SeisImager/SW^{TM} Manual

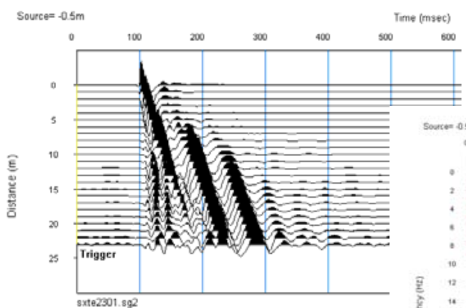
Windows Software for Analysis of Surface Waves

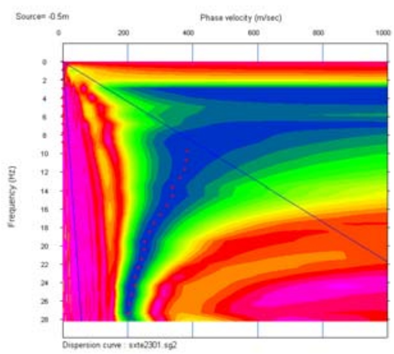
Pickwin^{TM} v. 4.0.1.5
WaveEq^{TM} v. 2.3.0.8
GeoPlot ^{TM} v. 8.4.1.3

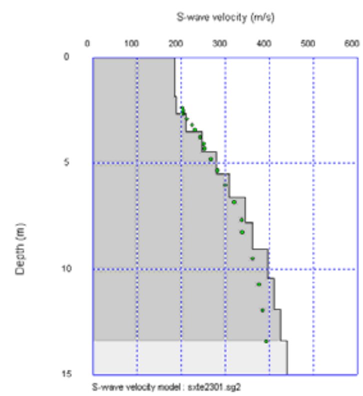
Manual v. 3.0

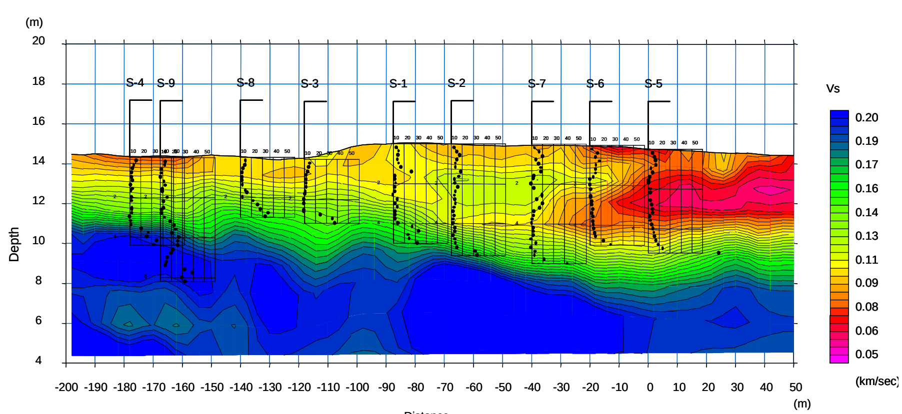
Including explanation of surface wave data acquisition using
Geometrics Seismodule Controller Software for
ES-3000, SmartSeis ST, Geode, and StrataVisor NZ seismographs

October 2009









dhu

Table of Contents

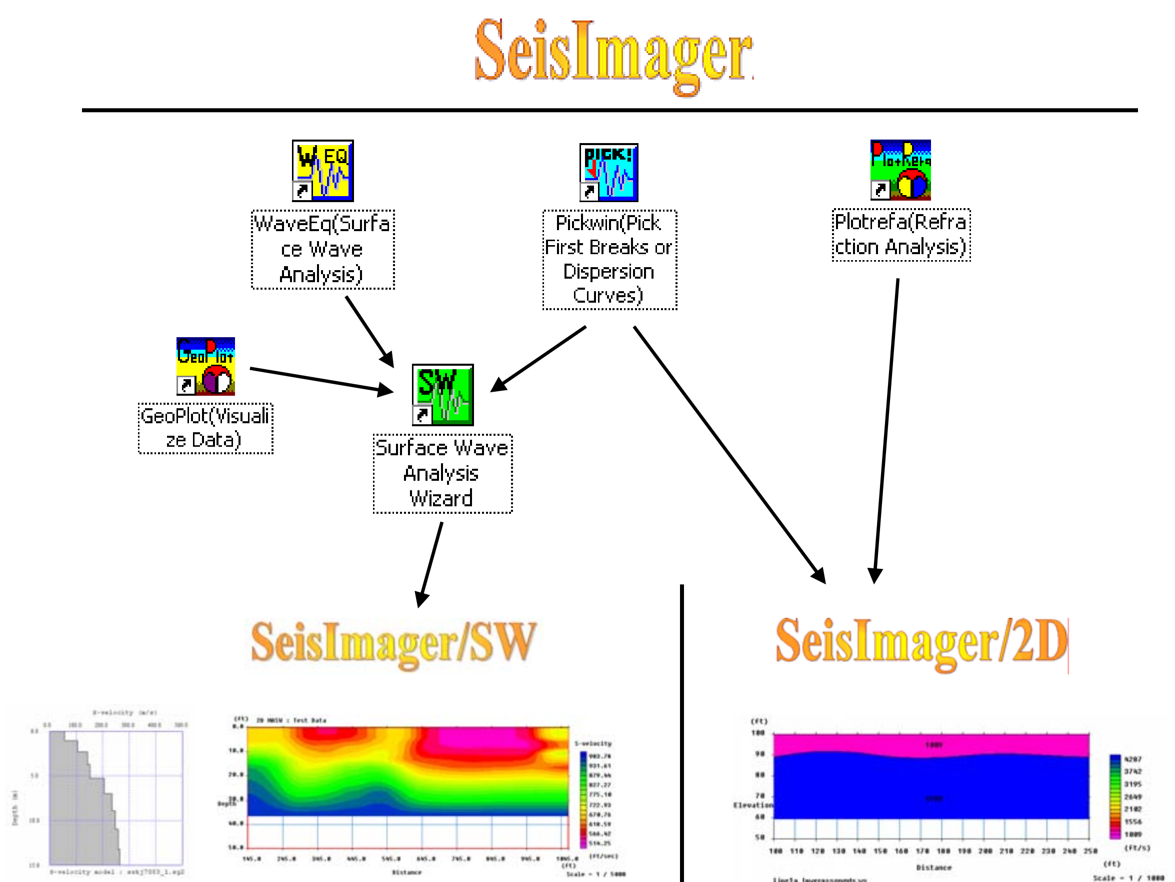
List of Figures

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 four modules for surface wave and refraction data analysis. The individual modules are Pickwin™, Plotrefa™, WaveEq™, 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.



1D curve　　2D cross-section　　2D cross-section

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 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. GeoPlot will eventually be available as a separate module; at that time, a full manual will also be released.

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, Sections 4, 5, 6, and 7 describe data processing, and Section 8 provides data examples. Some theory is touched on, 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 principals of seismology and mathematics in order to understand the principals behind the analysis techniques employed by the software. See Section 9 for a recommended reading list on surface wave theory and techniques.

Although the manual can be printed, it was designed as an online resource. It will be updated on a semi-regular basis, and a current version will always be available by contacting us at seismicsales@geometrics.com or support@geometrics.com. 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.

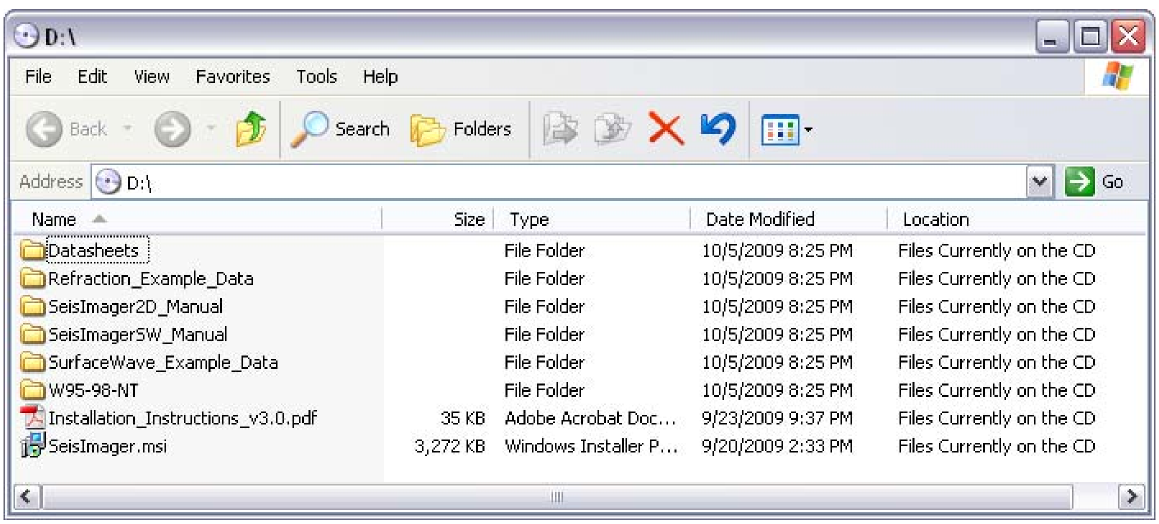
Note: *All screens in this manual were captured in Windows XP Home or Professional Edition. If you are running a different version of Windows, some dialog boxes may look slightly different than they appear here.*

2 – Installing the Software

The SeisImager software CD is supplied (1) for trial evaluation of the programs, (2) for purchase, rental, or upgrade of one of the programs, or (3) with purchase of an ES-3000, SmartSeis ST, Geode, or StrataVisor NZ seismograph, which all include the Lite version of SeisImager/2D. The single CD contains all programs and all documentation. Occasionally, there will be a software release in between CD releases. In this situation, the CD will be labeled with a notice to refer to the SeisImager website to download the latest version.

SeisImager is recommended for Windows XP Home or Professional but is compatible with all versions of Windows up to Vista. Note that you must have Administrator rights to install the software. After installation by an Administrator, users with lower level privileges can use the software.

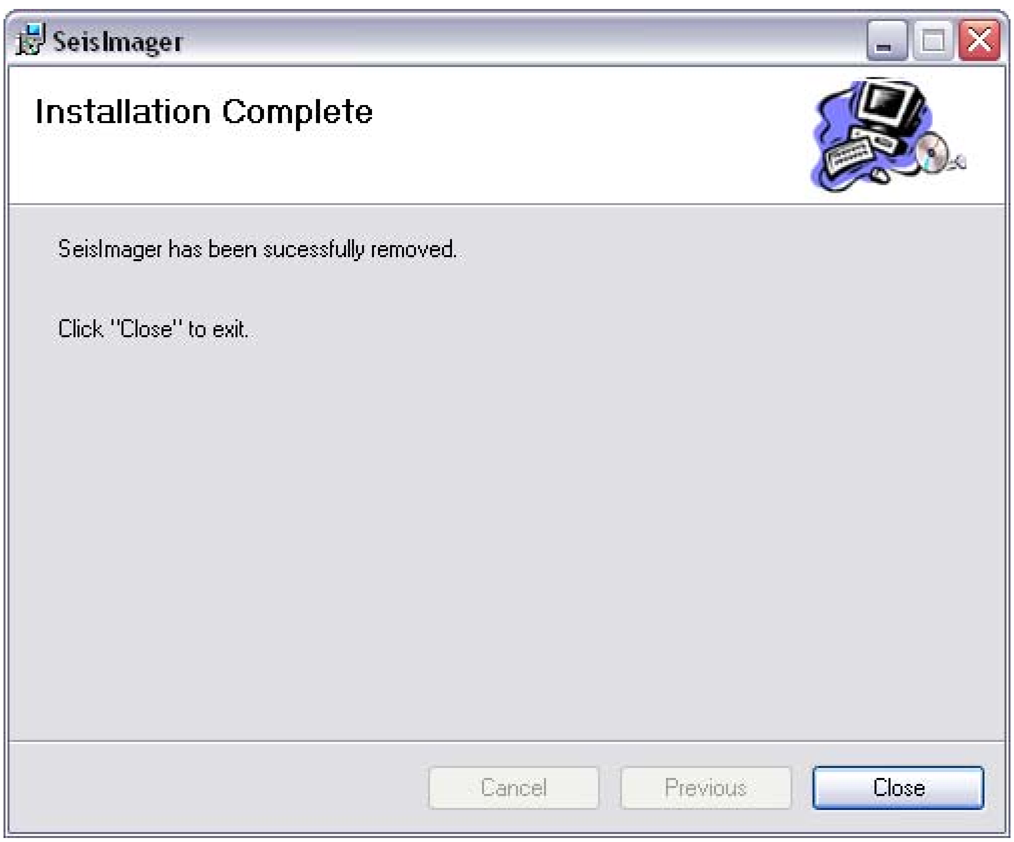
1. To install the software, insert the SeisImager CD into the CD drive. The contents of the CD will be listed as shown below.



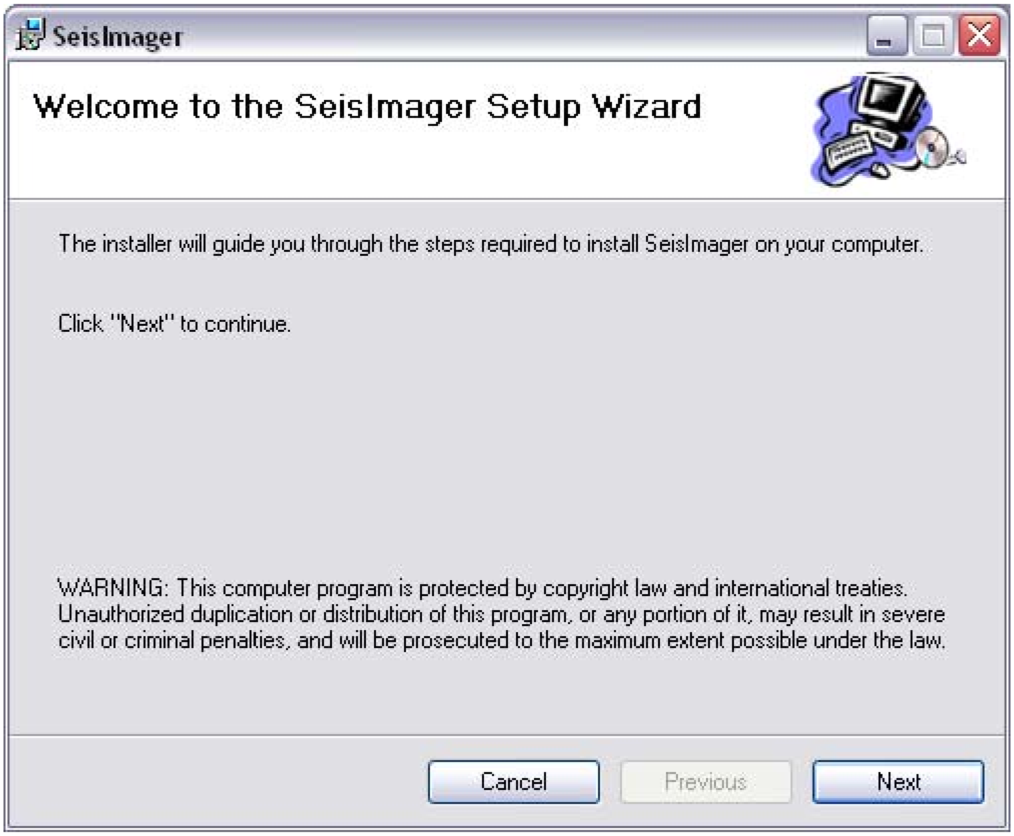
2. Double-click on the file named SeisImager.msi to install the software. The Welcome to the SeisImager Setup Wizard window will appear as follows.

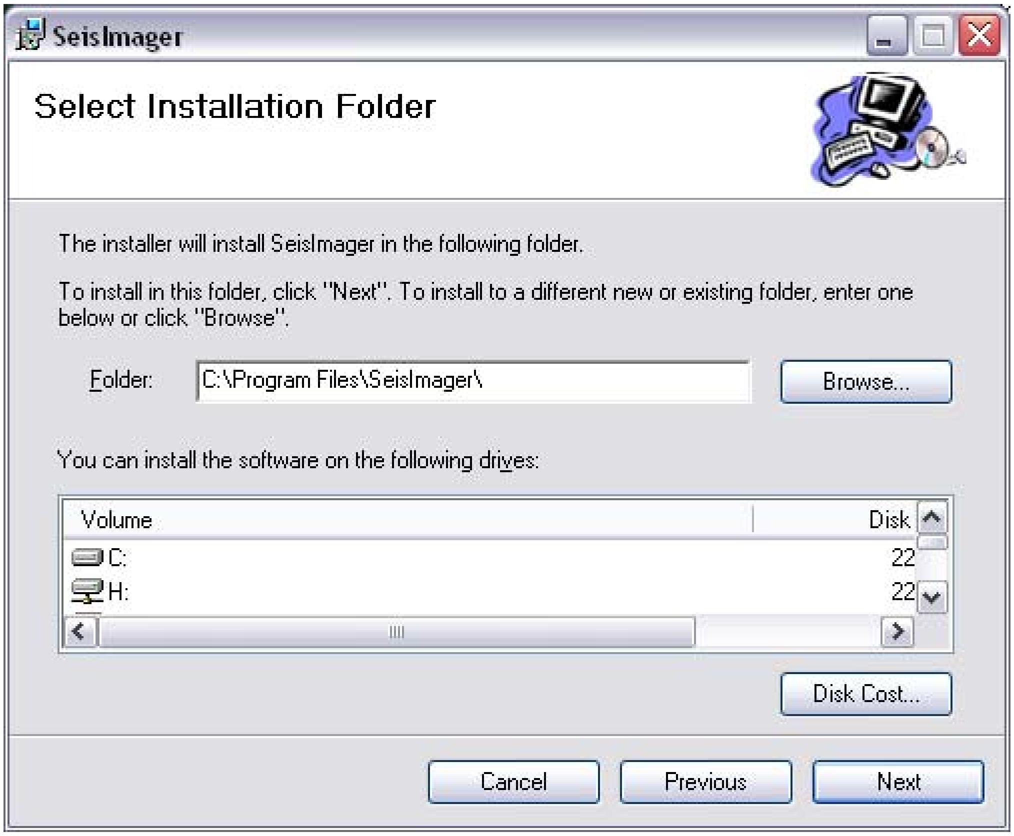
   a. **If you are presented with the option to *Repair SeisImager* or *Remove SeisImager* as shown below, the installer has detected an older version. Select *Remove SeisImager* and click on *Finish*, then *Close* after the uninstall process is complete.** Double-click again on the file SeisImager.msi to install the new version as described in Step 2b.

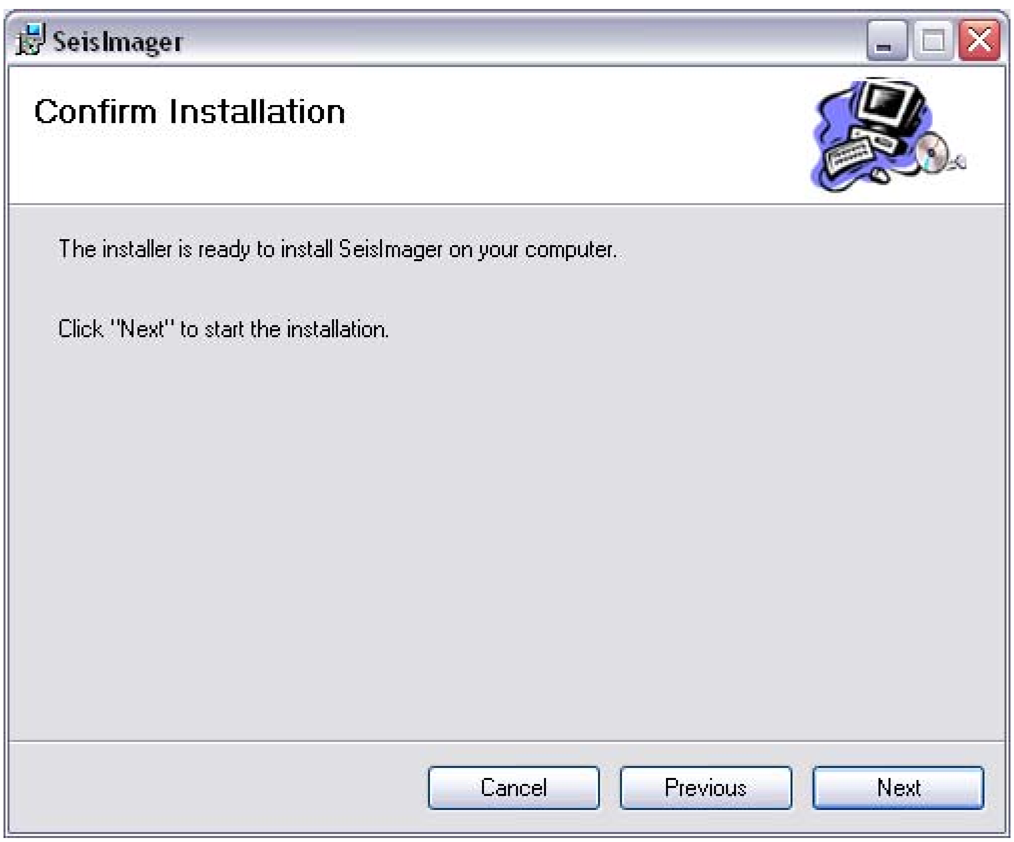

SeisImager
Welcome to the SeisImager Setup Wizard
Select whether you want to repair or remove SeisImager.
Repair SeisImager
Remove SeisImager
WARNING: This computer program is protected by copyright law and international treaties. Unauthorized duplication or distribution of this program, or any portion of it, may result in severe civil or criminal penalties, and will be prosecuted to the maximum extent possible under the law.
Cancel
Previous
Finish

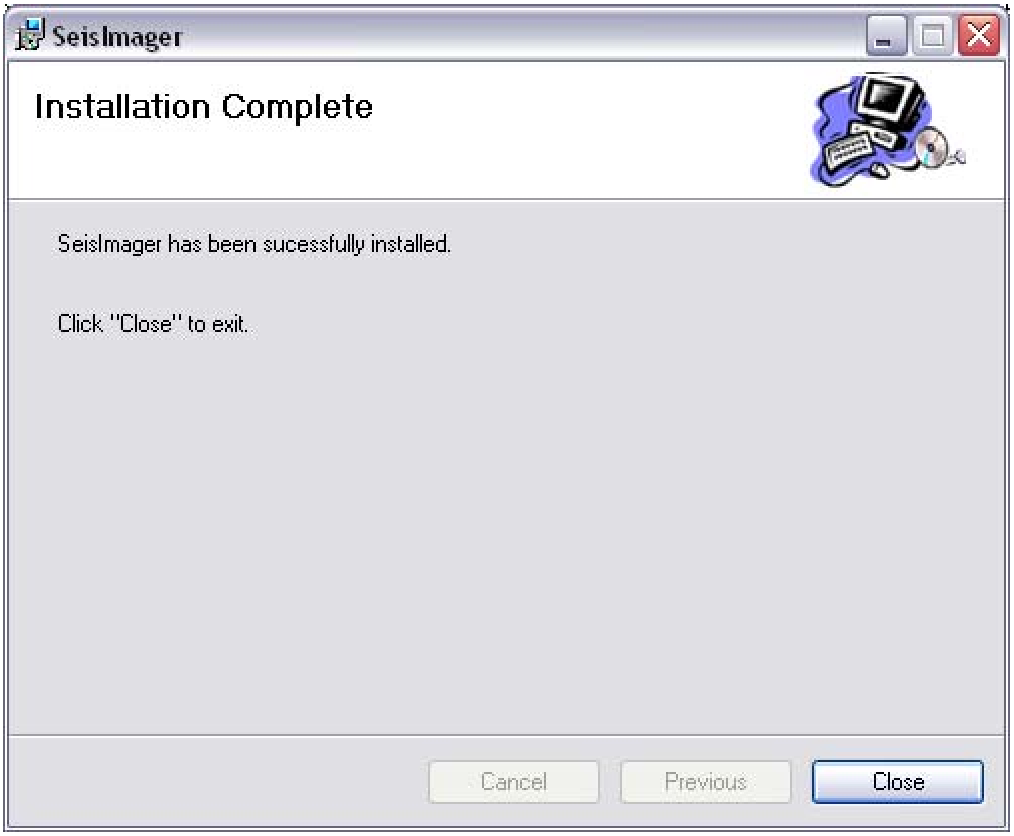

SeisImager
Installation Complete
SeisImager has been sucessfully removed.
Click "Close" to exit.
Cancel
Previous
Close

b. **If an older version is not detected**, you will be presented with the installer as shown below. Click on *Next*, indicate the directory for installation (the default directory is recommended), click on *Next*, *Next*, and *Close*. It is not necessary to reboot the PC after completing the installation.




SeisImager
Select Installation Folder
The installer will install SeisImager in the following folder.
To install in this folder, click "Next". To install to a different new or existing folder, enter one below or click "Browse".
Folder:
C:\Program Files\SeisImager\
Browse...
You can install the software on the following drives:
Volume
Disk
C:
22
H:
22
Disk Cost...
Cancel
Previous
Next

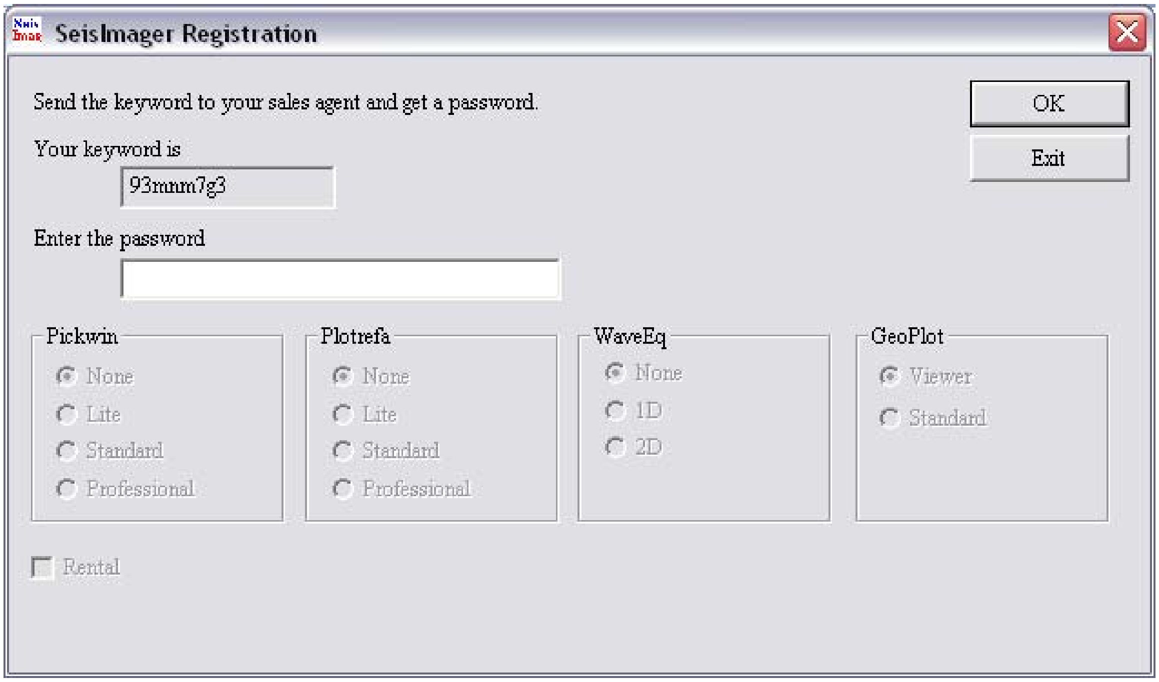

SeisImager
Confirm Installation
The installer is ready to install SeisImager on your computer.
Click "Next" to start the installation.
Cancel
Previous
Next



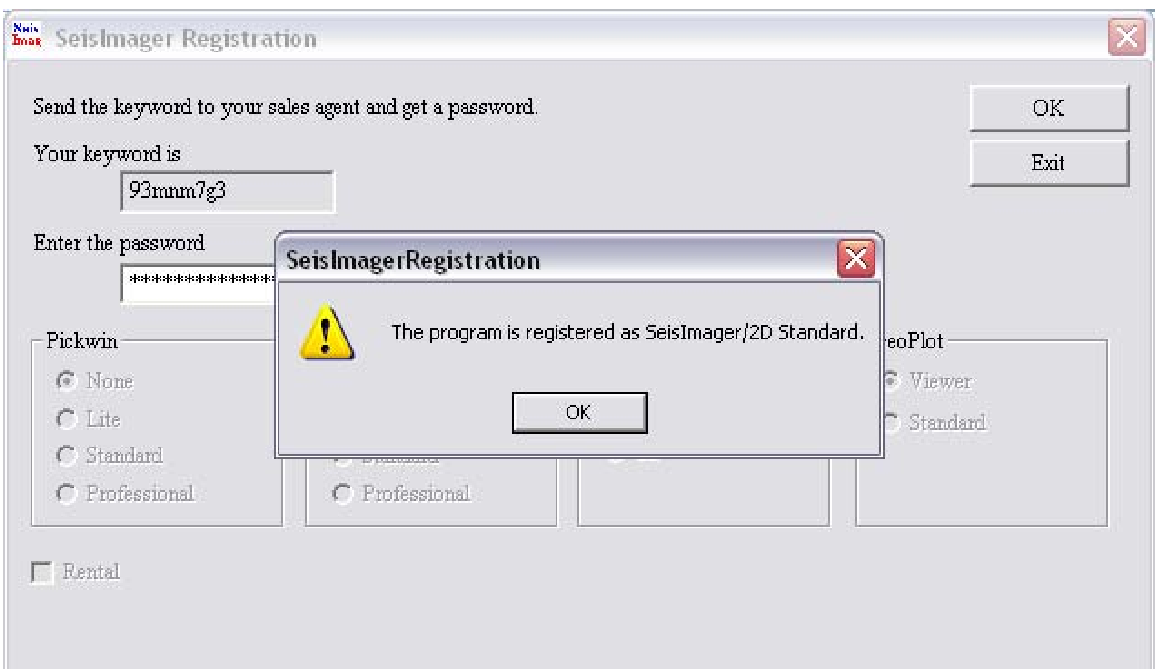
3. To copy the SeisImager manuals to your hard drive (~125 MB), select the folders SeisImager2D_Manual and SeisImagerSW_Manual on the CD and copy them to your hard drive in the desired location. Note that the SeisImager2D_Manual folder contains .avi video clips that must reside in the same location as the files SeisImager2D_Manual_vX.X.pdf and SeisImager2D_Examples_vX.X.pdf (where X.X is the current version).

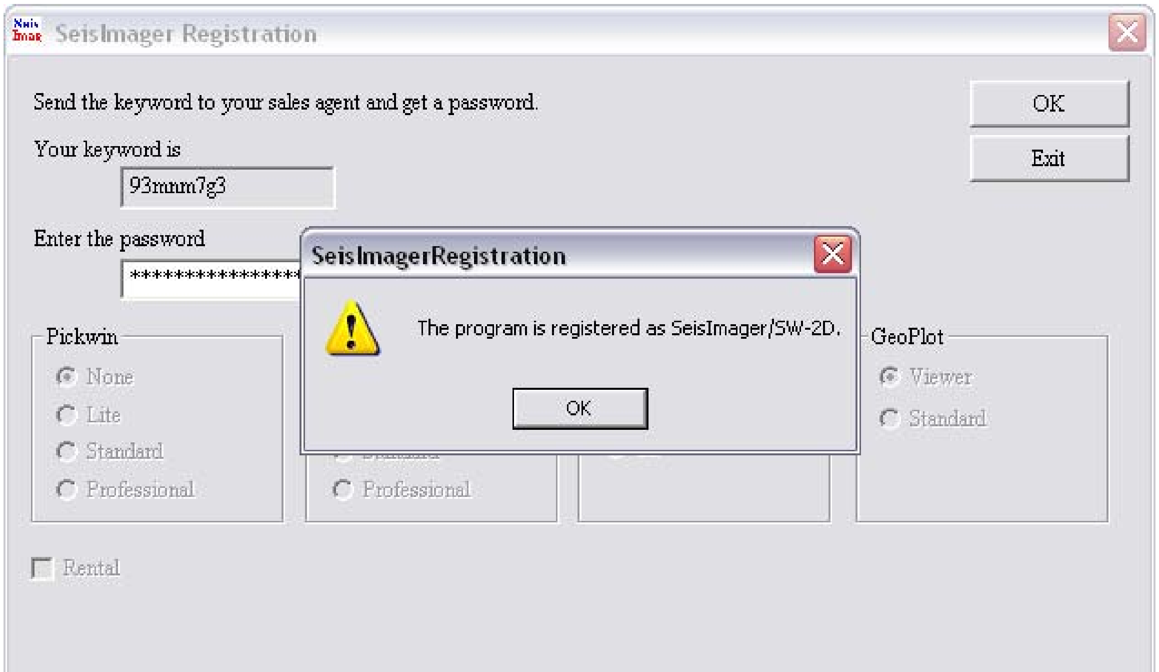
You will need Adobe's freeware program Acrobat Reader to view the manual files. If you need this program, go to the Adobe website to download the latest version compatible with your operating system.

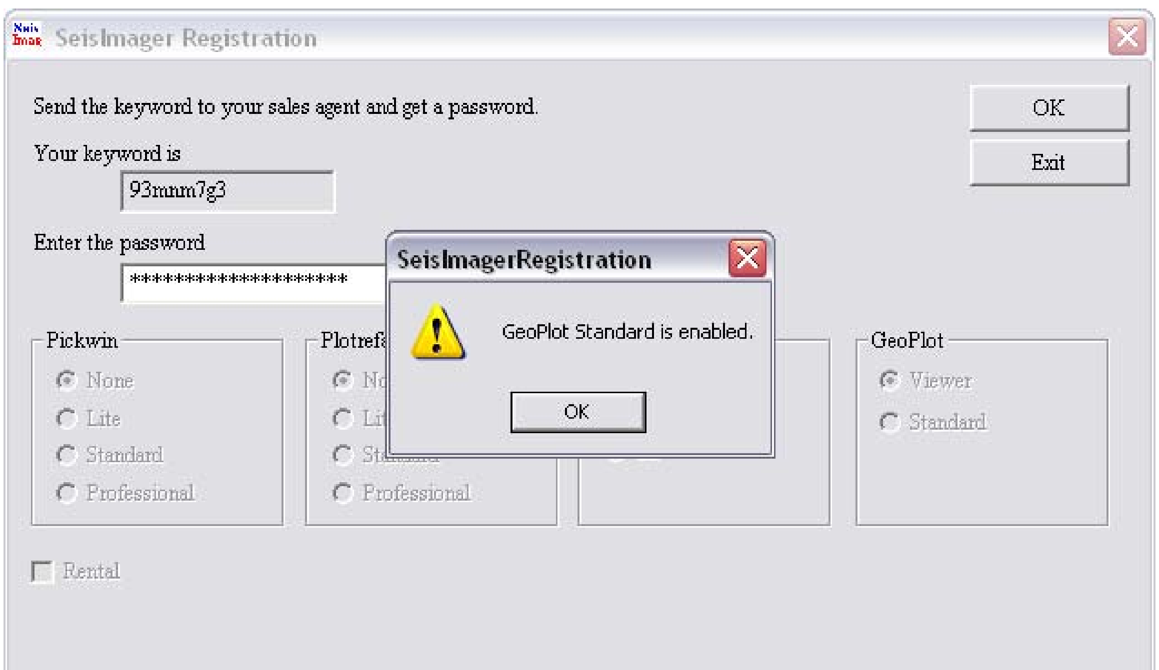
4. To register the software, go to the *Start* menu, under *All Programs*, *SeisImager* to find the SeisImager Registration SeisImager Registration program as shown below. **If you are using the software on a trial basis in demonstration mode, skip to Step 5.** Open the register and email the keyword shown 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 password to enable the version of the software you have purchased. Once received, enter the password into the password field and click *OK*.



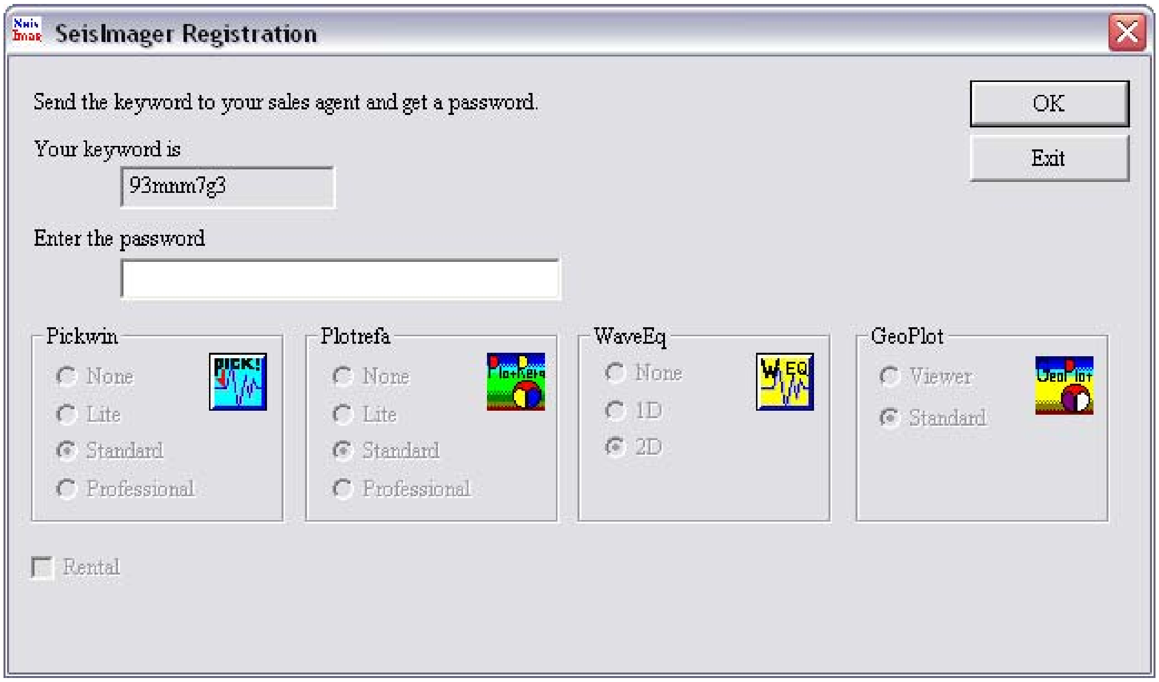
The programs enabled by the password will be reported in a series of messages. For example, as shown below, for purchase of SeisImager/2D Standard and SeisImager/SW-2D, the register reports that SeisImager/2D Standard, SeisImager/SW-2D, and GeoPlot Standard are registered. Click *OK* to accept each message.





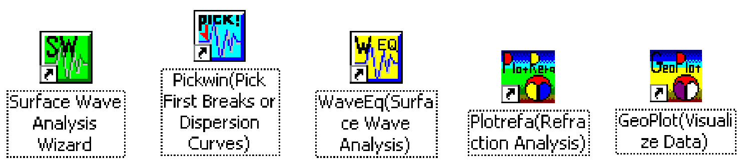


After these messages have appeared, the register will also reflect the programs that have been registered, as shown below.



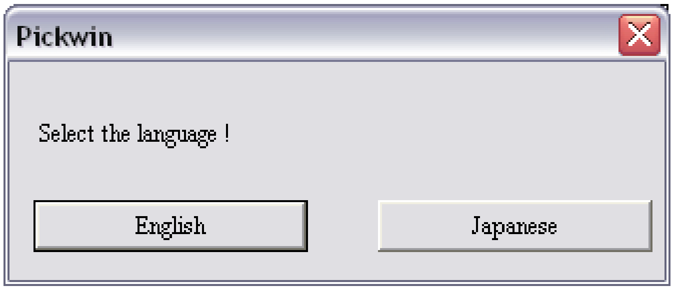
Typically, installing an upgrade of the software does not require re-registration, but if you are upgrading from a version older than April 2007, you will need to re-register.

5. Once installed, the program modules can be opened directly through the desktop icons shown below or through the links in the *SeisImager Start* menu folder.



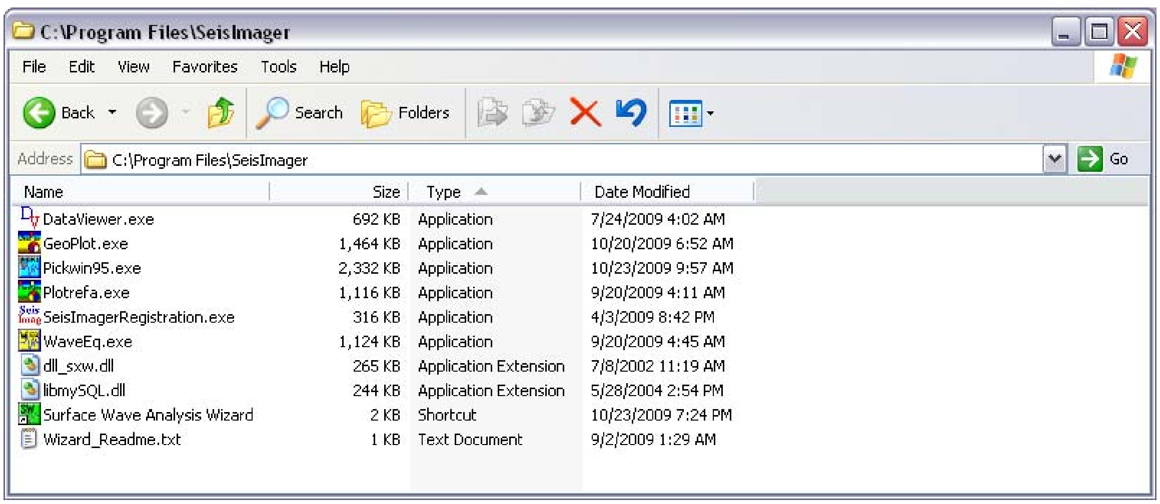
SeisImager/2D consists of the Pickwin and Plotrefa modules. SeisImager/SW-1D consists of the Pickwin and WaveEq modules. SeisImager/SW-2D consists of the Pickwin, WaveEq, and GeoPlot modules. The Surface Wave Analysis Wizard is not a separate module but automatically calls on specific functions from Pickwin, WaveEq, and GeoPlot to walk you through the analysis process. <u>All of the icons will be shown regardless of which program(s) have been purchased or will be used</u>.

To begin using the software, double-click the Pickwin module icon. If you have installed for the first time or upgraded from a version older than April 2007, a prompt will ask you to set the language as shown below. Choose *English*.

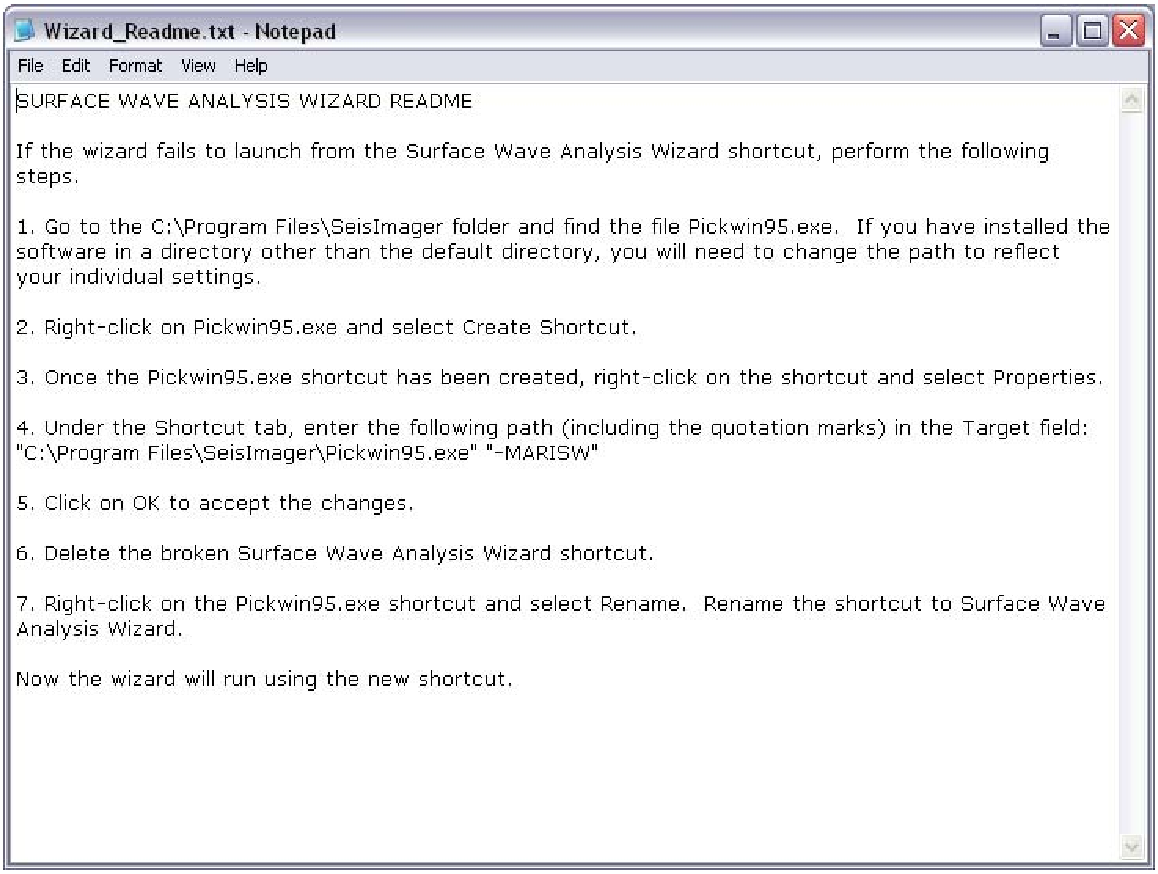


For registered installations, upon selection of the language, the module opens and is ready for use. As well, the other registered modules are ready for use. For unregistered installations running in demonstration mode, proceed to Step 6.

If the wizard icon is missing or when double-clicked does not open Pickwin, a new shortcut will need to be manually created. In the software installation directory there is a file called *Wizard_Readme.txt* as shown below.



Open the file for instructions on how to create a new shortcut for the wizard.



Wizard_Readme.txt - Notepad

File Edit Format View Help

SURFACE WAVE ANALYSIS WIZARD README

If the wizard fails to launch from the Surface Wave Analysis Wizard shortcut, perform the following steps.

1. Go to the C:\Program Files\SeisImager folder and find the file Pickwin95.exe. If you have installed the software in a directory other than the default directory, you will need to change the path to reflect your individual settings.

2. Right-click on Pickwin95.exe and select Create Shortcut.

3. Once the Pickwin95.exe shortcut has been created, right-click on the shortcut and select Properties.

4. Under the Shortcut tab, enter the following path (including the quotation marks) in the Target field:
"C:\Program Files\SeisImager\Pickwin95.exe" "-MARISW"

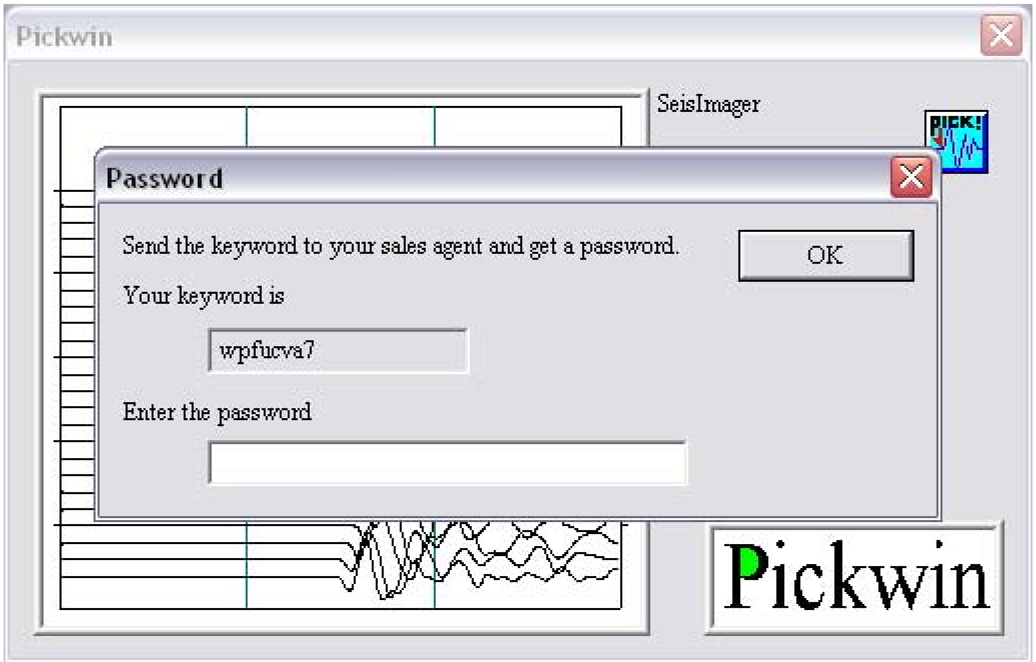
5. Click on OK to accept the changes.

6. Delete the broken Surface Wave Analysis Wizard shortcut.

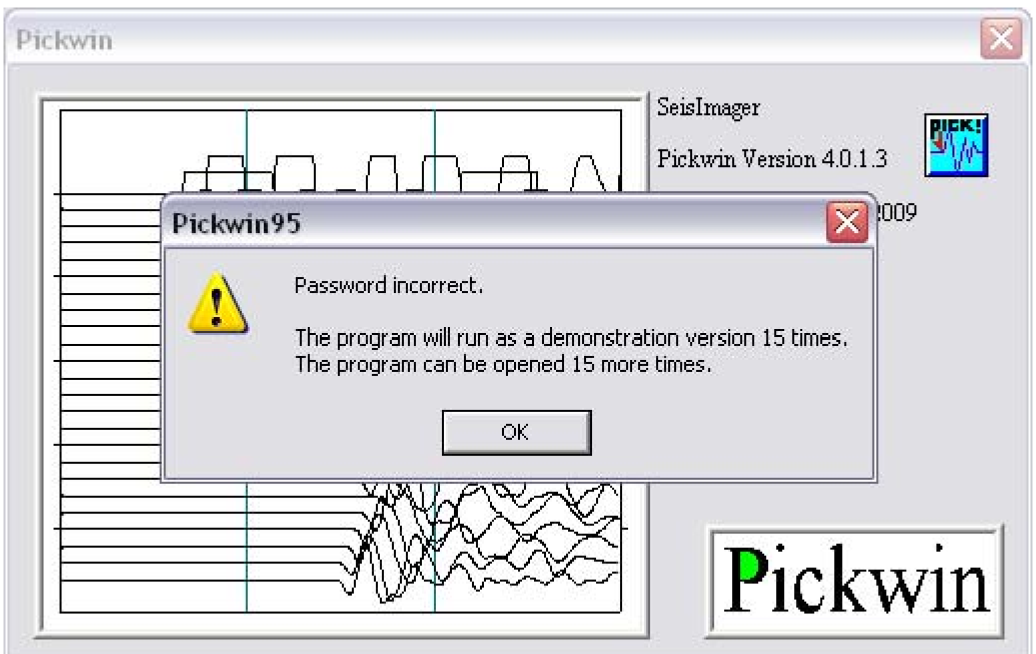
7. Right-click on the Pickwin95.exe shortcut and select Rename. Rename the shortcut to Surface Wave Analysis Wizard.

Now the wizard will run using the new shortcut.

6. If you are using the software in demonstration mode, after selecting the language you will be presented with the registration dialog box as shown below. Leave the password field empty and click *OK*.



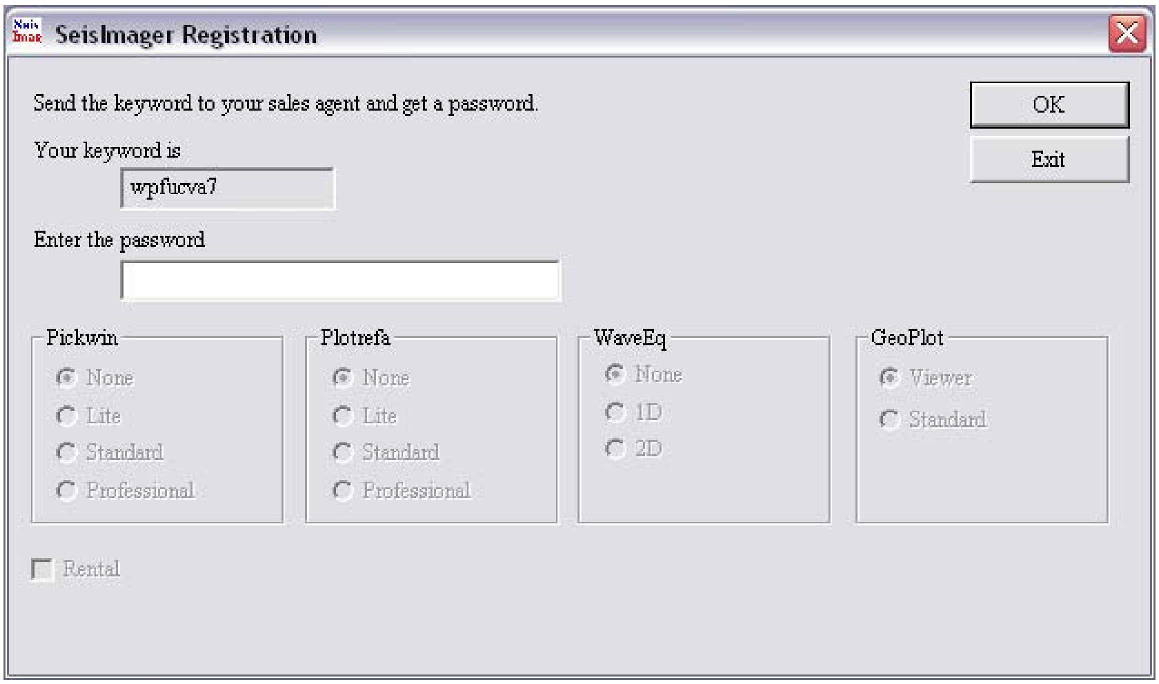
Detection of no password and the number of available run-times will be reported as shown below. Click *OK*.



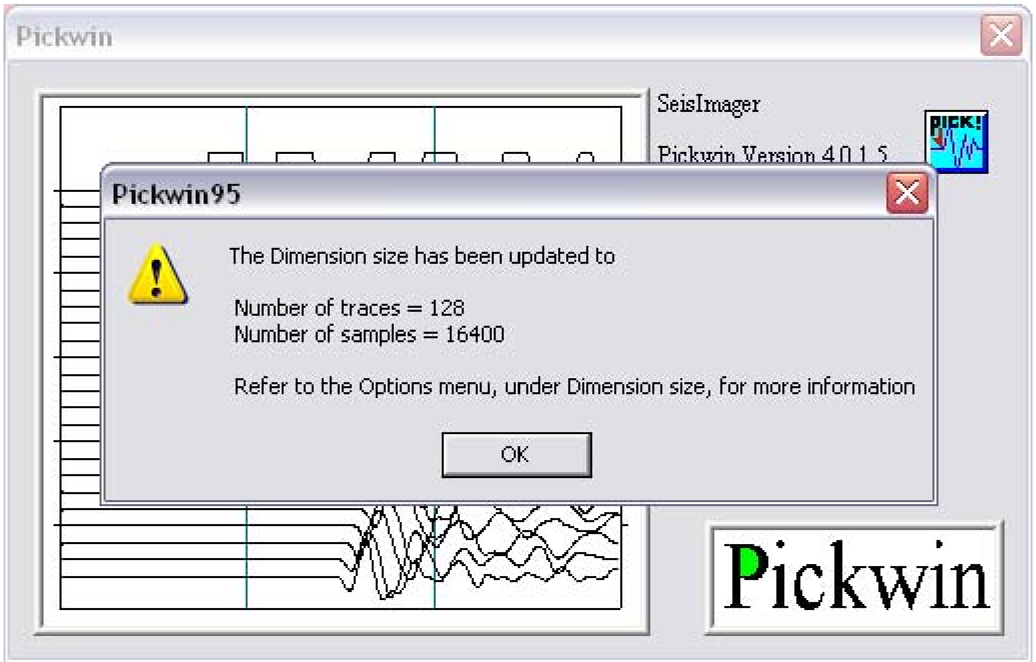
After running the software in demonstration mode, if you later purchase the software, refer to Step 7 on how to enter your registration password.

7. To enter your password after running the software in demonstration mode, go to the *Start* menu, under *All Programs*, *SeisImager* to find the SeisImager Registration

program as shown below. Open the register and email the keyword shown 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 password to enable the version of the software you have purchased. Once received, enter the password into the password field and click *OK*.



Once the software is registered (refer to Step 4 for a full description of the process), the data input dimensions of the demonstration version will be updated to reflect the limits of the program purchased. Click *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 of SeisImager/2D, Lite or otherwise, but would like to order a copy, please contact us at seismicsales@geometrics.com or support@geometrics.com.

A general recommendation when using SeisImager/SW 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 data processing.

If functions are selected in an illogical order for any given data processing flow, the program may crash and the standard Windows error message will appear. With each release, more SeisImager messages are being incorporated to communicate to the user that the functions selected do not make sense and to allow for more elegant recoveries.

Regarding making report graphics and documenting your data processing, it is handy to have a screen capture program such as HyperSnap from Hyperionics (www.hyperionics.com). Bitmap screen captures can be quickly and easily made at the desired stages of processing and saved for import to Microsoft Office or other programs.

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.

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 phase velocity of surface waves. Surface wave dispersion can be significant in the presence of velocity layering, which is common in the near-surface environment. There are other types of surface waves, or waves that travel along a surface, but 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 imparted into the ground. This is in contrast to “passive source” surveying, also called “microtremor surveying”, or sometimes referred to as “refraction microtremor” (or the commercial term “ReMi”) surveying, where there is no time break and motion from ambient 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 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 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 two. 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, because 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 one-half-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 need to 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 were only doing an active source survey and would not have passive data to resolve greater depths, it is recommended that the spread length equal 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.

Table 1. 1D MASW Acquisition Parameters

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 milliseconds (ms)
Record length	1 to 2 seconds (s), long enough to enclose the surface wave train
Stacking	As needed to improve data quality, wait for quiet times to shoot

*also refer to preceding discussion in text

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 fairly 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), 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 1). 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 geophone is the *spread length* or *total offset* 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.

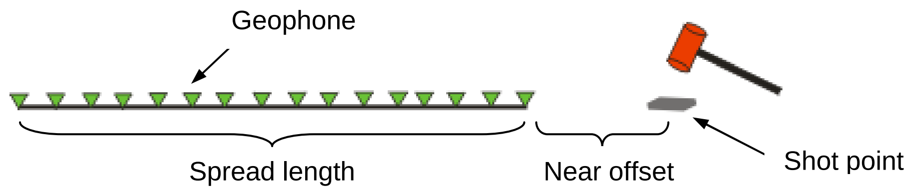
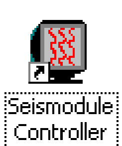


Figure 1. 1D MASW survey spread configuration.

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

The data acquisition set-up 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 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 the 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.

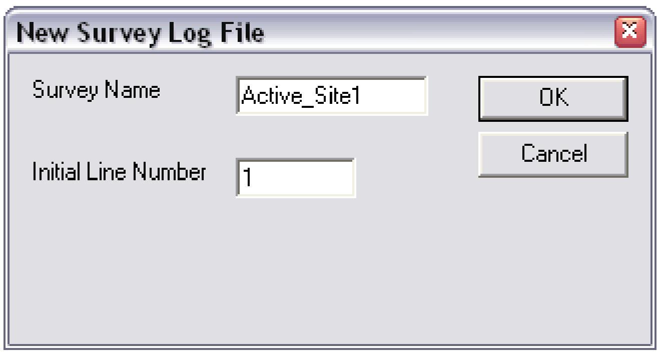
The first step is to install SCS. Once this is done, launch SCS from the icon on your desktop, or from the *Start* menu under *All Programs, Geometrics, Seismodule Controller*.



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.

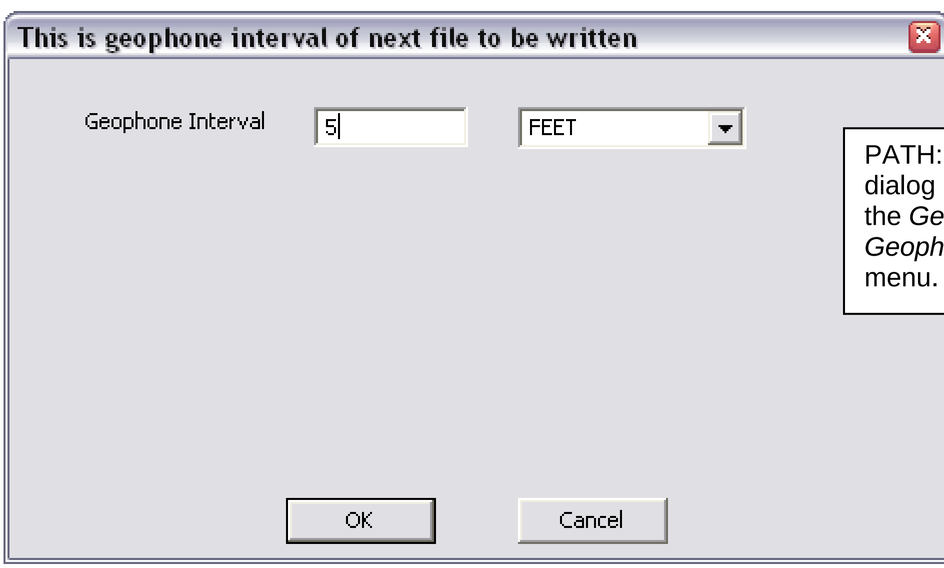
3.1.2.1 1D MASW Survey SCS Set-up

First, 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 at a later time for reference. Click *OK* when done.



PATH: Access dialog box through the *Survey* menu.

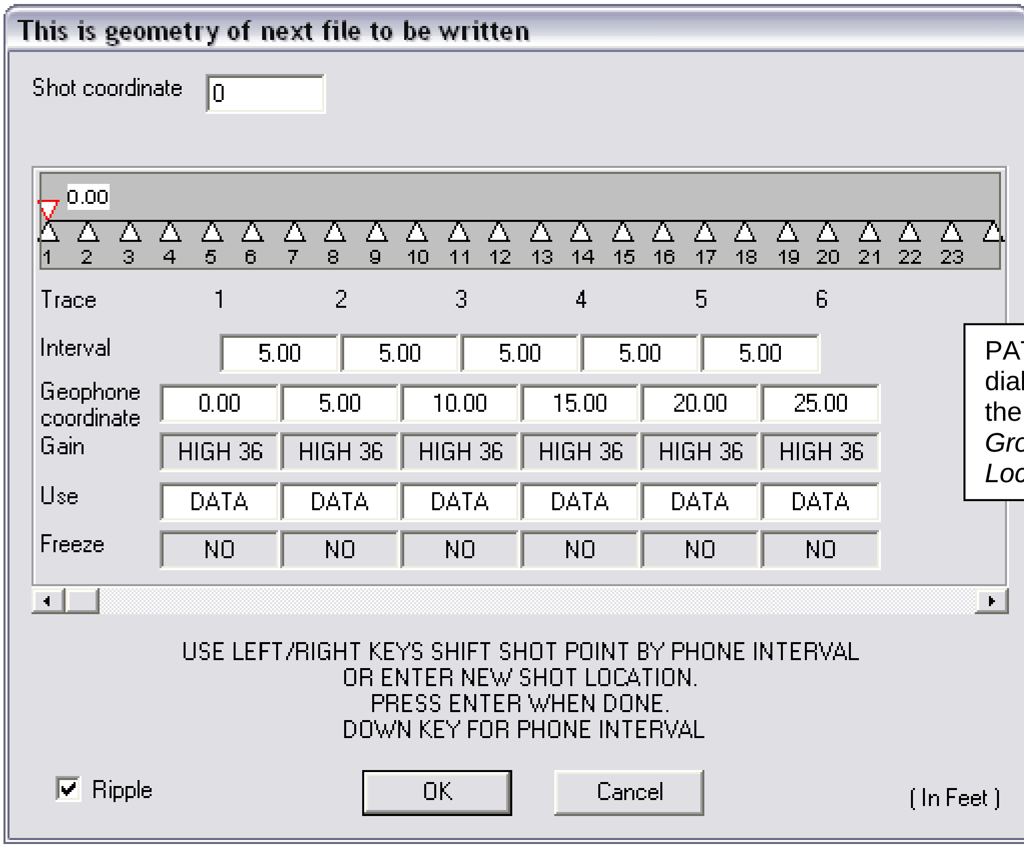
Next, set the *Geophone Interval*, or distance between each geophone in the line, and the applicable units. Click *OK* when done.



PATH: Access dialog box through the *Geom > Geophone Interval* menu.

Next, 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.



PATH: Access dialog box through the *Geom > Group/Shot Locations* menu.

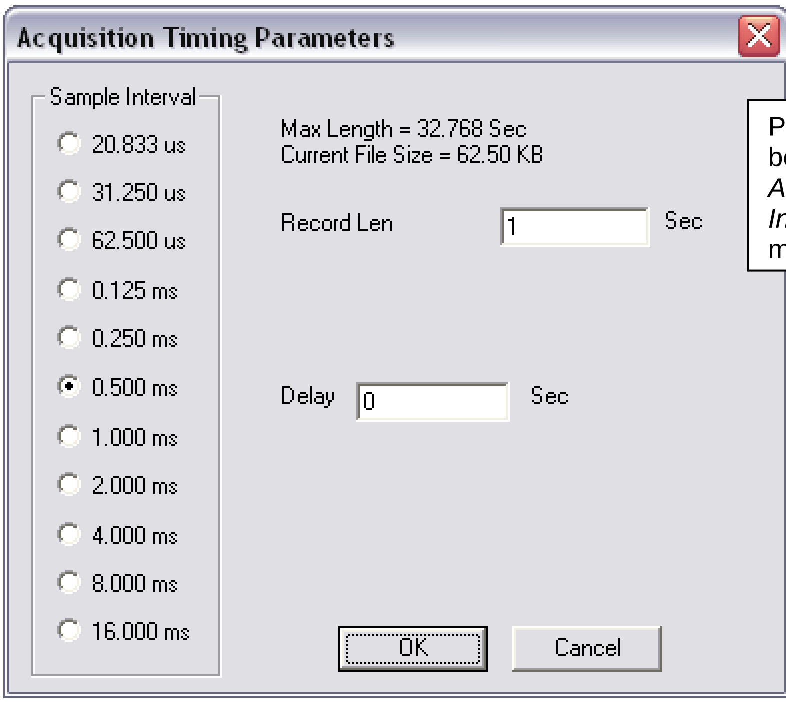
The *Geophone Interval* entered in the previous dialog box is shown. The default *Shot Coordinate* and starting *Geophone Coordinate* is zero, but whatever numerical coordinate system you wish may be used. If a value is changed, the change will ripple through the rest of the coordinates if *Ripple* is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

Note that the seismograph is wired so it 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 24-takeout spread cable, when the line is set up, the nearest geophone to the Geode will be 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 which end of the spread the shot is located, set the *Shot Coordinate* to reflect that location.

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

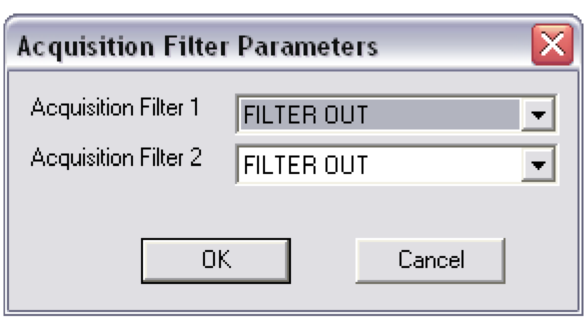
The default settings in the rows *Gain* (how much the signal is boosted before digitization) and *Use* (how a channel is used), require no adjustment. If your settings do not match the default settings shown, go ahead and change them. For all channels, the *Use* row should be *Data*. *Gain* is changed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

Next, set the *Sample Interval* and *Record Length*. Click *OK* when done.



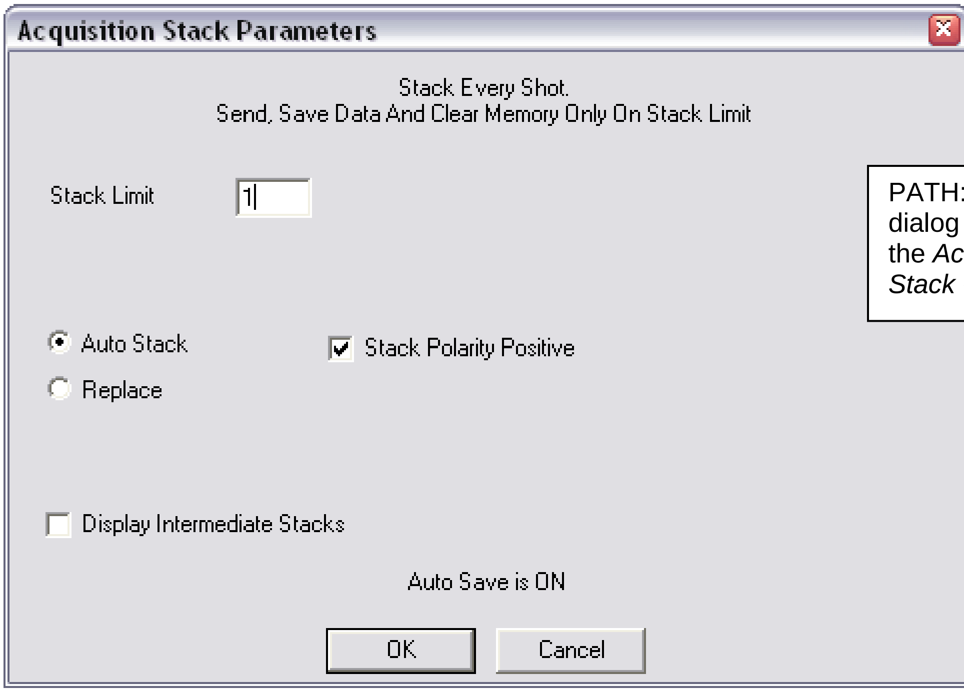
PATH: Access dialog box through the *Acquisition > Sample Interval/Record Length* menu.

Next, check the acquisition filter settings. Acquisition filters are destructive, any data filtered with an "acquisition" (versus "display") filter will be irretrievably removed. Acquisition filters are not typically needed when collecting surface wave data, and thus, should be disabled with the setting *Filter Out*. Click *OK* when done.



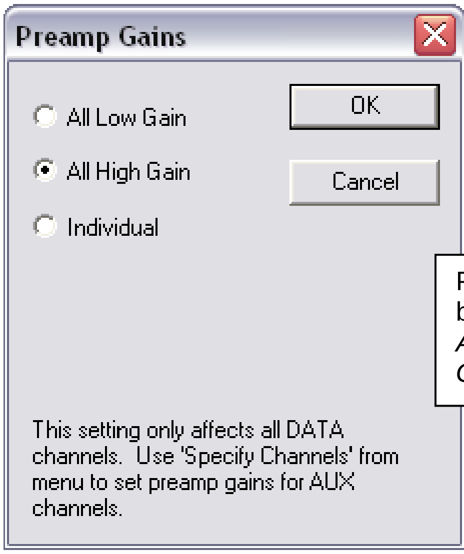
PATH: Access dialog box through the *Acquisition > Acquisition Filters* menu.

Next, set the stack options. 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 signal will add in and incoherent noise will cancel out. In many cases, stacking will not be needed, and thus, the *Stack Limit* default value is set to 1. If, for example, 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. (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 stacks. To stack 8 times, enter 8 as the *Stack Limit*. Click *OK* when done.



PATH: Access dialog box through the *Acquisition > Stack Options* menu.

Next, 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 applied. 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. Click *OK* when done.

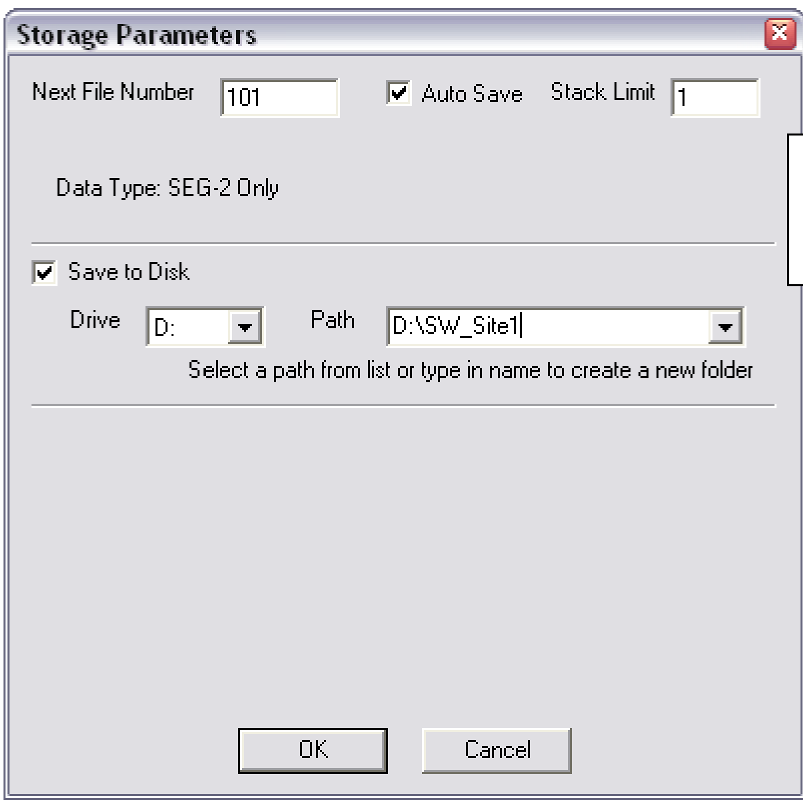


PATH: Access dialog box through the *Acquisition > Preamp Gains* menu.

Next, set up how the data files will be saved. 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. Since the survey line is called Line 1, the suggested starting file number is 101.

Auto Save checked means 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, note that only one folder deep can be created. Enter the desired folder name. Click *OK* when done.

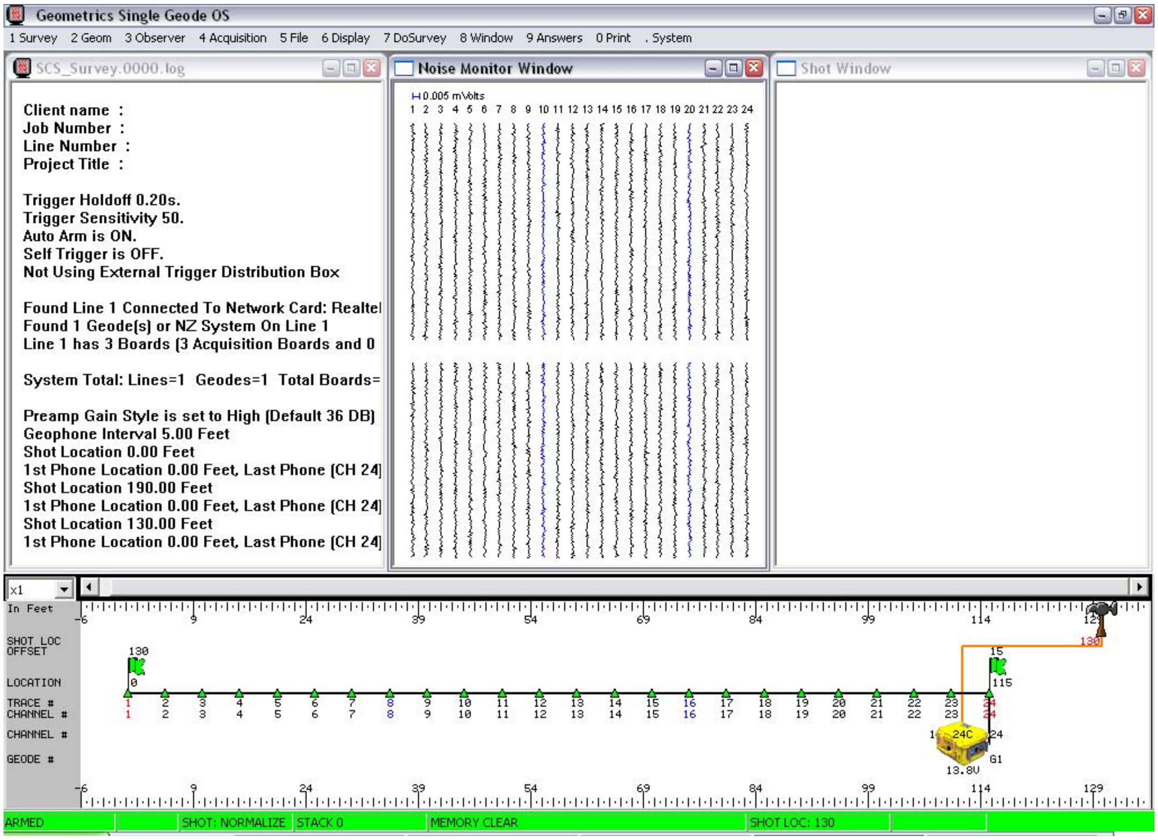


PATH: Access dialog box through the *File > Storage Parameters* menu.

This is the last essential dialog box in SCS for the 1D MASW survey set-up.

3.1.2.2 After Set-up – Acquiring, Displaying, and Quality Checking 1D MASW Data

Once the set-up is complete, you are ready to begin data collection. 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.

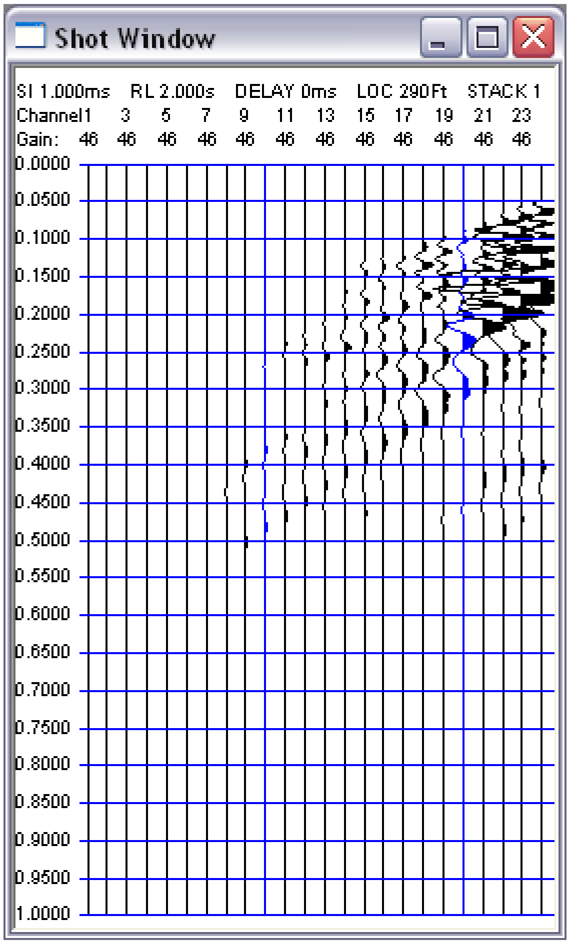


Before any data is recorded, use the *Noise Monitor Window* to check the line. Tap the top of the nearest geophone and watch which trace shows a response; it should be the geophone with the highest channel number. Check that the response level of all the geophones is about the same. If there is a trace with a dissimilar or atypical level of noise, walk down the line to check that the internal sensor element is able to 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.

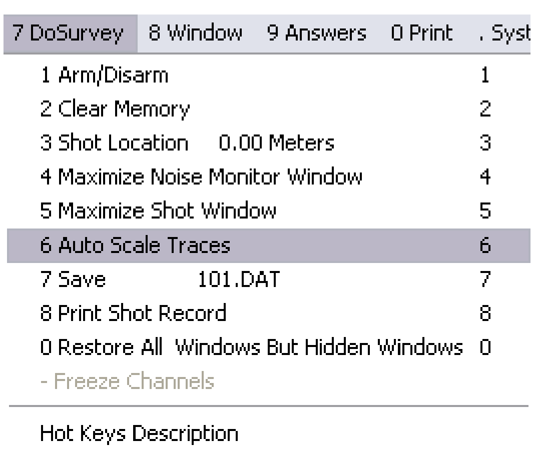
Next check that the status bar on the bottom of the window shows an *Armed* condition colored green. You may want to first press the *1* shortcut key to toggle the armed state off and practice swinging the hammer and hitting the striker plate.

When ready, 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.

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

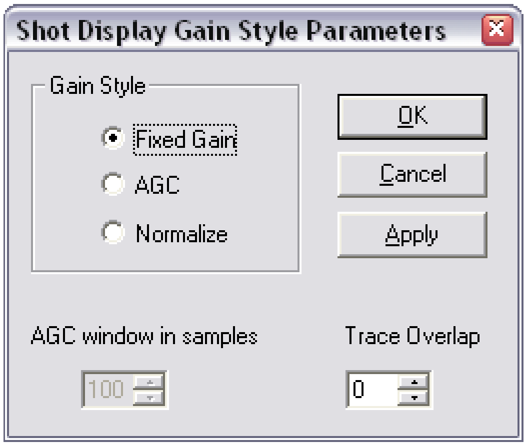


To adjust the display gains, select *Auto Scale Traces* or press the *6* shortcut key. By selecting *Auto Scale Traces*, the software finds the gain that optimizes the allotted space for each trace in the *Shot Window*.



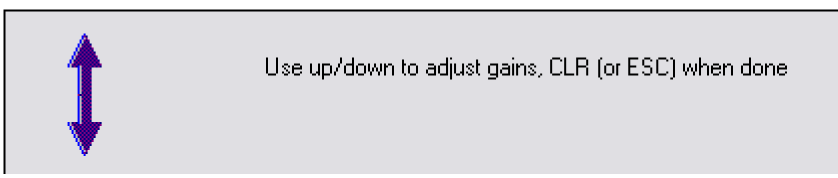
PATH: Access dialog box through the *DoSurvey > Auto Scale Traces* menu.

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*. Click *OK* when done.



PATH: Access dialog box through the *Display > Shot Parameters > Gain Style* menu.

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.

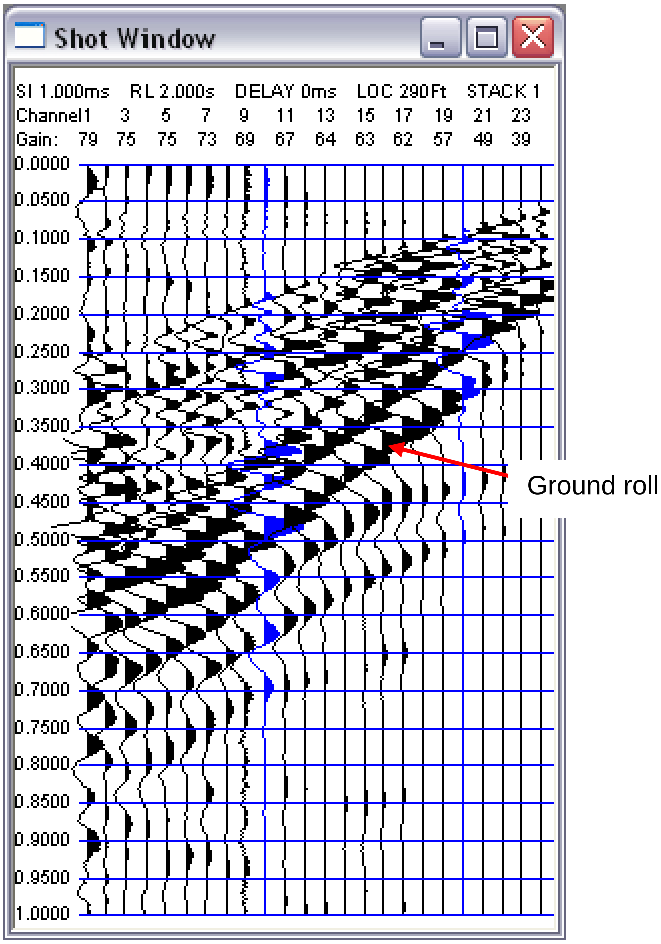


PATH: Access dialog box through the *right arrow* key when the *Shot Window* is selected.

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 similar to that shown below.



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 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. 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 locations. 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 long records (32 seconds) and at least 20 records. 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.

Table 2. MAM 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

3.2.1 MAM Survey Geometry

3.2.1.1 MAM Survey Spread Configurations

SeisImager/SW allows four set types of passive source spread or array configurations and a custom option. Figures 2 through 6 illustrate the various set configurations. As in Figure 1, the black line represents the spread cable and the green inverted triangles represent the geophones.

Of the four set arrays, one is linear and three are 2D, that is, geophones are distributed in two directions 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 of 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, sources 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 applied.

