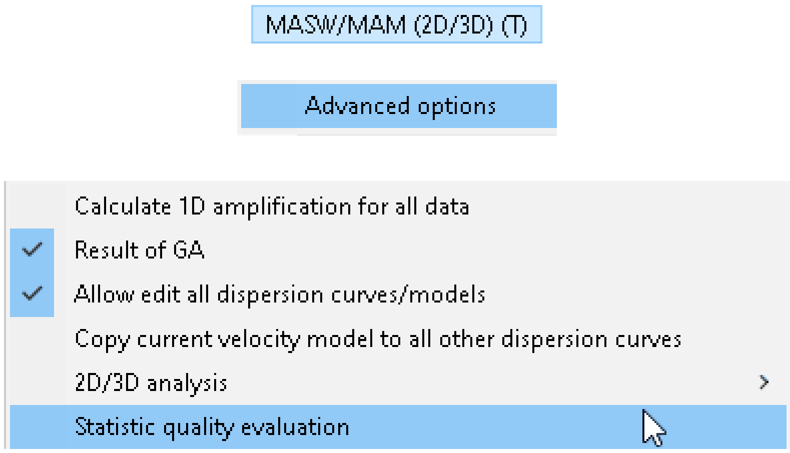
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.5.4 Save each dispersion curve as 1D RST or XML file



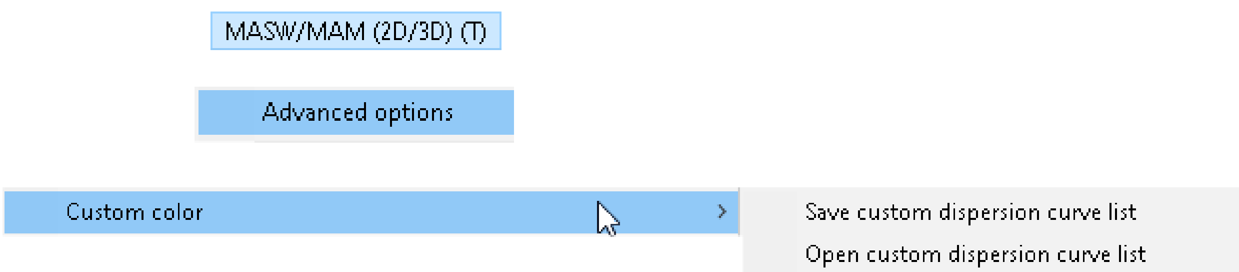
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.6 STATIC QUALITY EVALUATION



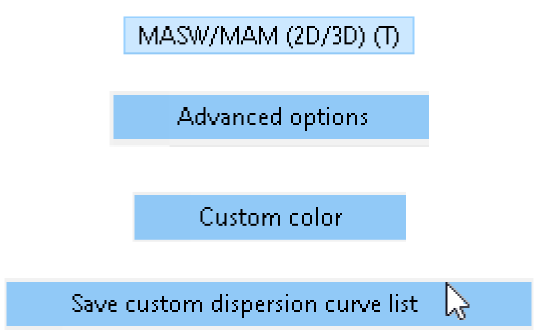
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.7 CUSTOM COLOR



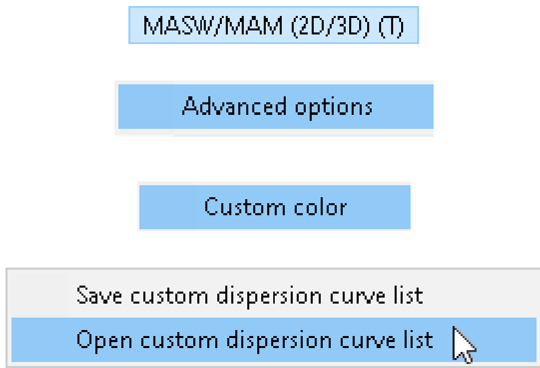
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.12.7.1 SAVE CUSTOM DISPERSION CURVE LIST



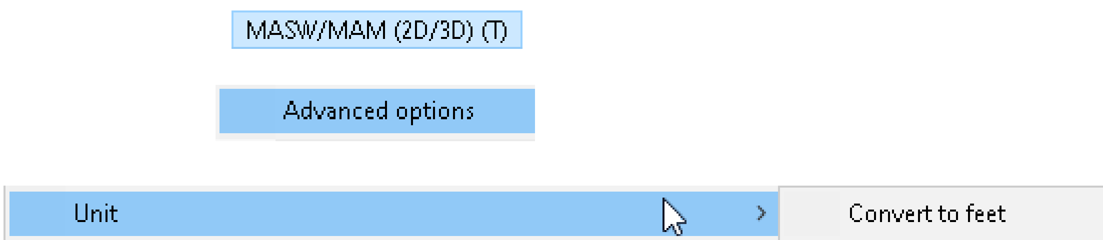
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.7.2 Open Custom Dispersion Curve List



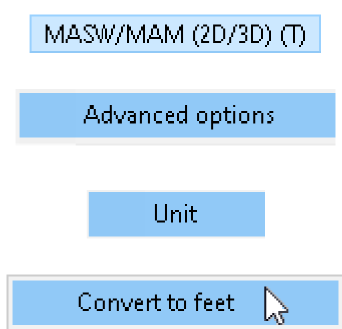
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.12.8 Unit



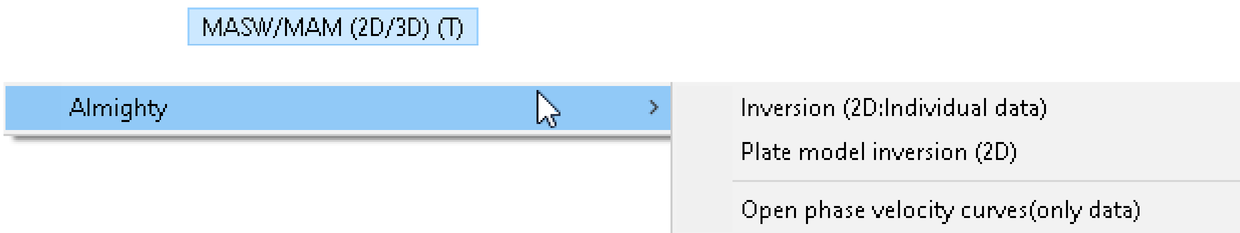
Continue.

7.8.12.8.1 Convert to Feet/Meters



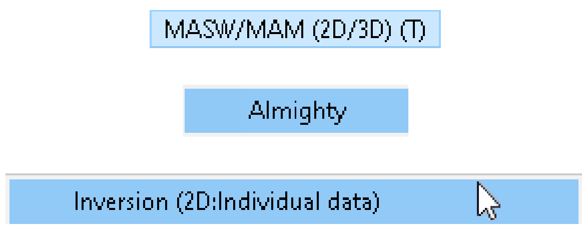
You may convert between units for 2D and 3D models in a manner similar to that described in Section 7.7.9.10.1, Page 526. If you are working in units of feet, it will say "Convert to meters" and vice-versa.

7.8.13 ALMIGHTY



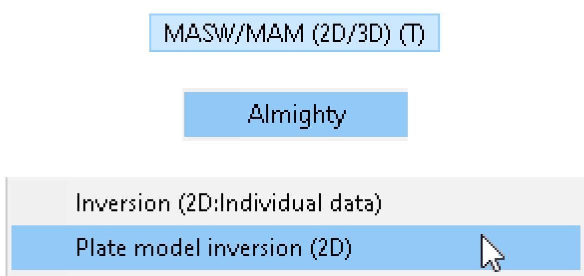
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.8.13.1 INVERSION (2D: INDIVIDUAL DATA)



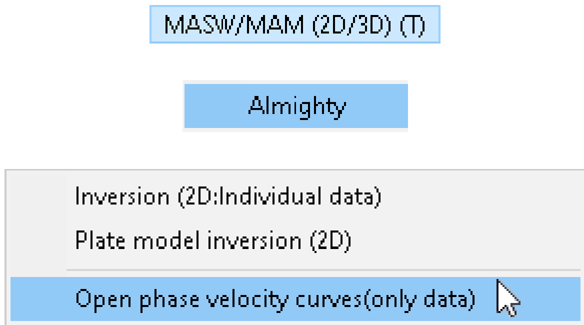
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.8.13.2 PLATE MODEL INVERSION (2D)



This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

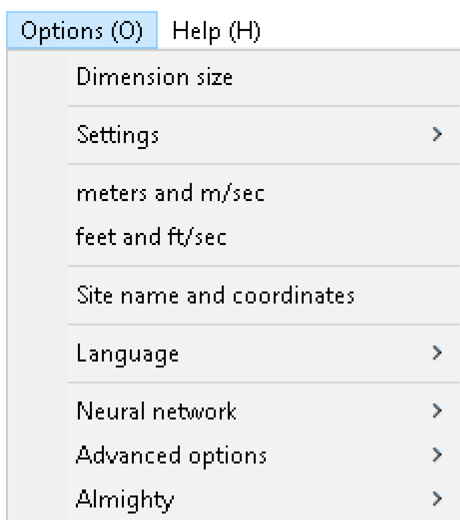
7.8.13.3 Open Phase Velocity Curves (Only Data)



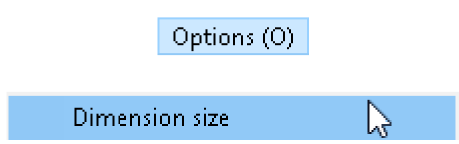
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9 Options Menu

The **Options** menu includes program controls and settings.

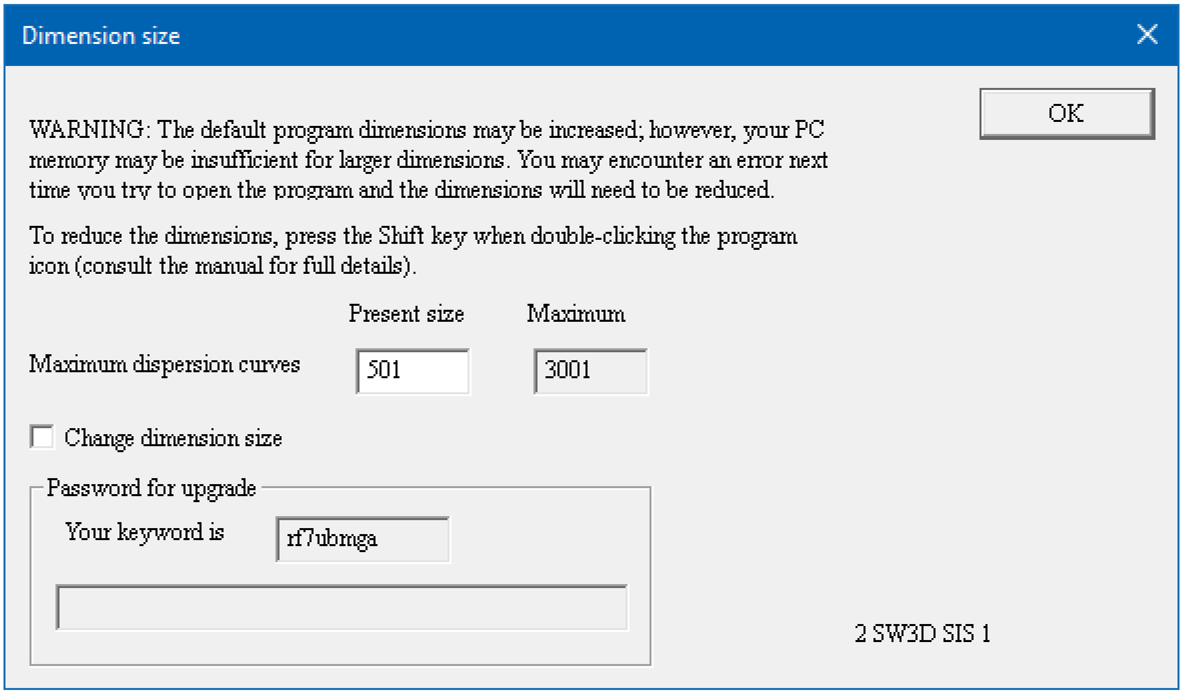


7.9.1 Dimension Size

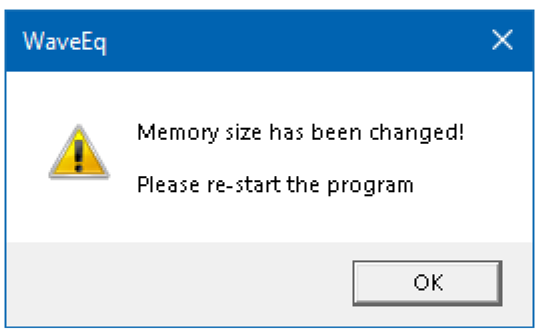


To view or change the program data input allowances, select *Dimension size*.

Present size reflects the current *Maximum dispersion curves* number for 2D MASW. The *Maximum* of 2001 is the highest possible value. To change the number, enter the new value, check *Change dimension size*, and press *OK*.



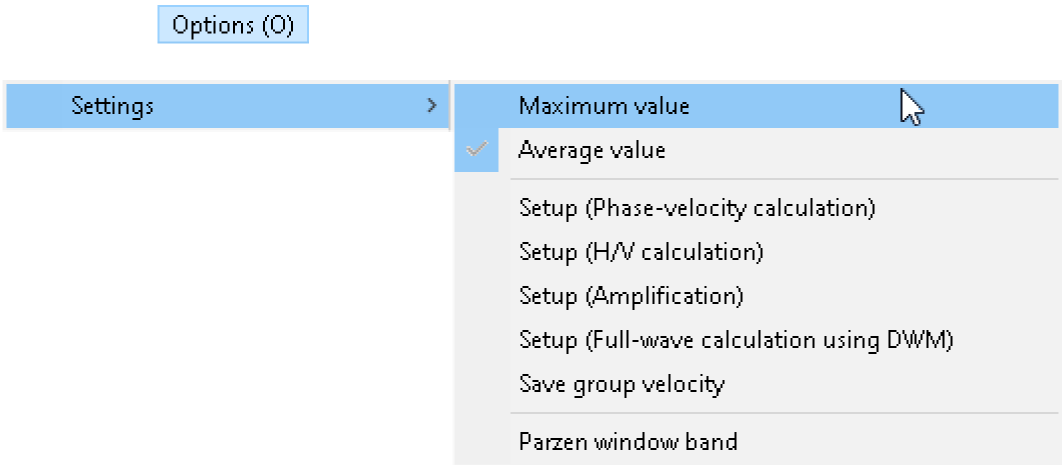
Press *OK* and restart the program.



The wizard automatically defaults to standard dimensions to run efficiently. To use non-standard dimensions, you will need to process data manually.

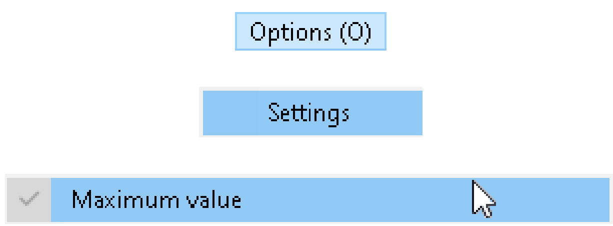
If a program upgrade is purchased, the new registration password can be directly entered in the **Dimension size** dialog box in the *Password for upgrade* field; however, it is strongly recommended to upgrade via the SeisImager Registration program instead.

7.9.2 SETTINGS



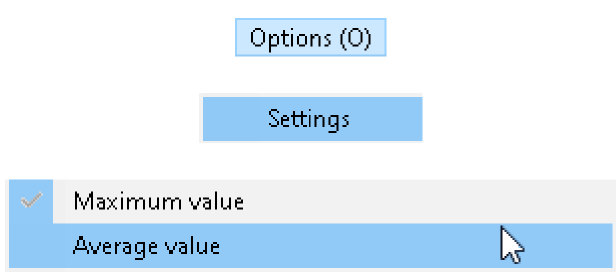
Various parameters can be set under *Options* | *Settings*. Some of the items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.9.2.1 MAXIMUM VALUE



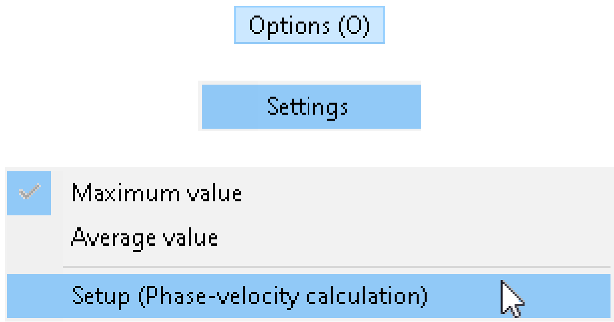
Theoretical phase velocity may be calculated under "averaged" or "maximum" dispersion curve assumptions. Activate *Maximum value* or *Average value* under *Options* | *Settings* to switch methods. We recommend using *Maximum* value and *Average value* for MASW and SPAC, respectively.

7.9.2.2 AVERAGE VALUE



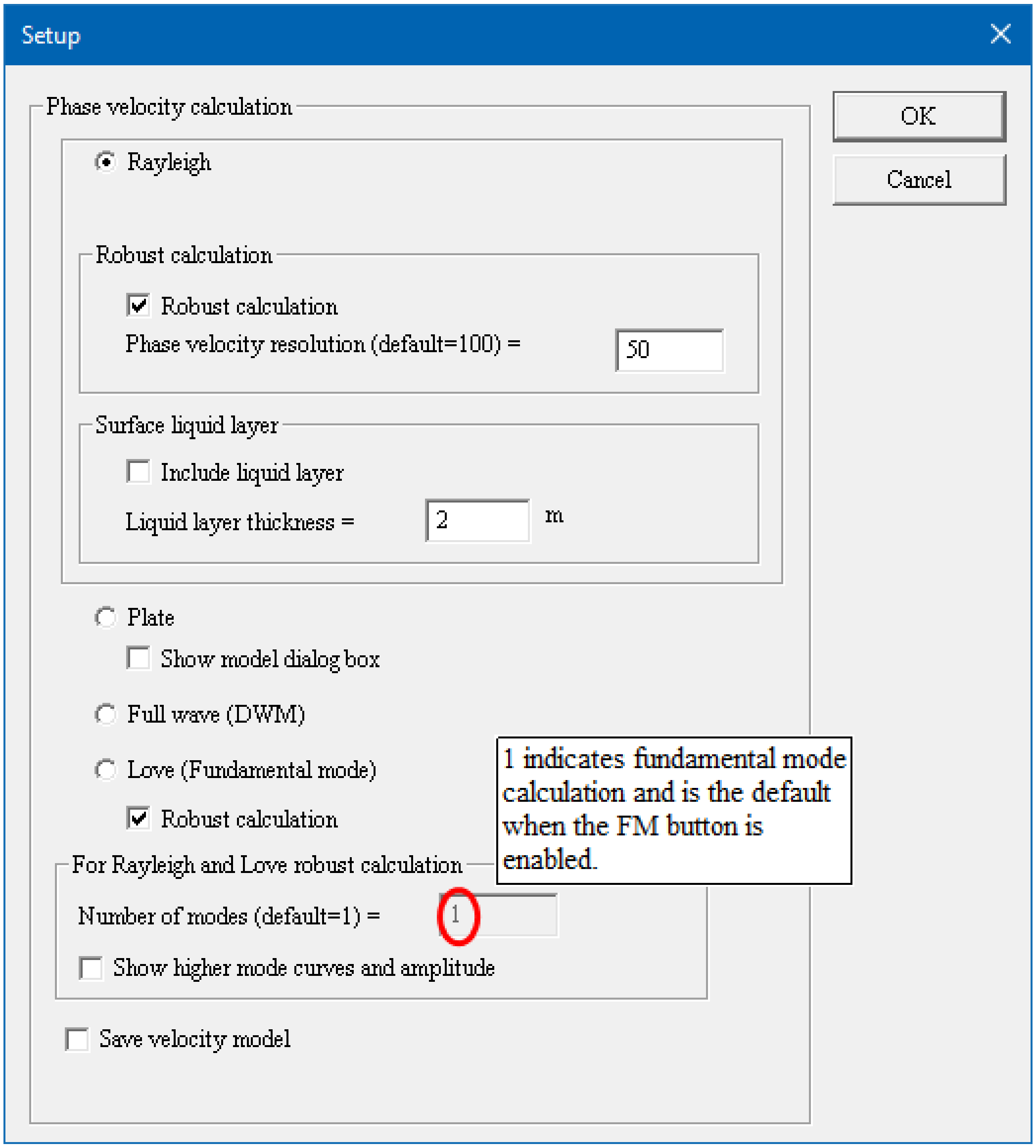
See prior section.

7.9.2.3 Set Up (Phase velocity Calculation)

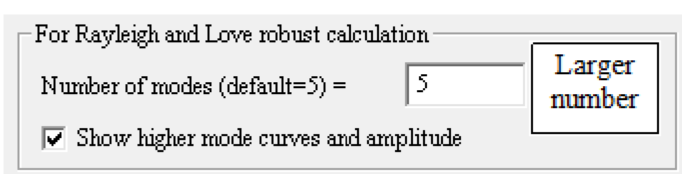


Select *Options* | *Settings* | *Setup (Phase velocity calculation)* to change the settings for higher mode calculations of phase velocity. The following dialog box appears when the fundamental mode calculation is selected. (Press 

before opening dialog.) Note that the number of modes is hardwired to one.

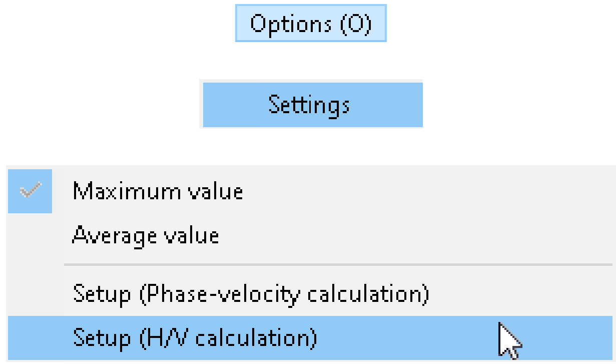


When the higher mode calculation is selected (press HM before opening dialog), the number of modes defaults to 5. Use 5 to 20 for the number of modes. The number of modes integrated is proportional to computation time. Calculating five to ten modes is suitable for most cases. Use a large number (20 to 50) if the data includes significant higher modes that are due to a high velocity thin layer underlying a low velocity layer.



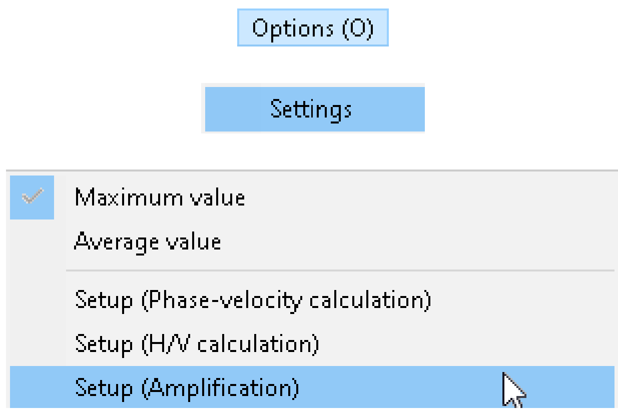
For more information on working with higher modes, see Section 5.1.1, Page 174.