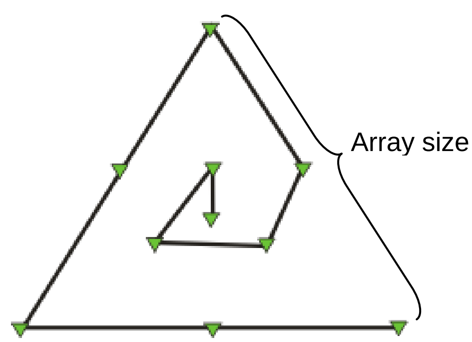


Figure 2. Map view of MAM survey equilateral triangle spread configuration with 10 geophones (*Triangle 10*).

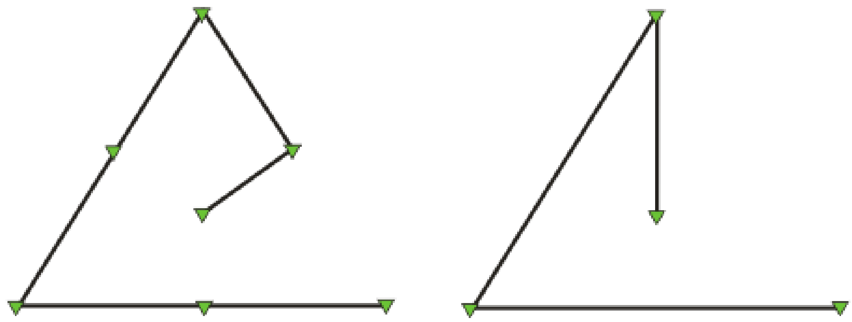


Figure 3. Map view of MAM survey equilateral triangle spread configurations with 7 (*Triangle 7*) and 4 geophones (*Triangle 4*).

For a triangle array (Figures 2 and 3), the *Array size* is equal to the side length. The resultant V_s curve is an average over the array and accordingly should be located at the center of the triangle.

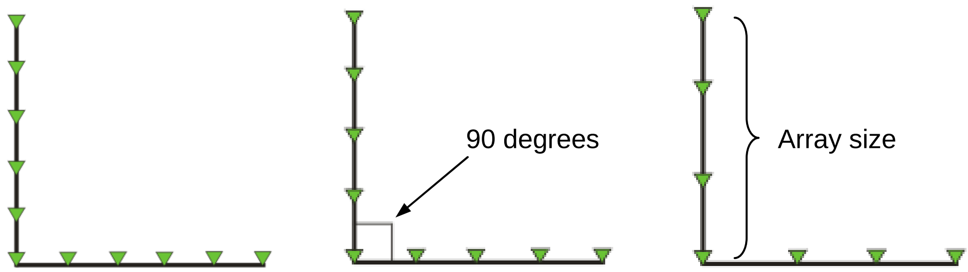


Figure 4. Map view of MAM survey L-shape spread configurations with 11 (*L11*), 9 (*L9*), and 7 (*L7*) geophones.

For an L-shape array (Figure 4), 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-shape 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*.

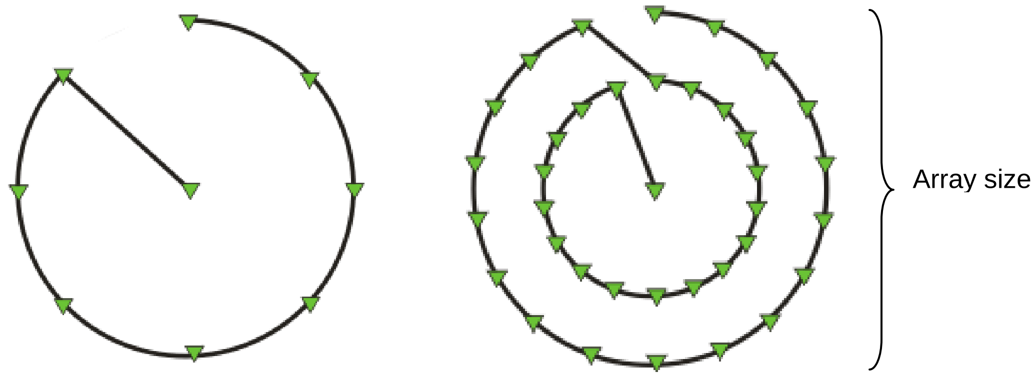


Figure 5. Map view of MAM survey circle spread configurations with 8 outer geophones on one circle and one center geophone (*Single circle 9*) and 18 geophones in two circles and one center geophone (*Double circle 37*).

For the *Double circle 37* array (Figure 5), 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.

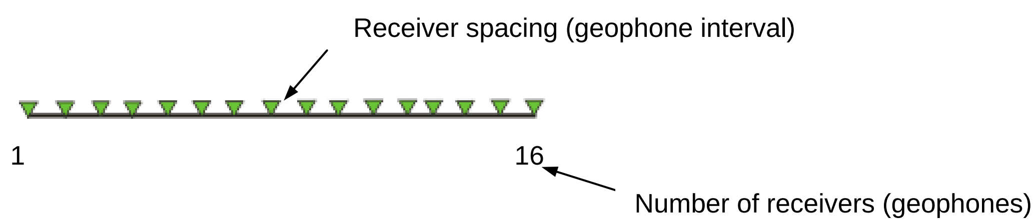


Figure 6. MAM survey linear spread configuration using all channels, one per geophone.

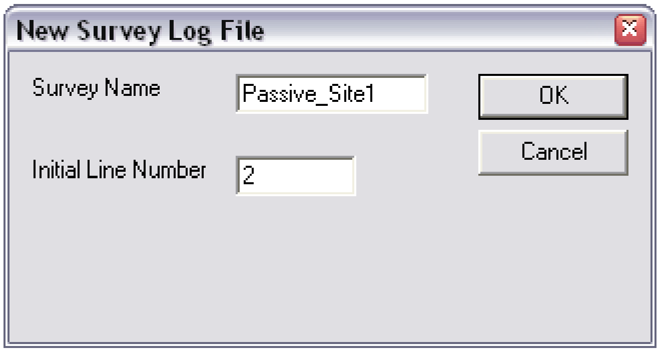
For a linear array (Figure 6), the *Receiver spacing* equals the geophone interval and the *Number of receivers* equals the number of geophones. The resultant V_s curve is an average over the array and accordingly should be located at the center of the spread.

3.2.2 MAM Survey Data Acquisition with Geometrics Seismodule Controller Software

The data acquisition set-up for MAM surveys involves the same dialog boxes used in the 1D MASW survey set-up. This section assumes that you have already worked through the 1D MASW survey set-up, that you are doing a MAM survey at the same site to supplement the 1D MASW survey, and that the MAM survey 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 for an introduction to the 1D MASW set-up process and for more detail on the dialog boxes common to both survey set-ups.

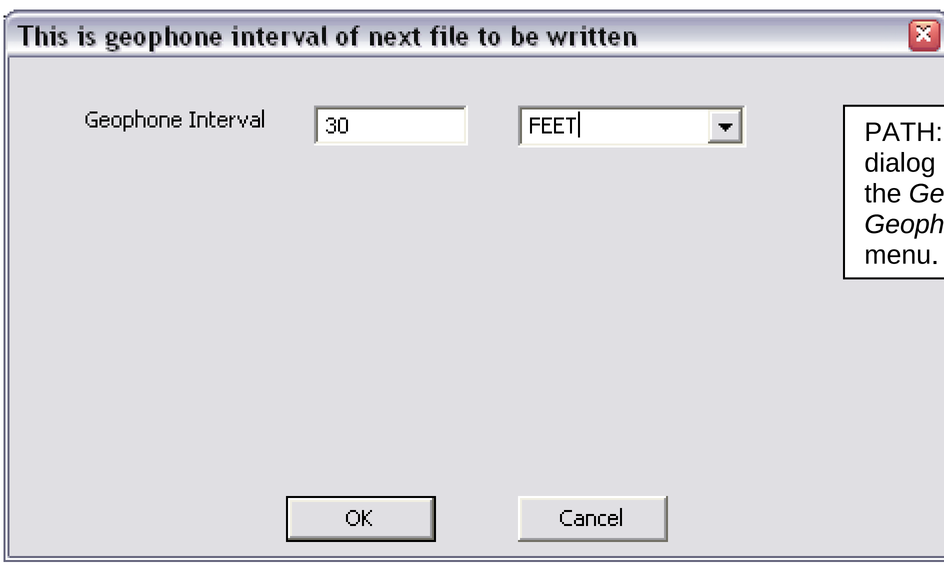
3.2.2.1 MAM Survey SCS Set-up

First, 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.



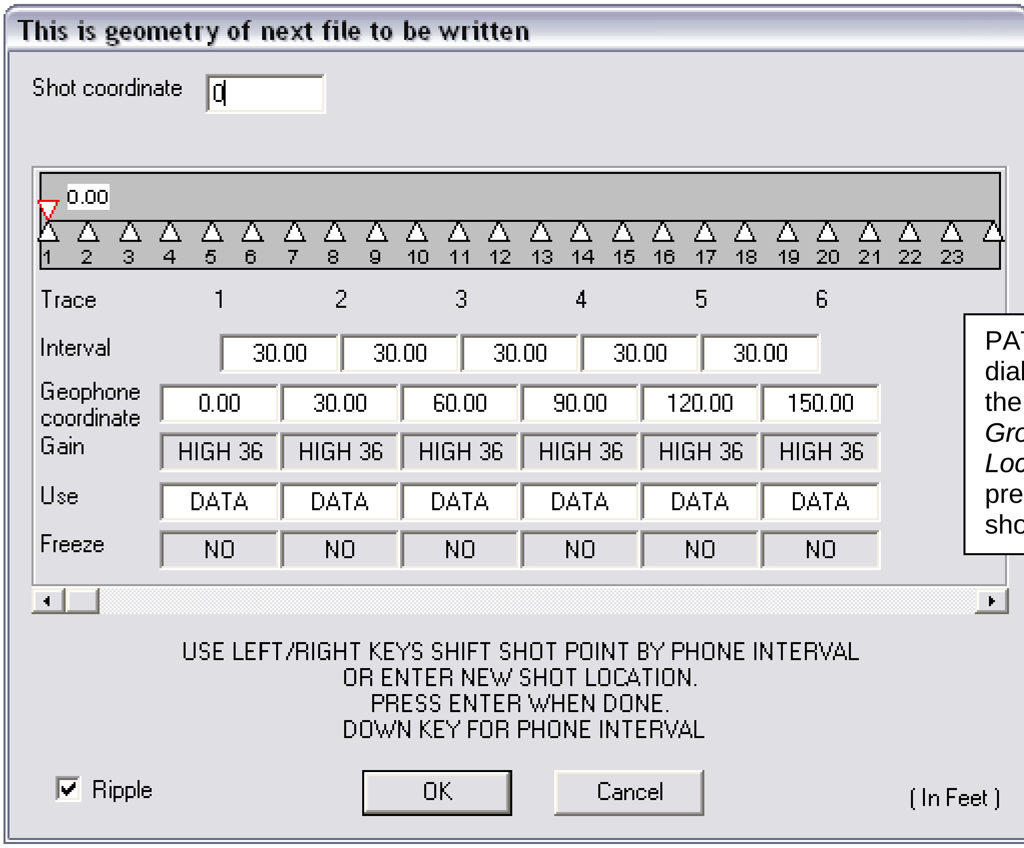
PATH: Access dialog box through the *Survey* menu.

Next, 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.



PATH: Access dialog box through the *Geom > Geophone Interval* menu.

Next, set up the survey geometry.



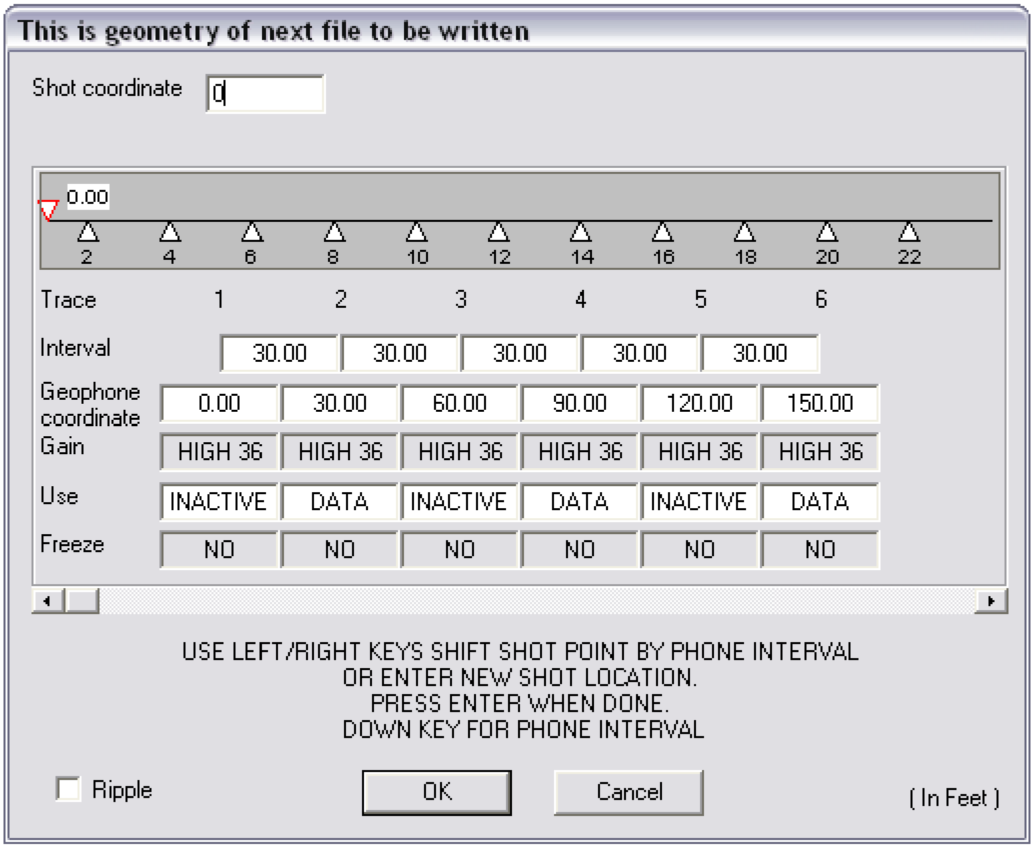
PATH: Access dialog box through the *Geom > Group/Shot Locations* menu or press the *3* shortcut key.

Since there is no active source at a single location, the *Shot Coordinate* is non-applicable and should equal 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 of dead channels can be done in SeisImager/SW, but it is most efficient to deactivate them at the time of acquisition. 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 to that takeout.

Example 3A For a 16-channel seismograph with 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 3A.

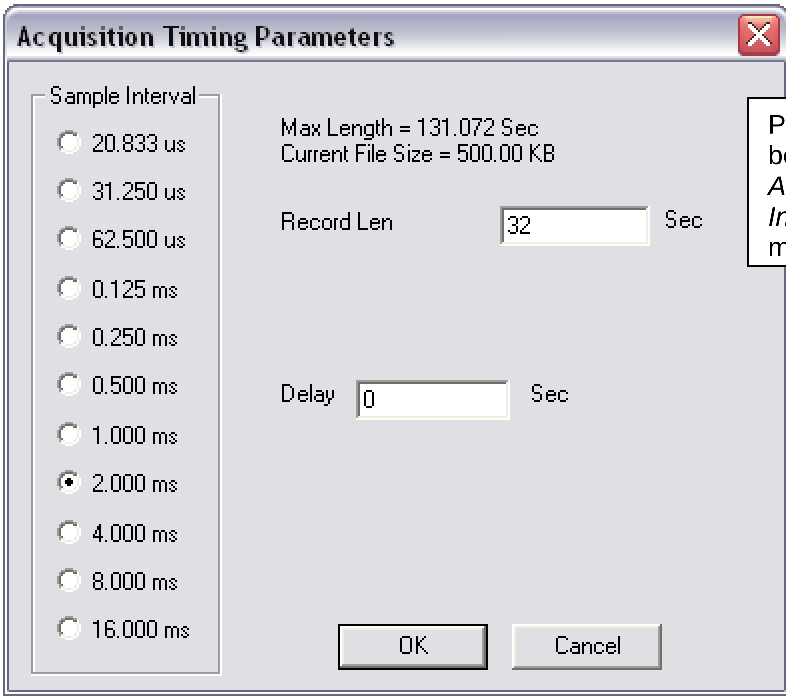
Example 3B For a 24-channel seismograph with 5-meter interval spread cable, in an *L11* array with geophones 10-meters apart, with channel 12 positioned at the corner of the L, channels 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, and 24 are deactivated.



End Example 3B.

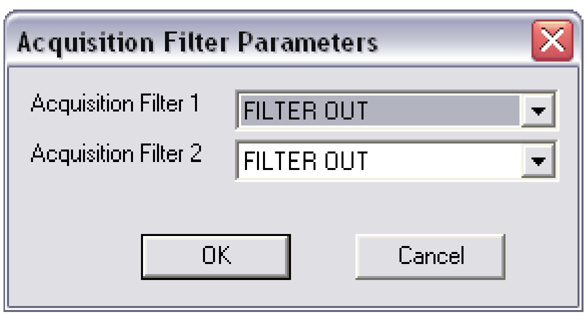
The *Geometry* dialog box only shows linear configurations of geophones, you will not see a graphic of the actual 2D L-shaped array. This is fine; as mentioned previously, the full geometry is set in SeisImager/SW at the time of data processing. The main setting here is deactivation of unused channels.

Next, set the *Sample Interval* and *Record Length*.



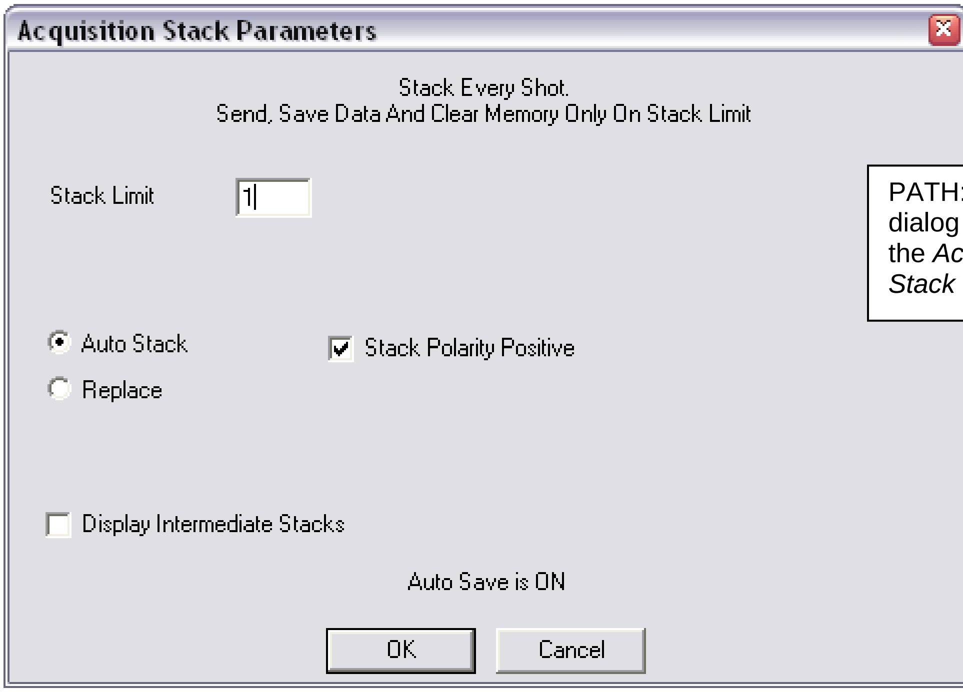
PATH: Access dialog box through the *Acquisition > Sample Interval/Record Length* menu.

Next, make sure the acquisition filters are disabled.



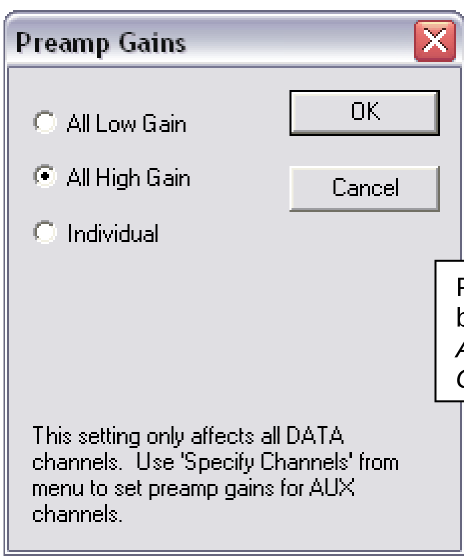
PATH: Access dialog box through the *Acquisition > Acquisition Filters* menu.

Next, set the *Stack Limit* to 1 since stacking is non-applicable to MAM surveys.



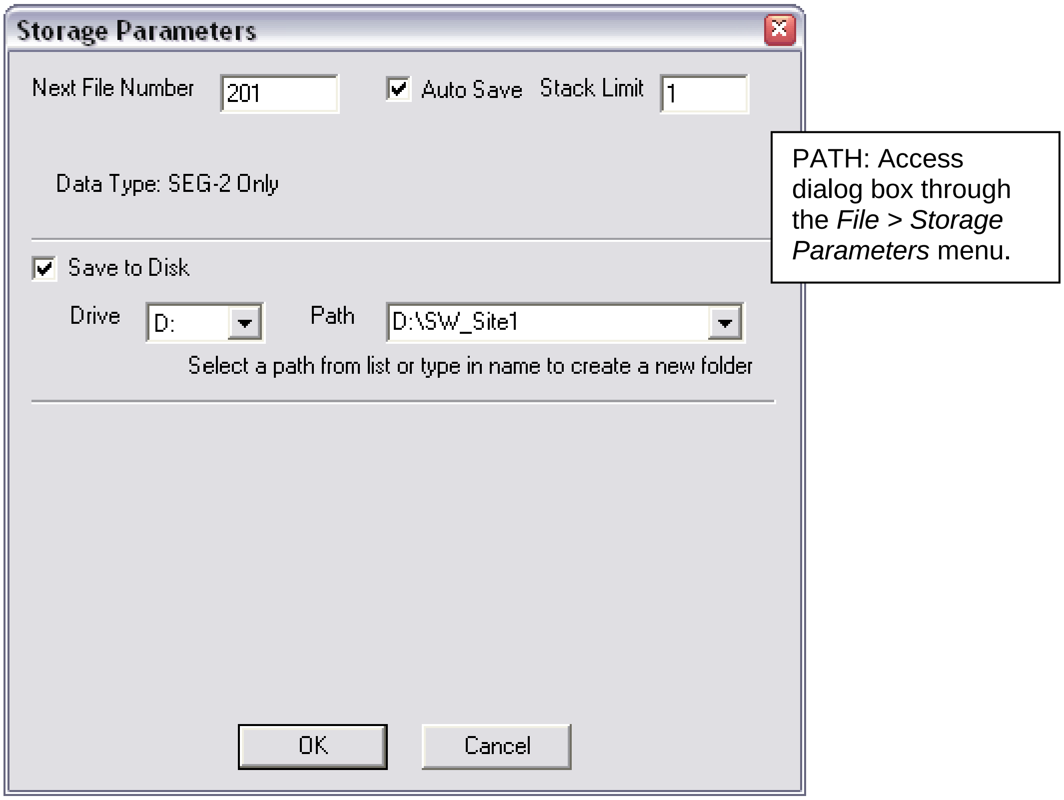
PATH: Access dialog box through the *Acquisition > Stack Options* menu.

Next, make sure the gains are set to *All High Gain*.



PATH: Access dialog box through the *Acquisition > Preamp Gains* menu.

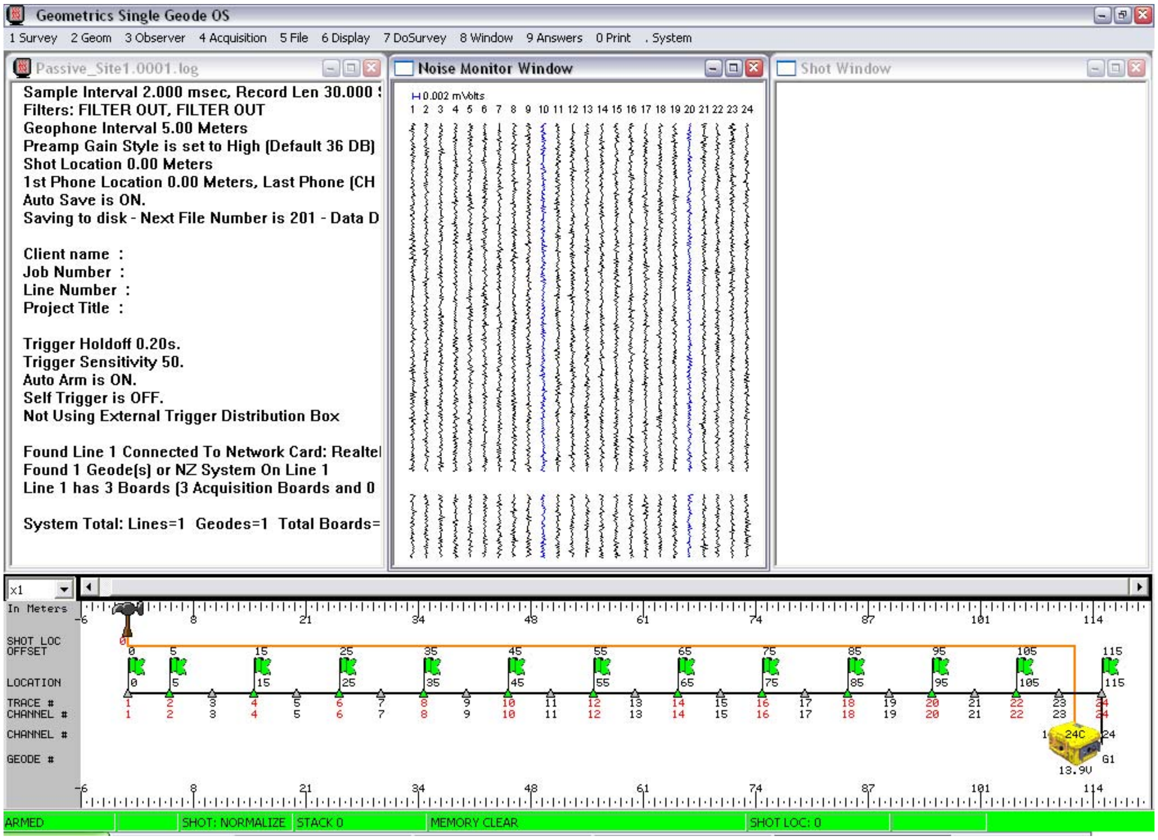
Next, set the *Next File Number*. Since the survey line is called Line 2, set the *Next File Number* to 201. Leave *Auto Save* on and the *Stack Limit* set at 1. For the *Path* of saved data, enter the desired folder name.



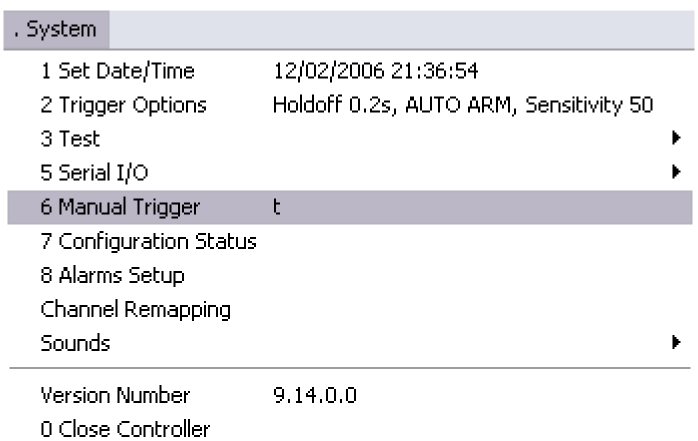
This is the last essential dialog box in SCS for the MAM survey set-up.

3.2.2.2 After Set-up – Acquiring, Displaying, and Quality Checking MAM Data

Once the set-up is complete, you are ready to begin data collection. 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.



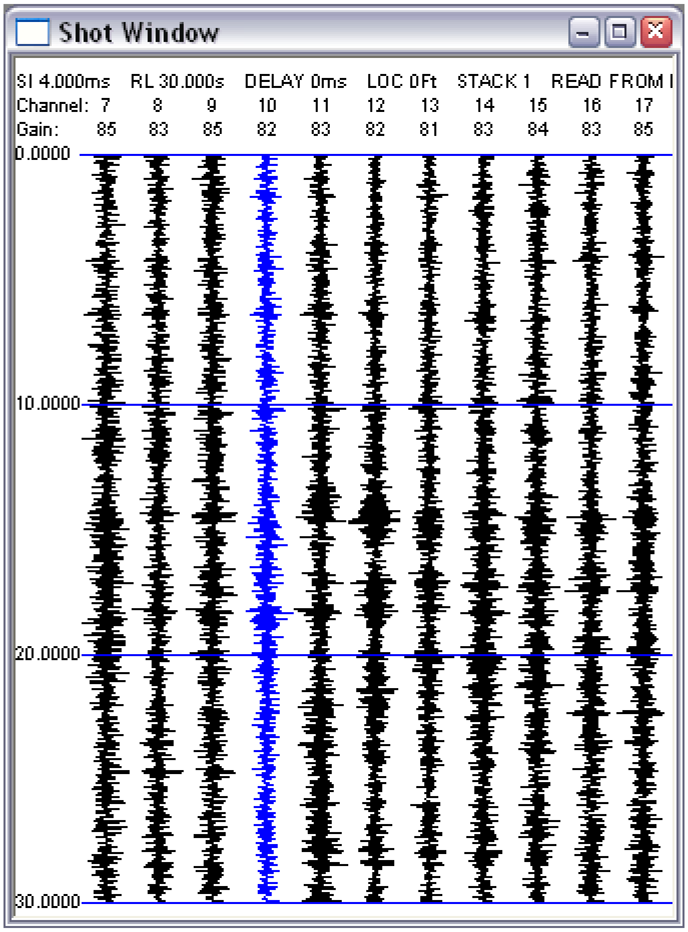
Once ready, manually trigger, by pressing the *t* shortcut key or select the *System* menu, *Manual Trigger*.



PATH: Access function through the *System* menu, *Manual Trigger* or press the *t* shortcut key.

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. With 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).



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 signal of noise without strong changes in amplitude throughout the record and from trace-to-trace is ideal.

In addition to visual analysis, refer to Sections 4 and 5 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 from Section 3.1 applies. Passive source data may not be available, or if available, will only supplement with a 1D V_s curve, so the active source energy level will have larger bearing on the maximum possible depth of penetration.

Table 3. 2D MASW Acquisition Parameters

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
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

Table 3. 2D MASW Acquisition Parameters

Parameter	Setting
Trigger	Hammer switch taped to sledgehammer handle and connected to seismograph trigger port
Sample interval	0.5 milliseconds (ms)
Record length	1 to 2 seconds (s), long enough to enclose the surface wave train
Stacking	As needed to improve data quality, wait for quiet times to shoot

3.3.1 2D MASW Survey Geometry

The basic linear geometry of MASW surveys is described in Section 3.1.1. The linear spread is simple, but with 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.

Table 4. Selected 2D MASW Geometry Plot Attributes

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)

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 correlation traces by CMP, then those traces having equal spacing are stacked 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 7, the top row (1) illustrates the distribution of CMPs for a shot record (1b) and a CMP gather (1c). Gathering by CMP (1c) 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 first processing by CMP (2c) increases lateral resolution and accuracy.

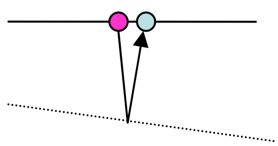
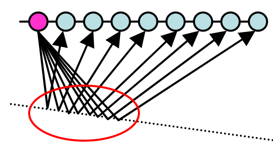
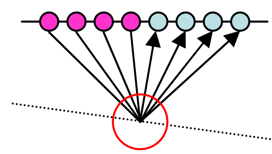
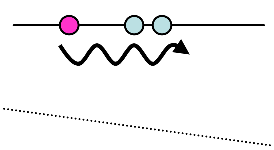
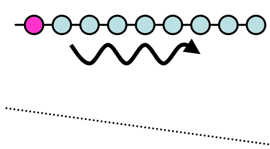
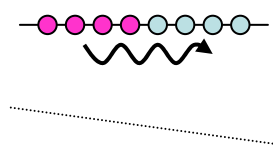
	Single channel record	Shot record	CMP gather
1. Distribution of sampling for reflection methods	 1a.	 1b.	 1c.
	Original surface wave method (SASW)	New surface wave method (MASW)	Advanced surface wave method (CMP-based MASW)
2. Distribution of sampling for active source surface wave methods	 2a.	 2b.	 2c.

Figure 7. 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 8). 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*.

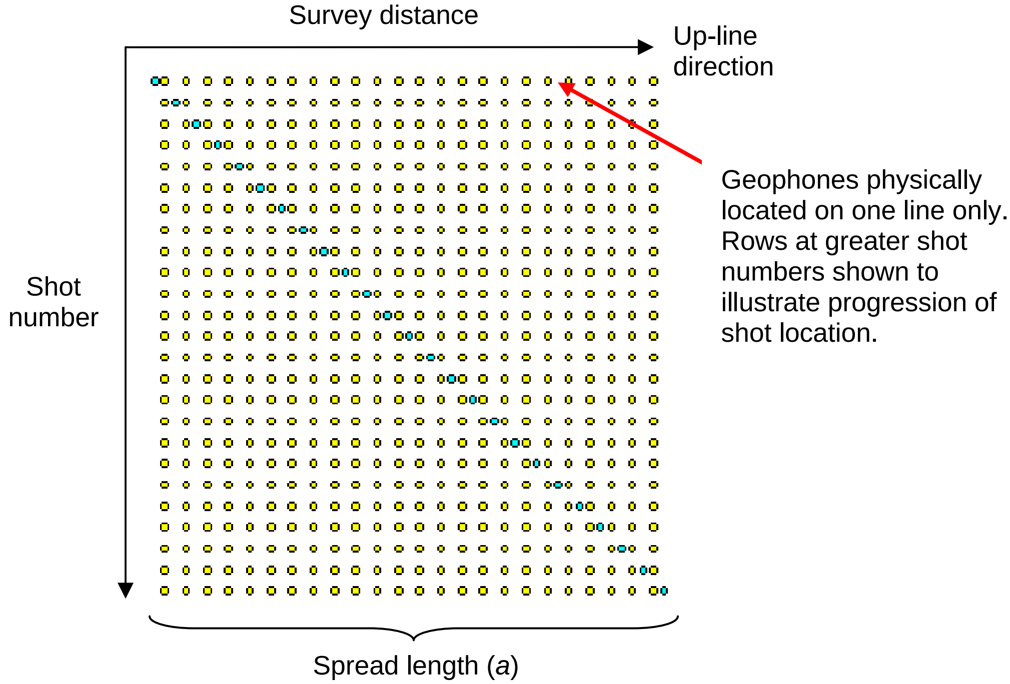


Figure 8. 2D MASW fixed receiver spread configuration.

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 there are limited channels and 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* or the *roll-along end-on spread* 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 9). 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 channels live for each shot. This process continues until the survey line length of interest has been covered.

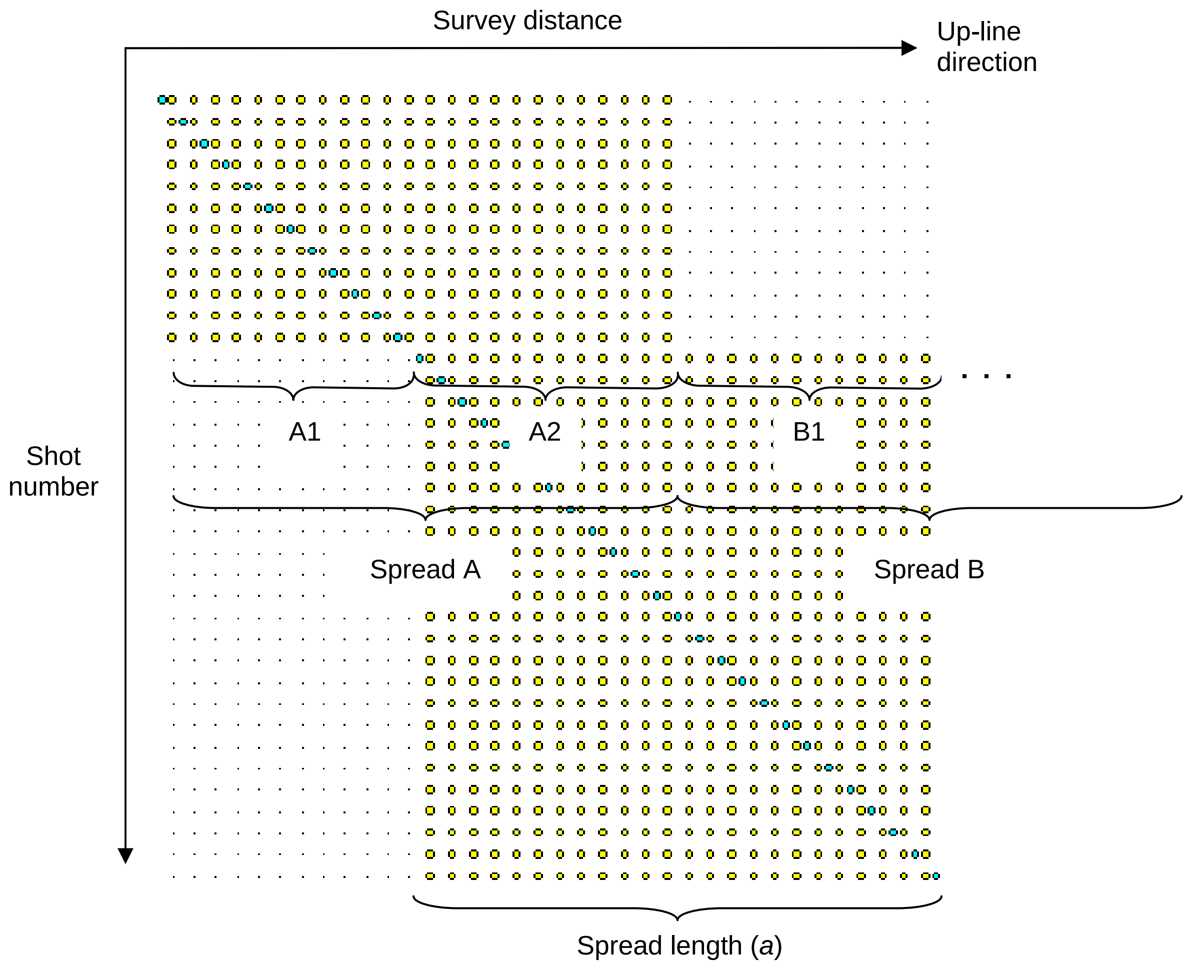


Figure 9. 2D MASW continuous fixed receiver geometry.

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 assuming that the shot interval equals the geophone interval). For the example in Figure 9, full fold will start 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 start 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 a 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 9, 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 on 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.

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 is 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 similarly 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.

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.

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 takeout 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 10 illustrates the *roll-along end-on spread* configuration with a *fixed receiver spread* configuration used at the end of the line.

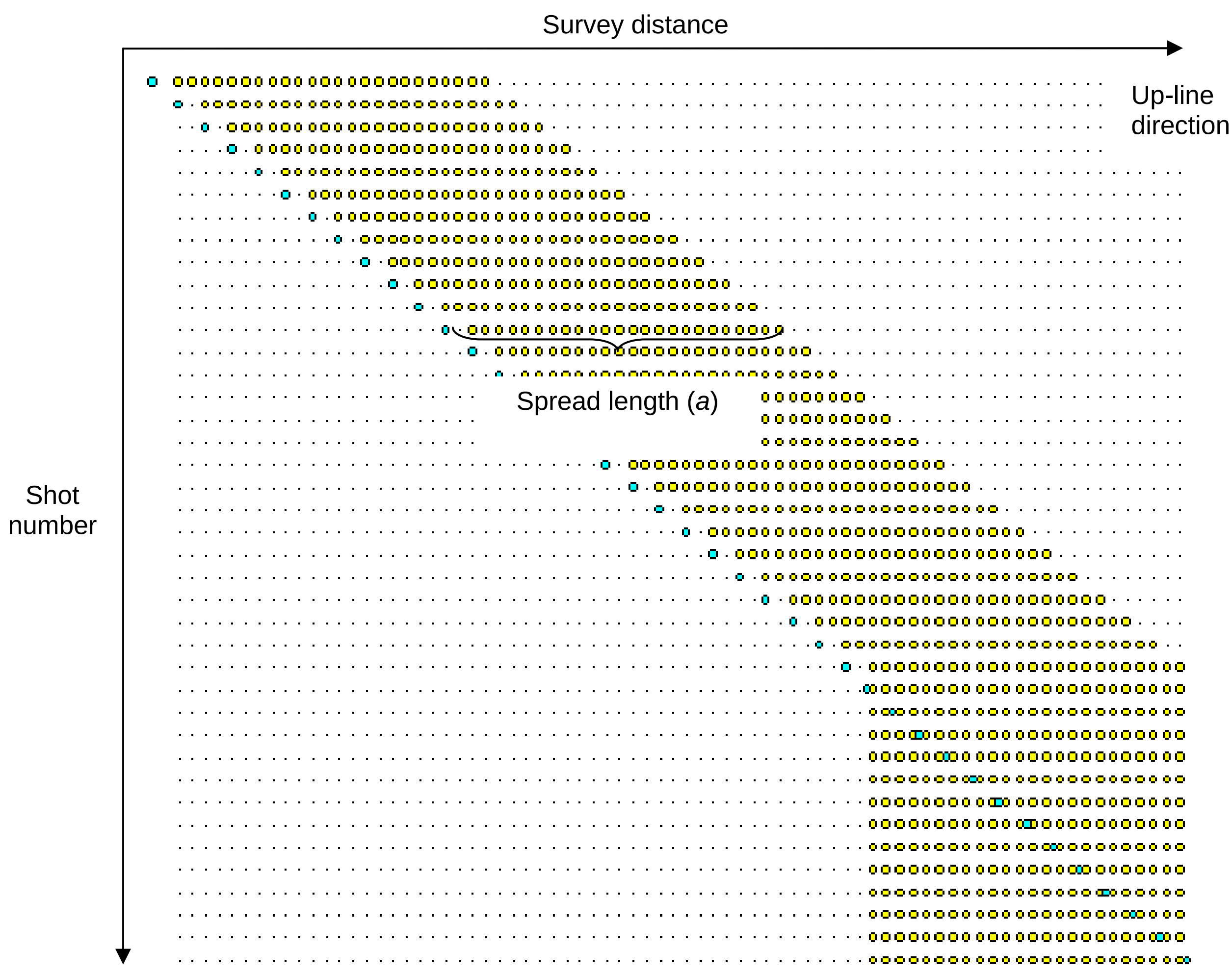


Figure 10. 2D MASW roll-along end-on geometry.

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

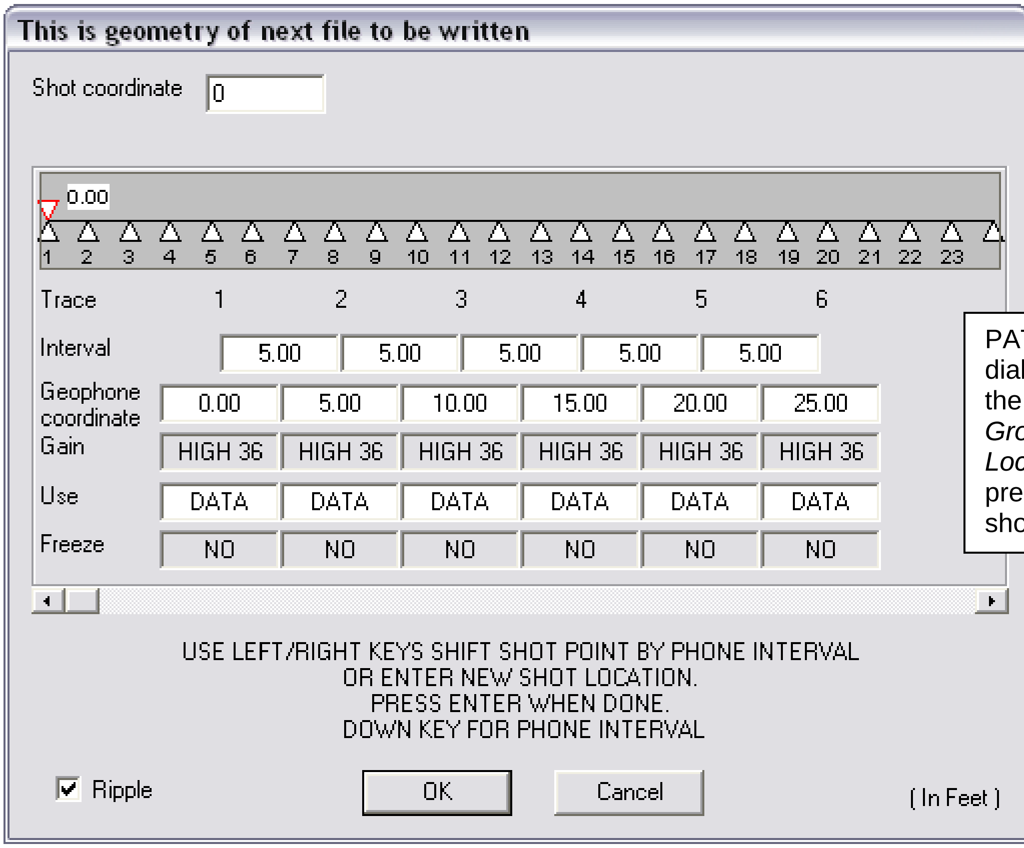
3.3.2.1 2D MASW Survey SCS Set-up

The difference between the 1D and 2D MASW survey set-ups 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 at the time of data processing. It is also possible to manually update the geometry in 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.

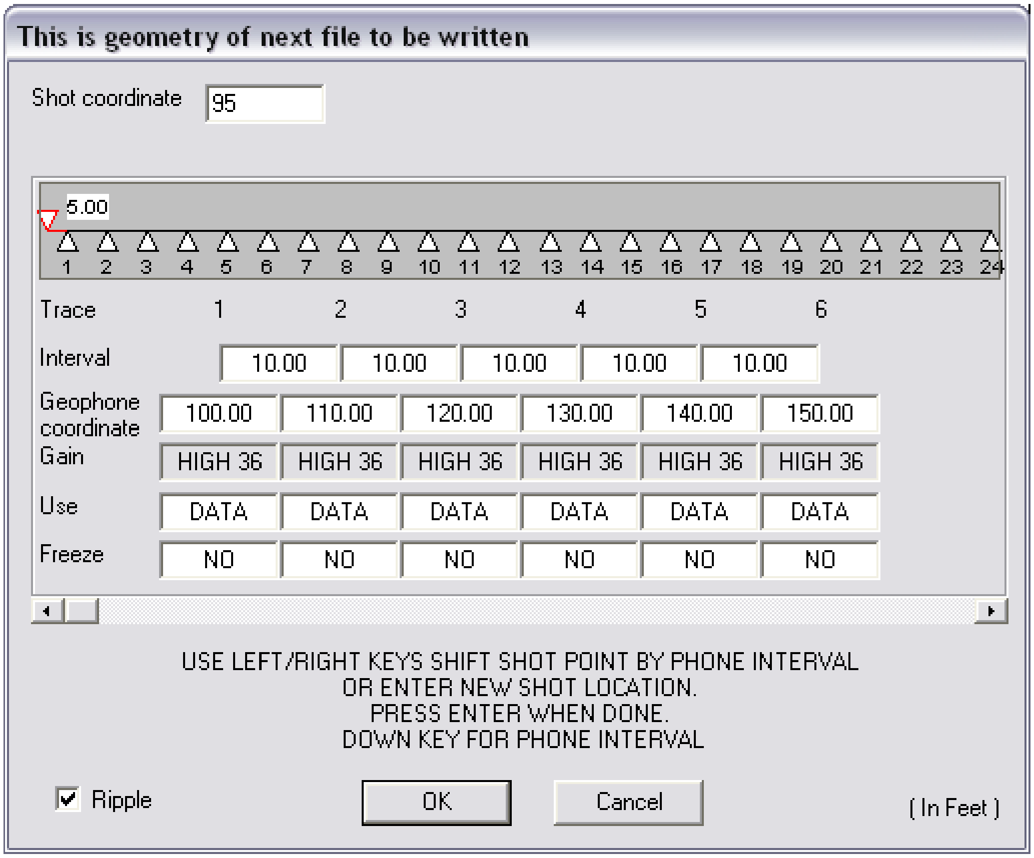
Once Section 3.1.2.1 has been completed, the shot and receiver coordinates can be set up to automatically increment depending on the configuration, either a *fixed receiver spread*, *continuous fixed receiver spread*, or *roll-along end-on spread*.

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.



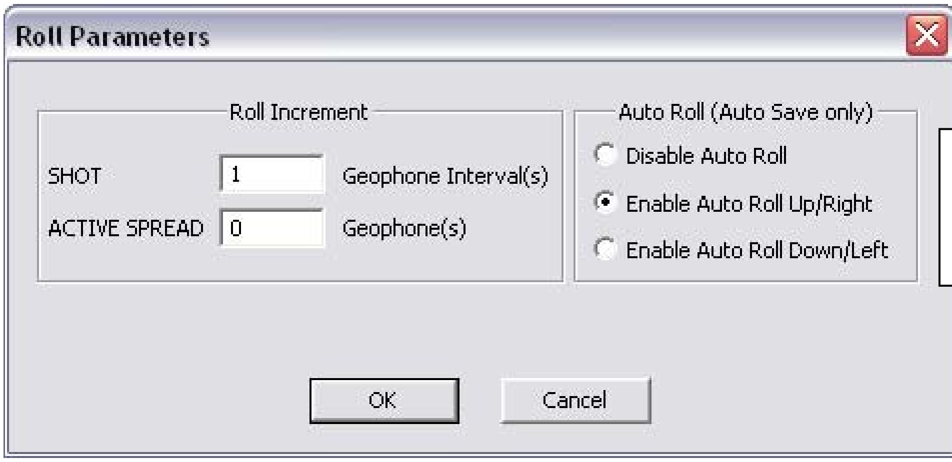
PATH: Access dialog box through the *Geom > Group/Shot Locations* menu or press the *3* shortcut key.

Example 3C 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.



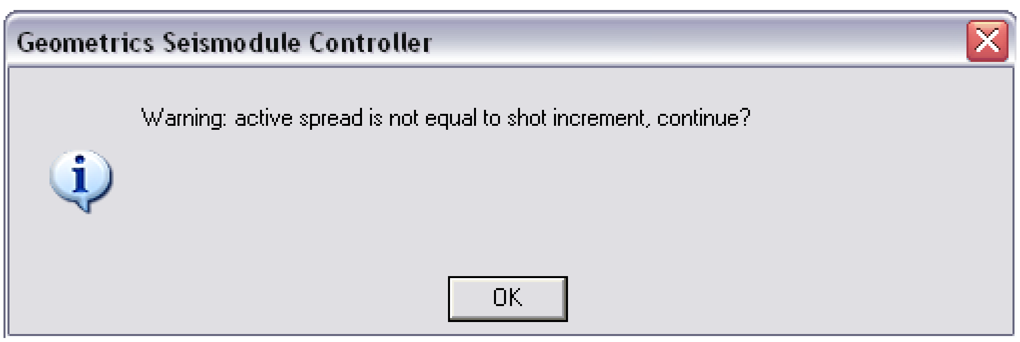
End Example 3C.

Next, set up rolling of the shot coordinate in the *Roll Parameters* dialog box. 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. Click *OK* when done.

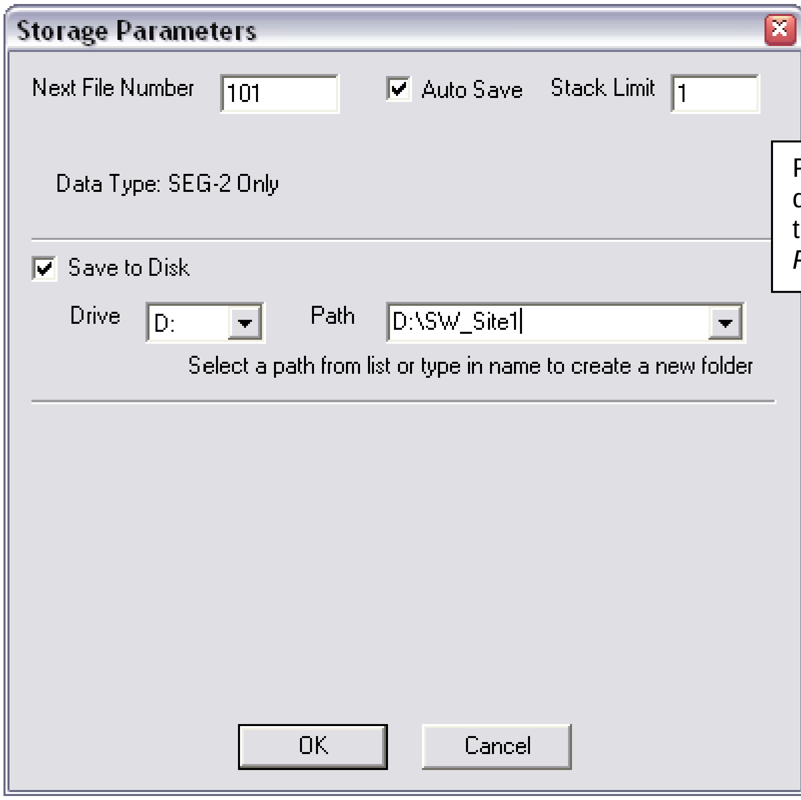


PATH: Access dialog box through the *Geom > Roll Parameters* menu.

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 click *OK*.



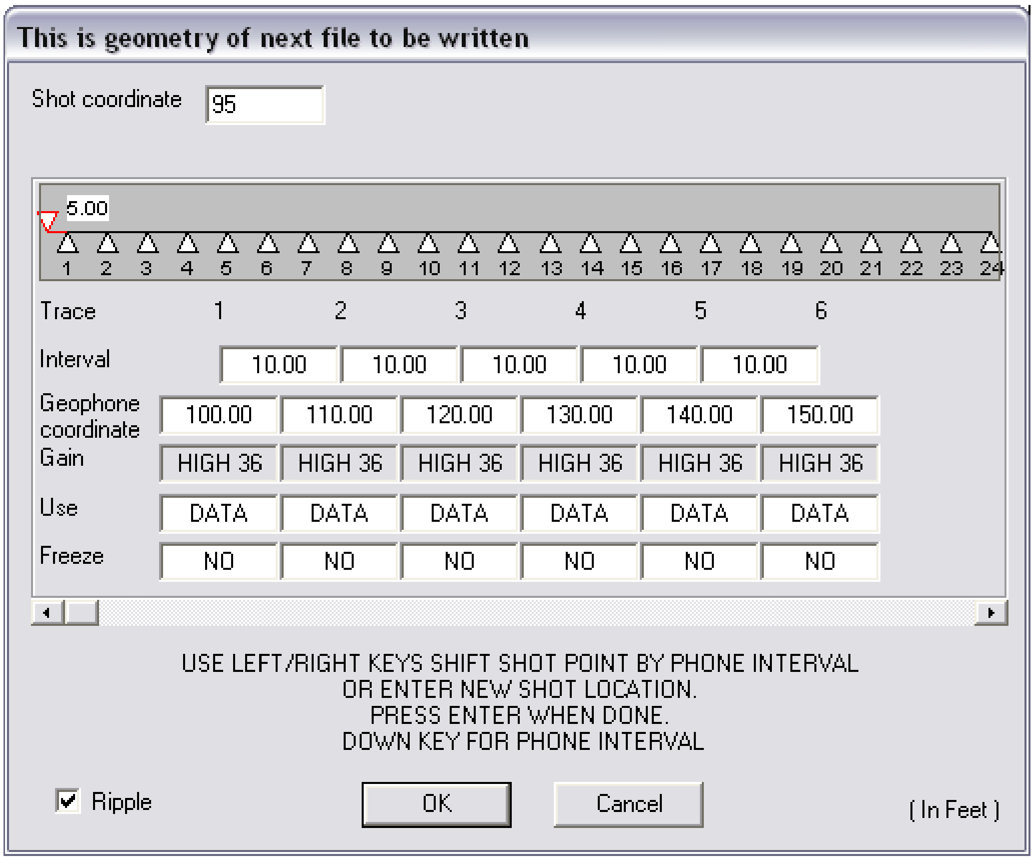
Next, activate *Auto Save* as required with automatic rolling.



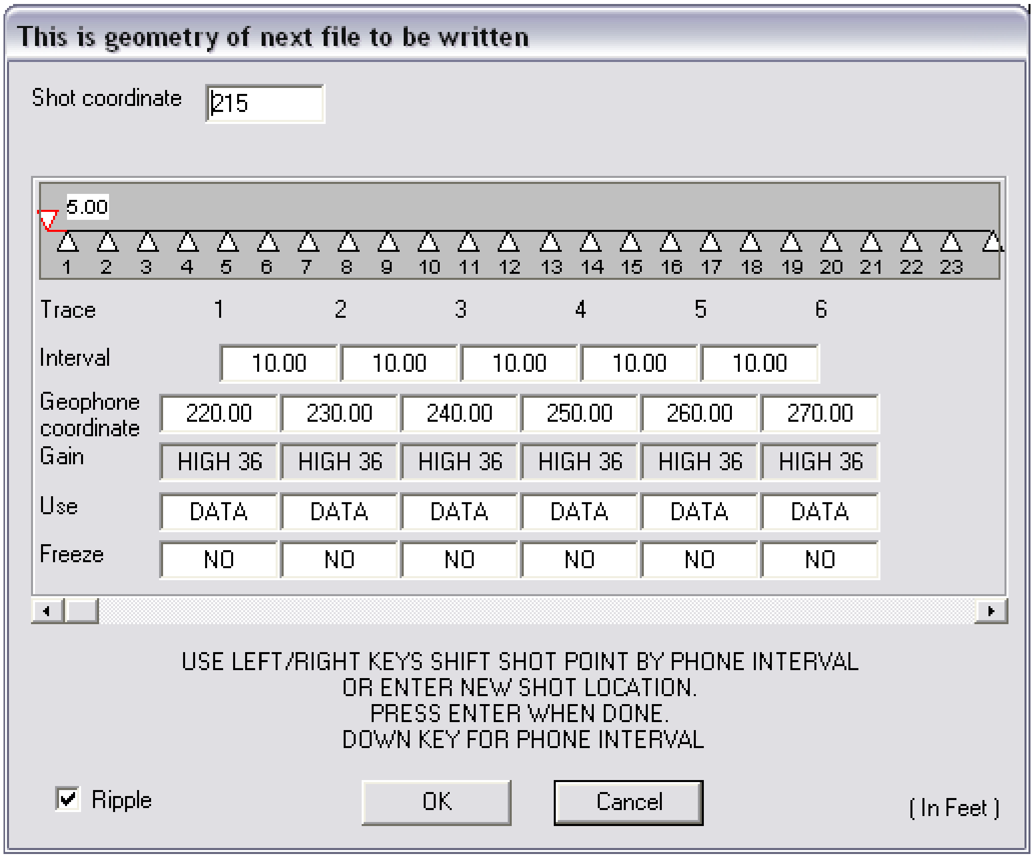
PATH: Access dialog box through the *File > Storage Parameters* menu.

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 3D 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.

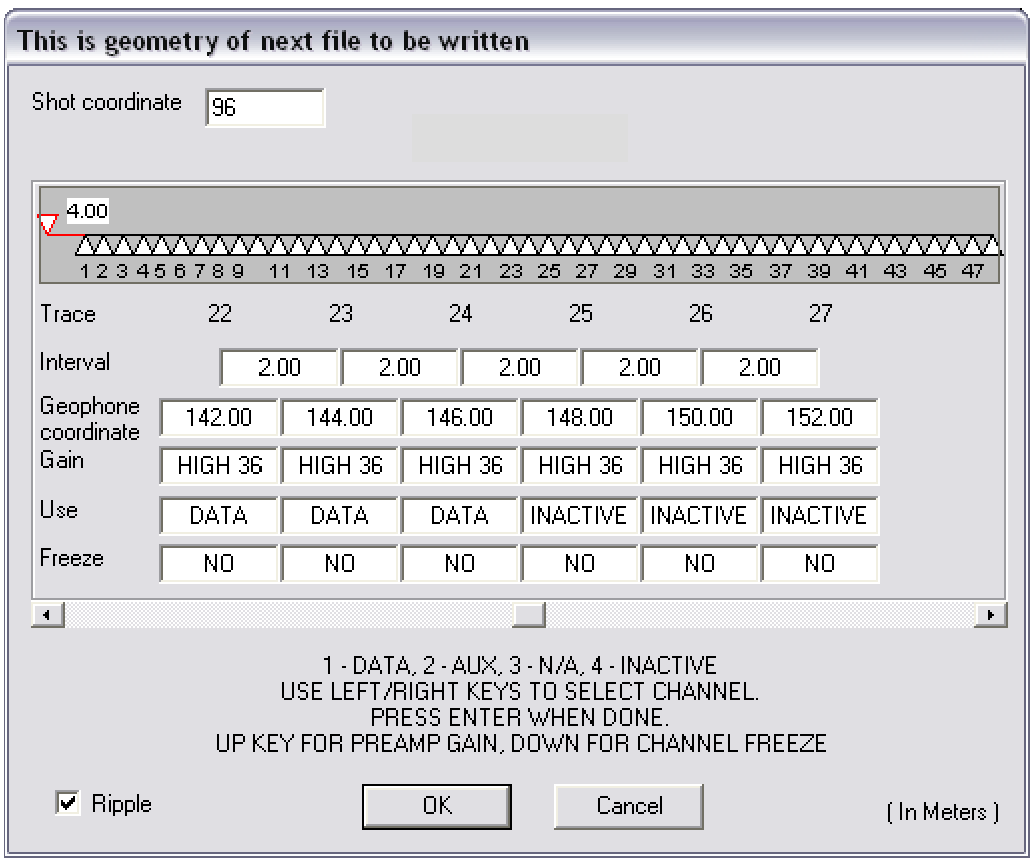


End Example 3D.

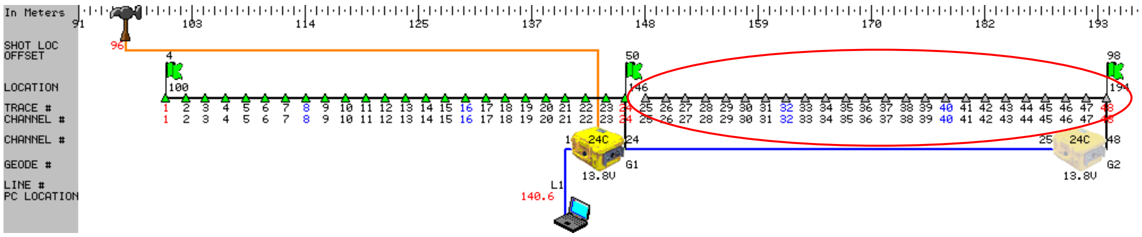
For a *roll-along end-on spread* configuration, the geometry set-up will depend on the rolling method (Section 3.3.1.3), using either software roll-along (Method A), a land streamer (Method B), or a mechanical roll box (Method C).

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, there will be an increasing number of inactive channels up-line and a decreasing number of inactive channels down-line.

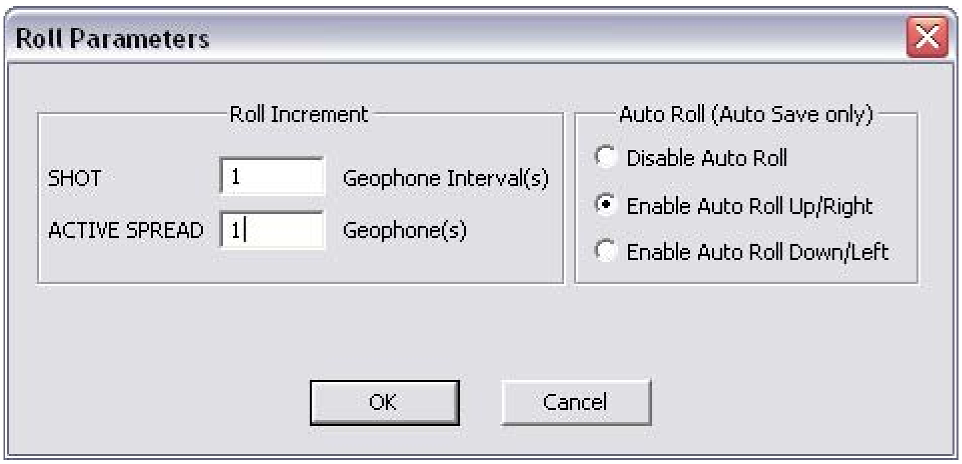
Example 3E For a *roll-along end-on spread* using Method A, with 48 channels and 24 channels live for each shot, channels 25 through 48 are deactivated.



After clicking *OK*, the *Geometry Toolbar* in the main SCS window reflects the deactivation by graying out the symbols for geophones 25 through 48 (circled in red).



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 3E.

To set up using Methods B and C, none of the channels would be deactivated 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 synch 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 Set-up – Acquiring, Displaying, and Quality Checking 2D MASW Data

Once the set-up is complete, you are ready to begin data collection. 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

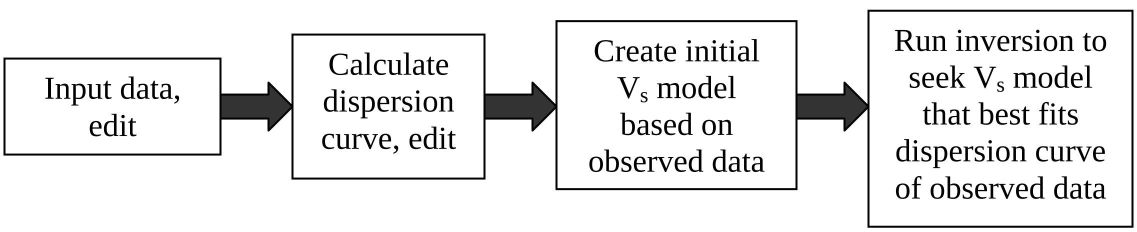
SeisImager/SW is capable of 1D and 2D MASW for active sources and MAM data analysis for passive sources. The 1D analyses output a V_s curve and the 2D analysis outputs a V_s cross-section.

4.1 Surface Wave Analysis Wizard

As discussed in Sections 1 and 2, the modules Pickwin, WaveEq, and GeoPlot 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), MAM passive source data (Section 4.1.2), and 2D MASW active source data (Sections 4.1.3 and 4.1.3.1).

This section provides an explanation of wizard operation, processing flows, and basic dialog box parameters. Please refer to Sections 5 and 6 for complete description and explanation of menu items and dialog box parameters (including the *Advanced menu* items) and Section 7 for an ordered list of the functions used in the wizard so the processing flows can be manually reproduced.

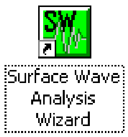
The general processing flows as follows:



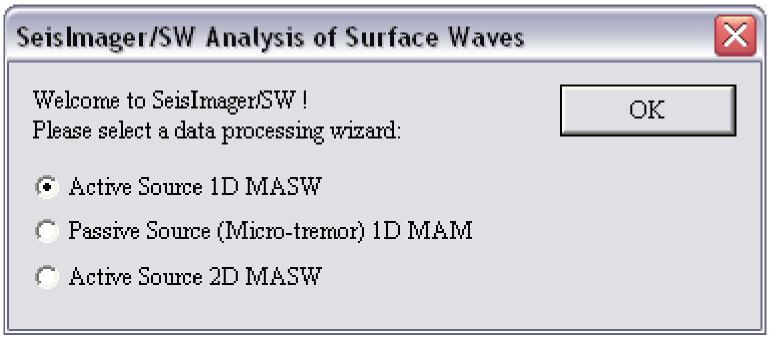
The wizard is based on the *Enter* key. At any time you can manually override the wizard by entering the menus. A complete 1D dataset is considered to consist of at least one active source file and a set of passive source files and a complete 2D dataset consists of a series of active source files (the 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).

4.1.1 Active Source 1D MASW Wizard

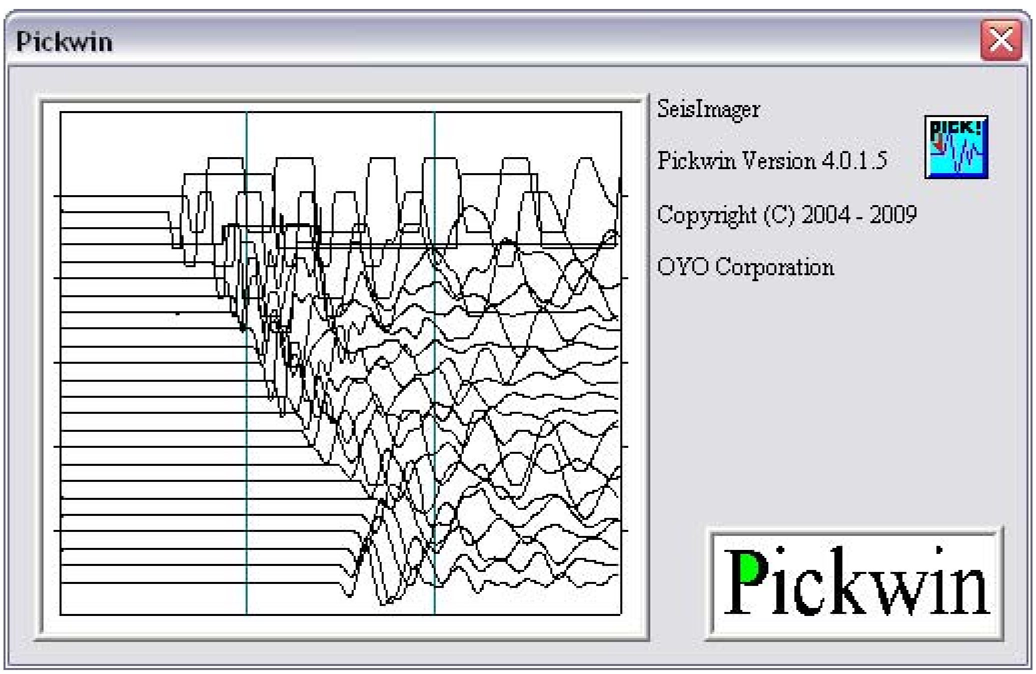
Double-click on the Surface Wave Analysis Wizard icon.



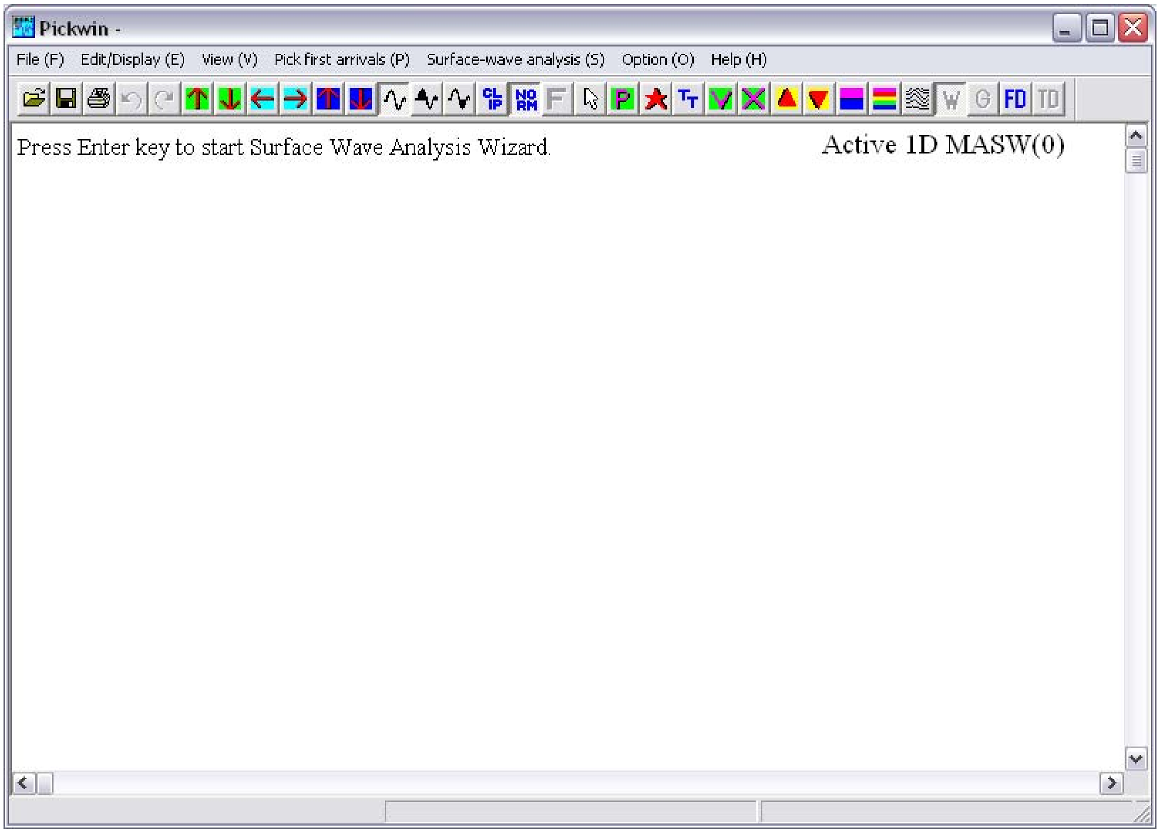
The *Welcome to SeisImager/SW* dialog box appears. Select *Active Source 1D MASW* and click *OK*.



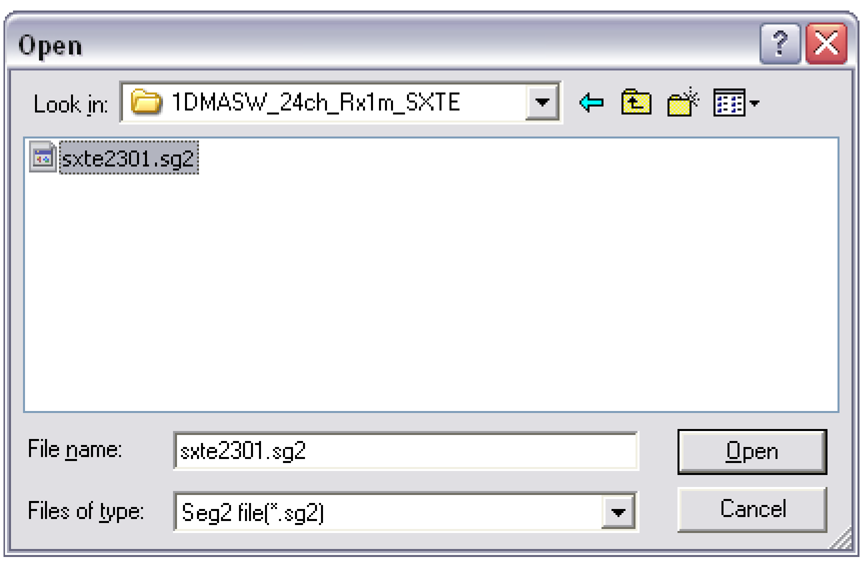
The Pickwin module is launched.



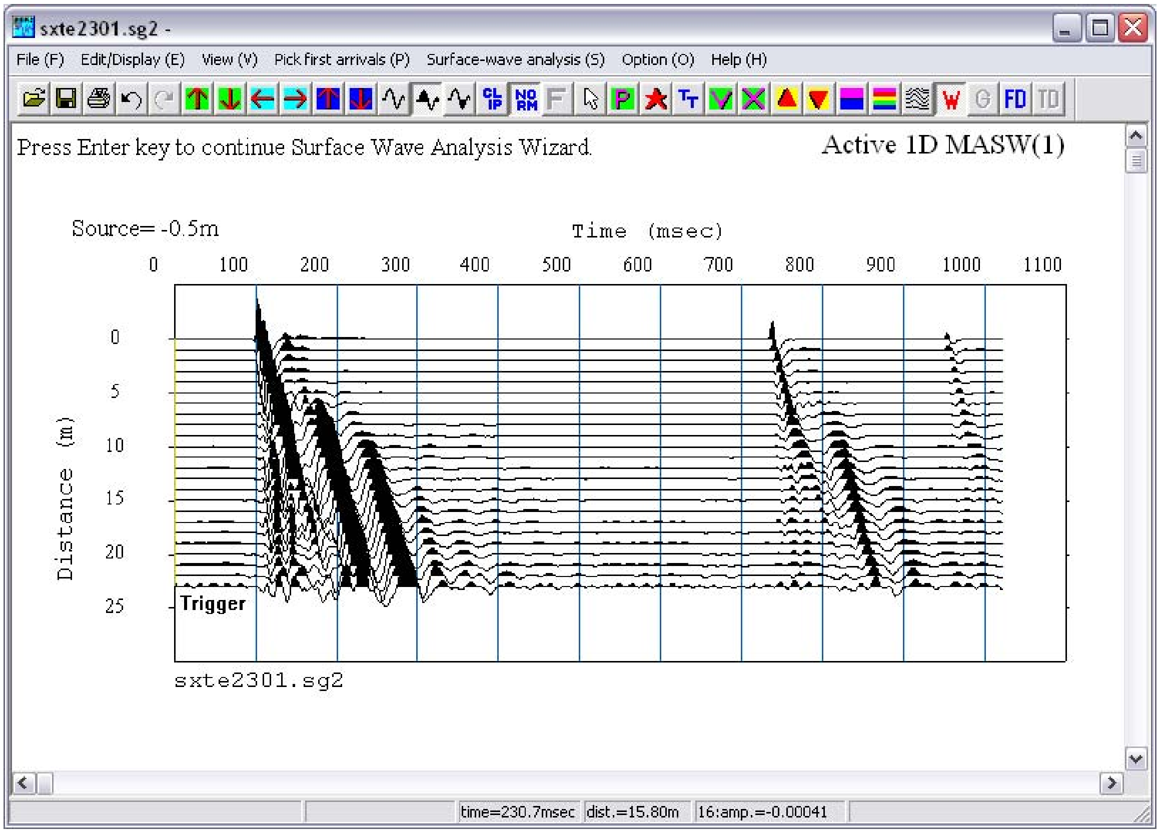
The main Pickwin window appears. The wizard calls functions from the *File* and *Surface Wave Analysis* menus. Press the *Enter* key as instructed in the upper left hand corner of the window to begin.



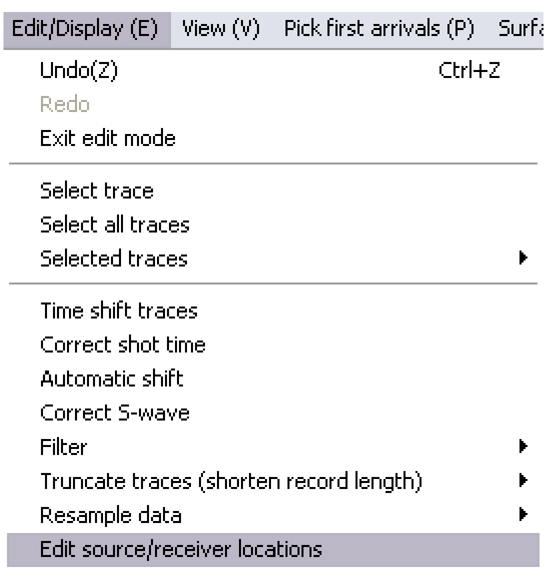
The first step is to input the active source data file. Highlight the file and click *Open*.



The waveform file is displayed.

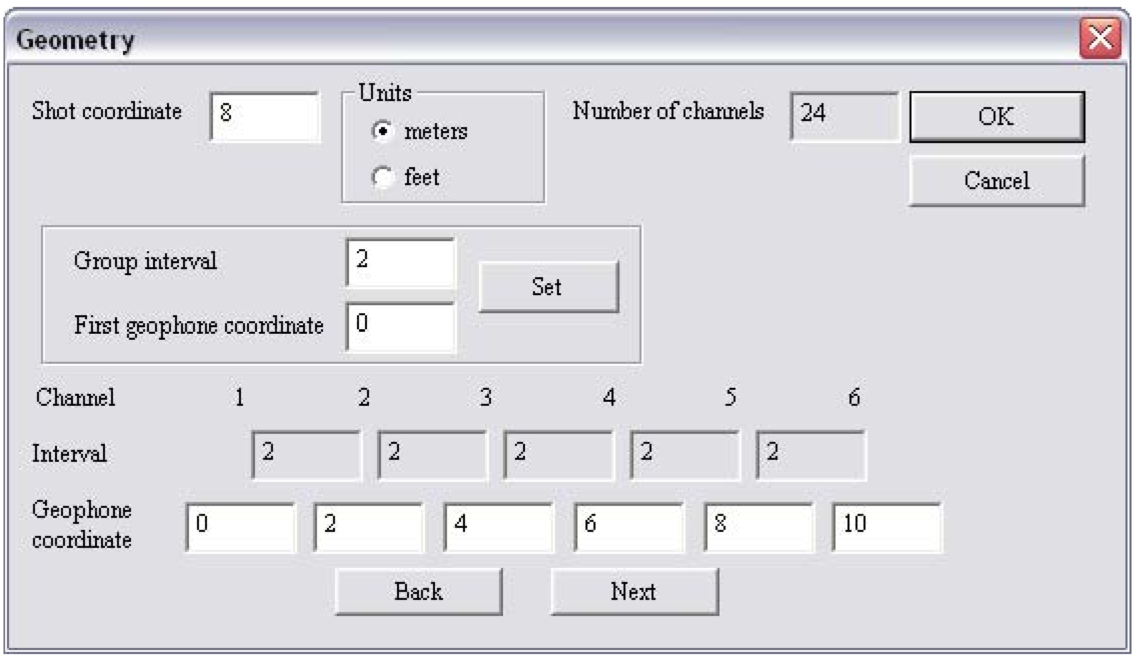


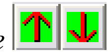
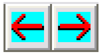
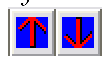
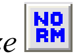
If the unit labels displayed are incorrect, select the *Edit/Display* menu, *Edit source/receiver locations*.



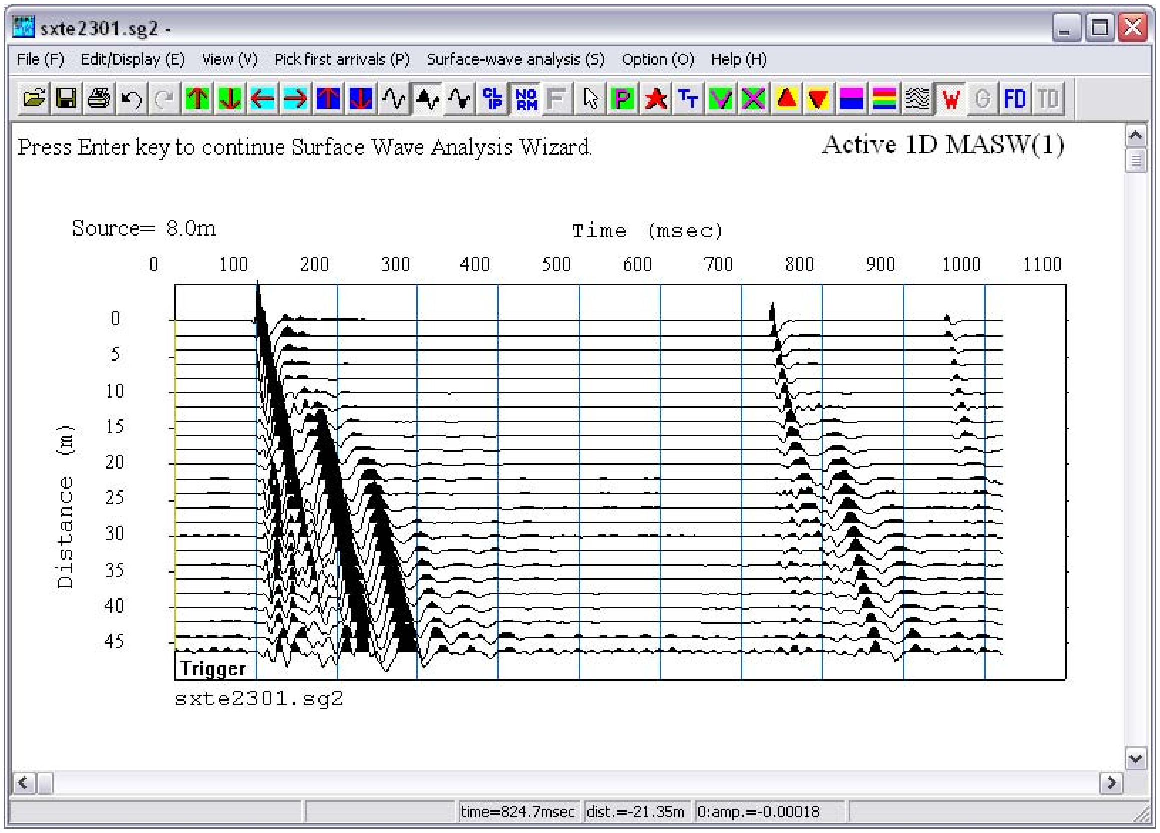
The *Geometry* dialog box appears and the *Units* setting allows selection between *meters* and *feet*. The *Units* setting will affect the unit labels shown in the dialog boxes as well as update the *Minimum phase velocity* default value used for picking the dispersion curve, which is 35 m/s or 150 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 applicable values for *Shot coordinate* and *Group interval*. Click on *Set* to apply the new *Group interval* and to recalculate the *Geophone coordinates.* Click *OK* when done.

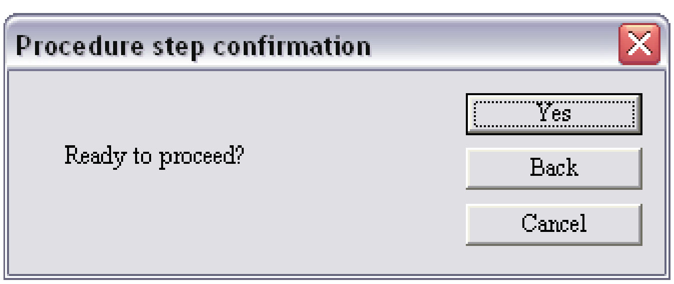


In the waveform view, the settings can be modified to optimize the display. All of these settings are common with SeisImager/2D for refraction data processing; refer to the SeisImager/2D manual included on the SeisImager CD for complete explanation. The main functions needed are the *Waveform amplitude*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

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

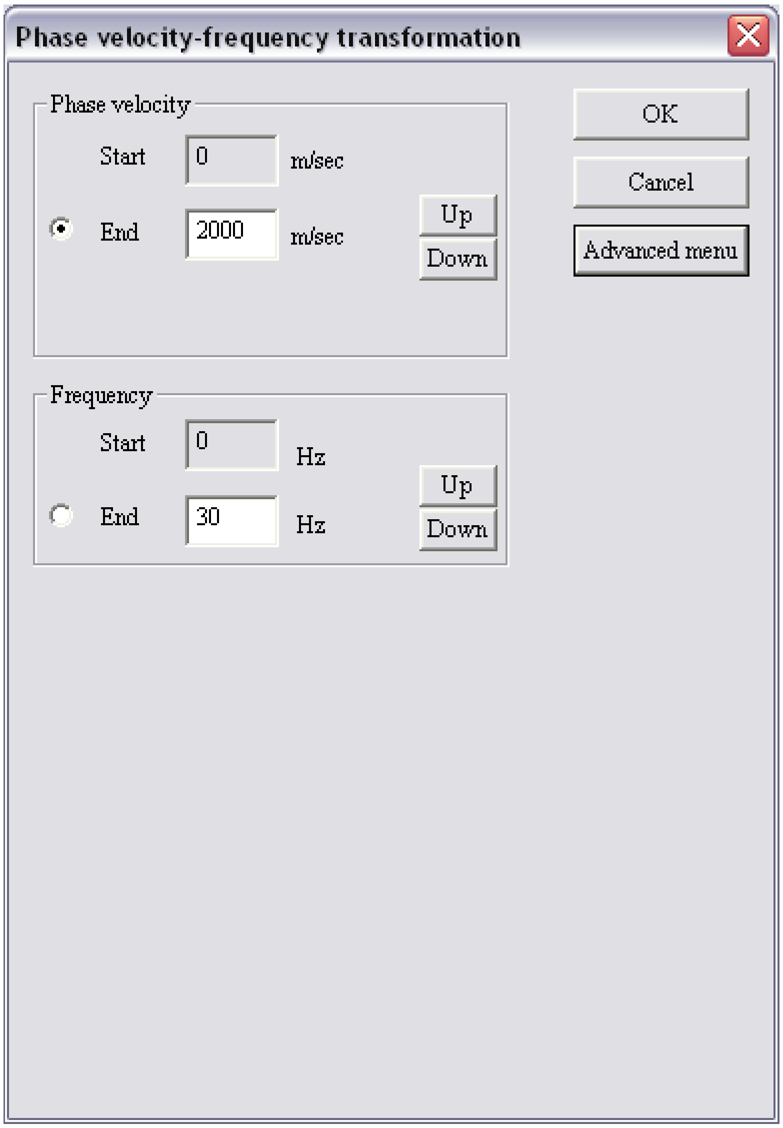


Click *Yes* when ready to proceed.



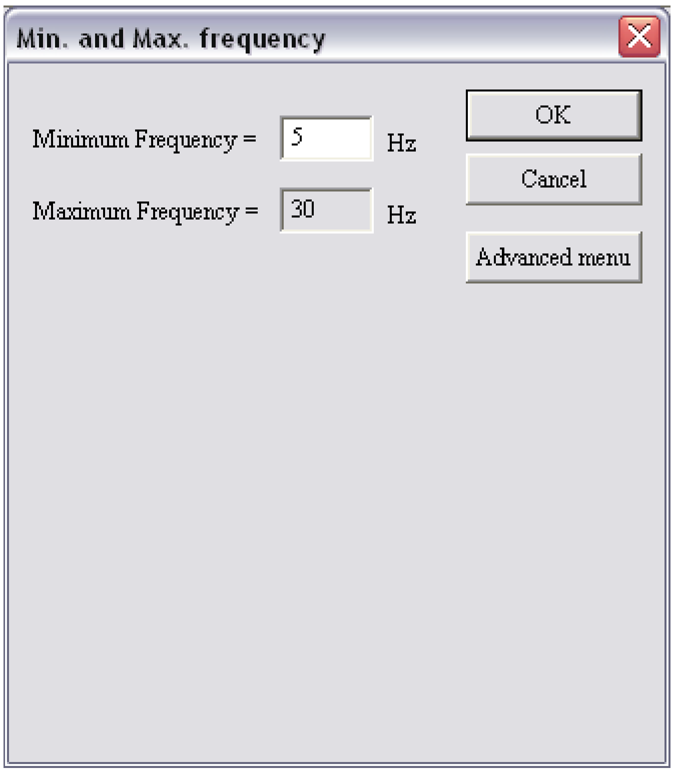
Next, set the parameters for calculation of phase velocity. Set the *Phase Velocity End* to suit the maximum velocity you expect for your site.

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. Click *OK* when done.

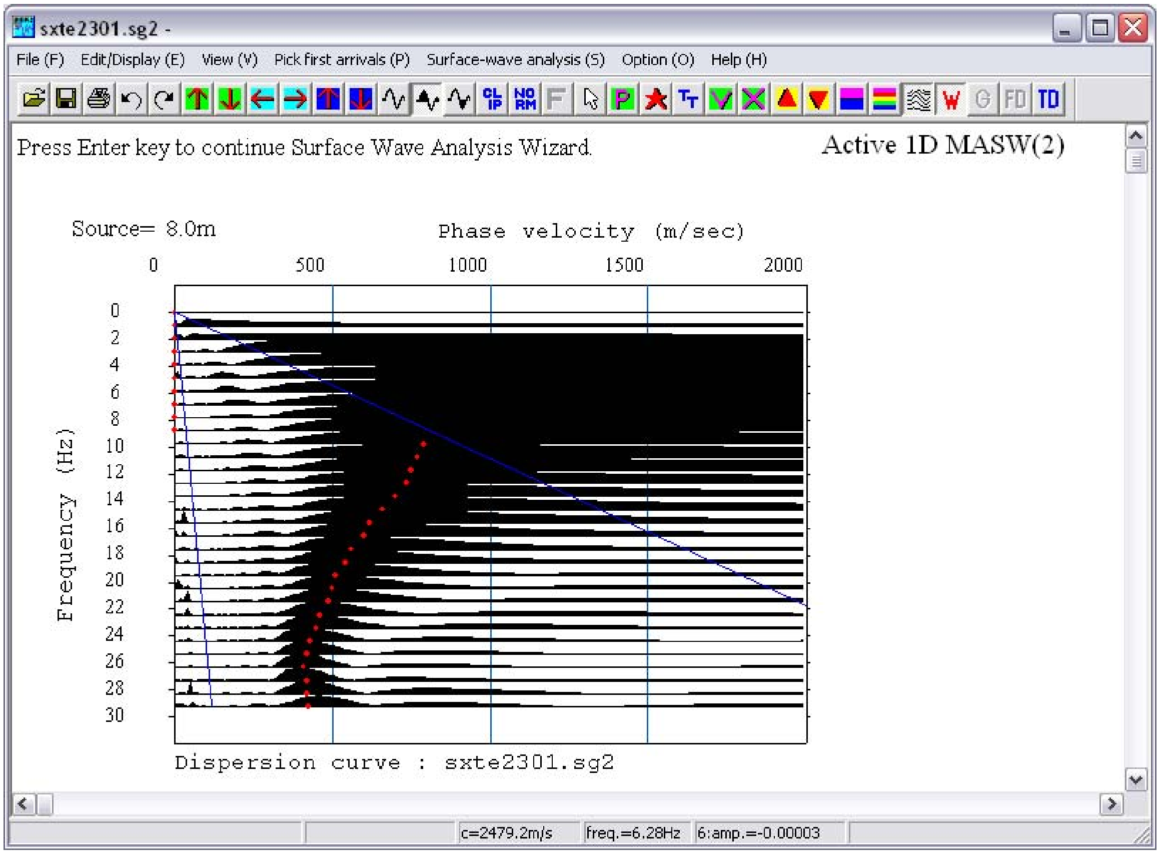


Next, set the parameters for picking the maximum amplitudes, which define the dispersion curve on the phase velocity-frequency plot. The *Minimum Frequency* default value is 5 Hz assuming that 4.5 Hz geophones were used. If other geophones were used, their natural frequency can be entered or use the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

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

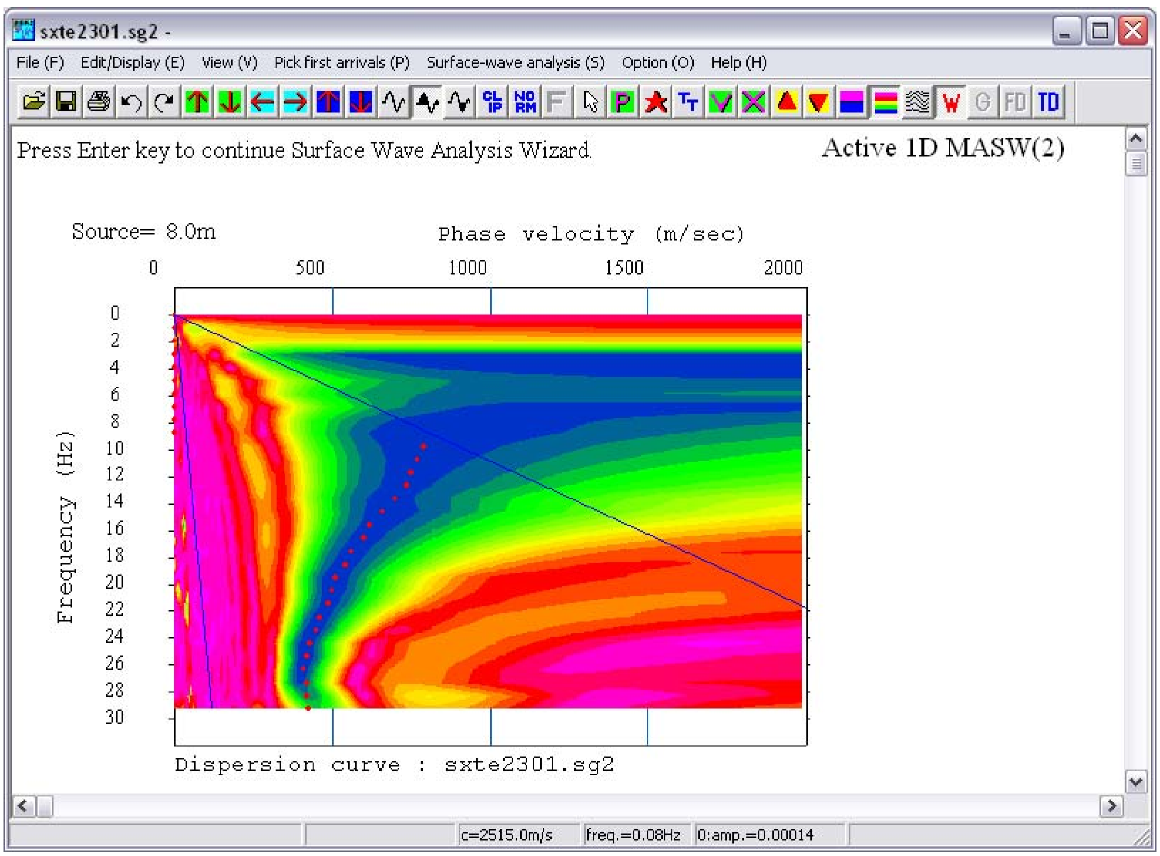


Once the calculations are complete, a phase velocity-frequency plot is displayed with the automatically determined maximum amplitudes shown as red points.

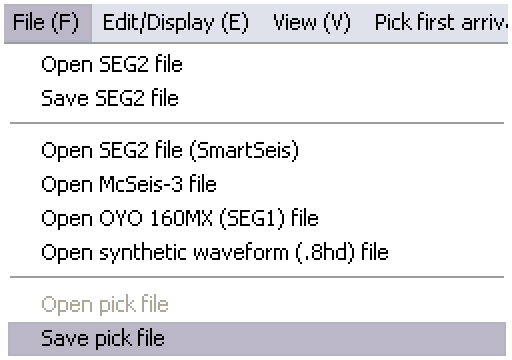


The default display settings for the phase velocity-frequency plot are *Wiggle trace* S*haded black* . Usually the dispersion curve is more obvious in color contours. Select the *Fine color contour* button to switch to a color plot and use the *Waveform amplitude* buttons, the *Horizontal scale* buttons,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

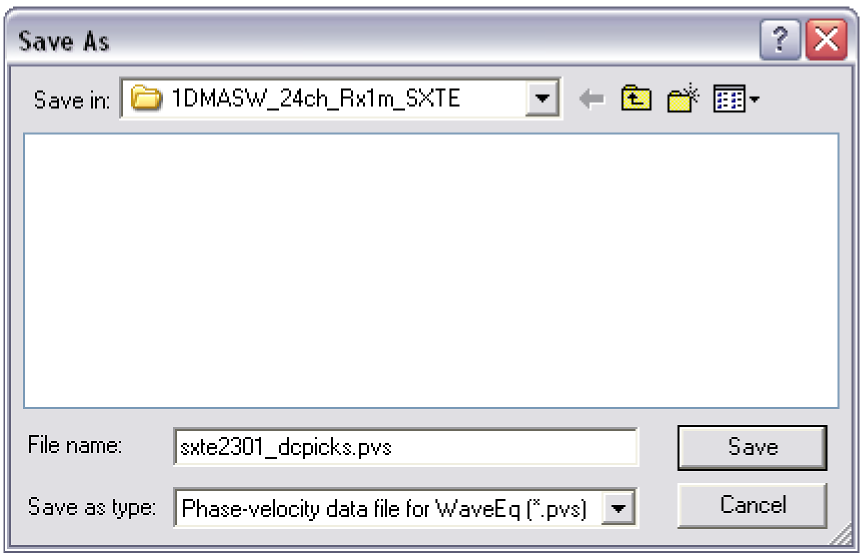
If you need to manually make or edit picks, you can do so by clicking the mouse at the desired pick location. To help identify maxima, as you drag the mouse over the plot the actual amplitude values can be read on the bottom bar 12:amp.=0.87285, where the value preceding the colon is the frequency and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



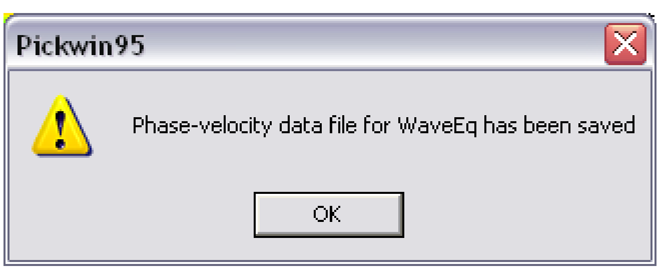
Save the dispersion curve picks if you would like to be able to input them again later. Select the *File* menu, *Save pick file*.



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

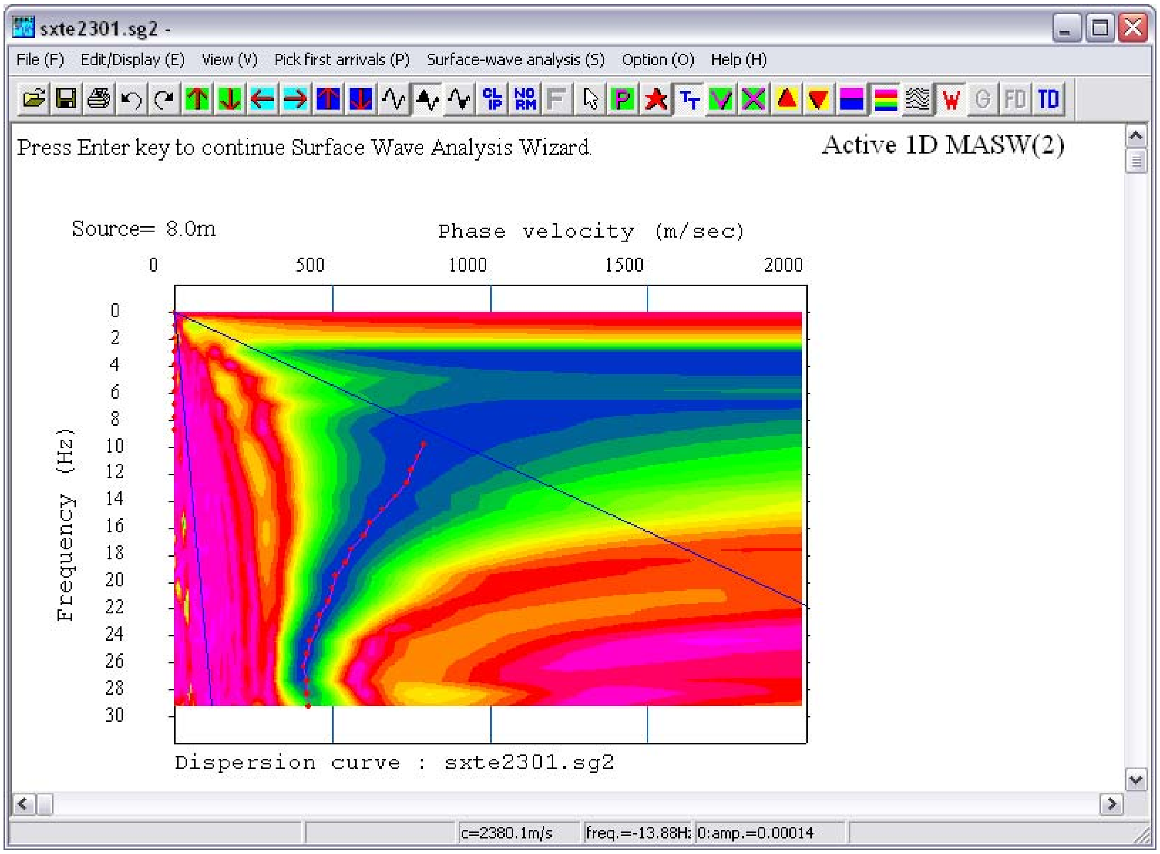


Once the file is saved, click *OK*.

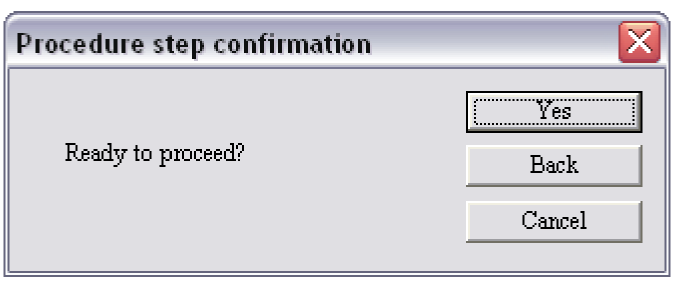


Once the file is saved, the dispersion curve is displayed with a pink line connecting the picks. Refer to Section 5.1.3 on how to re-input saved picks.

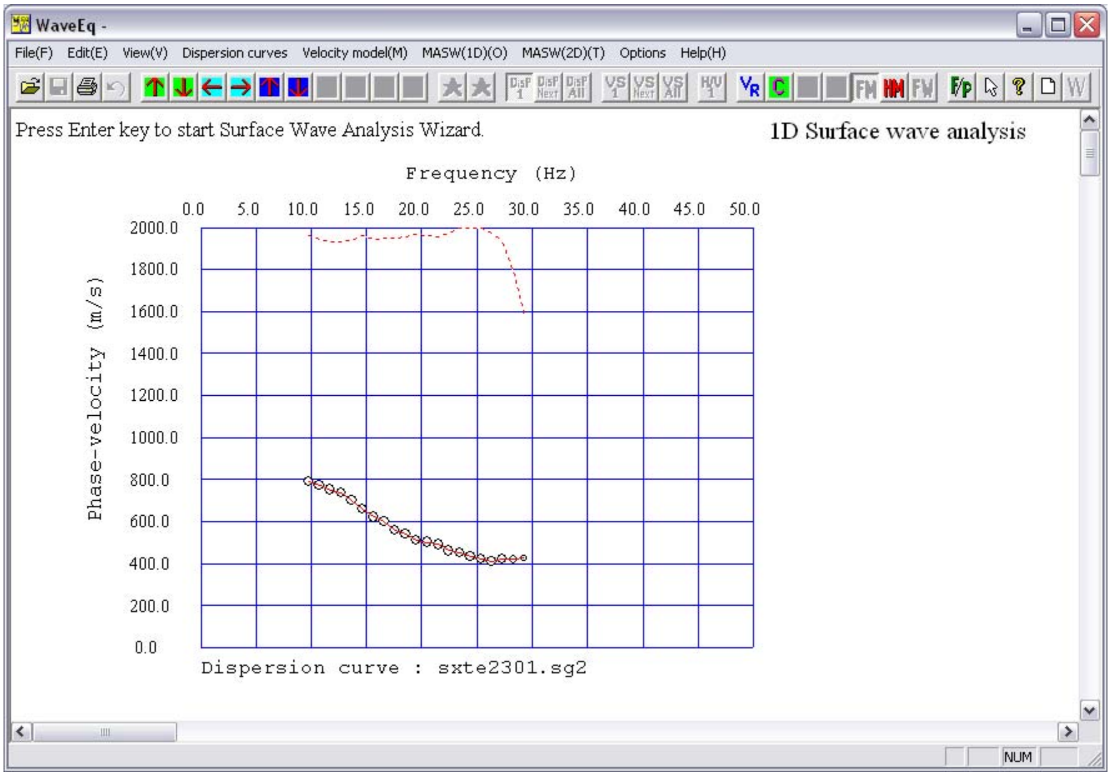
Press the *Enter* key to continue.



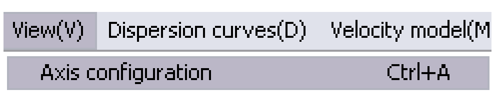
Click *Yes* when ready to proceed.



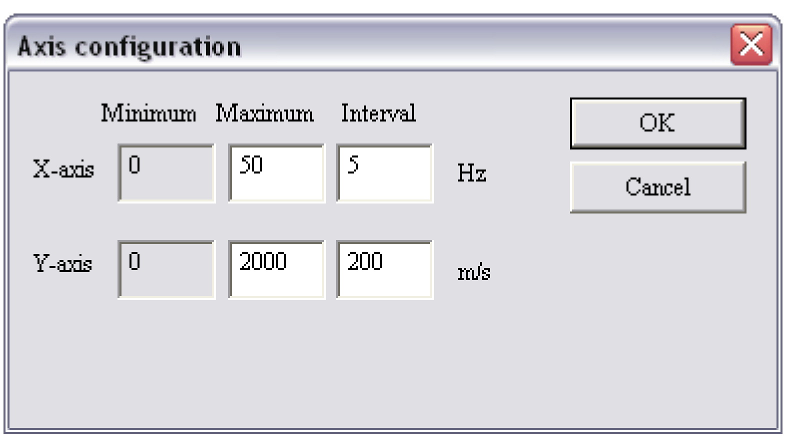
Next, the WaveEq module launches and the dispersion curve is displayed. Note that in WaveEq, *Phase velocity* is plotted on the vertical axis and *Frequency* is plotted on the horizontal axis. From this point on, the wizard calls functions from the *Dispersion curves* and *MASW (1D)* menus.



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

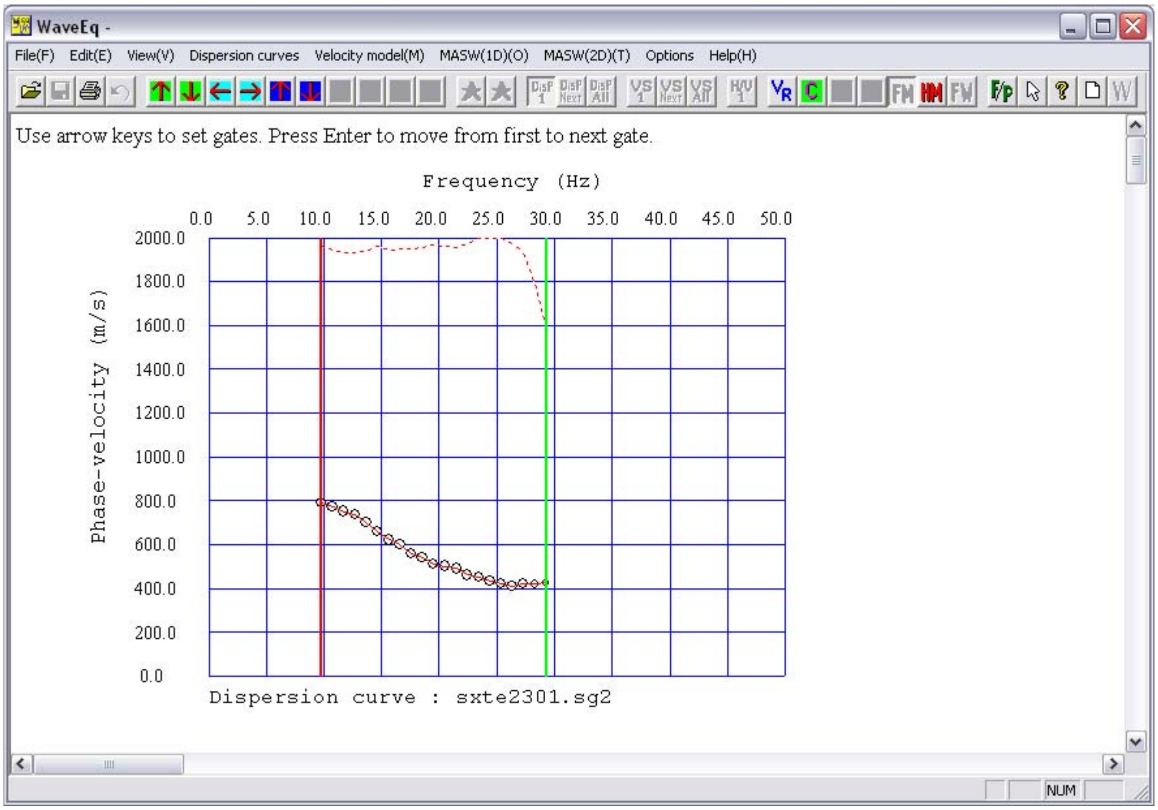


Enter the desired values for the *X-axis* and *Y-axis Maximum* scale and *Interval*. Click *OK* when done.



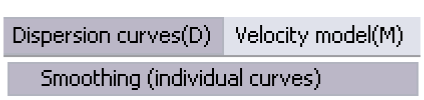
Next, edit the dispersion curve as needed. Commonly, there are noisy picks on the low and high frequency ends of the curve; a gate provides easy editing.

Follow the instructions in the upper left-hand corner of the window. The red gate is the active gate. Use the *right arrow* key 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 *left arrow* key. Press the *Enter* key when done.



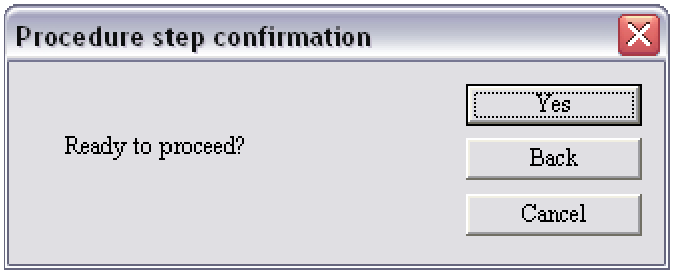
In addition to noisy picks on the edges of the curve, there may be outliers within the curve. Outliers can be deleted by clicking the *Selection*  button, selecting the outlying points on the curve, then pressing the *Delete* key. When done, unclick the *Selection* button.

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

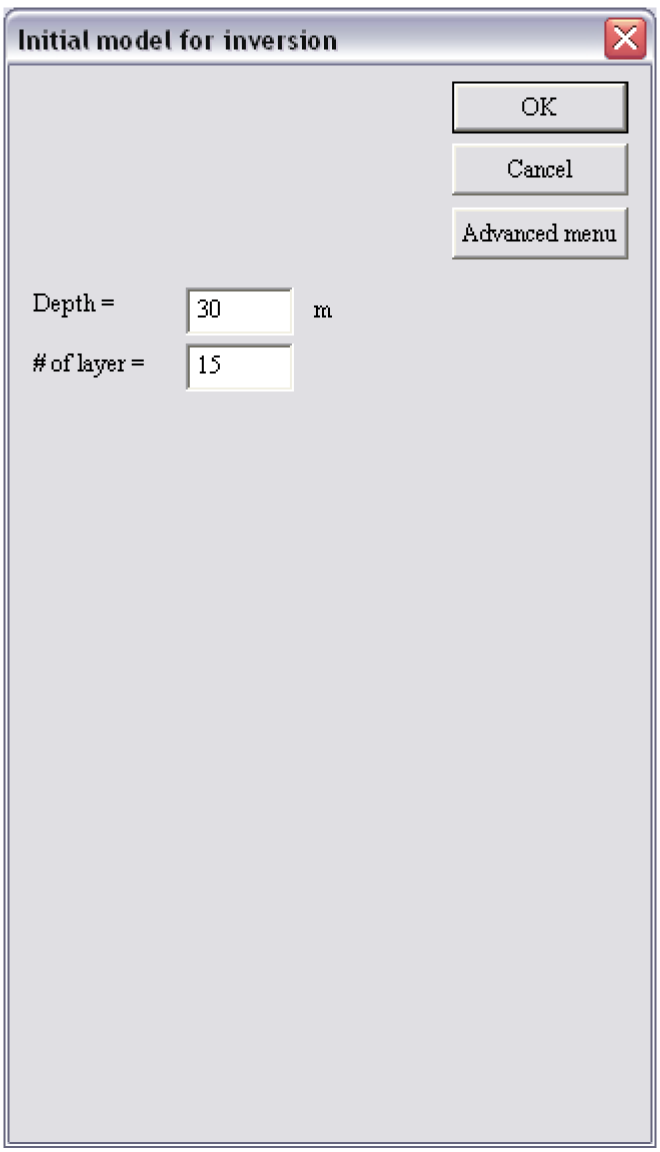


When done, press the *Enter* key to continue.

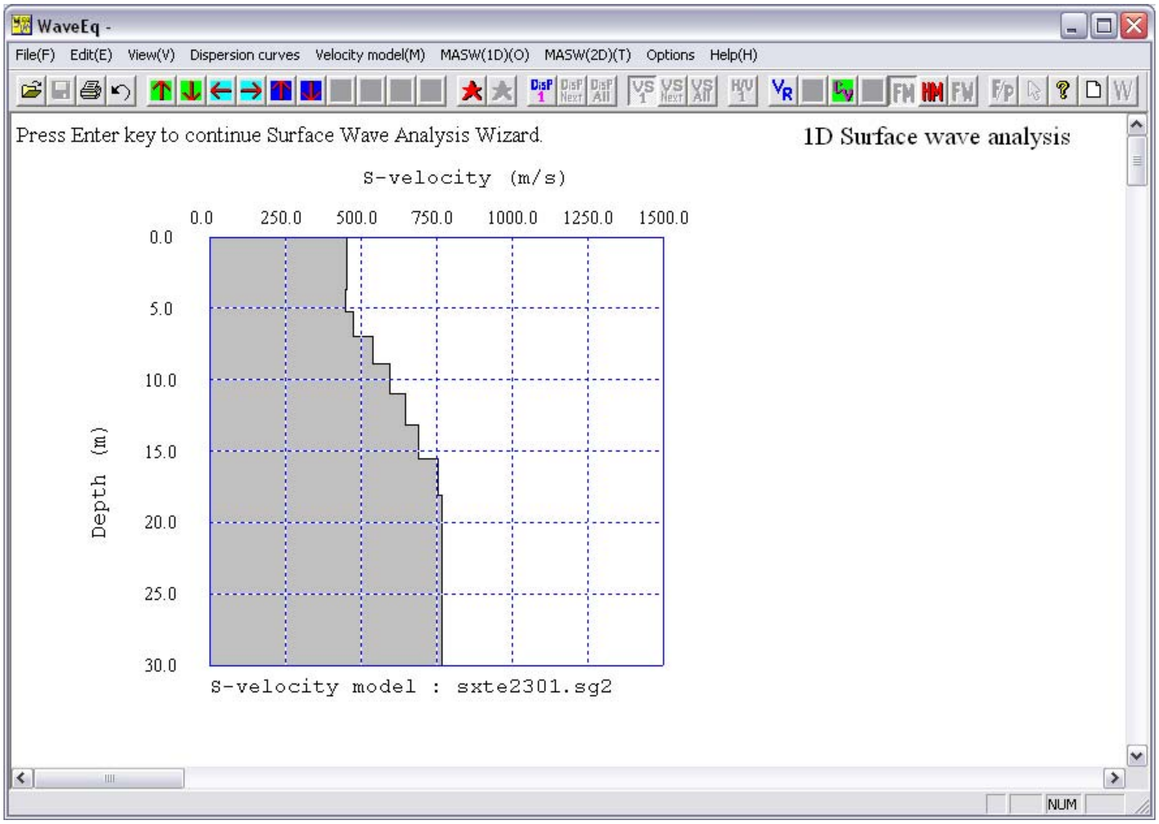
Click *Yes* when ready to proceed.



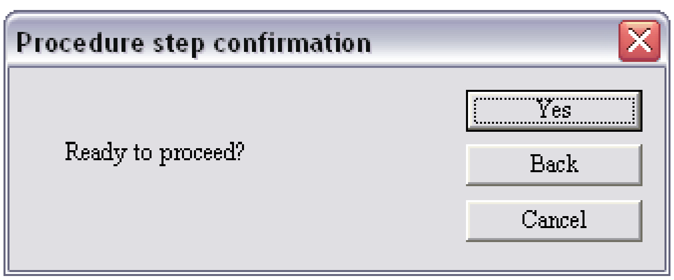
Next, set up the initial model of V_s with depth. The software default setting is to calculate the initial model from the one-third-wavelength approximation. For the *Depth* value, a good estimate to start with is one-half the spread length. The default value for the *Number of layers* is suitable for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



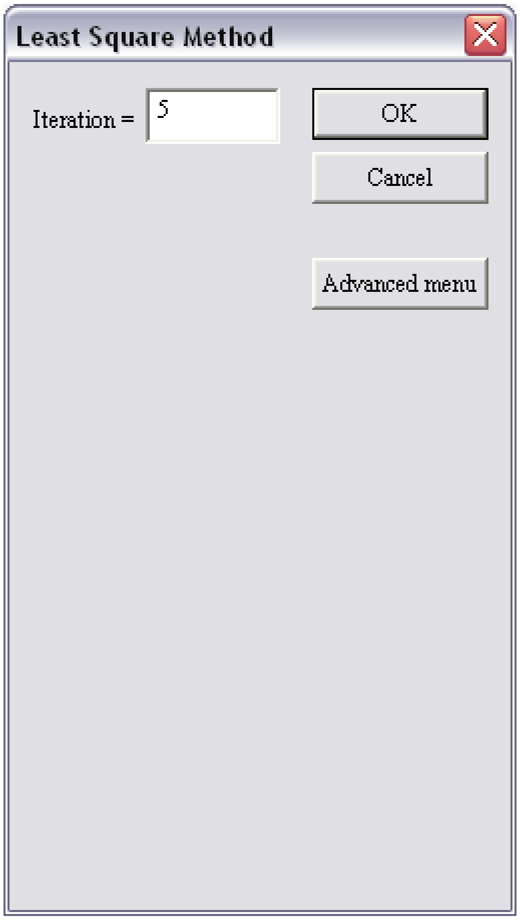
The initial model is displayed. Press the *Enter* key to continue.



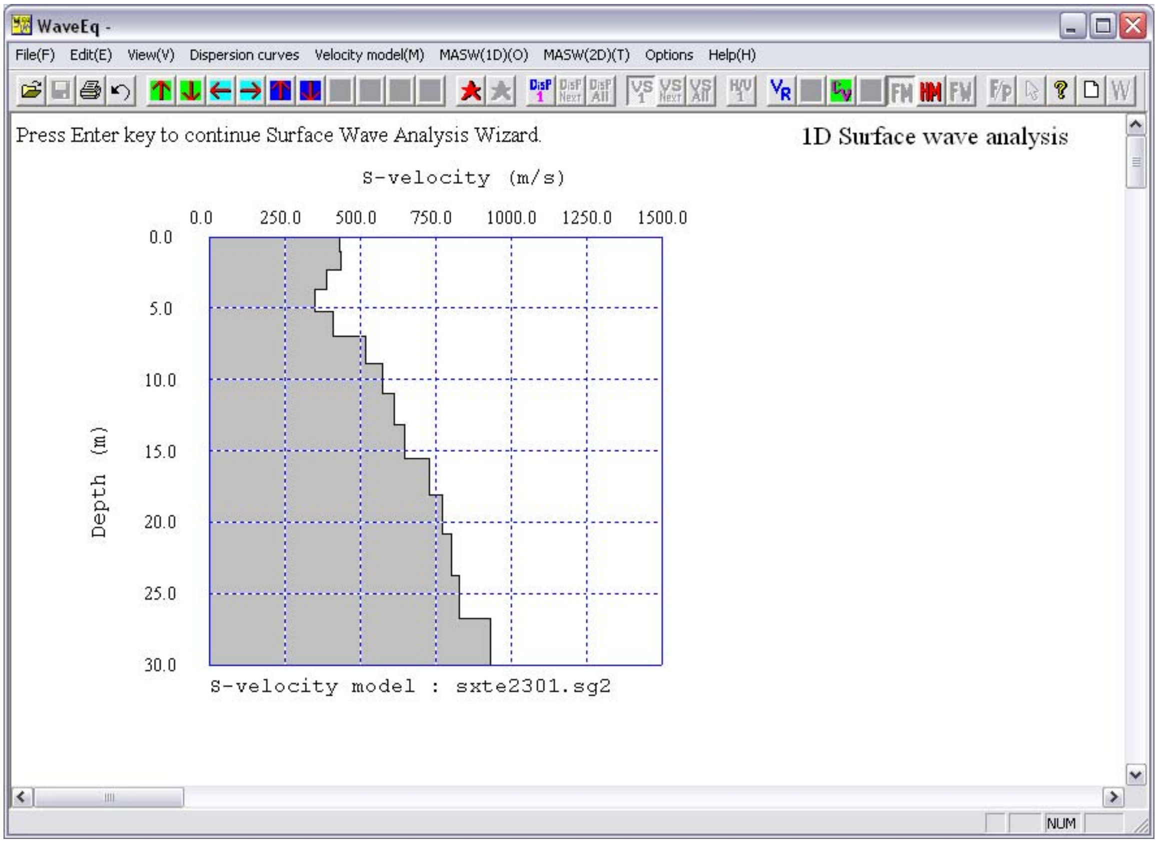
Click *Yes* when ready to proceed.

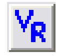


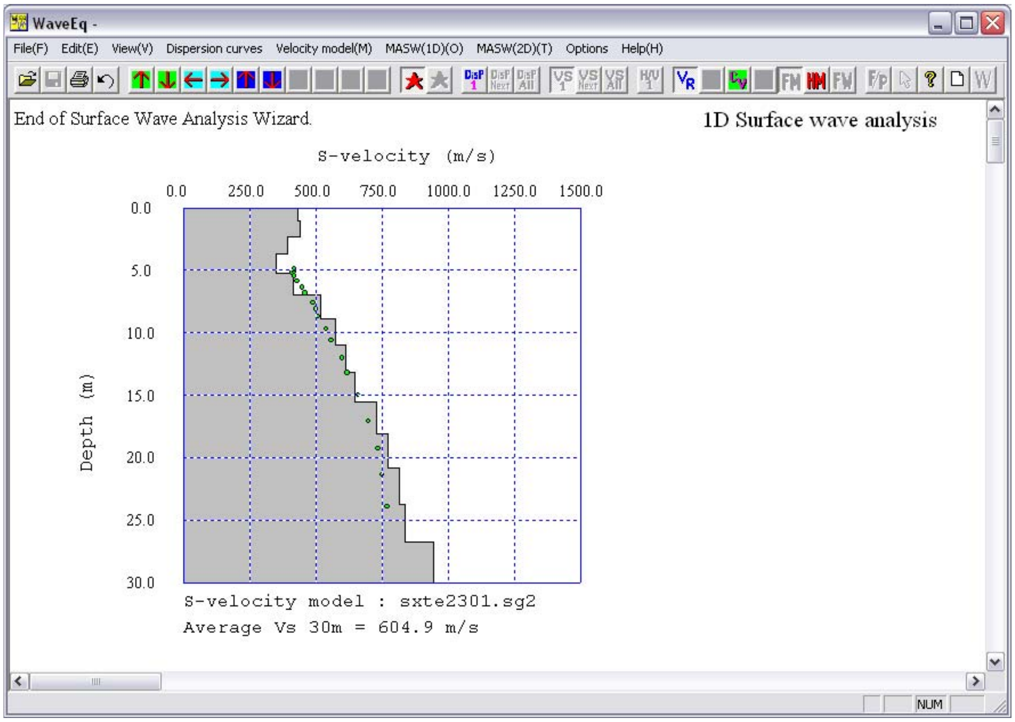
Next, set the number of iterations for the inversion. The software will iterate the number of times indicated to converge on the best fit of the initial model with the observed data. The default value of 5, up to 10, for *Iteration* is suitable for most cases. Click *OK* when done.



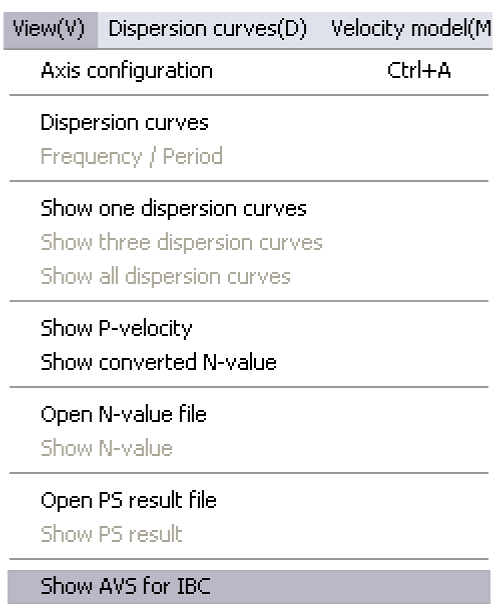
Once the inversion is complete, the final V_s curve is displayed.



Click on the *Show apparent velocity model*  button to overlay the one-third-wavelength approximation (green points), which is the best indicator of the actual depth range of penetration. In the latest version of the software, 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.

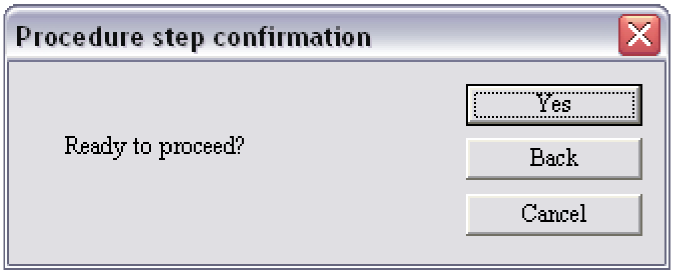


If there is good control to a depth of 30 m (100 ft), select the *View* menu, *Show AVS for IBC*, to calculate and display the average V_s value.

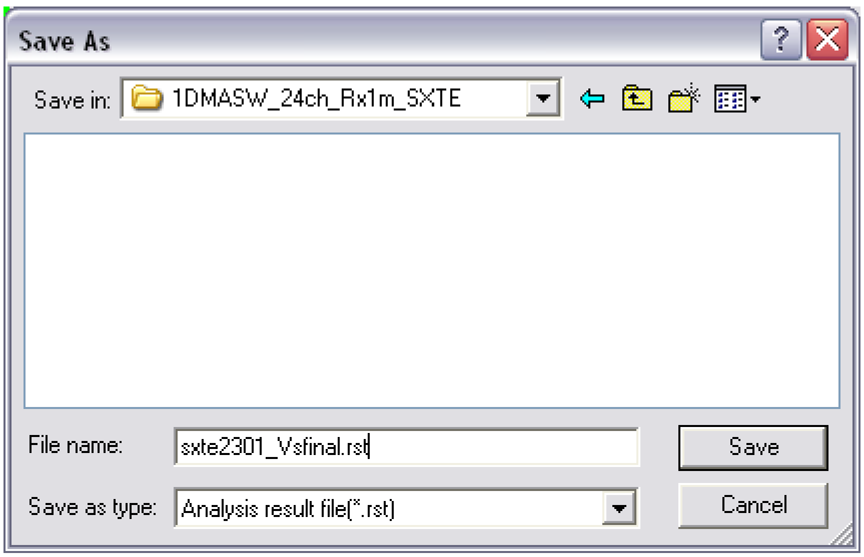


When done, press the *Enter* key to continue.

Click *Yes* when ready to proceed.

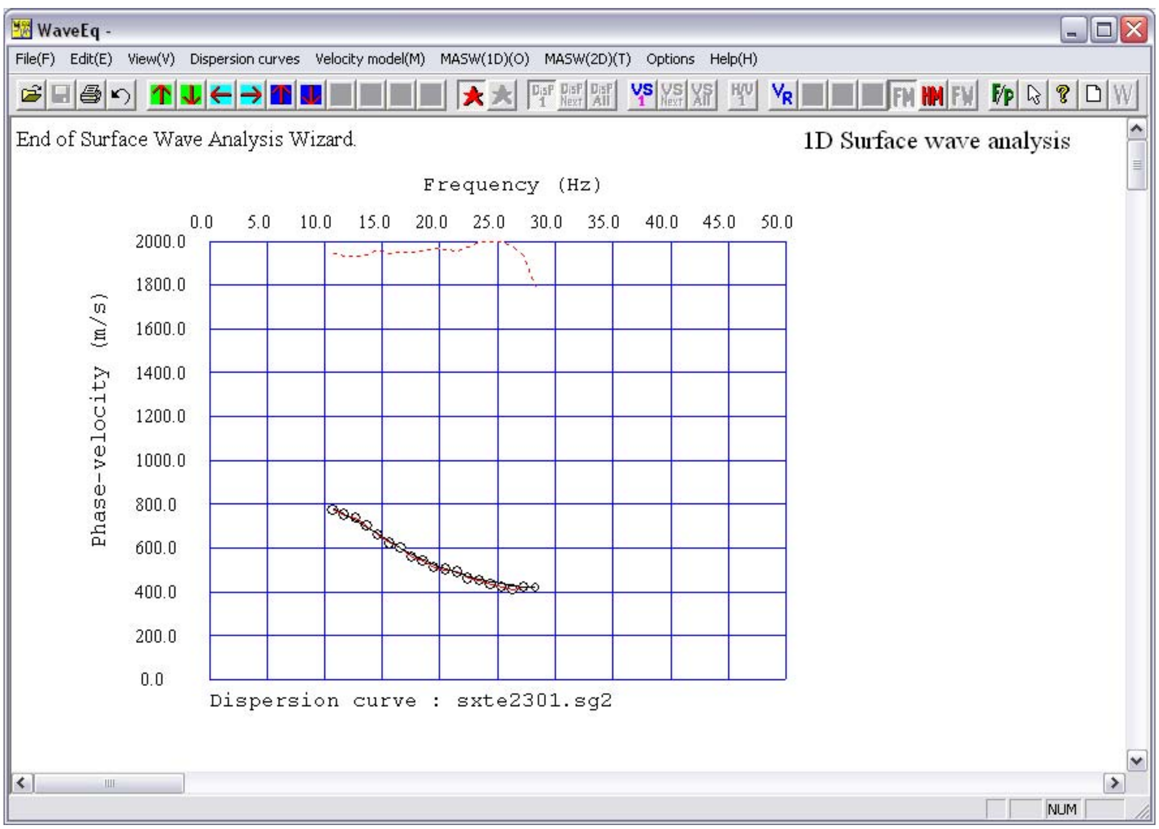


Lastly, save the result. Assign a file name with the extension *.rst* and click *Save*.



After the file is saved, check the fit of the calculated and observed dispersion curves. Click on the *Show one dispersion curve* button to display the original dispersion curve. Click on 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.

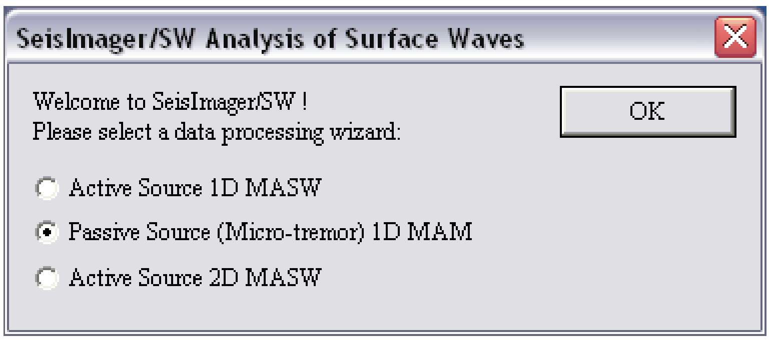
If there is a high degree of mismatch, it is likely due to dispersion curve anomalies such as sharp changes and/or outliers or due to low quality noisy picks on the low and high frequency ends of the curve. The mismatch will also be evident in the final V_s curve, usually as an unrealistic velocity inversion 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.



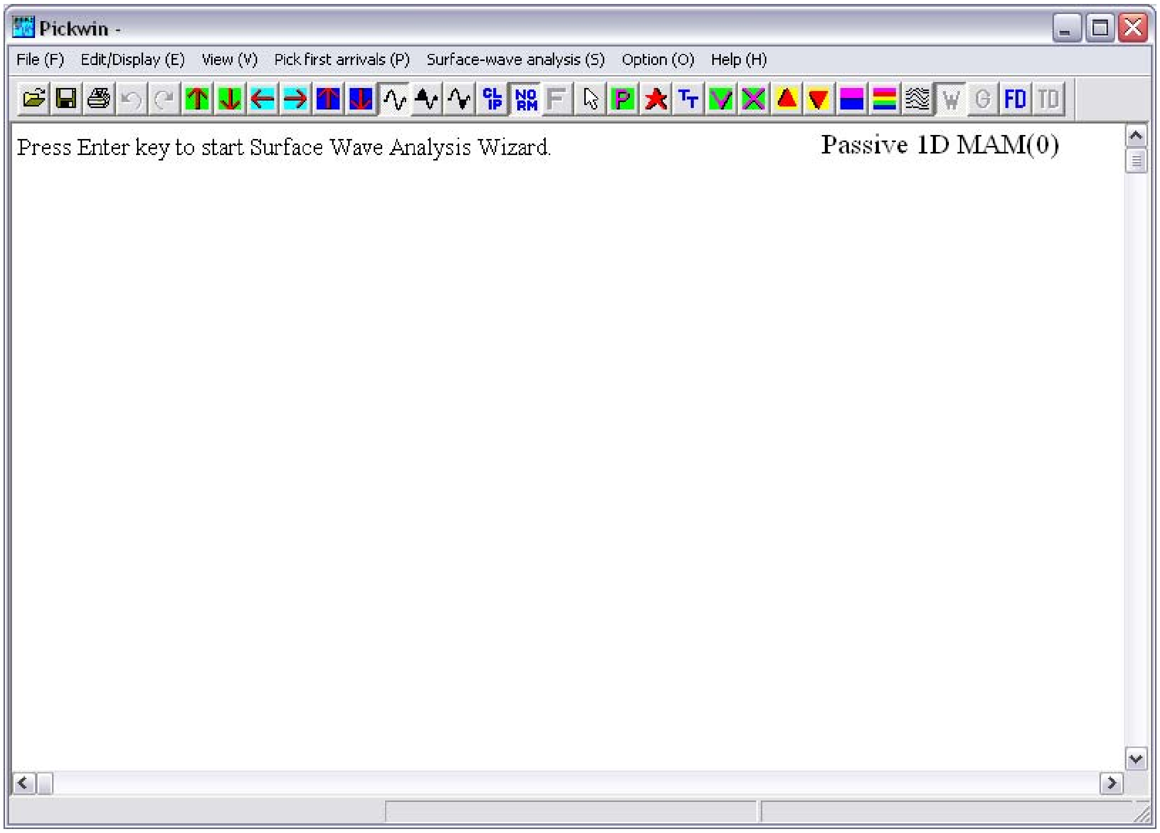
4.1.2 Passive Source (Microtremor) 1D MAM Wizard

The *Passive Source 1D MAM Wizard* process is essentially the same as for the *Active Source 1D MASW Wizard* (Section 4.1.1) 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.

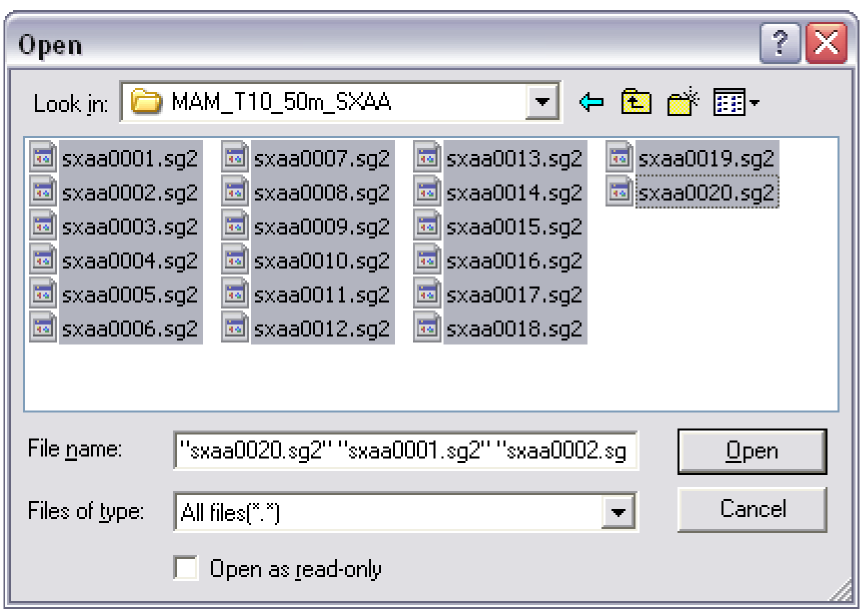
Double-click on the Surface Wave Analysis Wizard icon. Select *Passive Source (Microtremor) 1D MAM* and click *OK*.



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

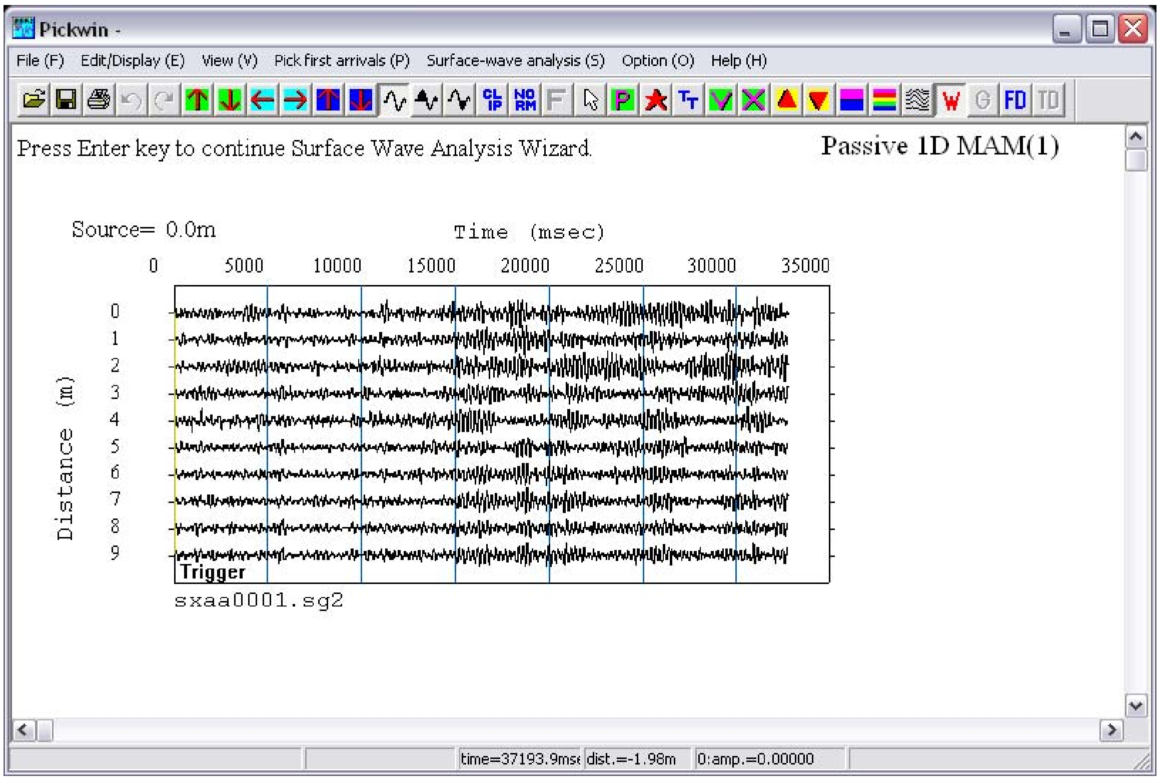


The first step is to input the dataset; all the dataset files are input at one time. Use the *Shift* key to highlight the first through last file in the dataset and click *Open*.

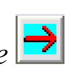


Once the selected files are open, click *OK*.

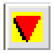
The first in the group of waveform files is displayed. Set the units if necessary.



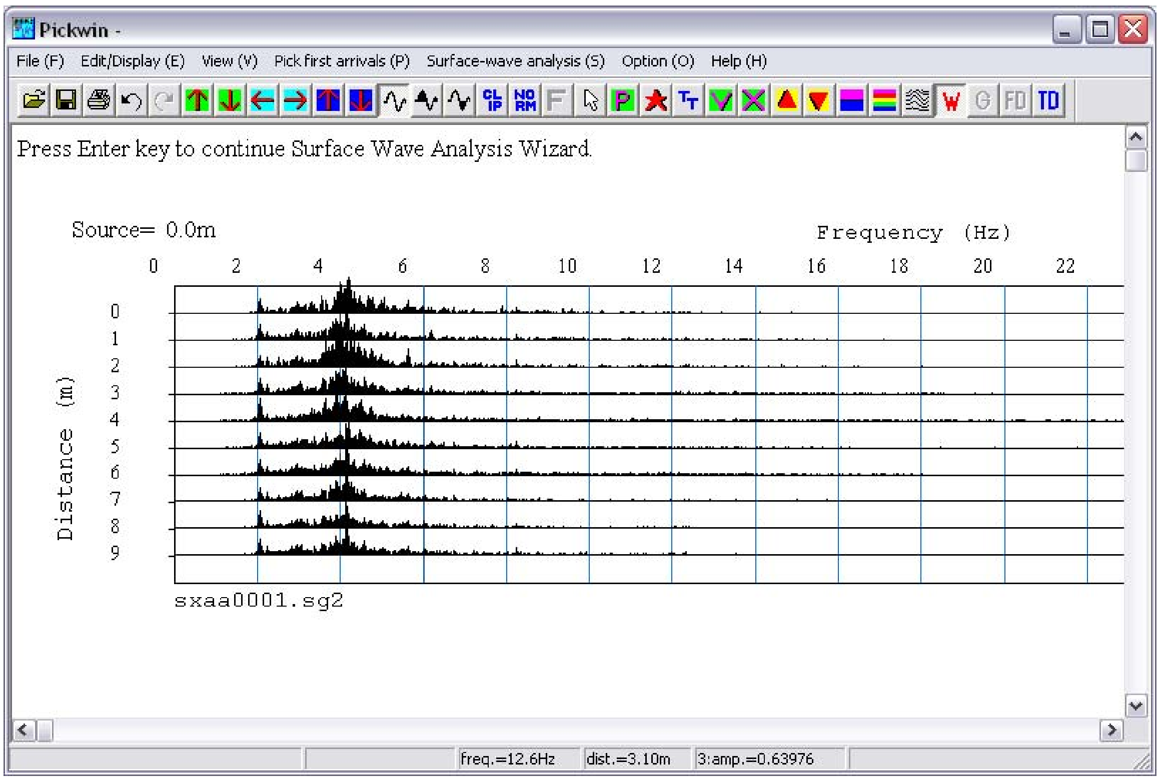
Unlike most active source data, it is usually difficult to evaluate the quality of passive source data by viewing the shot record in the time domain. You can quickly transform the data into the frequency domain by clicking on the *Frequency domain*  button. The view will change to a plot of the frequency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

After clicking on the *Frequency domain* button, click on 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 below indicates high-quality passive source data.

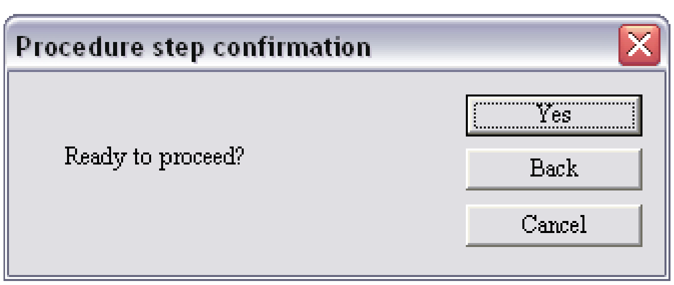
To toggle back to the waveform view, click the *Time domain*  button.

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

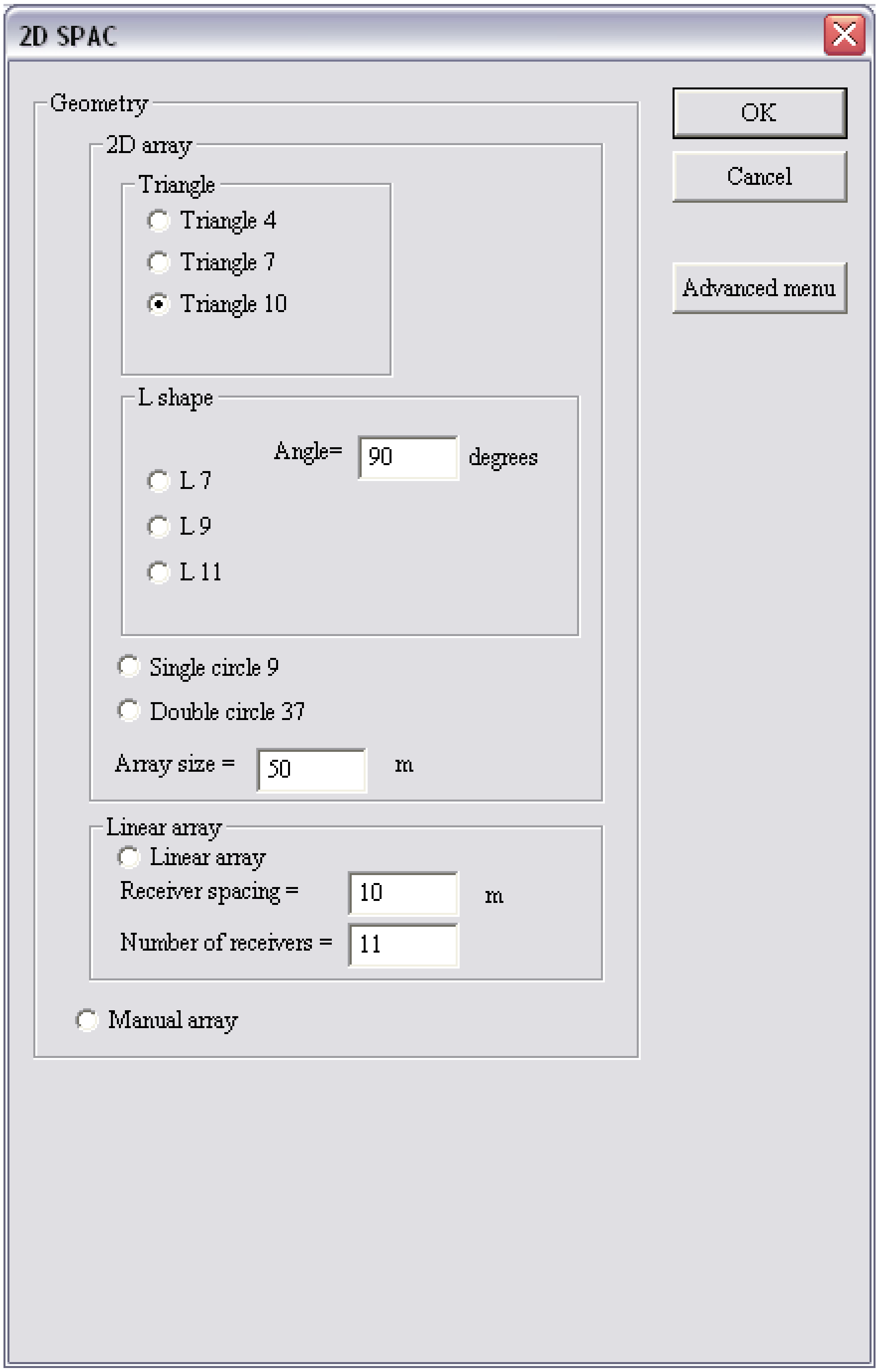
When done, from the waveform view, press the *Enter* key to continue.



Click *Yes* when ready to proceed.



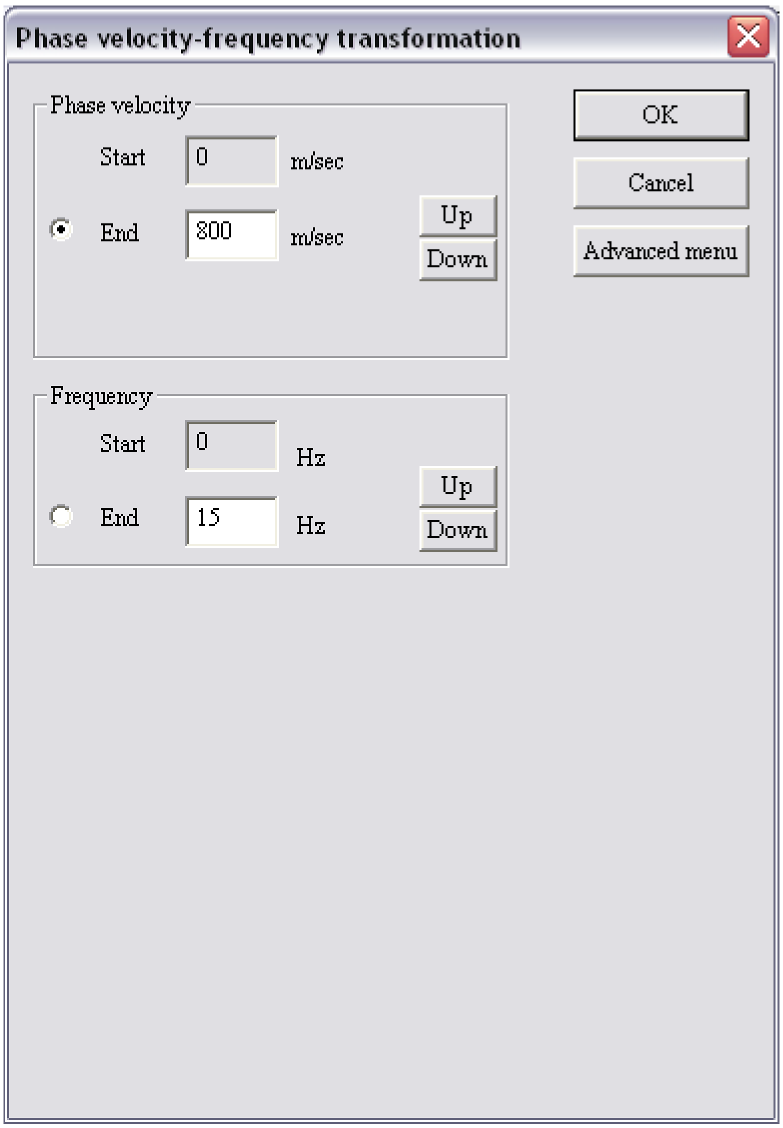
Next, set the array geometry for the SPAC calculation. Select which *2D array* type was used and the *Array size* or select *Linear array* and enter the *Receiver spacing* and *Number of receivers*. This example is based on a *Triangle 10* array with an *Array size* of 50 meters. Click *OK* when done.



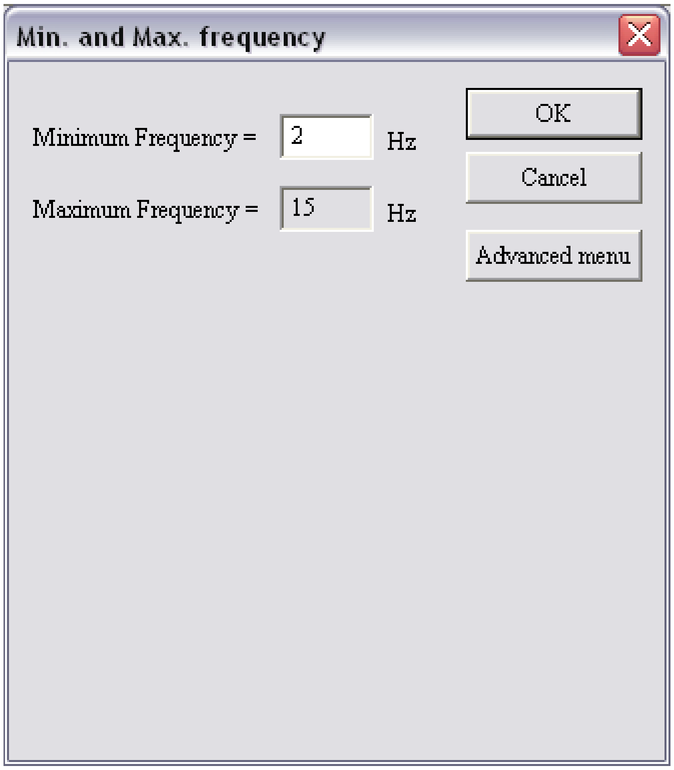
The rest of the steps are identical to the *Active Source 1D MASW Wizard*. Proceed to calculate phase velocity and pick the dispersion curve.

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.

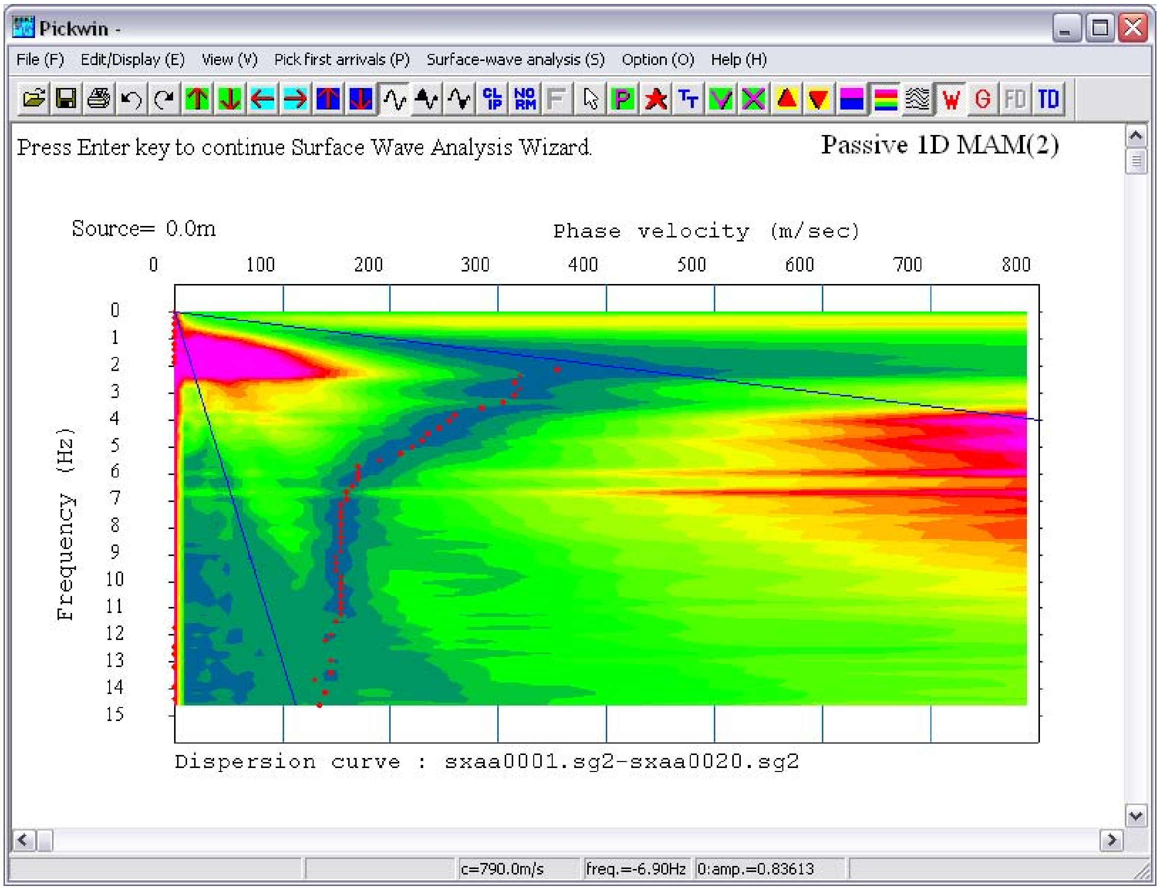
The default value for *Frequency End* suits most cases. To see the extent of fundamental mode velocity on the high frequency end, a higher value can be entered. Click *OK* when done.



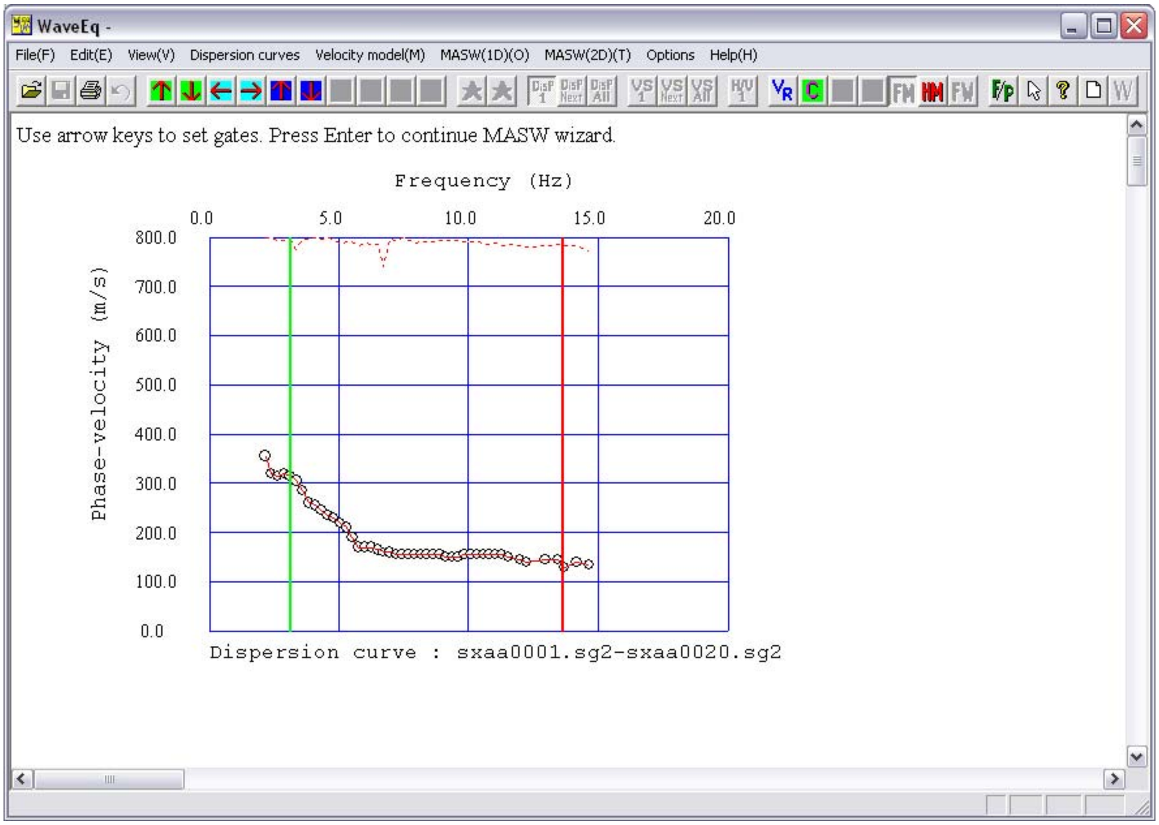
The *Minimum Frequency* default value is 2 Hz. If 4.5 Hz geophones were used, energy below 4.5 Hz may have been recorded, though dampened according to the sensitivity of the geophone. It is suggested to leave the default value of 2 Hz to allow the software to attempt to pick the amplitude maxima to this end (any bad picks can be manually edited later).



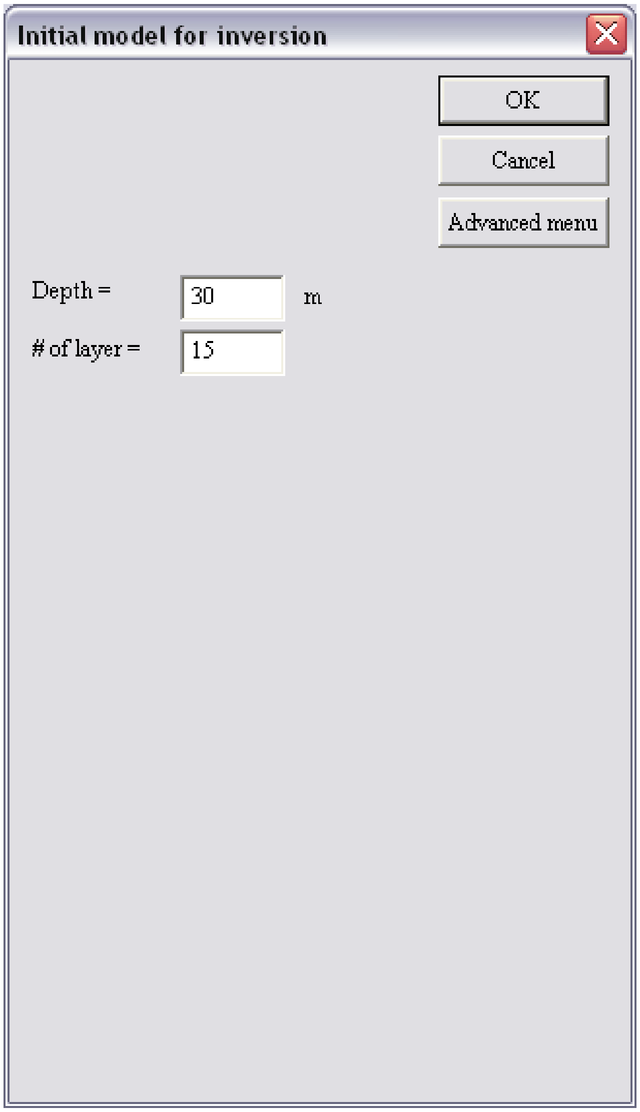
Convert the phase velocity-frequency plot to fine color contours, adjust the gain, and check the automatically determined dispersion curve picks. Save the dispersion curve picks if desired.

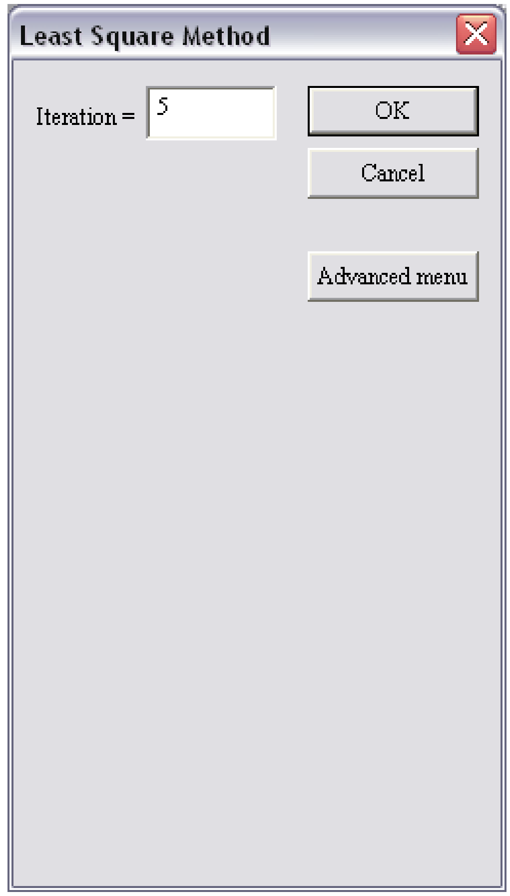


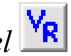
Once the dispersion curve is imported to WaveEq, edit the curve as necessary using the gates, the *Selection* button, and/or *Smoothing (individual curves)*.

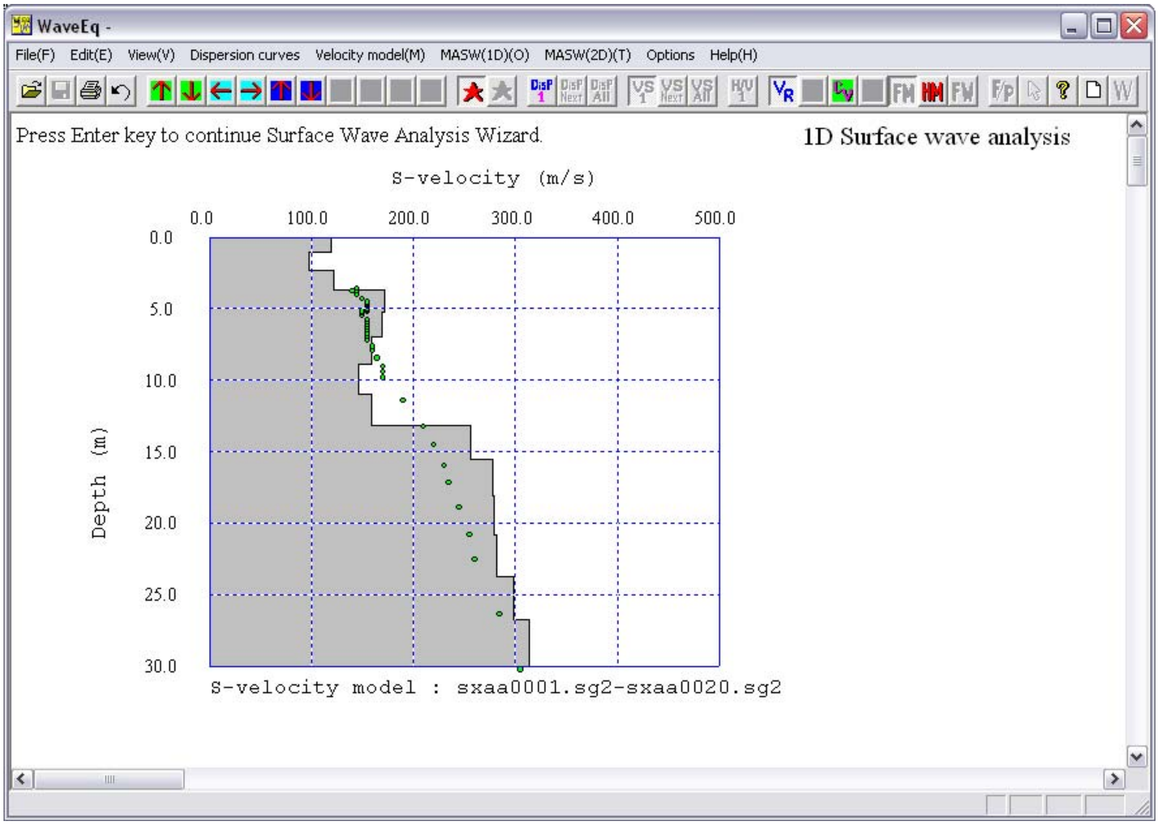


Set the maximum depth for the initial V_s model. A good *Depth* estimate to start with is the length of the array. Accept the default value or increase as desired for *Iteration*.





Once the inversion is complete, the final V_s curve is displayed. For indication of the actual depth range of penetration, click 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), select the *View* menu, *Show AVS for IBC*, to calculate and display the average V_s value.