7.9.2.4 Set Up (H/V Calculation)



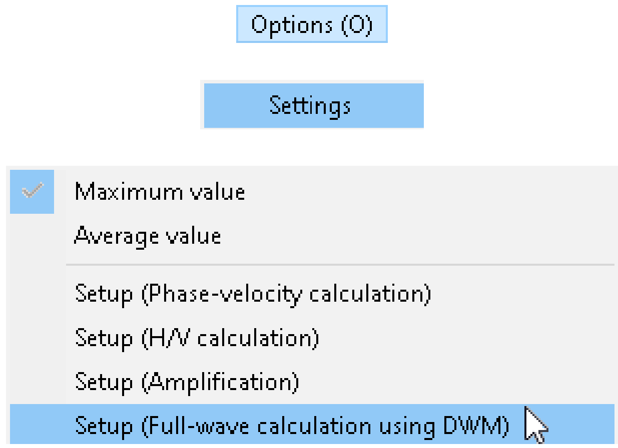
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.2.5 Set Up (Amplification)



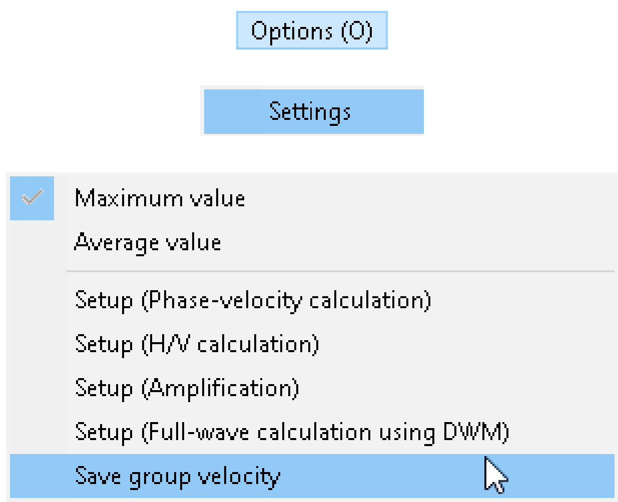
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.2.6 Set Up (Full-wave Calculation Using DWM)



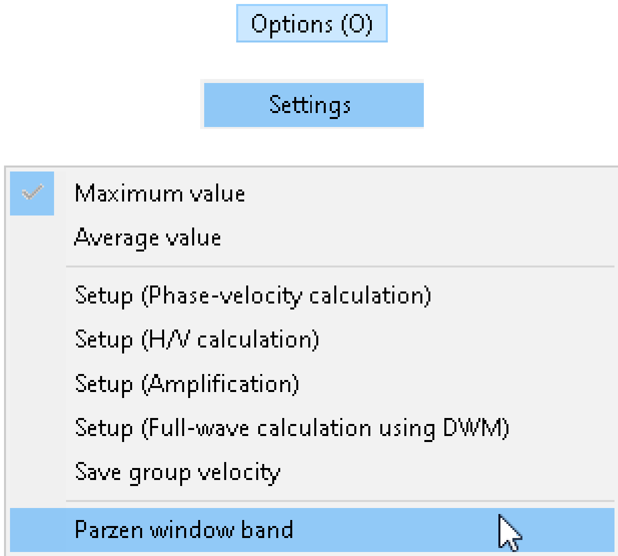
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.2.7 Save group velocity



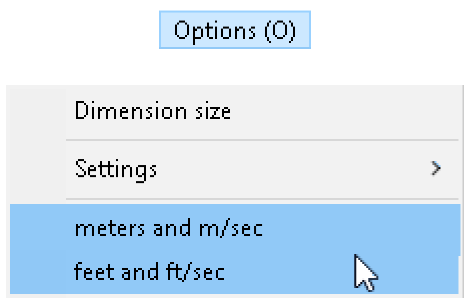
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.2.8 PARZEN WINDOW BAND



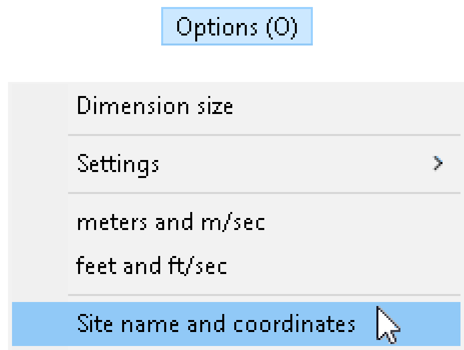
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

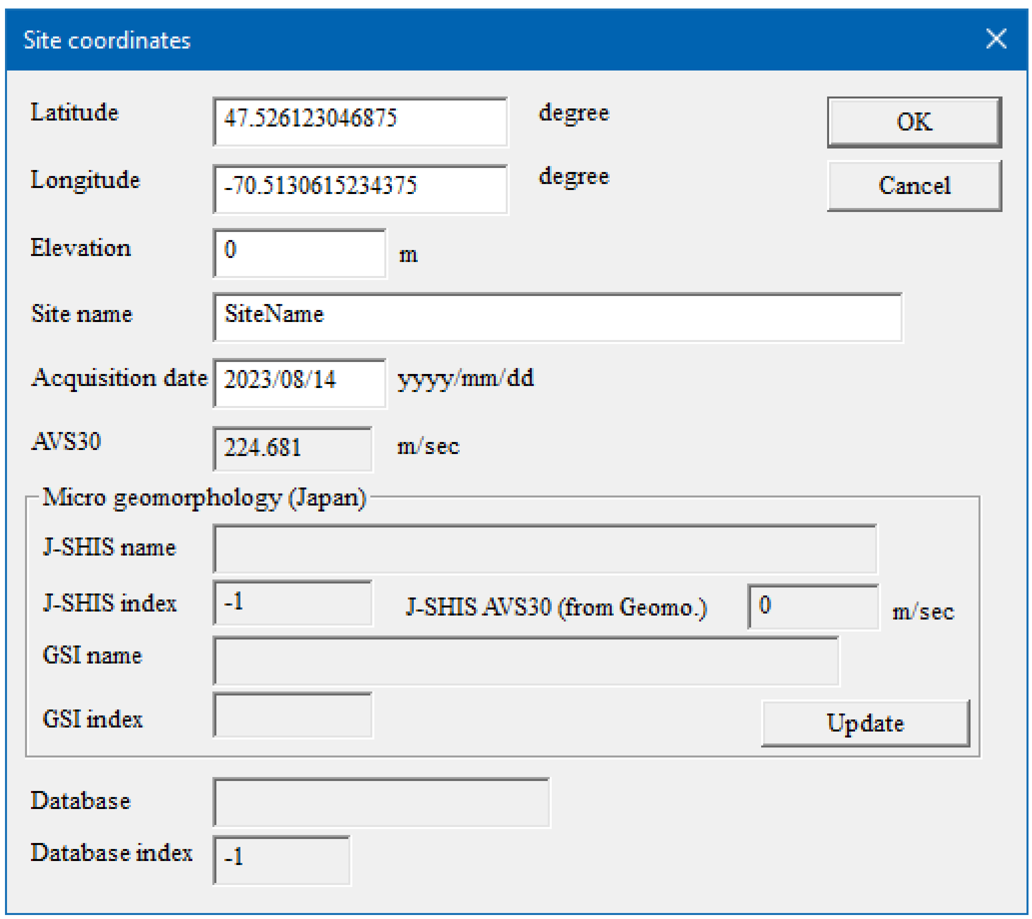
7.9.3 METERS AND M/SEC AND FEET AND FT/SEC



Select the desired unit labels by choosing *meters and m/sec* or *feet and ft/sec*. The setting is reflected in the display labels, dialog box labels, and default values where applicable.

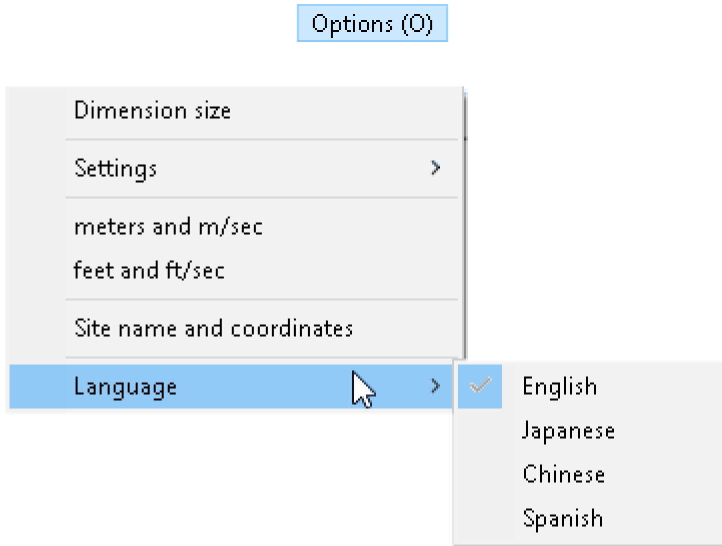
7.9.4 Site Name and Coordinates





You may update the survey data, including coordinates, elevation, site name, and date by selecting *Options* | *Site name and coordinates*. The lower half of the dialog is applicable for surveys conducted in Japan and is rarely used. Contact support@seisimager.com for assistance.

7.9.5 LANGUAGE

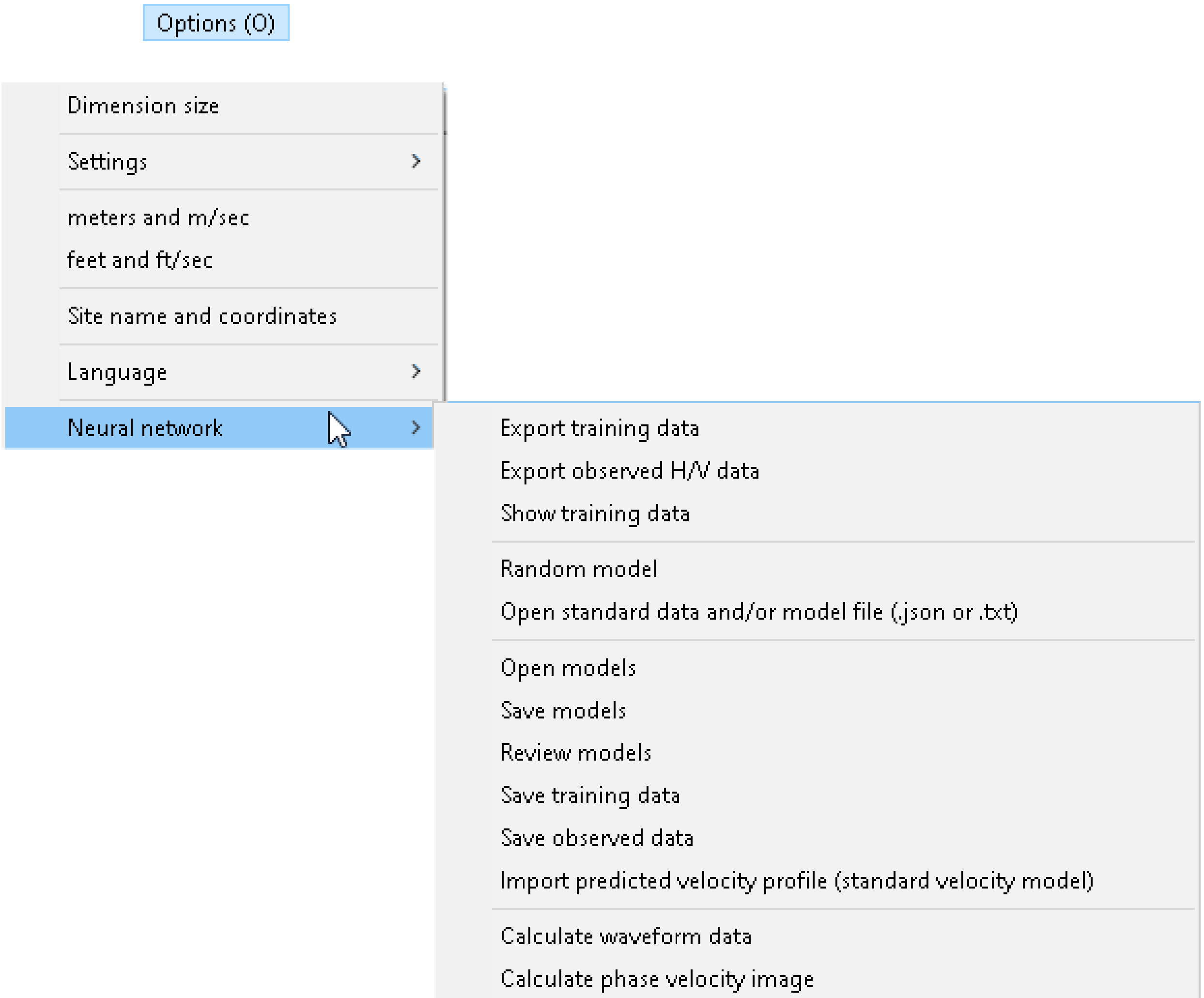


Continue

7.9.5.1 ENGLISH, JAPANESE, CHINESE, SPANISH

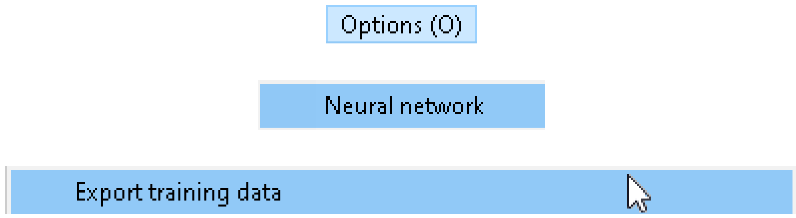
Choose your preferred language. At the time of this writing (July 2024), Chinese and Spanish were under construction.

7.9.6 NEURAL NETWORK



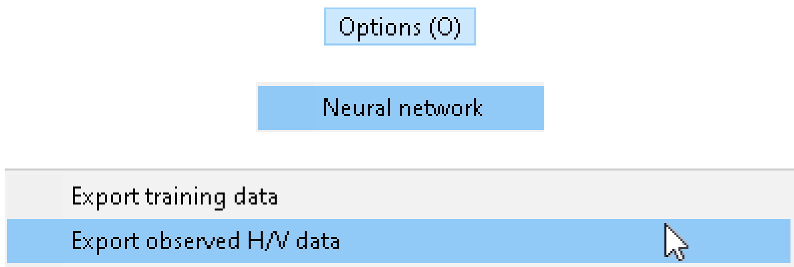
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.9.6.1 EXPORT TRAINING DATA



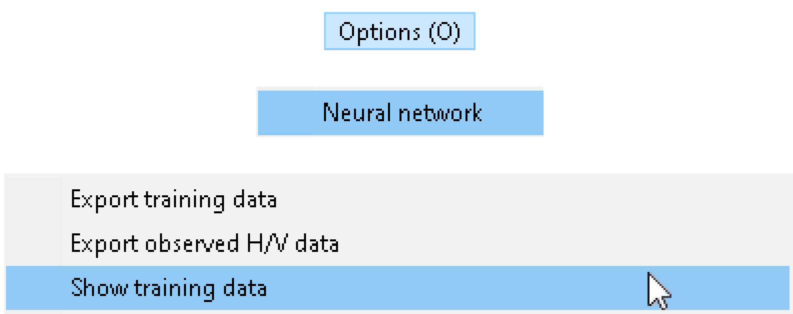
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.2 EXPORT OBSERVED H/V DATA



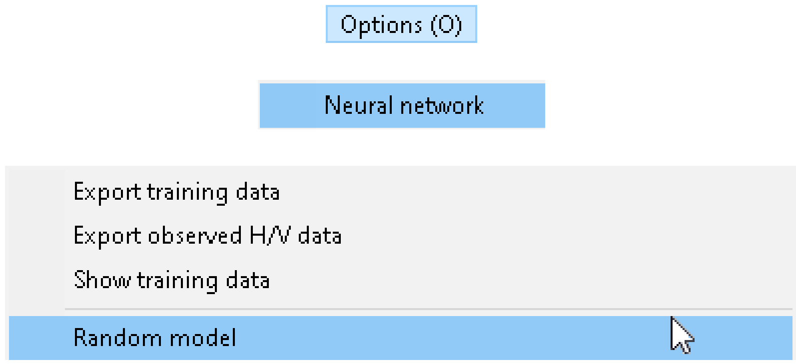
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.3 SHOW TRAINING DATA



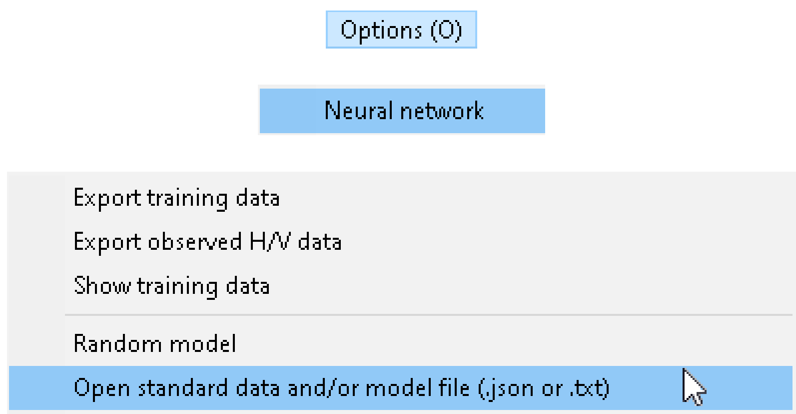
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.4 RANDOM MODEL



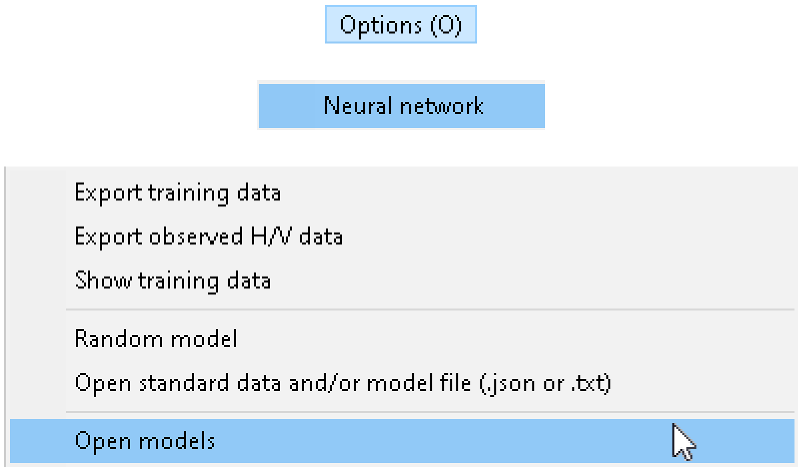
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.5 OPEN STANDARD DATA AND/OR MODEL FILE (.JSON OR .TXT)



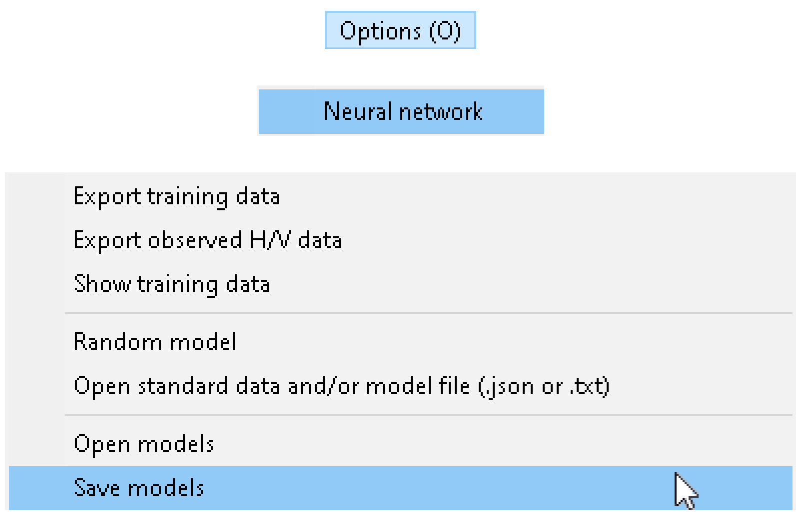
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.6 OPEN MODELS



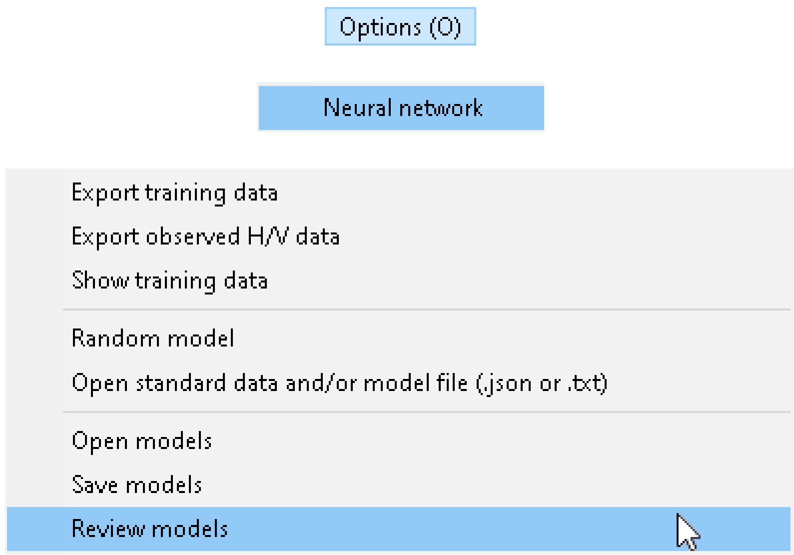
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.7 SAVE MODELS



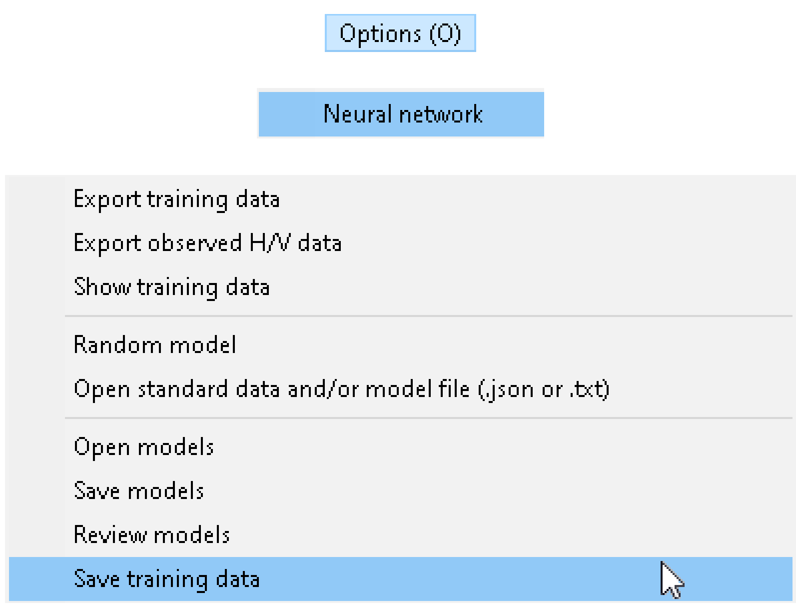
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.8 Review Models



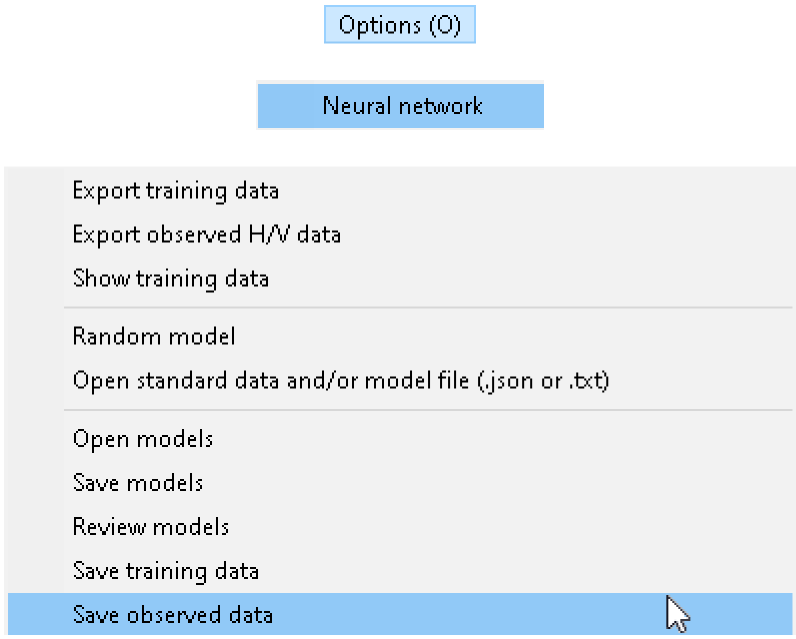
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.9 Save Training Data



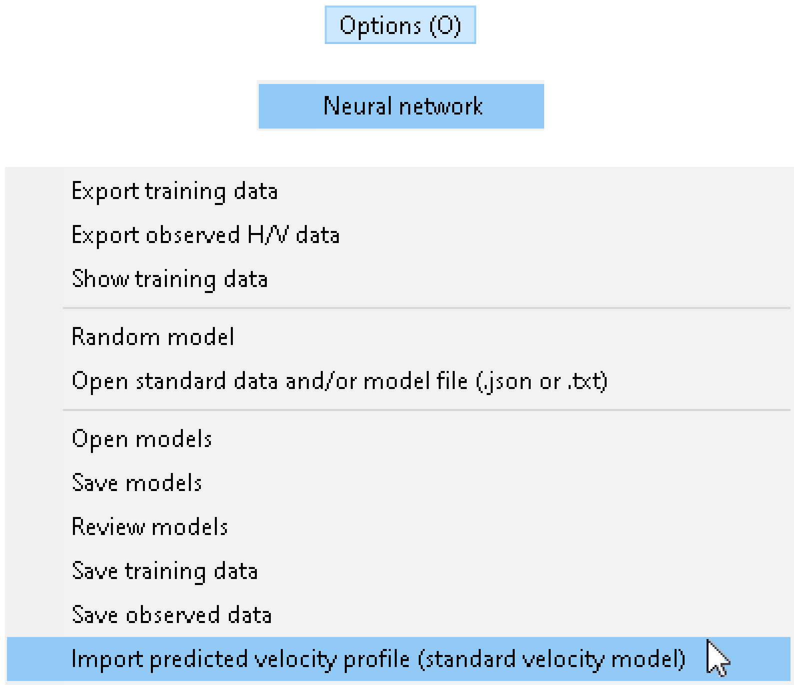
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.10 SAVE OBSERVED DATA