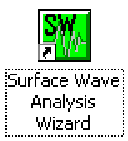
Lastly, complete the wizard by saving the results and check the fit between the calculated and observed dispersion curves.

Refer to Section 4.2 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.

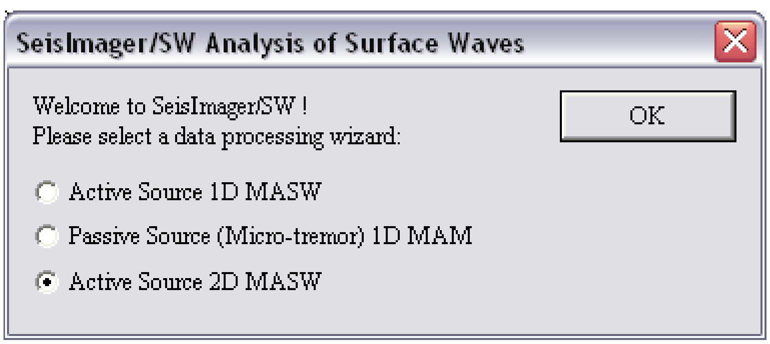
4.1.3 Active Source 2D MASW Wizard

The *Active Source 2D MASW Wizard* process is essentially the same as for the *Active Source 1D MASW Wizard* (Section 4.1.1) 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, only the GeoPlot functions needed for viewing 2D MASW initial and final V_s cross-sections are covered. As noted in Section 1, GeoPlot will eventually be made available as a separate module; at that time, a full manual will also be released.

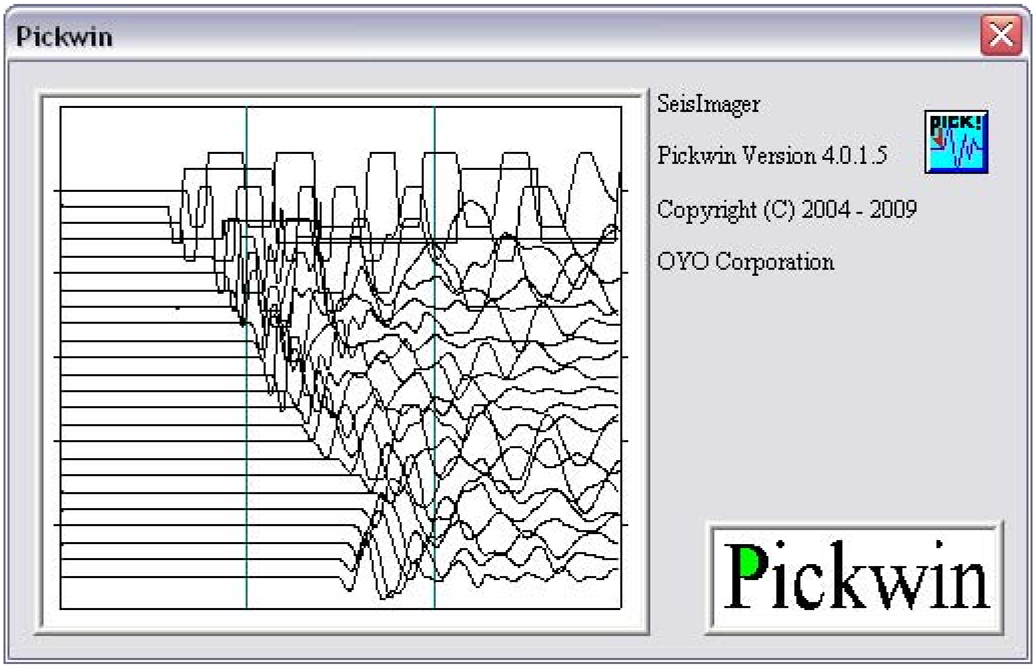
Double-click on the Surface Wave Analysis Wizard icon.



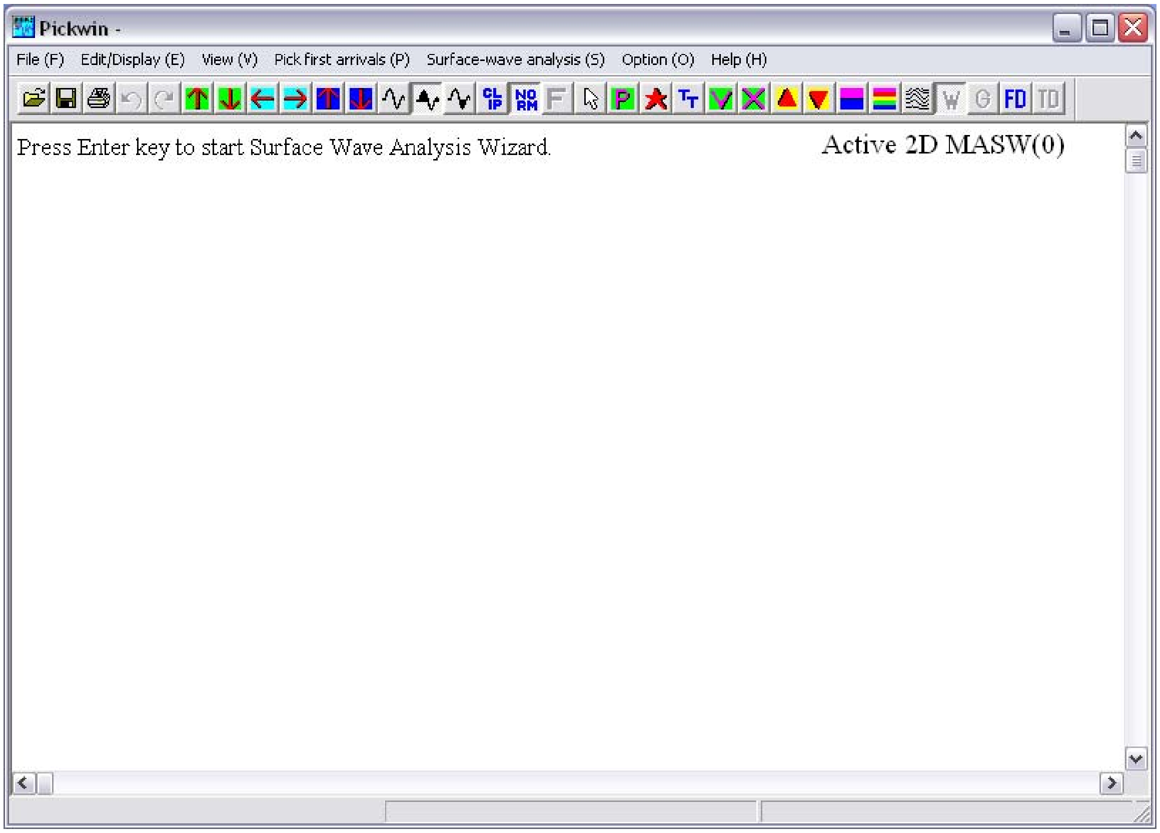
The *Welcome to SeisImager/SW* dialog box appears. Select *Active Source 2D MASW* and click *OK*.



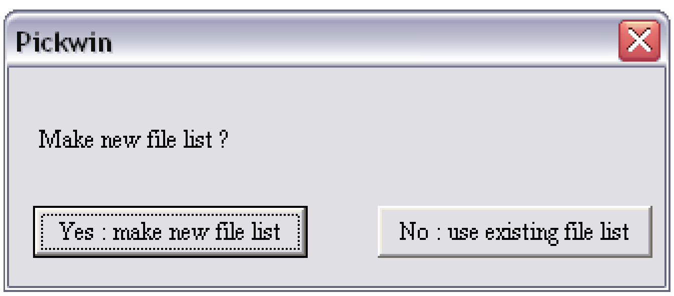
The Pickwin module is launched.



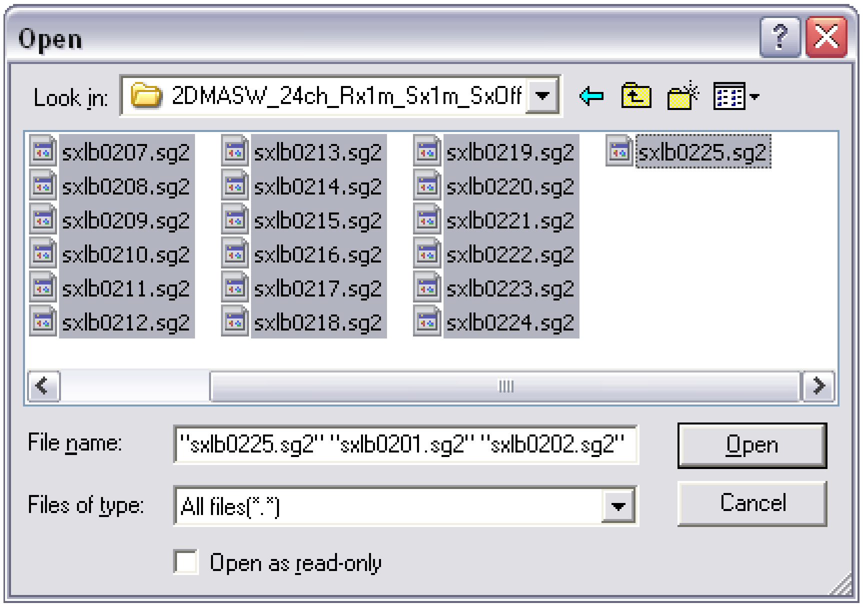
The main Pickwin window appears. The wizard calls functions from the *File* and *Surface Wave Analysis* menus. Press the *Enter* key as instructed in the upper left hand corner of the window to begin.



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

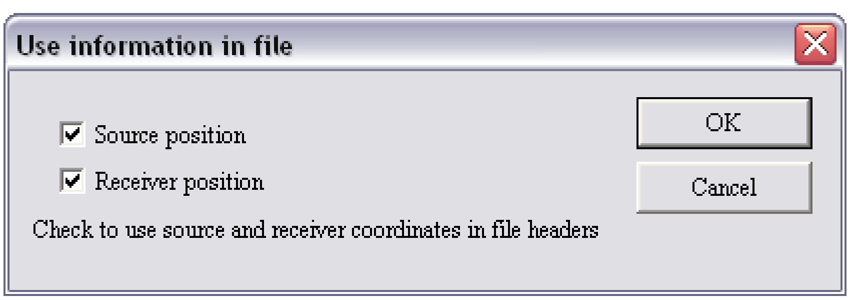


Use the *Shift* key to highlight the first through last file in the dataset and click *Open*.

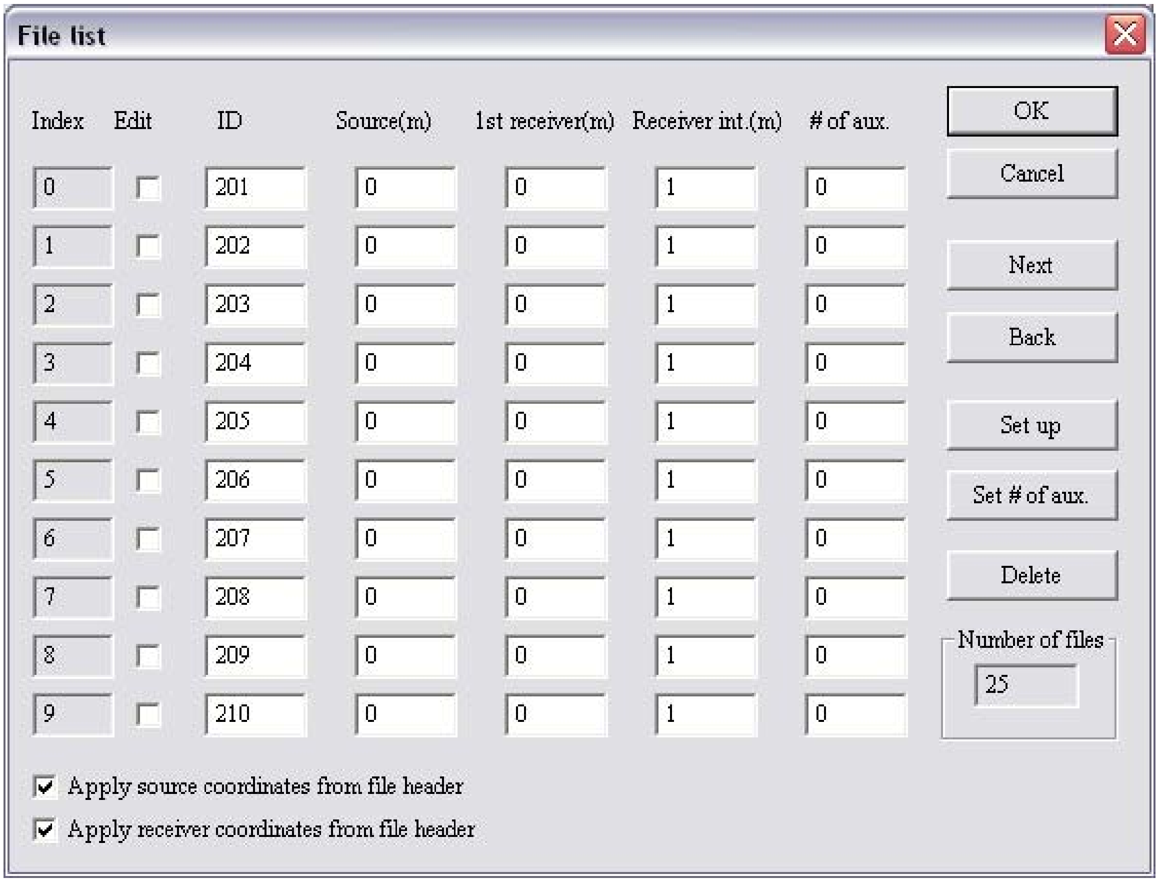


Once the selected files are open, click *OK*.

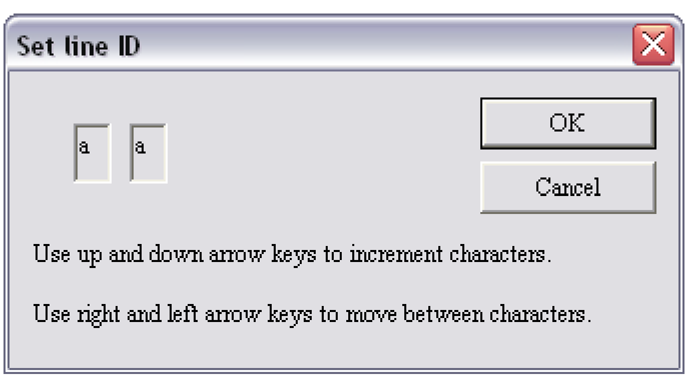
Next, indicate if the source and receiver coordinates stored in the file headers should be used for the geometry. Explanation of the wizard assumes that the correct source and receiver coordinates were saved to the file headers; working on that assumption, check *Source position* and *Receiver position*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



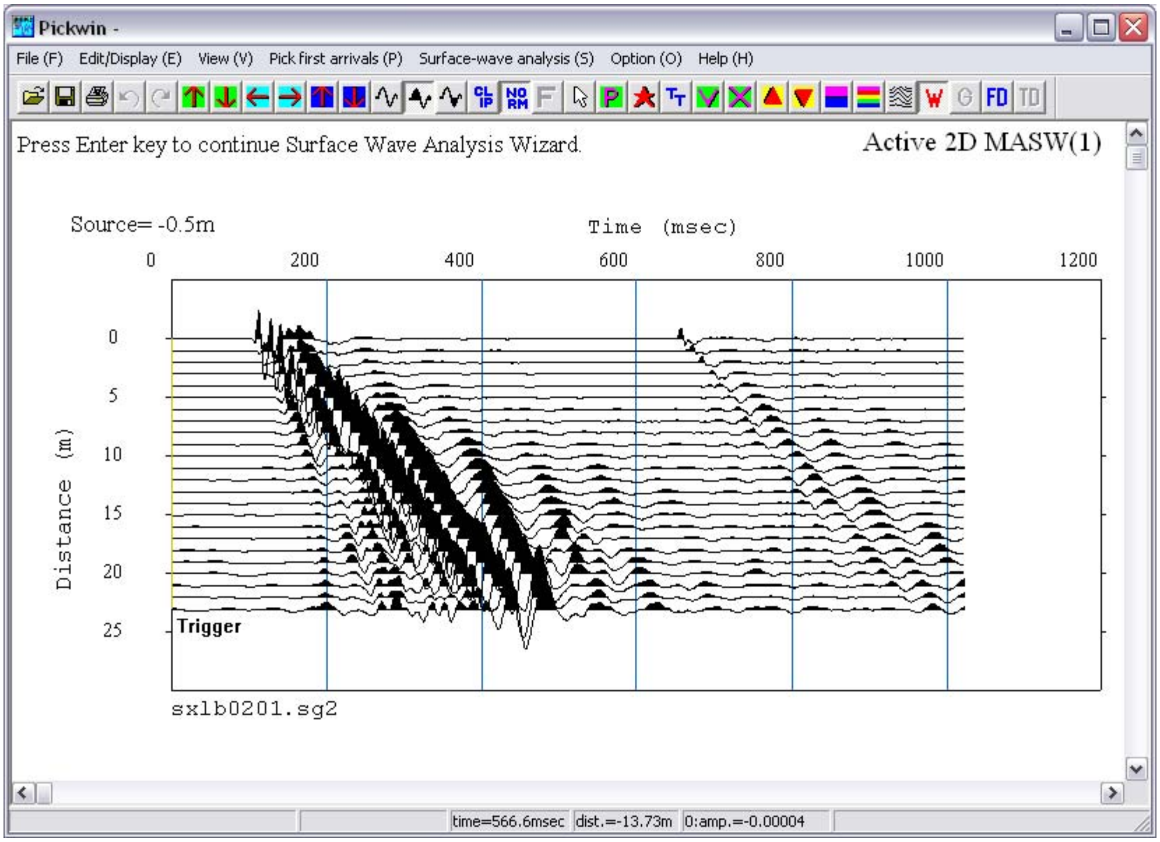
A list of the files is presented in the *File list* dialog box. Note that if the coordinates from the header are to be applied, they will not be reflected here in the *Source*, *1st Receiver*, and *Receiver* columns; only the *Apply source coordinates from file header* and *Apply* *receiver coordinates from file header* boxes will be checked. (If coordinates need to be entered manually, click on *Set up* to enter the pattern that describes the geometry. Refer to Section 5.1.4 for a full explanation of how to enter coordinates manually.) Click *OK* when done.



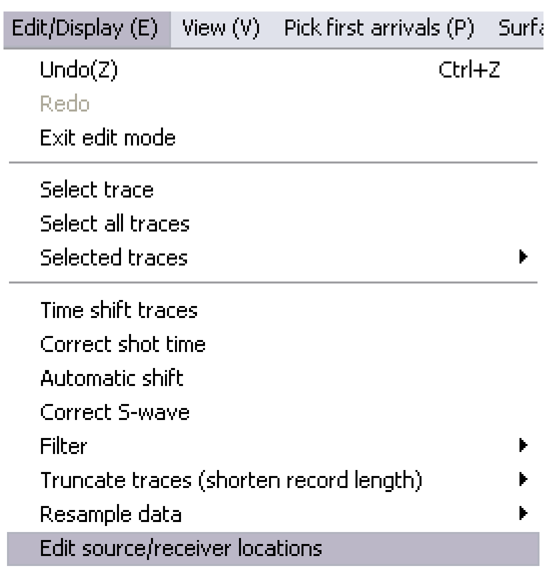
Next, assign the file list a unique alpha-character tag. The characters indicated are prefixed by the letters "sx" and used to name all output from analysis of the dataset. The files are automatically saved in the dataset directory. Use the *up* and *down arrow* keys to increment or decrement a character and use the *right* and *left arrow* keys to toggle between characters. Click *OK* when done.



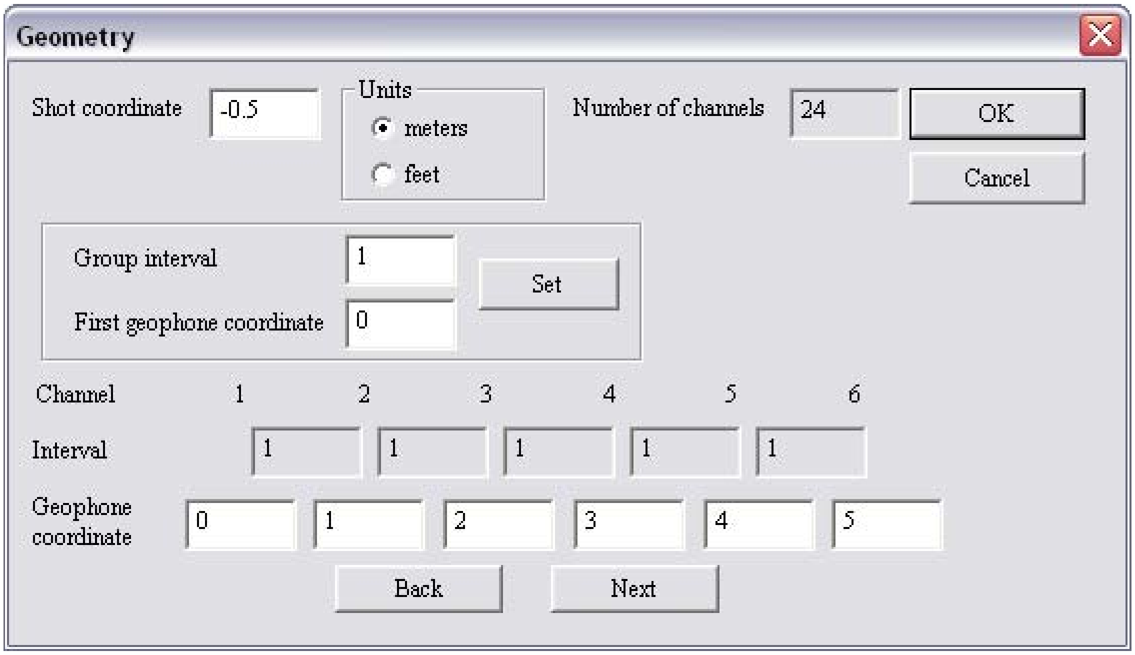
The first in the group of waveform files is displayed.

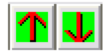
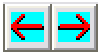
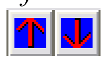
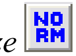


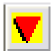
If the unit labels displayed are incorrect, select the *Edit/Display* menu, *Edit source/receiver locations*.



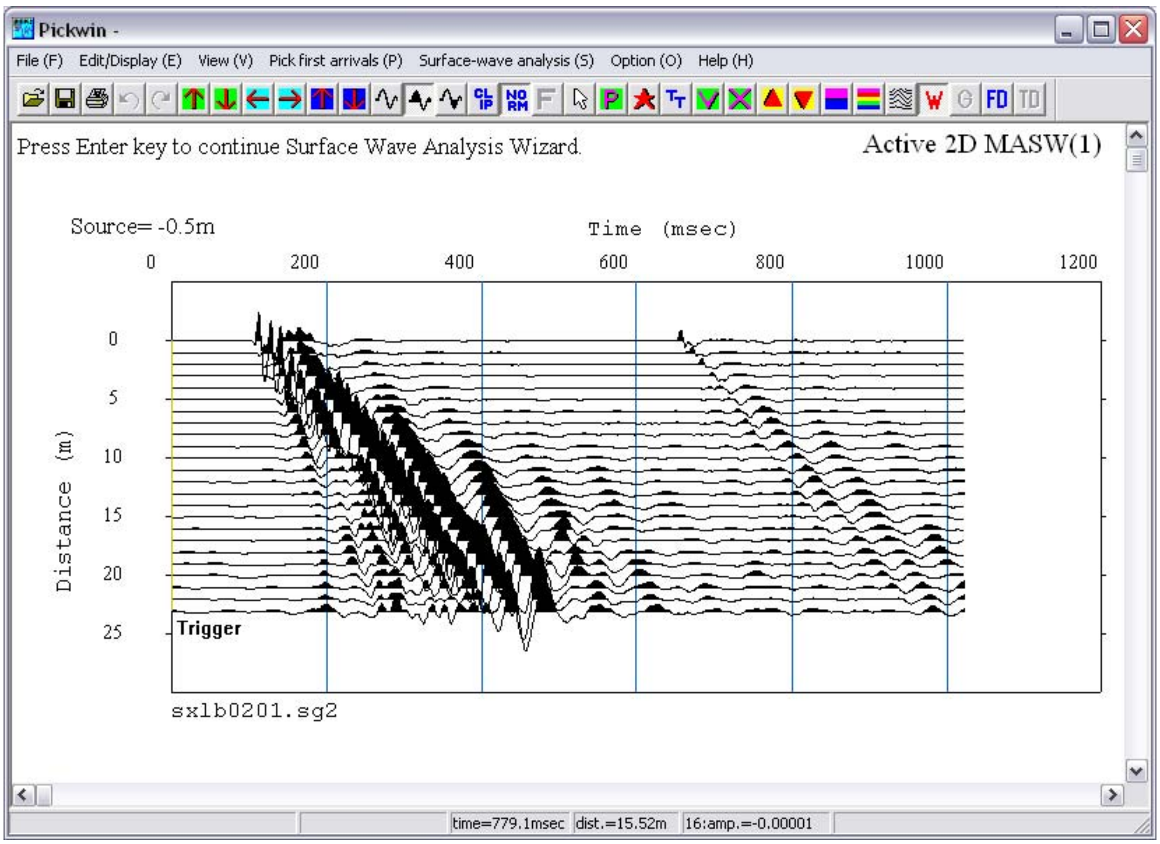
The *Geometry* dialog box appears and the *Units* setting allows selection between *meters* and *feet*. The *Units* setting will affect the unit labels shown in the dialog boxes as well as update the minimum phase velocity default value, which is 35 m/s or 150 ft/s. Once set (and Pickwin is closed), 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.) Click *OK* when done.



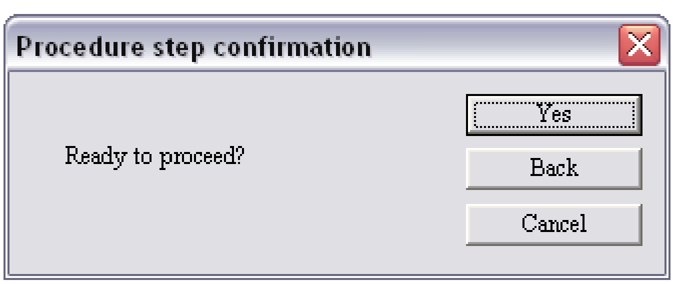
In the waveform view, the settings can be modified to optimize the display. All of these settings are common with SeisImager/2D for refraction data processing; refer to the SeisImager/2D manual included on the SeisImager CD for complete explanation. The main functions needed are the *Waveform amplitude*  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.

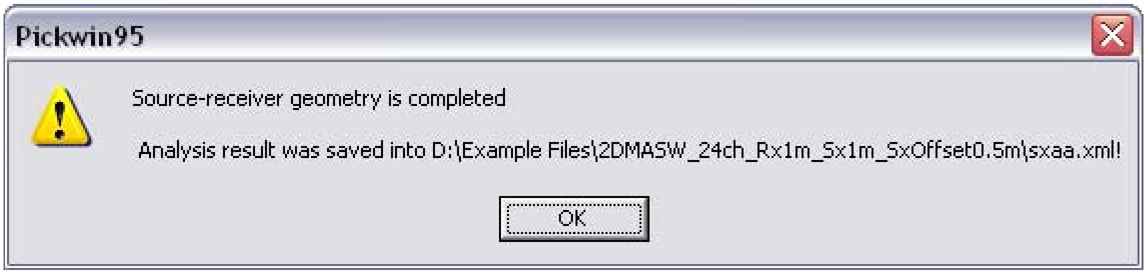
When done, press the *Enter* key to continue.



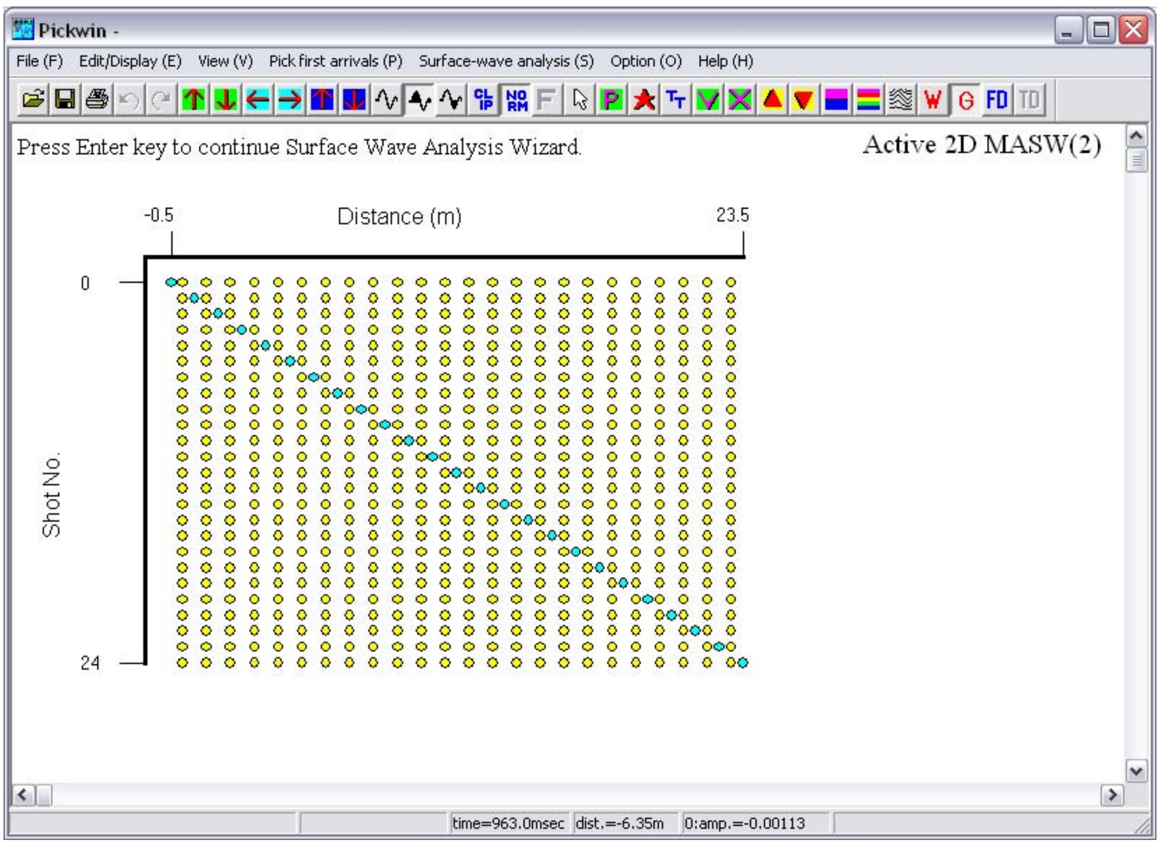
Click *Yes* when ready to proceed with calculation and assignment of the geometry.



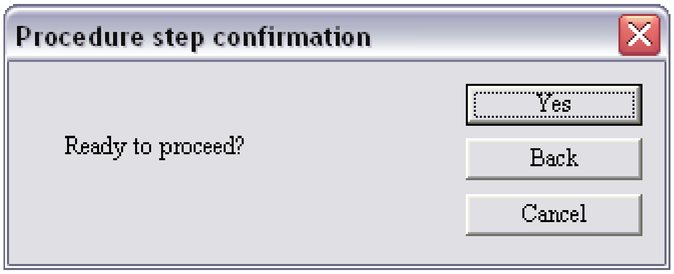
Once the geometry calculation is complete, the file list with geometry assignments is saved as an *.xml* file named with the tag set earlier in the process, click *OK*. This list can later be opened directly without having to reassign the geometry.



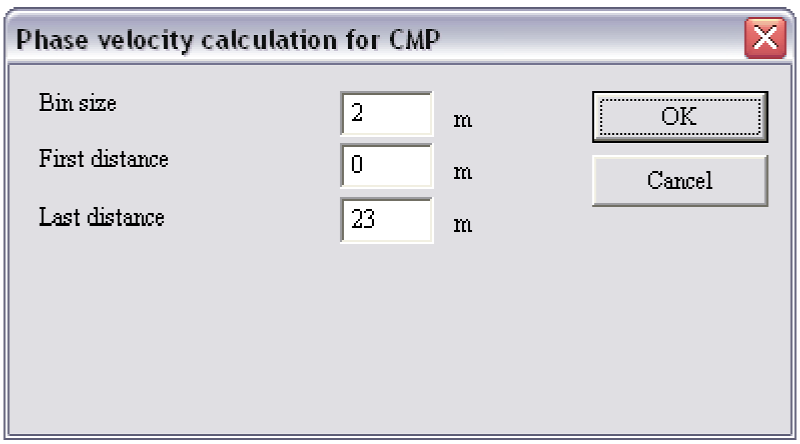
A plot of the geometry is displayed. Press the *Enter* key to continue.

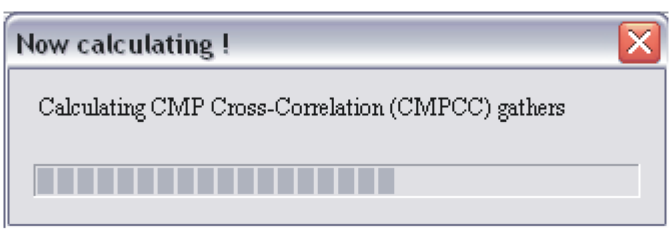


Click *Yes* when ready to proceed.



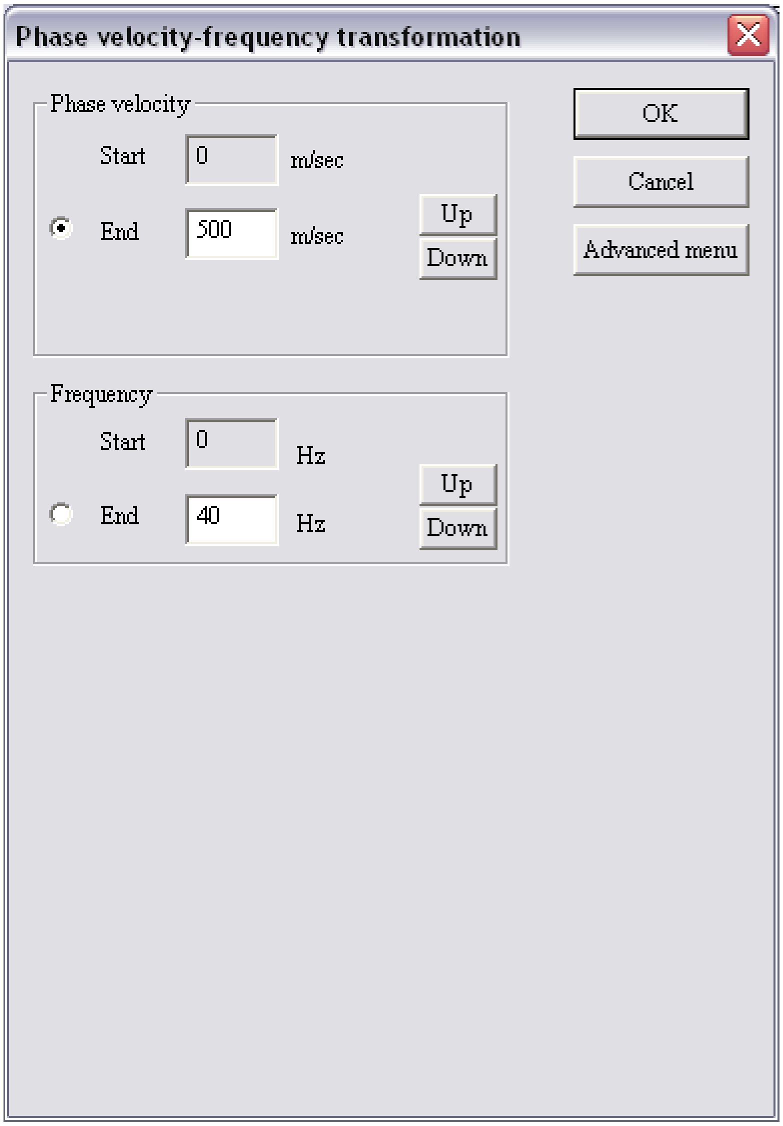
Next, calculate the CMP cross-correlation gathers. The *First distance* and *Last distance* are taken from the first and last coordinates of the receiver spread and the *Bin size* is automatically calculated as two times the receiver interval. The default value for *Bin size* is recommended. The effect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





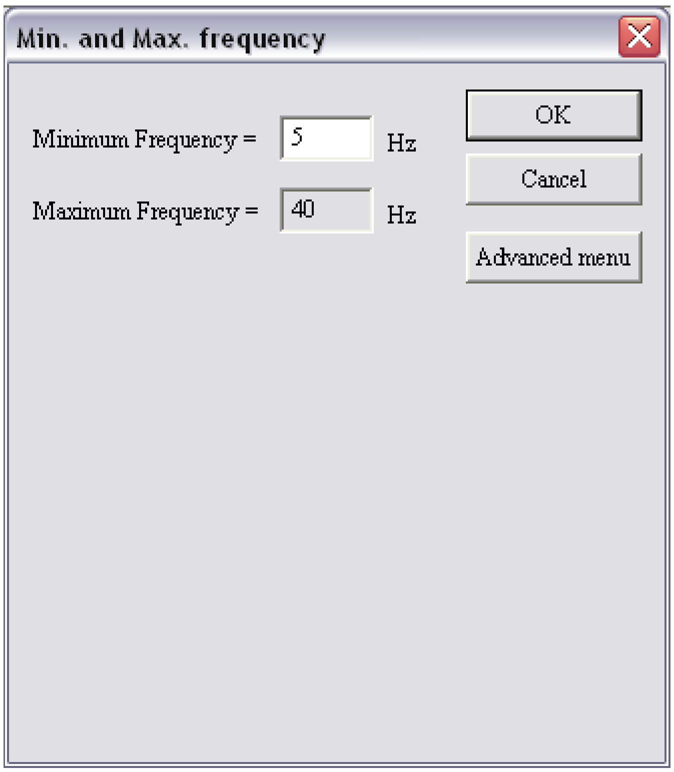
Next, set the parameters for calculation of phase velocity for the CMP cross-correlation gathers. Set the *Phase Velocity End* to suit the maximum velocity you expect for your site.

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. Click *OK* when done.



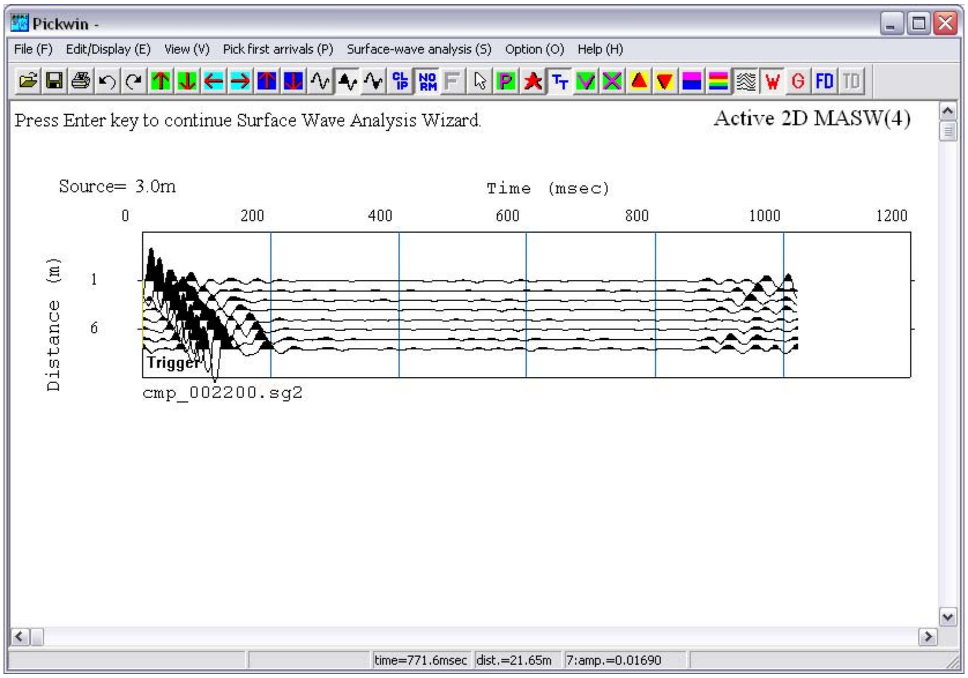
Next, set the parameters for picking the maximum amplitudes, which define the dispersion curve on the phase velocity-frequency plot. The *Minimum Frequency* default value is 5 Hz assuming that 4.5 Hz geophones were used. If other geophones were used, their natural frequency can be entered or use the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

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

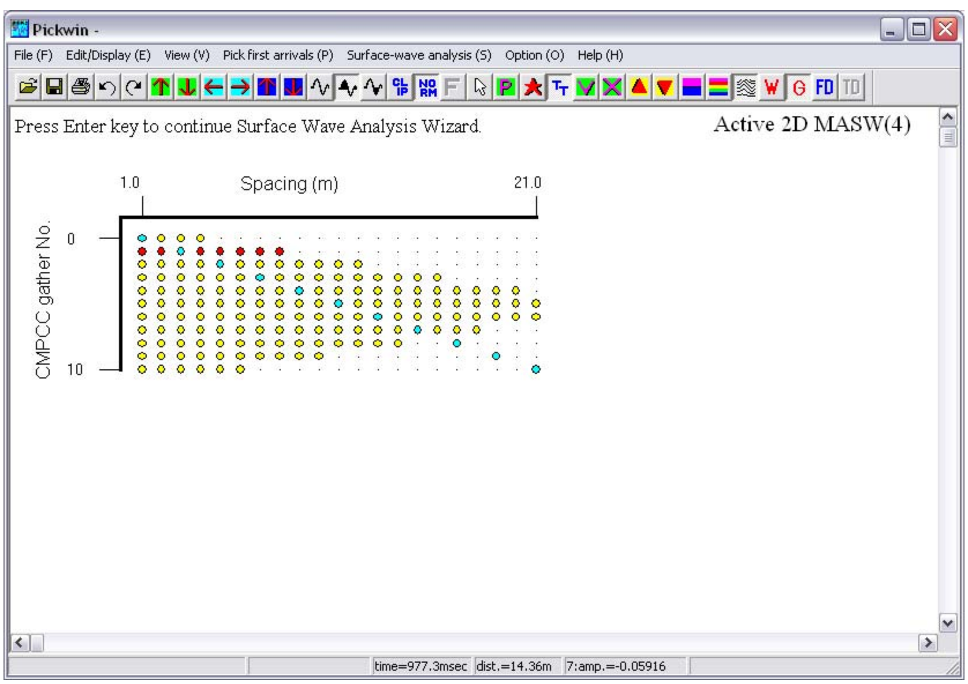


Once calculation of phase velocity and picking of dispersion curves is complete, the picks are automatically saved as a *.pvs* file named with the applicable tag, click *OK*. Refer to Section 5.1.2 on how to re-input saved picks.

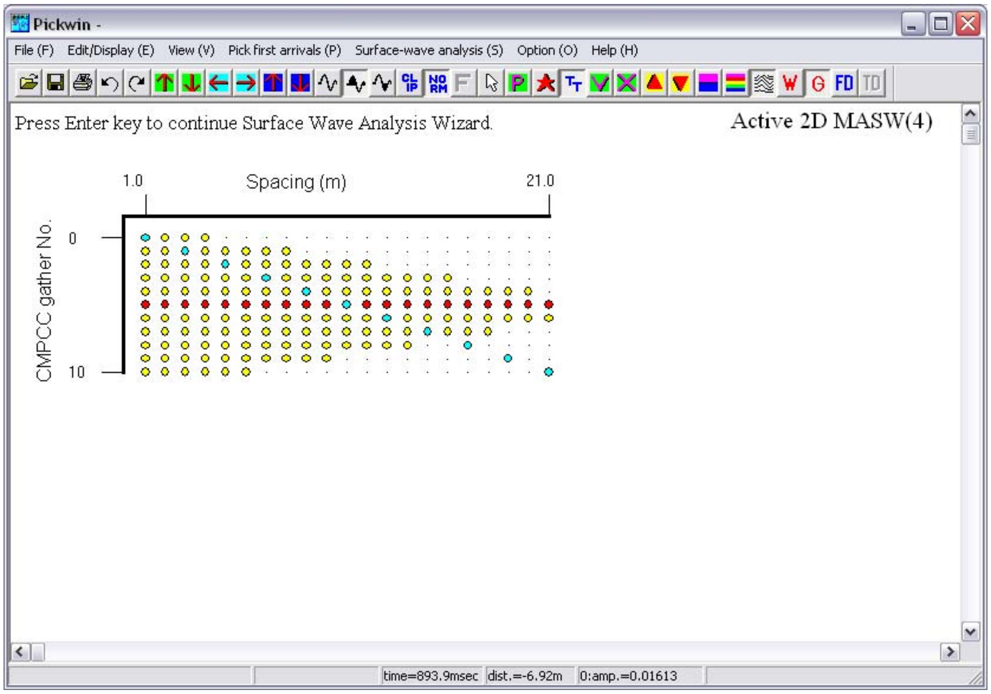
The first in the group of CMP cross-correlation gathers is displayed. To scroll through the files, use the *Show previous waveform* button and *Show next waveform* buttons.



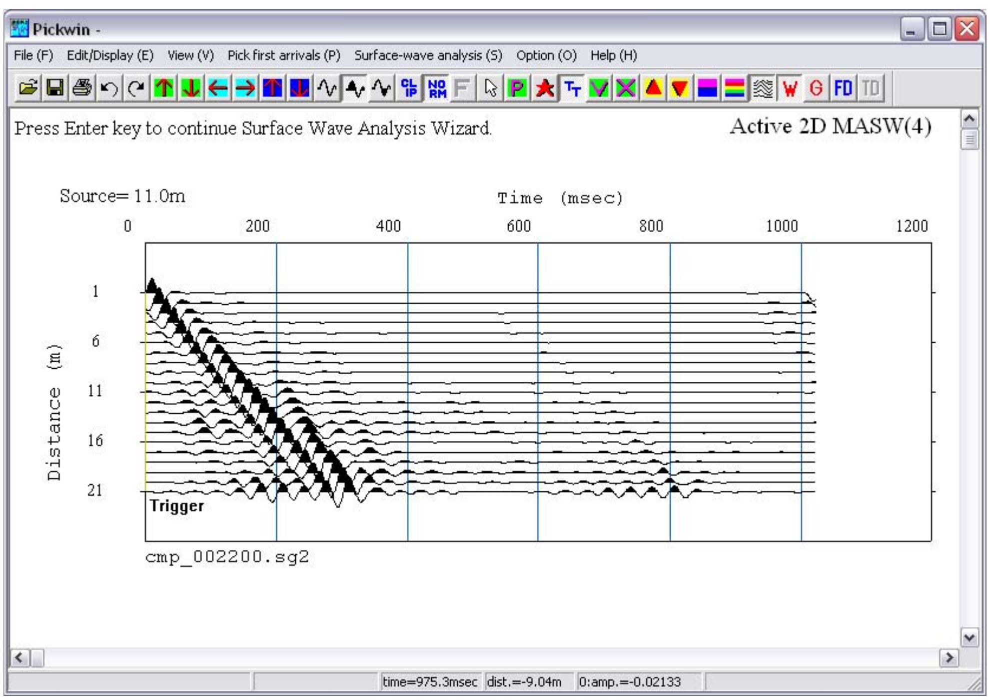
To display a file with a specific geometry, click on the *Geometry* button to toggle to the geometry view. The geometry of the waveform file currently displayed in the waveform view is highlighted in red.



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

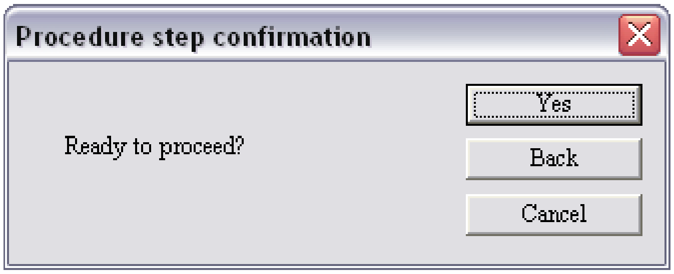


Toggle back by clicking on the *Waveform* button to display the selected file.

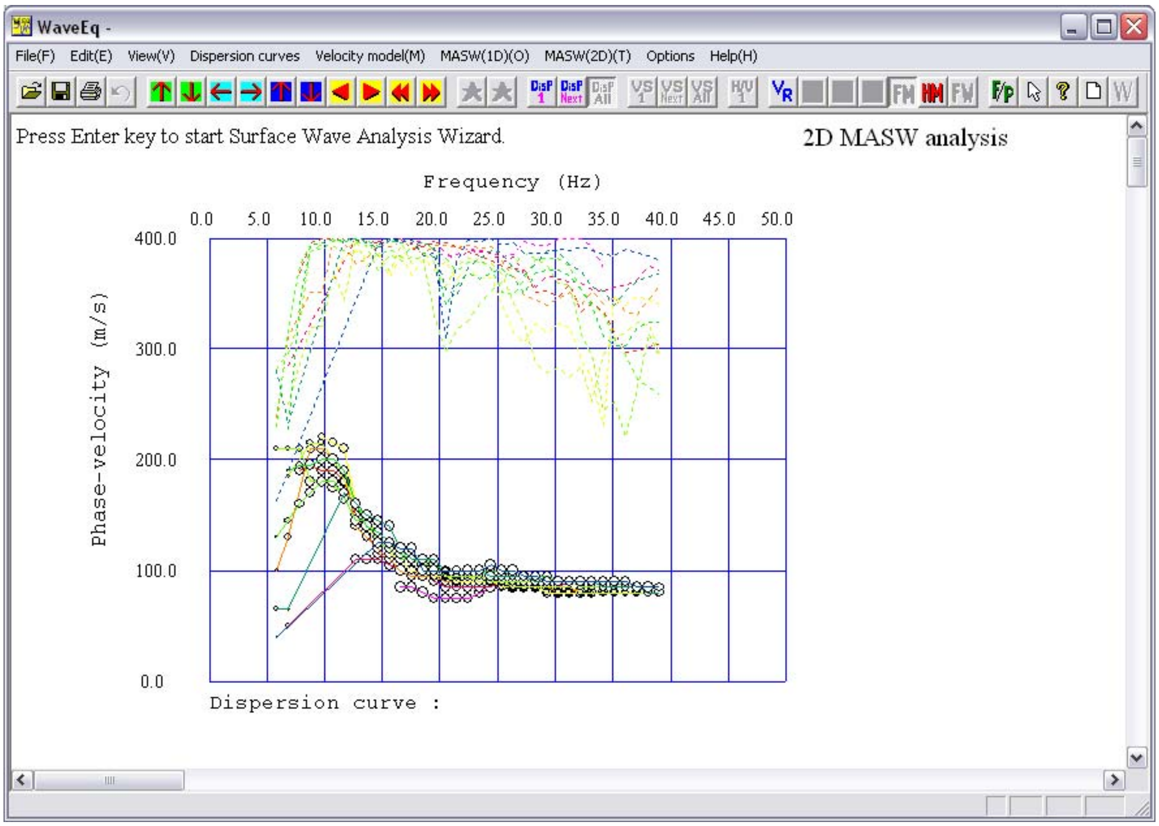


When done, press the *Enter* key to continue.

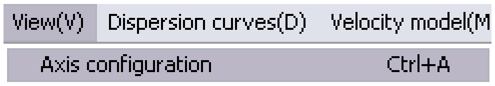
Click *Yes* when ready to proceed.



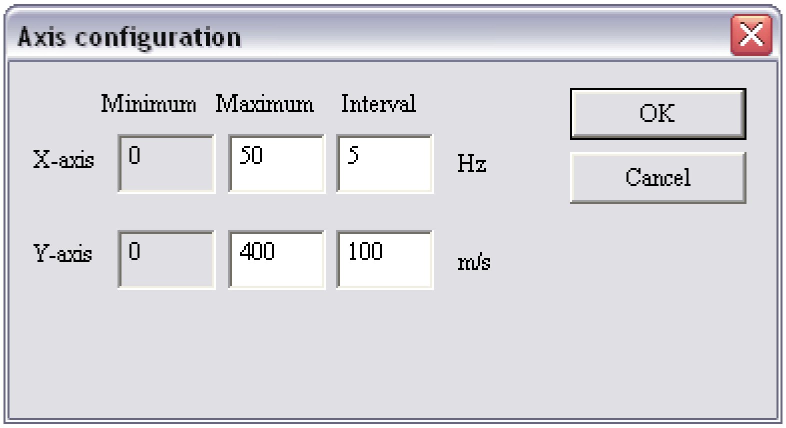
Next, the WaveEq module launches and the dispersion curves are displayed. From this point on, the wizard calls functions from the *Dispersion curves* and *MASW (2D)* menus.



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



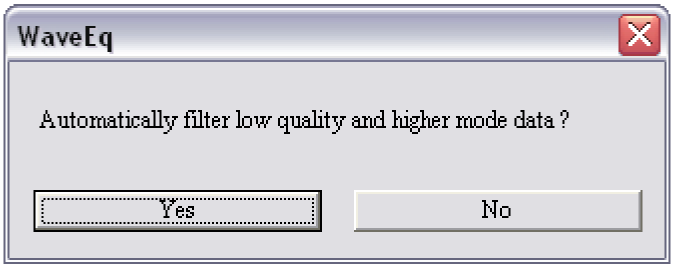
Enter the desired values for the *X-axis* and *Y-axis Maximum* scale and *Interval*. Click *OK* when done.



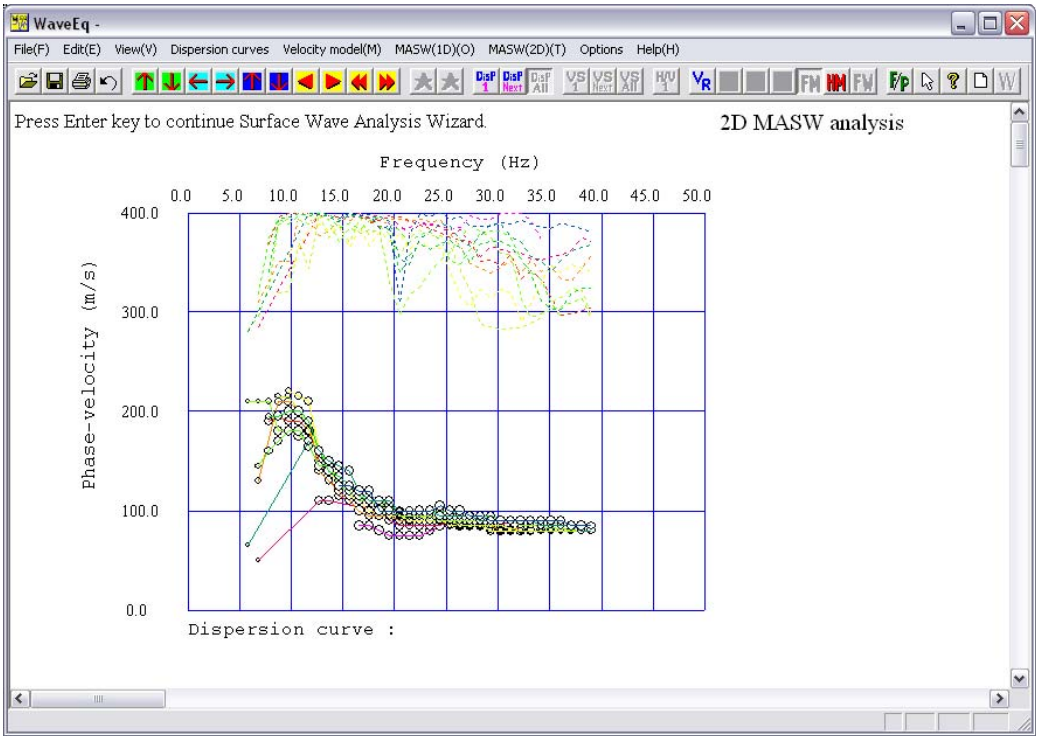
Press the *Enter* key to continue.

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 clicking *No*. Refer to Section 6.4 for a complete explanation of the dispersion curve editing functions.

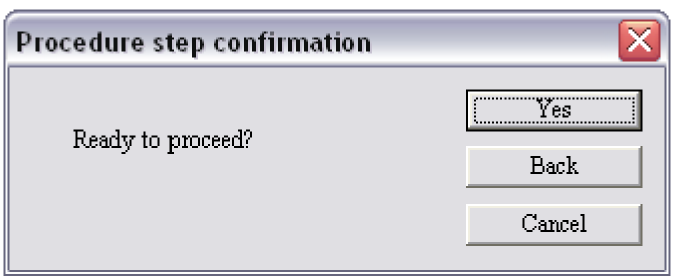
Select *Yes*.



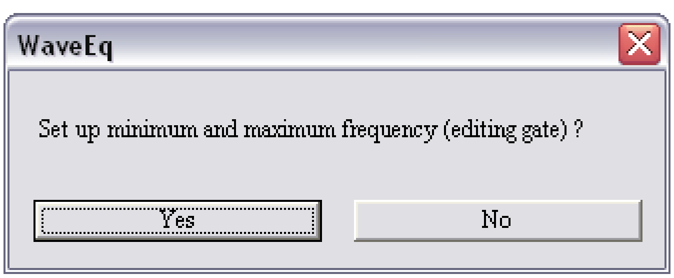
The edited dispersion curves are displayed. Press the *Enter* key to continue.



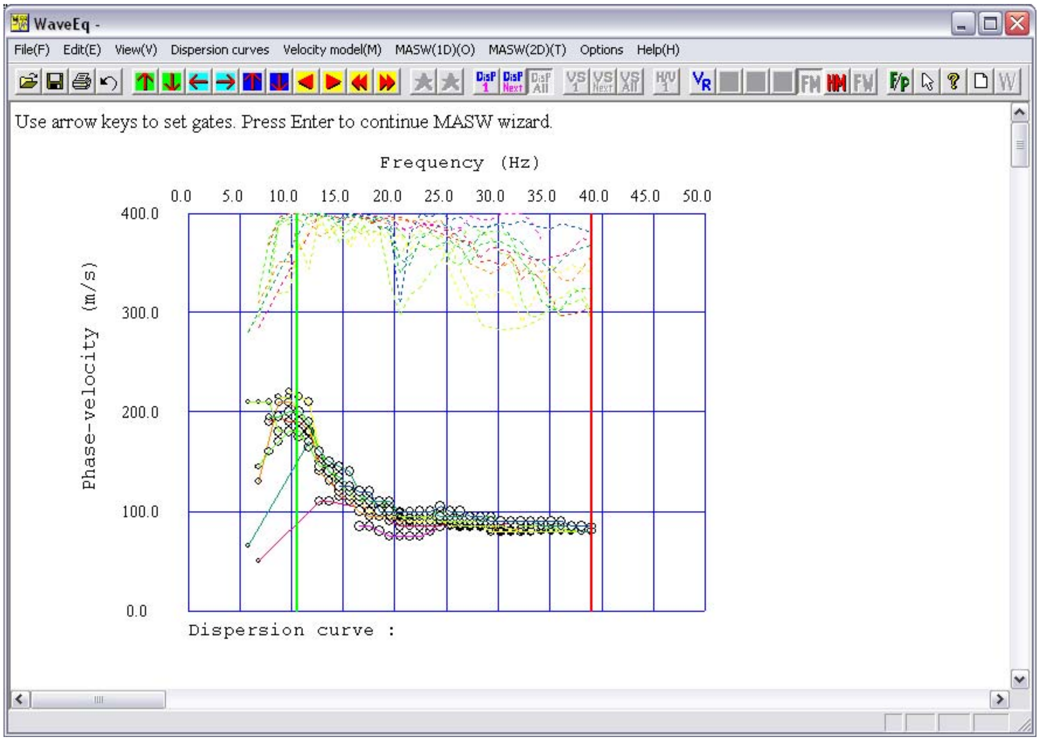
Click *Yes* when ready to proceed.



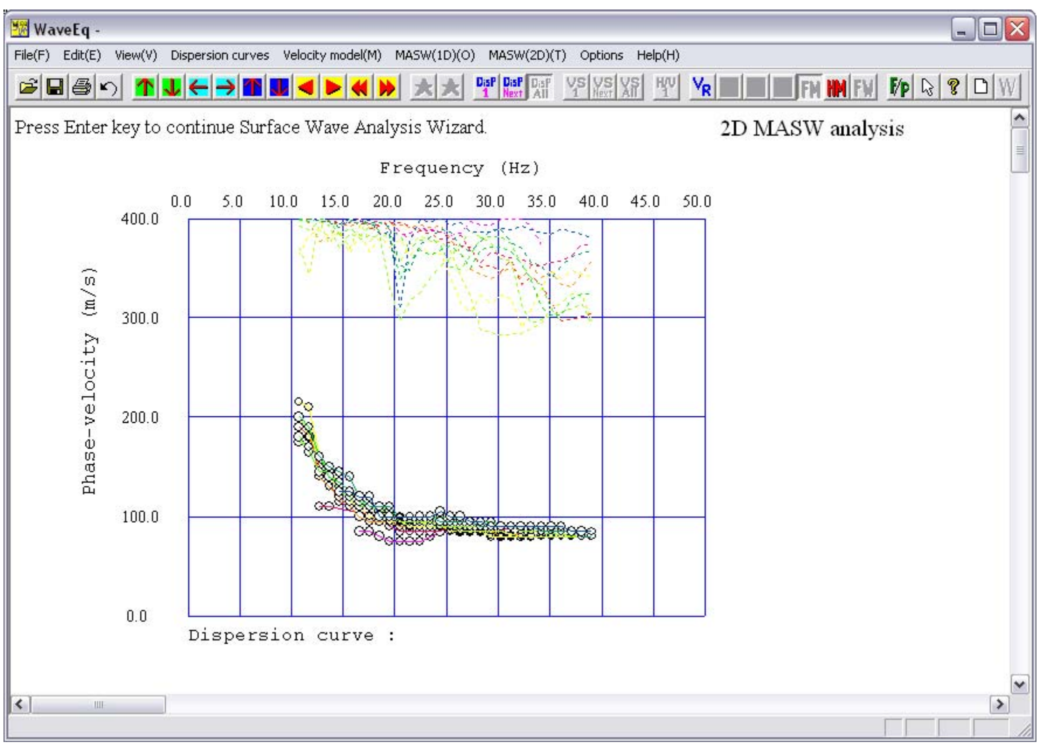
Select *Yes*.



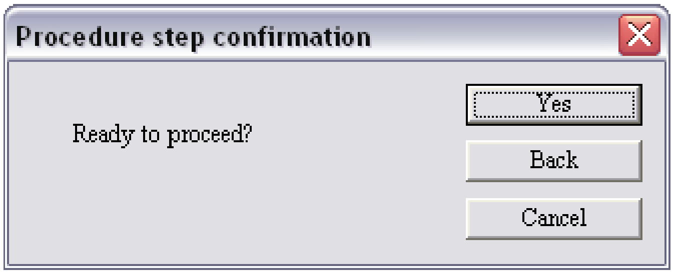
Follow the instructions in the upper left-hand corner of the window. The red gate is the active gate. Use the *right arrow* key to position the gate at the frequency, phase velocity point up to which you want to delete. Press the *Enter* key to activate the right-hand side gate and position it the same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



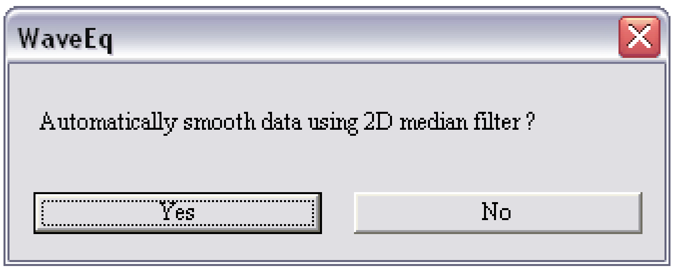
The edited dispersion curves are displayed. Press the *Enter* key to continue.



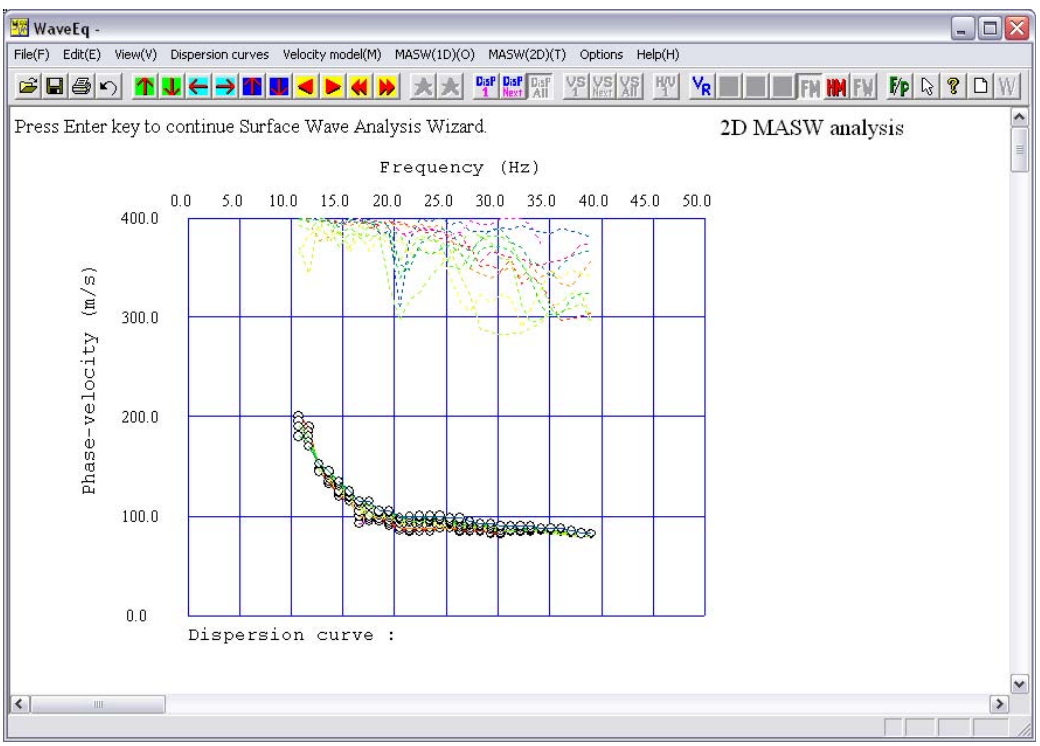
Click *Yes* when ready to proceed.



Select *Yes*.

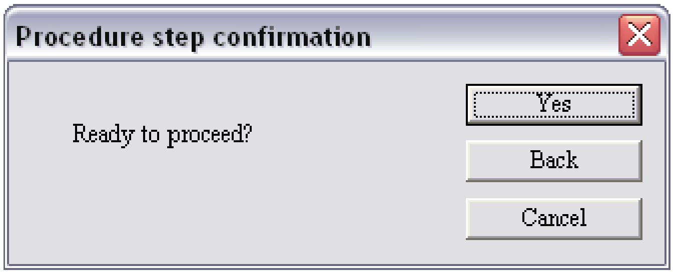


The edited dispersion curves are displayed.

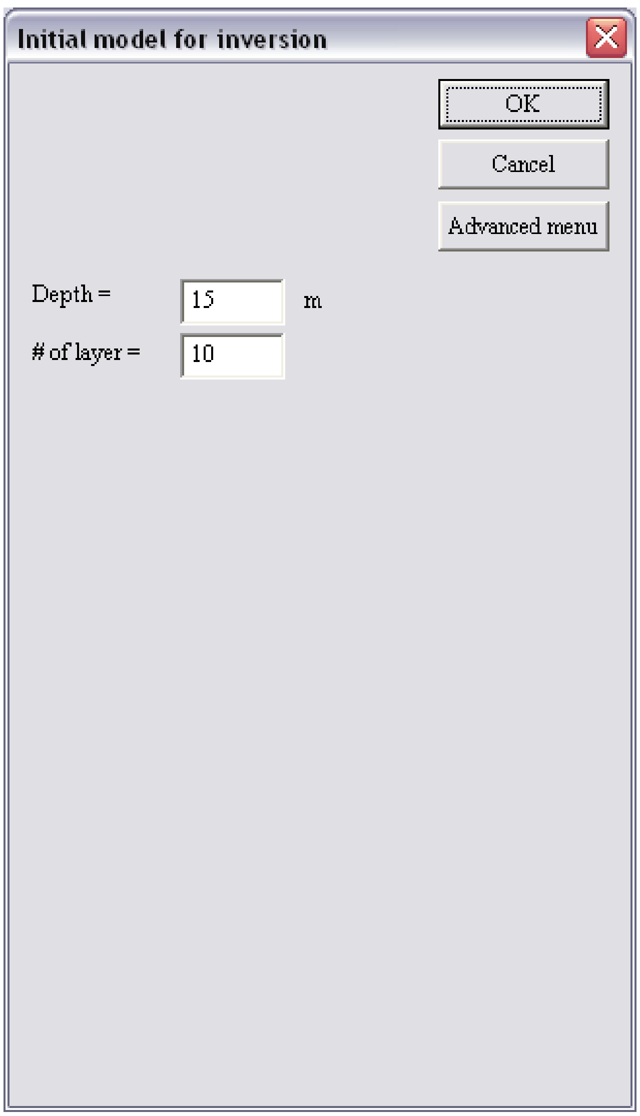


This is the last editing step. Press the *Enter* key to continue.

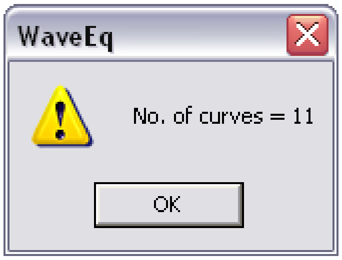
Click *Yes* when ready to proceed.



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. Click *OK* when done.

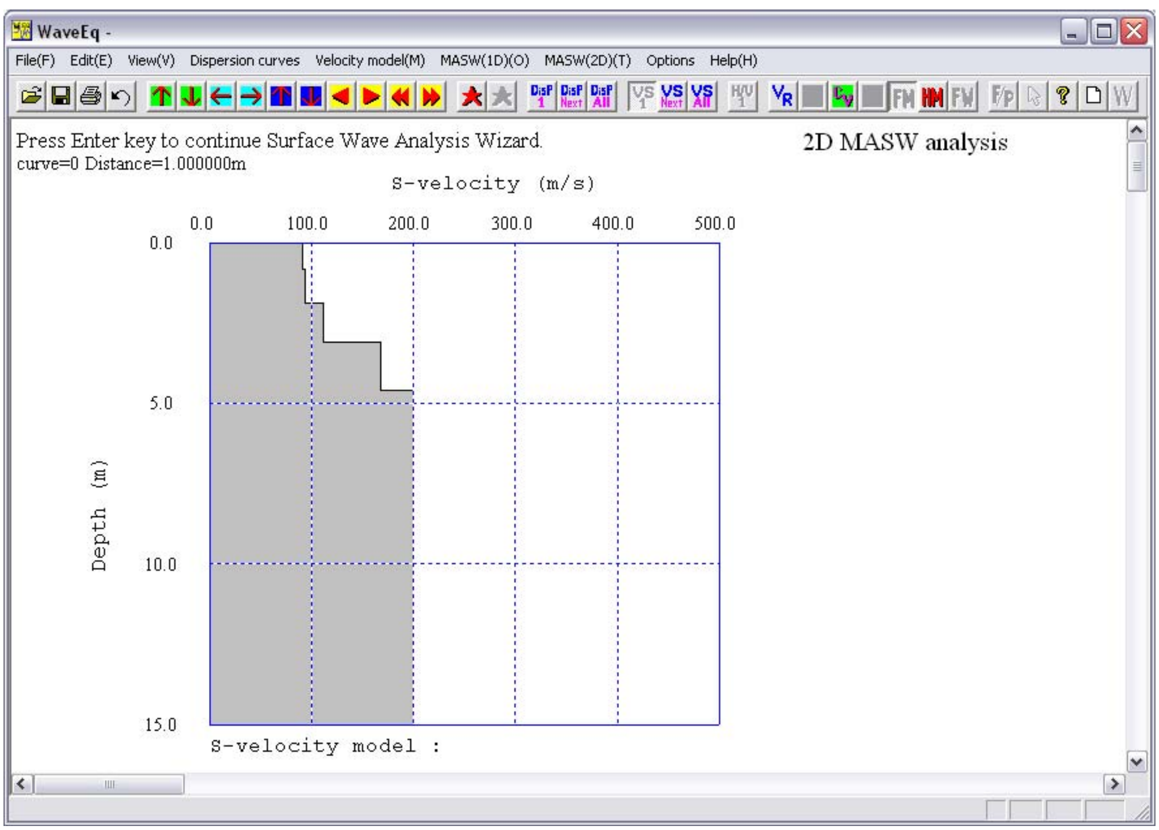


Once the initial cross-sectional model is calculated, the number of curves used in the model is reported, click *OK*.

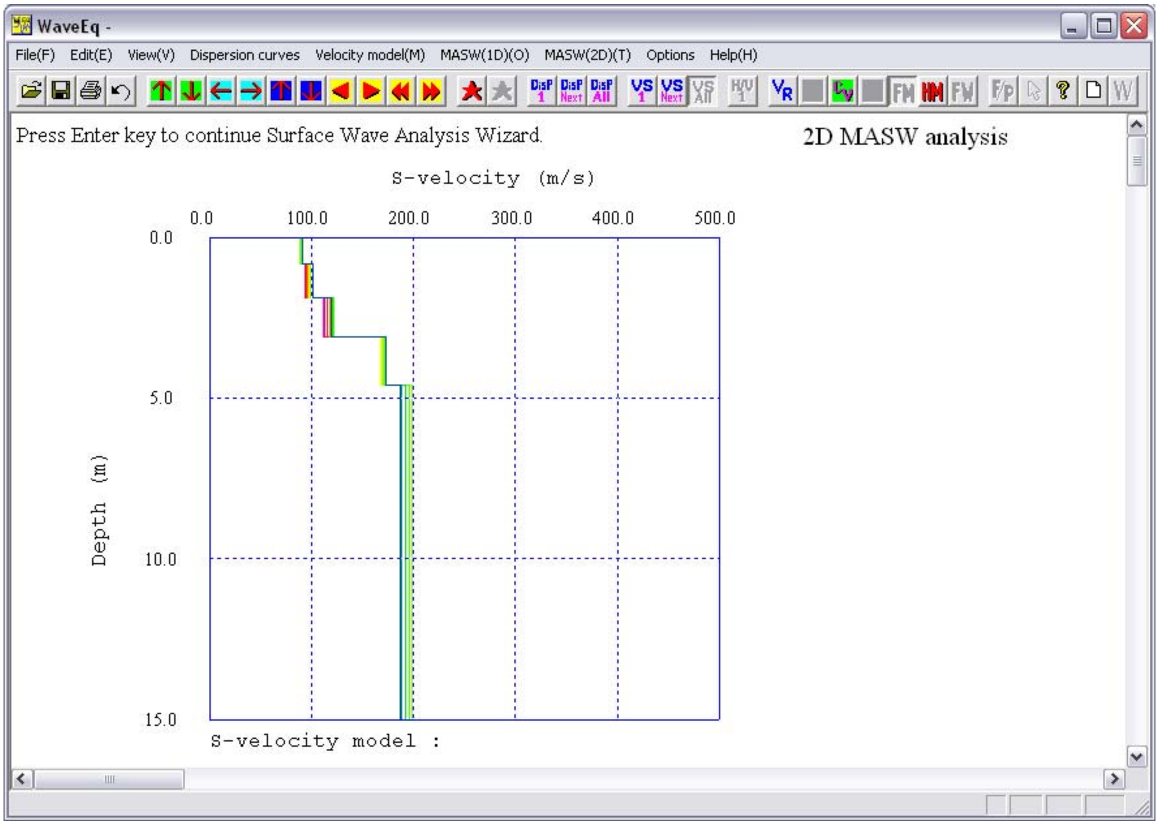


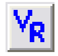
The initial model file is automatically saved, click *OK*.

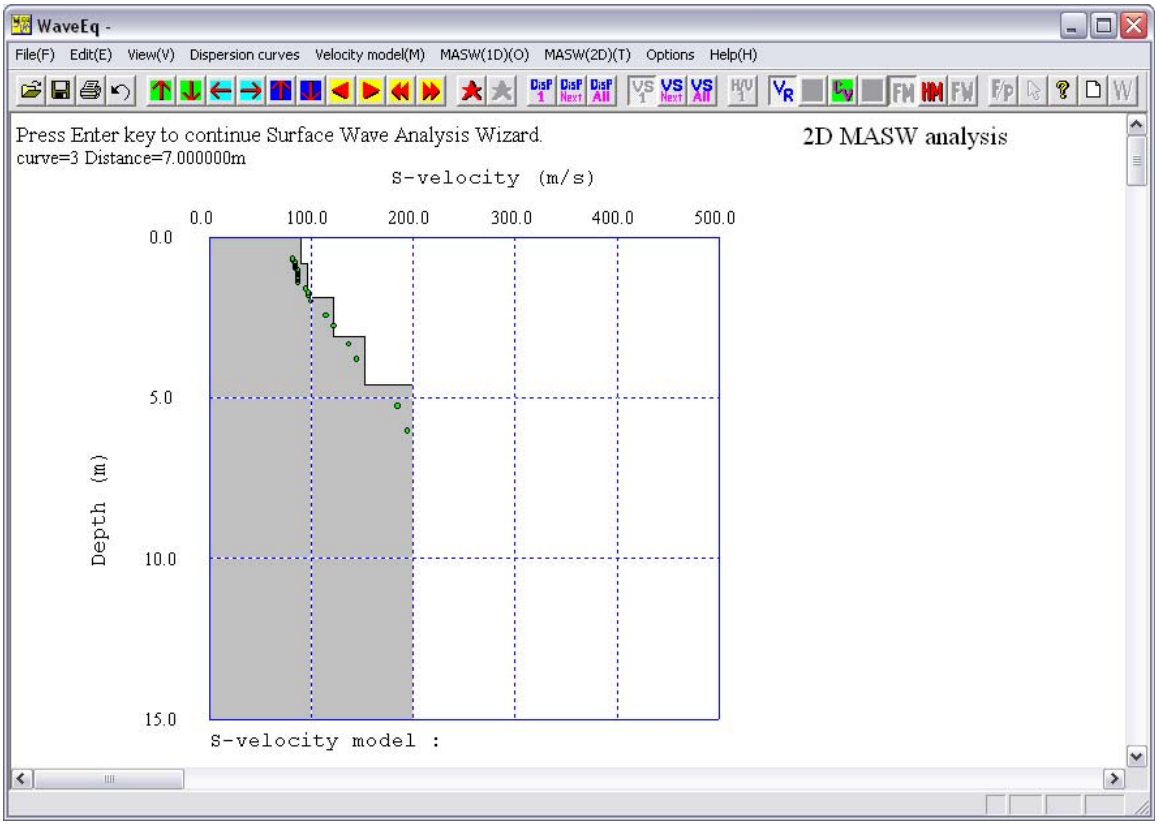
The first in the group of individual initial models is displayed.



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.

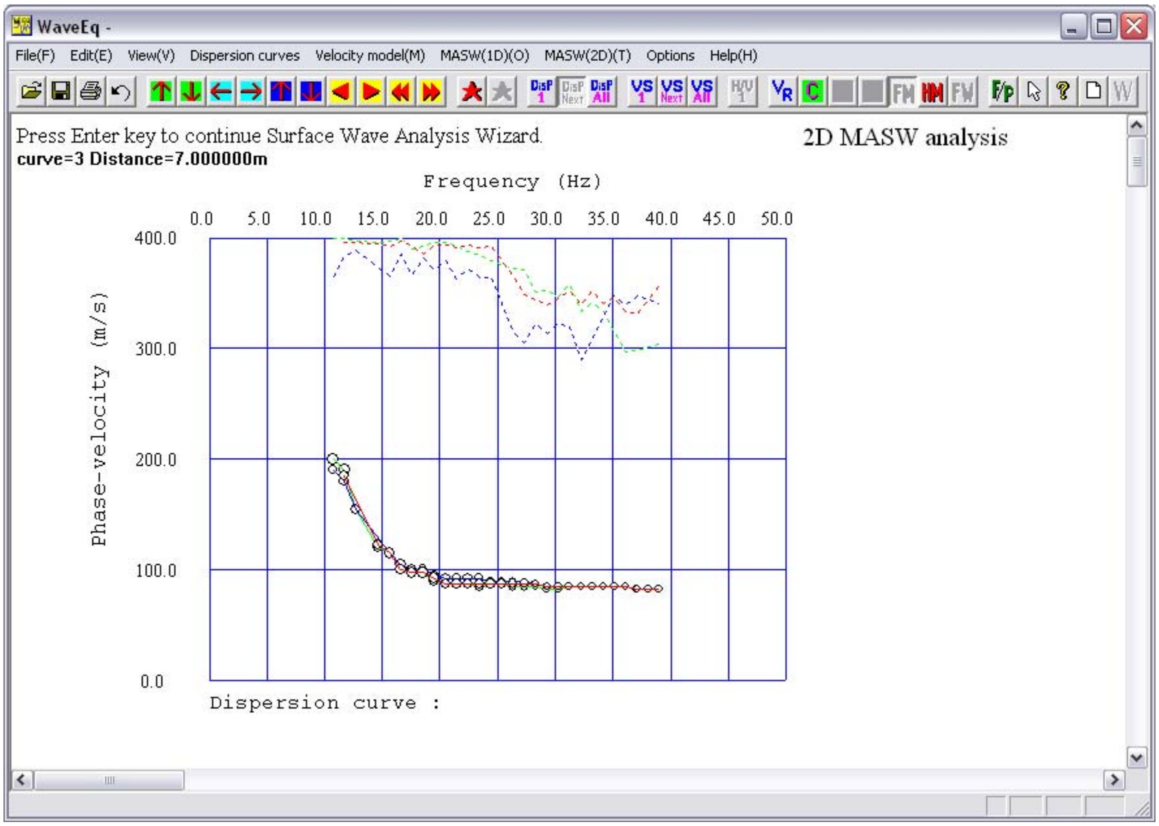


Click on the *Show apparent velocity model*  button to overlay the one-third-wavelength approximation (green points), which is the best indicator of the actual depth range of penetration. In the latest version of the software, by default, the shade of the model changes to light grey starting at the deepest apparent velocity to call attention to the limits of the data.

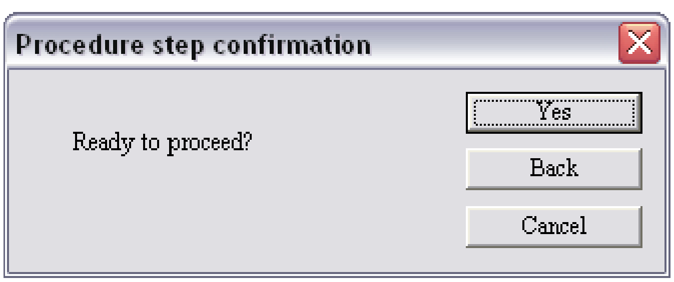


For the dispersion curves, the *Dispersion curve 1* and *Dispersion curve next* buttons, the *Show previous* and *Show next* buttons, the *Home* and *End* buttons, and the *Dispersion curve all* button, function the same as described for the velocity curve display.

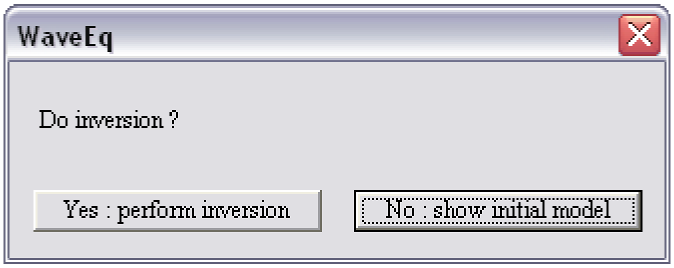
When done, press the *Enter* key to continue.



Click *Yes* when ready to proceed.



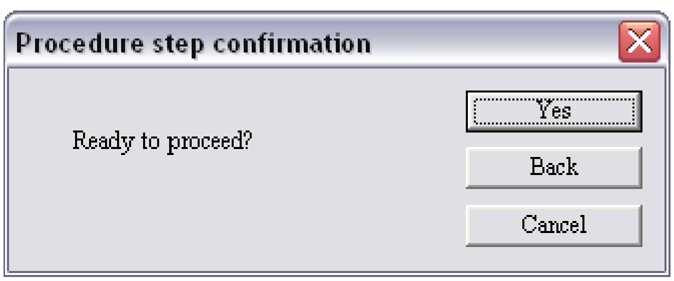
Select *No: show initial model* to display the initial cross-sectional model in GeoPlot. (To skip this step, select *Yes: perform inversion*.)