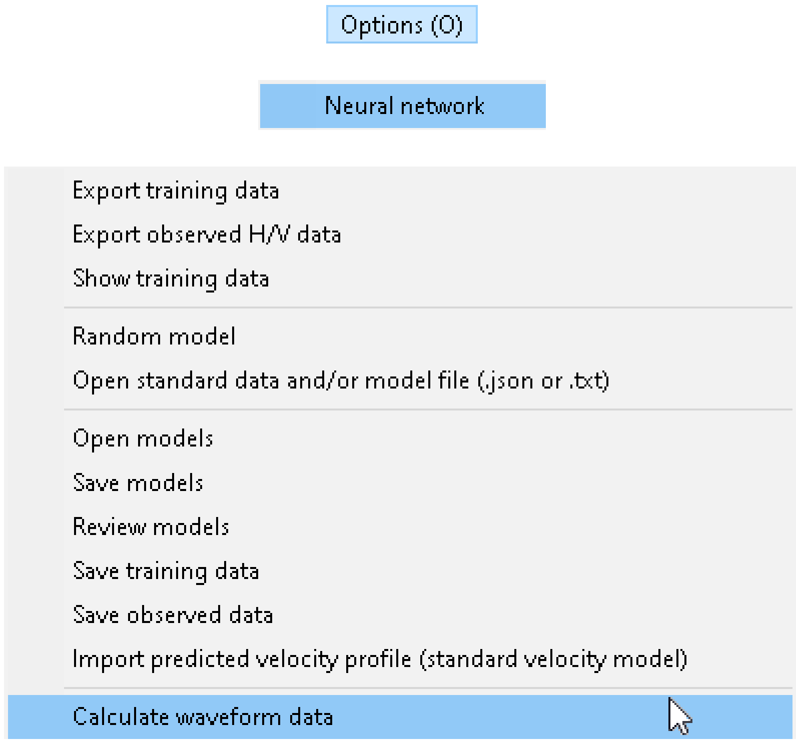
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.11 IMPORT PREDICTED VELOCITY PROFILE (STANDARD VELOCITY MODEL)



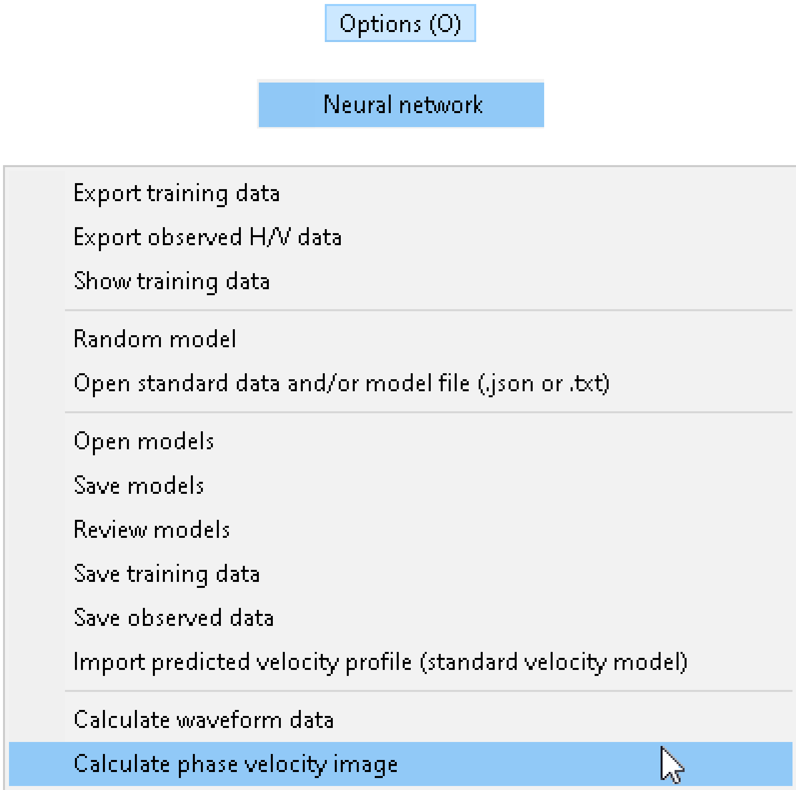
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.12 Calculate Waveform Data



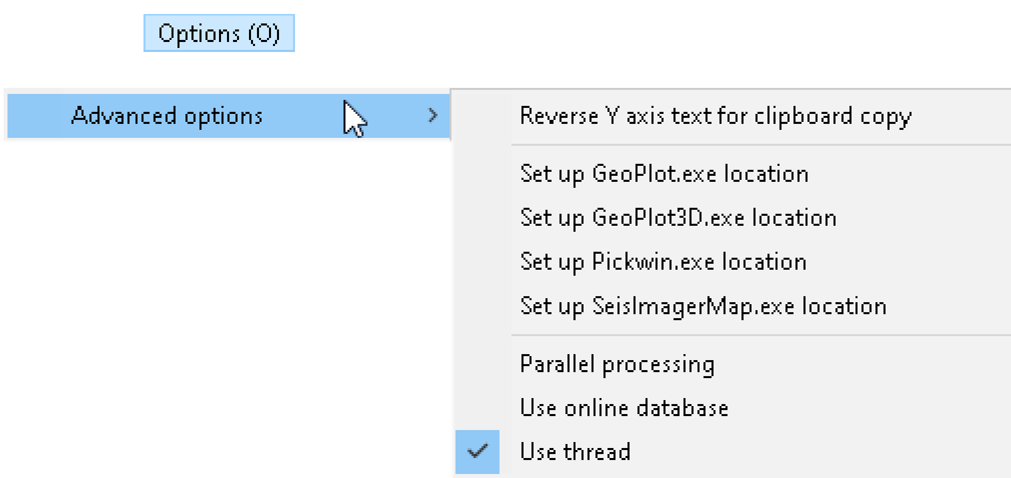
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.6.13 CALCULATE PHASE VELOCITY IMAGE



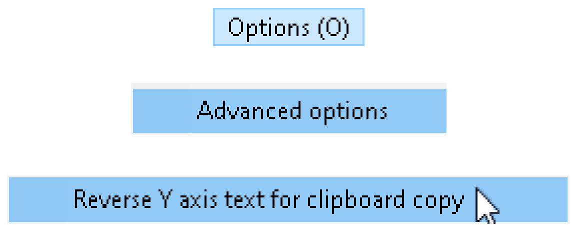
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.7 ADVANCED OPTIONS



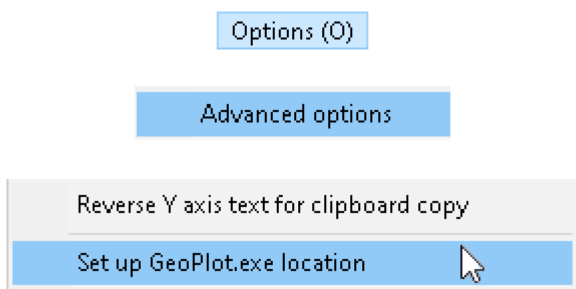
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.9.7.1 Reverse Y-Axis Text for Clipboard Copy



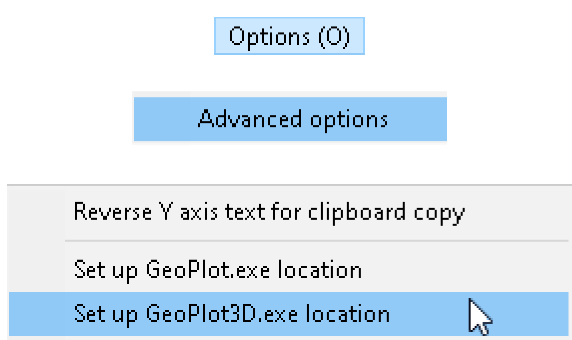
Reverse Y-axis text for clipboard copy controls how the label for the vertical axis appears when *Copy to clipboard* (Section 7.2.3, Page 342) is selected from the **Edit** menu. If *Reverse Y-axis text for clipboard copy* is selected, the vertical axis label appears written top to bottom. If not selected (the default), the vertical axis label appears written bottom to top.

7.9.7.2 Set Up GeoPlot.exe Location



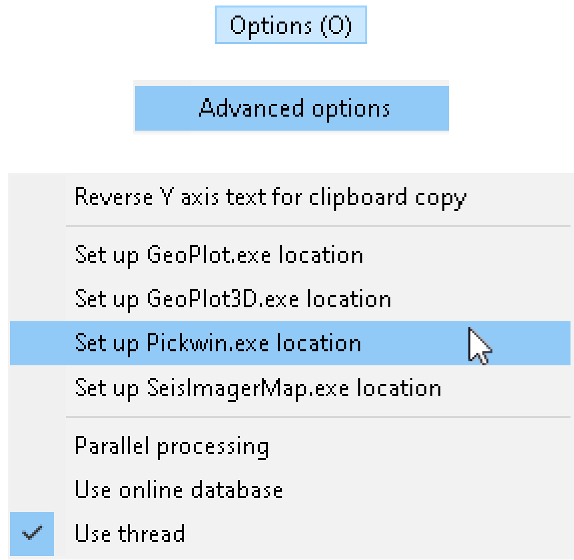
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.7.3 Set Up GeoPlot3D.exe Location



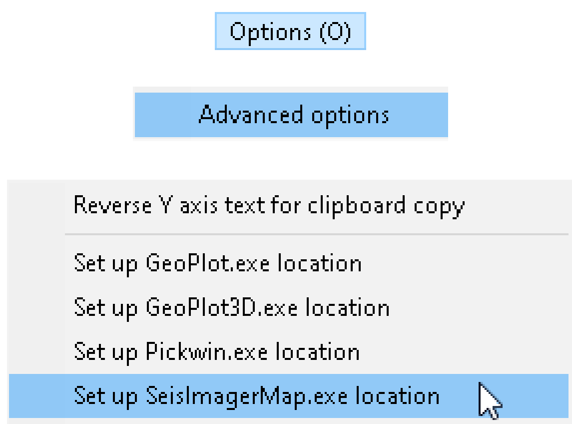
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.7.4 Set Up Pickwin.exe Location



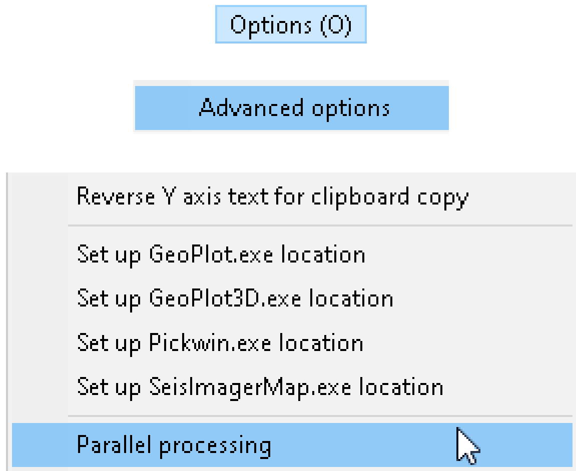
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.7.5 Set Up SeisImagerMap.exe Location



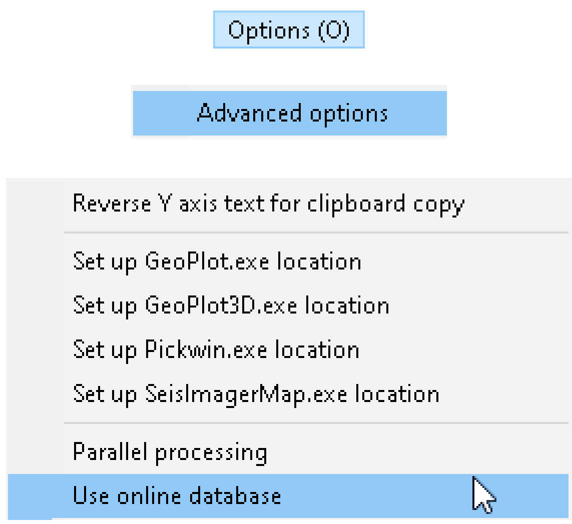
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.7.6 PARALLEL PROCESSING



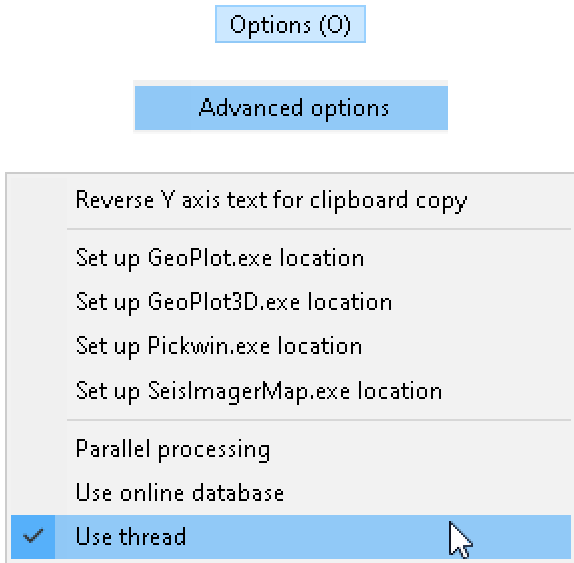
If parallel processing is enabled, processing will be faster, but other apps may run slower.

7.9.7.7 USE ONLINE DATABASE



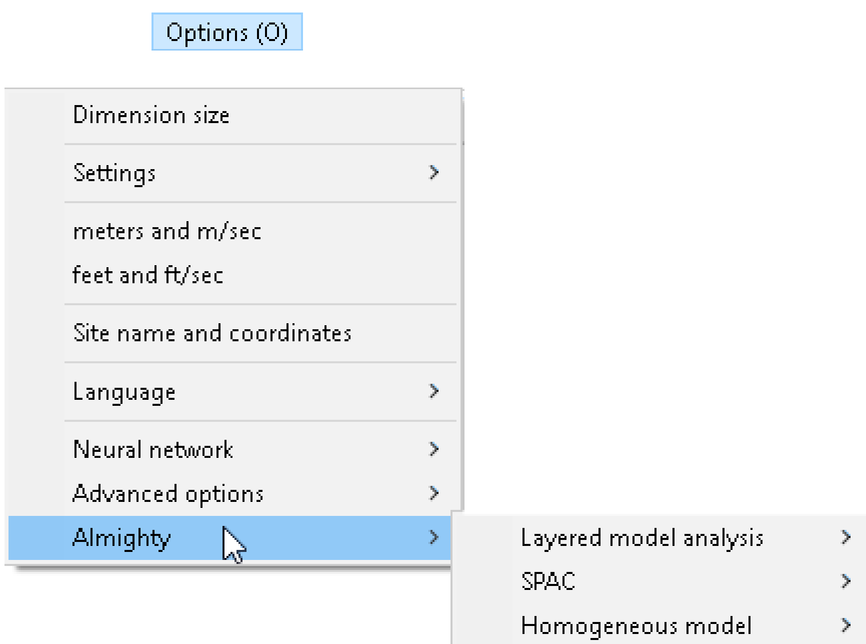
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.7.8 USE THREAD



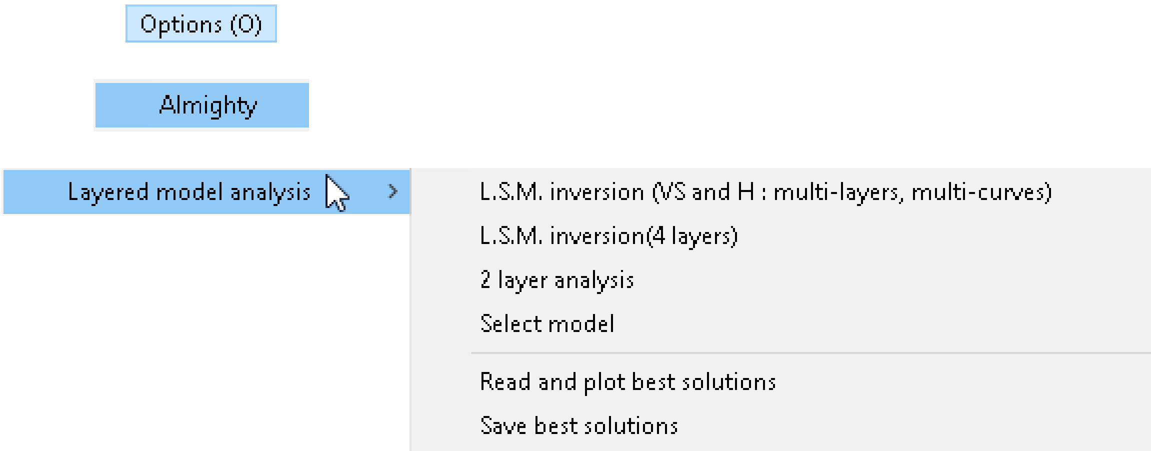
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8 ALMIGHTY



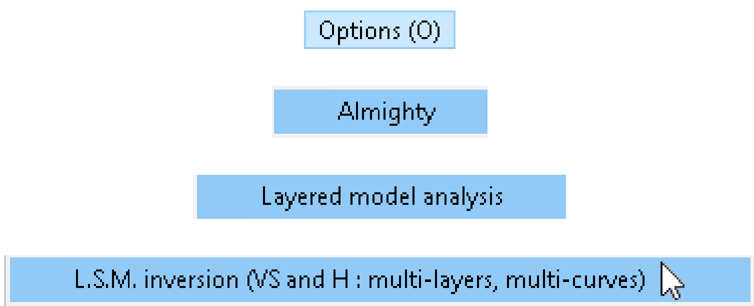
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.9.8.1 Layered Model Analysis



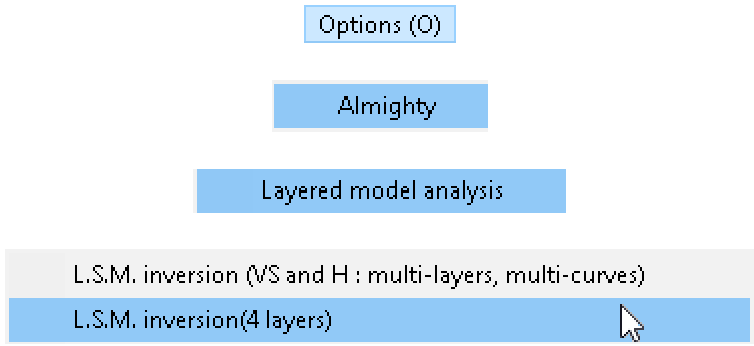
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.9.8.1.1 L.S.M. Inversion (V_S and H: Multi-layers, Multi-curves)



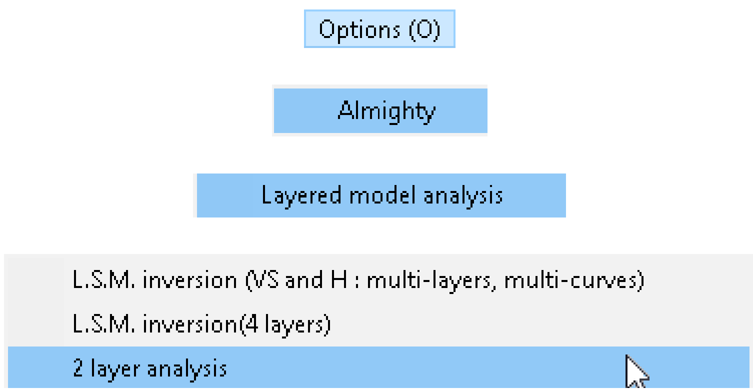
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.1.2 L.S.M. Inversion (2 Layers)



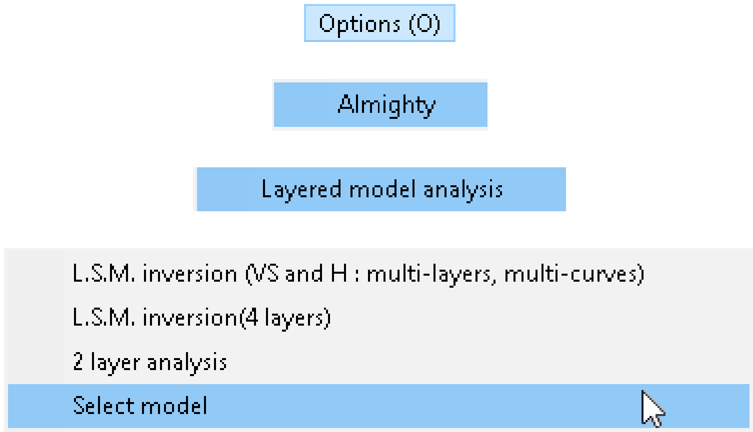
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.1.3 2 Layer Analysis



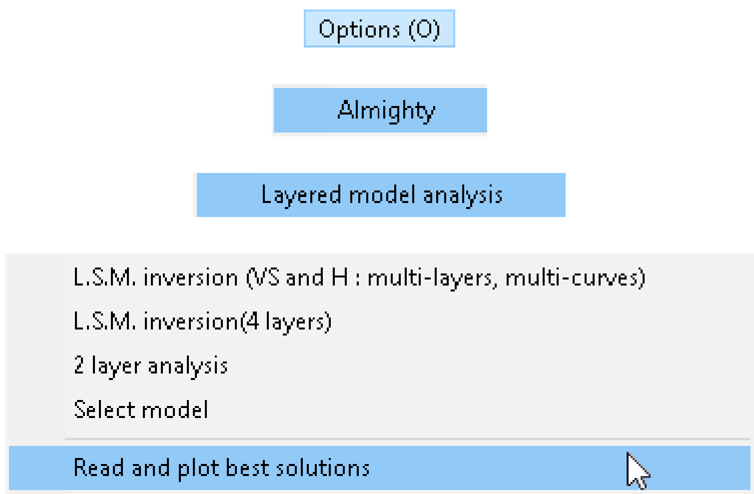
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.1.4 SELECT MODEL



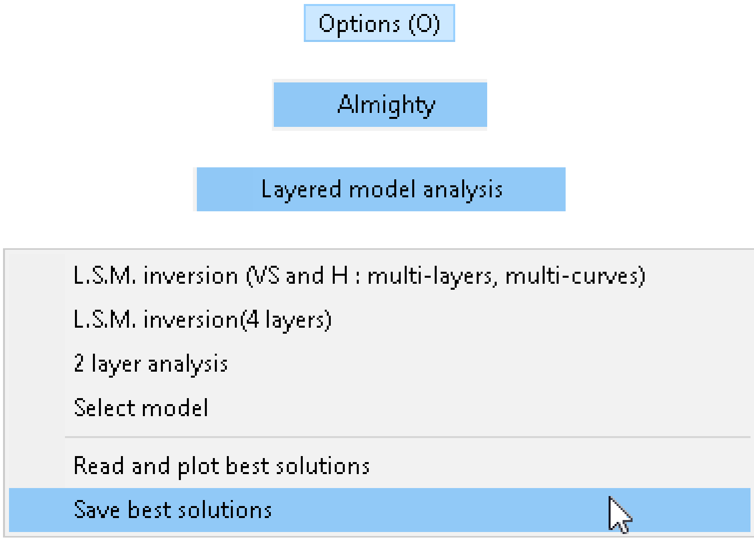
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.1.5 READ AND PLOT BEST SOLUTIONS



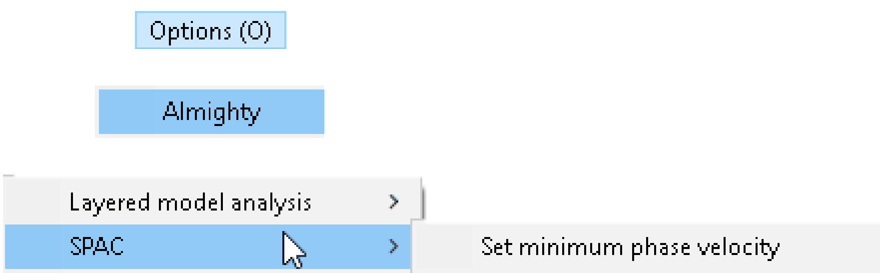
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.1.6 Save Best Solutions



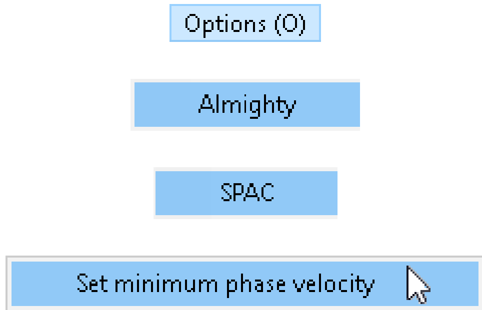
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.2 SPAC



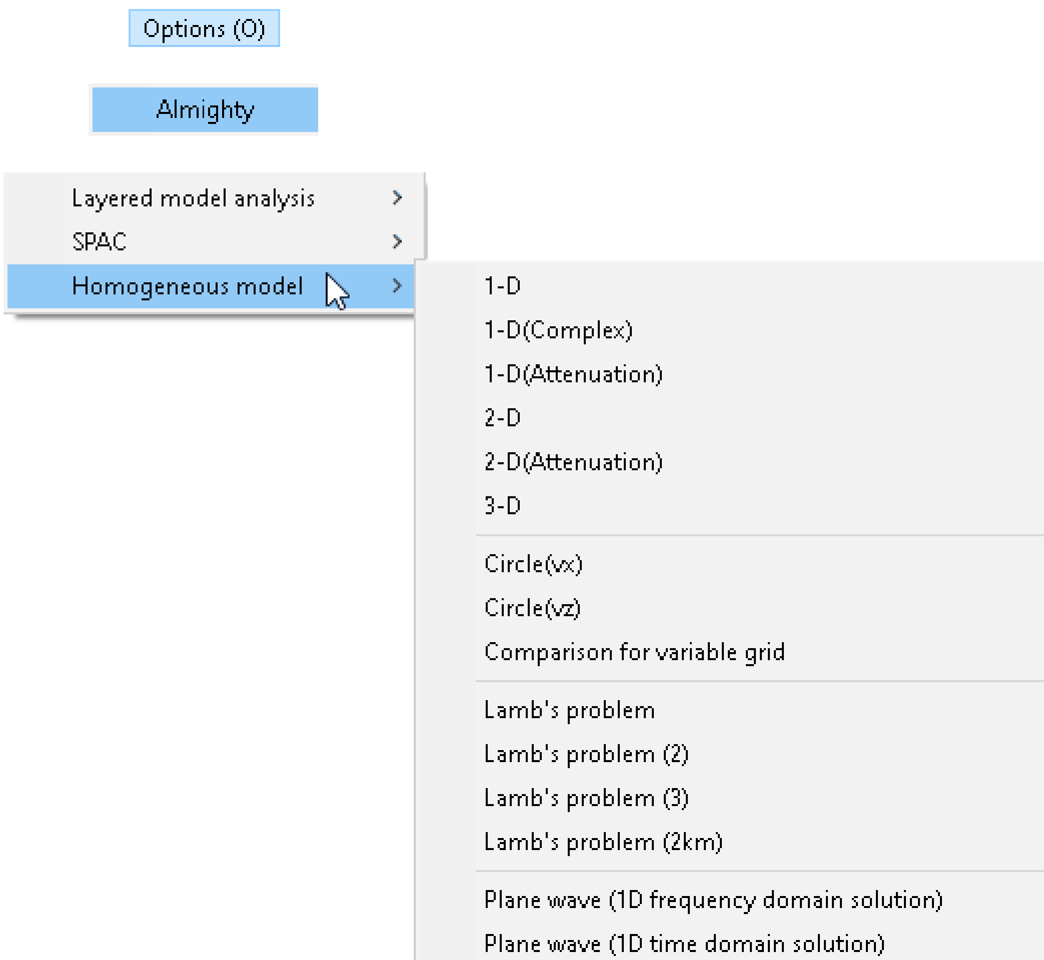
The item in the following sub-menu is rarely used, and when it is, support from Geometrics is generally required.