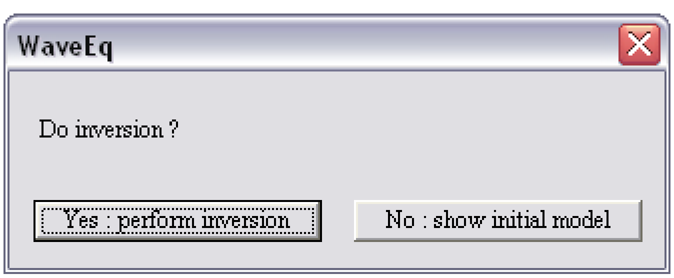
The GeoPlot module launches, click *OK*. Refer to Section 4.1.3.1 for an explanation of the GeoPlot functions used for viewing initial V_s cross-sections.

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.

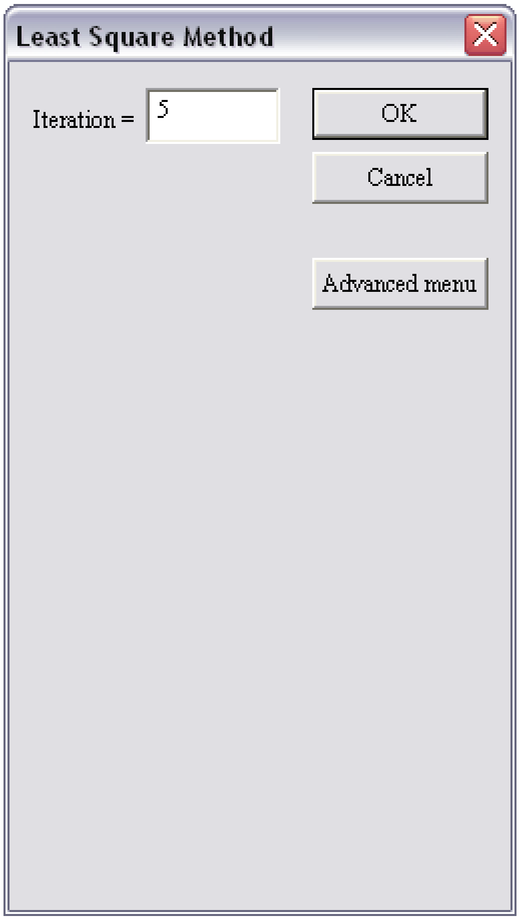
In WaveEq, press the *Enter* key and click *Yes* when ready to proceed.



Select *Yes: perform inversion*.



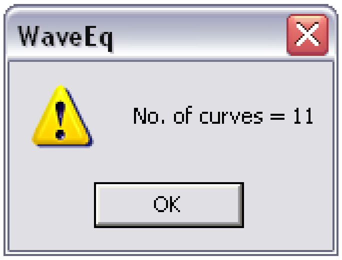
Set the number of iterations for the inversion. The software will iterate the number of times indicated to converge on the best fit of the initial model with the observed data. The default value of 5, up to 10, for *Iteration* is suitable for most cases. Click *OK* when done.



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.

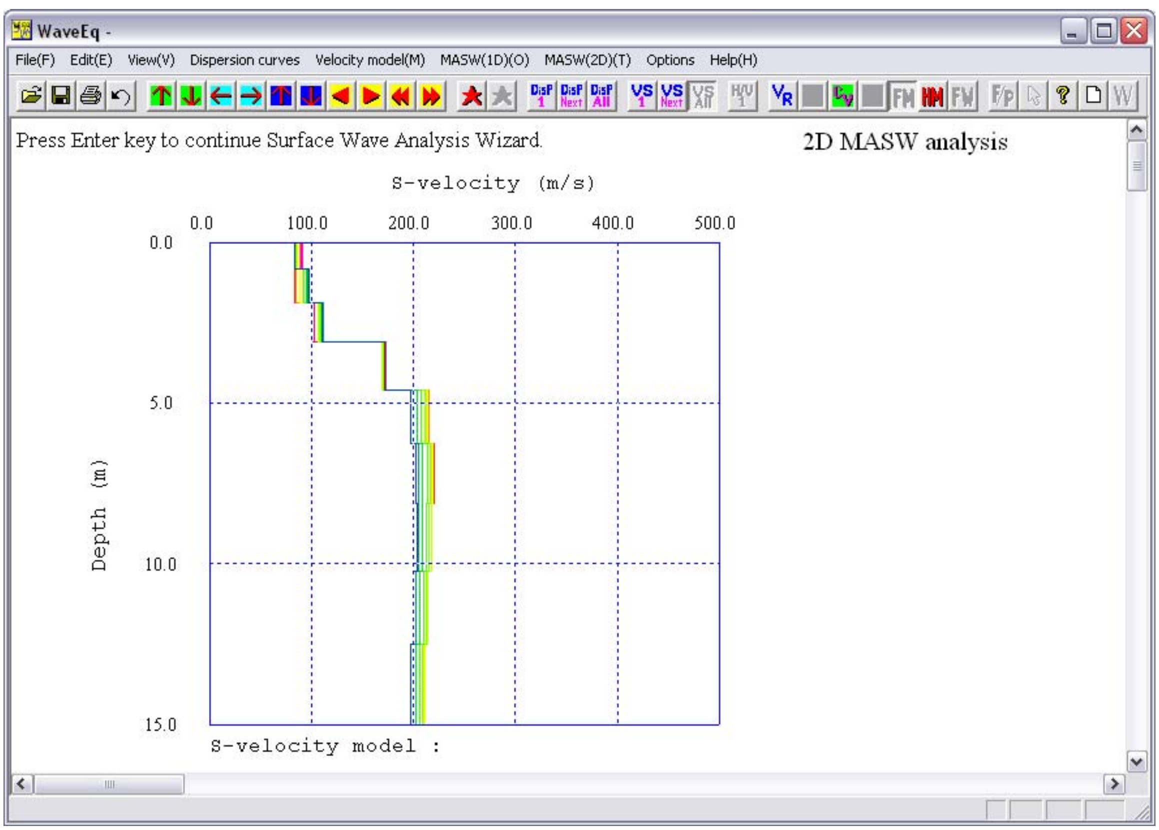
Once the inversion is completed, click *OK*.

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



The final model file is automatically saved, click *OK*.

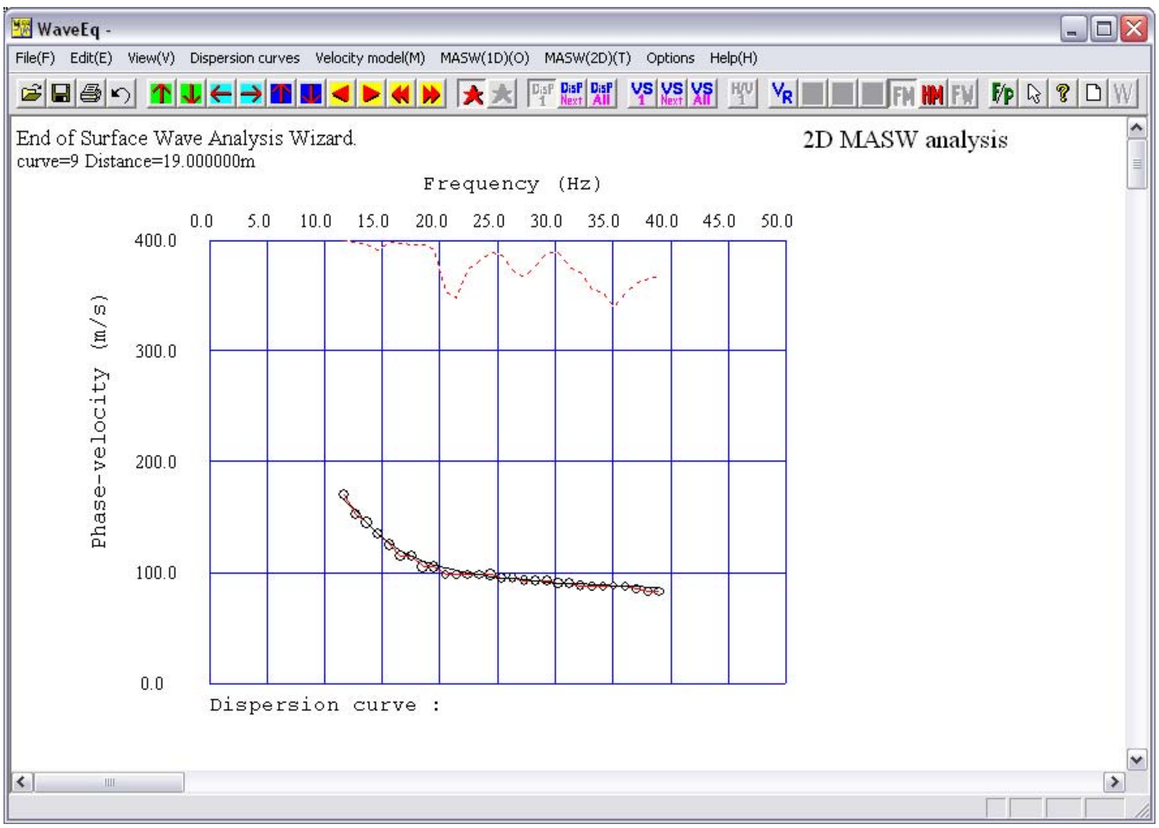
The first in the group of individual final models is displayed.



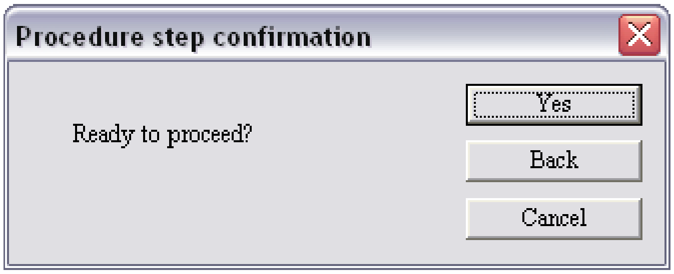
Check the fit of the calculated and observed dispersion curves. Click on the *Show one dispersion curve* button to display the original dispersion curve. Click on the *Comparison* button to overlay the calculated dispersion curve (black line) and visually assess the degree of mismatch. The matching error 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.

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 curves should be double checked and the process re-run to improve the match.

Press the *Enter* key to continue.



Click *Yes* to proceed.

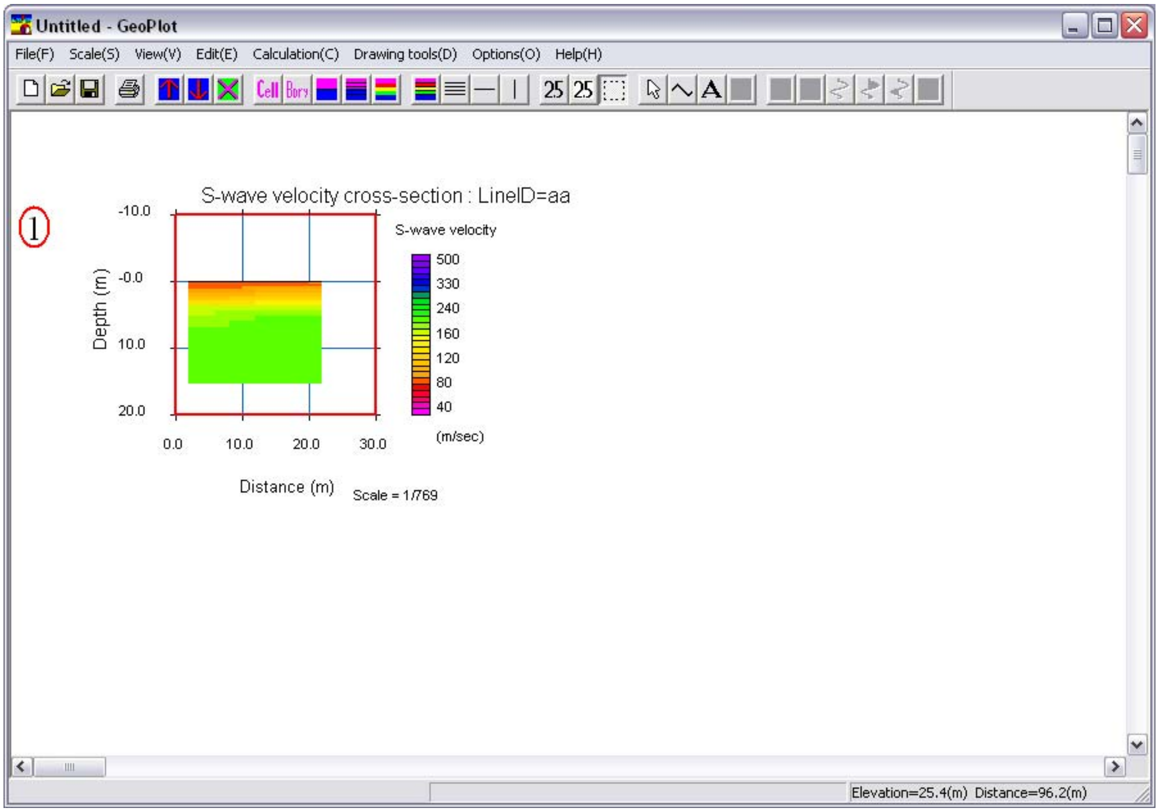


The GeoPlot module launches again to display the final model, click *OK*. Refer to Section 4.1.3.1 for an explanation of the GeoPlot functions used for viewing final V_s cross-sections.

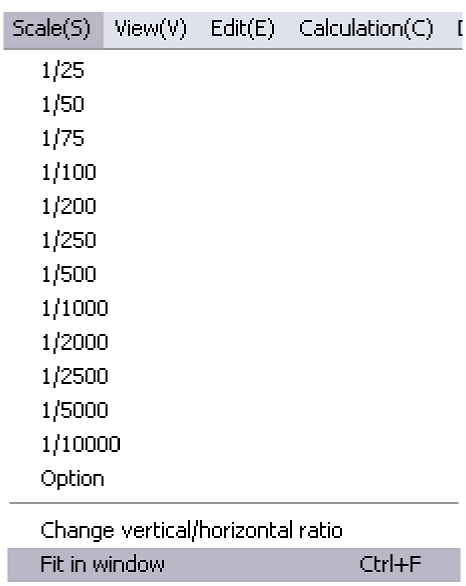
Refer to Section 4.2 on how to combine active and passive source dispersion curves for a given site and maximize the depth range of the cross-section.

4.1.3.1 The GeoPlot Module Surface Wave Analysis Functions

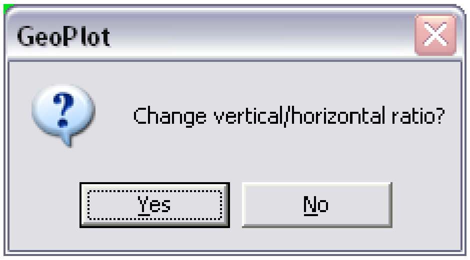
After the Surface Wave Analysis Wizard launches GeoPlot the main GeoPlot window appears and the subject model is displayed. The subject model may be an initial or final model. The model is outlined in red to indicate is it active for editing.

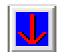


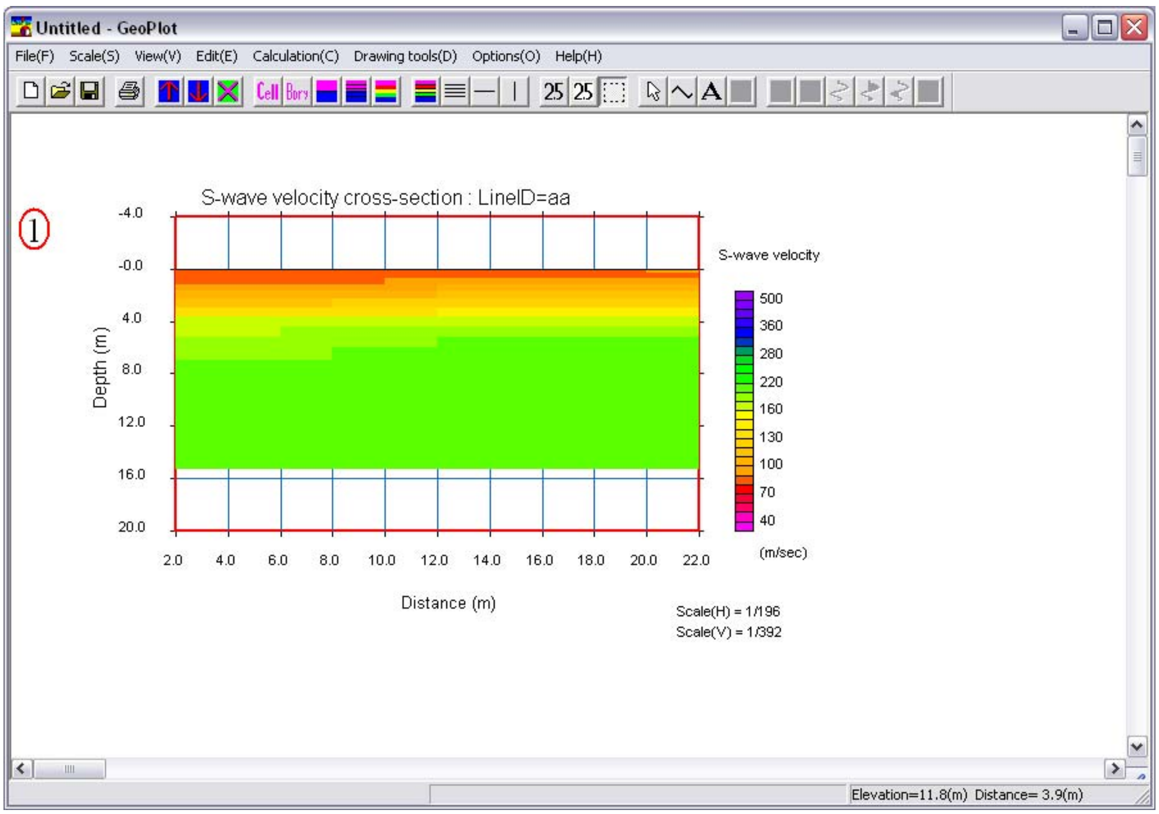
To optimize the display of the model, first select the *Scale* menu, *Fit in window* to maximize the display area.



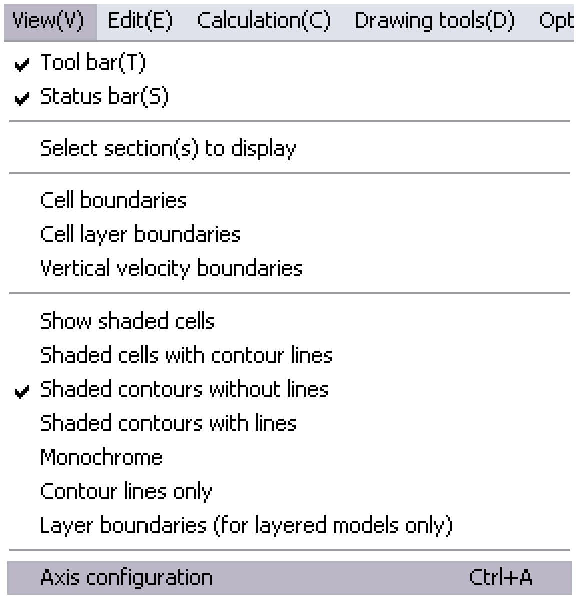
Click *Yes* to auto-scale the display.



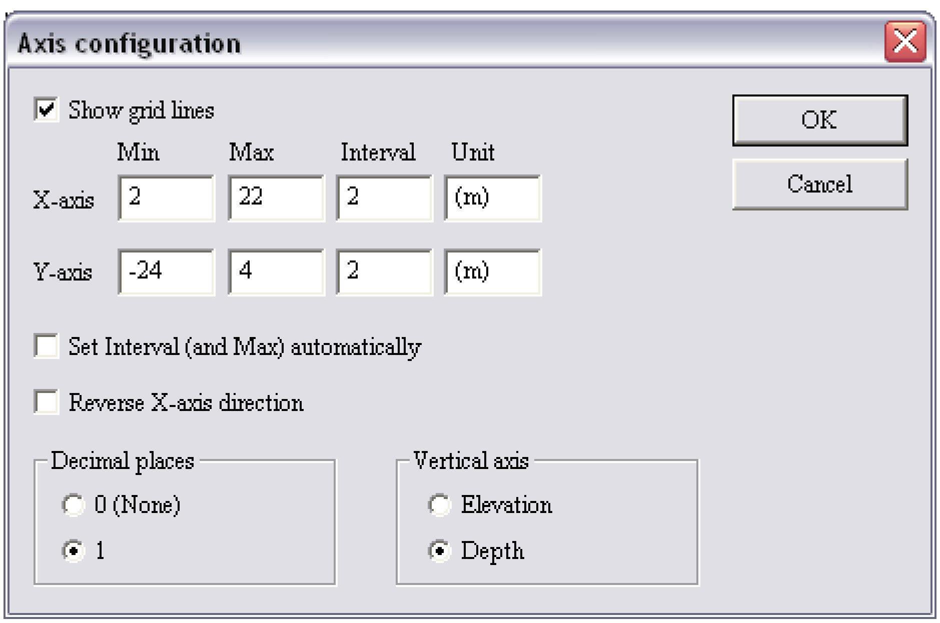
Use the *Enlarge scale*  and *Reduce scale*  buttons to further adjust the plot size.



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

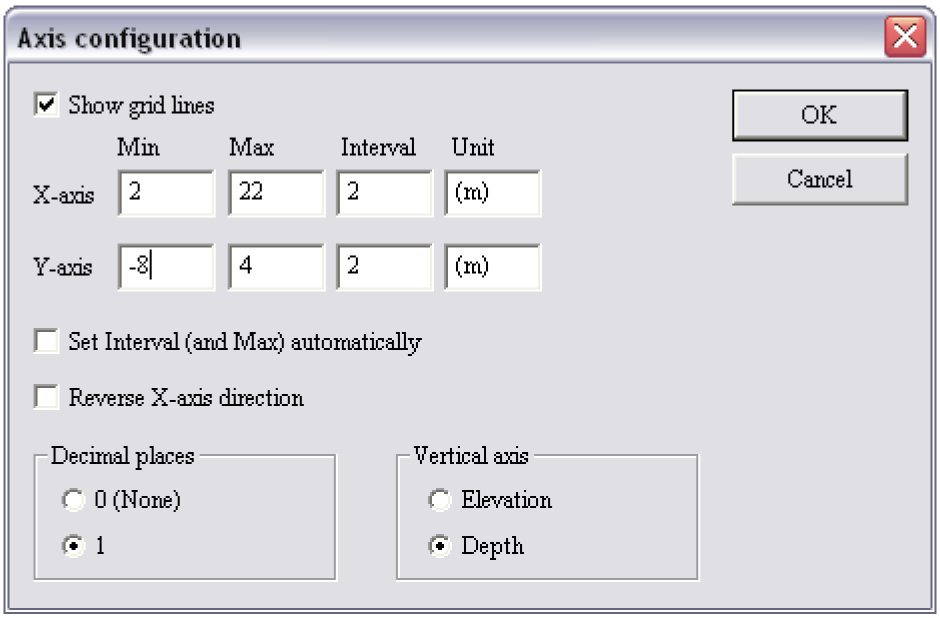


Enter the desired values for the *X-axis* and *Y-axis Min*, *Max*, and *Interval*. The unit label fields reflect the units imported with the model from WaveEq. To make changes to the labels enter the desired text in the *Unit* fields.

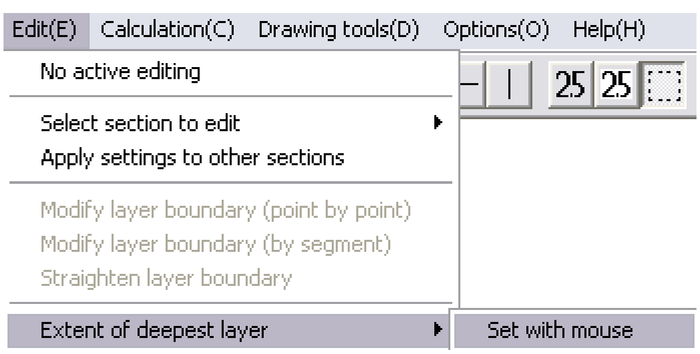


When *Show grid lines* is checked, blue horizontal and vertical lines will be displayed at each tick interval. Checking *Set Interval (and Max) automatically* will allow the tick intervals to dynamically decimate when the scale is reduced to prevent the axis labels from overlapping; the *Max* values cannot be fixed in this mode. *Reverse X-axis direction* decreases the horizontal scale 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.

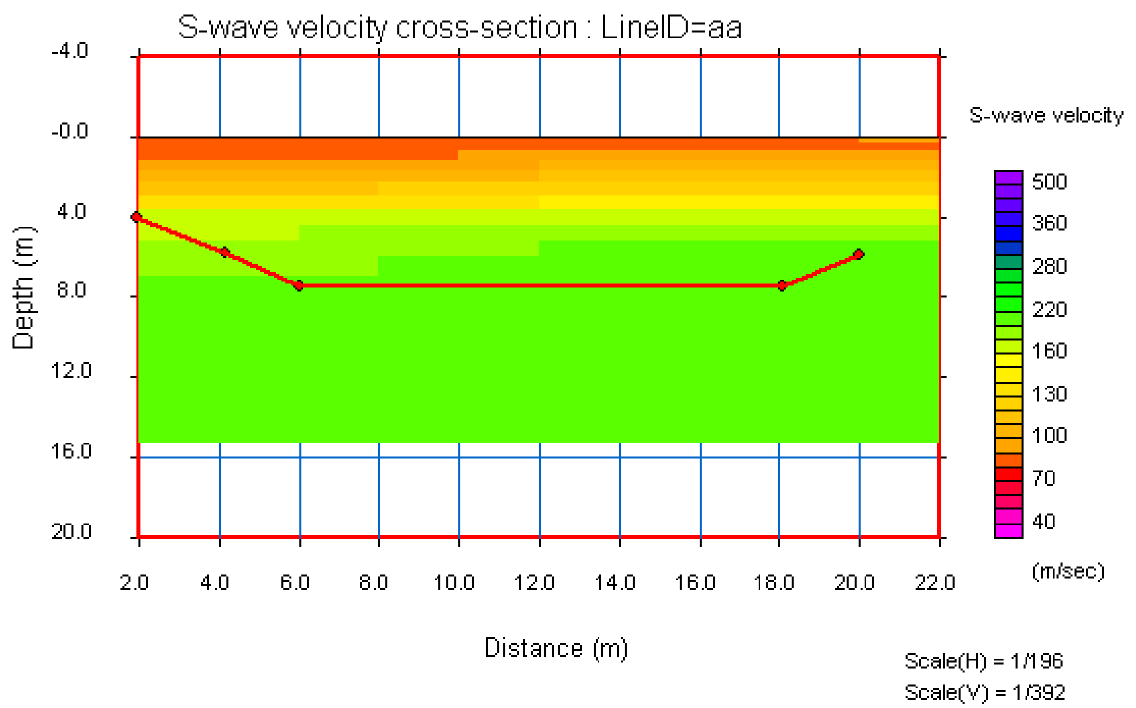
If the cross-section display extends beyond the deepest apparent velocity indicated by the one-third wavelength approximation, it is recommended that the display be adjusted to that depth to prevent interpretation beyond the constraints of the data. Enter the deepest extent of the display in the *Y-axis Min* field. The cross-section will be uniformly shortened to that value. Click *OK* when done.



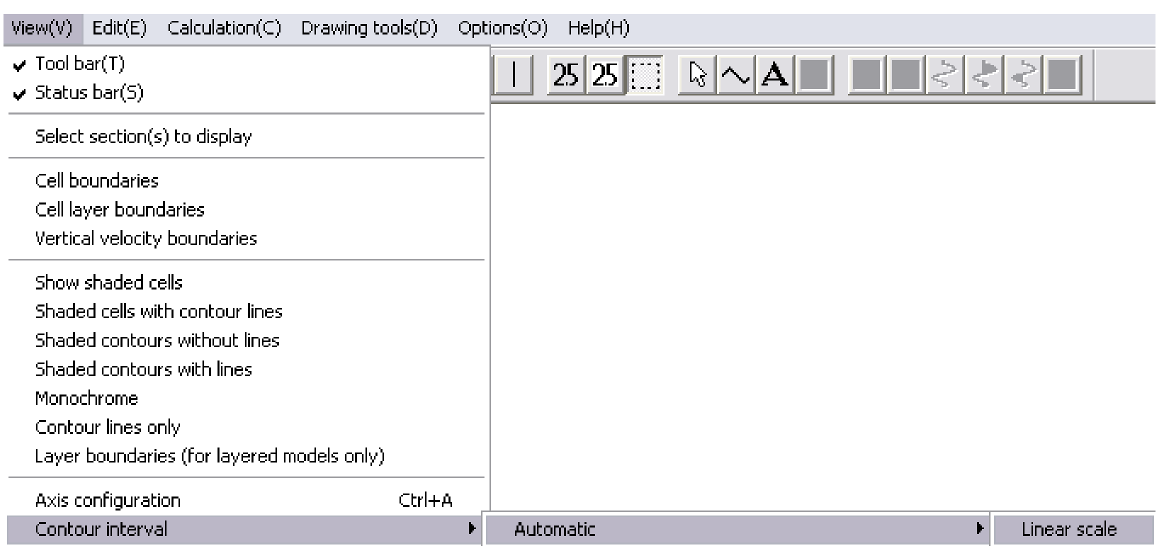
To shorten the cross-section non-uniformly, select the *Edit* menu, *Extent of deepest layer*, *Set with mouse*.

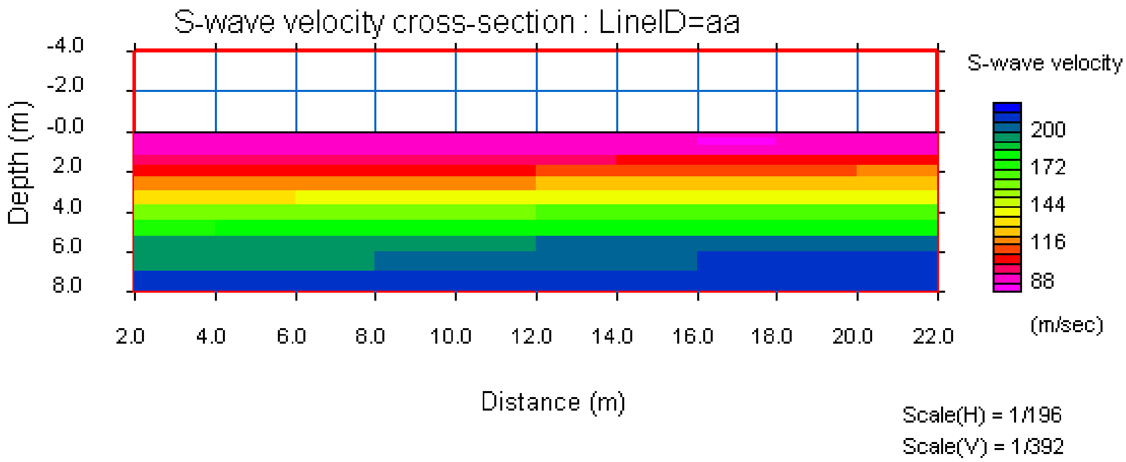


Starting on the left vertical axis and ending on the right vertical axis, select new depth points using the left mouse button to define the base of the cross-section. The best guide to what depth points should be selected will be the fold taper. A minimum of two depth points are required.

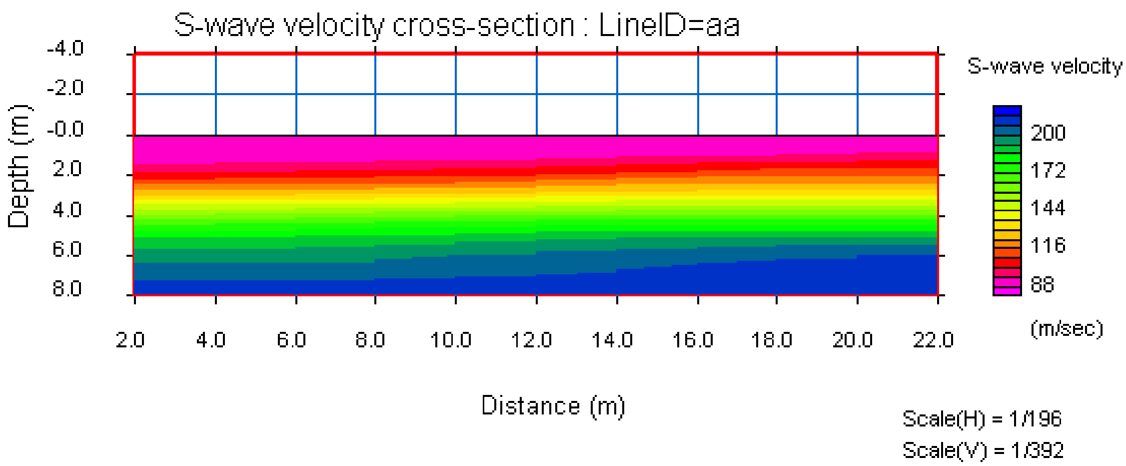


Next, select the *View* menu, *Contour interval*, *Automatic*, *Linear scale*, to automatically adjust the contour interval.

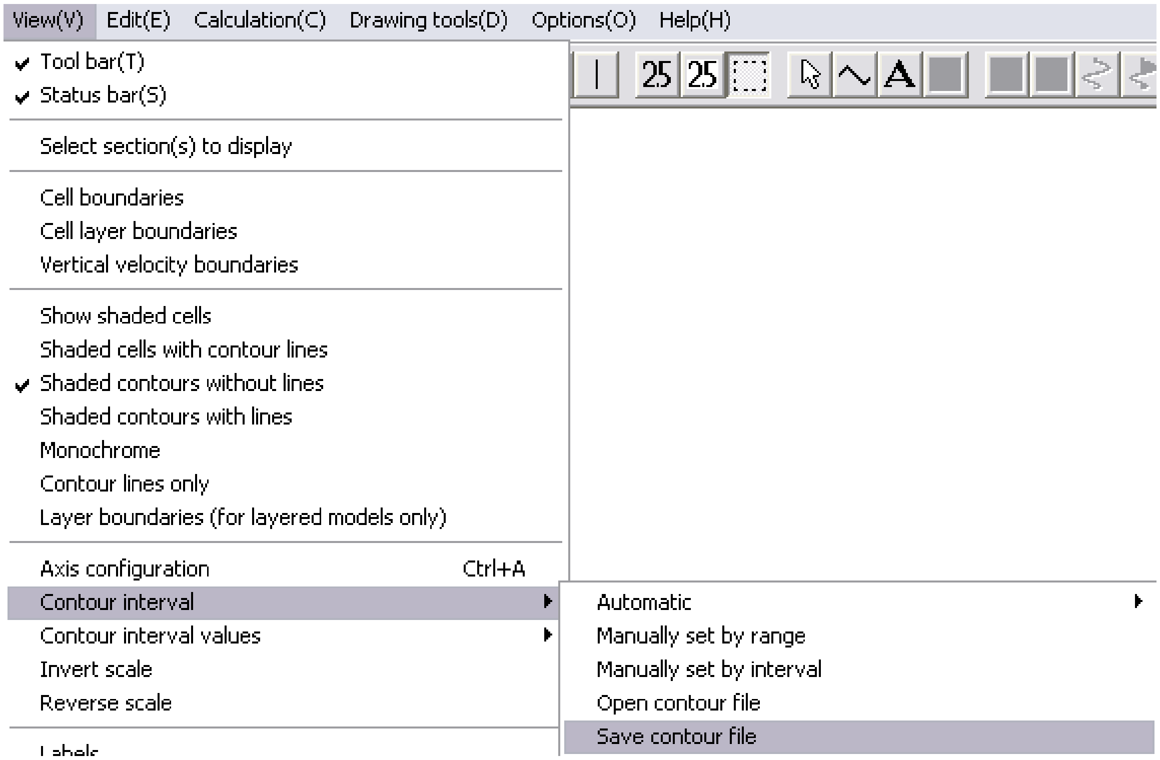




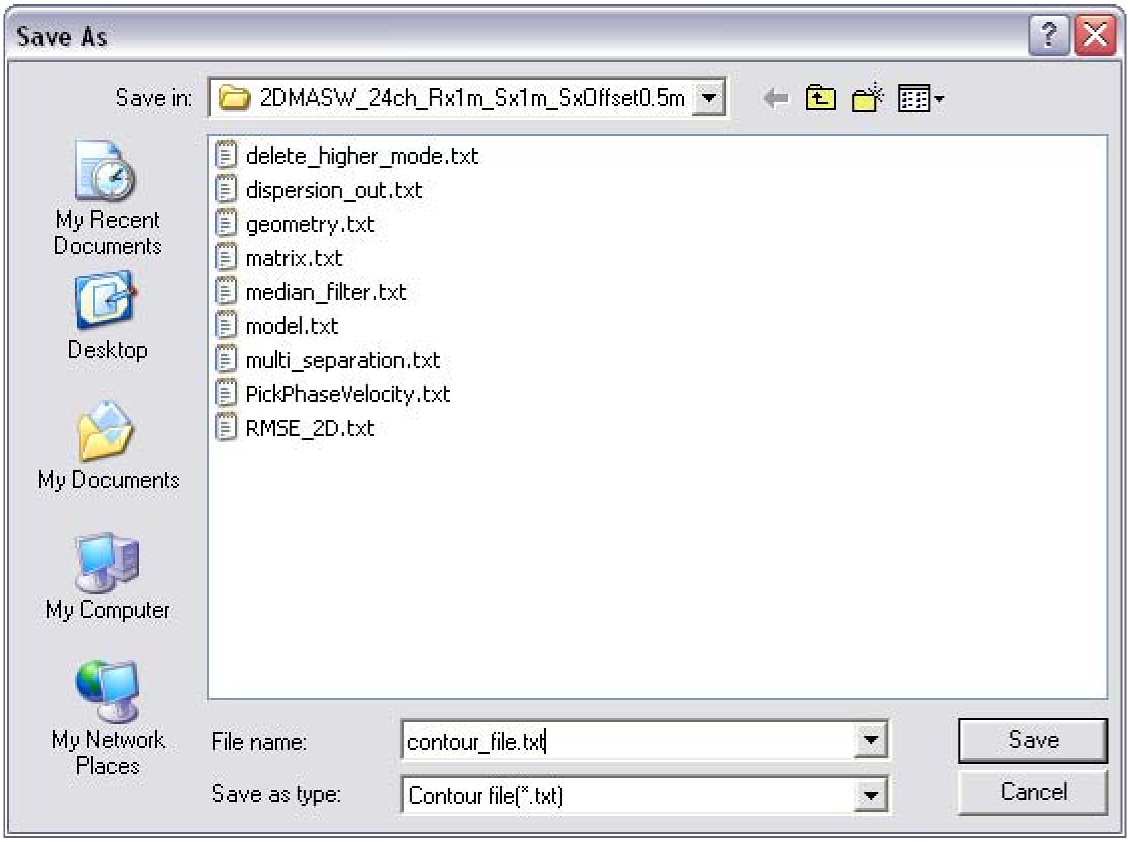
Click the *Fine color contour*  button to increase the display resolution.



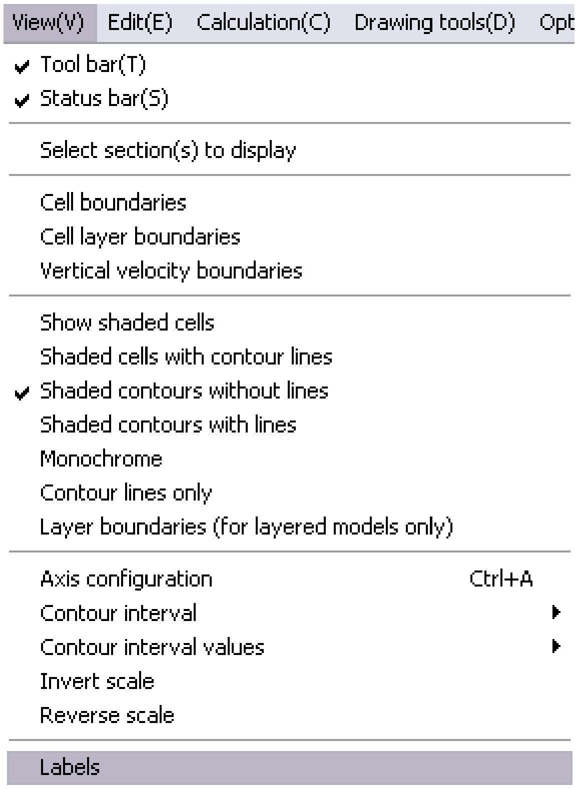
To save a custom contour file so that it can be applied again later, select the *View* menu, *Contour*, *Save contour file*.



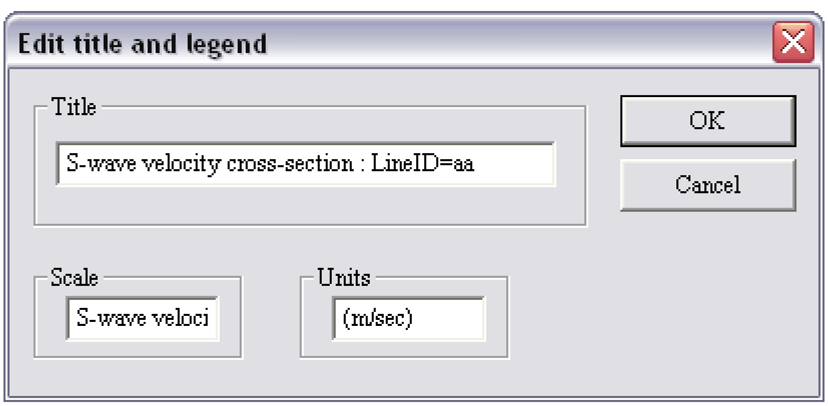
Assign a file name with the extension *.txt* and click *Save*.



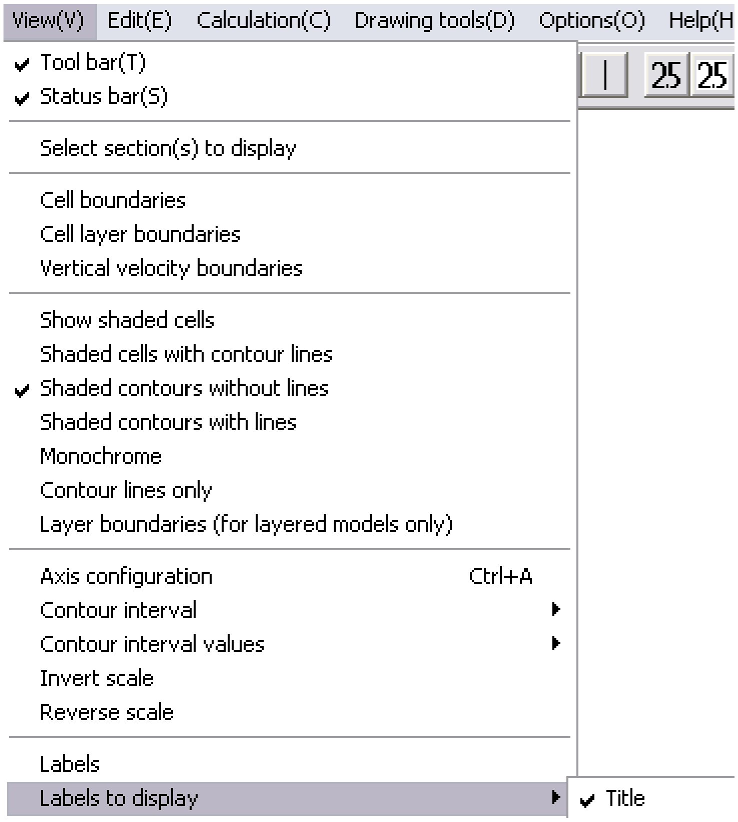
Next, edit the title of the cross-section by selecting the *View* menu, *Labels*.



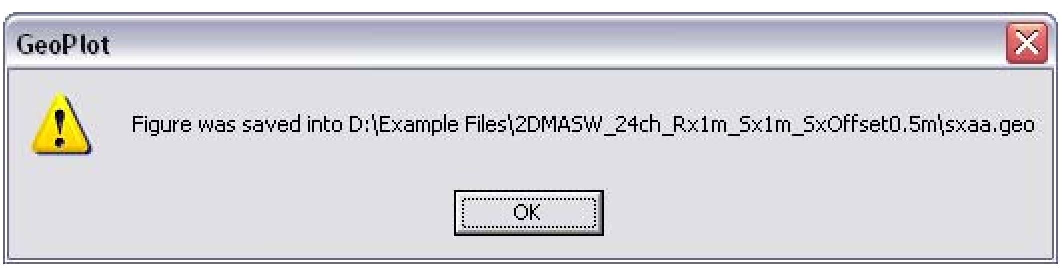
Enter the desired text in the *Title*, *Scale*, and *Units* fields and click *OK* when done.



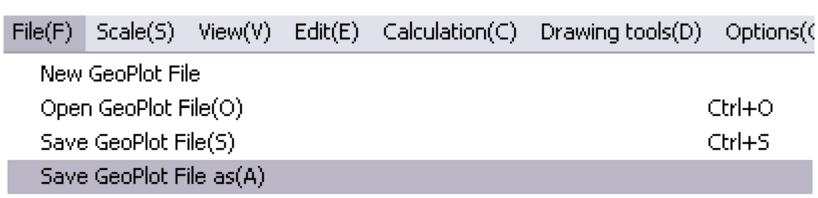
If you do not want to display the *Title*, select the *View* menu, *Labels to display* and uncheck *Title*.



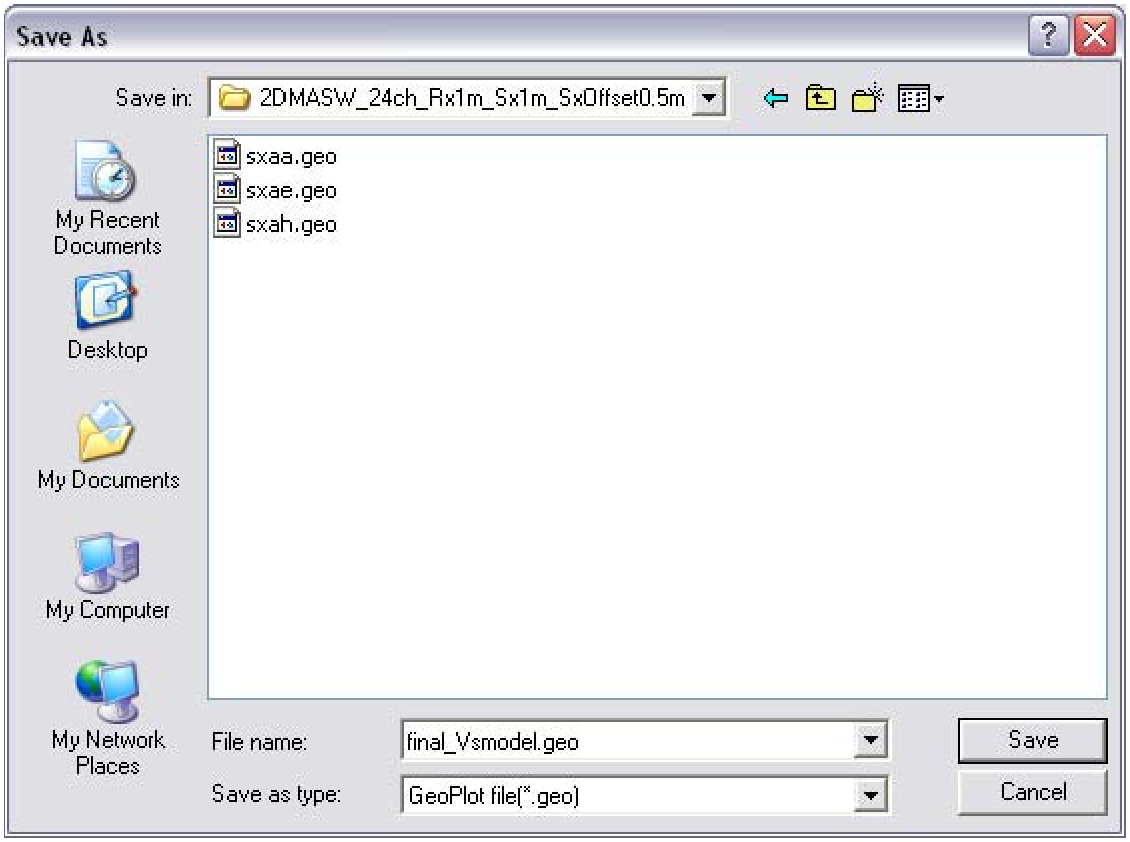
Now is a good time to save the file. If you are running the wizard, press the *Enter* key, and the GeoPlot file is automatically named and saved with the extension *.geo*, click *OK* and return to WaveEq to continue the wizard.



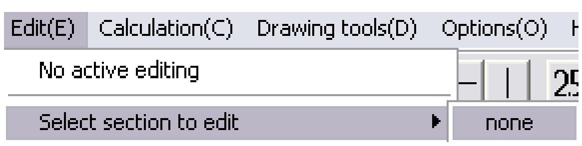
To save the file by hand, select the *File* menu, *Save GeoPlot file as*.

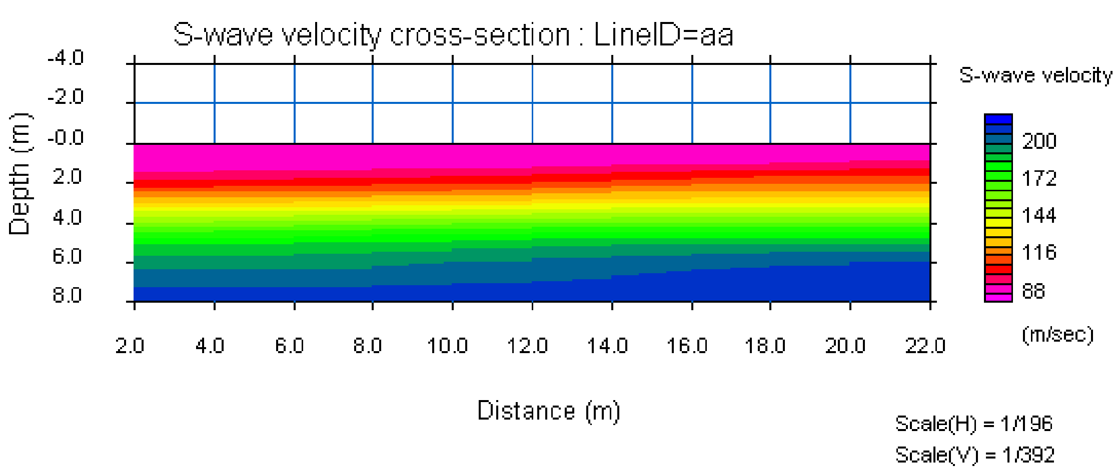


Assign a file name with the extension *.geo* and click *Save*.

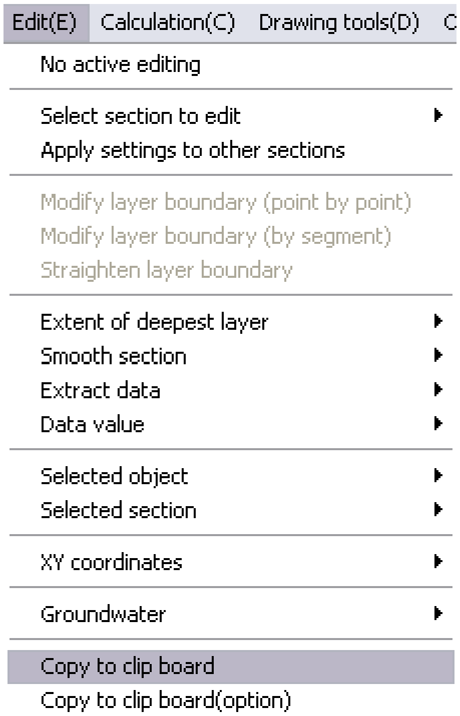


When you are done editing, to deactivate the cross-section and turn off the red outline, select the *Edit* menu, *Select section to edit*, *none*.

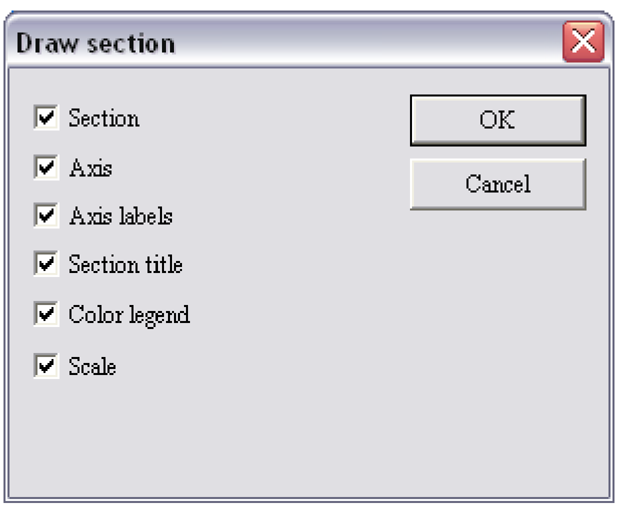




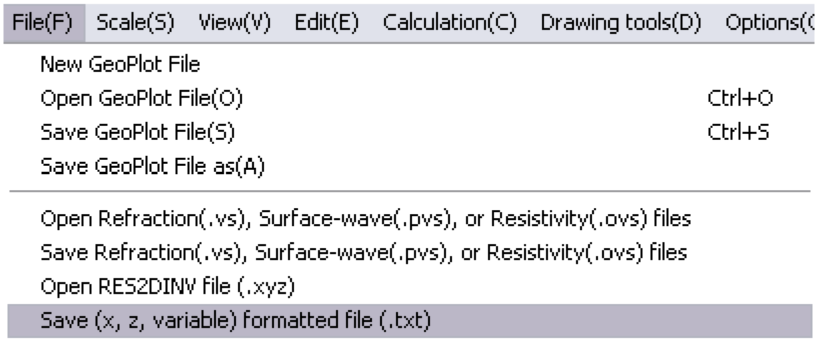
To capture an image of the cross-section for report graphics, select the *Edit* menu, *Copy to clipboard*, and then paste the image into the program of choice.



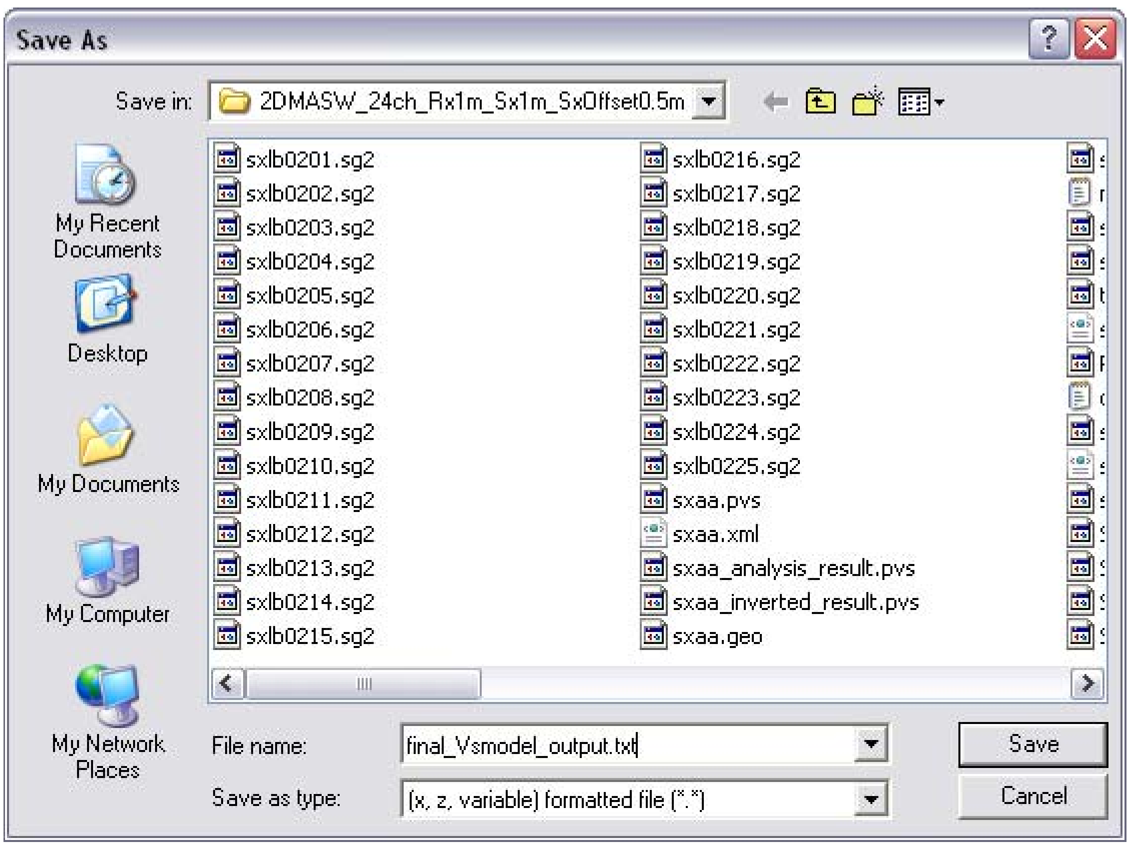
Copy to clipboard (option) allows you to select which features are included with the image capture.



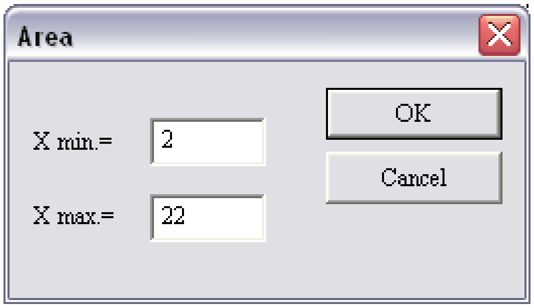
To output the cross-section data in text format for input into other data visualization programs, select the *File* menu, *Save (x, z, variable) formatted file (.txt)*.



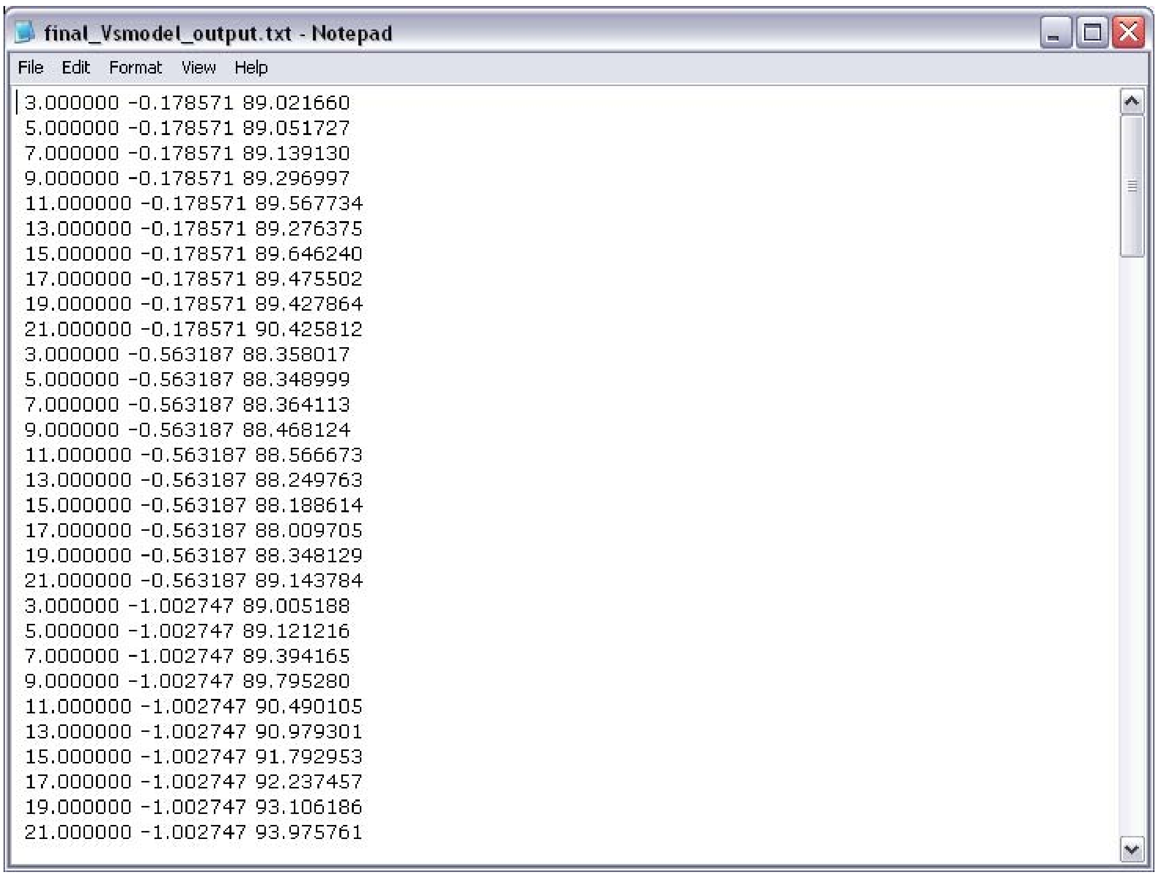
Assign a file name with the extension *.txt* and click *Save*.



Confirm the x-value range of data points to output and click *OK*.



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

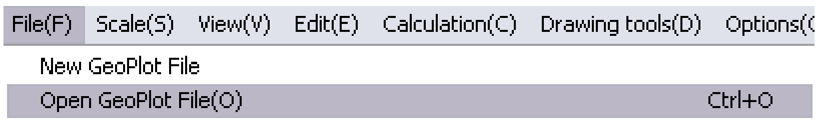



```
3.000000 -0.178571 89.021660
5.000000 -0.178571 89.051727
7.000000 -0.178571 89.139130
9.000000 -0.178571 89.296997
11.000000 -0.178571 89.567734
13.000000 -0.178571 89.276375
15.000000 -0.178571 89.646240
17.000000 -0.178571 89.475502
19.000000 -0.178571 89.427864
21.000000 -0.178571 90.425812
3.000000 -0.563187 88.358017
5.000000 -0.563187 88.348999
7.000000 -0.563187 88.364113
9.000000 -0.563187 88.468124
11.000000 -0.563187 88.566673
13.000000 -0.563187 88.249763
15.000000 -0.563187 88.188614
17.000000 -0.563187 88.009705
19.000000 -0.563187 88.348129
21.000000 -0.563187 89.143784
3.000000 -1.002747 89.005188
5.000000 -1.002747 89.121216
7.000000 -1.002747 89.394165
9.000000 -1.002747 89.795280
11.000000 -1.002747 90.490105
13.000000 -1.002747 90.979301
15.000000 -1.002747 91.792953
17.000000 -1.002747 92.237457
19.000000 -1.002747 93.106186
21.000000 -1.002747 93.975761
```

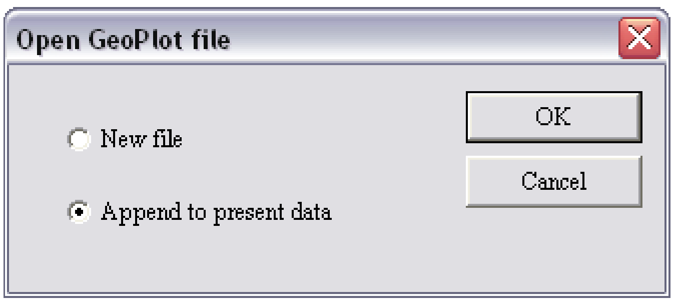
Some other useful GeoPlot functions include the following:

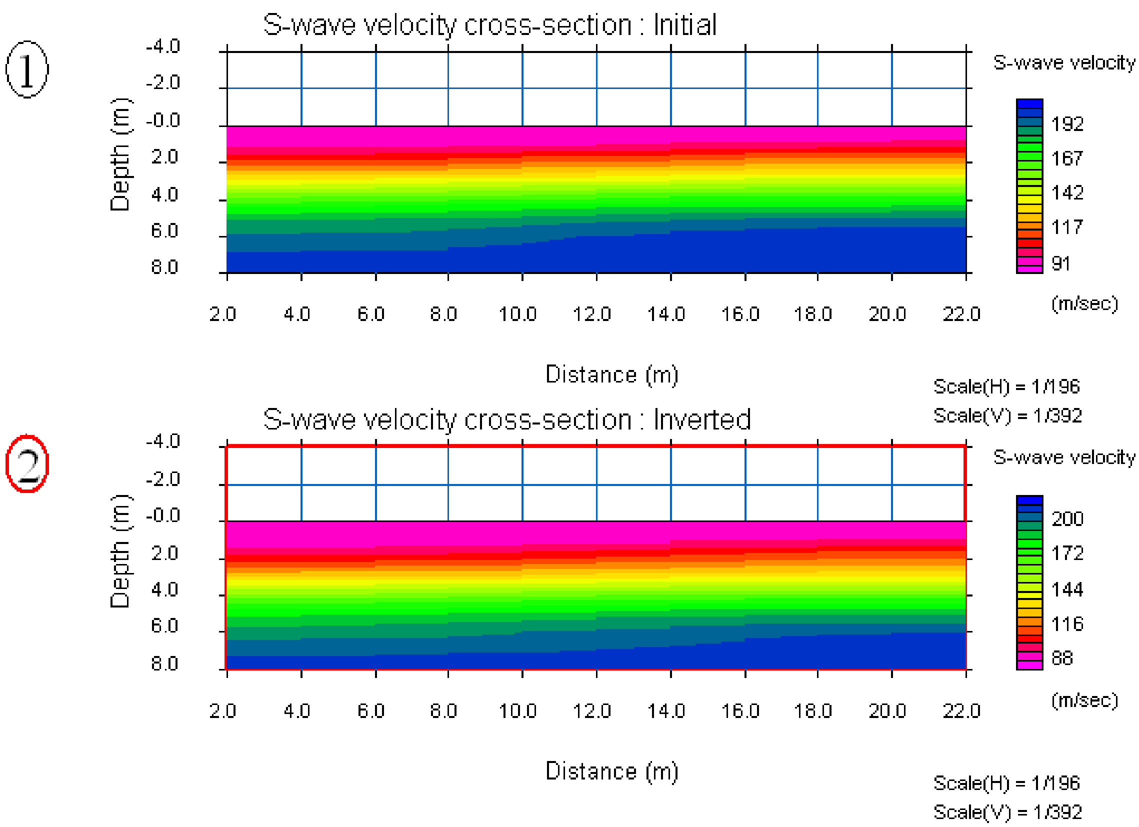
- opening and appending other cross-sections
- applying a saved contour file
- displaying the contour interval values
- inverting and reversing the velocity scale
- applying settings from one cross-section to others

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, select the *File* menu, *Open GeoPlot file,* to open and append another cross-section to the display.

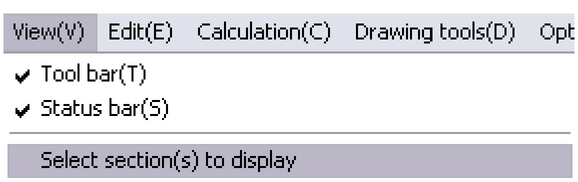


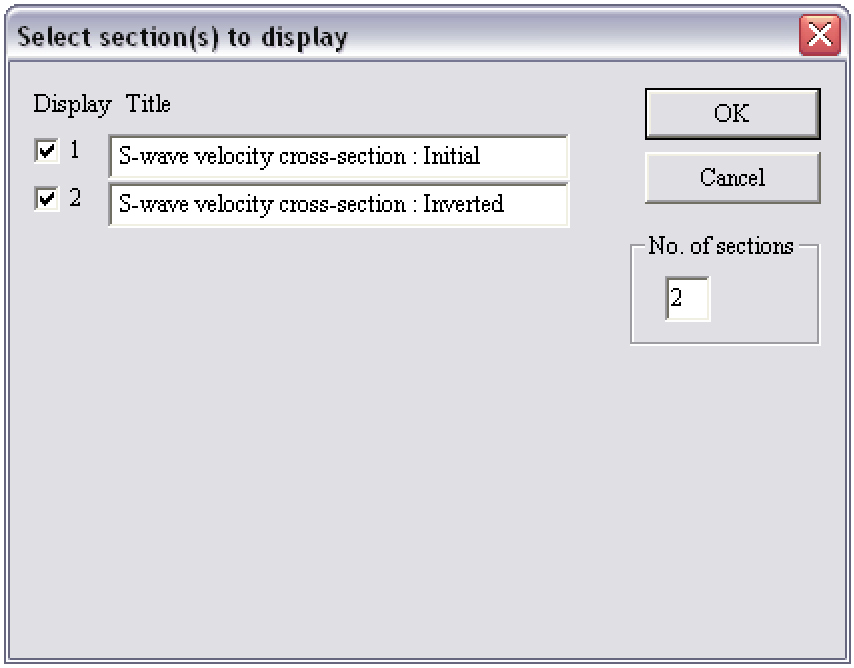
Select to *Append to present data* and click *OK*.



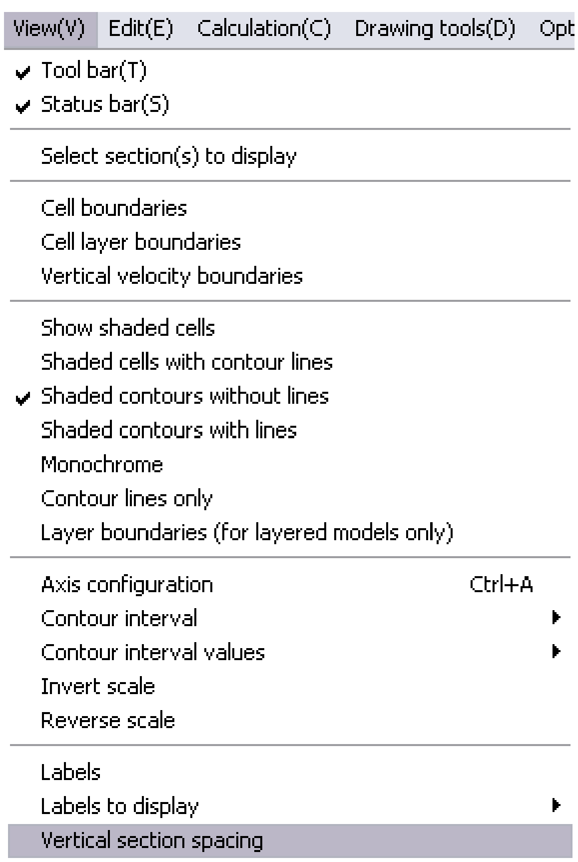


To select between cross-sections, click on the cross-section number. When selected, the circle around the cross-section number and the cross-section outline turns red. When there is more than one cross-section displayed, select the *View* menu, *Select section(s) to display* should you wish to uncheck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

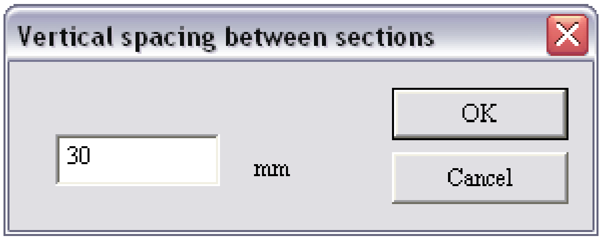




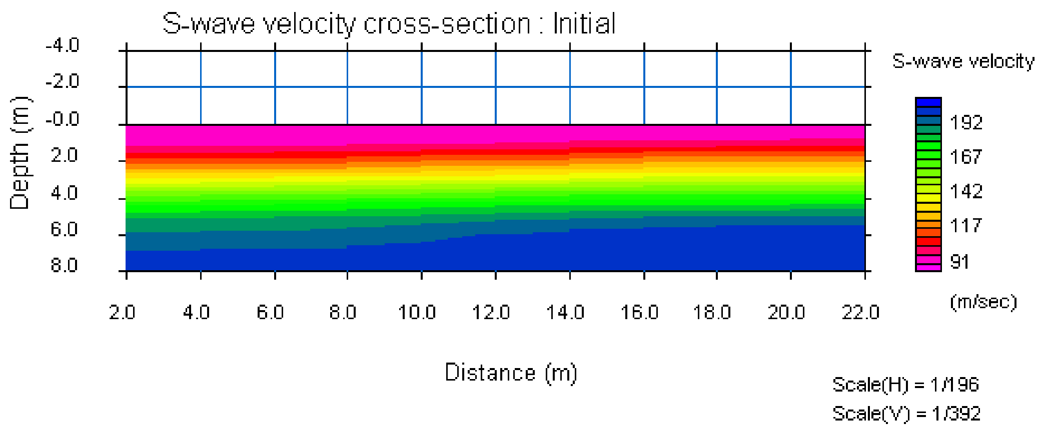
To change the vertical separation between the cross-sections, select the *View* menu, *Vertical section spacing*.



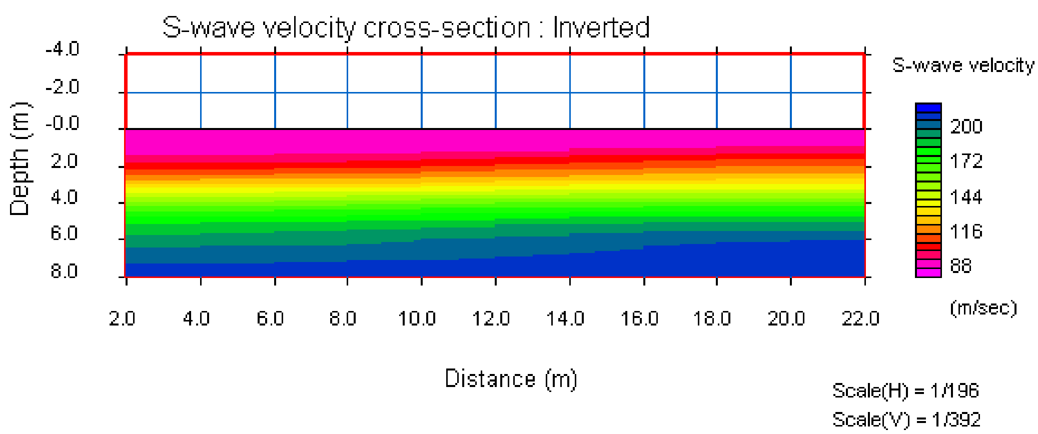
Enter the desired spacing and click *OK*.



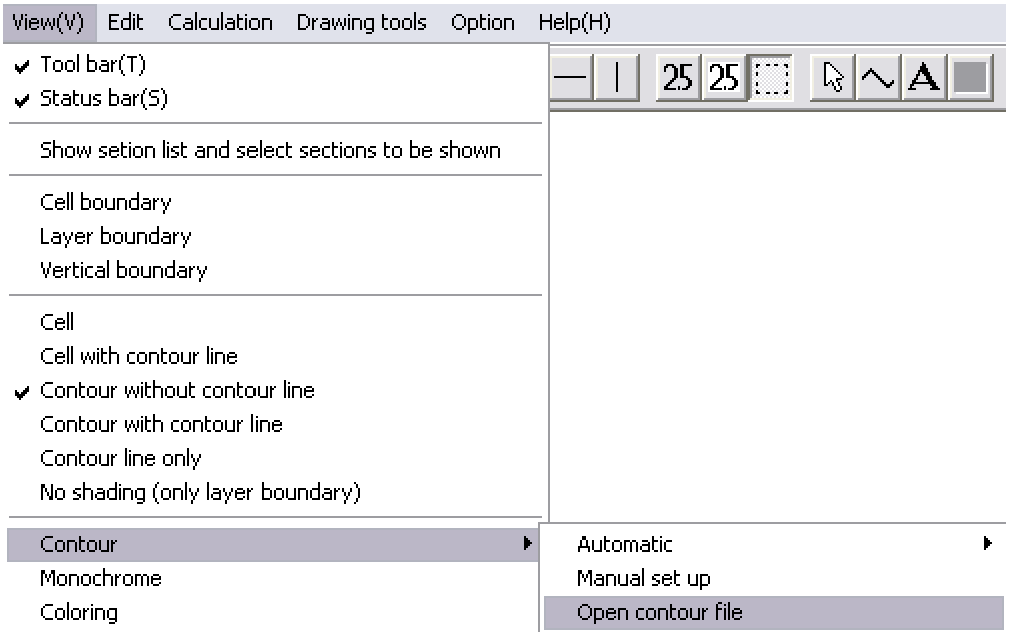
1



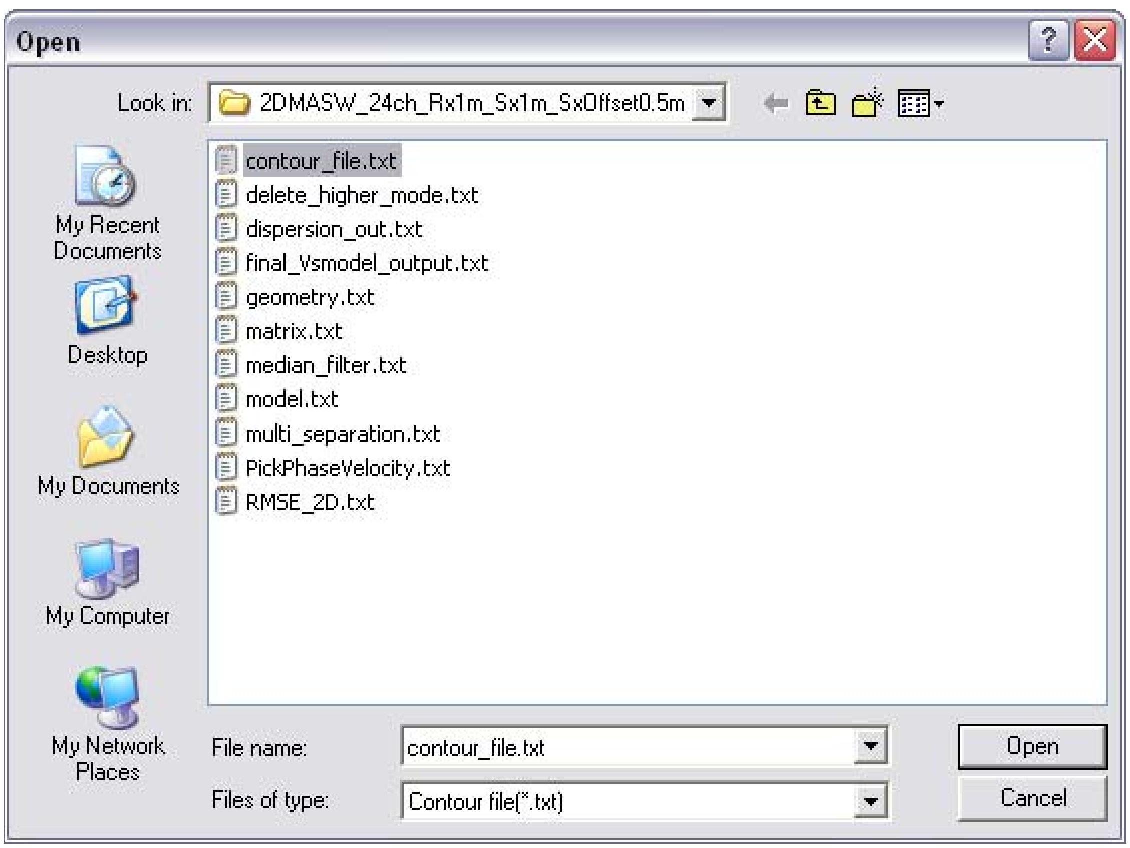
2



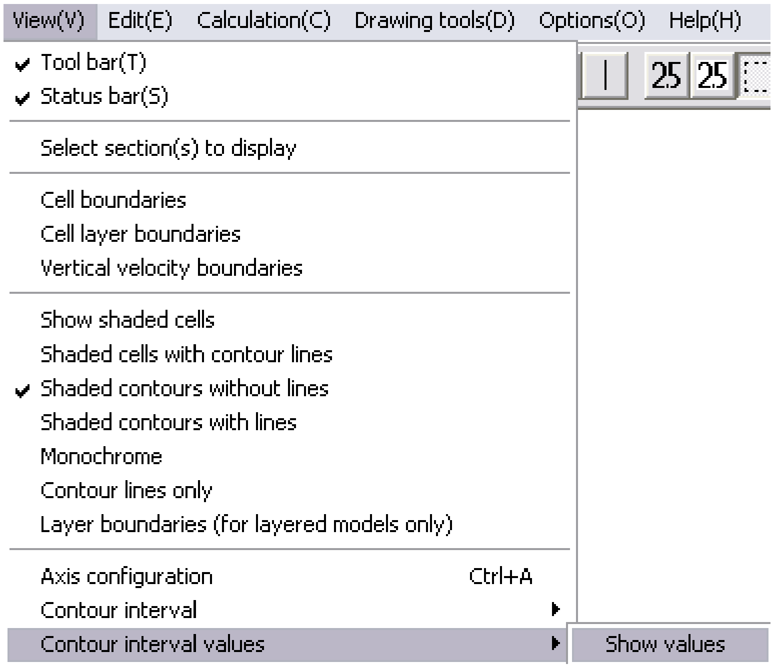
To apply a saved custom contour file to another cross-section, select the *View* menu, *Contour*, *Open contour file*.

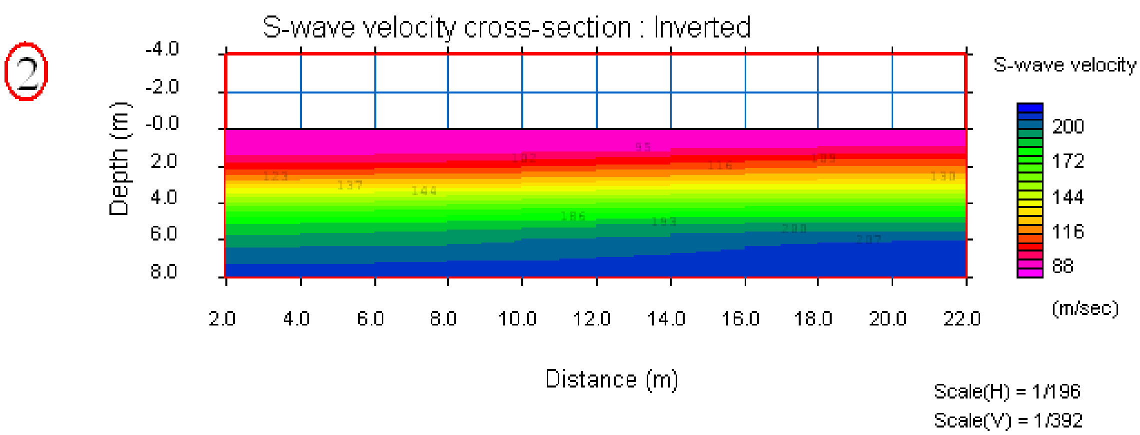


Highlight the contour file and click *Open*.

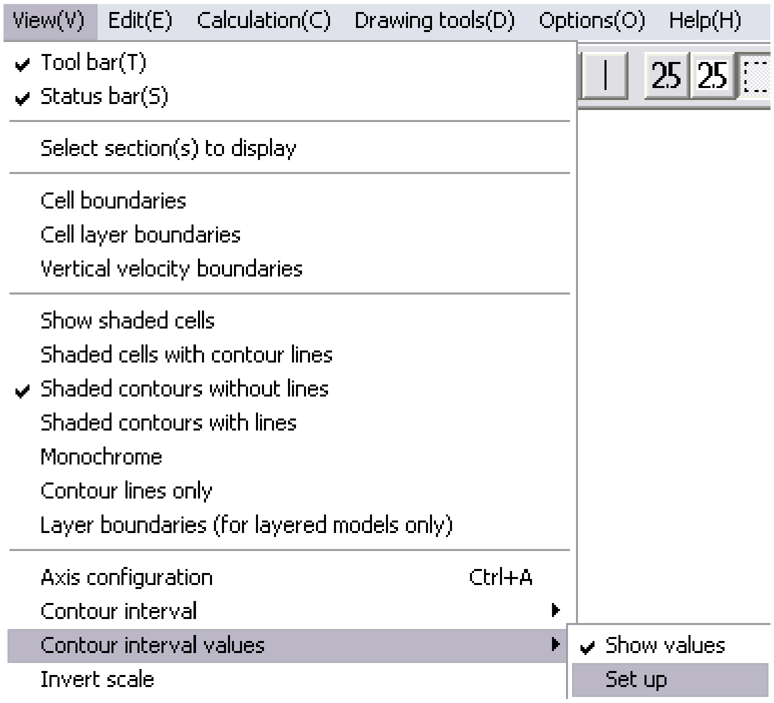


To overlay the values of the contour intervals, select the *View* menu, *Contour interval values*, *Show values*.

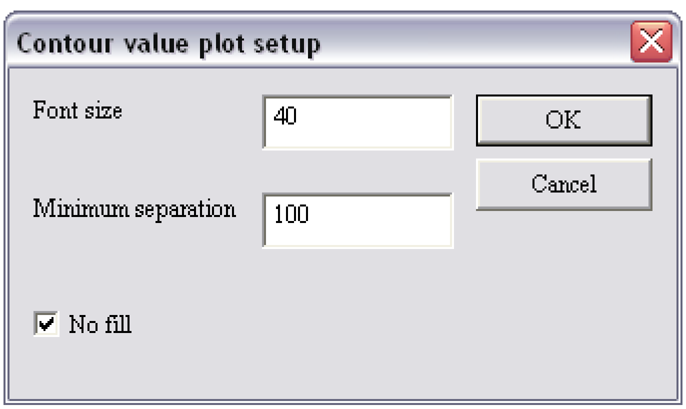




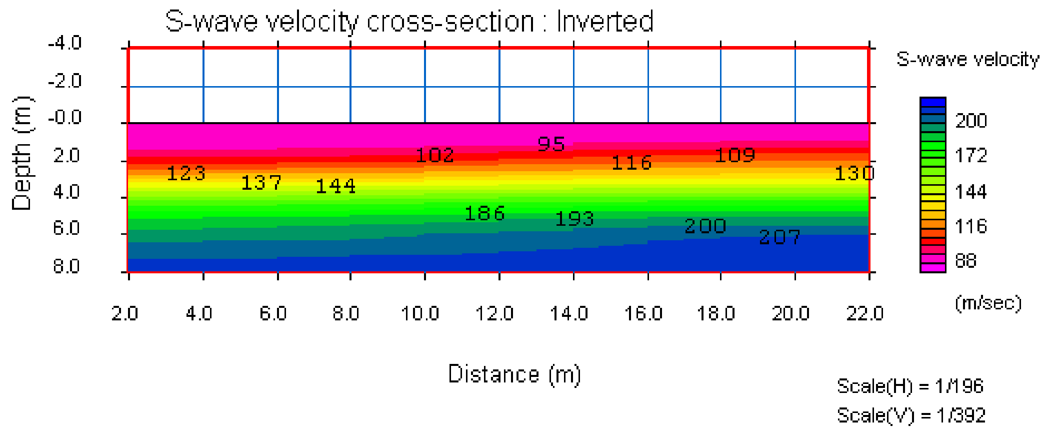
If the font size of the contour interval values needs to be increased, select the *View* menu, *Contour interval values, Set up*.



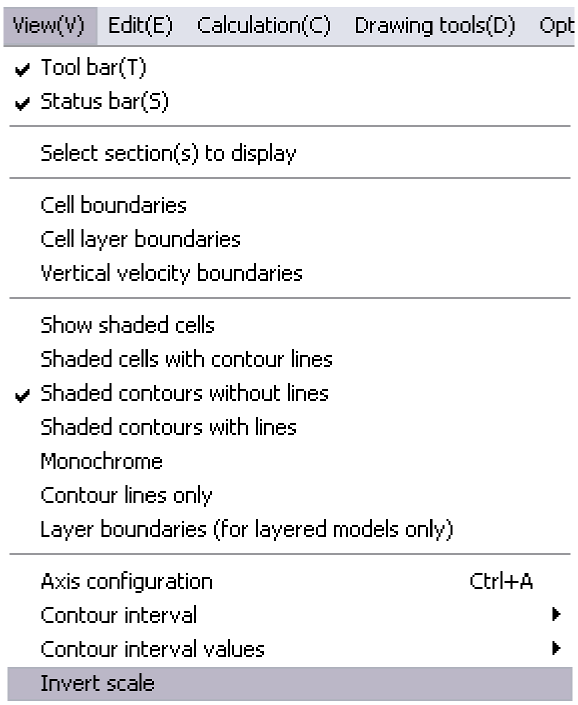
Increase or decrease the *Font size* as desired. The default *Minimum separation* at which the values appear suits most displays. If *No fill* is checked (the default), there will be no background behind the values. Uncheck *No fill* to turn on a white background.

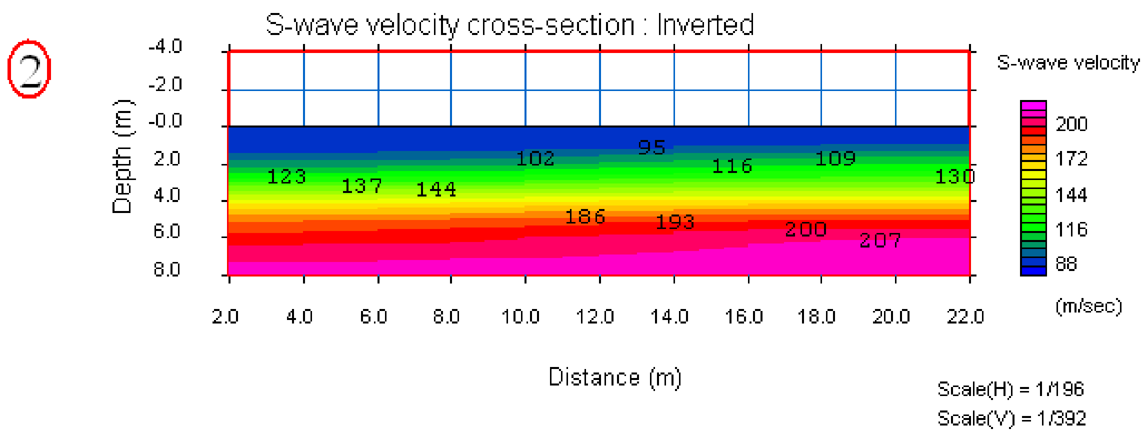


2

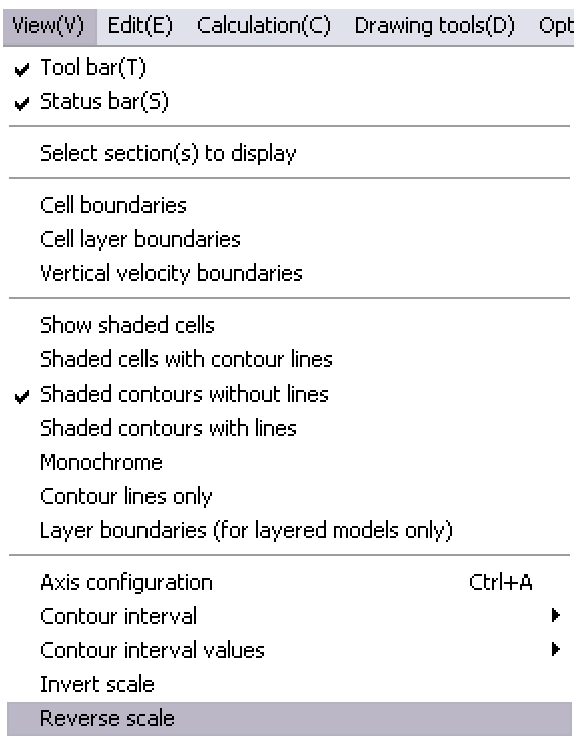


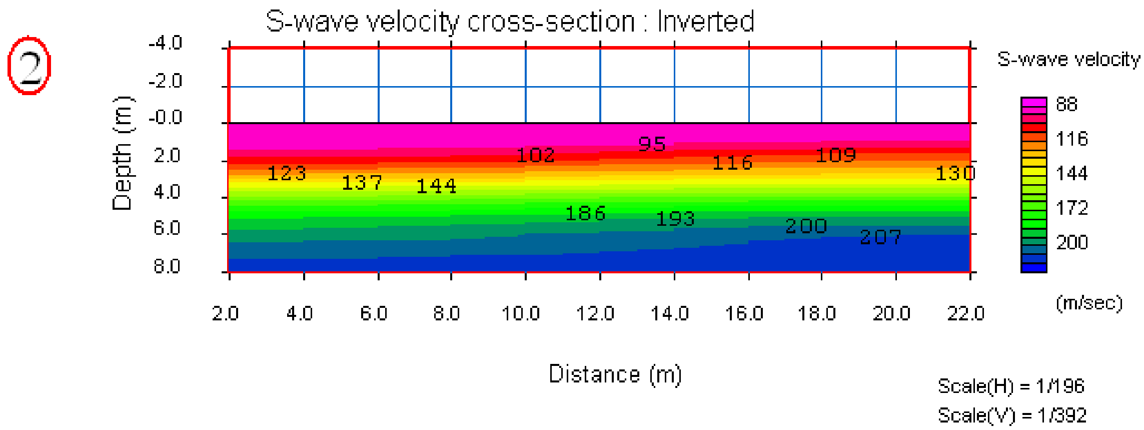
To invert the color gradient of the scale, select the *View* menu, *Invert scale*.



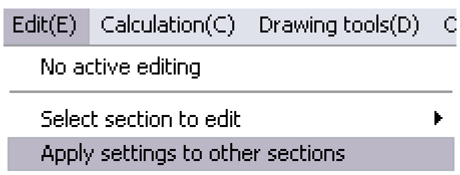


To flip the direction of the scale so that it increases downwards, select the *View* menu, *Reverse scale*.

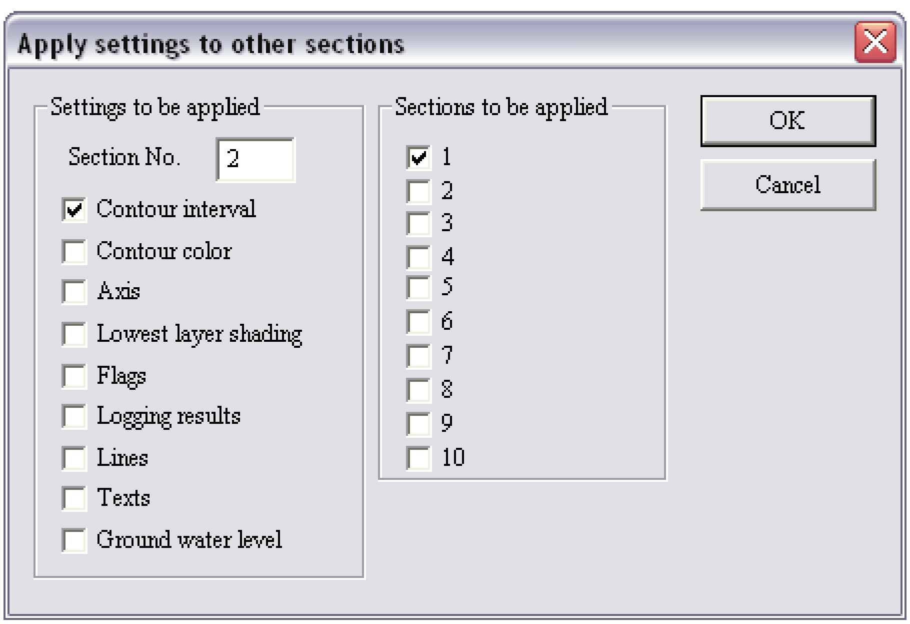




To apply the settings for a given cross-section in the current display, select the *Edit* menu, *Apply settings to other sections*.



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*.

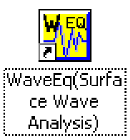


4.2 Combining Active and Passive Source Results

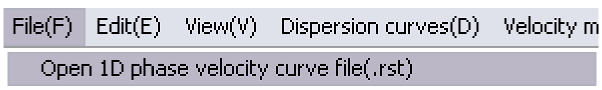
Typically MASW datasets will have higher frequency content and MAM datasets will have lower frequency content. Once active and passive source dispersion curves are picked for a given site, it is simple to combine the curves to obtain the highest resolution over the entire sampled depth range. This section 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

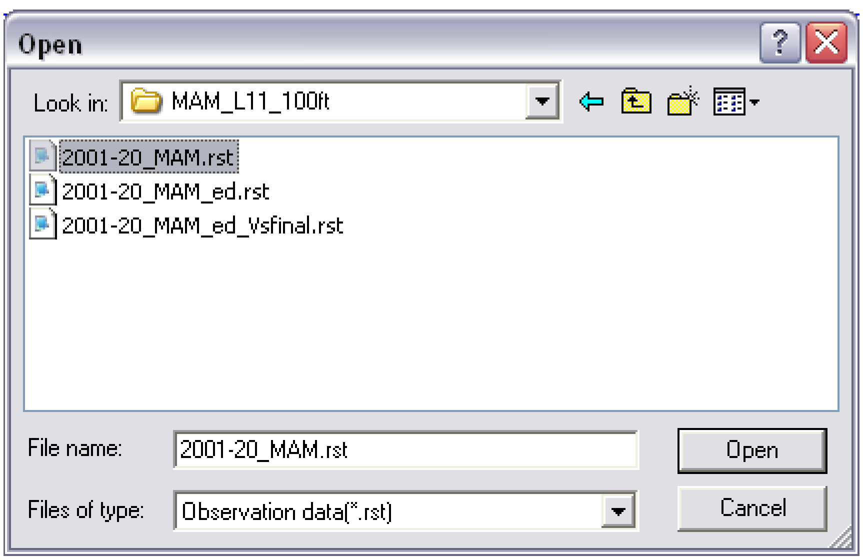
Double-click on the WaveEq icon.



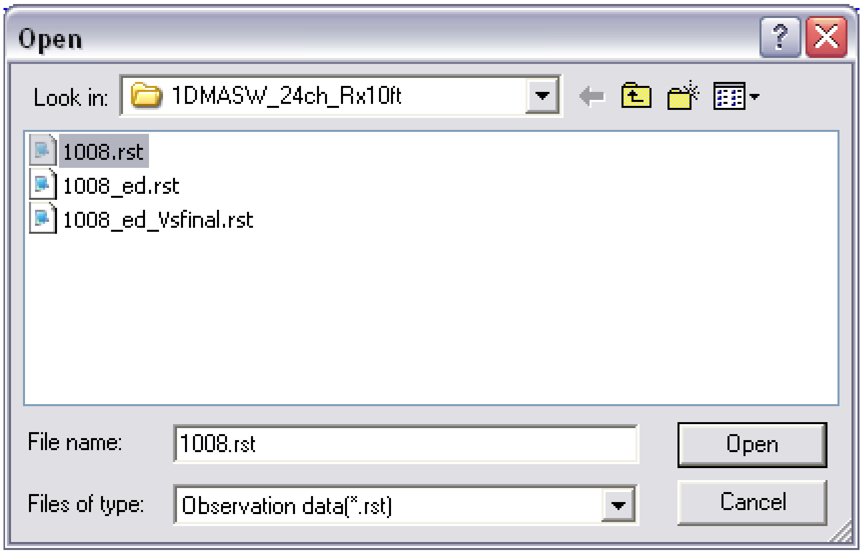
Open the dispersion curve result file for either the 1D MASW active or MAM passive source dataset by selecting the *File* menu, *Open velocity or dispersion curve file (.rst)*.



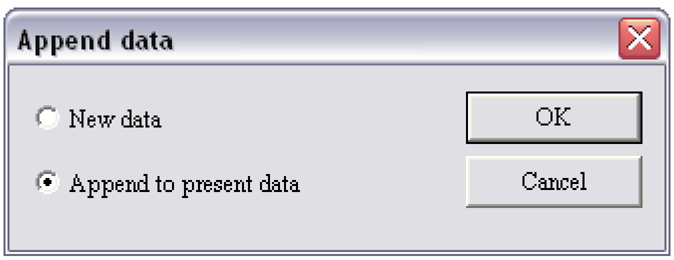
For this example, the passive source result file is opened first. In general, it is best to input raw dispersion curves so that any smoothing is applied to the composite curve. Highlight the file and click *Open*.



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

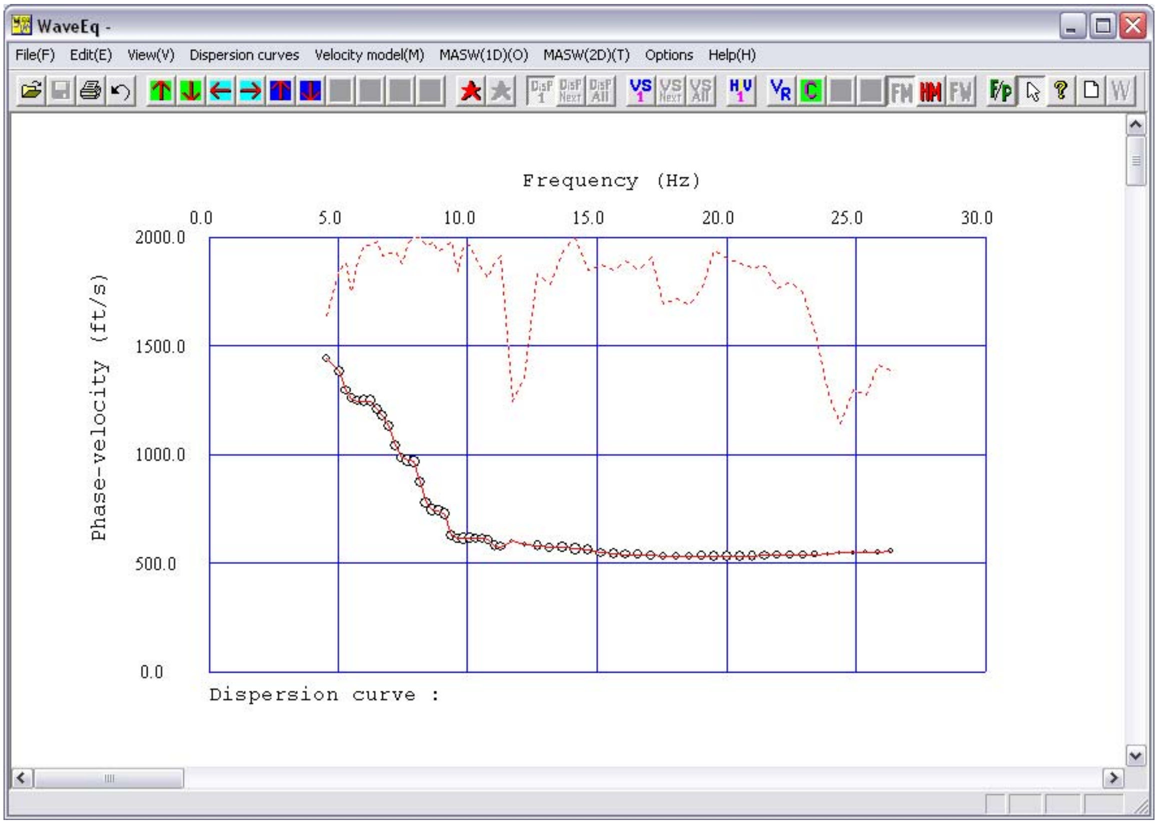


To combine the 1D MASW dispersion curve with the MAM curve, select *Append to present data*. Click *OK* when done.

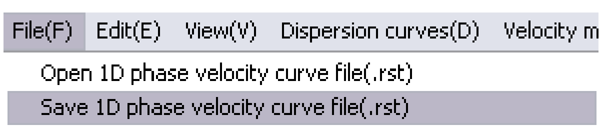


If you had more dispersion curves to append, say from additional active source shots for the same spread, repeat these steps.

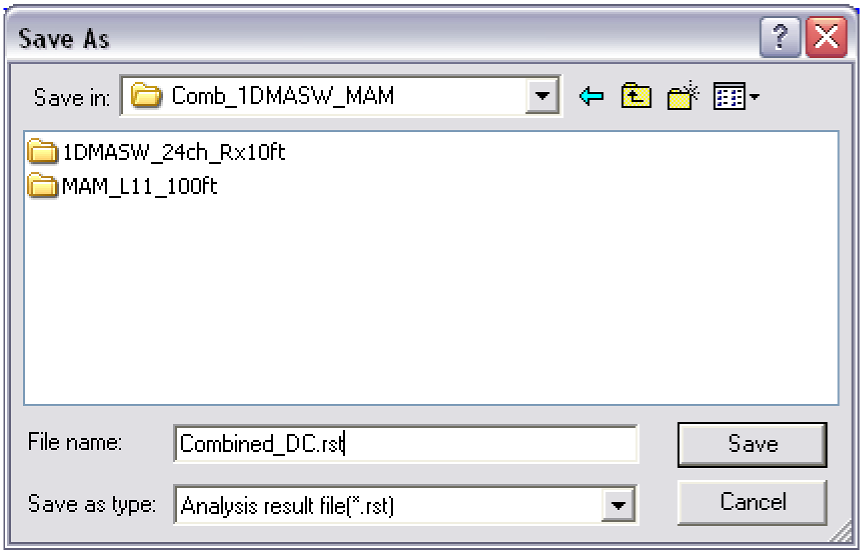
The dispersion curves will typically have some overlap. If the curves are not aligned, double-check the picks. Usually the problem lies in noisy or spurious picks on the high frequency end of the passive source dispersion curve and/or the low frequency end of the active source dispersion curve.



Select the *File* menu, *Save 1D phase velocity curve file (.rst)* to save the combined results as a new file.

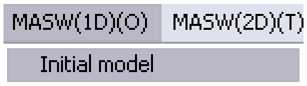


Assign a file name with the extension *.rst* and click *Save*.

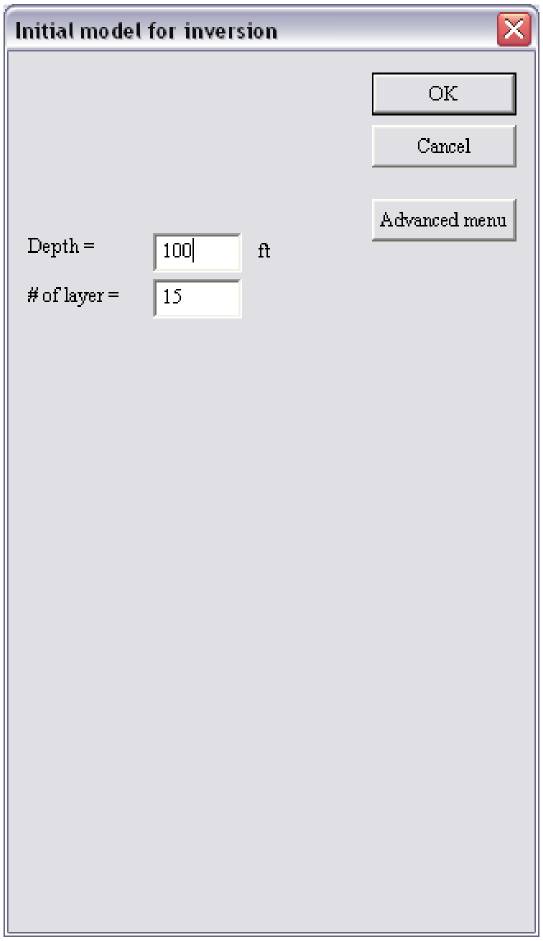


Edit the dispersion curve as needed and save the edited results as a new file if desired.

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

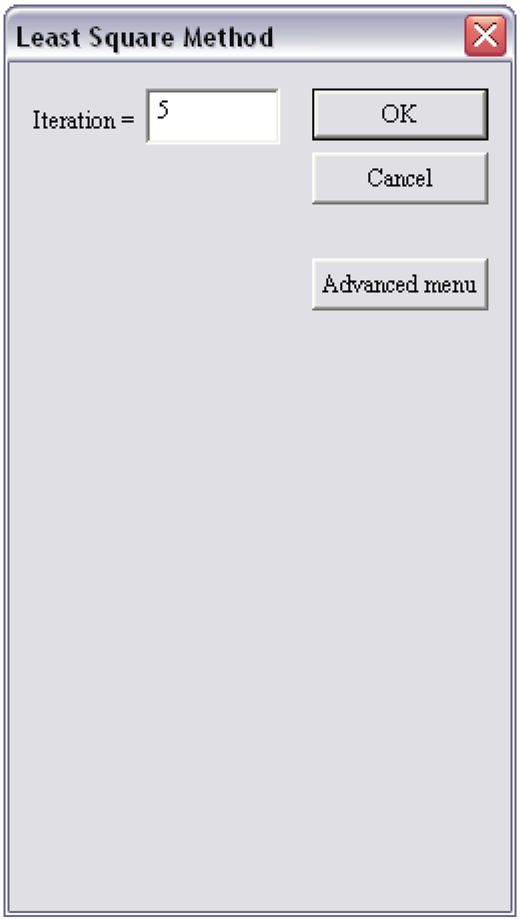


Set the maximum depth for the initial model.

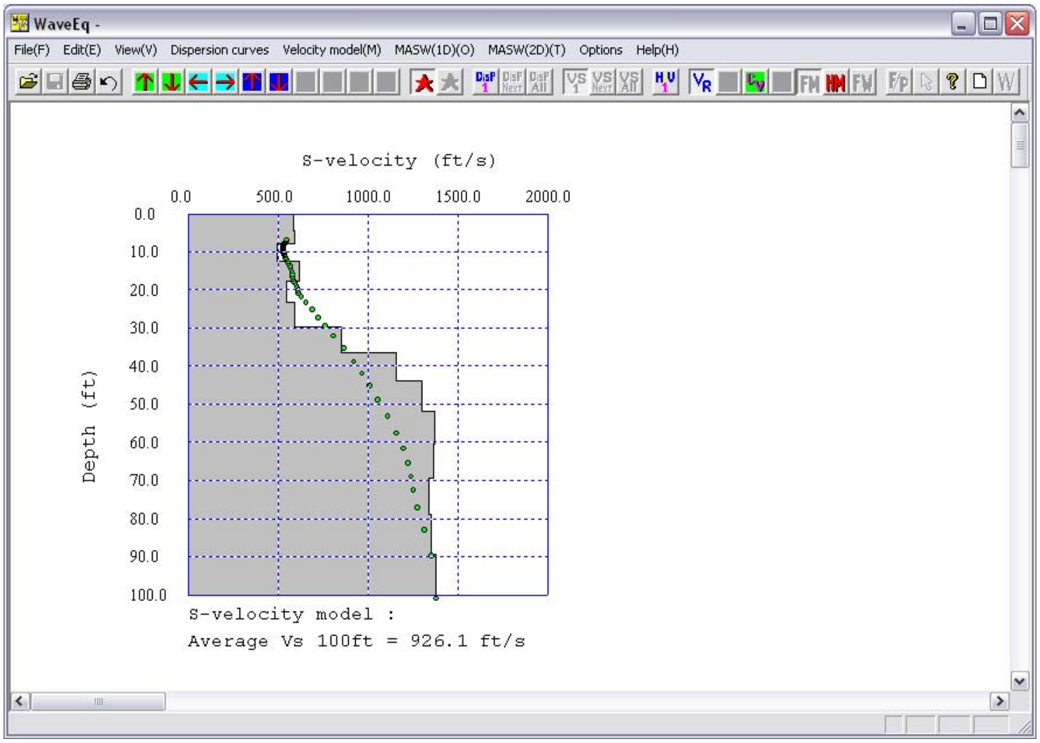


Run the inversion by selecting the *MASW (1D)* menu, *Inversion*.

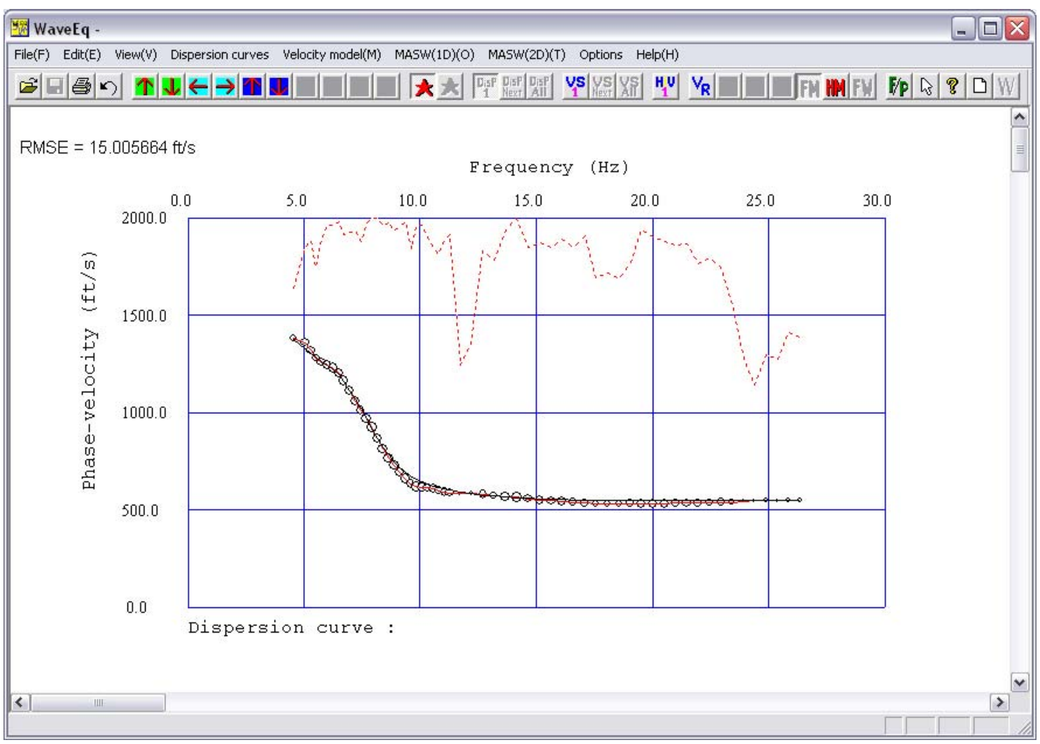
Accept the default value or increase as desired for *Iteration*.



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



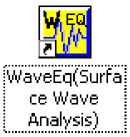
In the dispersion curve view, compare the observed and calculated dispersion curves.



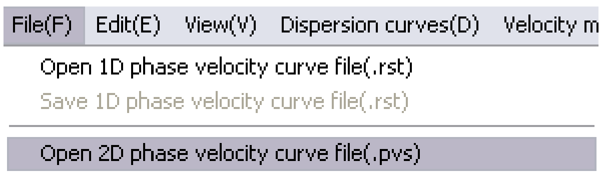
Save the final result by selecting the *File* menu, *Save 1D phase velocity curve file (.rst)*.

4.2.2 Combining 2D MASW and MAM Results

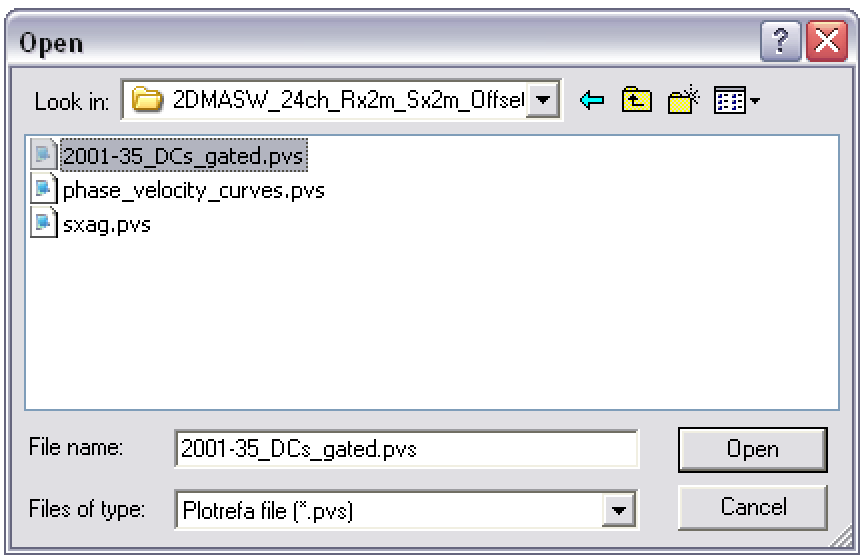
Double-click on the WaveEq icon.



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

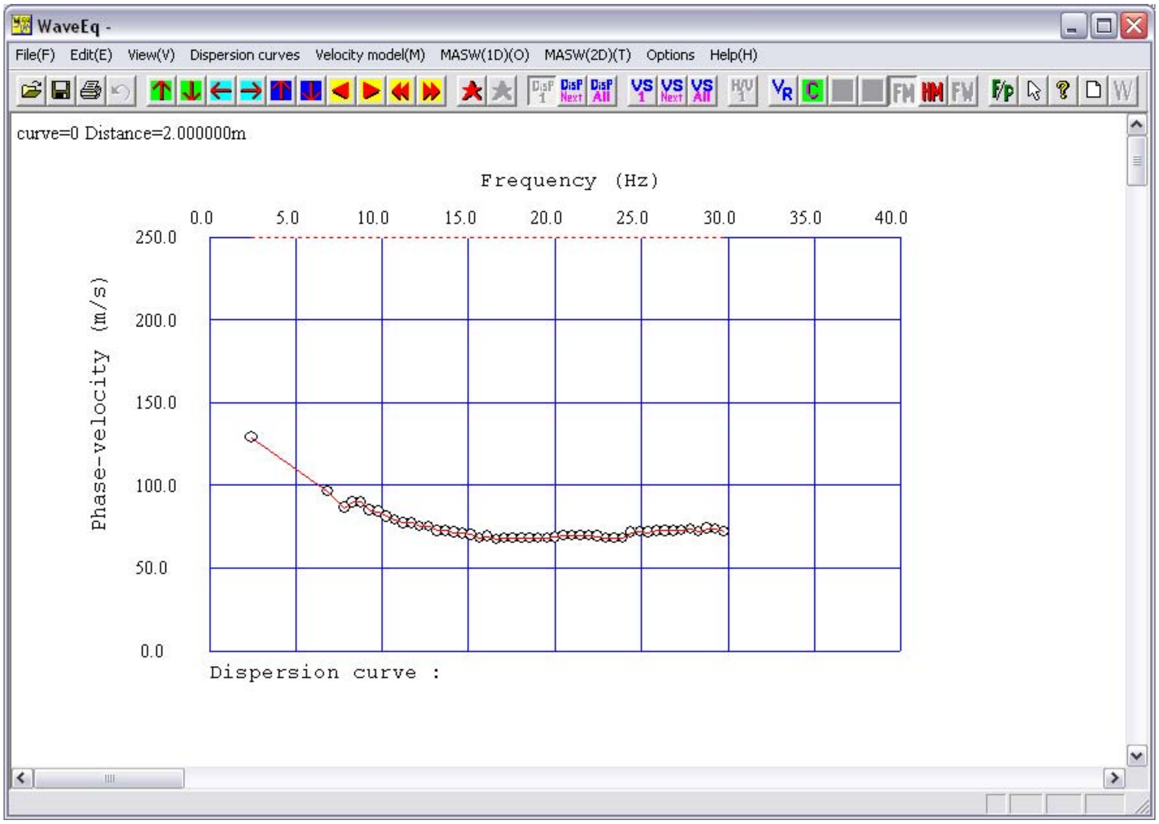


In general, it is best to input raw dispersion curves so that any smoothing is applied to composite curves. Highlight the file and click *Open*.

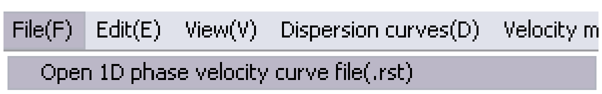


The number of imported dispersion curves is shown, click *OK*.

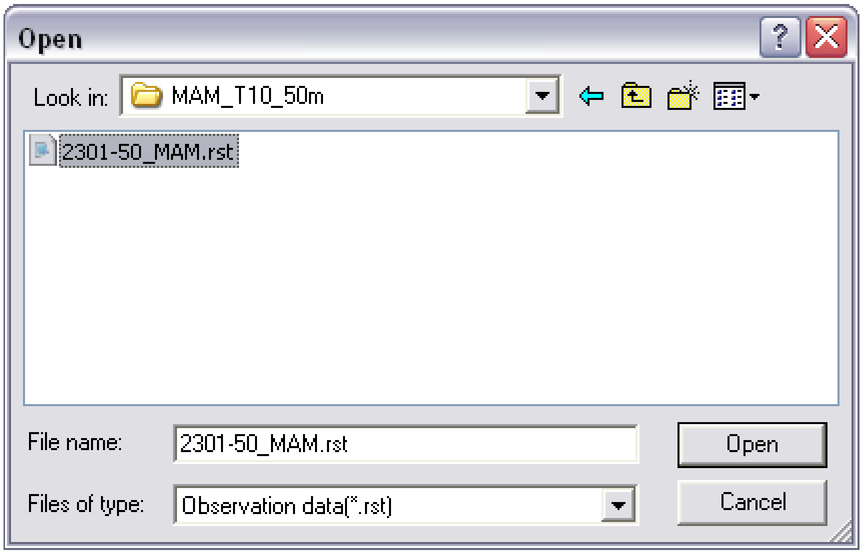
The first in the group of dispersion curves is displayed.



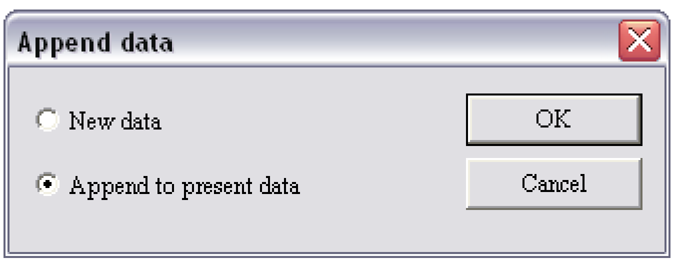
Open the dispersion curve from the MAM dataset by selecting the *File* menu, *Open 1D phase velocity curve file (.rst)*.



Highlight the file and click *Open*.



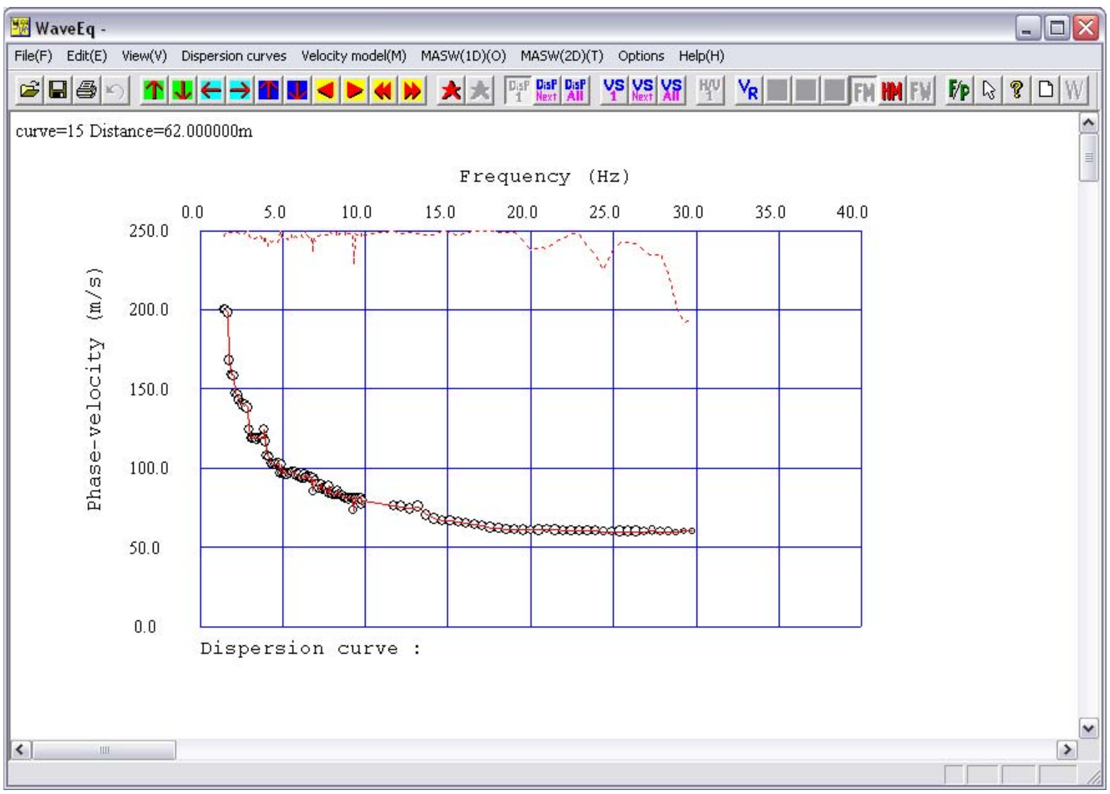
Select *Append to present data* to combine the MAM dispersion curve with the 2D MASW dispersion curves. Click *OK* when done.



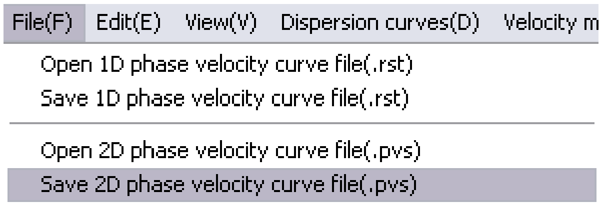
Next, a prompt asks whether the MAM dispersion curve should be appended to only the currently displayed 2D MASW dispersion curve or to all of the 2D MASW curves. The MAM dispersion curve should be appended to each MASW curve. If it is only appended to one MASW curve, it will create a velocity anomaly 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.

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

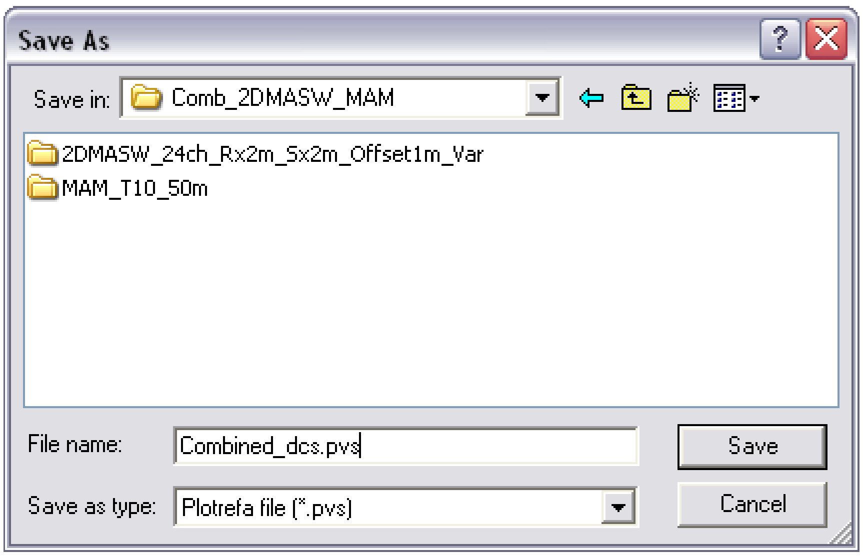
The first in the group of composite dispersion curves is displayed. The MAM and MASW dispersion curves will typically have some overlap. If the curves are not aligned, double-check the picks. Usually the problem lies in noisy or spurious picks on the high frequency end of the passive source dispersion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



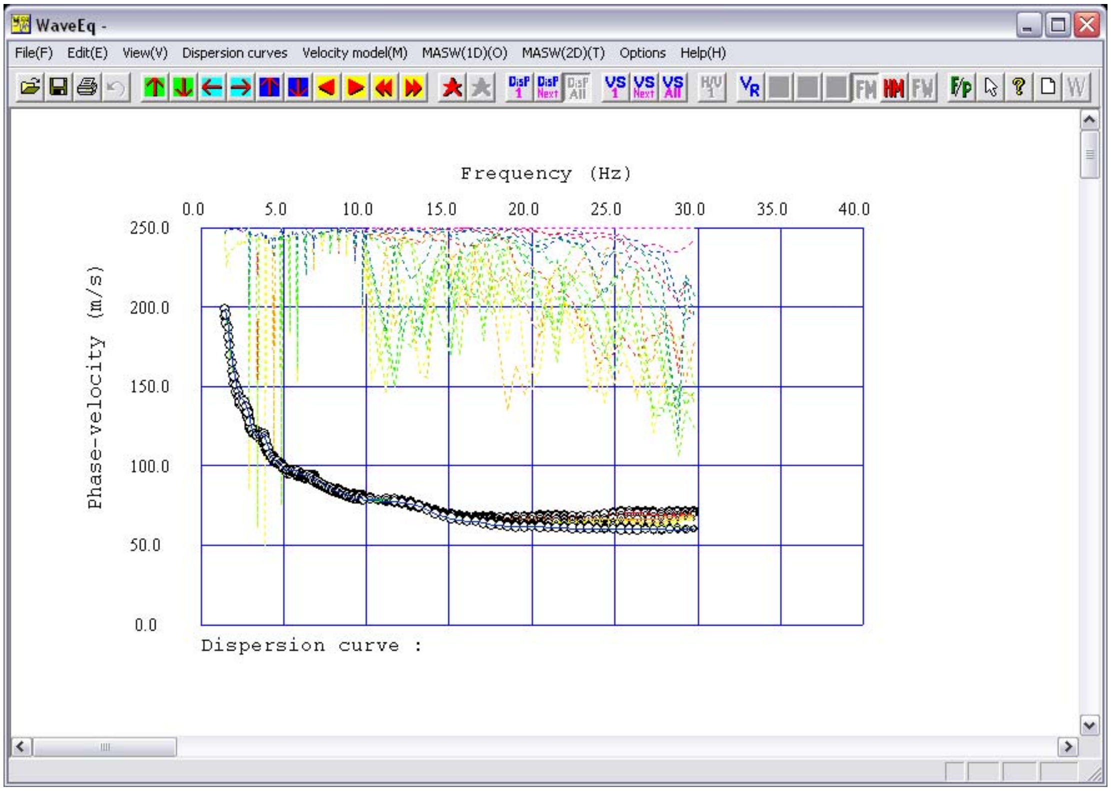
Select the *File* menu, *Save 2D phase velocity curve file (.pvs)* to save the combined results as a new file.



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

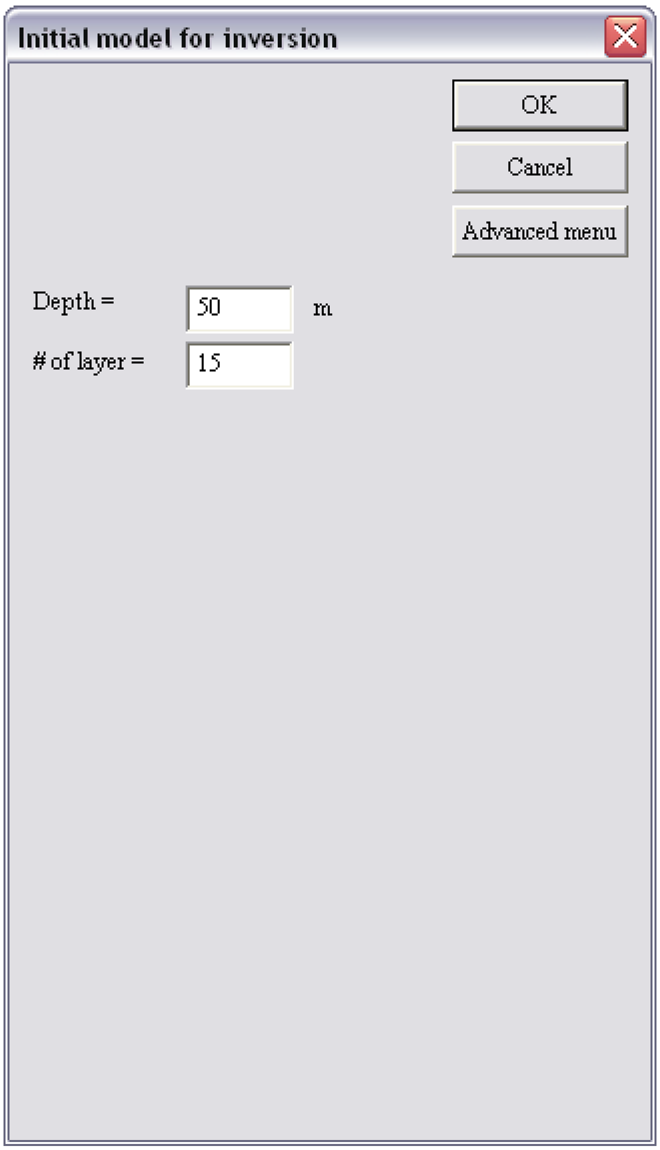


Edit the dispersion curves as needed and save the edited results as a new file if desired.



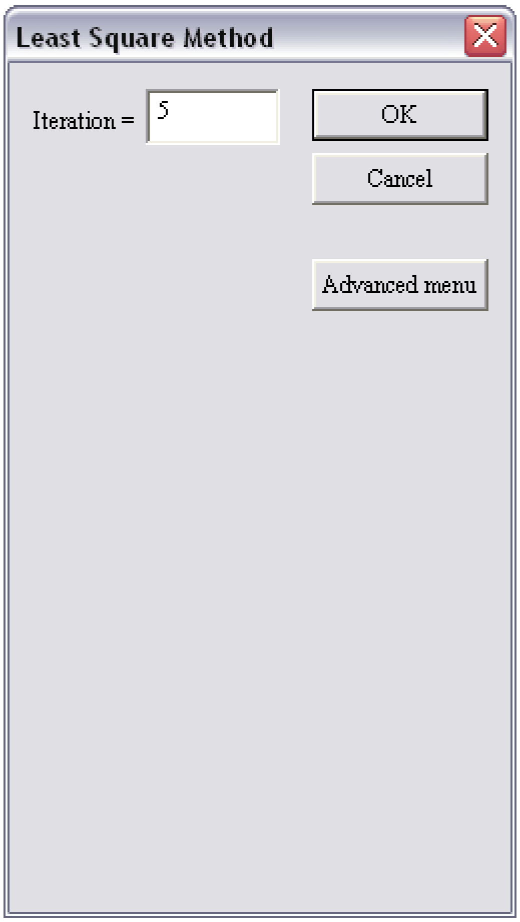
Generate an initial model by selecting the *MASW (2D)* menu, *Initial model*.

Set the maximum depth for the initial model.



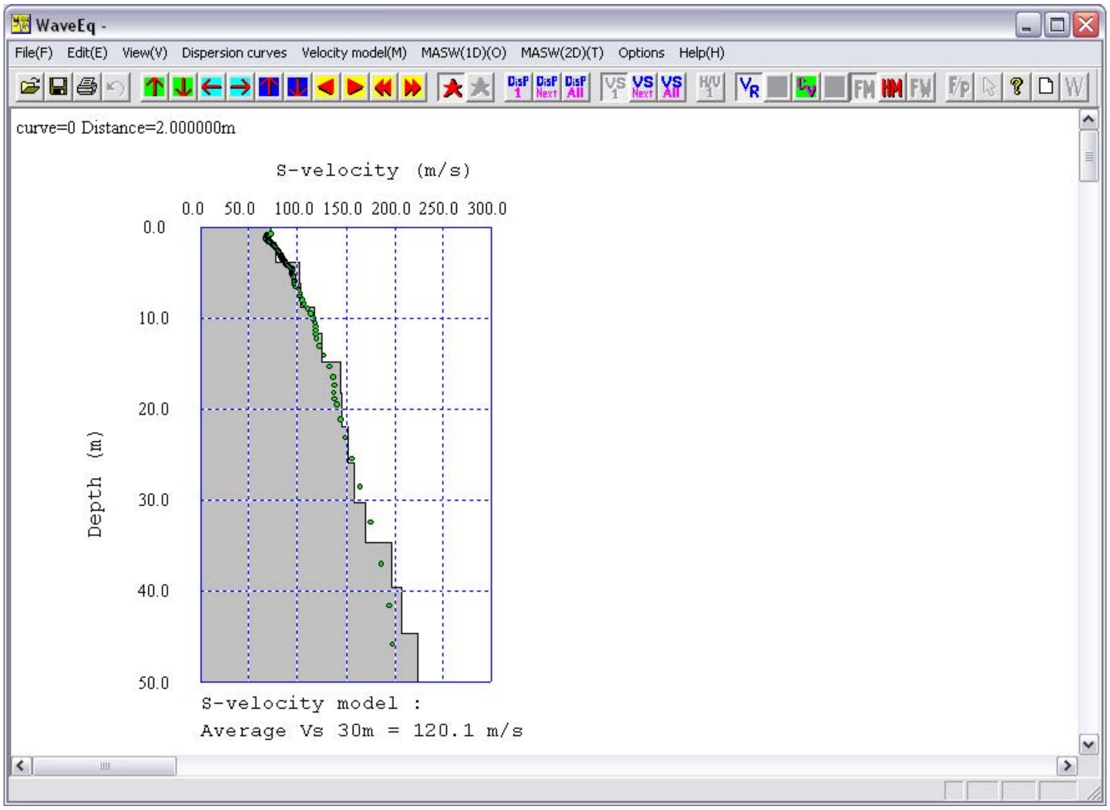
Run the inversion by selecting the *MASW (2D: All data)* menu, *Inversion*.

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

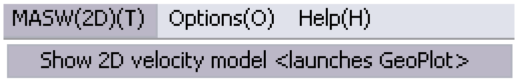


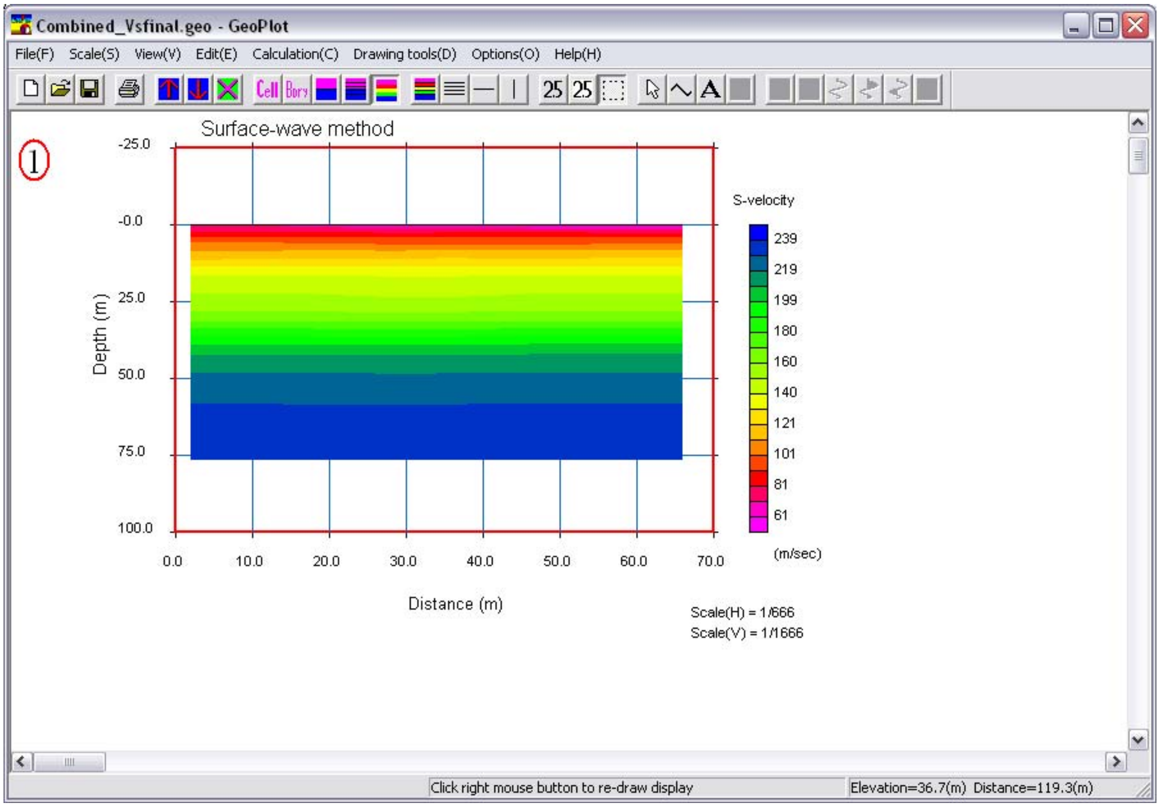
Note that depending on the dataset size, the inversion can be computationally intensive and may take some time to complete. Also, the higher the *Iteration* value, the longer the process will take. In the Windows Task Manager, WaveEq may report as “Not Responding”, but if the memory usage is dynamically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

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

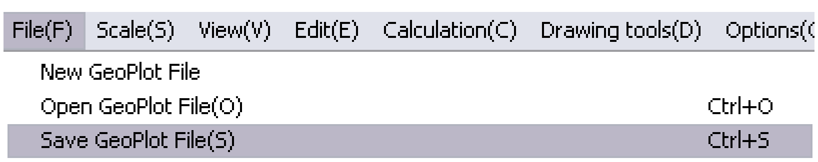


Display the final cross-sectional model in GeoPlot by selecting the *MASW (2D)* menu, *Show 2D velocity model*.

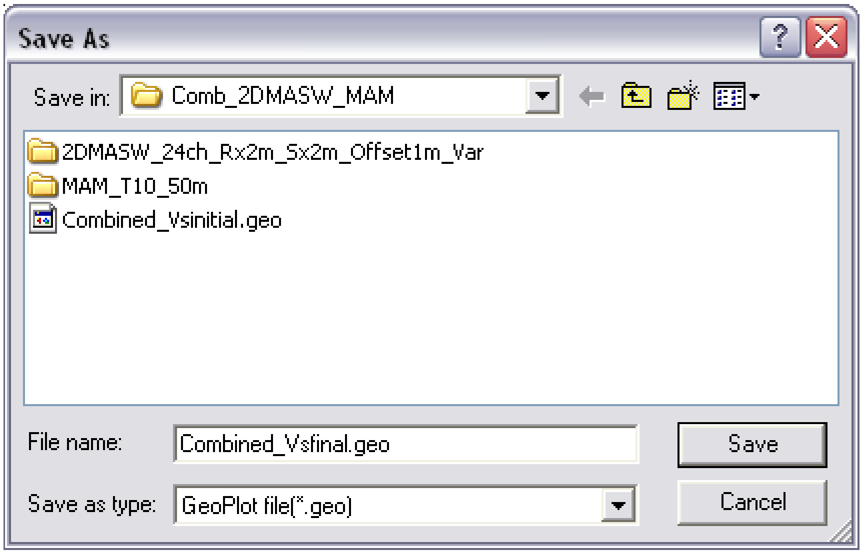




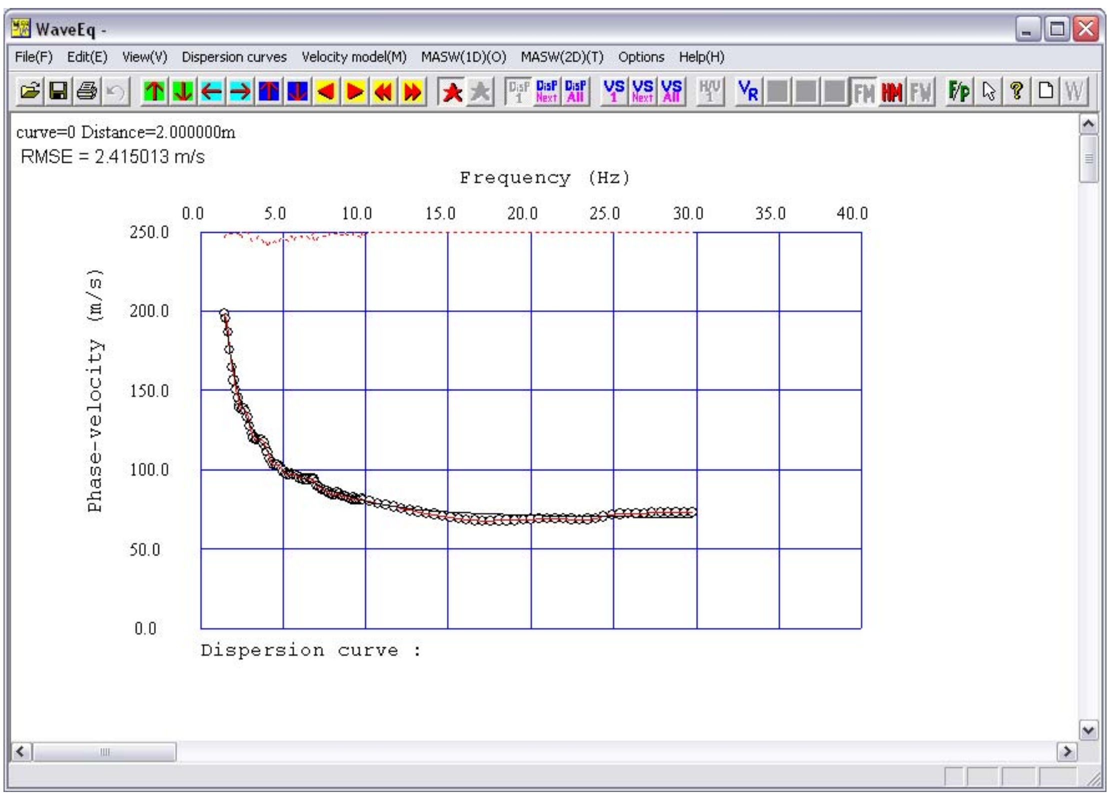
Save the final model display as a *.geo* file by selecting the *File* menu, *Save GeoPlot File*.



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



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

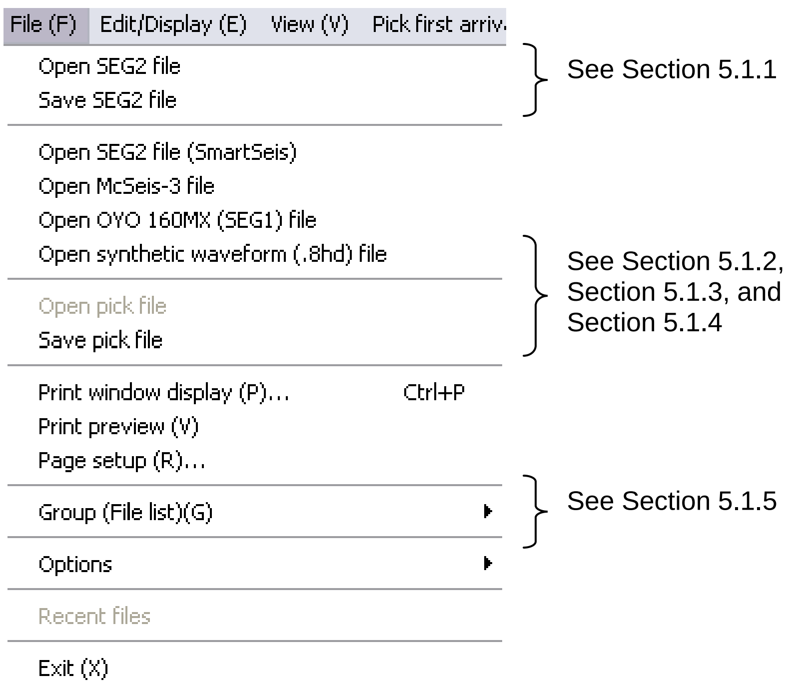


Save the final result by selecting the *File* menu, *Save 2D phase velocity curve file (.pvs)*.

5 – The Pickwin Module Surface Wave Analysis Functions

5.1 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, refer to the separate SeisImager/2D manual included on the SeisImager CD.

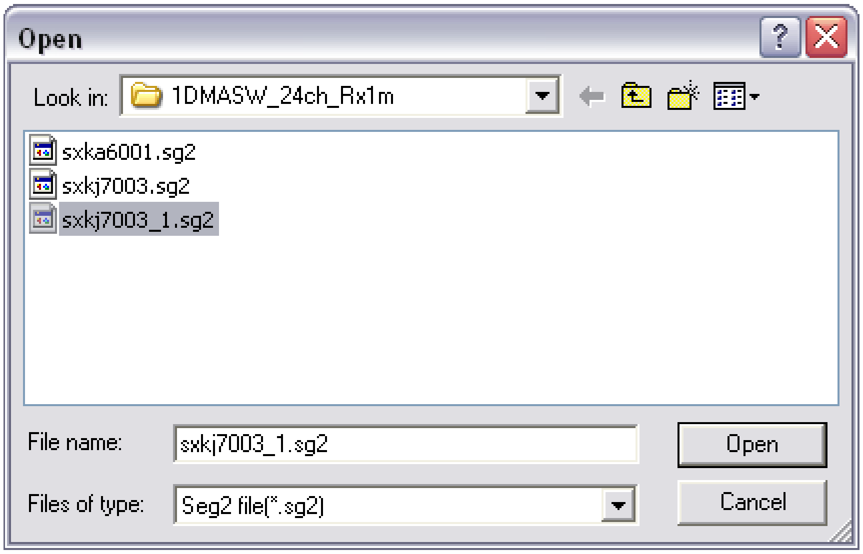


5.1.1 File Menu: Open SEG2 File 

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

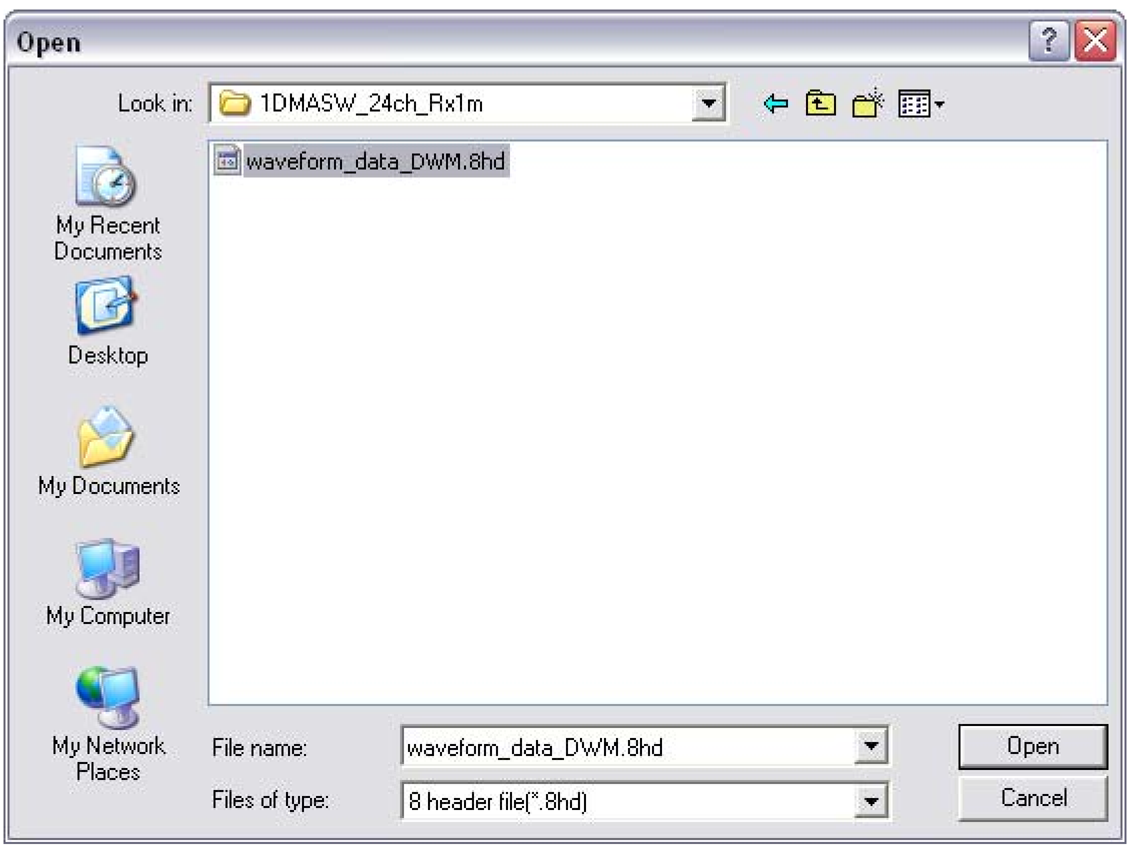
Depending on the model of seismograph used to collect the data, the *Files of type* setting may need adjustment for SEG-2 formatted files. Geometrics seismographs use the file extension *.dat* and OYO seismographs use the extension *.sg2*.

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



5.1.2 File Menu: Open Synthetic Waveform (.8hd) File

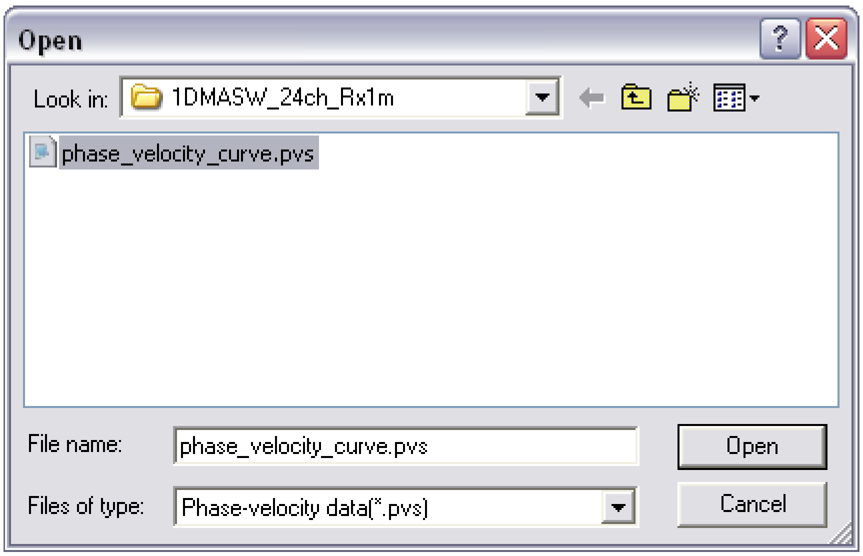
To open a waveform file generated from a synthetic velocity model, select *Open synthetic waveform (.8hd) file*. Highlight the file and click *Open*.



5.1.3 File Menu: 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.

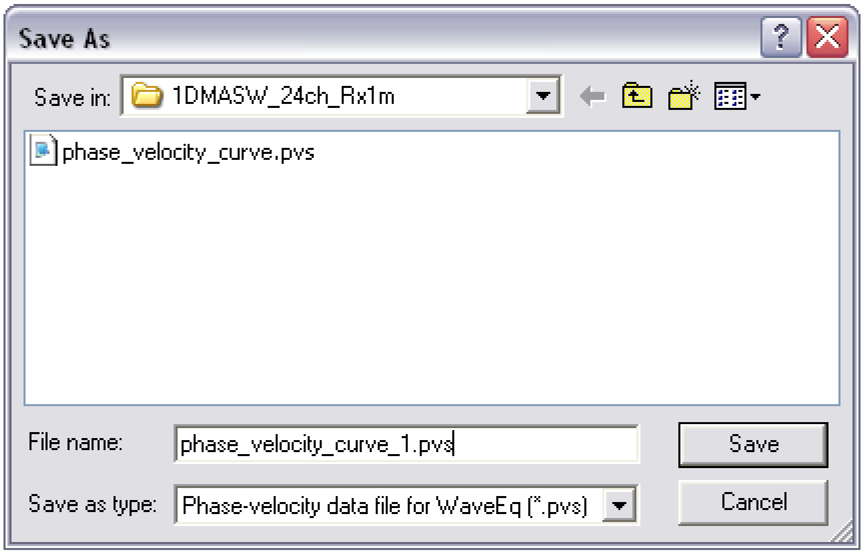
Open pick file is used to open a file of saved dispersion curve picks with the file extension *.pvs*. First the waveform file(s) from which the dispersion curve picks were derived should be opened by selecting the applicable *Open __ file* function or the *Open file list* function. Next, select *Open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



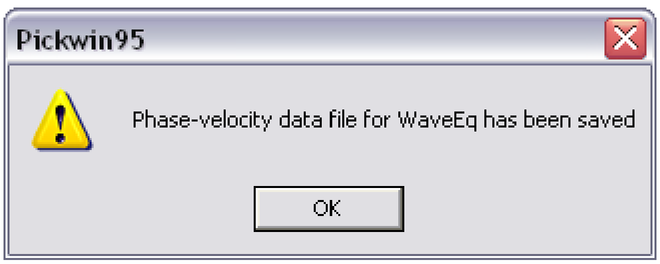
The dispersion curve picks will not be visible until the phase velocity is recalculated. Refer to Section 5.3 on how to calculate phase velocity.

5.1.4 File Menu: Save Pick File

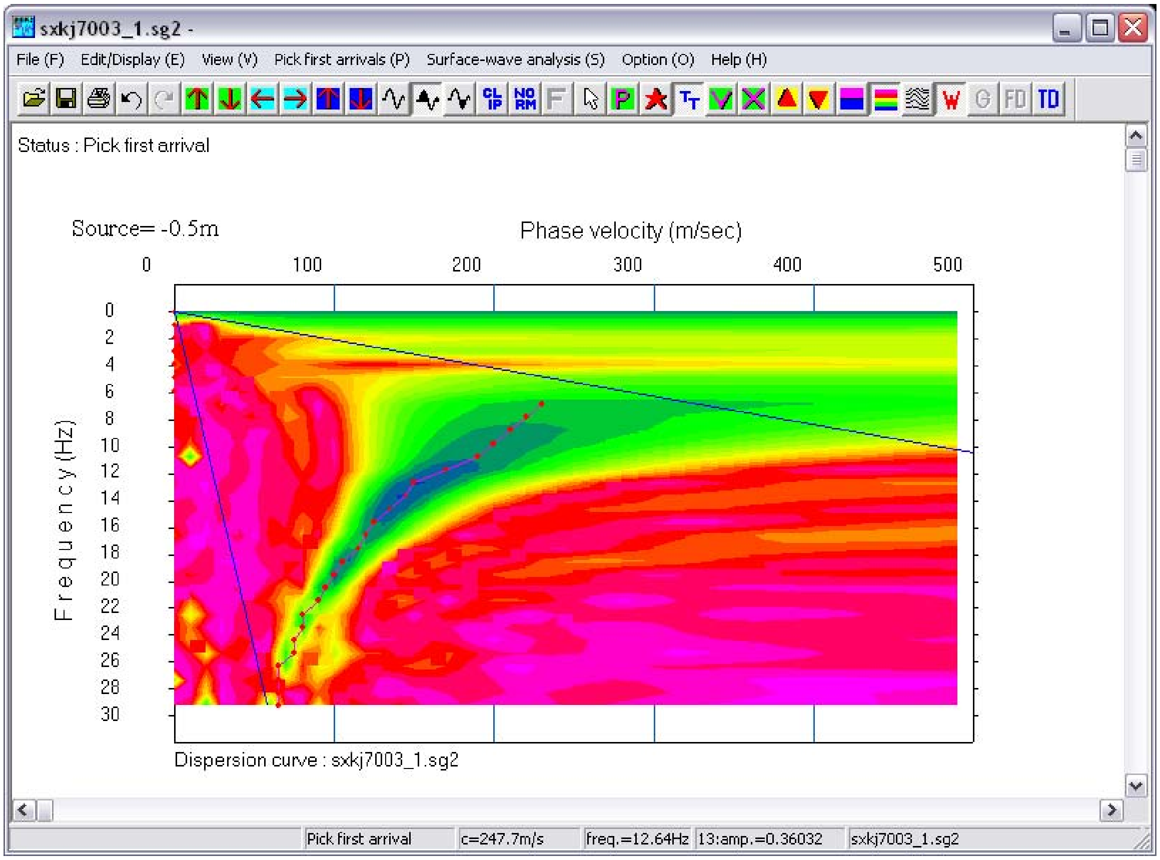
To save dispersion curve picks, select *Save pick file*. Assign a file name with the extension *.pvs* and click *Save*.



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

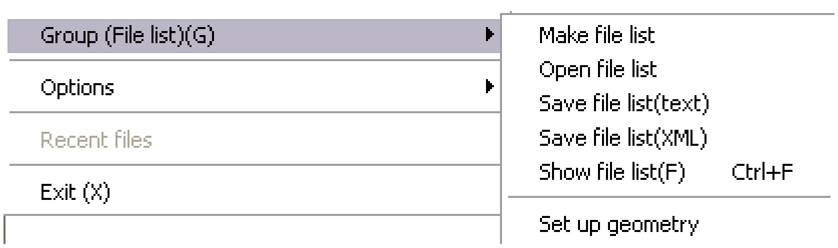


In the phase velocity-frequency plot view, the picks will be connected by a pink line.



5.1.5 File Menu: Group (File List)

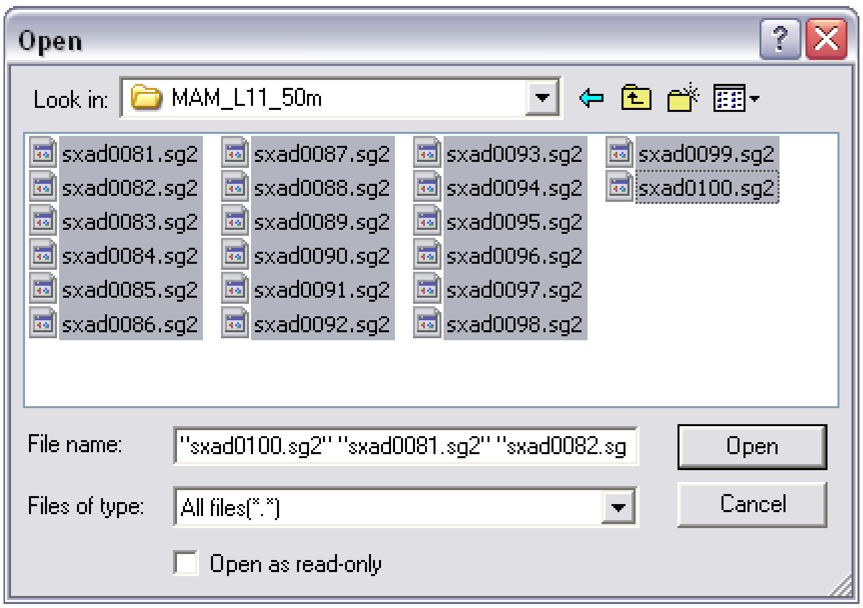
The functions included in *Group (File List)* allow processing of a range of records, as with a MAM or 2D MASW dataset.



5.1.5.1 File Menu: Group (File List): Make File List

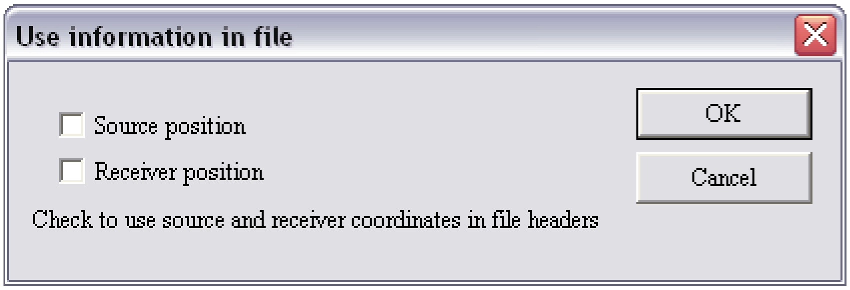
A *File list* is an inventory of data files from any given survey and includes essential information for each waveform trace such as the associated field file identification number and source and receiver locations. For surveys where multiple files are processed together, such as MAM or 2D MASW, the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

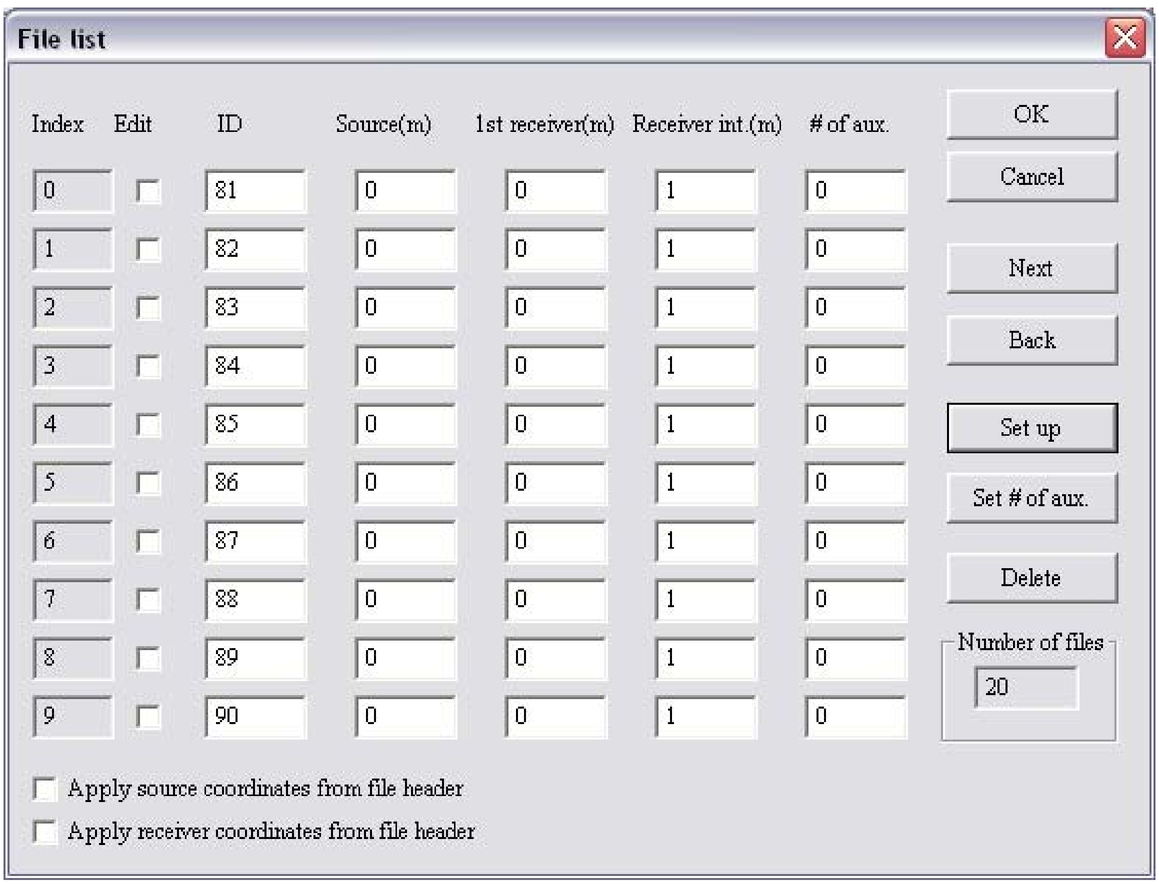


Confirmation that the files are input is displayed, click *OK*.

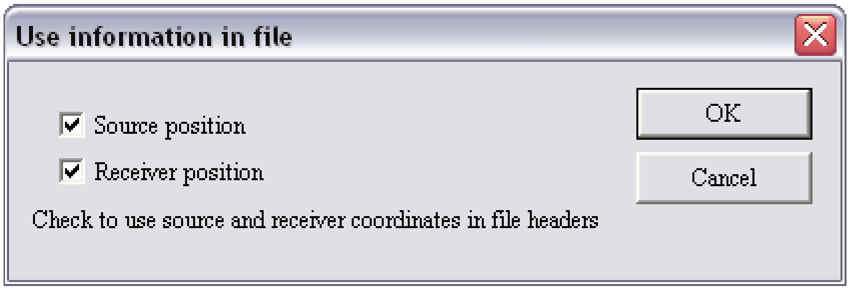
Next, you will be prompted to set up the geometry. For MAM datasets, the source locations are non-applicable and the geometry of the spread/array is set in another separate dialog box. Any coordinates saved in the file headers are not needed, so leave the boxes for *Source position* and *Receiver position*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



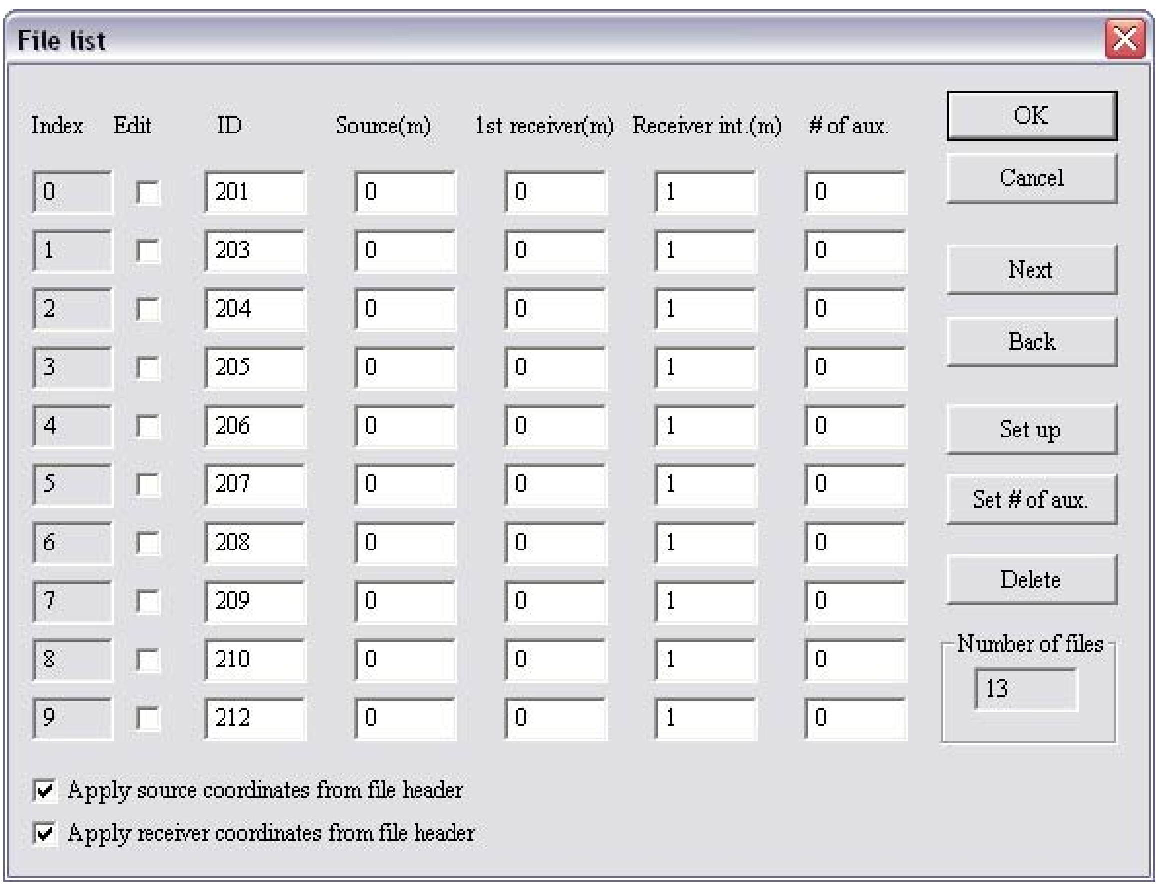
Next, the *File list* dialog box presents the data files listed by file *ID*. No action is needed for MAM datasets. Click *OK* to proceed to viewing the waveform files.