7.9.8.2.1 SET MINIMUM PHASE VELOCITY



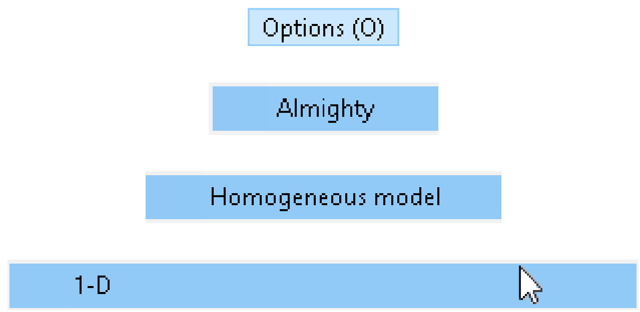
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3 HOMOGENEOUS MODEL



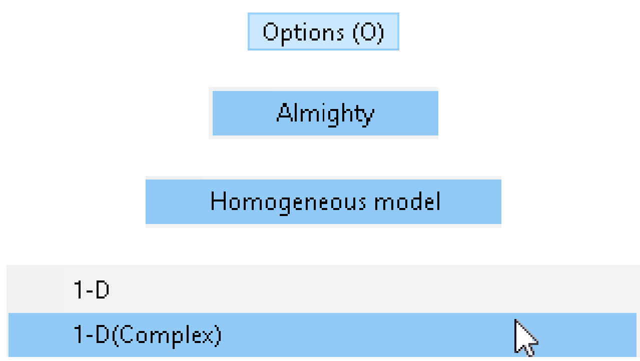
The items in the following sub-menus are rarely used, and when they are, support from Geometrics is generally required.

7.9.8.3.1 1D



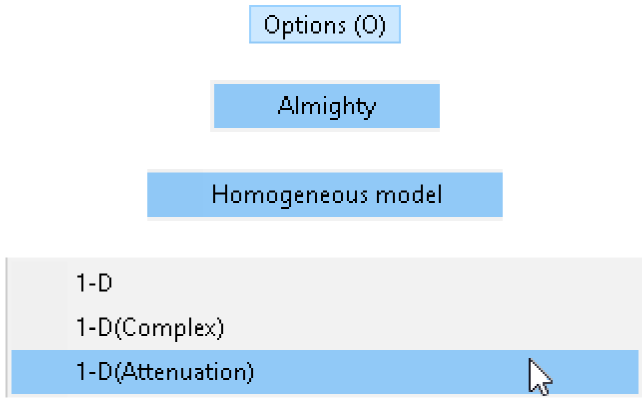
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.2 1D (Complex)



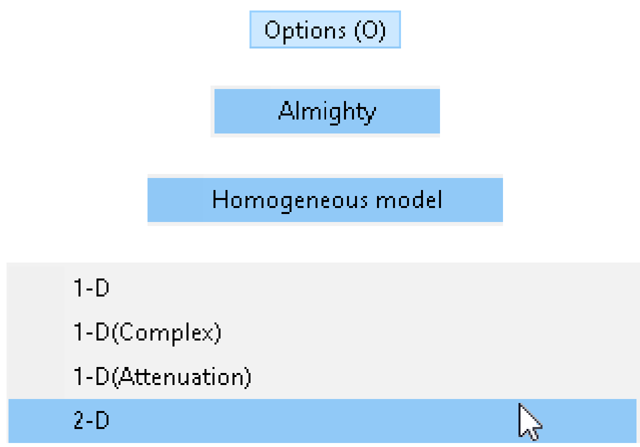
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.3 1D (Attenuation)



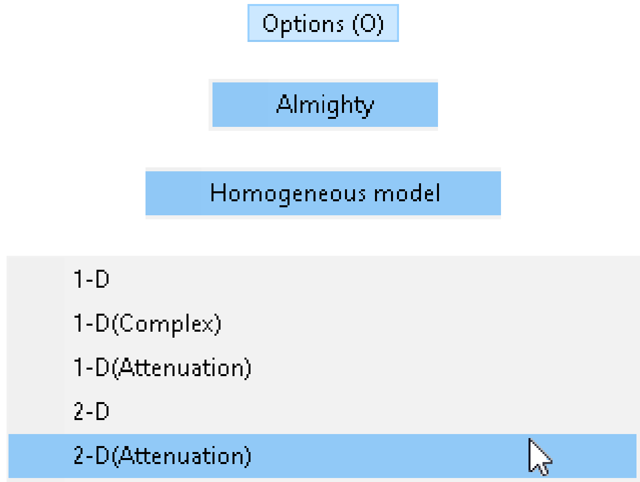
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.4 2D



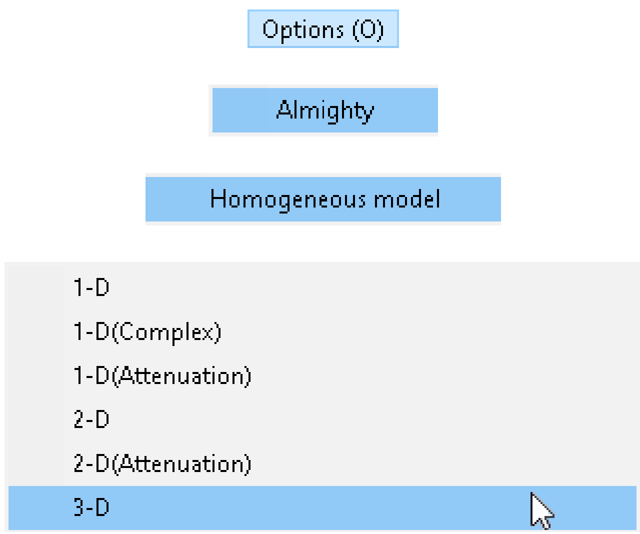
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.5 2D (ATTENUATION)



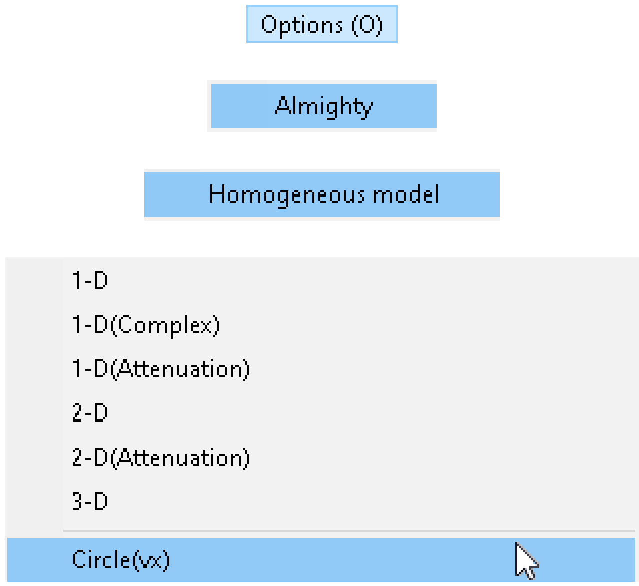
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.6 3D



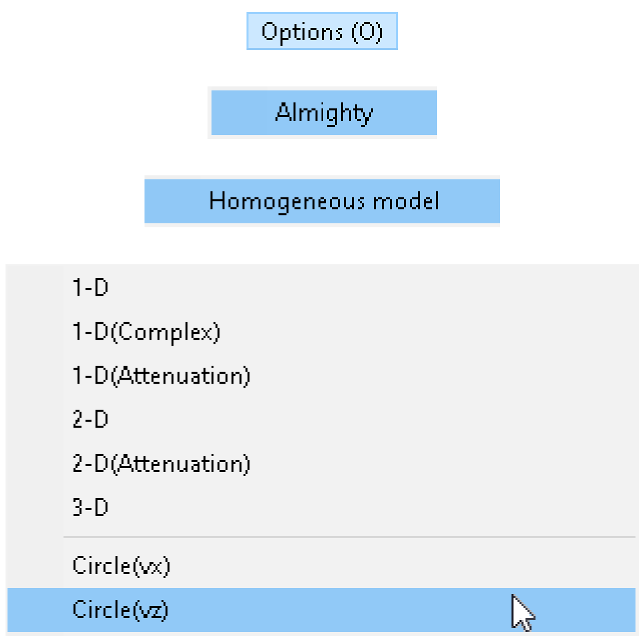
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.7 CIRCLE (VX)



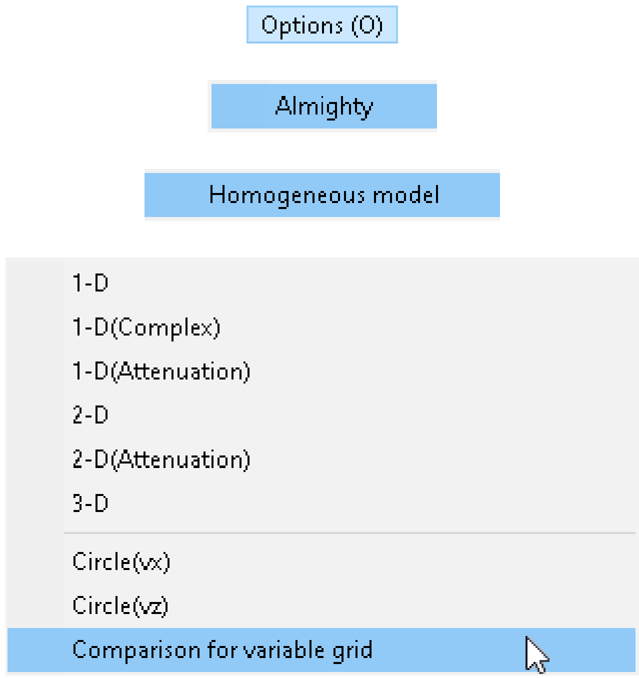
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.8 CIRCLE (VZ)



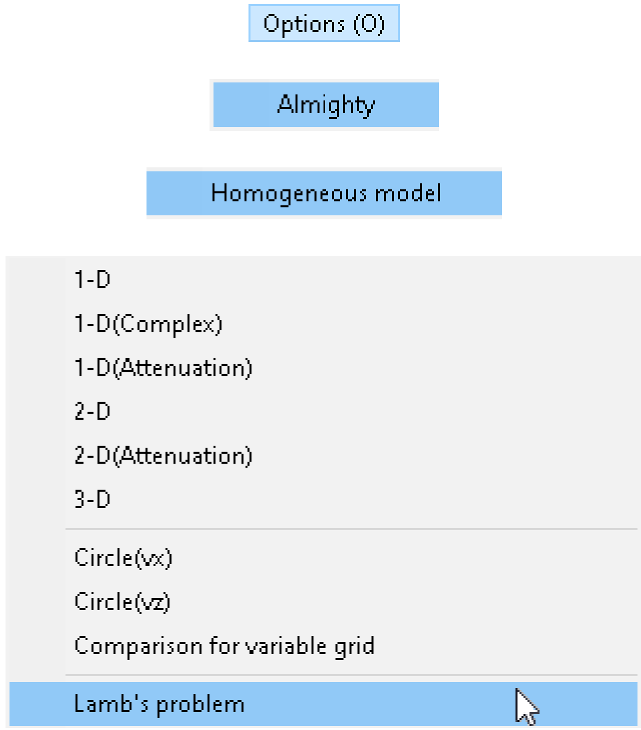
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.9 Comparison for Variable Grid



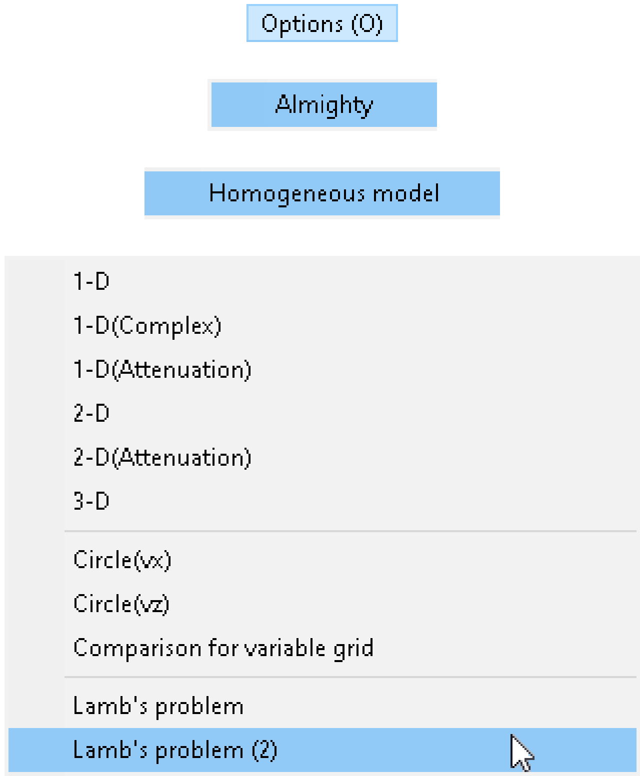
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.10 LAMB'S PROBLEM



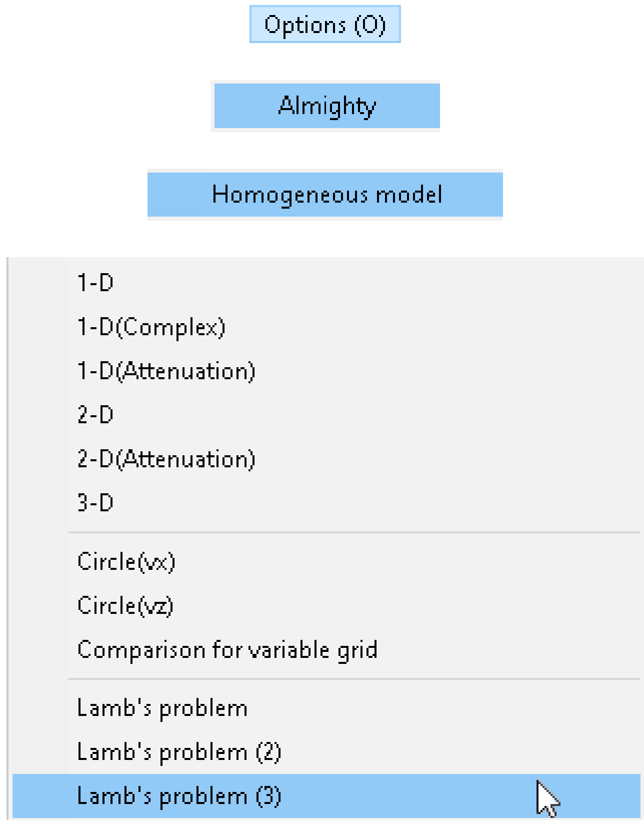
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.11 Lamb's Problem (2)



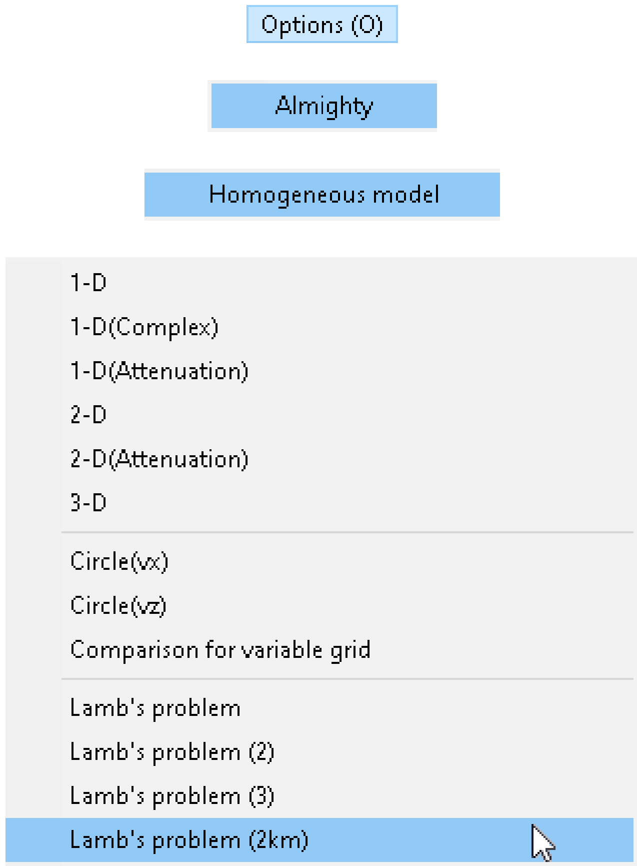
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.12 Lamb's Problem (3)



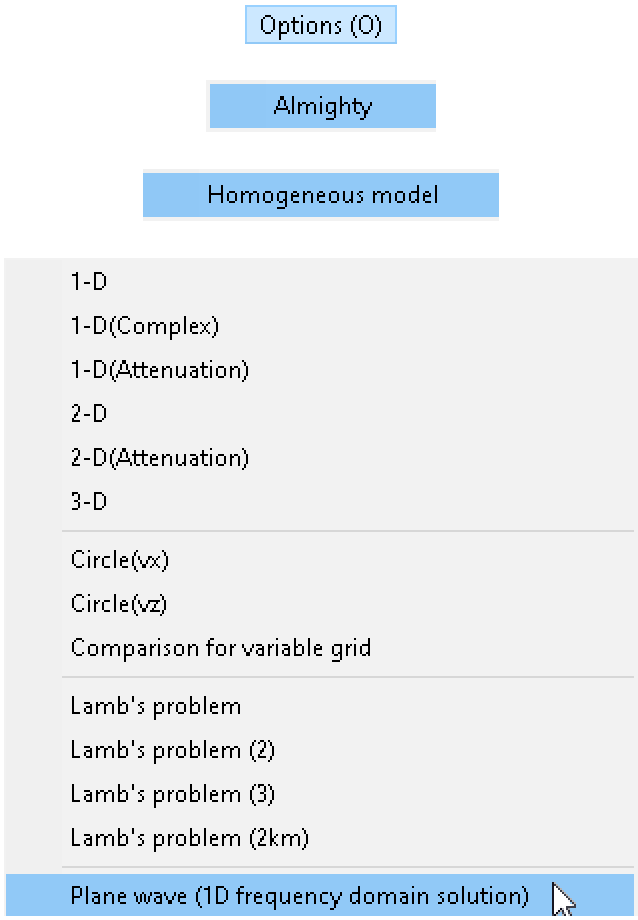
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.13 LAMB'S PROBLEM (2 KM)



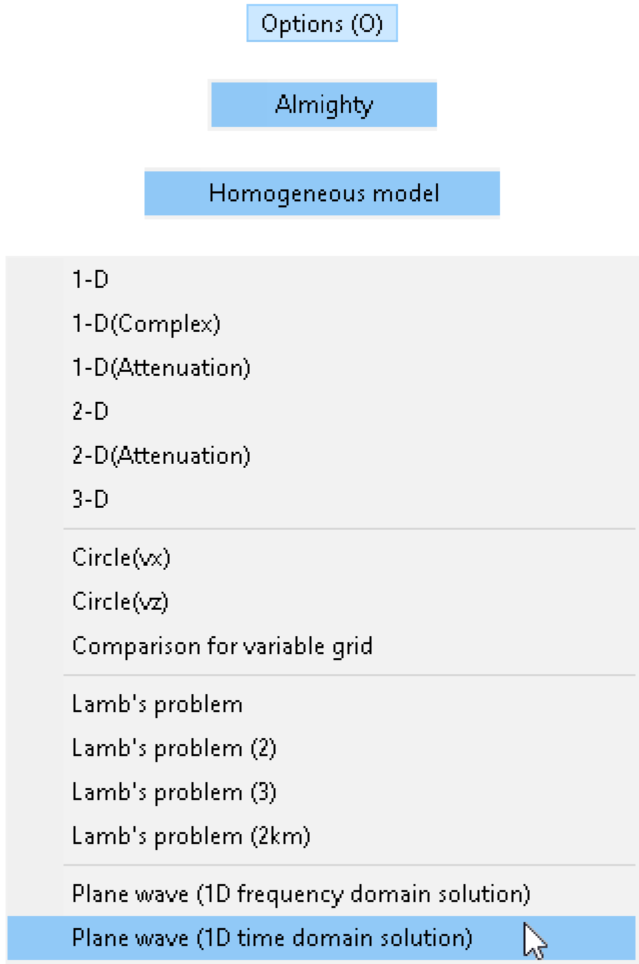
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.14 PLANE WAVE (1D FREQUENCY DOMAIN SOLUTION)



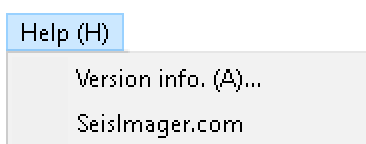
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.9.8.3.15 Plane Wave (1D Time Domain Solution)



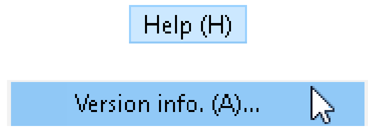
This feature is highly specialized and rarely used. Please contact support@seisimager.com for assistance.

7.10 Help Menu

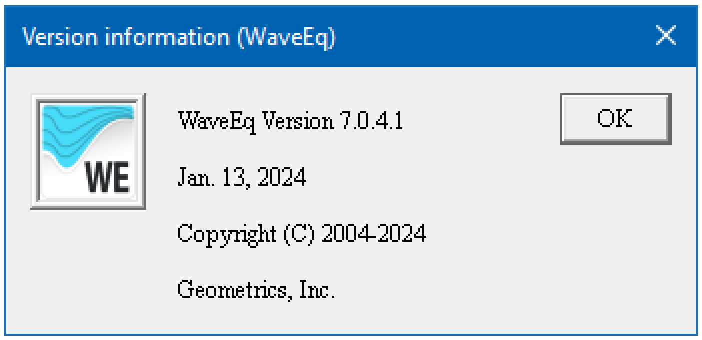


Continue.

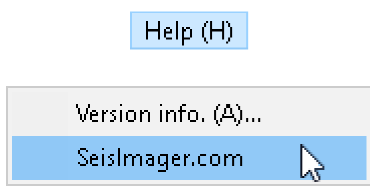
7.10.1 VERSION INFO



The **Help** menu or *Version info*  button reports the software version information.



7.10.2 SEISIMAGER.COM



Selecting this item will take you to the SeisImager.com website.

7.11 TOOL BUTTONS

The WaveEq Tool Button functions not already discussed in association with specific menu functions are explained in this section.

7.11.1 ENLARGE WAVEFORM AMPLITUDE  AND REDUCE WAVEFORM AMPLITUDE 

The *Enlarge waveform amplitude* and *Reduce waveform amplitude* buttons have no meaning in WaveEq.

7.11.2 Reduce Horizontal Scale and Enlarge Horizontal Scale

To reduce or enlarge the horizontal scale of plots of dispersion curves, geometry, and velocity models, press the *Reduce horizontal scale* and *Enlarge horizontal scale* buttons. The associated keyboard shortcuts are the *left-arrow* and *right-arrow* keys, respectively.

7.11.3 Enlarge Vertical Scale and Reduce Vertical Scale

To enlarge or reduce the vertical scale of plots of dispersion curves, geometry, and velocity models, press the *Enlarge vertical scale* and *Reduce vertical scale* buttons. The associated keyboard shortcuts are the *up-arrow* and *down-arrow* keys, respectively.

7.11.4 Show Previous and Show Next

To scroll through individual dispersion curves or velocity models, press the *Show previous* and *Show next* buttons. In the geometry plot view, these buttons are also used to select a specific geometry of a waveform file to display.

7.11.5 Home and End

To jump to the first or last of a set of dispersion curves or velocity models, press the *Home* and *End* buttons.

7.11.6 Calculate Theoretical Dispersion Curve by Fundamental Mode

The *Calculate theoretical dispersion curve by fundamental mode* button toggles off *Calculate theoretical dispersion curve by harmonic mode*.

7.11.7 Calculate Theoretical Dispersion Curve by Higher Mode

In the dispersion curve view for synthetic modeling, higher modes can be modeled by first pressing on the *Calculate theoretical dispersion curve by higher mode* button, then pressing on the *Calculate theoretical dispersion curves* button. The dispersion curve view will display a set of curves. The curves with connected open circles are fundamental mode dispersion curves and the solid lines are the higher mode dispersion curves, associated with each fundamental mode curve by color. The dashed lines are the relative amplitudes of the higher modes, also associated by color.

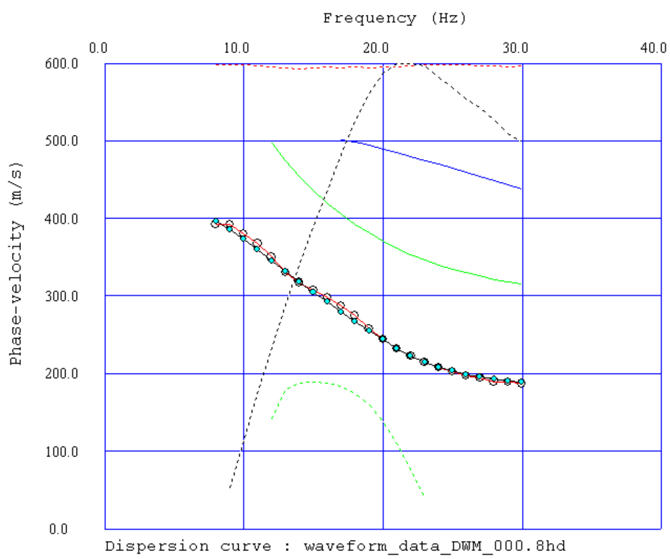


Figure 248: Theoretical fundamental dispersion curve with higher modes shown.

To toggle off the higher mode dispersion curves, press the *Calculate theoretical dispersion curves* button again. To return to the fundamental mode, press the *Calculate theoretical dispersion curve by fundamental mode* button.

7.11.8 Select Dispersion Curve and Correct Dispersion Curve

The *Select dispersion curve* and *Correct dispersion curve* buttons can be used for point-based editing. To reverse any changes, press the *Undo* button.

Press the *Select dispersion curve* button, then click on the point(s) on the dispersion curve that you wish to delete. The selected points will be highlighted in red.

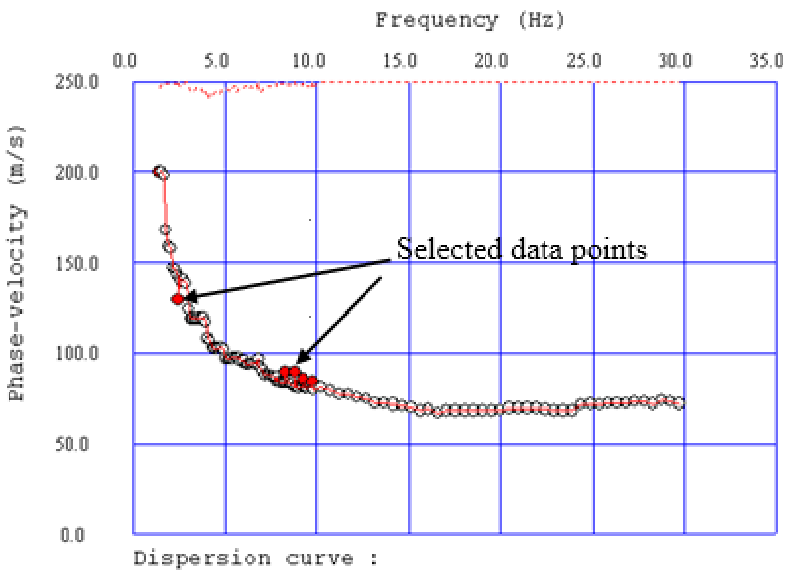


Figure 249: Date points selected for deletion.

When done selecting points, hit the *Delete* key or select *Delete* from the **Edit** menu. If you change your mind and do not want to delete the selected points, press the *Select dispersion curve* button to deselect the points and exit editing mode.

To edit the dispersion curve by dragging points to new positions in the direction of phase velocity on the plot, press the *Correct dispersion curve* button. Left click on the point and drag to adjust; it will turn red and then revert to white at the new position when the mouse button is released.

The *Undo* button can be pressed after any deletion or repositioning to reverse the effect.

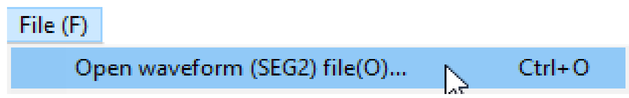
APPENDICES

Appendix A BASIC PROCESSING FLOWS

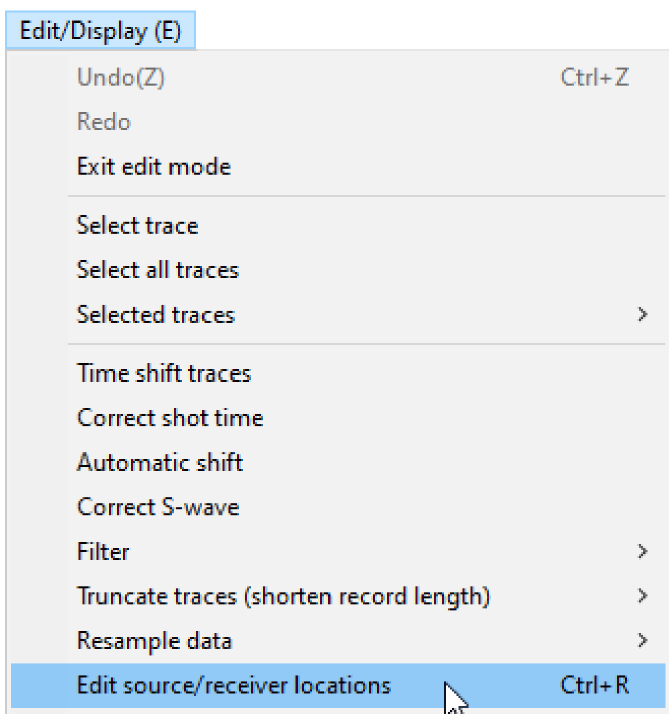
The basic processing flows for 1D MASW, MAM, and 2D MASW datasets are summarized in this section.

A.1 Active source 1D MASW

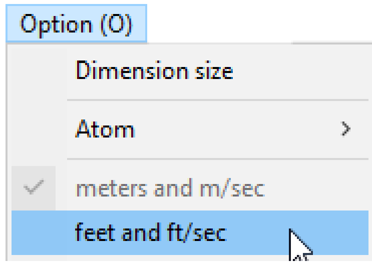
1. In Pickwin, open a waveform file.



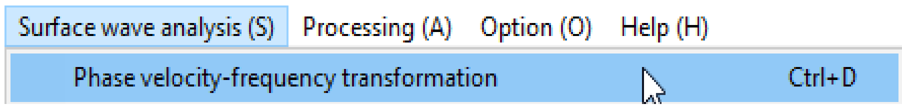
2. In Pickwin, set the unit labels to *meters* or *feet* by opening the **Edit/Display** menu and selecting *Edit source/receiver locations* (this is not an automatic part of the wizard, but should be done if there is a change from the unit labels last used).



Alternatively, the unit labels may be set by opening the **Options** menu and selecting *meters and m/sec* or *feet and ft/sec*.

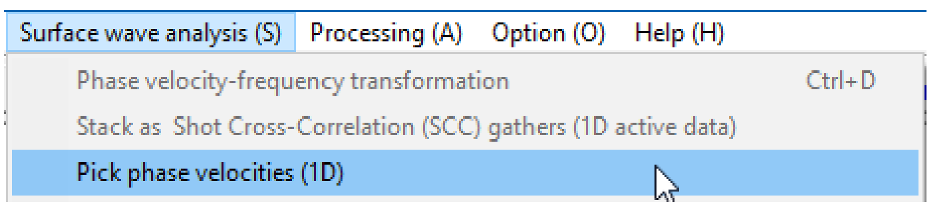


3. In Pickwin, calculate phase velocity.

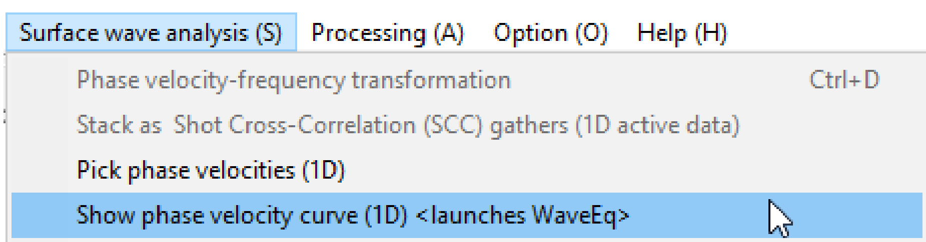


Upon viewing the phase velocity-frequency plot, if the calculation parameters need to be changed, press the *Undo* button, and re-run the process (this is not an automatic part of the wizard).

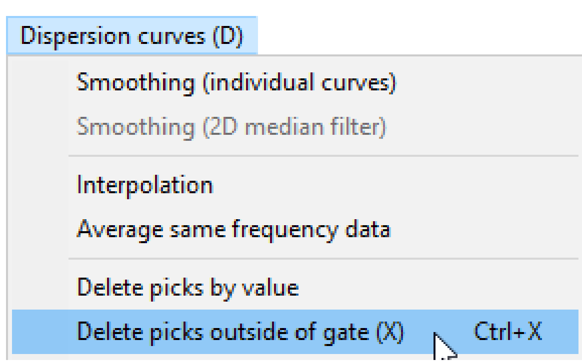
4. In Pickwin, pick the dispersion curve.



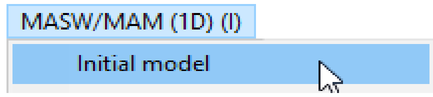
5. In Pickwin, import the picks into WaveEq.



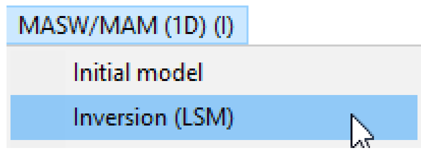
6. In WaveEq, edit the dispersion curve.



7. In WaveEq, calculate the initial model.

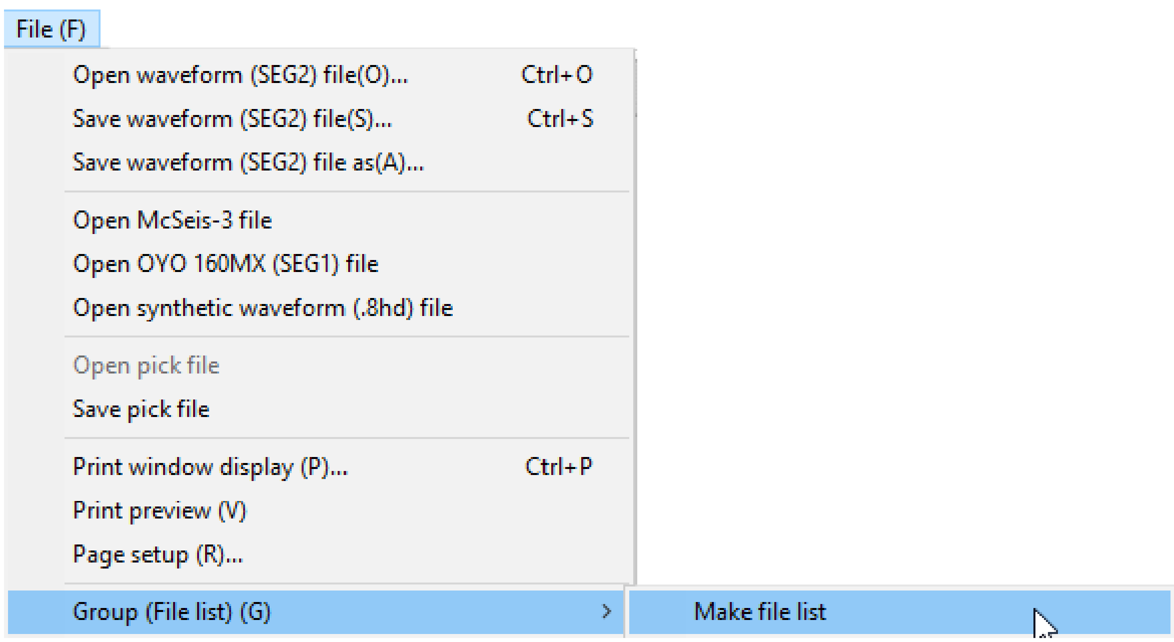


8. In WaveEq, run the inversion.

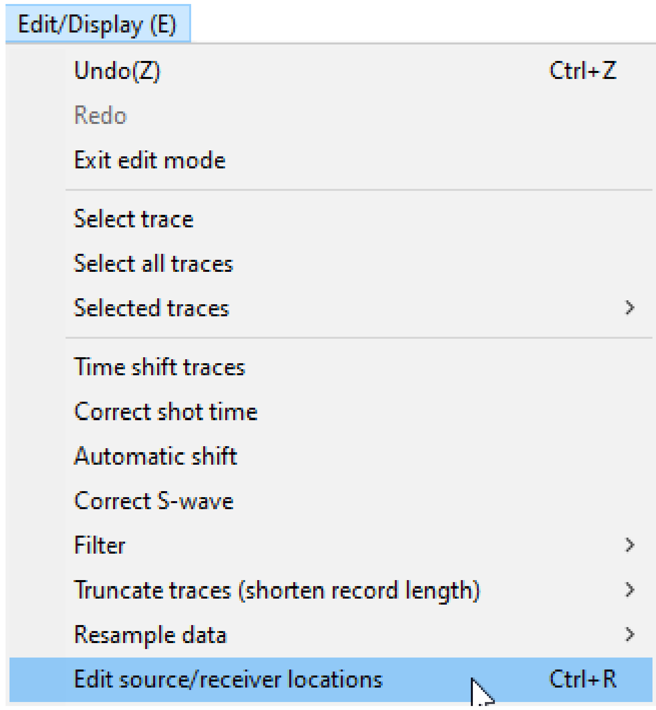


A.2 passive source MAM

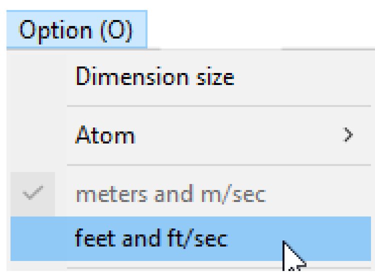
1. In Pickwin, make a list of the waveform files in the dataset.



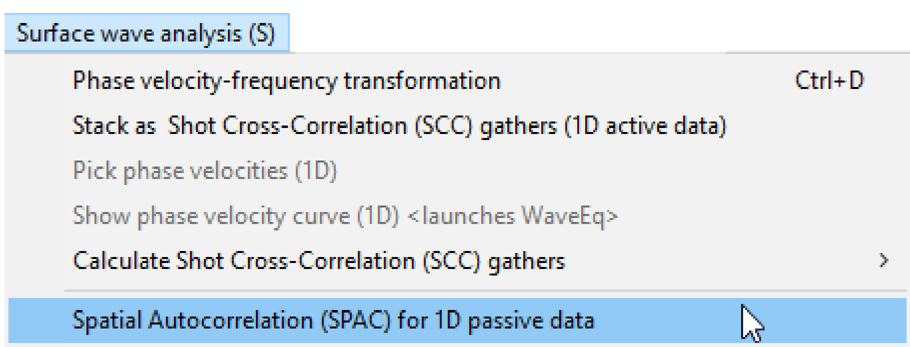
2. In Pickwin, set the unit labels to *meters* or *feet* by opening the **Edit/Display** menu and selecting *Edit source/receiver locations* (this is not an automatic part of the wizard, but should be done if there is a change from the unit labels last used).



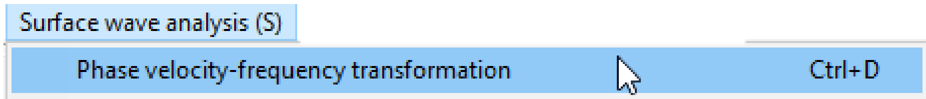
Alternatively, the unit labels may be set by opening the **Options** menu and selecting *meters and m/sec* or *feet and ft/sec*.



3. In Pickwin, run the spatial autocorrelation.

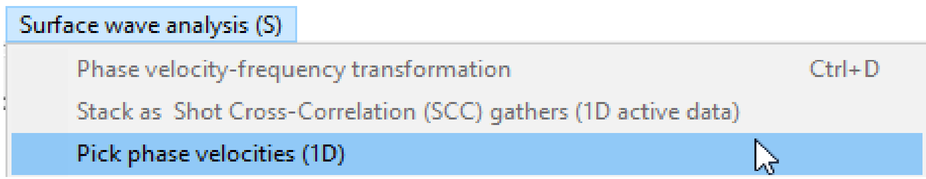


4. In Pickwin, calculate phase velocity.

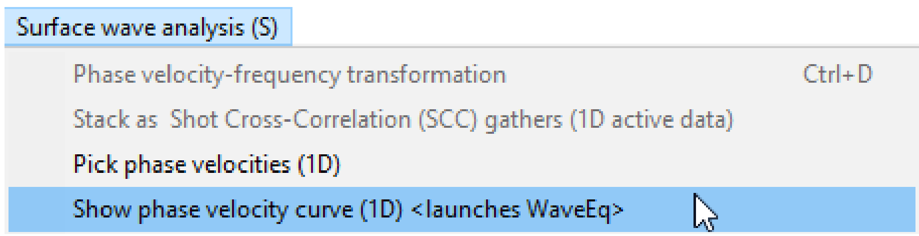


Upon viewing the phase velocity-frequency plot, if the calculation parameters need to be changed, press the *Undo* button, and re-run the process (this is not an automatic part of the wizard).

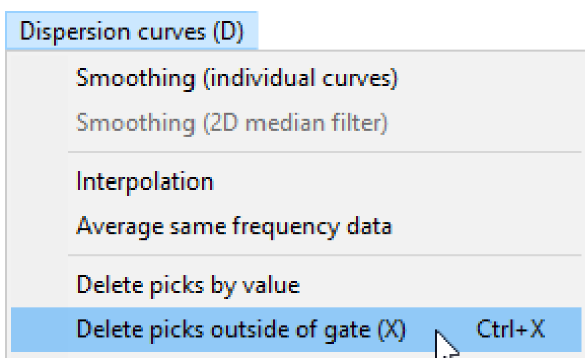
5. In Pickwin, pick the dispersion curve.



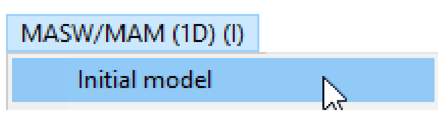
6. In Pickwin, import the picks into WaveEq.



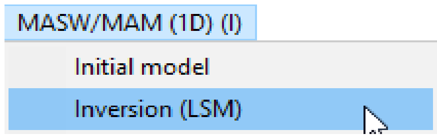
7. In WaveEq, edit the dispersion curve.



8. In WaveEq, calculate the initial model.

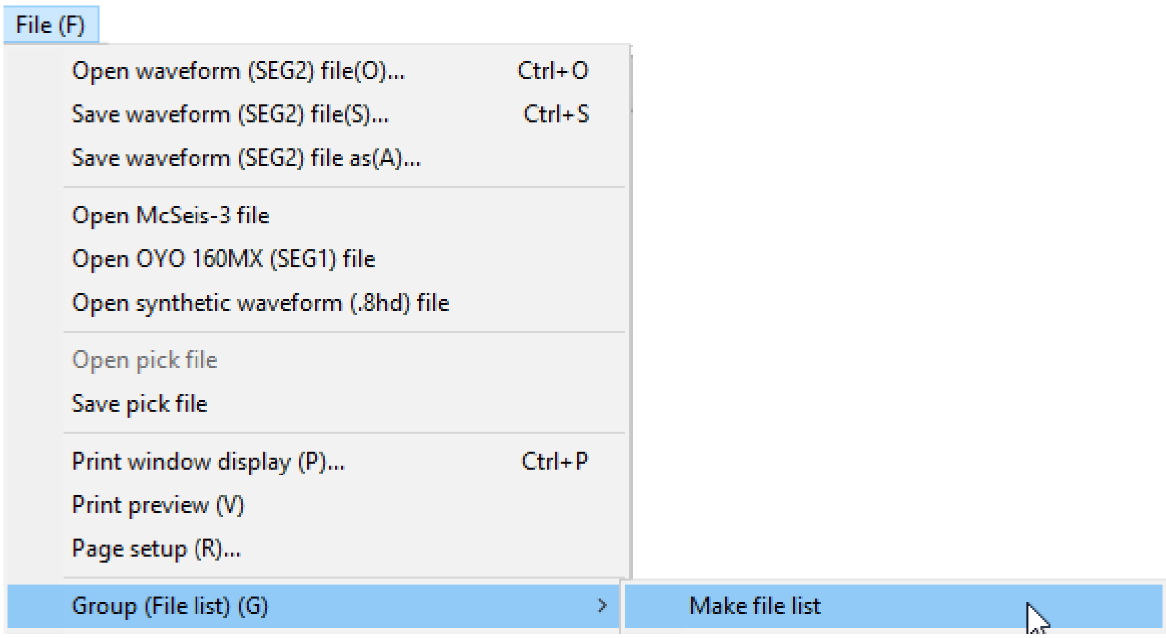


9. In WaveEq, run the inversion.

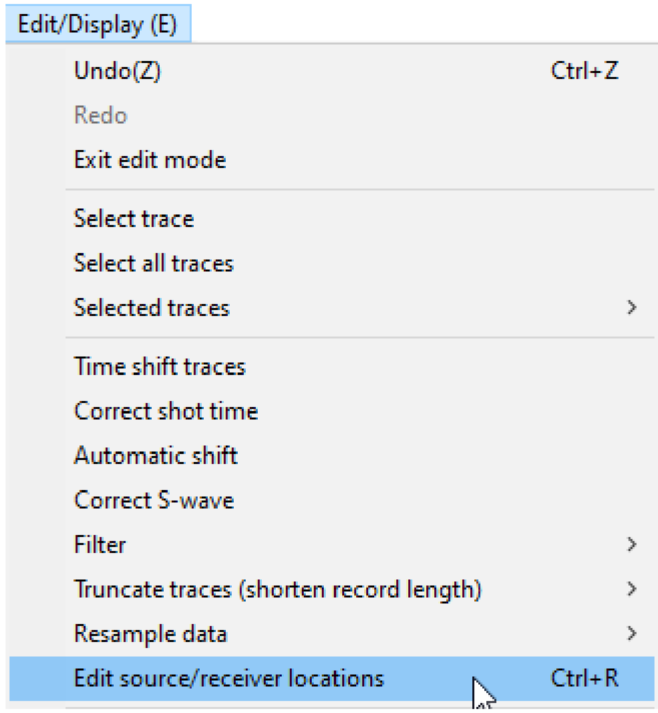


A.3 Active source 2D MASW

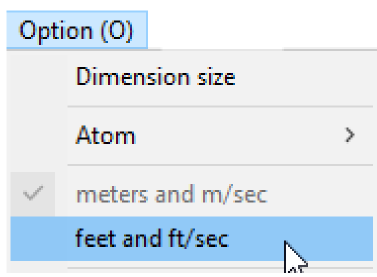
1. In Pickwin, make a list of waveform files in the dataset.