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 click *OK*.

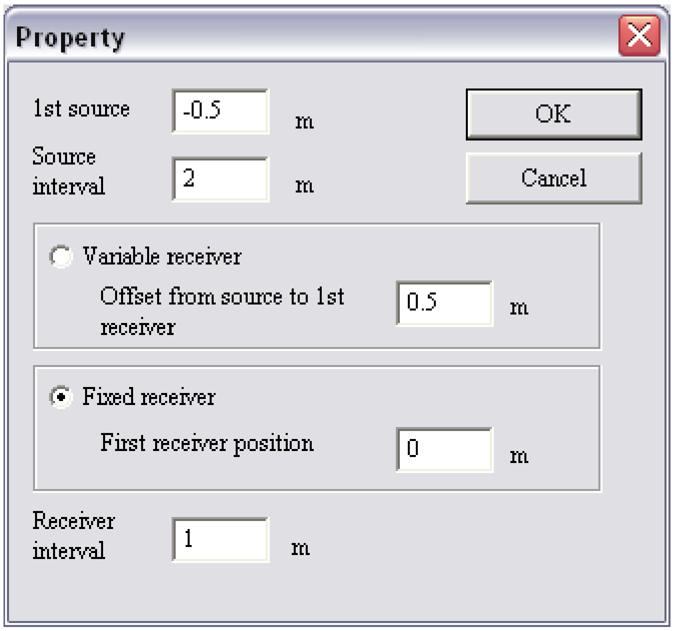


Next, the *File list* dialog box presents the data files listed by file *ID*. Even if *Source position* and *Receiver position* were checked in the previous dialog box, note that the actual values from the file headers will not yet be shown here in the *Source*, *1st Receiver*, and *Receiver int.* columns.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



If coordinates are to be imported from the file headers, confirm the options *Apply source coordinates from header* and *Apply receiver coordinates from header* are checked. Click *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*, *1^{st} Receiver*, and *Receiver int.* columns individually or by setting up and applying a geometry pattern via the *Set up* button. The default *Set up* parameters are as shown below.



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

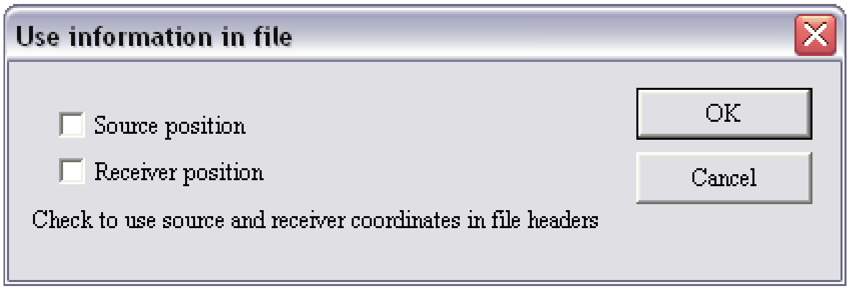
For a dataset collected with a rolling spread, that is, the geophone locations were not fixed, check the *Variable receiver* option. The *Offset from source to 1^{st} receiver* is the distance from the location of the shot to the location of the nearest live geophone (the near offset). It is assumed that the line has been shot from lowest to highest channel number, indicated by a positive polarity for the *Source interval*. If the data was shot toward the lowest channel number, the *Source Interval* should have a negative polarity to indicate that the source rolled 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 collected with a fixed receiver spread where the shot location was incremented through the spread, check the *Fixed Receiver* option. The *First receiver position* is the location of the first live geophone.

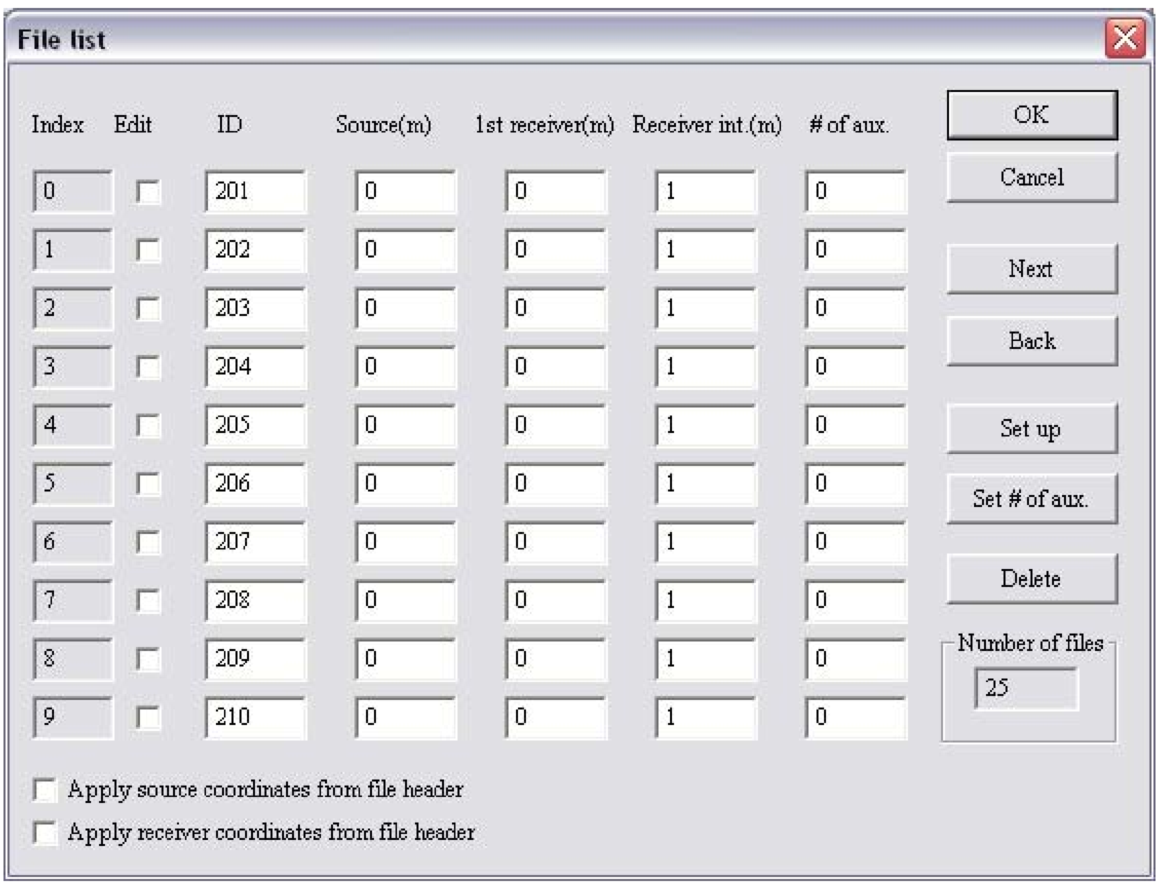
The *Receiver interval* is the spacing between each geophone.

Example 5A Set up a *Fixed receiver* geometry for a 2D MASW dataset (201.dat-225.dat) with no file header coordinates. The dataset consists of 25 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.

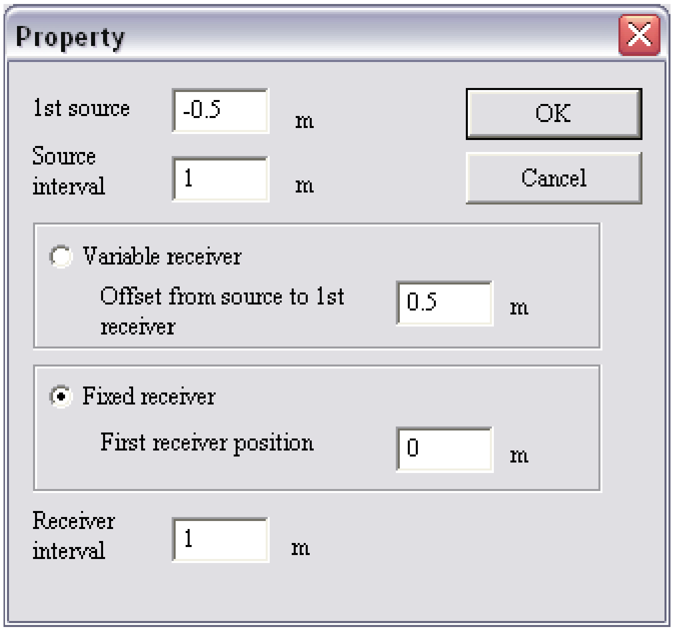
Starting at the geometry prompt, *Source position* and *Receiver position* are left unchecked.



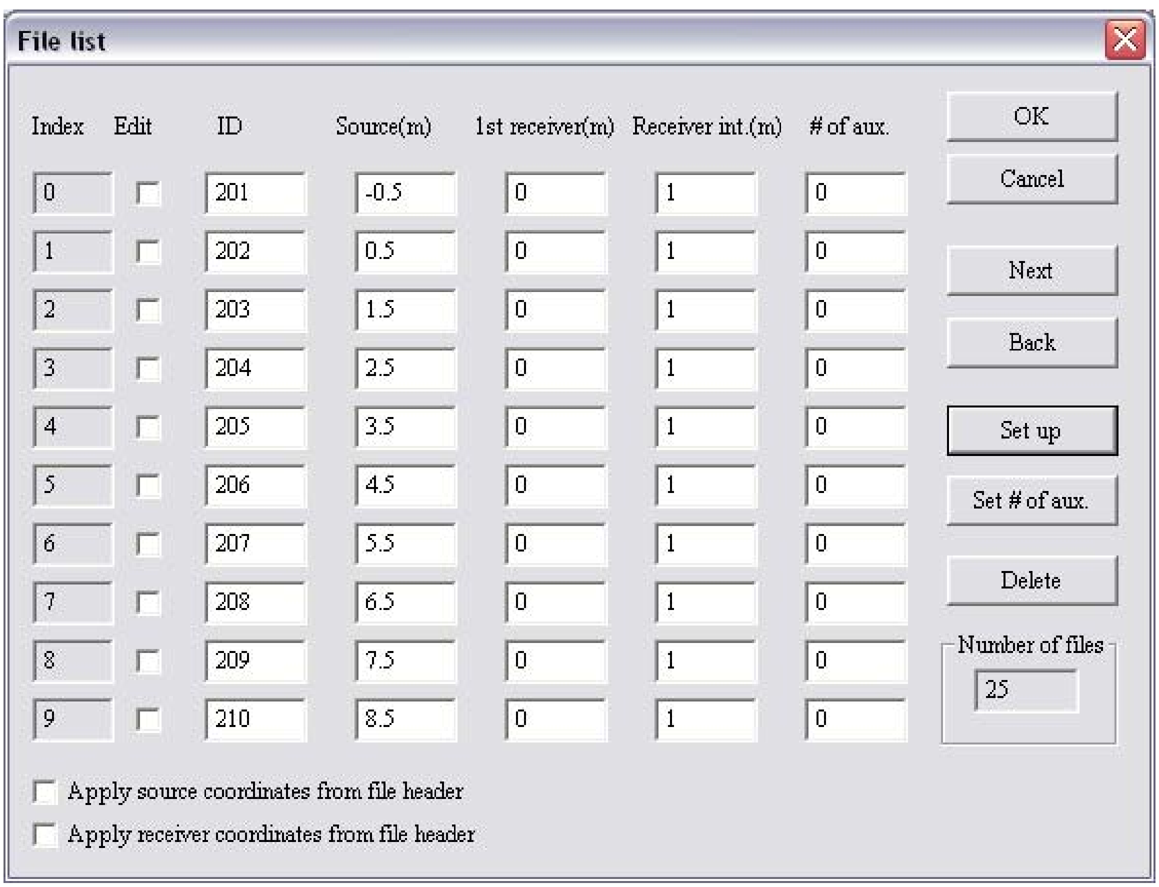
The *File list* dialog box shows the file *ID*s but only default values for the *Source*, *1st Receiver*, and *Receiver int.* columns. Also, *Apply source coordinates from header* and *Apply receiver coordinates from header* are unchecked.



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



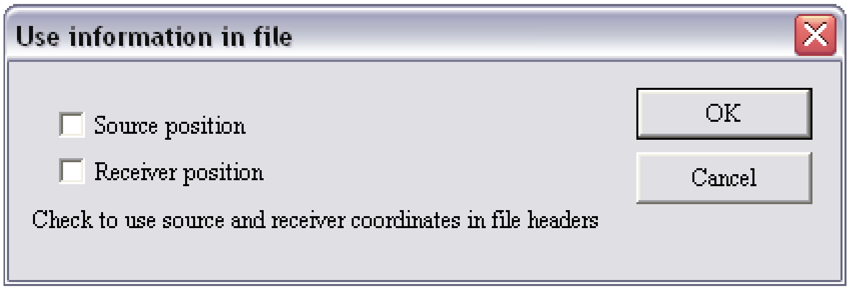
The *File list* dialog box reflects the geometry pattern.



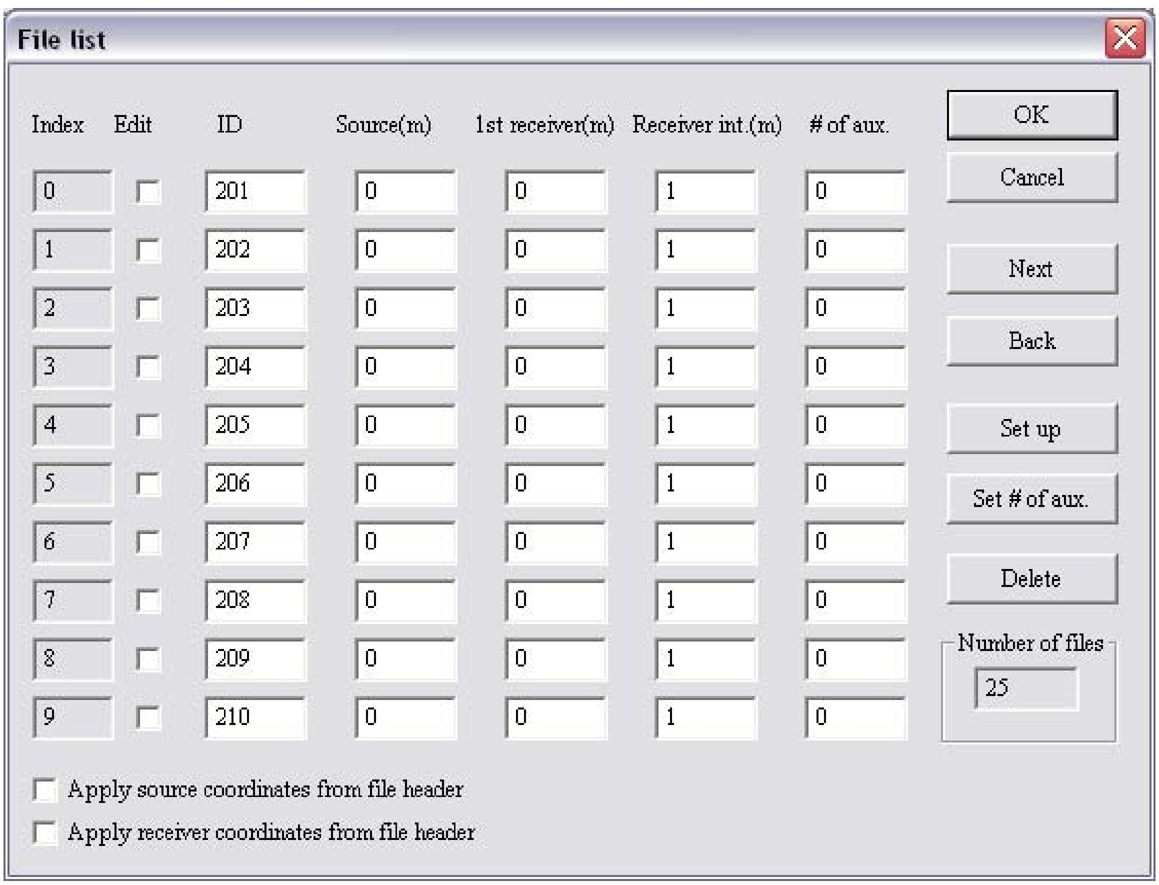
End Example 5A.

Example 5B Set up a *Variable receiver* geometry for a 2D MASW dataset (201.dat-225.dat) 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.

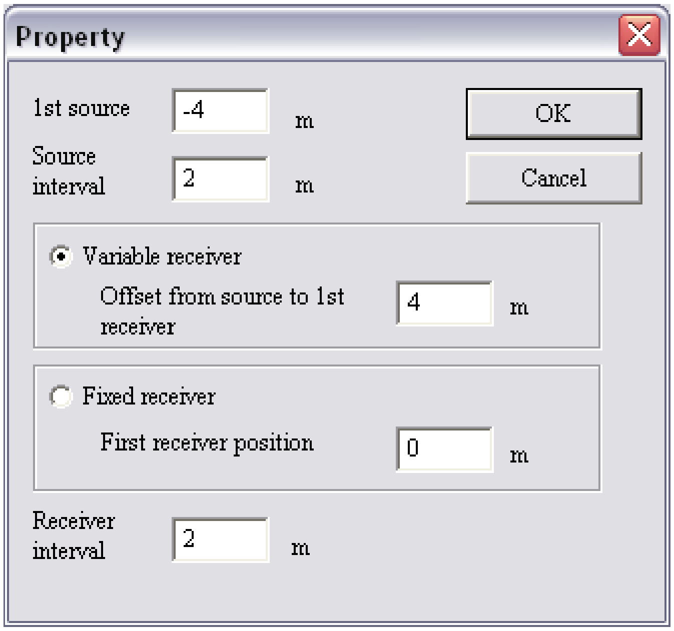
Starting at the geometry prompt, *Source position* and *Receiver position* are left unchecked.



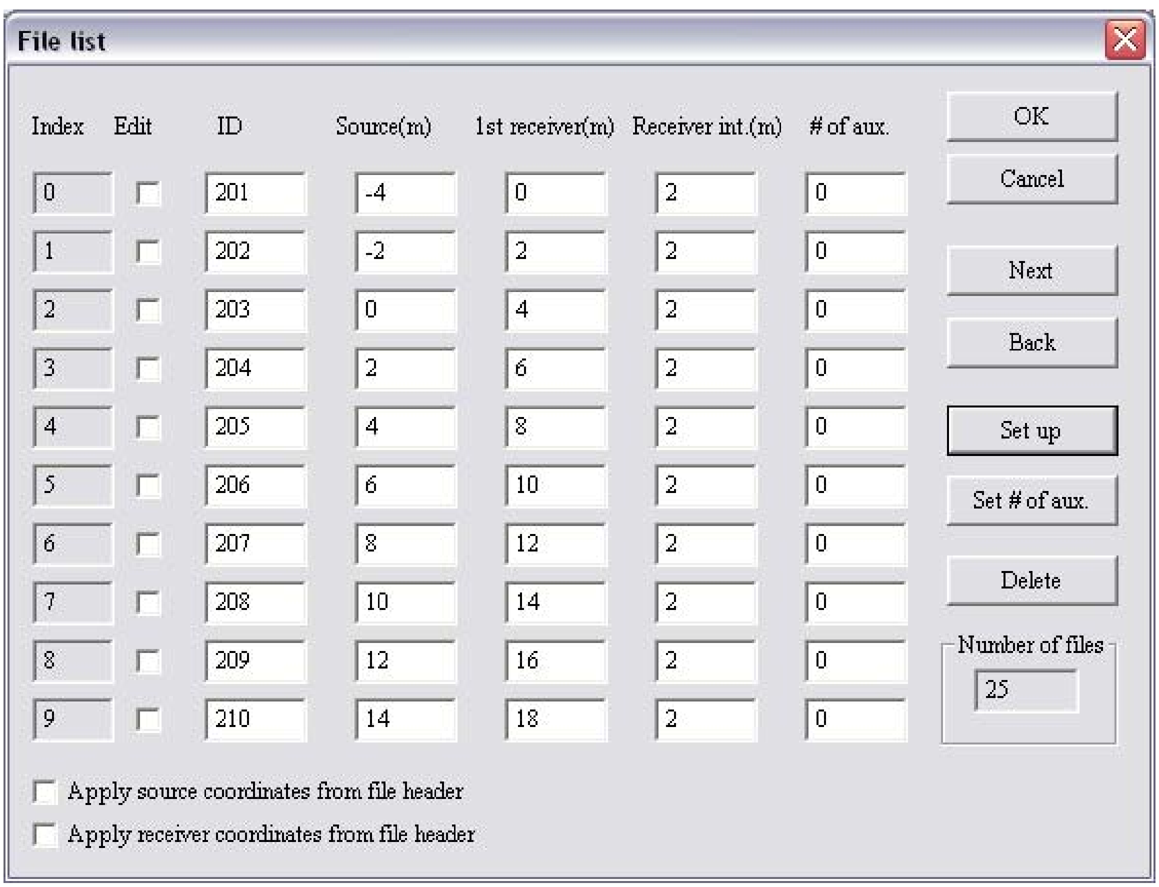
The *File list* dialog box shows the file *ID*s but only default values for the *Source*, *1st Receiver*, and *Receiver int.* columns. Also, *Apply source coordinates from header* and *Apply receiver coordinates from header* are unchecked.



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



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



End Example 5B.

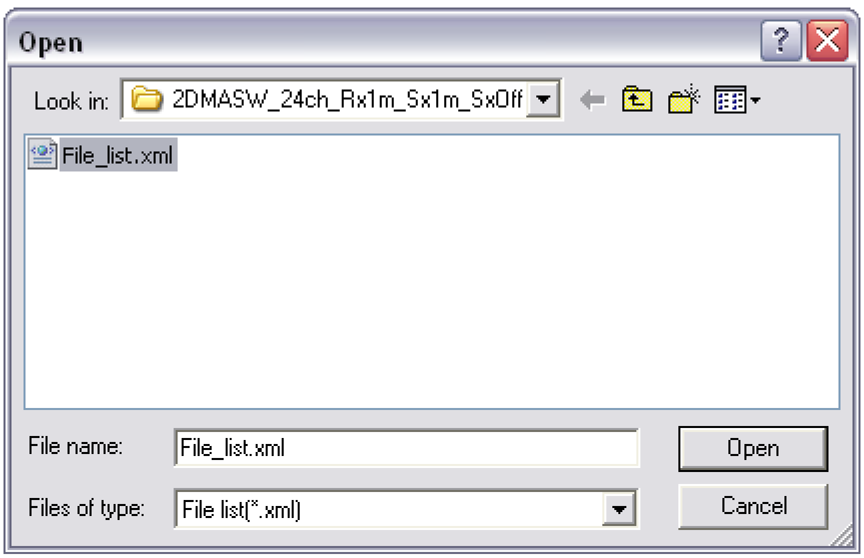
Additional information on the *File list* dialog box includes the *Next* and *Back* buttons, which allow scrolling through the next, or last, ten file *ID*s, respectively. For users of OYO seismographs an auxiliary channel is automatically recorded; the number of the auxiliary channel can be indicated by clicking 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 click on the *Delete* button.

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

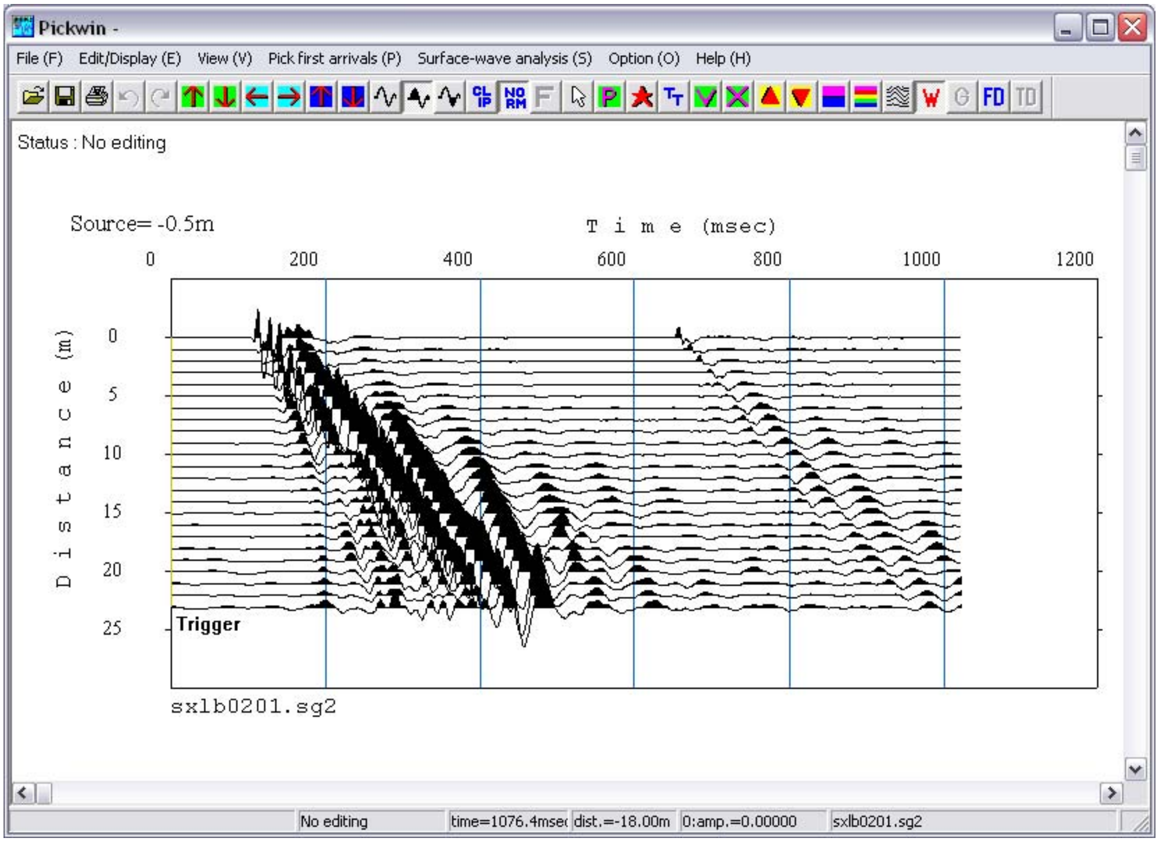
To view the assigned geometry again, the *File list* dialog box can be directly accessed at any time through the *Show File List* function.

5.1.5.2 File Menu: Group (File List): 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 click *Open*.



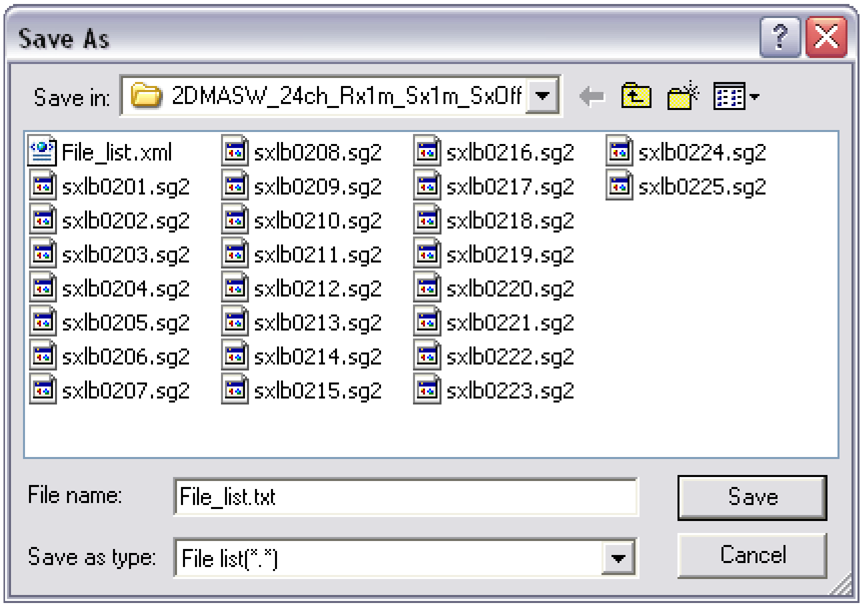
The waveform files with assigned geometry are displayed.



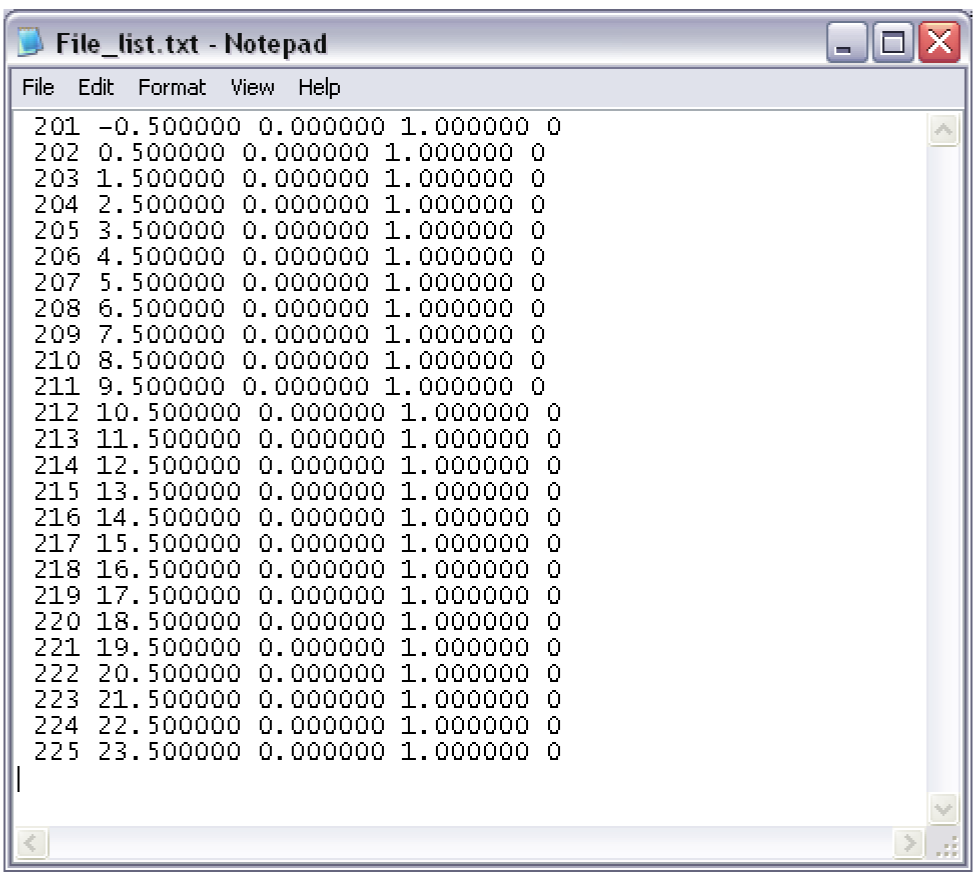
5.1.5.3 File Menu: Group (File List): Save File List (Text)

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 click *Save*.



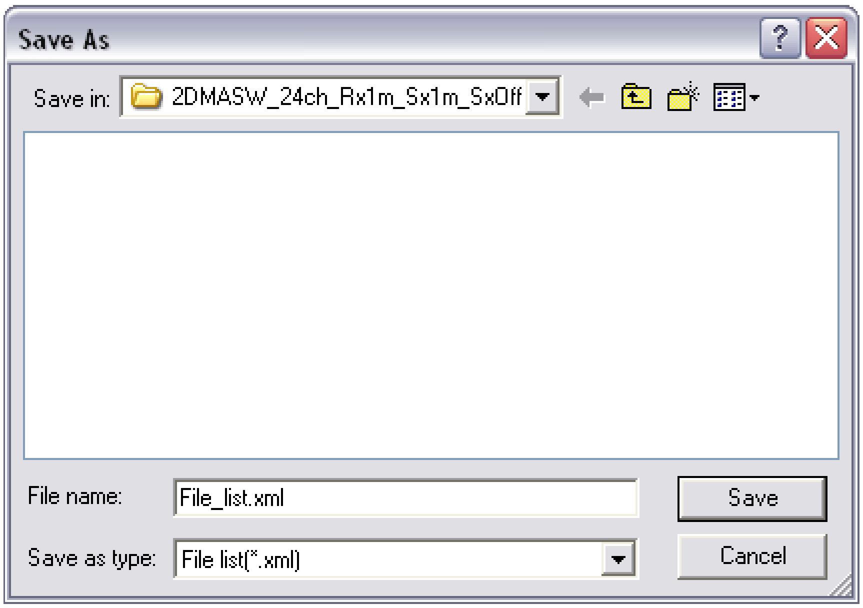
The file is formatted in space-delimited columns by file ID, shot location, geophone location, receiver interval, and auxiliary channel number.



5.1.5.4 File Menu: Group (File List): 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 click *Save*.

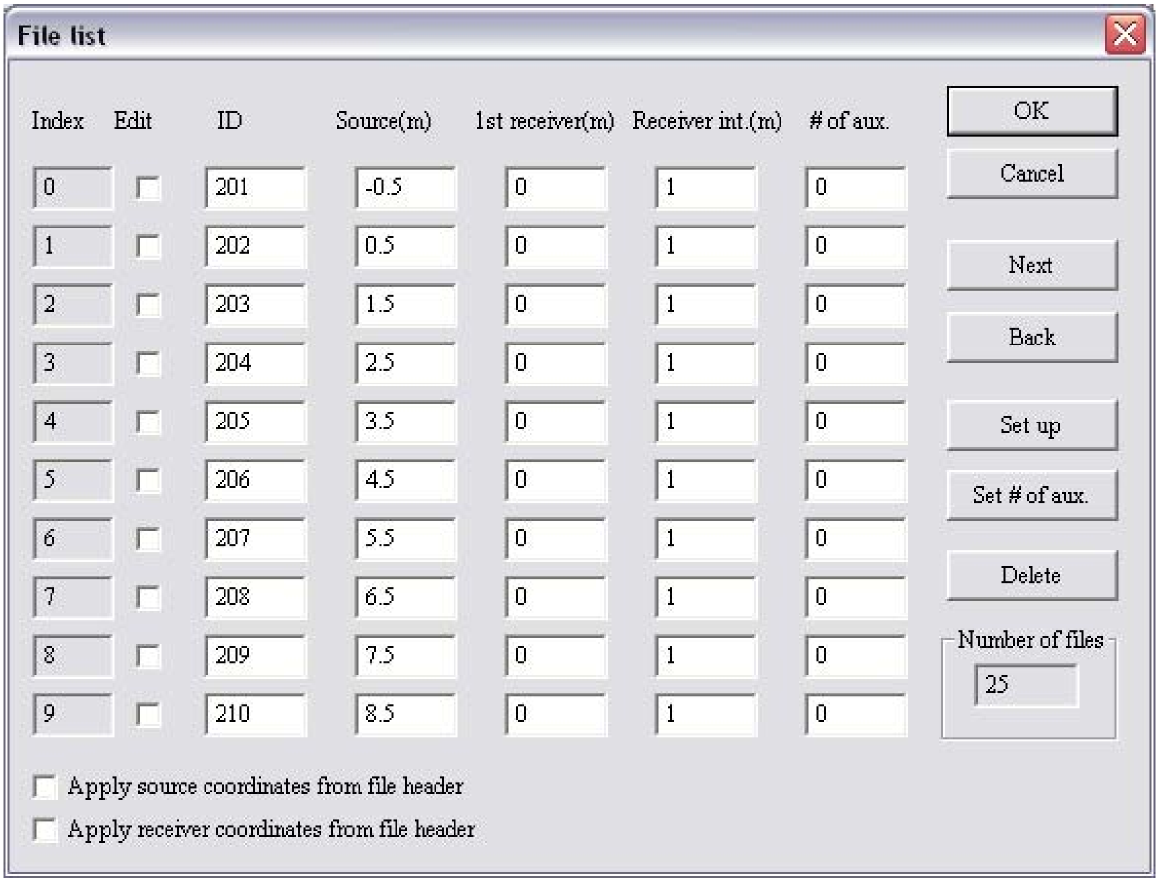


The file is formatted in XML with general line information at the top followed by the shot location, geophone location, receiver interval, and auxiliary channel number for each file ID.


```
  <?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>
```

5.1.5.5 File Menu: Group (File List): Show File List

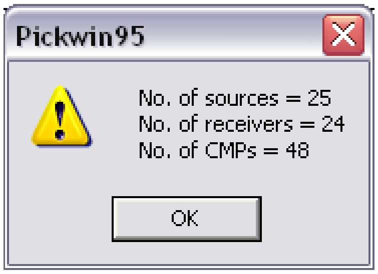
To open the *File list* dialog box, select *Show file list*. The *File list* dialog box is displayed and reflects the current geometry assignment for the subject dataset.



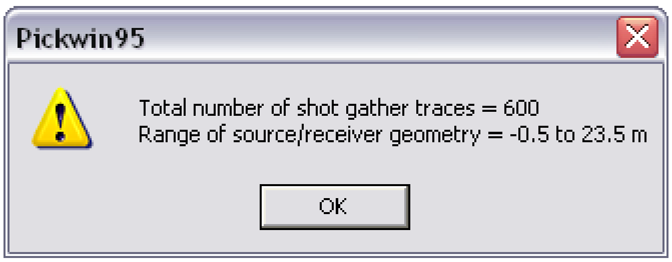
5.1.5.6 File Menu: Group (File List): Set Up Geometry

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

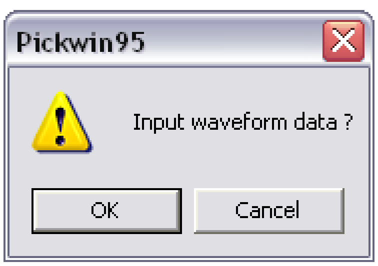
To calculate CMP locations for a 2D MASW file list, select *Set up geometry*. First, the number and location of CMPs are calculated using the source and receiver coordinates. A report of the number of sources and receivers detected in the file list and the number of CMPs calculated from the source and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



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

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

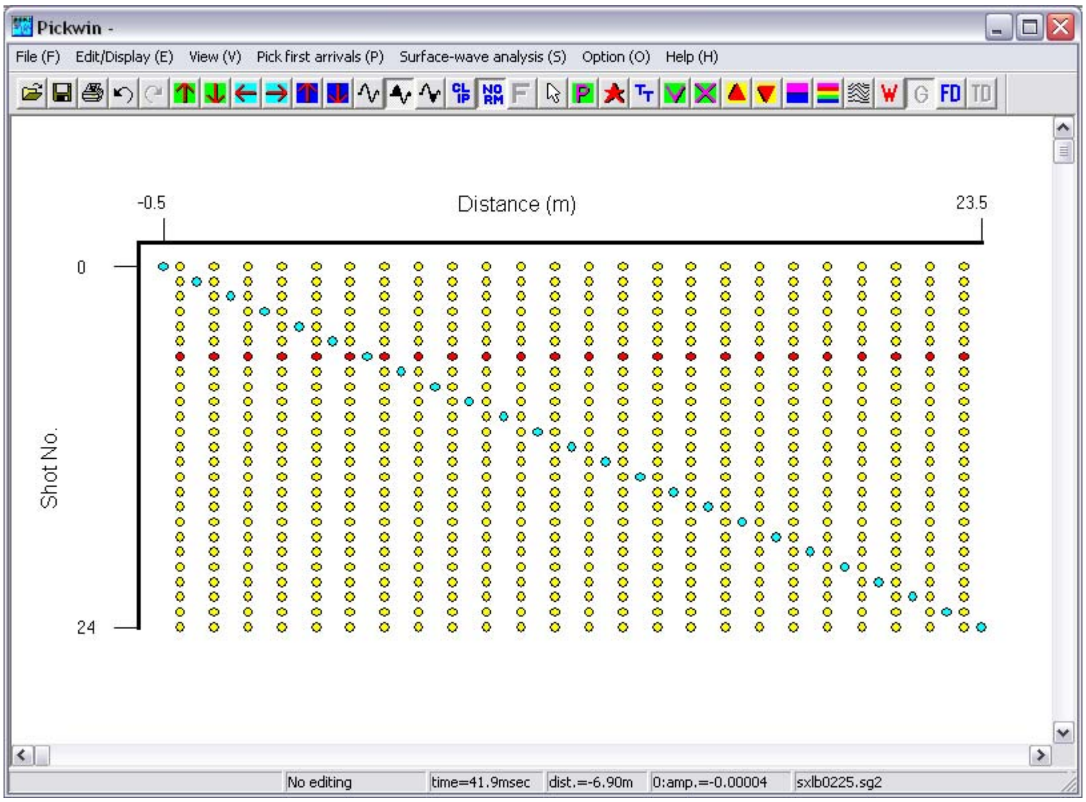
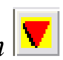


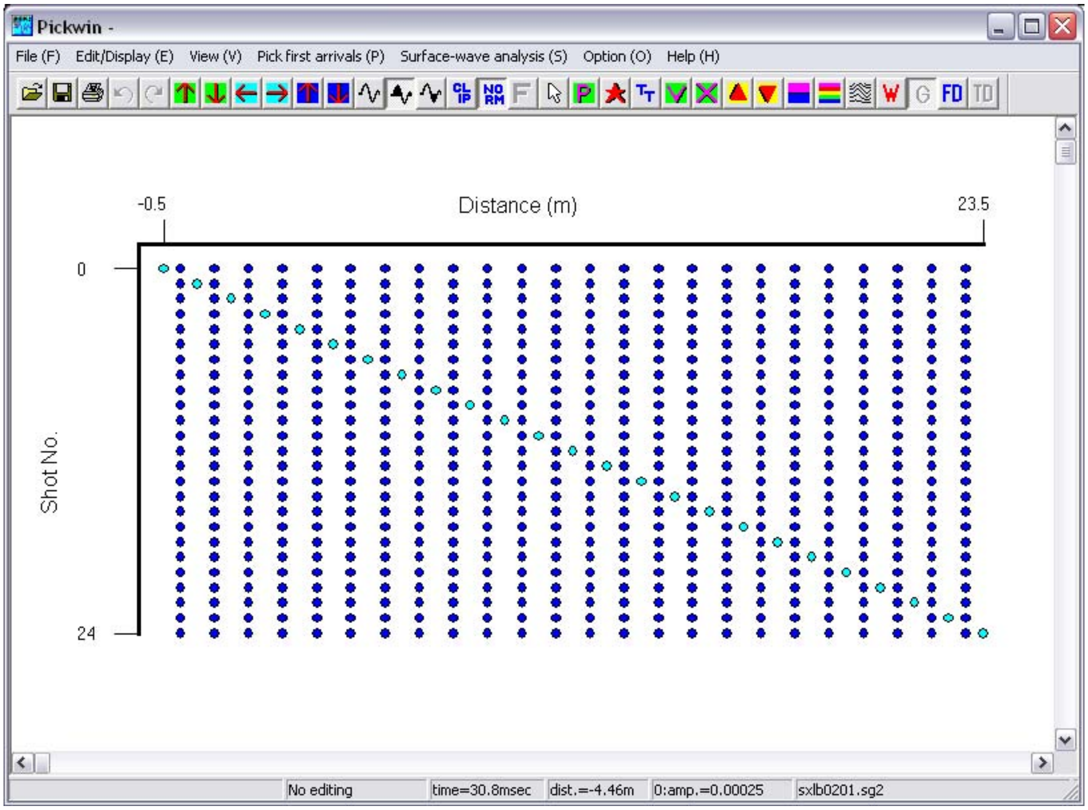
Table 5 summarizes all the attributes used in geometry plots. The horizontal axis, *Distance*, is the distance along the survey line. The vertical axis, *Shot No.*, is the number of the shot as the data was sequentially collected.

Table 5. 2D MASW Geometry Plot Attributes

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)

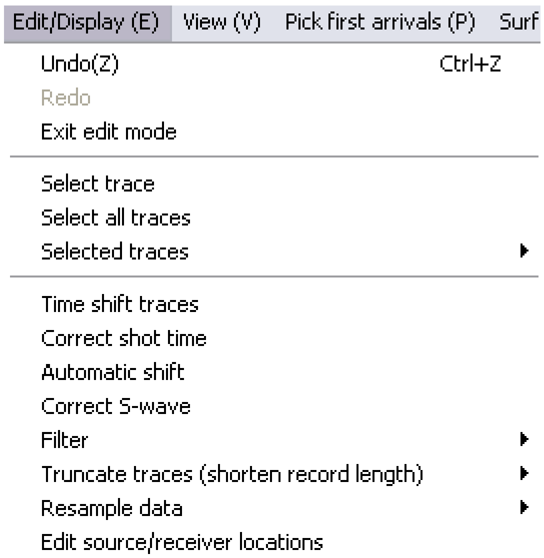
The *Show previous waveform*  and *Show next waveform*  buttons can be used in the geometry view to select a waveform shot record to display, as well these buttons can be used to scroll through waveform files in the waveform view. Click on the *Waveform*  and *Geometry*  buttons to toggle between the 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.



5.2 Edit/Display Menu

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



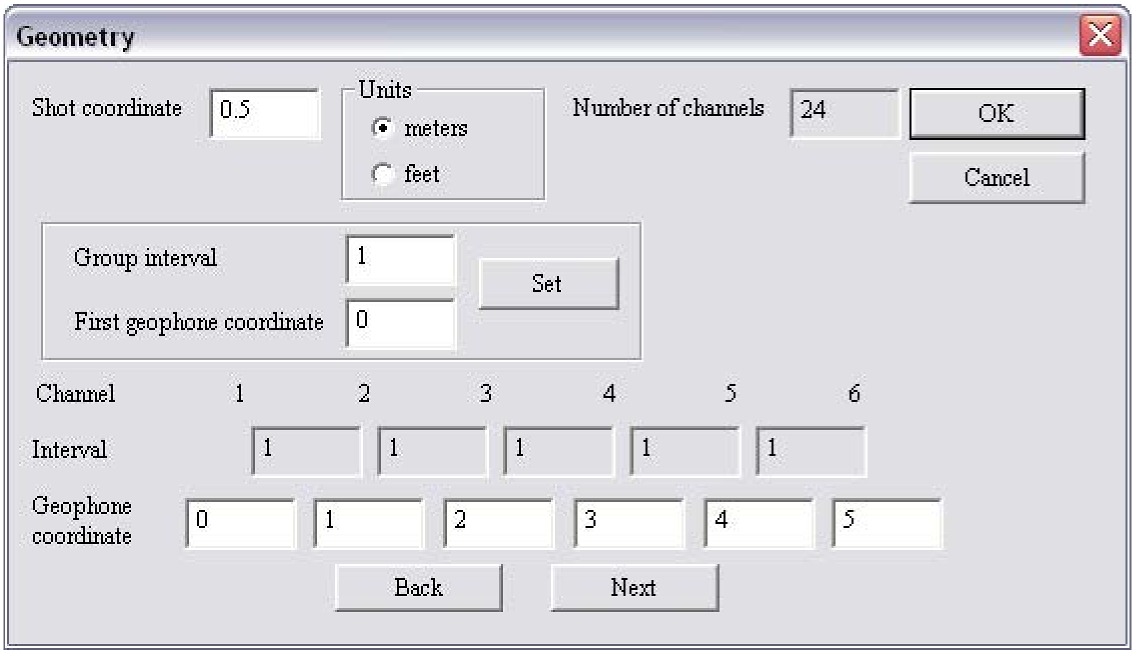
See Section 5.2.1

5.2.1 Edit/Display Menu: Edit Source/Receiver Locations

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.)

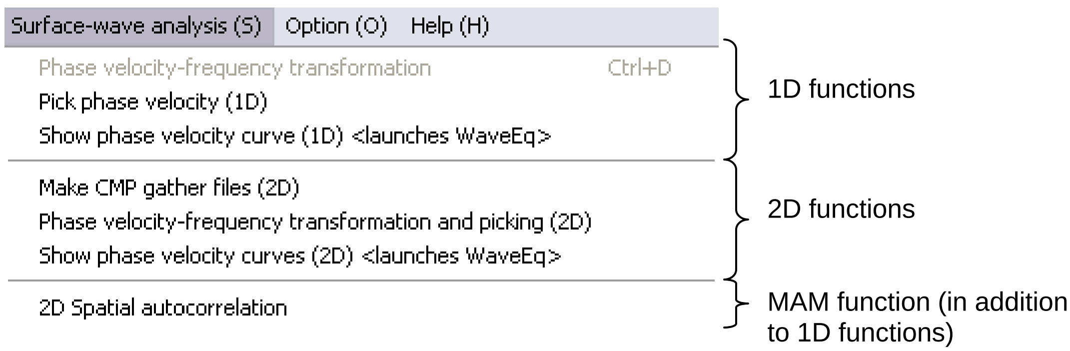


The *Geometry* dialog box can also be used to set up or edit the source-receiver geometry for single shot records for 1D MASW. For 2D MASW, the *File list* and *Set up geometry* functions should be used.

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 click on *Set* to calculate all the *Geophone coordinates*. *Next* and *Back* can be used to scroll through the coordinate values in sets of six channels. Click *OK* when done to apply the changes. A new SEG-2 file will need to be saved by selecting the *File* menu, *Save SEG2 file* to preserve the changes, otherwise they will need to be made each time the shot record is input.

5.3 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 three sections, the top for functions that pertain to 1D MASW and MAM data processing, the middle for 2D MASW data processing, and the bottom for an additional function for MAM data processing. For purchases of SeisImager/SW-1D, the top and bottom sections are active and the middle section is grayed out. For purchases of SeisImager/SW-2D, all three sections are active.

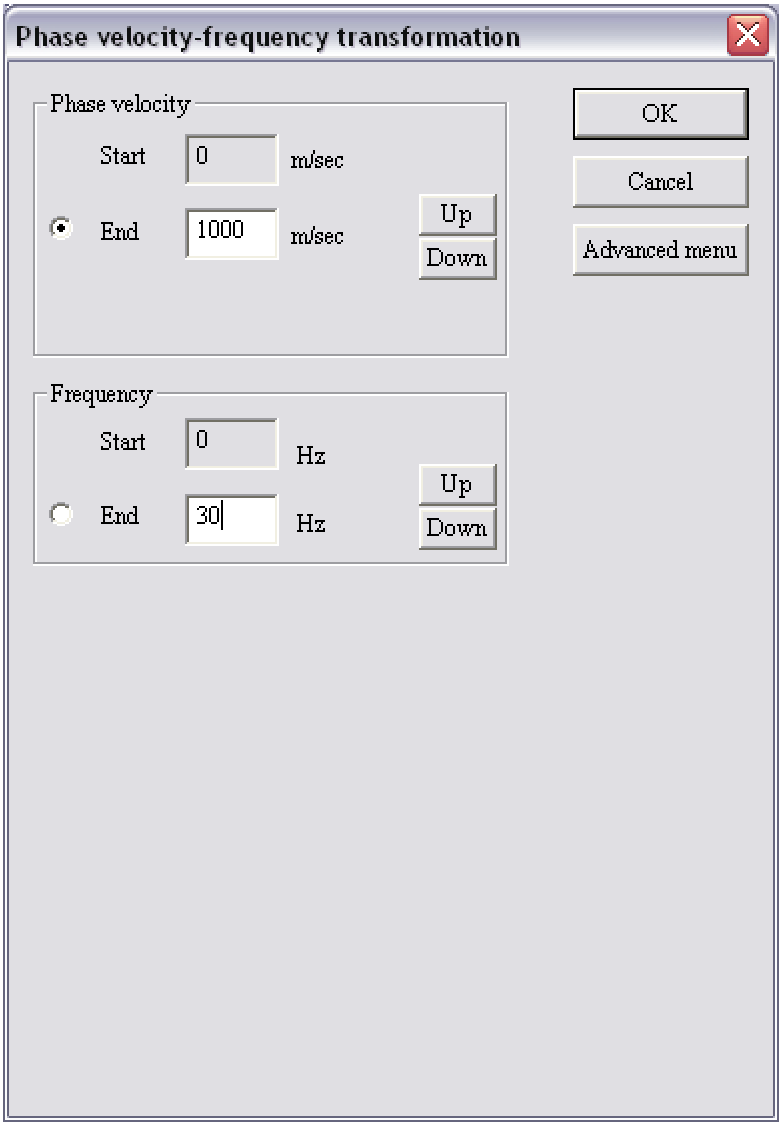


5.3.1 Surface-Wave Analysis Menu: Phase Velocity-Frequency Transformation

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 5.3.7 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.

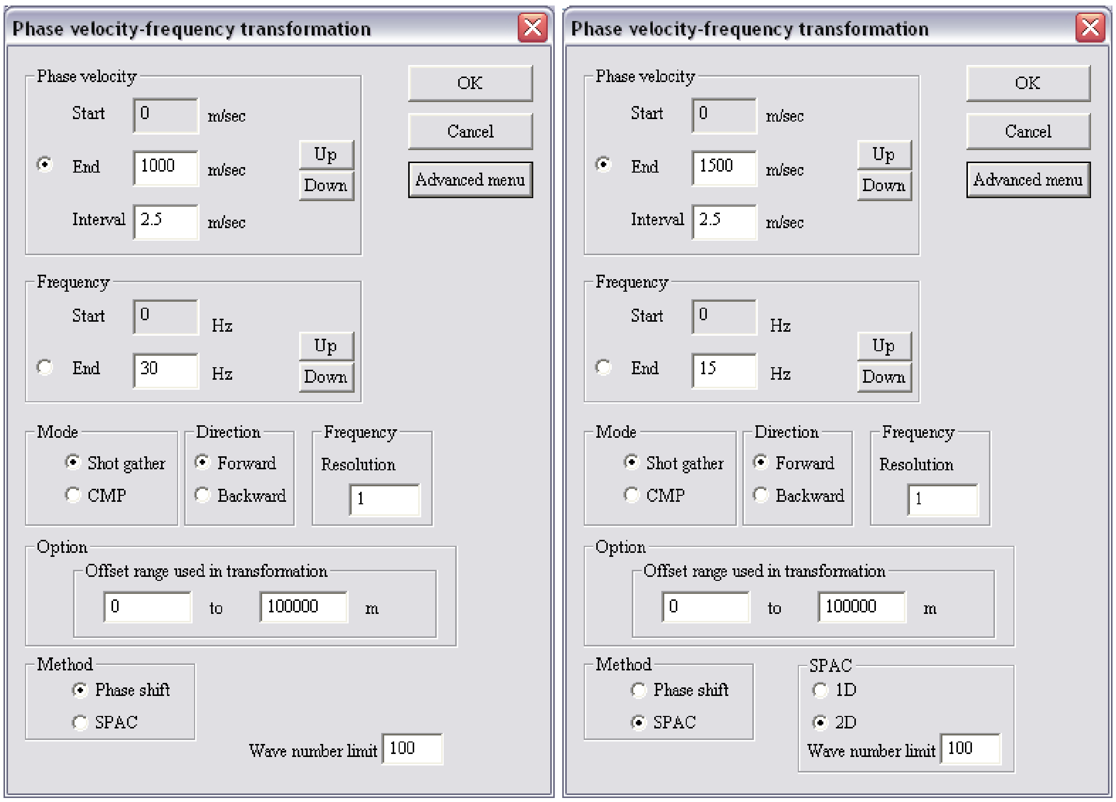


The *Start Phase Velocity* and *Start Frequency* are set fixed at 0.

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 enclose 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*. Clicking 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.

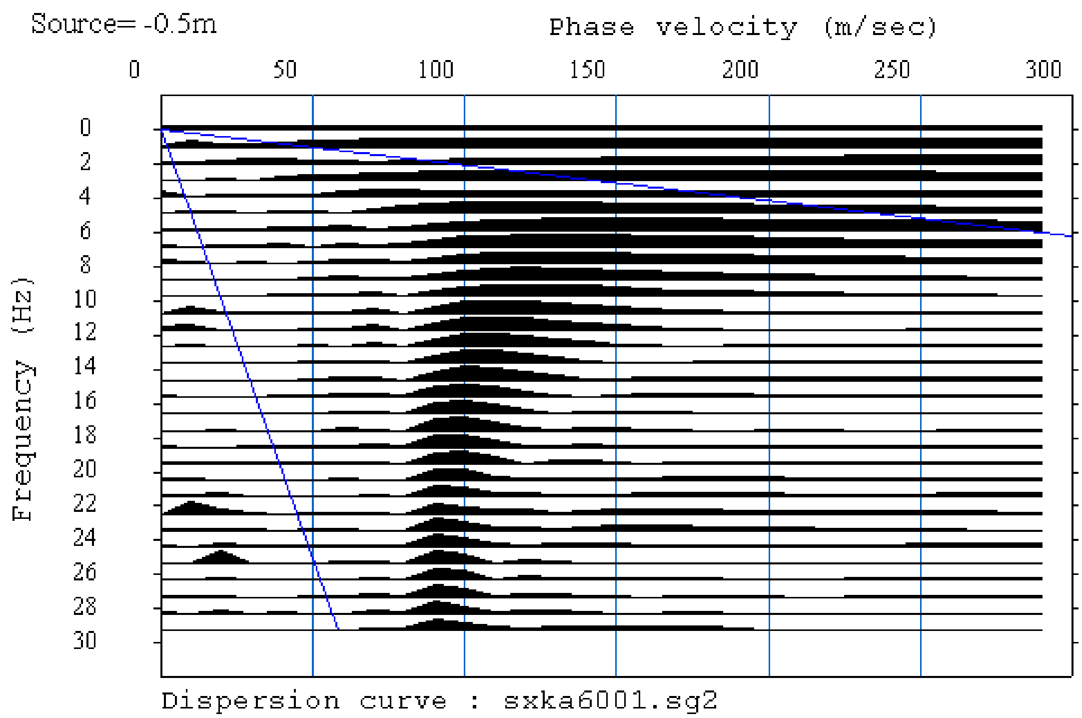
Direction of *Forward* means that the shot coordinate is less than the coordinate of the first geophone. *Backward* means the shot coordinate is greater than the coordinate of the first geophone. The software assumes that that the same gain was used on all traces and automatically attempts to determine 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 non-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 correspond 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.



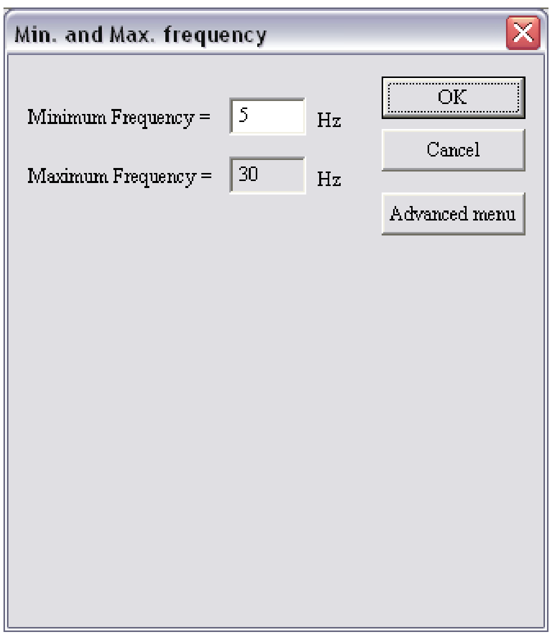
5.3.2 Surface-Wave Analysis Menu: Pick Phase Velocity (1D)

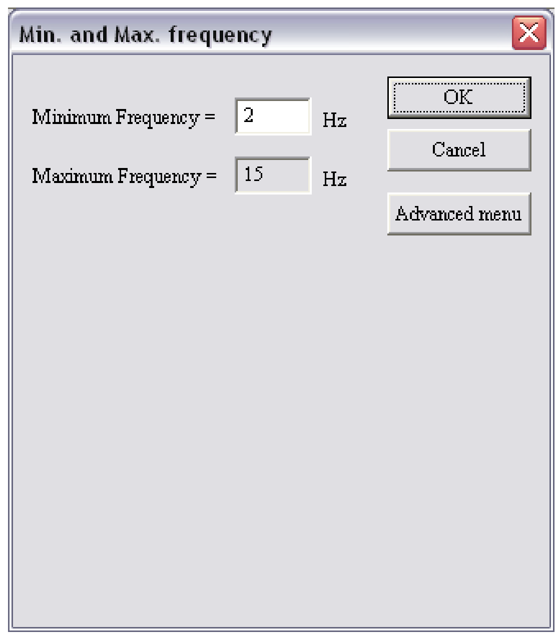
To automatically pick the maximum amplitudes on the phase velocity-frequency plot which define the dispersion curve, select *Pick Phase Velocity (1D)*.

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.

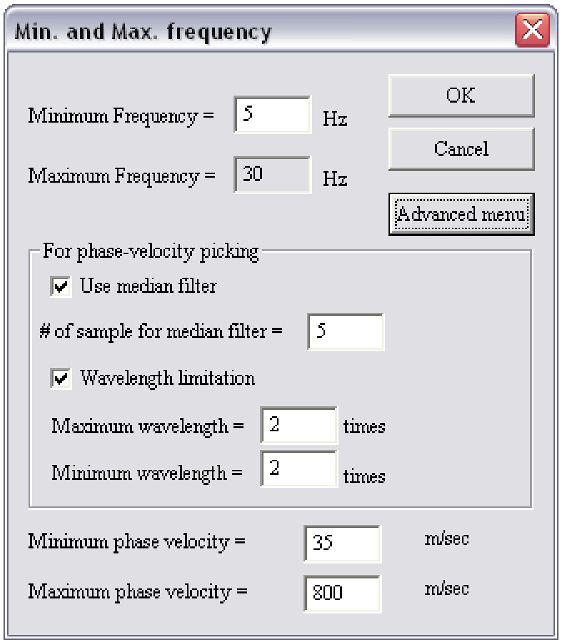
For passive source data processing (shown on right), the *Minimum Frequency* default value is 2 assuming that 2 Hz seismometers were used. If the dataset was acquired with 4.5 Hz geophones, the *Minimum Frequency* can be increased to 5 if desired; however, there may be signal below 5 Hz and any spurious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

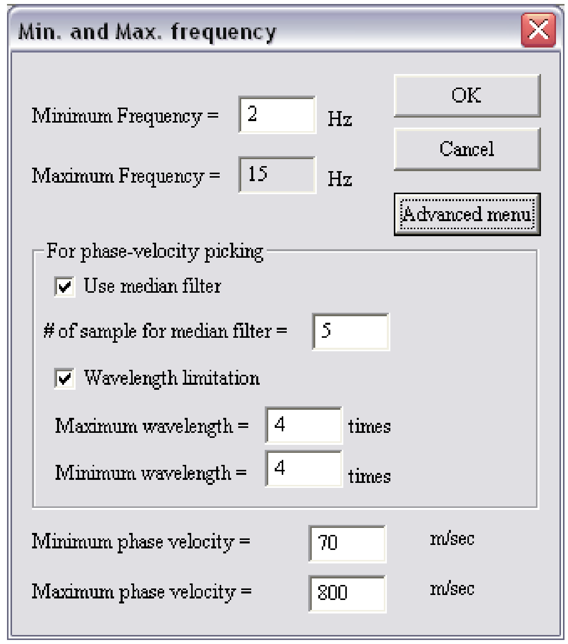
The value shown for the *Maximum Frequency* reflects in Fourier space the value closest to that set in the *Phase velocity-frequency transformation* dialog box.





The default dialog box format hides the *Advanced menu*. Clicking 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.

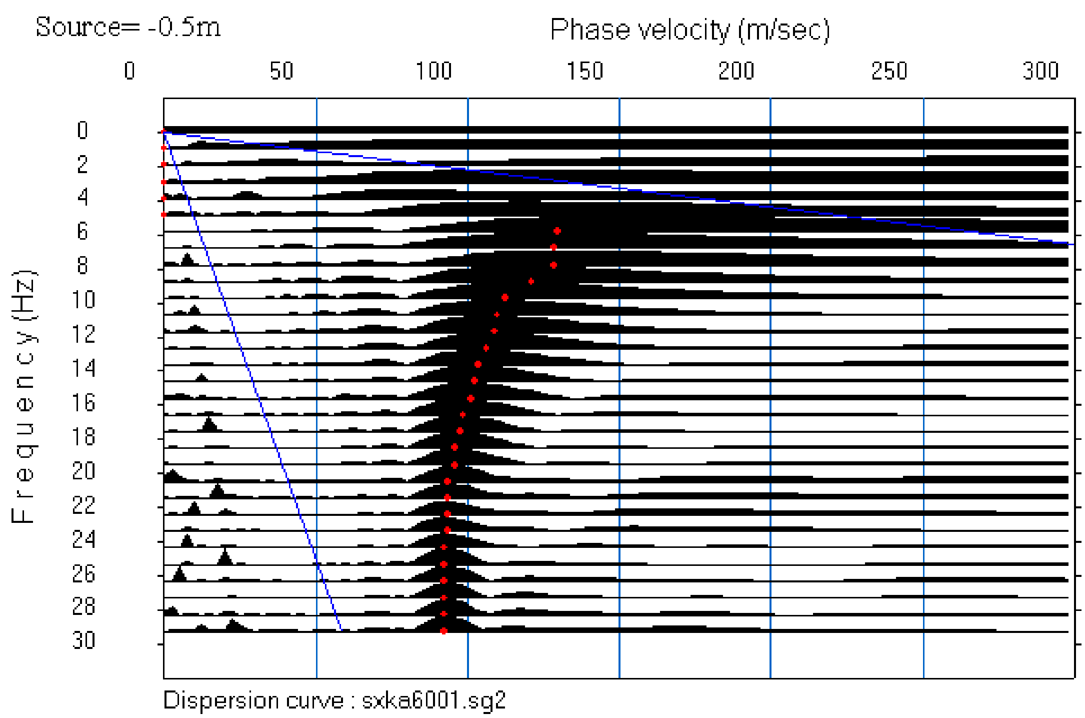
The *Wavelength limitation* defines the wavelength (phase velocity divided by frequency) boundaries for picking. If this option is checked, the limits as defined will be used for picking. The *Maximum wavelength* limit is calculated by the total offset or array length multiplied by the scalar value entered. 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 Section 8.3.1 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.



Picks are automatically made at the mathematical maximum amplitude for each frequency. The x, 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 included on the SeisImager CD for 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.

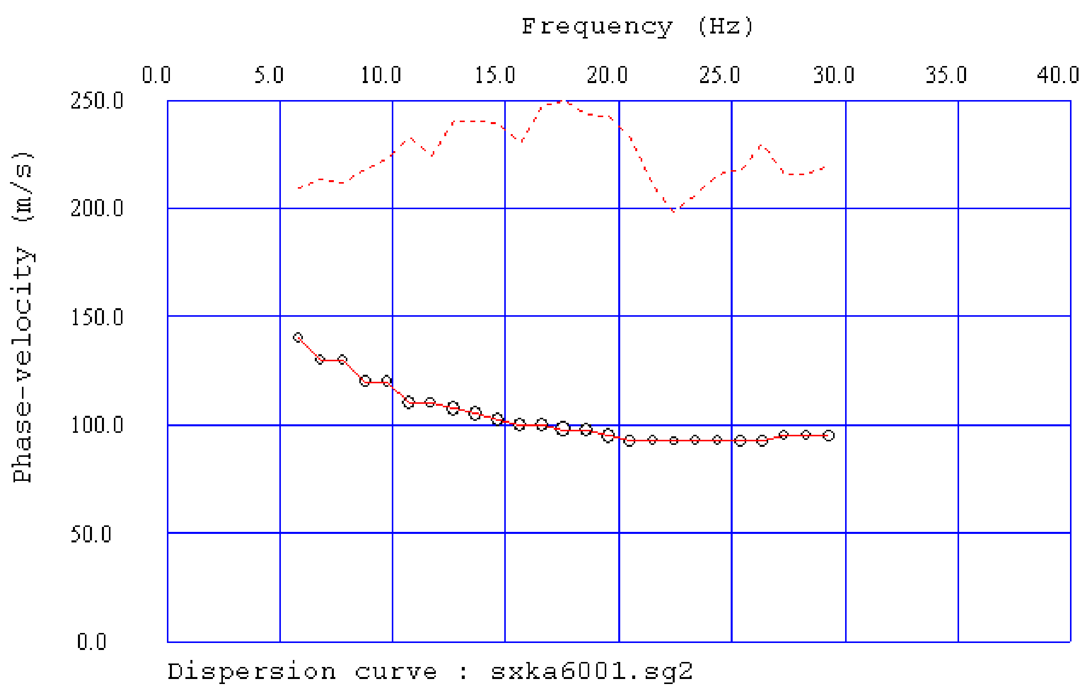
Any picks lying on the y-axis have a phase velocity value of zero and are automatically excluded from further analysis.

5.3.3 Surface-Wave Analysis Menu: 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 6 for a complete explanation of this plot.



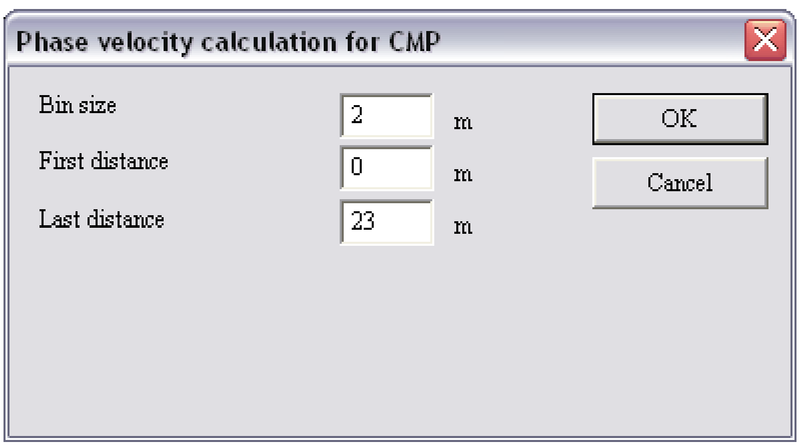
5.3.4 Surface-Wave Analysis Menu: Make CMP Gather Files (2D)

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.

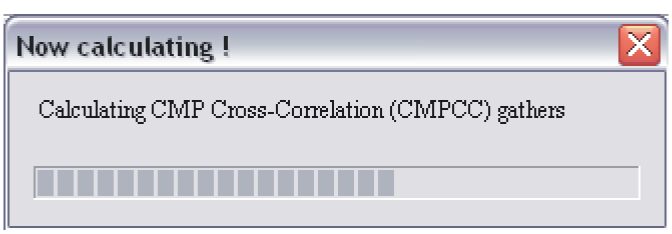
First, a file list with assigned geometry is opened using the *Group (File List)* menu, *Open File List* or *Make File List* and *Set Up Geometry* as applicable. Once opened, select *Make CMP gather files (2D)*.

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. Click *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. Click *OK*.

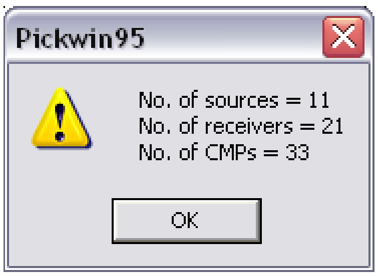


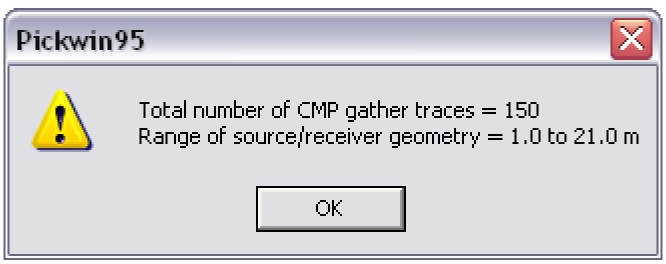
CMP cross-correlation traces are calculated and CMP cross-correlation gathers are assembled. A new set of CMP cross-correlation gather SEG-2 files are written to the dataset directory with the name *cmp_XXXXX.sg2* where the X values are the CMP locations.



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

A series of reports on the process statistics are displayed, click *OK* to each report.

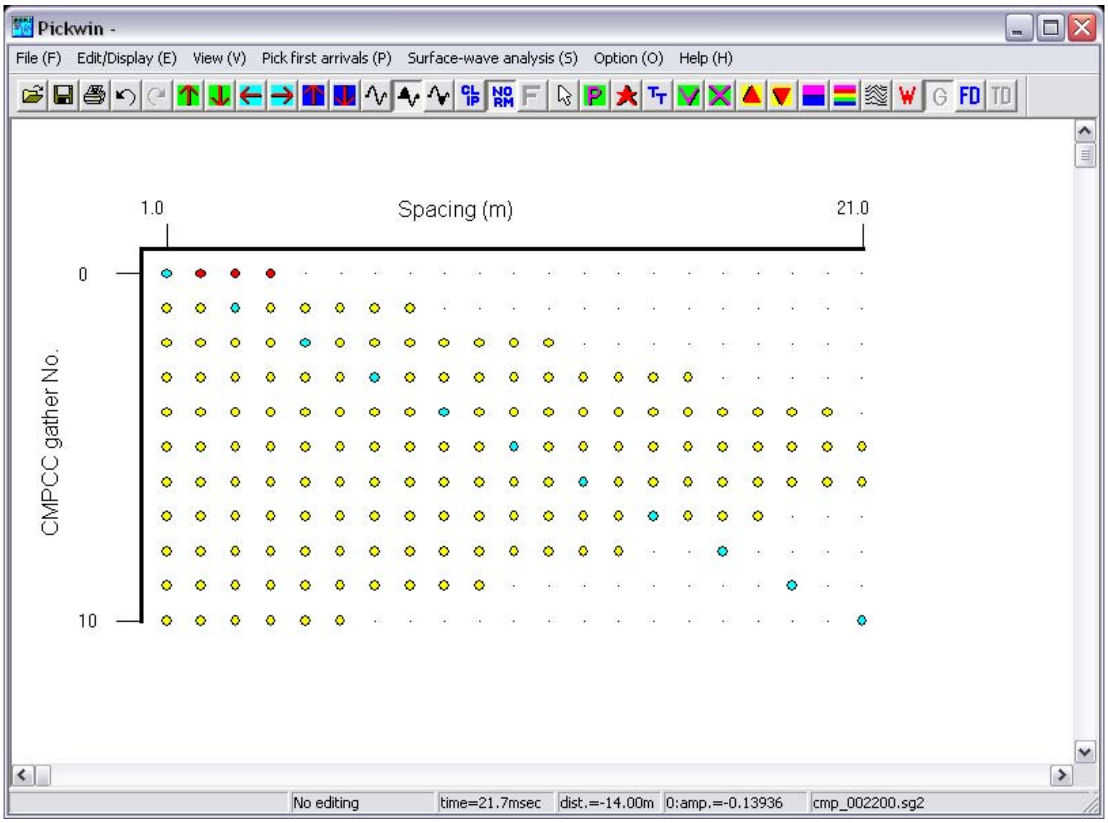




Once calculation of the CMP cross-correlation gathers is complete, a plot of the CMP cross-correlation gather geometry is displayed. Refer to Table 5 in Section 5.1.4.6 for explanation of the geometry plot attributes and display functionality.

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.

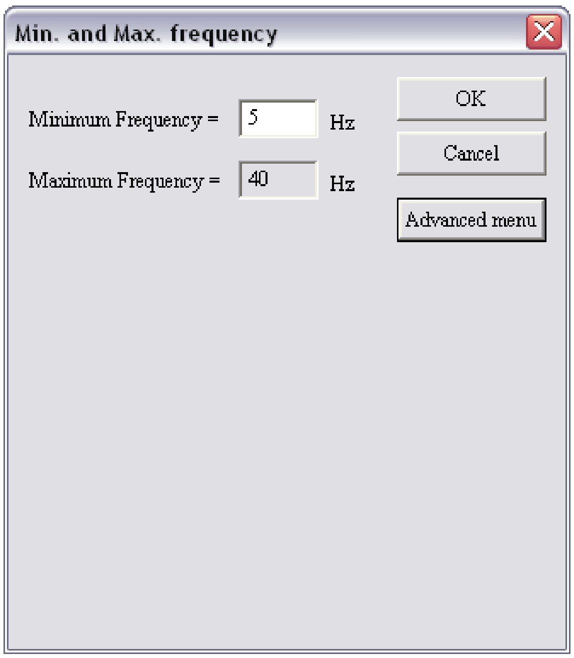


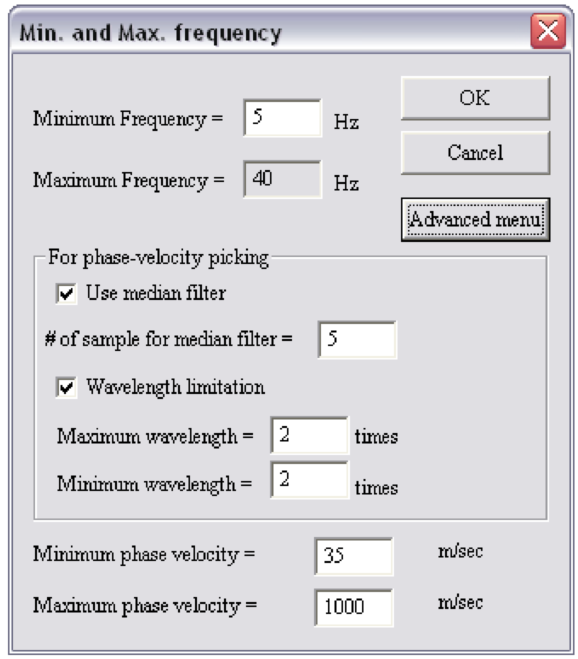
5.3.5 *Surface-Wave Analysis Menu: Phase Velocity-Frequency Transformation and Picking (2D)*

Once CMP cross-correlation gathers are assembled, select *Phase velocity-frequency transformation and picking (2D)* 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 5.3.1. Click *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 5.3.2. Click *OK* when done.





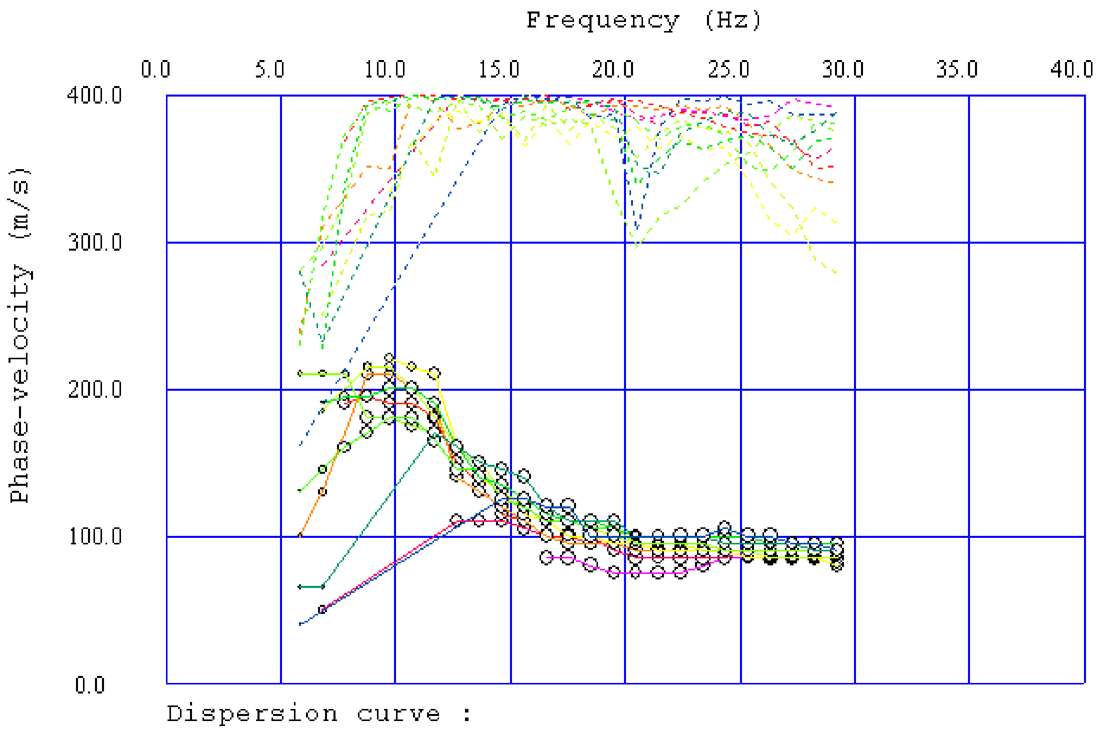
Upon completion of picking, because 2D MASW datasets include many files, all of the individual dispersion curves are not shown in Pickwin. The picks are automatically saved as a *.pvs* file in the dataset directory and held in memory for import to WaveEq.

5.3.6 Surface-Wave Analysis Menu: Show Phase Velocity Curves (2D)

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)* to automatically launch WaveEq and import the dispersion curves from Pickwin.

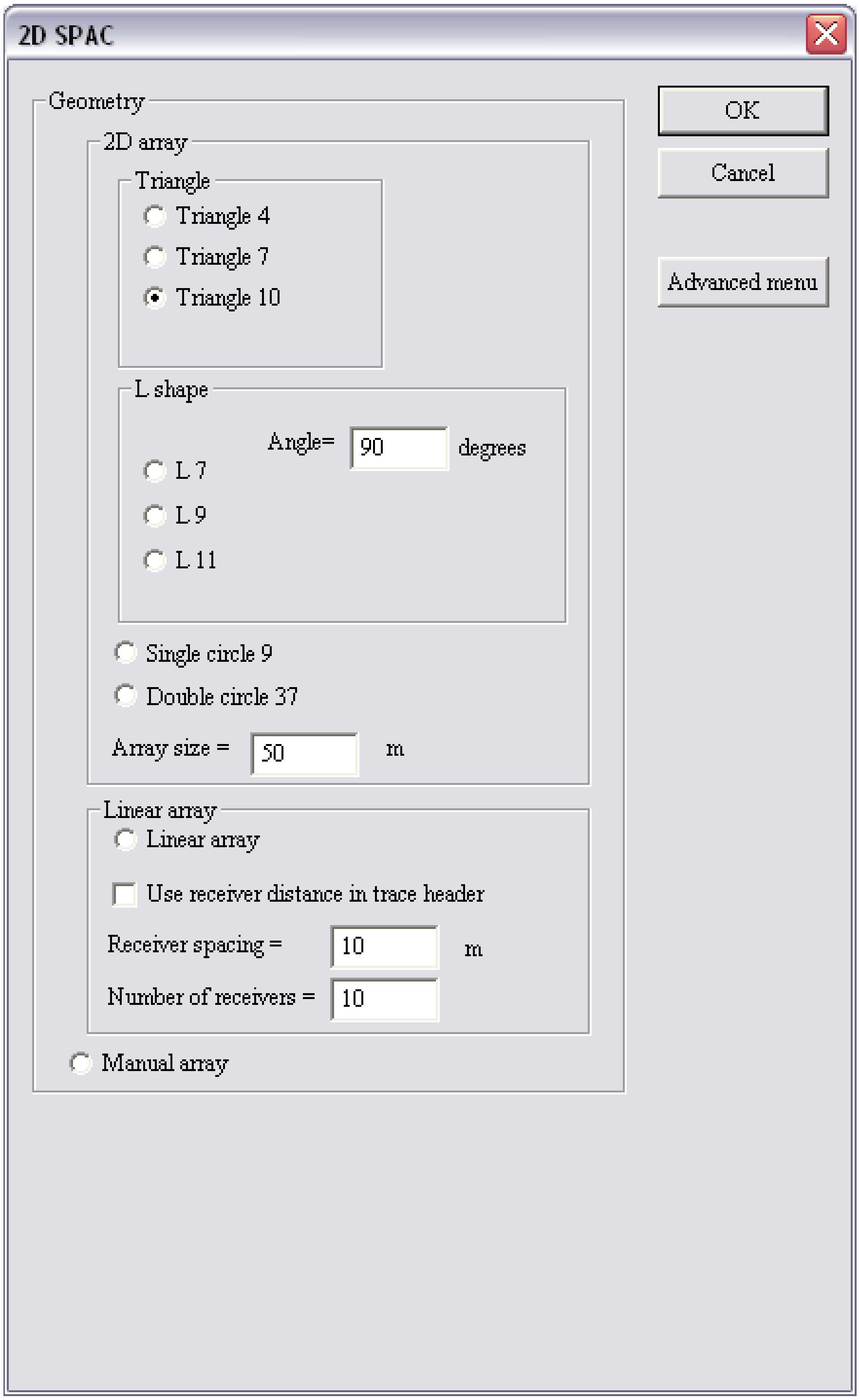
WaveEq is launched and the dispersion curve plot is displayed. The unit labels set in Pickwin carry over.   Note that in WaveEq, *Phase velocity* is plotted on the vertical axis and *Frequency* is plotted on the horizontal axis. Refer to Section 6 for a complete explanation of this plot.