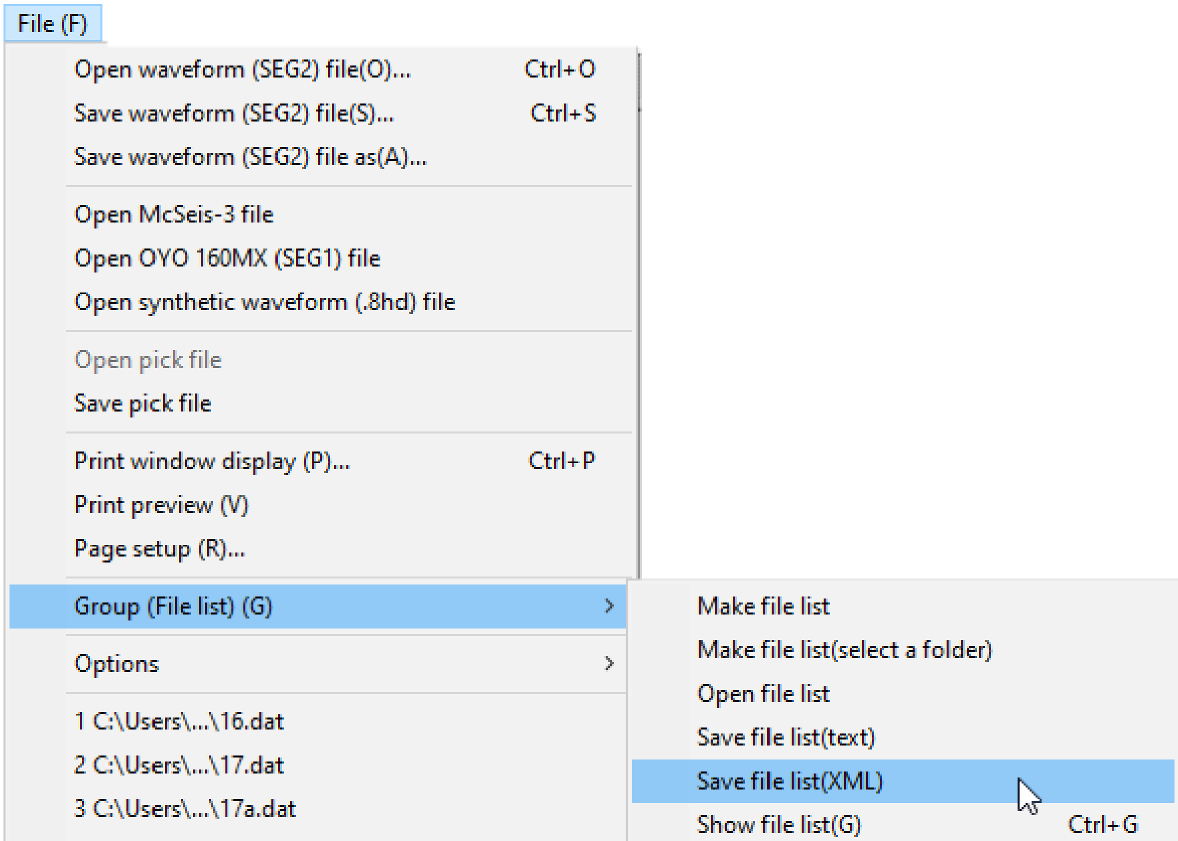
2. In Pickwin, set the unit labels to *meters* or *feet* by opening the **Edit/Display** menu and selecting *Edit source/receiver locations* (this is not an automatic part of the wizard, but should be done if there is a change from the unit labels last used).



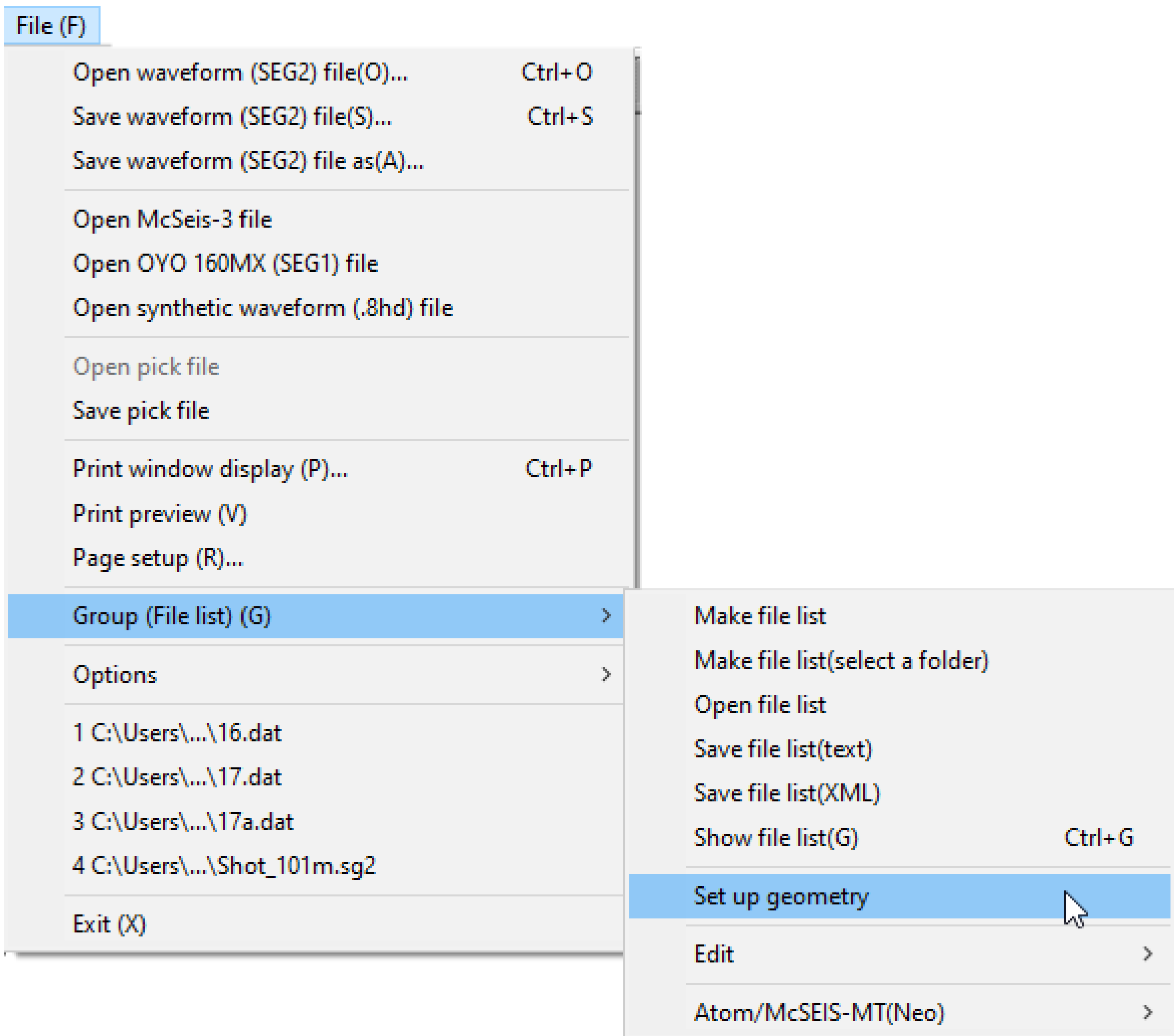
Alternatively, the unit labels may be set by opening the **Options** menu and selecting *meters and m/sec* or *feet and ft/sec*.



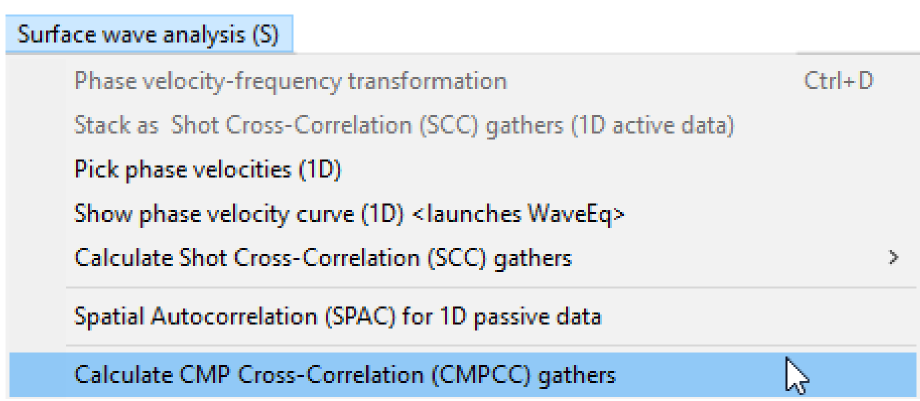
3. In Pickwin, save the file list for future use.



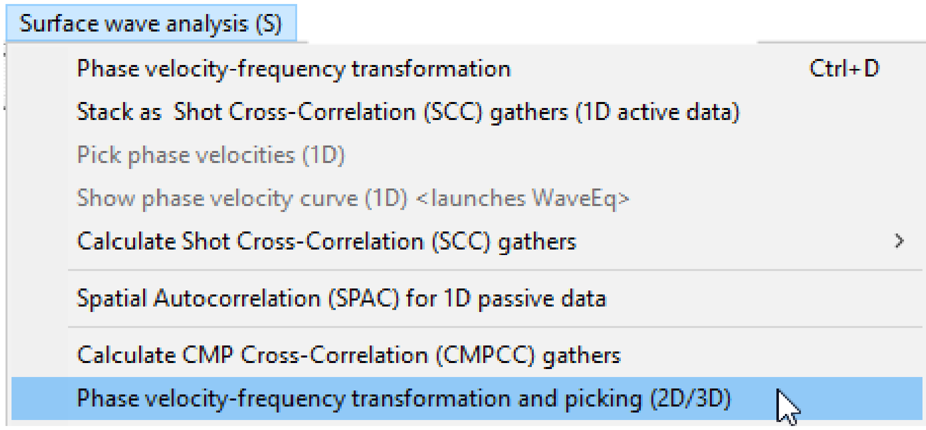
4. In Pickwin, set up the source-receiver geometry.



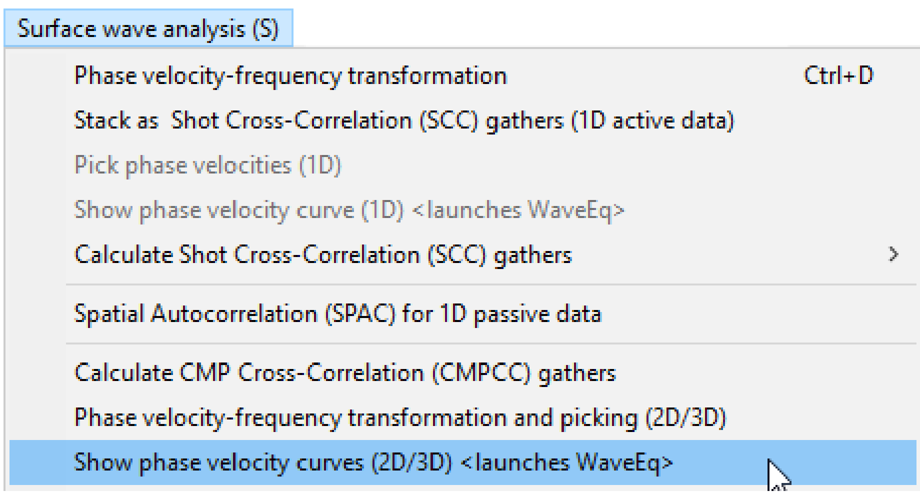
5. In Pickwin, calculate and assemble the CMP cross-correlation gathers.



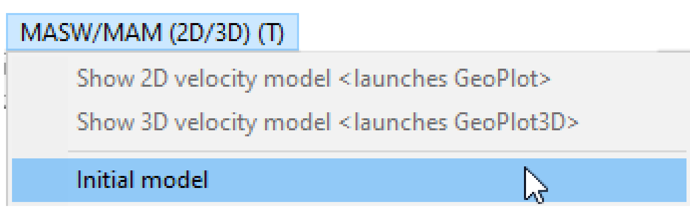
6. In Pickwin, calculate phase velocity for the CMP cross-correlation gathers and automatically pick the dispersion curves.



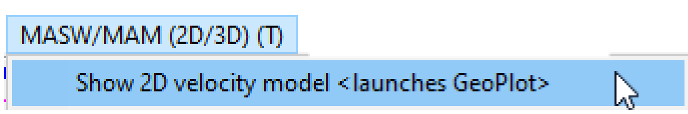
7. In Pickwin, import the dispersion curves into WaveEq.



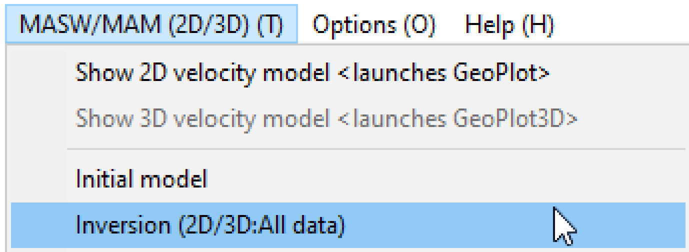
8. In WaveEq, calculate the initial model.



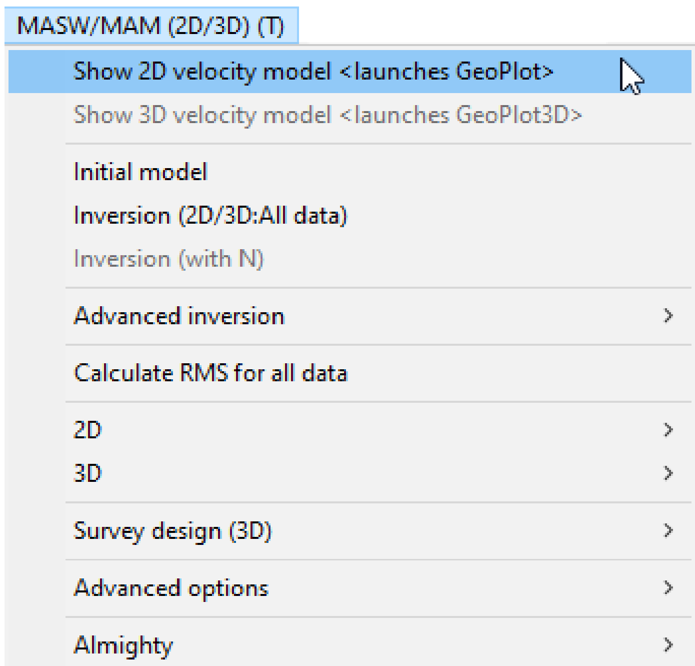
9. In GeoPlot, view the initial model.



10. In WaveEq, run the inversion.



11. In GeoPlot, view the final model.



A.4 Viewing and Editing Individual Dispersion Curves in Pickwin

In Pickwin, prior to launching WaveEq, dispersion curves from a 2D MASW dataset may be individually edited in the phase velocity-frequency plot view. Usually, with 2D MASW datasets, there are too many curves to pick manually, and the automatic picker is more precise than the human eye. Occasionally, however, there may be a need to override the automatic picks. This section describes the processing flow; these steps would be added in between Steps 6 and 7 on Page A-11.

1. In Pickwin, press the *Geometry*  button to display the geometry view. Use the *Show previous waveform*  and *Show next waveform*  buttons to select the CMP cross-correlation gather for which you want to view and edit the dispersion curve.

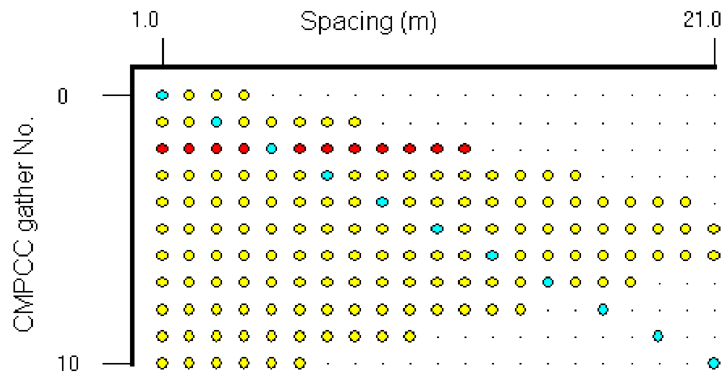
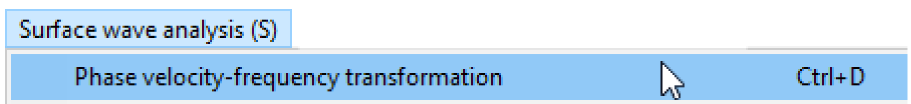


Figure A-1: Geometry plot with CMP cross-correlation gather selected (red).

2. Press the *Waveform*  button to display the waveform file for the selected CMP cross-correlation gather.

3. Calculate phase velocity for the CMP cross-correlation gather.



4. The phase velocity-frequency plot for the selected CMP cross-correlation gather is displayed with the rest of the dispersion curves picked in Step 6 on Page A-11. The pink line connecting red picks is the individual dispersion curve associated with the selected CMP cross-correlation gather. The rest of the curves are shown in green.

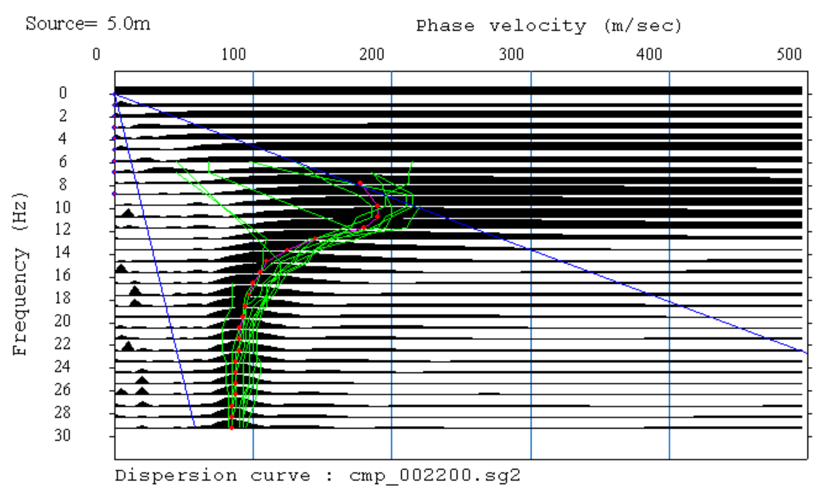


Figure A-2: Phase velocity-frequency plot for selected CMP cross-correlation gather.

Adjust the dispersion curve picks as desired and use the *Update*  button to register the new picks.

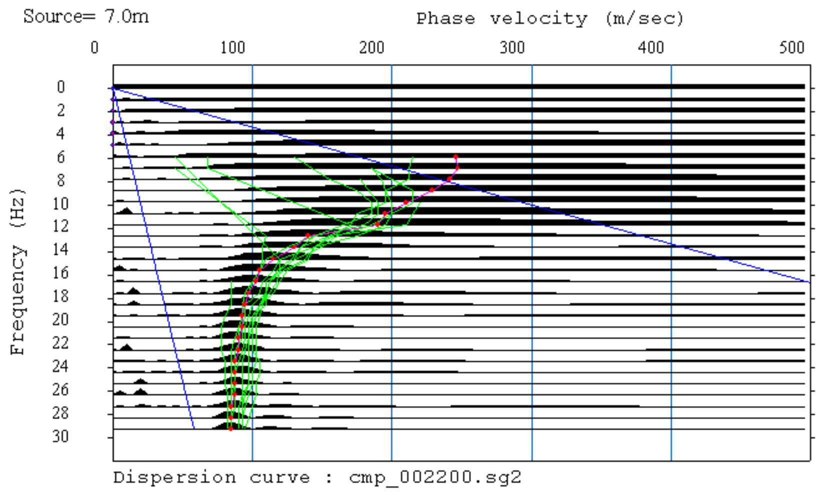
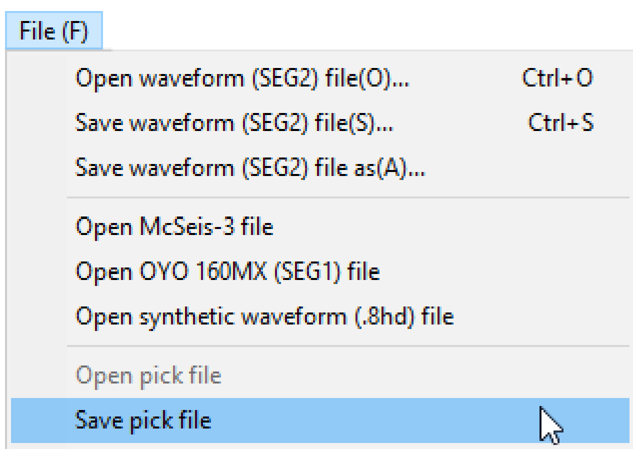


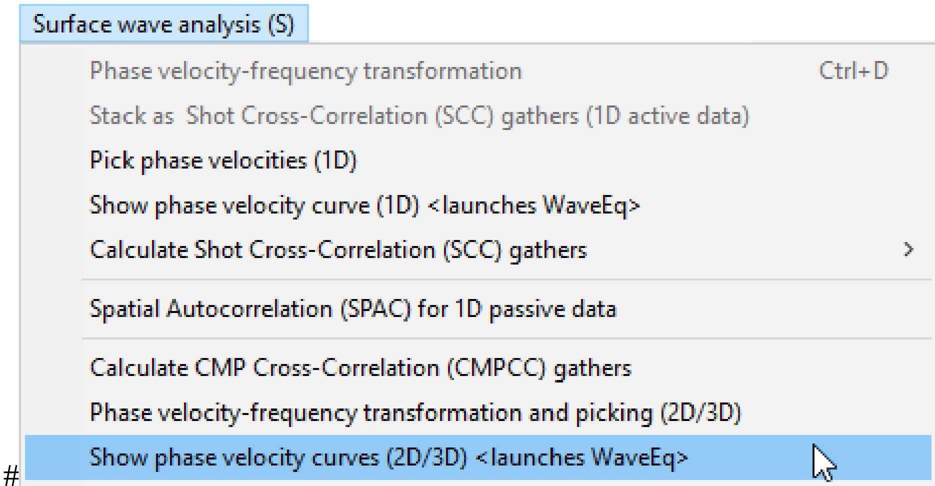
Figure A-3: Adjusted dispersion curve picks.

5. To edit other dispersion curves, repeat the process from Step 1.

6. Once editing is complete, save the revised dispersion curves.

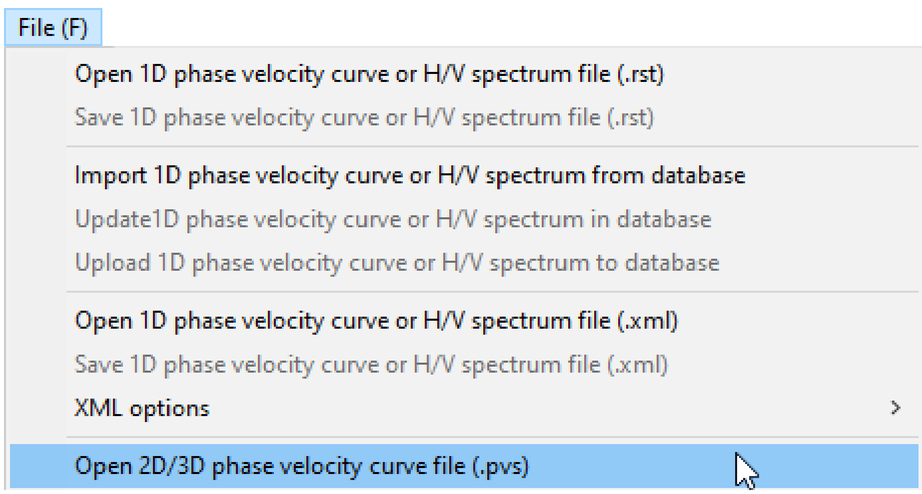


7. Import the revised dispersion curves into WaveEq.



#

As an alternative, the saved dispersion curve file can be opened in WaveEq.



Appendix B DATA EXAMPLES AND QUALITY CONTROL

Continue.

B.1 Active source Waveform Data

Continue.

B.1.1 Lower Quality

The shot record below lacks coherent surface wave signal from the near to far traces and is heavily contaminated with relatively lower frequency noise, particularly from 75 to 170 feet. Shot stacking or a larger source, and waiting for a quieter recording period, would probably help.

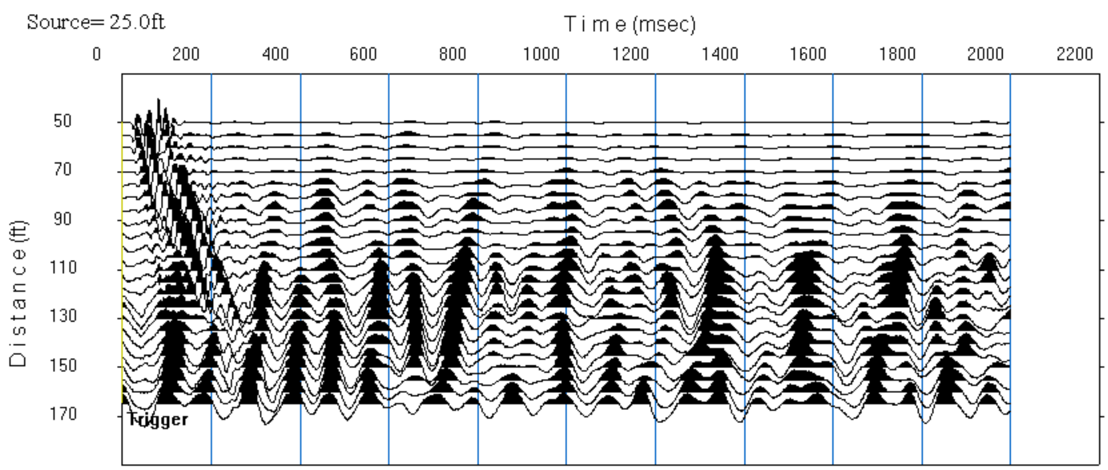


Figure B-1: Example of low-quality active source record due to poor signal-to-noise ratio.

In this shot record, the takeouts for channels 6, and 12 through 16 were left open with no geophones connected. No signal was recorded, giving up 100 ft of offset on the far end of the spread and creating a 40-foot gap in between traces 5 and 7.

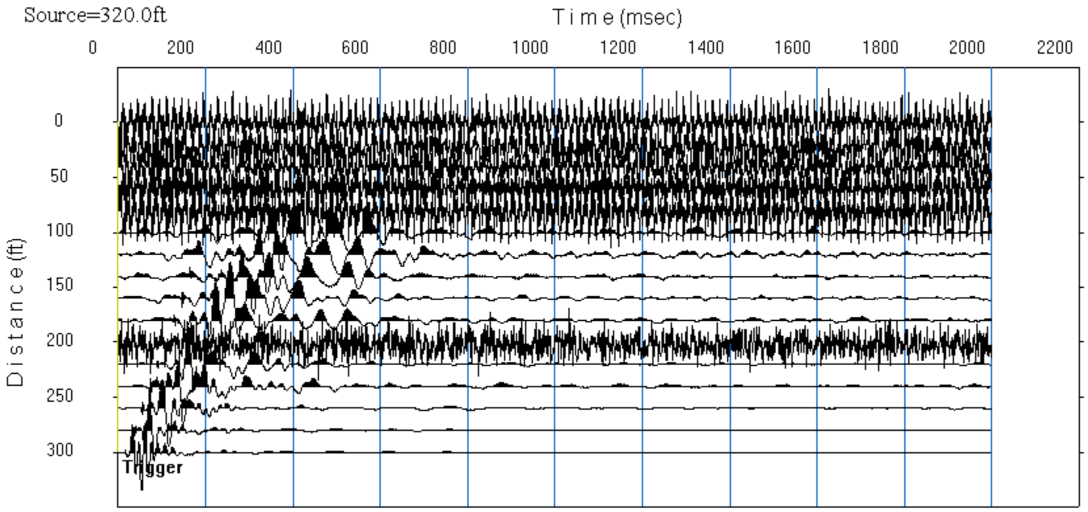


Figure B-2: Example of low-quality active source record due to dead traces.

Due to a small near offset, in this shot record, the signal on the geophone at 51 feet was clipped. A few overdriven channels can be tolerated but it is best practice to not record clipped signal.

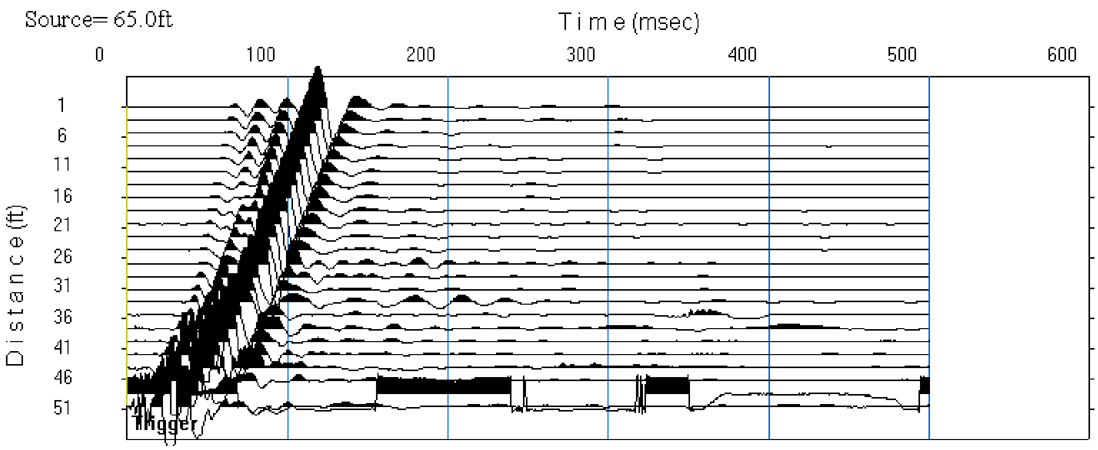


Figure B-3: Example of low-quality active source record due to small near-offset, resulting in clipped traces.

B.1.2 Higher Quality

The shot record below displays high signal-to-noise ratio, no clipped traces, and coherency from trace-to-trace.

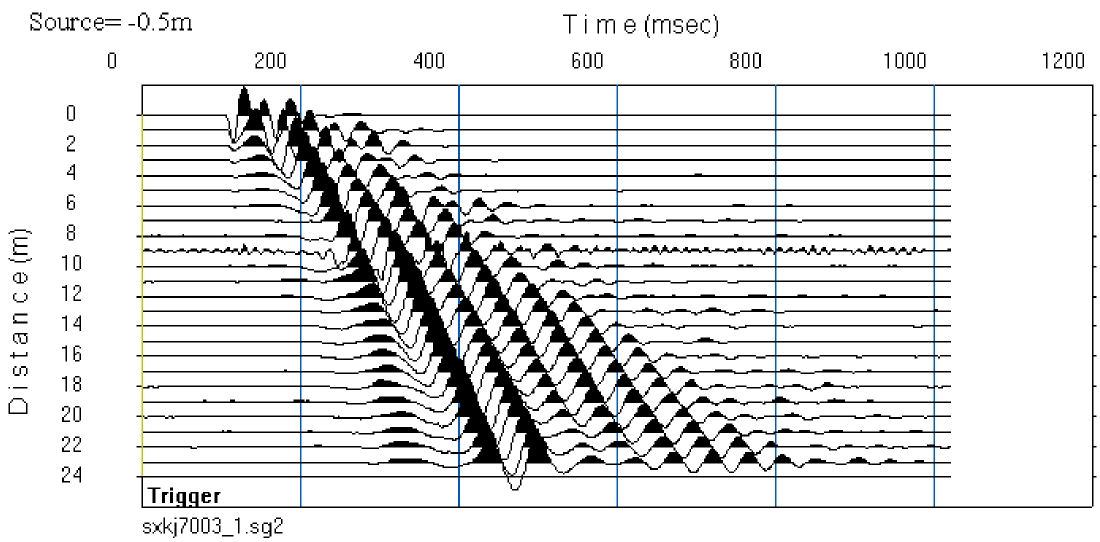


Figure B-4: High-quality active source record.

B.2 Passive Source Waveform Data

Continue.

B.2.1 Lower Quality

The record below shows wide variation in trace amplitude from trace-to-trace.

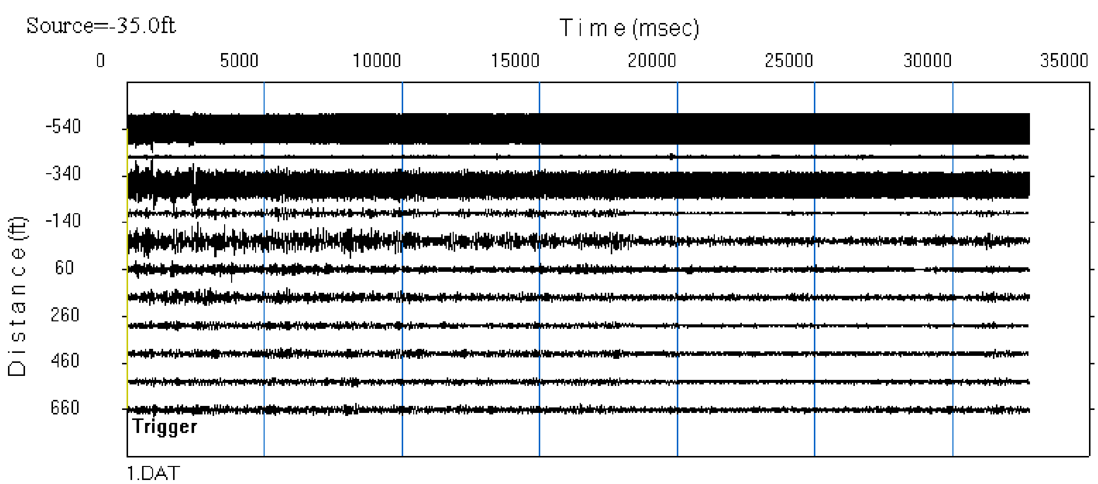


Figure B-5: Low-quality passive source record due to large amplitude variation between traces.

Upon viewing the spectrum, it is clear that the frequency content is uneven.

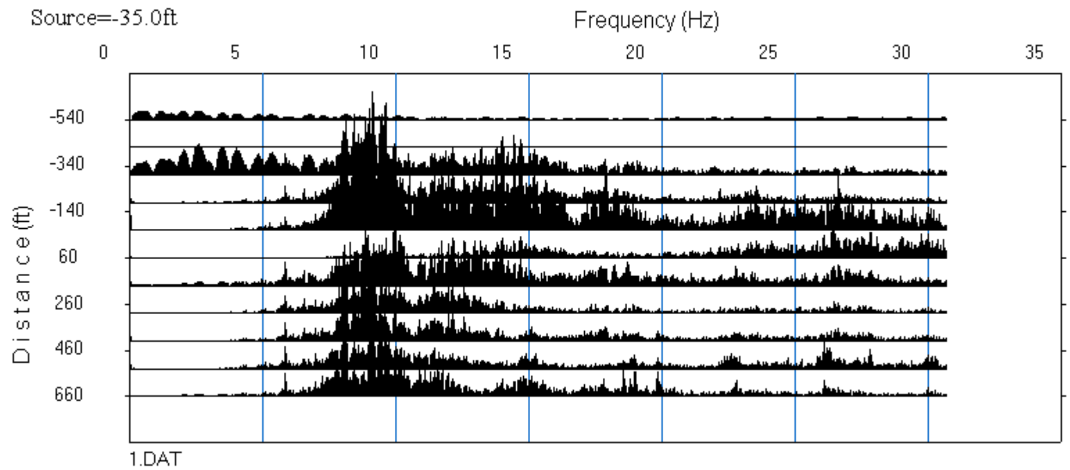


Figure B-6: Frequency spectrum of record shown in Figure B-5.

A similar condition is evident in this record and associated frequency spectrum.

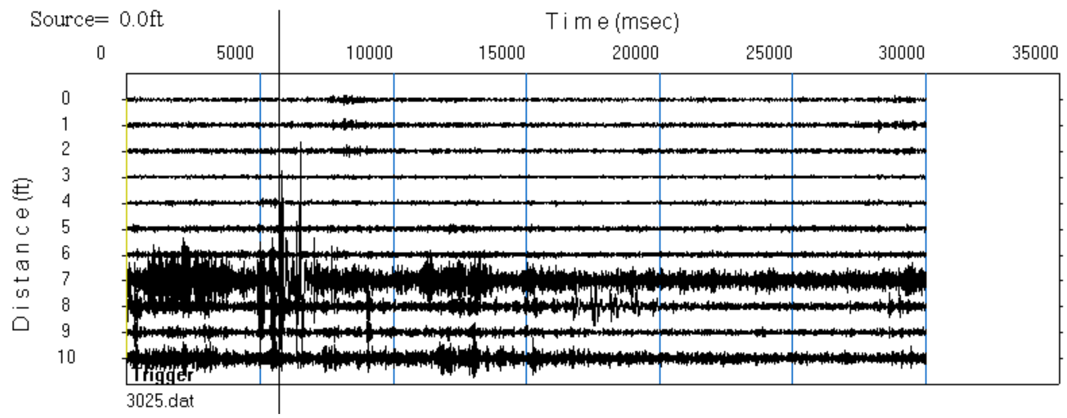


Figure B-7: Second example of low-quality passive source record due to large amplitude variation between traces.

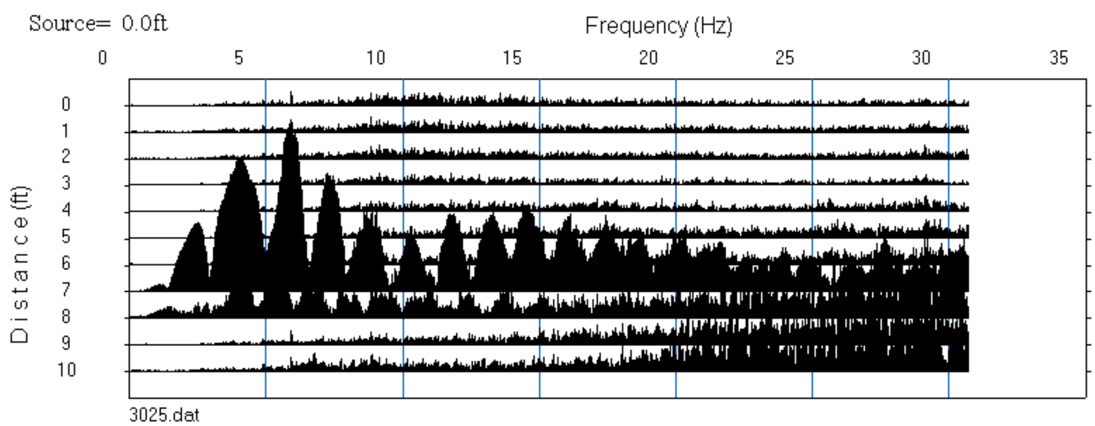


Figure B-8: Frequency spectrum of record shown in Figure B-7.

In this record, the traces are similar to each other, but over time, there is a wide range in amplitude.

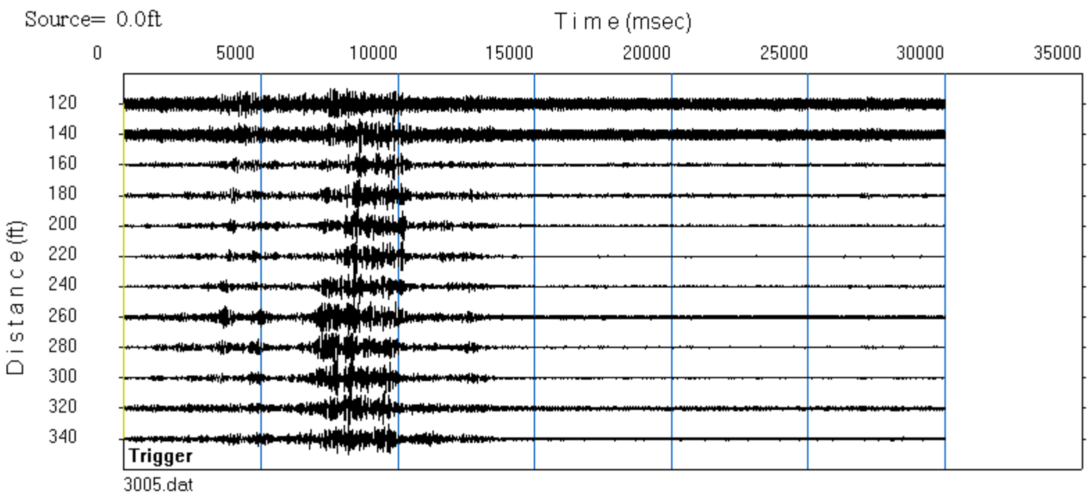


Figure B-9: Example of low-quality passive source record due to large amplitude variation over times.

The spectrum shows fairly consistent frequency content from trace-to-trace, but not as tight as it could be.

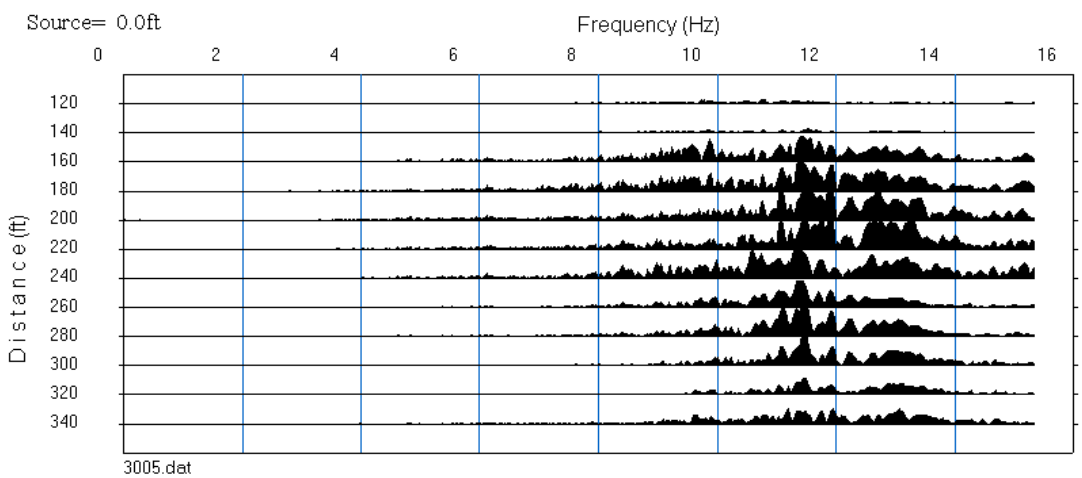


Figure B-10: Frequency spectrum of record shown in Figure B-9.

B.2.2 Higher Quality

The record below is ideal, showing even signal amplitude from trace-to-trace and in time.

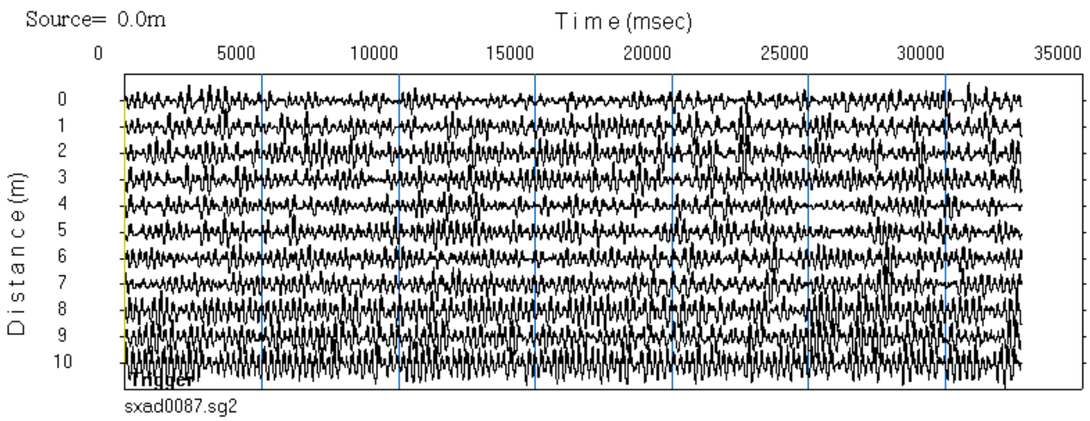


Figure B-11: Ideal passive source record.

The corresponding frequency spectrum shows the energy contained in a neat envelope from approximately 2 to 7 Hz.

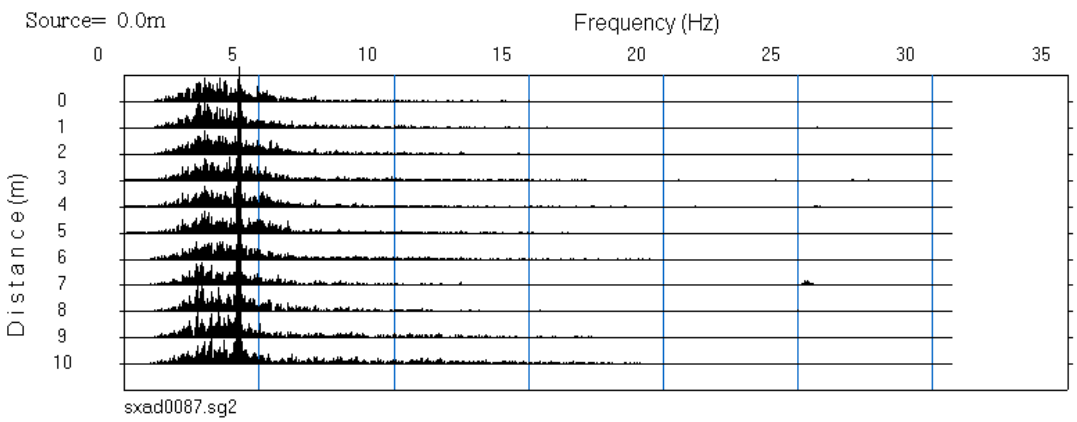


Figure B-12: Frequency spectrum of record shown in Figure B-11.

This record has some intermittent higher-amplitude noise from passing cars (between 21 and 26 seconds).

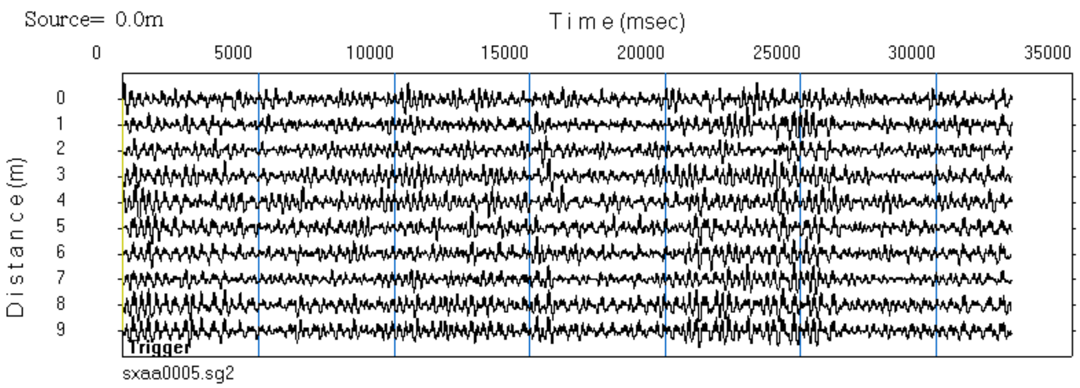


Figure B-13: passive source record with noise from passing car.

The frequency spectrum shows the car noise has relatively little impact on the record quality since it was of short duration compared to the total recording time.

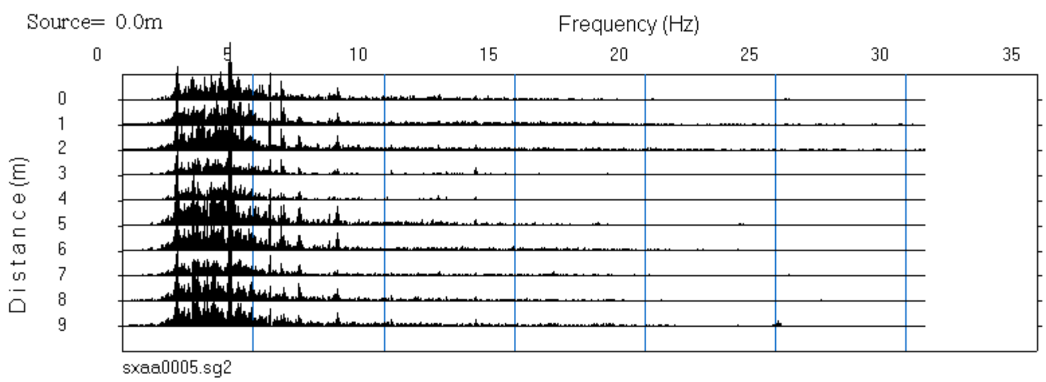


Figure B-14: Frequency spectrum of record shown in Figure B-13.

B.3 Dispersion Curves

Continue.

B.3.1 Characteristics

Dispersion curves are smooth, curved or straight lines.

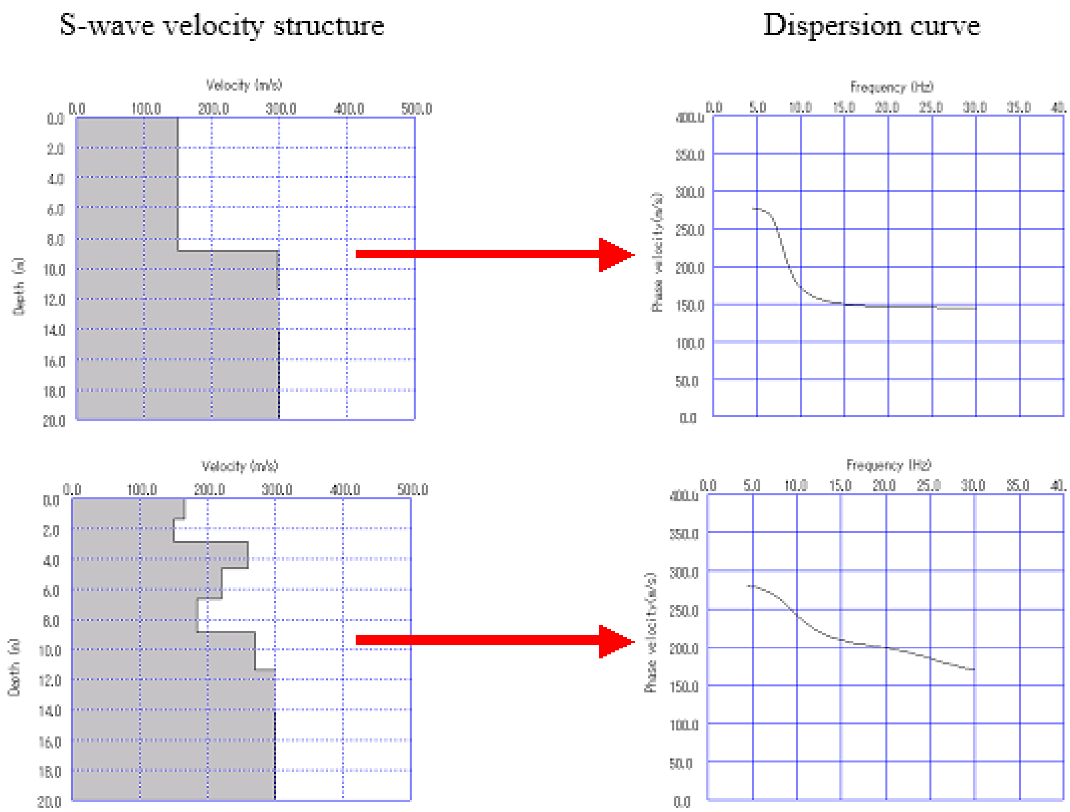


Figure B-15: VS models and corresponding dispersion curves.

Dispersion curves reflect the *average* velocity model beneath the geophone spread.

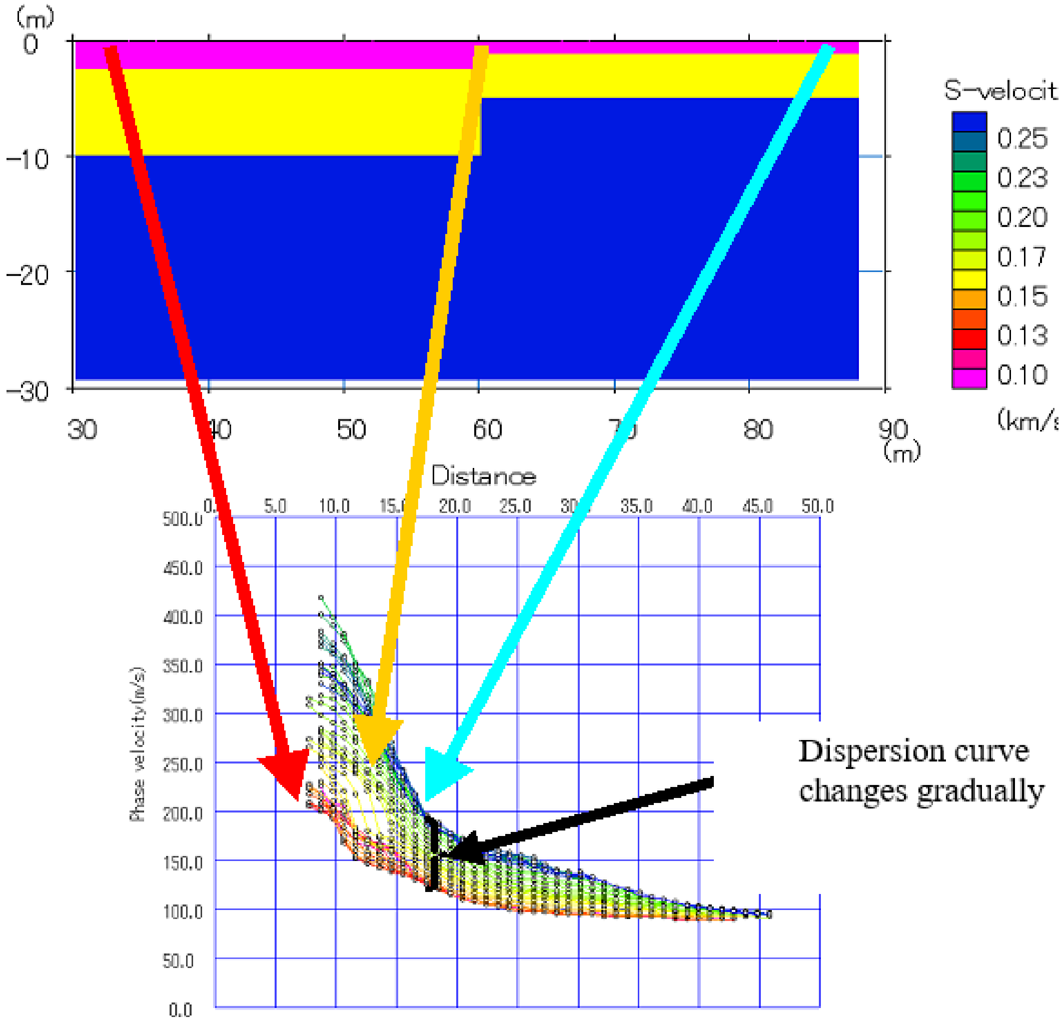


Figure B-16: Gradual change of dispersion curves over abrupt change in velocity.

Only the Rayleigh wave fundamental mode is used for analysis, although higher modes are present and often visible.

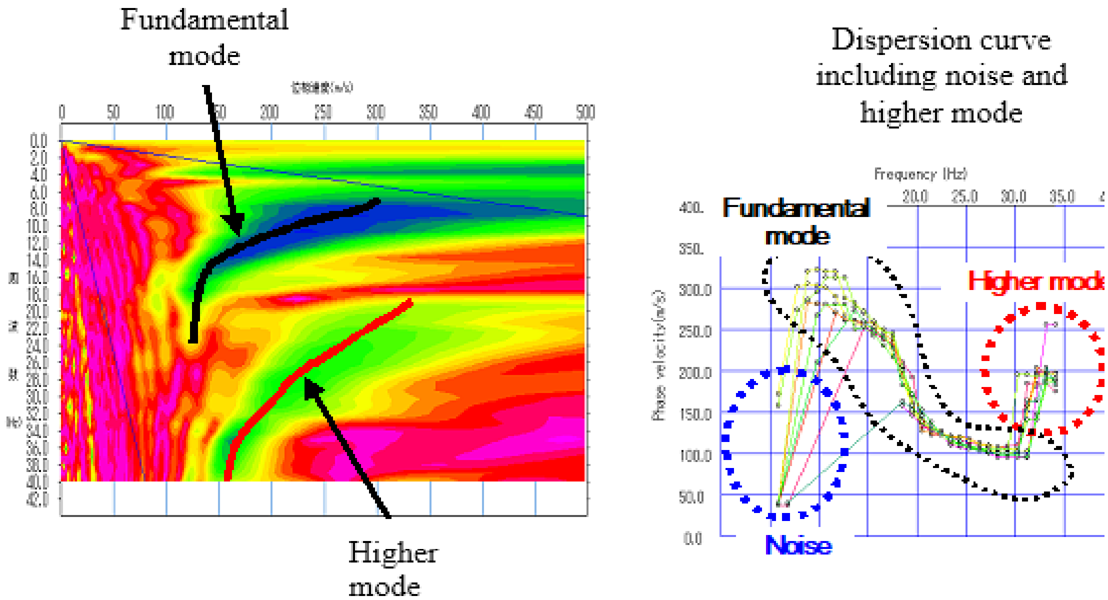


Figure B-17: Phase velocity-frequency plot and dispersion curve indicating fundamental mode, higher mode, and noise.

The frequency range within which phase velocity is considered stable corresponds to the minimum and maximum wavelengths recorded, and there is generally a one-to-one relationship between the minimum and maximum wavelength, and the geophone interval and total offset (spread length), respectively.

The bounds of the stable frequency range are depicted on the phase velocity-frequency plot by blue lines (shown above) and by bold black lines (shown below), with slopes that correspond to the minimum and maximum wavelengths.

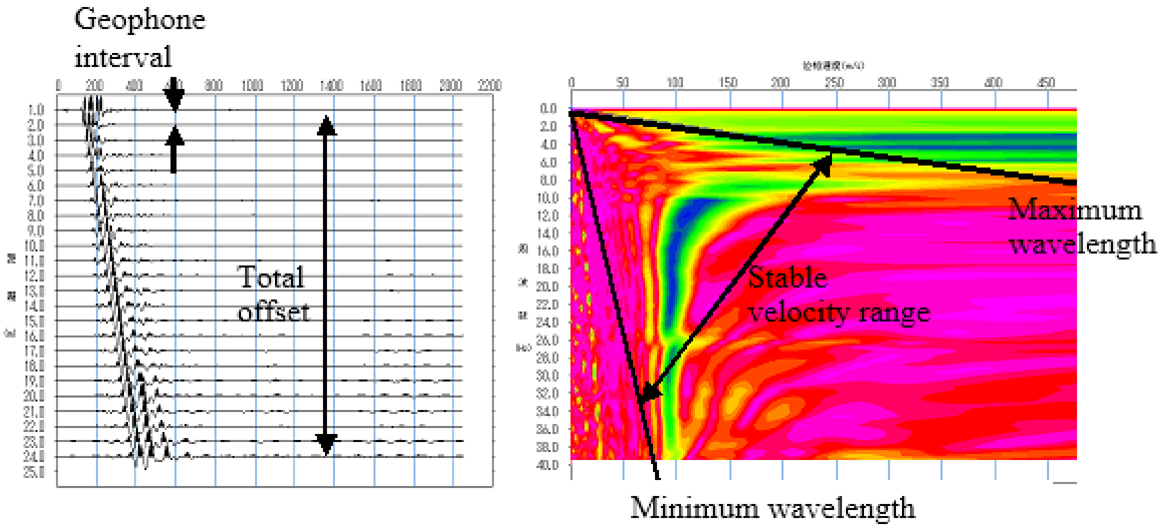


Figure B-18: Bounds of the stable frequency range.

B.3.2 Comparison of data from ground with variable stiffness

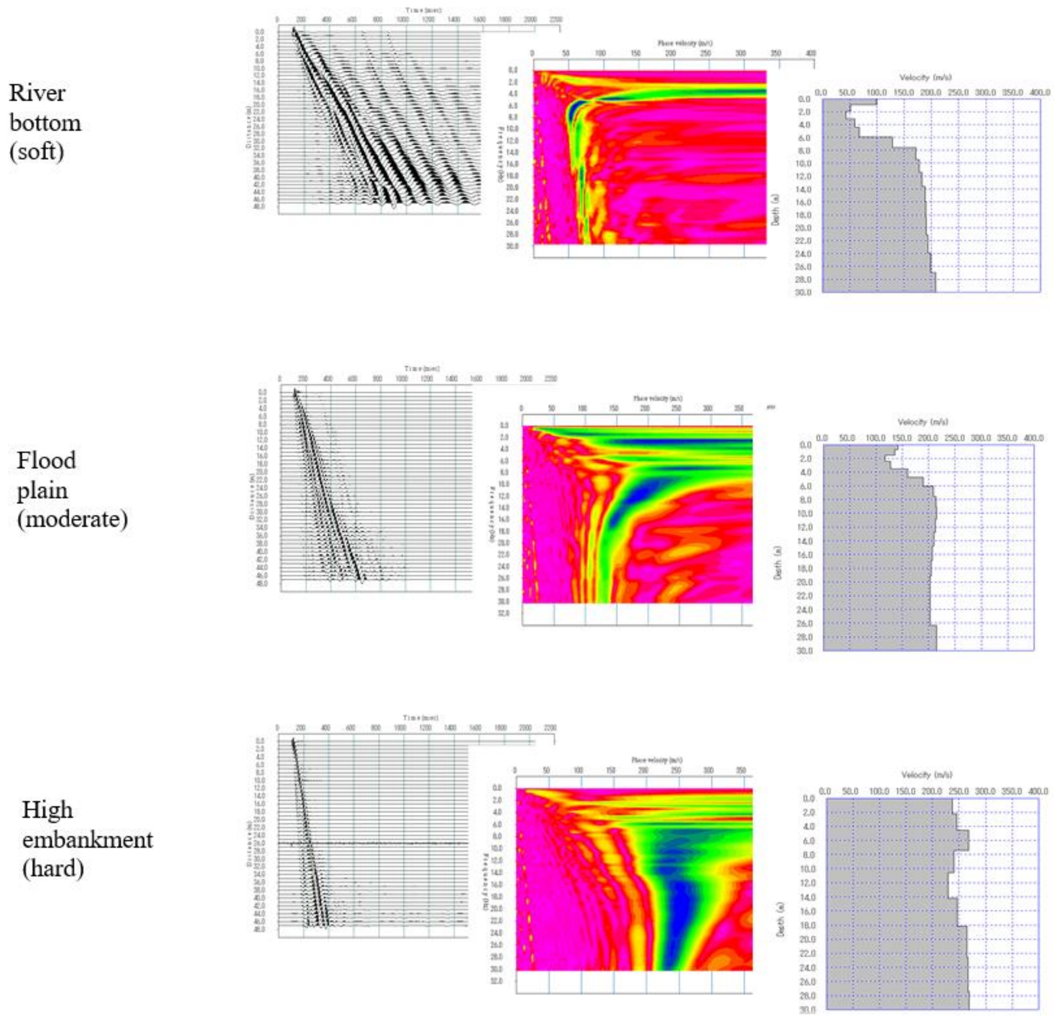


Figure B-19: Comparison of waveform files, phase velocity-frequency plots, and Vs models for different geology types.

Appendix C H/V THEORY

Theory and methods of the Horizontal to Vertical Spectral Ratio Method, or H/V method, are summarized from the USGS publication, *Estimation Of Bedrock Depth Using The Horizontal-To-Vertical (H/V) Ambient-Noise Seismic Method* by Lane et al.

The H/V method uses passive seismic data to evaluate a site's resonant frequency. Three-component ambient seismic data is collected and used to calculate the horizontal-to-vertical spectral ratio. The method has primarily been used for micro zonation studies to characterize earthquake site response, and to estimate depth to bedrock.

The theoretical seismic resonant frequency may be estimated for a two-layer model according to the equation below, where n, V_S, and Z correspond to mode, average shear-wave velocity of the upper layer in m/s, and sediment thickness respectively.

$$fn = (2n + 1)(\frac{Vs}{4Z})$$

Nakamura (1989) demonstrated how the fundamental resonant frequency of a site can be approximated from the H/V spectral ratio. The H/V spectral ratio is calculated as follows.

$$H/V(w) = ((S^2(w)_{NS} + S^2(w)_{EW})/2S^2(w)_V)^{\frac{1}{2}}$$

The method assumes an acoustic impedance contrast equal to or greater than two between the bedrock and overlying sedimentary layer. Case studies have shown the inability of the method to accurately determine depth to bedrock where this assumption does not hold (Lane et al., 2008). The assumption may not hold if gradational cementation, strong heterogeneity, or deep weathering exists.

Please see the referenced article for further discussion on H/V theory.

Appendix D TUTORIALS AND EXAMPLE DATA

Atom: Active and Passive surface wave methods using Atom for AVS30 investigation: Tutorial

Atom: 3D ambient noise tomography using Atom and SeisImager/SW3D: Tutorial

Atom: 2D MASW (Atom data) processing using SeisImager/SW 2D: Tutorial

Atom-3C: 3C SPAC processing using Atom and SeisImager/SW3C: Tutorial

Atom-3C: Horizontal to vertical spectral ratio (H/V) using Atom-3C and SeisImager/SW: Tutorial

Atom-3C: Horizontal to vertical spectral ratio (H/V) using Atom-3C and SeisImager on mobile devices: Tutorial

Atom-3C: 3D and 3C ambient noise tomography using Atom/Atom-3C and SeisImager/SW3D: Tutorial

Geode/Atom: Calculate a dispersion curve from multi-shots in 1D MASW: Tutorial

Geode: 2D SPAC processing using Geode and SeisImager/SW2D: Tutorial

Geode: 2D MASW (Geode data) processing using SeisImager/SW2D: Tutorial

Instant downloads

Atom: 3D passive: Tutorial and example data (108.5 Mb)

Atom: 1D active (2 m spacings) and passive (Triangle 10 50 m): Tutorial and example data (19.7 Mb)

Atom: 1D passive (L-shape 11 75 m): Data only (22.6 Mb)

Atom: 1D passive (Triangle 10 50 m with 3C): Tutorial and example data (9.6 Mb)

Atom: Horizontal to vertical spectral ratio (H/V or HVSR): Tutorial and example data (1.2 Mb)

Atom: 2D Passive: Tutorial and example data (97.7 Mb)

Geode: 1D MASW: Data only (0.2 Mb)

Geode: 2D MASW (variable receiver): Tutorial and example data (5.8 Mb)

Geode: 2D MASW (fixed receiver): Data only (1.4 Mb)

Geode: 1D Passive: Data only (7.8 Mb)

Geode: 1D active and Passive (linear array with 10 ft receiver spacing): Data only (14.6 Mb)

Appendix E SHORT COURSE PRESENTATIONS

Appendix F REFERENCES AND RECOMMENDED READING

Continue.

F.1 Theory and Methods

Aki, K., 1957, Space and time spectra of stationary stochastic waves, with special reference to microtremors: Bulletin of the Earthquake Research Institute, 35, 415-456.

Aki, K. and Richards, P.G. (1980), *Quantitative seismology*, W.H. Freeman and Co.

Building Seismic Safety Council (1997), *Uniform Building Code (UBC).*
Crice, D. (2002), Borehole shear-wave surveys for engineering site investigations, 14 pgs.

Dorman, J. and Ewing, M. (1962), Numerical inversion of seismic surface wave dispersion data and crust-mantle structure in the New York-Pennsylvania area, *Journal of Geophysical Research*, 67: 5227-5241.
Fowler, C.M.R. (1990), *The Solid Earth: an Introduction to Global Geophysics*, Cambridge University Press.

Hayashi, K., 2012, Analysis of surface wave data including higher modes using the Genetic Algorithm, GeoCongress 2012: American Society of Civil Engineers, 2776-2785.

Hayashi, K. and Suzuki, H. (2004), CMP cross-correlation analysis of multi-channel surface wave data, *Exploration Geophysics,* 35: 7-13.

Hayashi, K., Inazaki, T. and Suzuki, H. (2004), Buried channel delineation using a passive surface wave method, *Proceedings of the 7th SEGJ International Symposium*, 395-400.

Hayashi, K. (2003), Data Acquisition and Analysis of Active and Passive Surface Waves, Symposium on the Application of Geophysics to Environmental and Engineering Problems Short Course Notes, 106 pgs.

Heisey, J.S., Stokoe II, K.H., Meyer, A.H. (?), Moduli of pavement systems from spectral analysis of surface waves, *Transportation Research Record*, 852: 22-31.

Imai, T. and Tonouchi, K. (1982), Correlation of N-value with S-wave velocity and shear modulus, *Proceedings of the Second European Symposium on Penetration Testing*, Amsterdam, 67-72.

International Code Council (2000, 2003), *International Building Code (IBC).*

Kitsunezaki, C., Goto, N., Kobayashi, Y., Ikawa, T., Horike, M., Saito, T., Kurota, T., Yamane, K., and Okuzumi, K. (1990), Estimation of P- and S-wave velocities in deep soil deposits for evaluating ground vibrations in earthquakes, *SIZEN-SAIGAI-KAGAKU*, 9(3): 1-17 (in Japanese).
Lay, T. and Wallace, T.C. (1995), *Modern Global Seismology*, Academic Press.

Lane, J. W., (2008), Estimation of bedrock depth using the horizontal-to-vertical (H/V) ambient-noise seismic method, *Symposium on the Application of Geophysics to Engineering and Environmental Problems*, Society of Exploration Geophysicists conference paper, pp 490-502.

Louie, J.N. (2001), Faster, better: shear-wave velocity to 100 meters depth from refraction microtremor arrays, *Bulletin of the Seismological Society of America*, 91(2): 347-364.

Ludwig, W.J., Nafe, J.E. and Drake, C.L. (1970), Seismic Refraction, *The Sea*, 4: 53-84.

Mari, J.L. (1984), Estimation of static correction for shear-wave profiling using the dispersion properties of Love waves, *Geophysics*, 49: 1169-1179.

Marosi, K.T. and Hiltunen, D.R. (2004), Characterization of spectral analysis of surface waves and shear-wave velocity measurement uncertainty, *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 130(10): 1034-1041.

Martin, A.J. and Diehl, J.G. (2004), Practical experience using a simplified procedure to measure average shear-wave velocity to a depth of 30 m (V_S30), 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada.

Mayne, P.W. and Rix, G.J. (1995), Correlations between shear-wave velocity and cone tip resistance in natural clays, *Soils and Foundations*, 35(2): 107-110.

Menzies, B. (?), Near-surface site characterization by ground stiffness profiling using surface wave geophysics, unpublished, 14 pgs.

Nazarian, S. (1989), *Applicability of spectral-analysis-of-surface waves method in determining moduli of pavements*, Symposium on the State of the Art of Pavement Response Monitoring Systems for Roads and Airfields, 16 pgs.

Nazarian, S., Stokoe II, K.H., and Hudson, W.R. (?), Use of spectral analysis of surface waves method for determination of moduli and thicknesses of pavement systems, *Transportation Research Record*, 930: 38-45.

Okada, H. (2003), *The Microtremor Survey Method*, Geophysical Monograph Series No. 12, The Society of Exploration Geophysicists, 135 pgs.

Park, C.B., Miller, R.D., and Miura, H. (?), *Optimum field parameters of an MASW survey*, unpublished, 6 pgs.

Park, C.B., Miller, R.D. and Xia, J. (1999), Multi-channel analysis of surface waves, *Geophysics*, 64(3): 800-808.

Park, C. B., Miller, R. D., and Xia, J., 1999, Multimodal analysis of high frequency surface waves, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems '99, 115-121.

Reynolds, J.M. (1997), An Introduction to Applied and Environmental Geophysics, John Wiley and Sons.

Roberts, J.C. and Asten, J. (2004), Resolving a velocity inversion at the geotechnical scale using the microtremor (passive seismic) survey method, *Exploration Geophysics*, 35: 14-18.

Schneider, J.A., Hoyos Jr., L., Mayne, P.W., Macari, E.J., Rix, G.J. (1999), Field and laboratory measurement of dynamic shear modulus of Piedmont residual soils, *Behavioral Characteristics of Residual Soils*, GSP 92, ASCE, Reston, VA, 12-25.

Sheriff, R.E. (1994), *Encyclopedic Dictionary of Exploration Geophysics*, 3rd ed., Society of Exploration Geophysicists.

Sheriff, R.E. and Geldart, L.P. (1995), *Exploration Seismology*, Cambridge University Press.

Suzuki, H., and Yamanaka H., 2010, Joint inversion using earthquake ground motion records and microtremor survey data to S-wave profile of deep sedimentary layers, BUTSURI-TANSA 2010, 65, 215-227 (in Japanese).

Underwood, D.H. and Hayashi, K. (2005), Seismic Surface Wave Surveying With Geometrics, Inc. Seismographs and SeisImager/SW Software, *Geometrics, Inc. Short Course Notes*, San Jose, California and London, United Kingdom, 83 pgs.

Xia, J., Chen, C., Tian, G., Miller, R.D., and Ivanov, J. (2005), Resolution of high frequency Rayleigh-wave data, *Journal of Engineering and Environmental Geophysics, Special Issue: Seismic Surface Waves*, 10(2): 99-110.

Xia, J., Miller, R.D. and Park, C.B. (1999), Estimation of near-surface shear-wave velocity by inversion of Rayleigh waves, *Geophysics*, 64(3): 691-700.

Yamanaka, H. and Ishida, J., 1995, Phase velocity inversion using genetic algorithms, Journal of Structural and Construction Engineering 468, 9-17 (in Japanese).

F.2 Land Streamers

Dolena, T.M., Speece, M.A., Link, C.A., Miller, P.F., and Duaime, T.E. (2005), A land streamer aided, three-dimensional (3-D) seismic reflection survey, Belt, Montana: *Proceedings of the Symposium on the Applications of Geophysics to Engineering and Environmental Problems*, 971-978.

Huggins, R. (2004), A report on land streamers: the last geophone you will ever plant, *Near-Surface Views*, Newsletter of the Near-Surface Geophysics Section of the SEG, First Quarter, 11(1): 3-4.

Inazaki, T. (1999), Land streamer: a new system for high-resolution S-wave shallow reflection surveys, Geological Survey of Japan publication, 10 pgs.

Jensen, J.F., Ringgaard, J., Skjellerup, P., Vangkilde-Pedersen, T. (?), *Pulled array seismic (PAS) – a new method for shallow, high-resolution reflection seismic data acquisition*, Department of Geophysics, RAMBOLL, Denmark, 4 pgs.

Miller, C., Link, C., and Speece, M. (2003), Modified land streamer configuration for shallow seismic data acquisition, *Proceedings of the Symposium on the Application of Geophysics to Environmental and Engineering Problems*, 857-865.

Miller, C., Allen, A., Speece, M., El-Werr, A., and Link, C. (2005), Land streamer aided geophysical studies at Saqqara, Egypt, *Journal of Environmental and Engineering Geophysics*, 10(4): 371-380.

Pugin, A.J.M., Larson, T.H., and Sargent, S. (2004), 3.5 Km/day of high-resolution seismic reflection data using a land streamer, *Proceedings of the Symposium on the Application of Geophysics to Environmental and Engineering Problems*, 1380-1388.

van de Veen, M. and Green, A.G. (1998), Land streamer for shallow data acquisition: evaluation of gimbal-mounted geophones, *Geophysics*, 63: 1408-1413.

van der Veen, M. Spitzer, R., Green, A.G., and Wild, P. (2001), Design and application of a towed land-streamer for cost-effective 2D and pseudo-3D shallow seismic data acquisition, *Geophysics*, 66: 482-500.

van der Veen, M., Wild, P., Spitzer, R., and Green, A.G. (1999), Design characteristics of a seismic land streamer for shallow data acquisition, *Extended Abstracts of the European Association of Geoscientists and Engineers (EAGE)*, 40-41.

Arai, H., & Tokimatsu, K. (2004). S-wave velocity profiling by inversion of microtremor H/V spectrum. *Bulletin of the Seismological Society of America*, 94(1), 53–63.

Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Quarterly Report of Railway Technical Research*, 30(1), 25–33.

Molnar, S., Sirohey, A., Assaf, J. *et al.* A review of the microtremor horizontal-to-vertical spectral ratio (MHVSR) method. *Journal of Seismology* 26, 653–685 (2022).