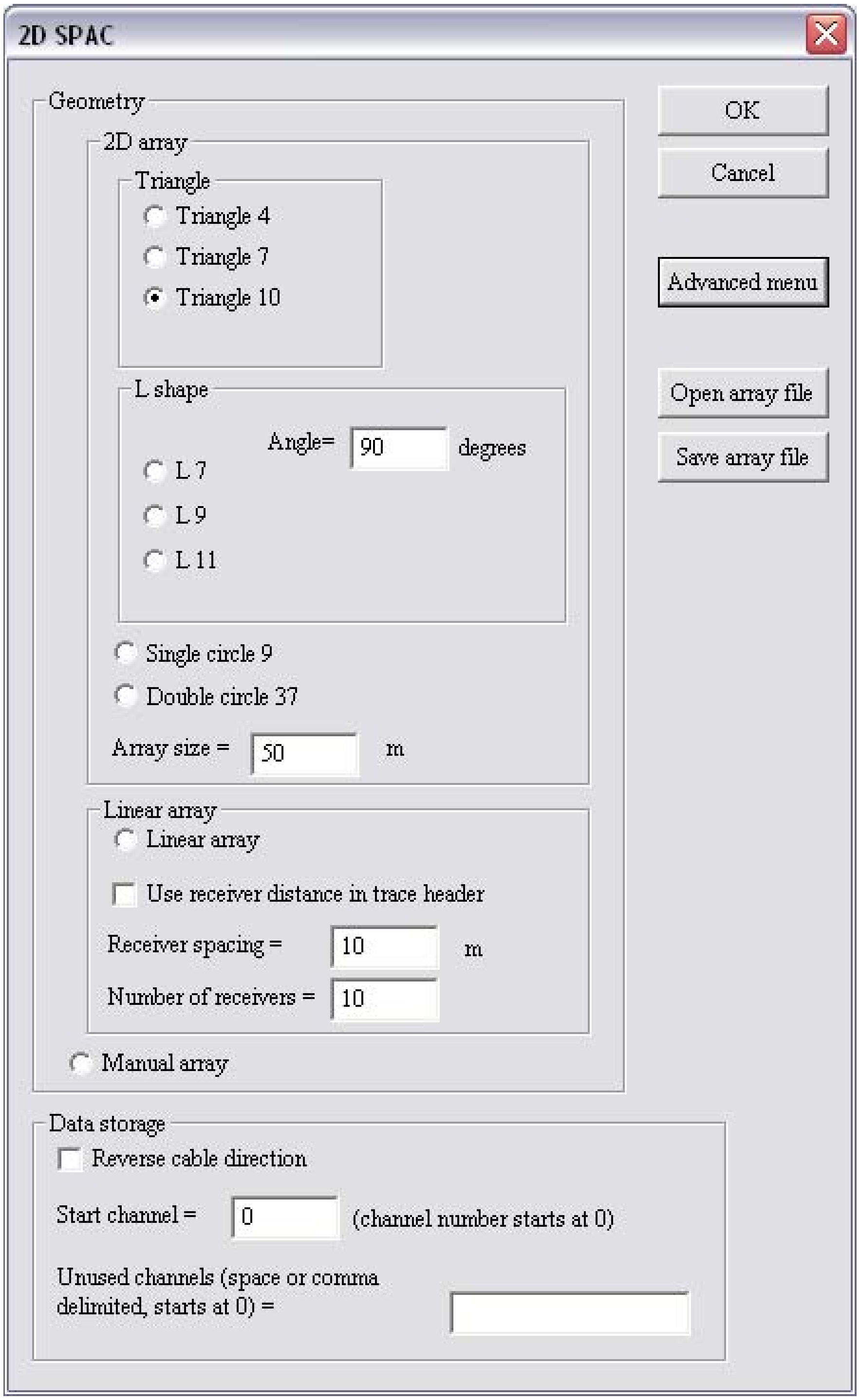
5.3.7 Surface-Wave Analysis Menu: 2D Spatial Autocorrelation

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.

Once selected, set the geometry of the passive source array in the *2D SPAC* dialog box. Refer to Section 3.2.1 for explanation of the different array types and *Array size*.

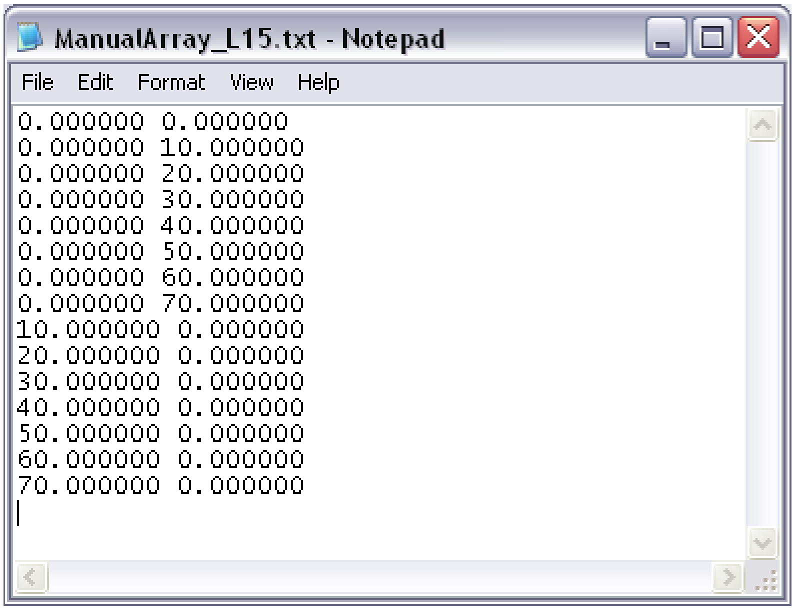


The default dialog box format hides the *Advanced menu*. Clicking *Advanced menu* reveals options to define a *Manual array*, *Open array file*, *Save array file*, and to set *Data storage* parameters.

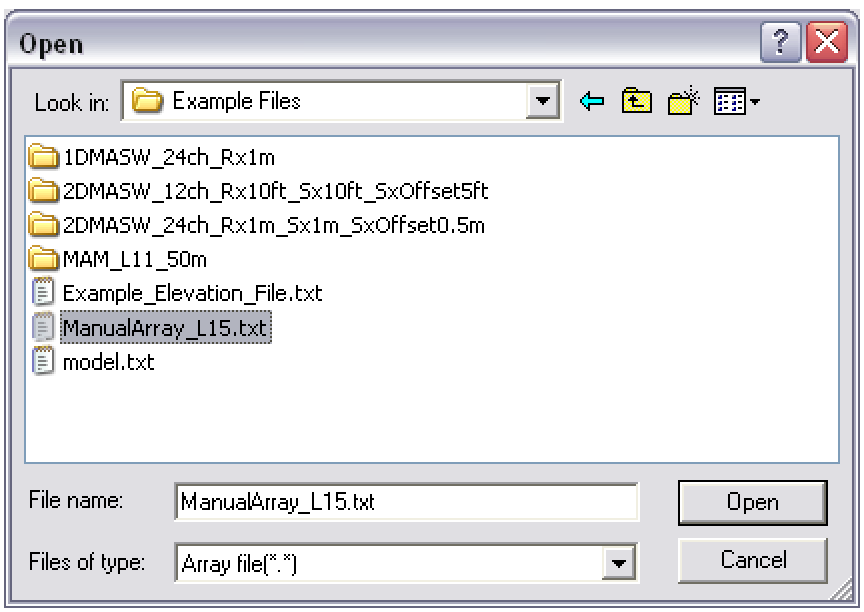


Data storage allows a particular array geometry to be applied to other data. *Reverse cable direction* will flip the channel order, *Start channel* sets the new start channel number, and *Unused channels* allows dead or unused channels to be deleted.

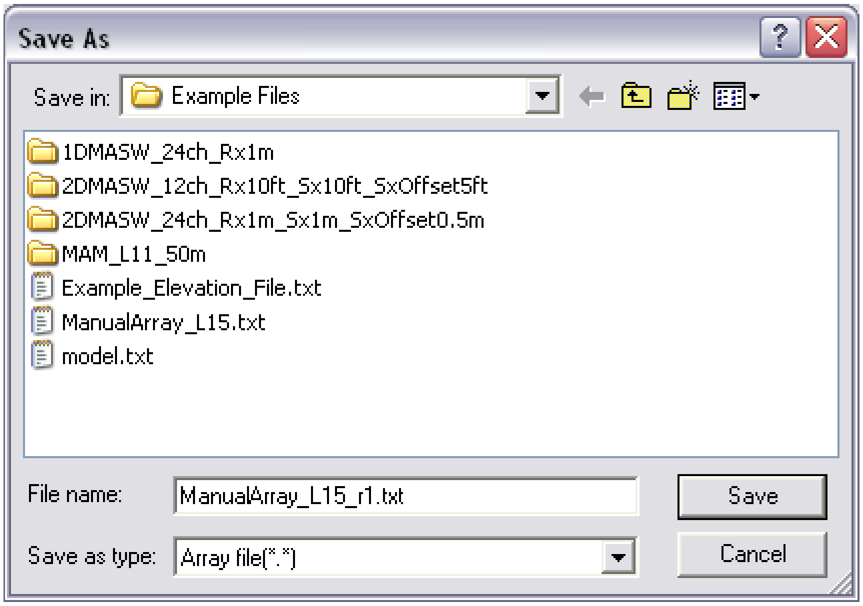
If your array does not conform to one of the standard geometries, a *Manual array* can be defined in a simple space-delimited text file where each row is a pair of x- and y-coordinates.



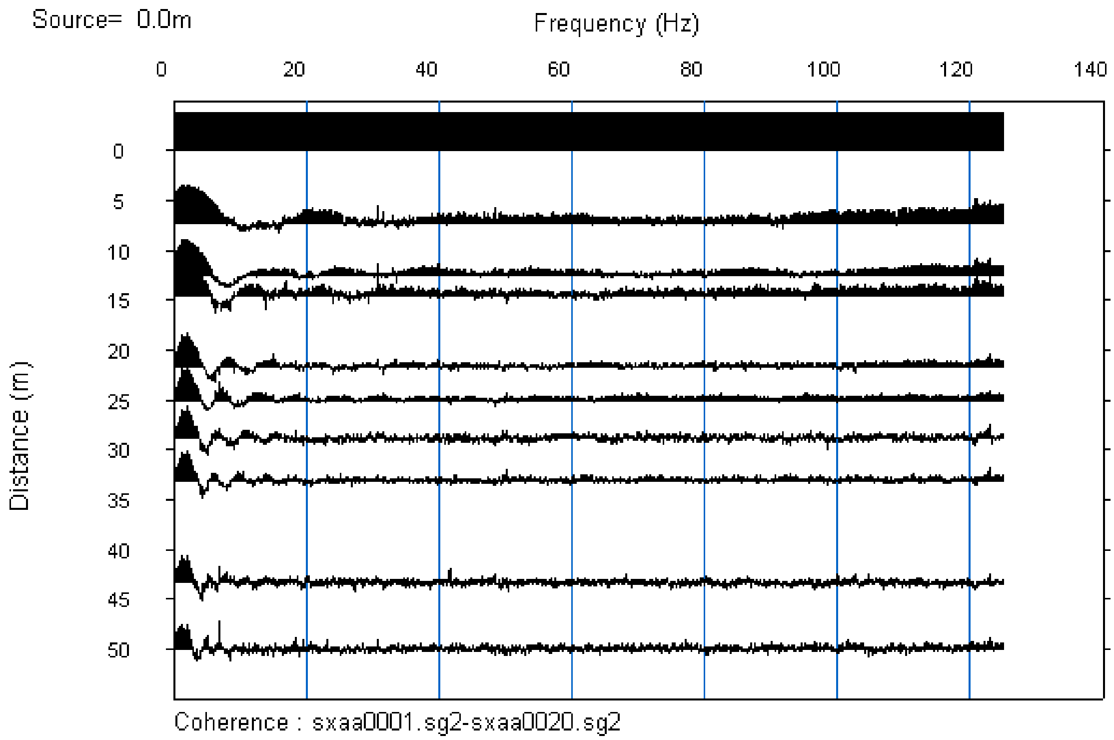
Once the *Array file* is prepared, click on *Open array file*, highlight the file, and click *Open*.



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



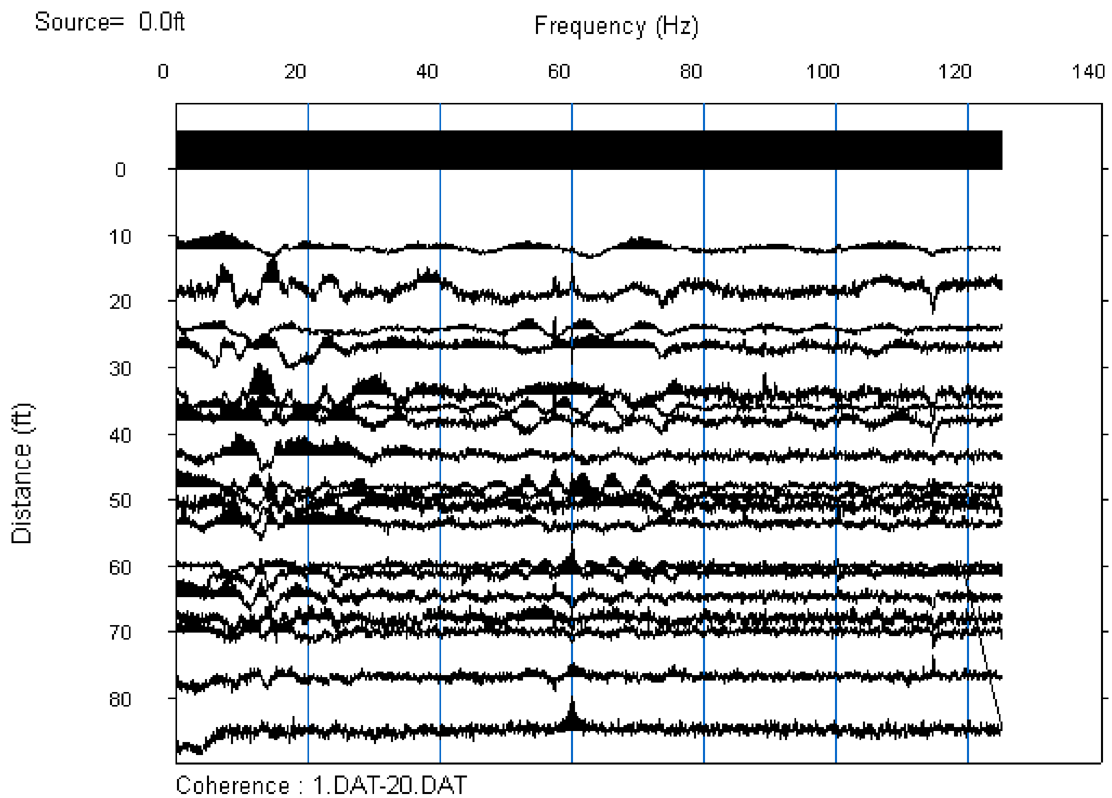
Once the *2D Spatial autocorrelation* process is complete, a signal coherency plot is displayed.



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.

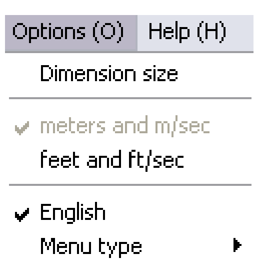
The shape of a coherency curve by nature is a Cosine function with 1D arrays and a Bessel function (decaying Cosine function) with 2D arrays (shown above). The coherency curve for each separation is well shaped (calculated from what is considered an ideal dataset). Compare this with the coherency plot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



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

5.4 Option Menu

The Options menu includes program controls and display settings.

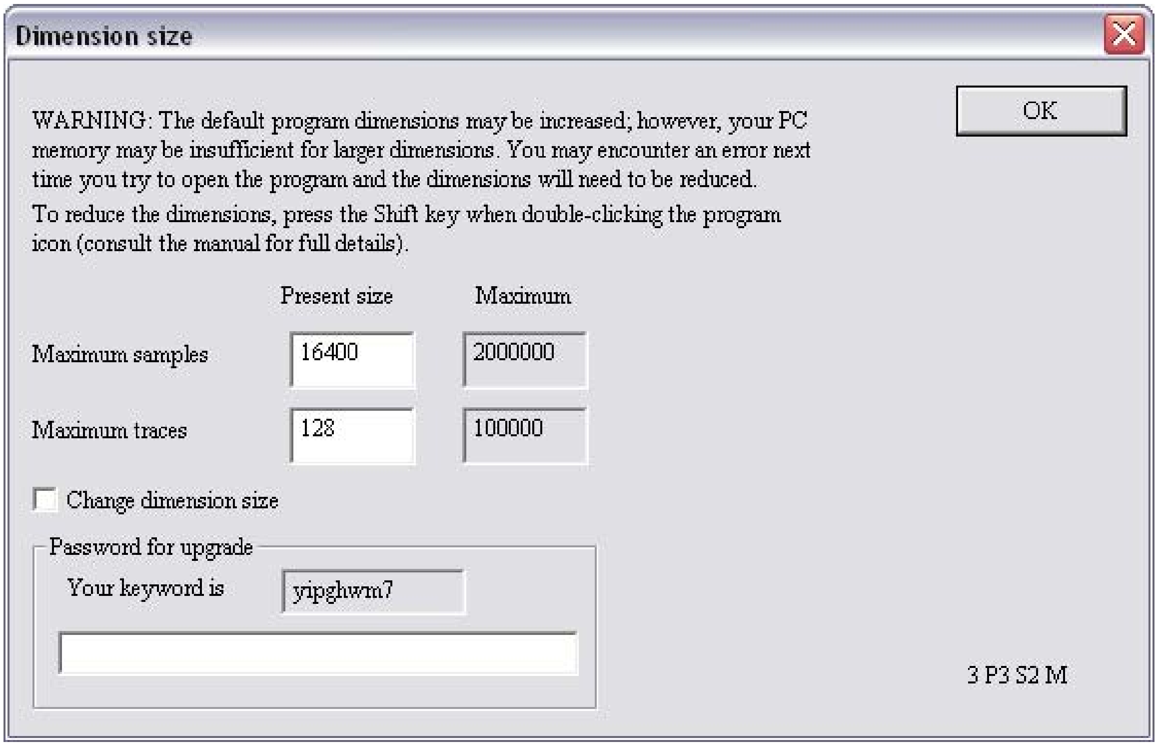


5.4.1 Option Menu: Dimension Size

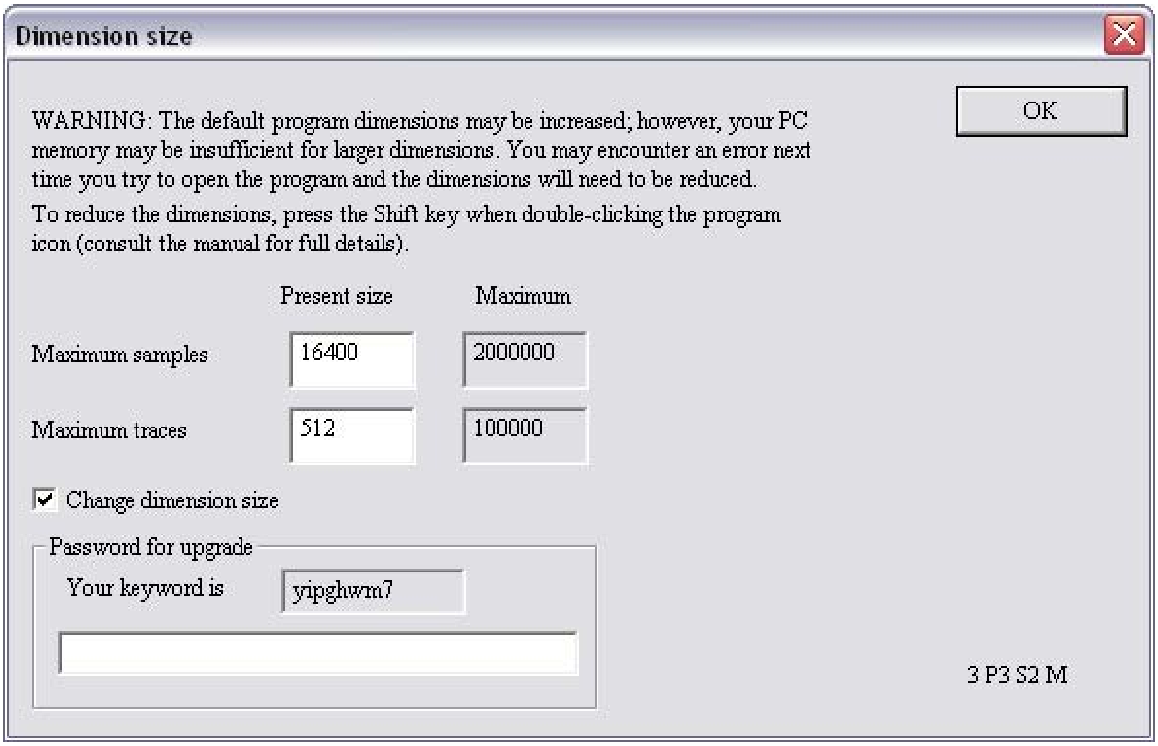
To view or change the program data input allowances, select *Dimension size*.

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 be increased if you are processing a passive source dataset with a large number of traces, for example, greater than 48.

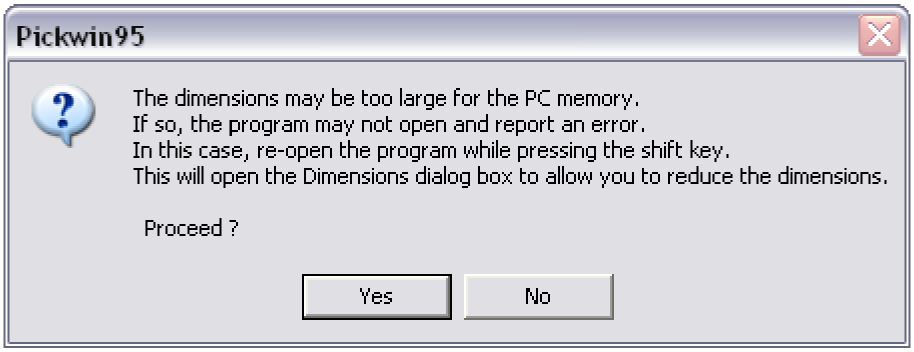


To change the dimensions, enter the new value(s), check *Change dimension size*, and click *OK*.



Click *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.

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.

5.4.2 Option Menu: 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.

5.4.3 Option Menu: English

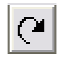
The program language can be converted between English and Japanese. To convert to Japanese, uncheck *English*. Obviously, this is not recommended unless you want to use the software in Japanese and have the necessary version of Windows. If symbols appear in various places, it is likely that the language is not set to English and Windows is unable to render the program in Japanese.

5.4.4 Option Menu: Menu Type

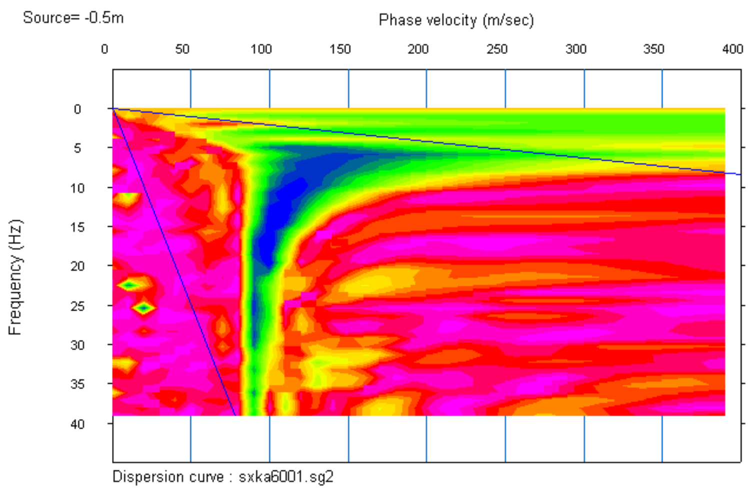
Menu type of *Simple* pertains to the menu structure of SeisImager/2D.

5.5 Button Bar Functions

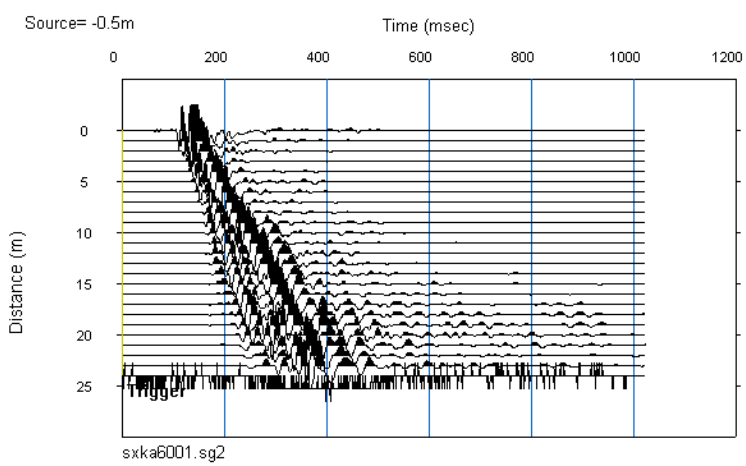
The button bar functions essential or uniquely used for surface wave data processing are covered in this section. For a complete description of the button bar functions common to SeisImager/SW and SeisImager/2D, please refer the separate SeisImager/2D manual included on the SeisImager CD.

5.5.1 Button Bar: Undo  and Redo 

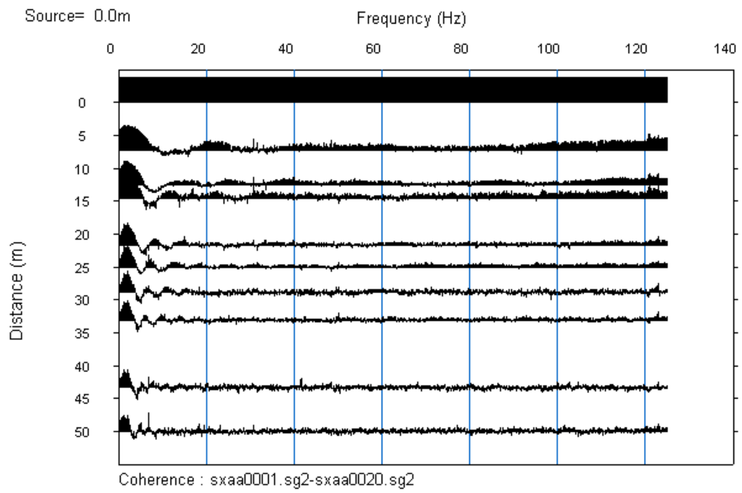
After the phase velocity-frequency transformation has been calculated for a given waveform file or dataset, click on the *Undo* button to cancel the phase velocity plot.



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



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



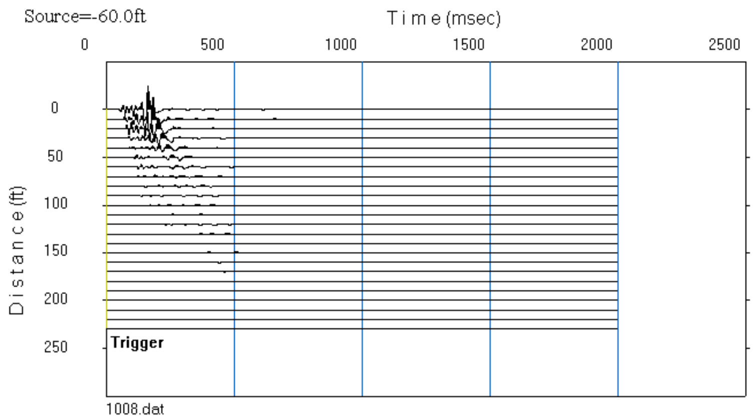
To return to the phase velocity plot in either case, click the *Redo* button. Note that the *Undo* and *Redo* functions run only one cycle, so if *Undo* is clicked again, the waveform and coherency files will not be found and it will necessary to restart the program.

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

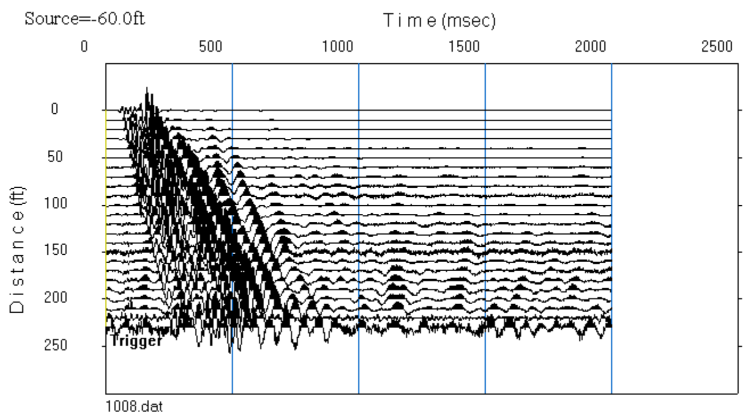
5.5.2 Button Bar: Normalize 

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.

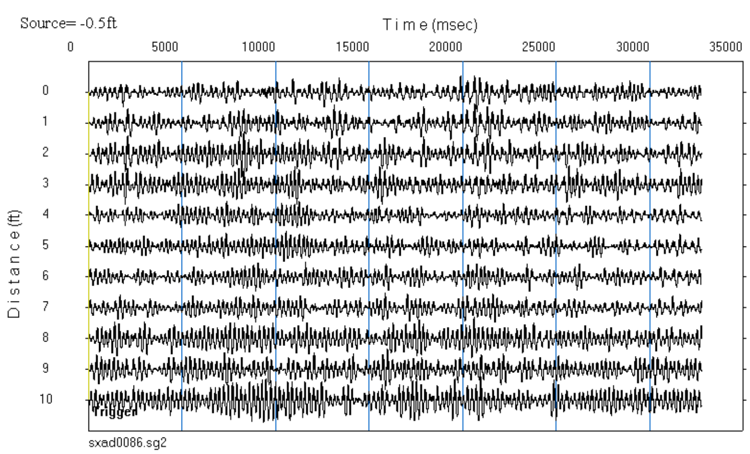
With *Normalize* off, the traces distant from the source are not visible.



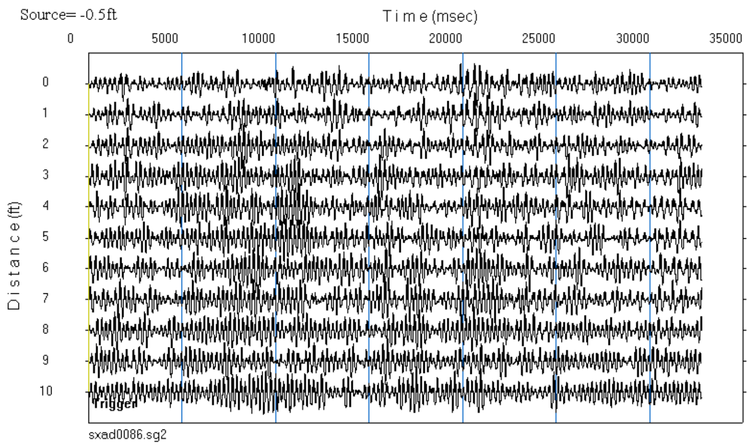
With *Normalize* on, traces at all distances are visible.



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

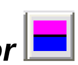


With *Normalize* off, traces 4 through 7 are slightly higher amplitude.

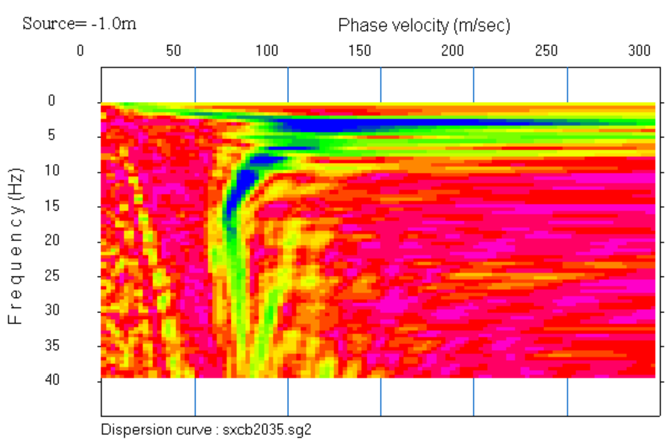


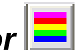
5.5.3 Button Bar: Show Previous Waveform File  *and Show Next Waveform File* 

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.

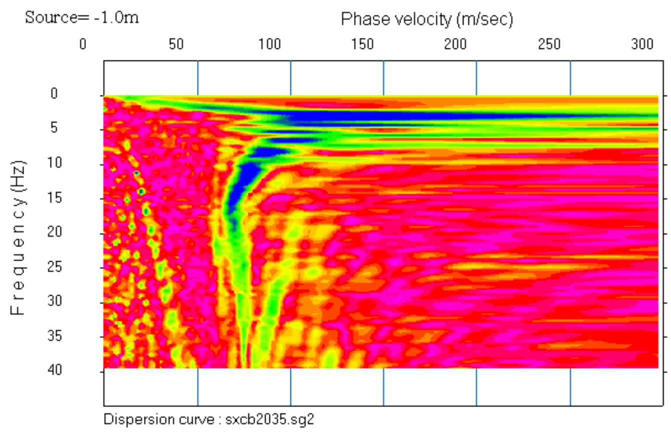
5.5.4 Button Bar: Coarse Contour Color 

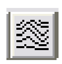
The phase velocity-frequency plot display is enhanced with color gradients. To apply a coarse contour color scale, click the *Coarse contour color* button.



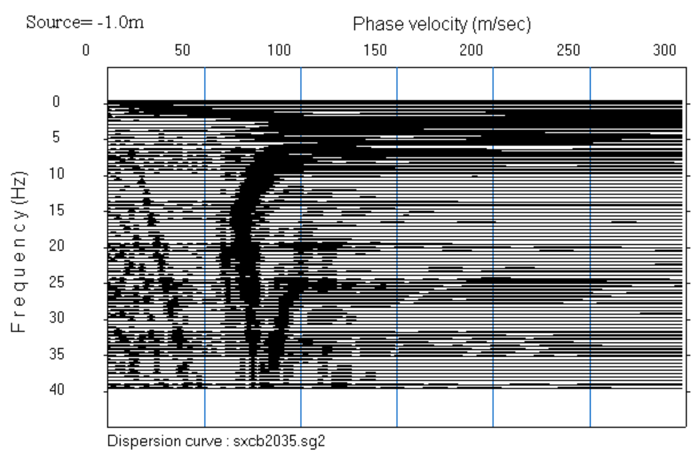
5.5.5 Button Bar: Fine Contour Color 

The phase velocity-frequency plot display is enhanced with color gradients. To apply a fine contour color scale, click 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*.



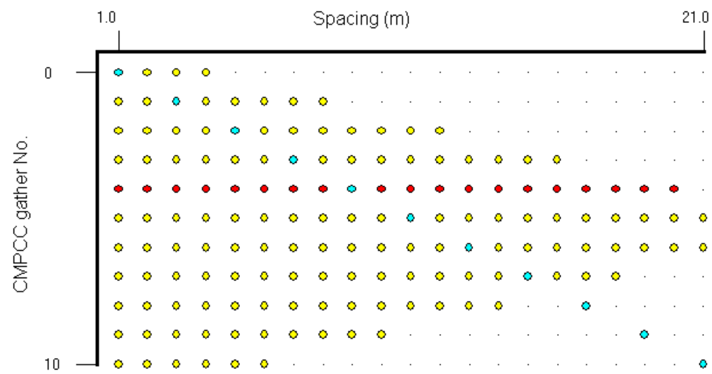
5.5.6 Button Bar: Wiggle Line  and Shaded Black 

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.

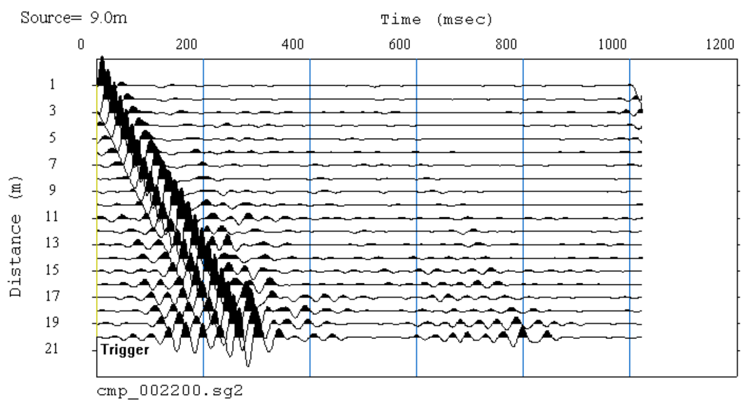


5.5.7 Button Bar: Show Waveforms  and Show Geometry 

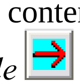
After the geometry has been calculated and applied for a given dataset, the *Show waveforms* button and the *Show geometry* button are activated and allow toggling between the two views. In the *Show geometry* view, the *Show previous waveform file* and *Show next waveform file* buttons allow selection of a shot or CMP cross-correlation gather's geometry.



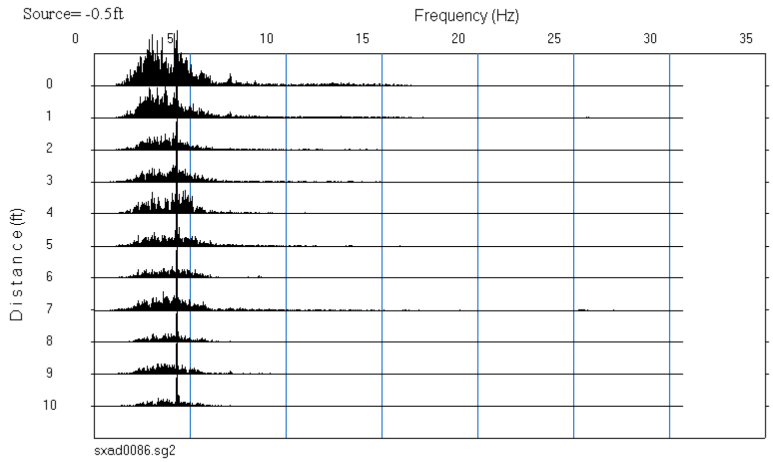
Click the *Show waveforms* button to display the gather associated with the selected geometry.



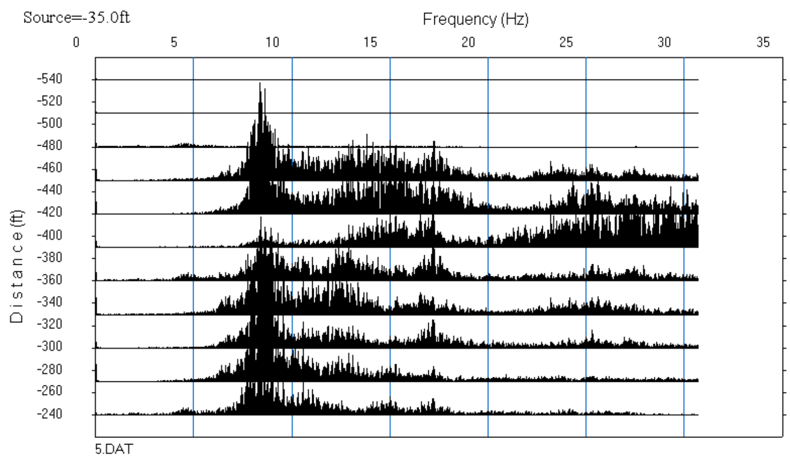
5.5.8 Button Bar: Frequency Domain 

The *Frequency domain* button transforms a time-domain waveform file to the frequency domain. Clicking on 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.



Uneven frequency content from trace-to-trace indicates lower-quality data.



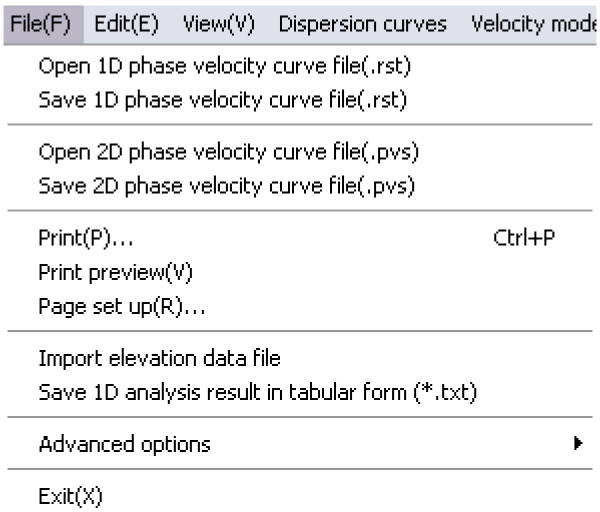
5.5.9 Button Bar: Time Domain 

The *Time Domain* button toggles out of the *Frequency domain* view.

6 – The WaveEq Module Functions

6.1 File Menu

The *File* menu includes functions for opening WaveEq result files, importing and exporting various files, and printing.

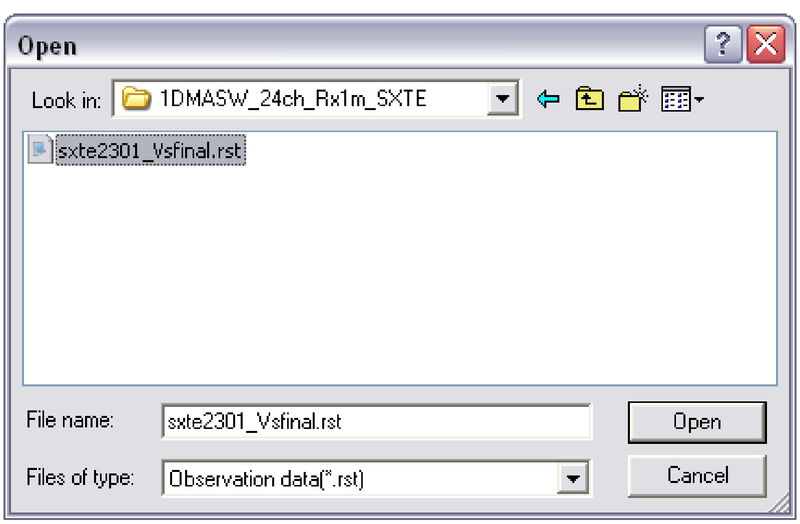


The *Advanced options* are not active at this time.

6.1.1 File Menu: Open 1D Phase Velocity Curve File (.rst)

To open a single dispersion curve or V_s curve previously saved with the extension *.rst*, select *Open 1D phase velocity curve file (.rst)*.

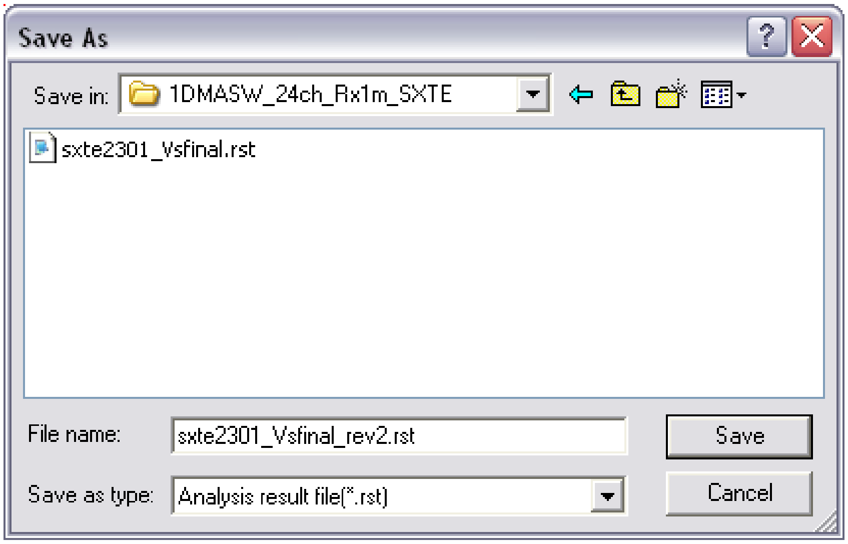
Highlight the file and click *Open*.



6.1.2 File Menu: Save 1D Phase Velocity Curve File (.rst)

To save a single dispersion curve or V_s curve, select *Save 1D phase velocity curve 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.

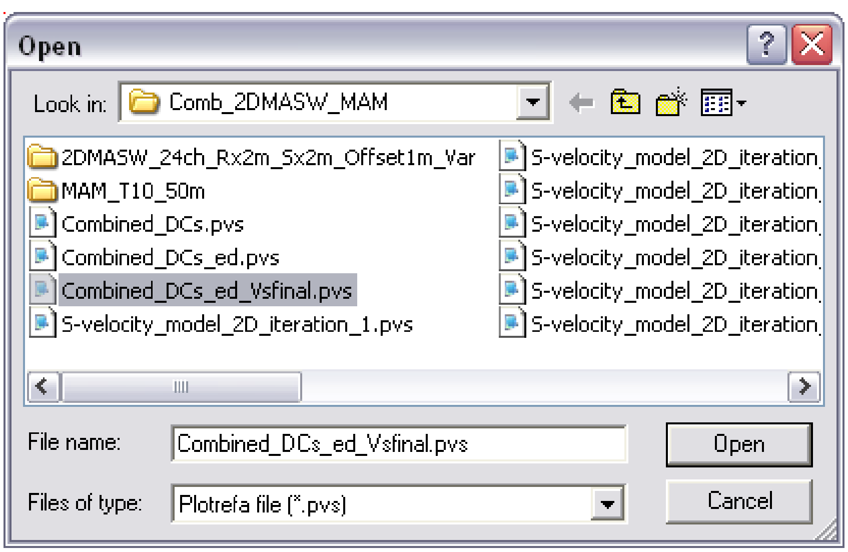
Assign a file name with the extension *.rst* and click *Save*.



6.1.3 File Menu: Open 2D 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)*.

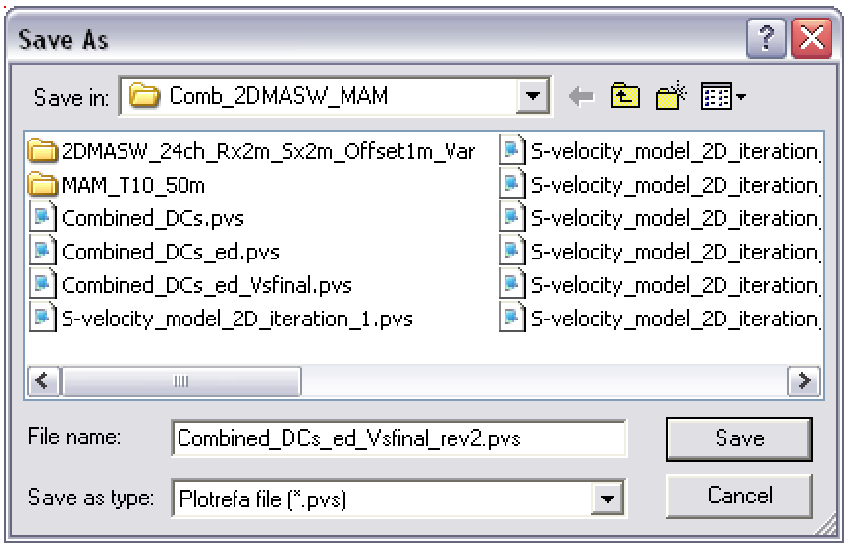
Highlight the file and click *Open*.



6.1.4 File Menu: Save 2D Phase Velocity Curve File (.pvs)

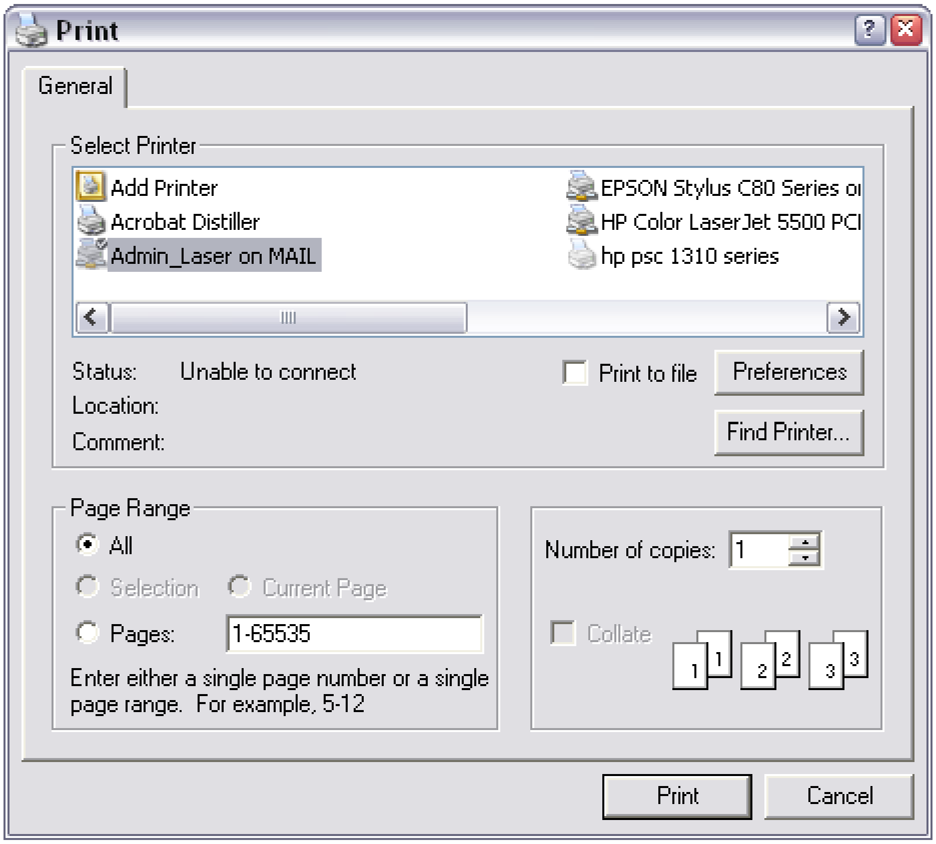
To save a set of dispersion curves, select *Save 2D Phase Velocity Curve File (.pvs)*. A curve file can be saved at any time in the processing flow and will reflect the extent of results at the time of save.

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

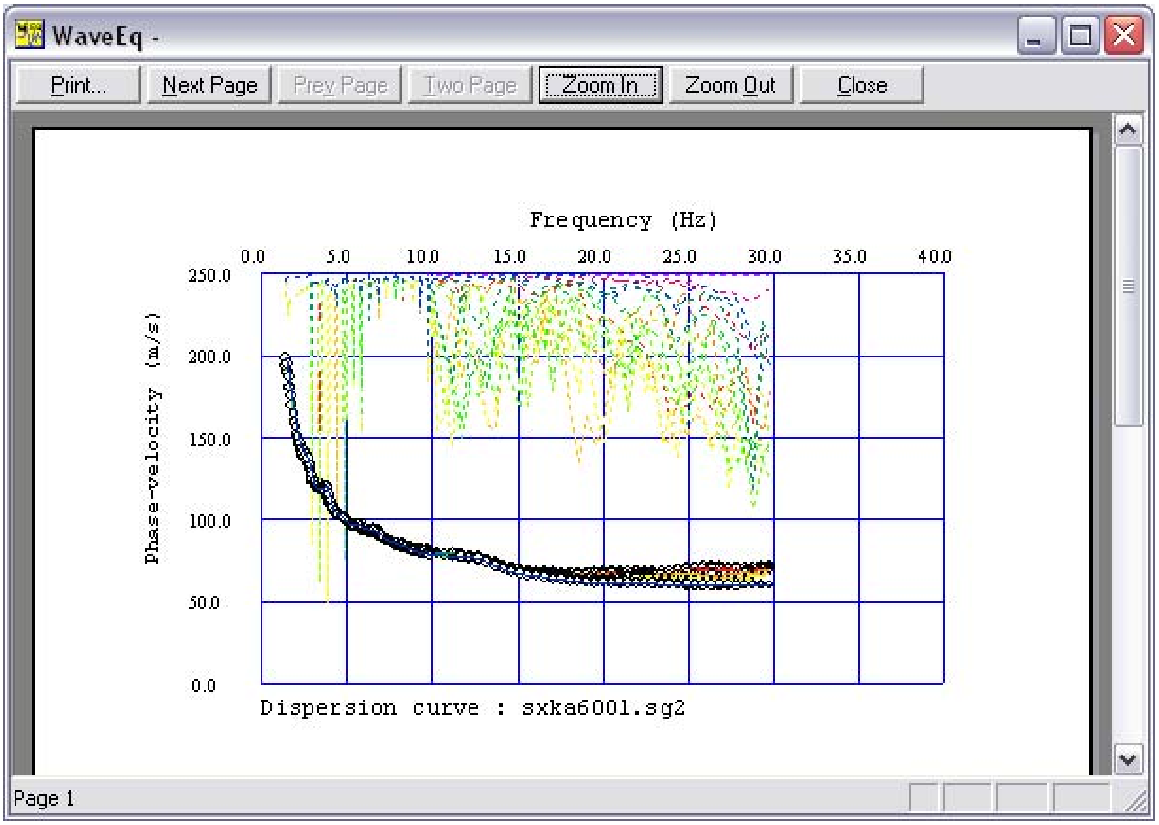


6.1.5 File Menu: Print , Print Preview, and Page Set-up

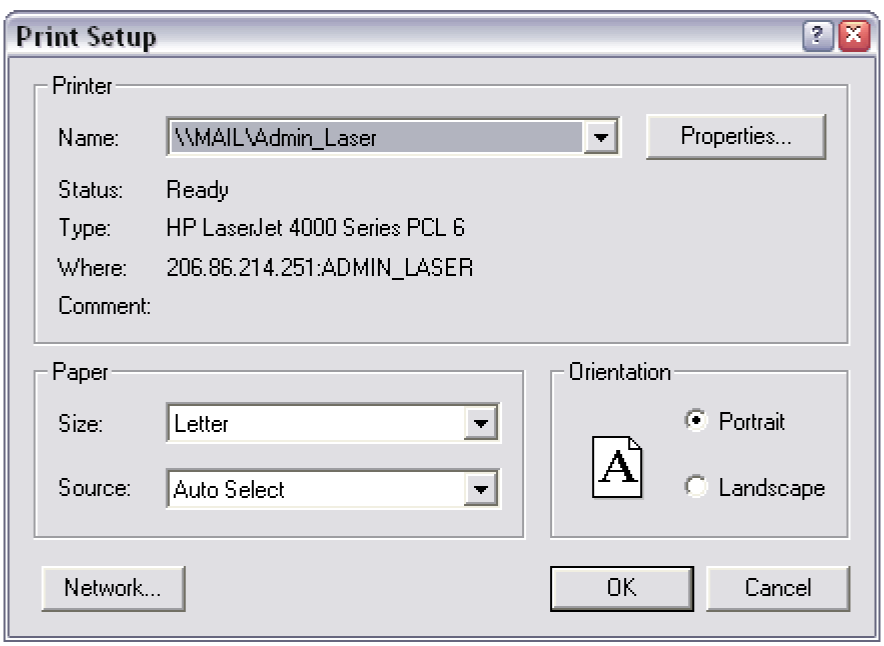
To print the current WaveEq display, choose *Print (P)*, press Ctrl-P, or click the *Print*  button.



To preview the WaveEq display before printing, select *Print preview (V)*.



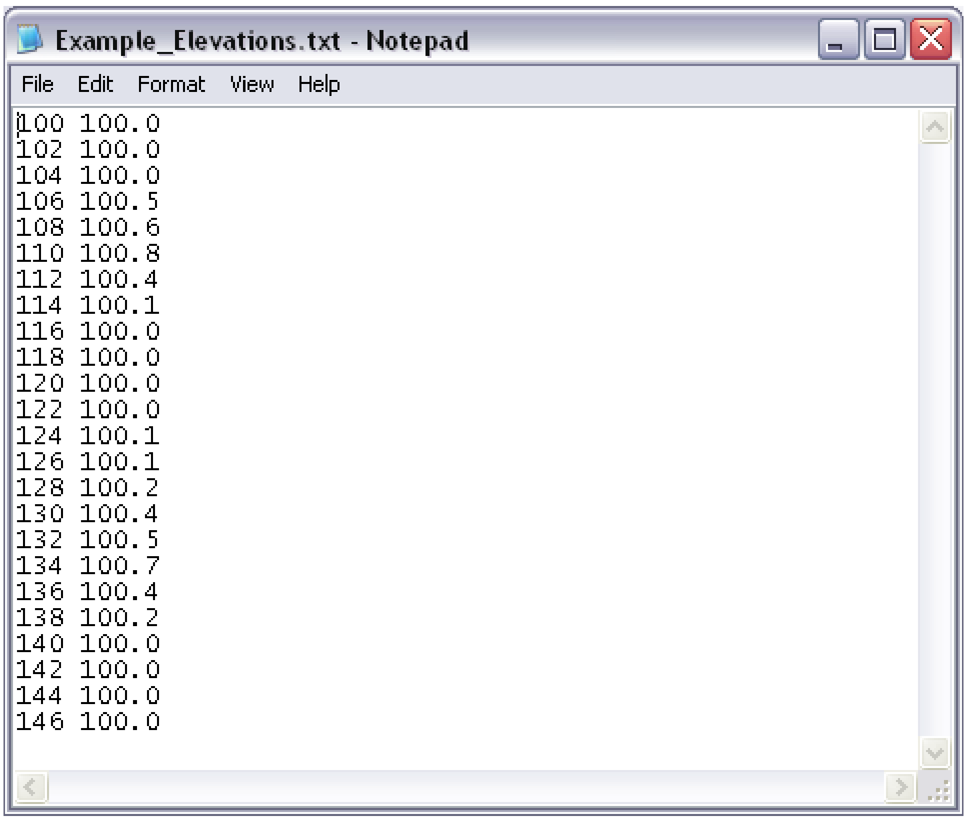
To set up a page for printing, select *Page set up(R)*.



6.1.6 File Menu: 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.

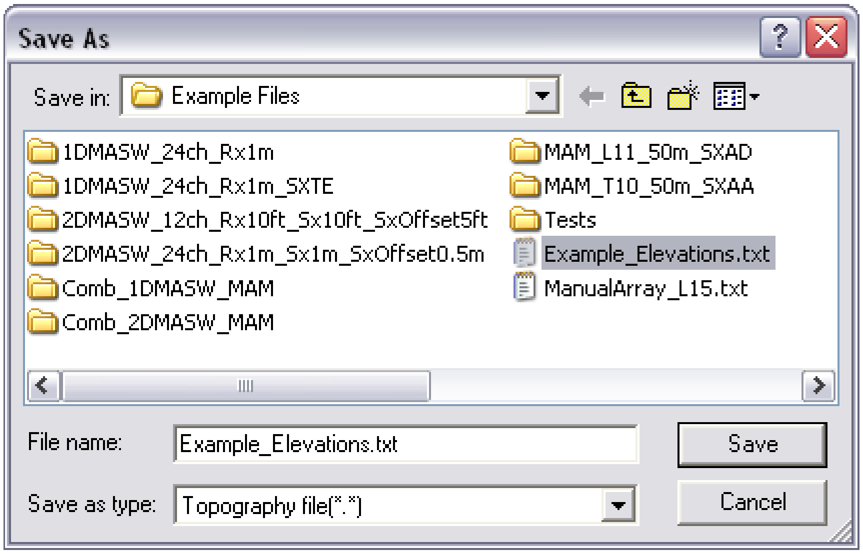


Example_Elevations.txt - Notepad

File Edit Format View Help

```
100 100.0
102 100.0
104 100.0
106 100.5
108 100.6
110 100.8
112 100.4
114 100.1
116 100.0
118 100.0
120 100.0
122 100.0
124 100.1
126 100.1
128 100.2
130 100.4
132 100.5
134 100.7
136 100.4
138 100.2
140 100.0
142 100.0
144 100.0
146 100.0
```

To open an elevation file, select *Import elevation data file*, highlight the file and click *Open*.

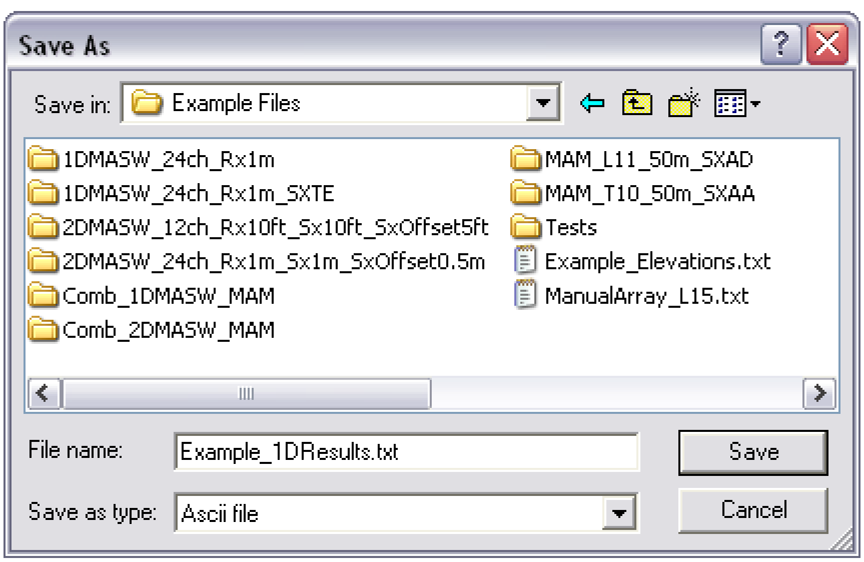


If not imported here, elevation data can also be imported in GeoPlot by selecting the *File* menu, *Open topography data file*.

6.1.7 File Menu: 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 click *Save*.



The file is a simple text file with *Depth*, *S-wave velocity*, *P-wave velocity*, *Density*, and *N* (or blow counts). Refer to Section 6.5.4 for more information on the relationships used for calculating the equivalent *P-wave velocity*, *Density*, and *N*.

Example_1DResults.txt - Notepad

File Edit Format View Help

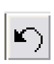
Depth(m)	S-velocity(m/s)	P-velocity(m/s)	Density(g/cc)	N
0.000000	240.201656	478.715135	2.451794	17.953686
0.535714	241.759526	480.818502	2.451794	18.327154
1.153846	206.903282	416.289685	2.451794	11.162379
1.854396	171.800114	349.477288	2.450823	6.174623
2.637363	203.229841	405.725995	2.453108	10.543385
3.502748	272.539965	538.438611	2.459779	26.844084
4.450550	317.506564	631.251244	2.466313	43.658286
5.480770	339.260817	676.979654	2.470901	53.917032
6.593407	357.446472	716.906592	2.475054	63.671732
7.788462	391.665652	784.423694	2.481561	85.191053
9.065934	421.149715	840.609763	2.484316	107.344413
10.425825	438.123030	872.368271	2.484316	121.738446
11.868132	448.739565	891.207761	2.484316	131.384254
13.392857	523.269116	1036.073513	2.484316	214.319468
18.214285	523.269117	1036.073565	2.484316	214.319468

6.2 Edit Menu

The *Edit* menu contains functions for making and reversing edits and copying graphical displays to the clipboard.

Edit(E) View(V) Disper

Undo
Delete
Copy to clipboard

6.2.1 Edit Menu: Undo 

The *Undo* function can be used to reverse the selection 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.

6.2.2 Edit Menu: Delete

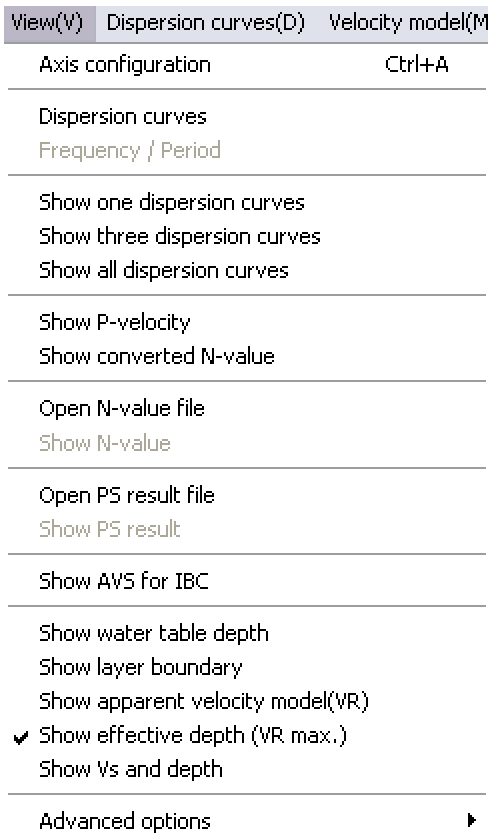
The *Delete* function or *Delete* key becomes active when a point on the dispersion curve has been selected using the *Select dispersion curve*  button. To delete a point on a dispersion curve, activate editing with the *Select dispersion curve* button, then use the mouse to select the point(s) on the dispersion curve to be deleted. The selected points are highlighted in red. Select *Delete* or press the *Delete* key to remove the selected points.

6.2.3 Edit Menu: Copy to Clipboard

To copy the current display to the clipboard for pasting in Microsoft Word or other program, select *Copy to clipboard*.

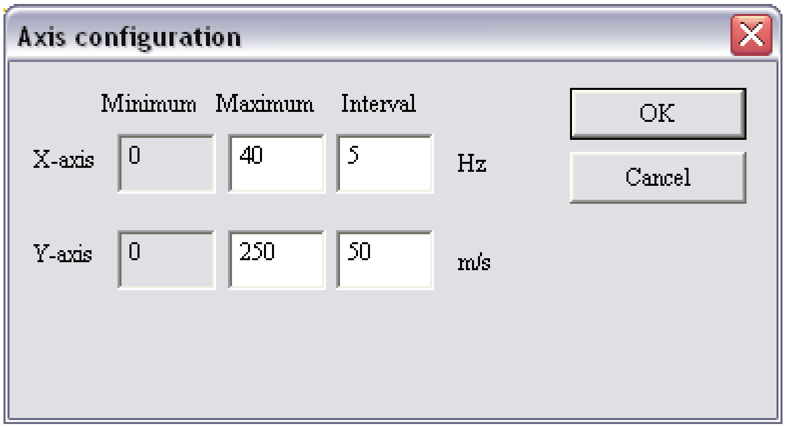
6.3 View Menu

The *View* menu includes functions to configure scales, alter displays, and overlay or import other types of data.



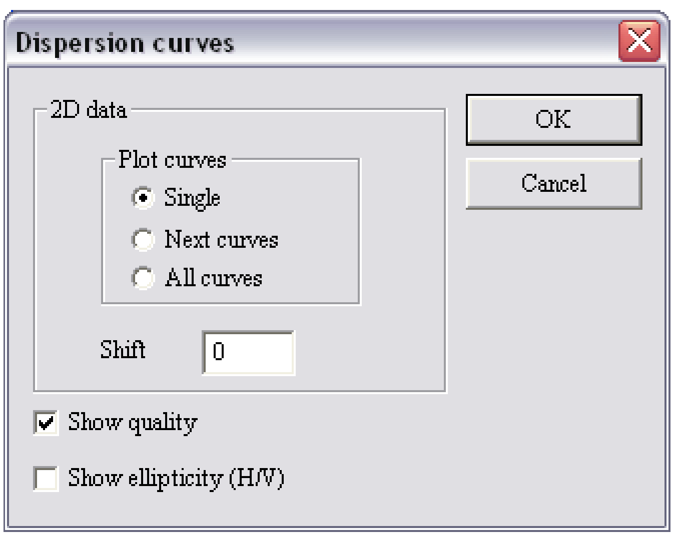
6.3.1 View Menu: Axis Configuration

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.



6.3.2 View Menu: Dispersion Curves

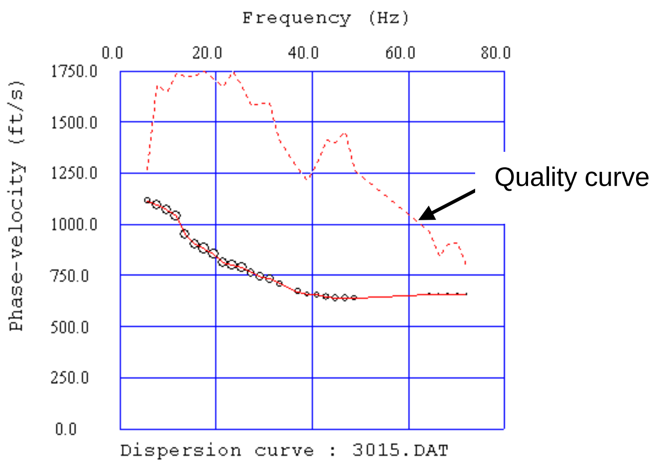
The *Dispersion curves* dialog box controls how dispersion curves are displayed. The *Plot curve* options allow *Single*, *Next curves*, or *All curves* to be displayed. These settings correspond to the *Show one dispersion curve* 
, *Show next dispersion curve* 
, and *Show all dispersion curves* 
 buttons, respectively.



Single and the *Show one dispersion curve* button display one dispersion curve in red. *Next 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. *All curves* and the *Show all dispersion curves* button display all curves starting with red, blue, green, and with the rest unique in color but undefined. They are undefined since with all curves displayed, it the overall trend that is meant to be discerned, not the individual curves.

Shift allows the curves to be bulk shifted by the value entered.

Show quality checked (the default) displays a dashed quality curve 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.

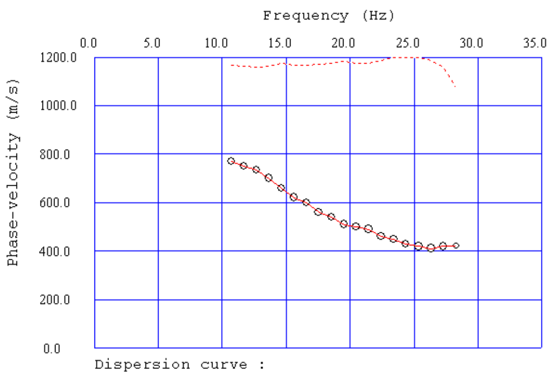


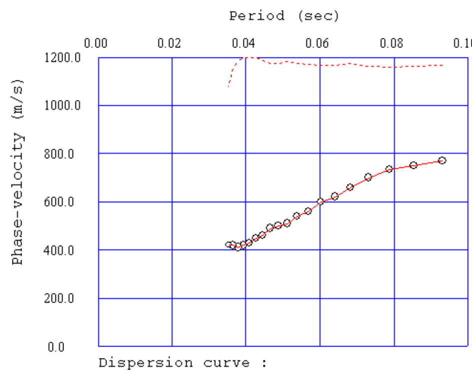
For display of a *Single*, *Next curves*, or *All curves*, the quality curve has the same colors as the associated dispersion curves. Refer to Sections 6.4.4 and 6.4.5 for more information on quality.

Show ellipticity (H/V), allows the horizontal over vertical amplitude ratio for three-component passive source data to be plotted.

6.3.3 View Menu: 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.





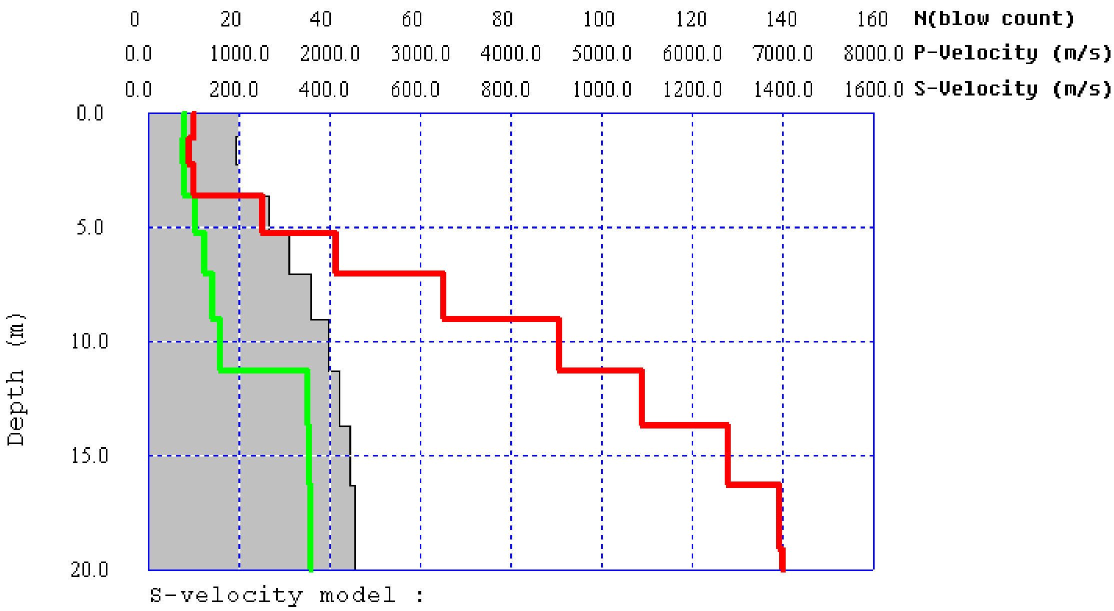
It may be more intuitive to think in terms of seconds, which directly relates to the natural period of buildings, etc.

6.3.4 View Menu: Show One , Three , and All  Dispersion Curves

Show one dispersion curve, *Show three dispersion curves*, and *Show all dispersion curves* are the menu items associated with the button bar functions described in Section 6.3.2.

6.3.5 View Menu: Show P-Velocity and Show Converted N-Value

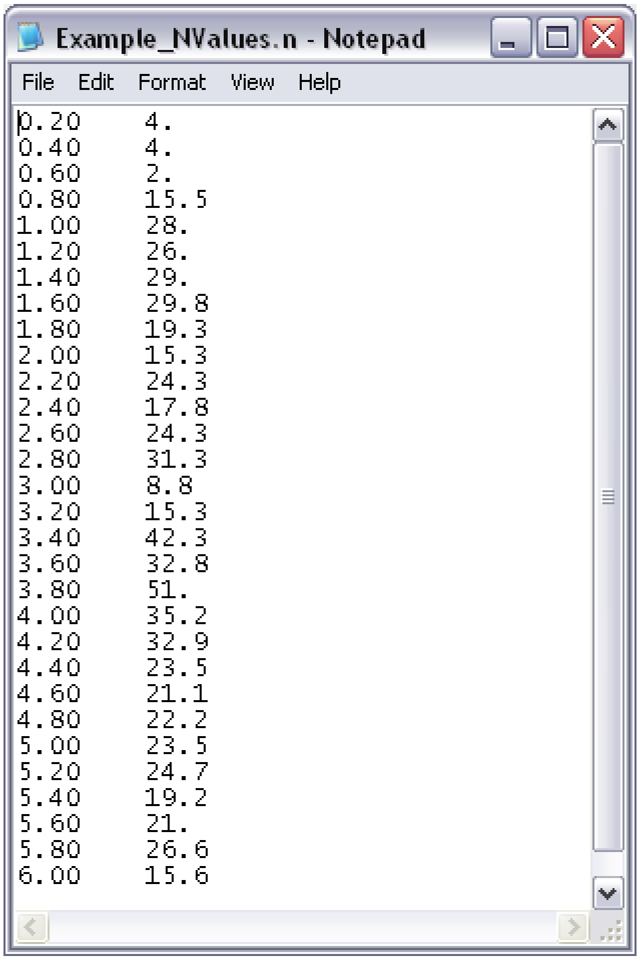
To overlay calculated P-wave velocities (V_p) and N-values on a V_s curve, select *Show P-velocity* and *Show converted N-value*. A green curve is displayed for V_p and the horizontal axis will include a second scale corresponding to the V_p values. A red curve is displayed for N-values and the horizontal axis will include a third scale corresponding to the N-values.



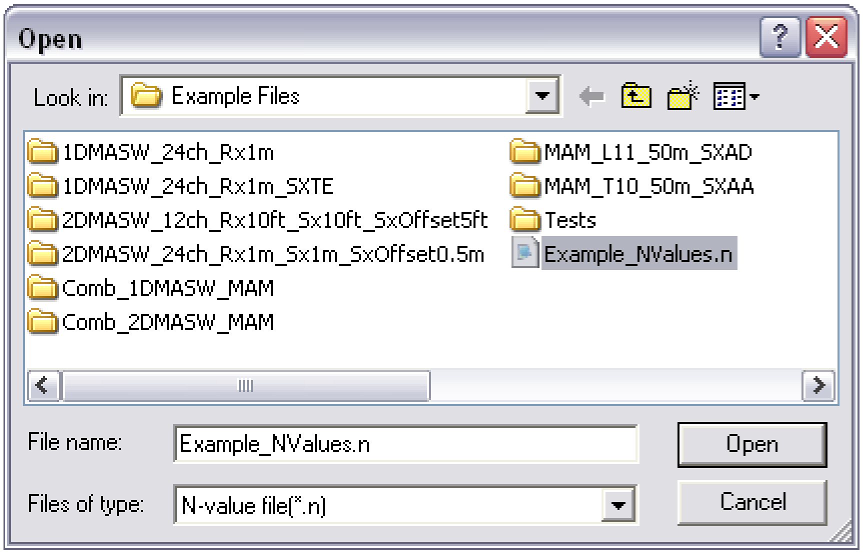
The V_p values and N-values are calculated using the equations defined in the *Velocity model* menu, *Advanced options*, *V_p and V_s relationship* and *N and V_s relationship*. Refer to Section 6.5.4 for more information.

6.3.6 View Menu: Open N-Value File and Show N-Value File

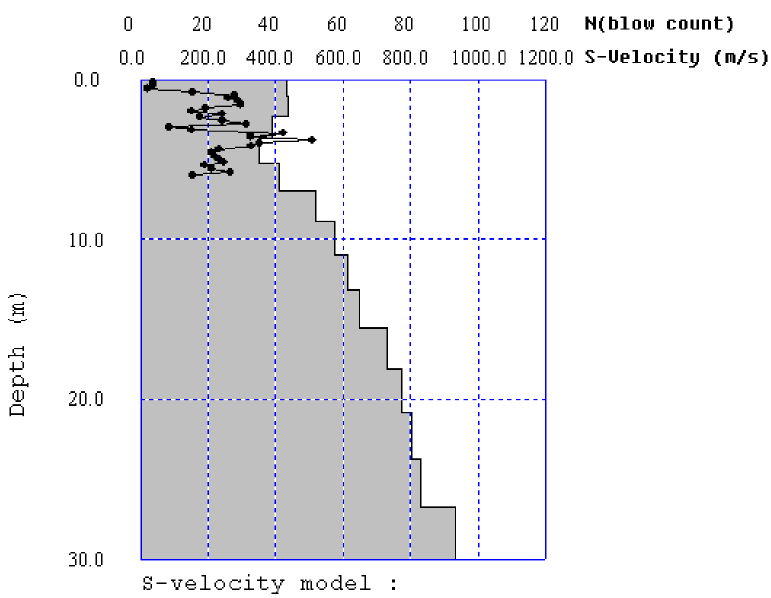
Measured N-values can be used to define the initial V_s model used for inversion. The values are formatted in a space- or tab-delimited text file with a depth and corresponding N-value in each row. The file can have the extension *.n* or *.txt*.



Once the file is prepared, select *Open N-value file*, highlight the file, and click *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.



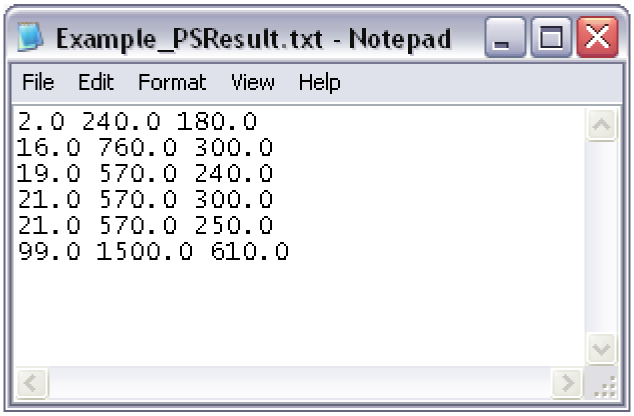
The N-values are stored in memory until the initial V_s model is created, at which time the initial model will be displayed with the N-values. When an N-value file has been opened, by default the initial model will be based on the N-values. Refer to Section 6.6.1 for more information.



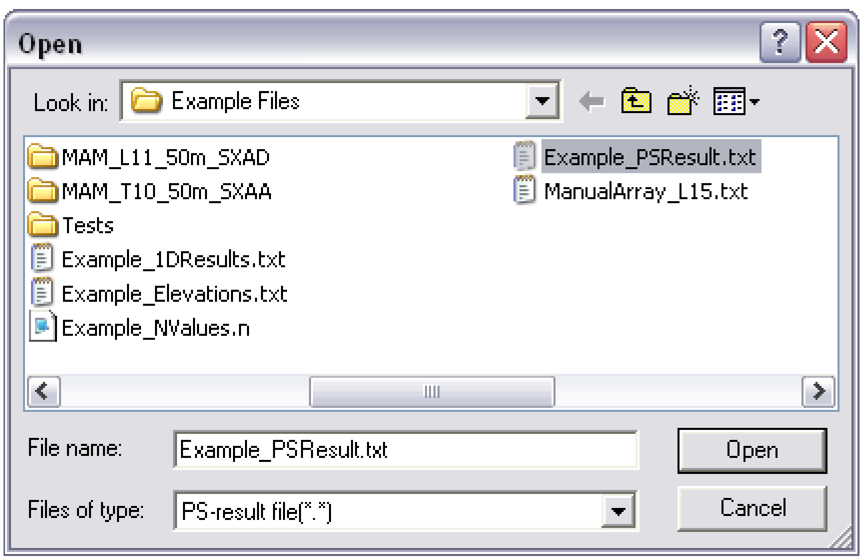
To toggle between viewing the V_s curve with and without N-values, select *Show N-value*.

6.3.7 View Menu: Open PS Result File and Show PS Result

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.



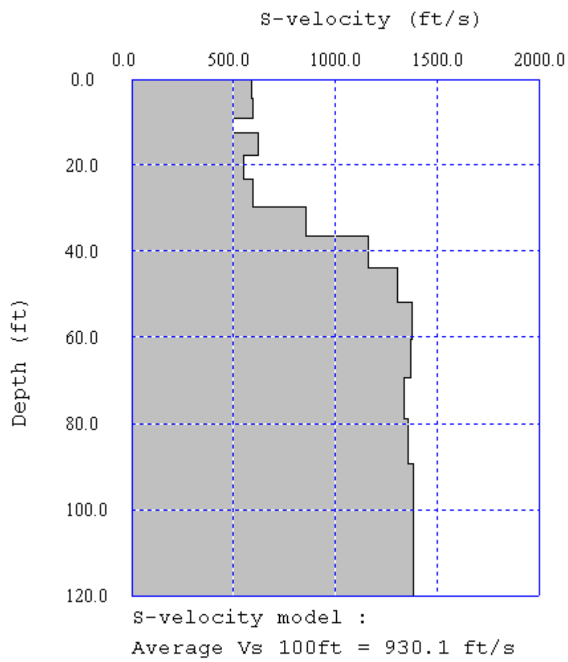
Once the file is prepared, select *Open PS result file*, highlight the file, and click *Open*.



To toggle between viewing the model with and without the measured V_p and V_s data, select *Show PS result*.

6.3.8 View Menu: 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.



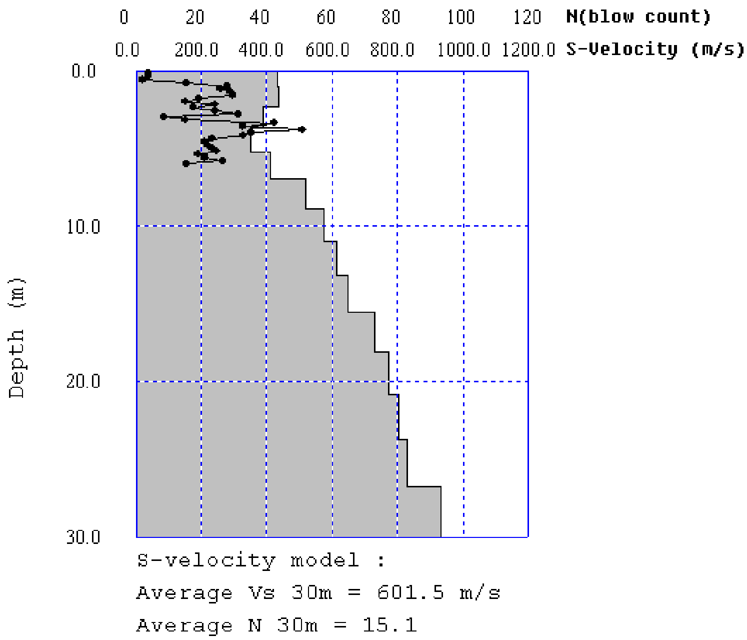
The result is saved to a text file with the name *AVS.txt* in the dataset directory. The first row reports the applicable *Units* and maximum *Depth* used for the calculation. Following are six columns of data, one row for each layer. The columns from left to right are: layer number (*No.)*, shear-wave 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

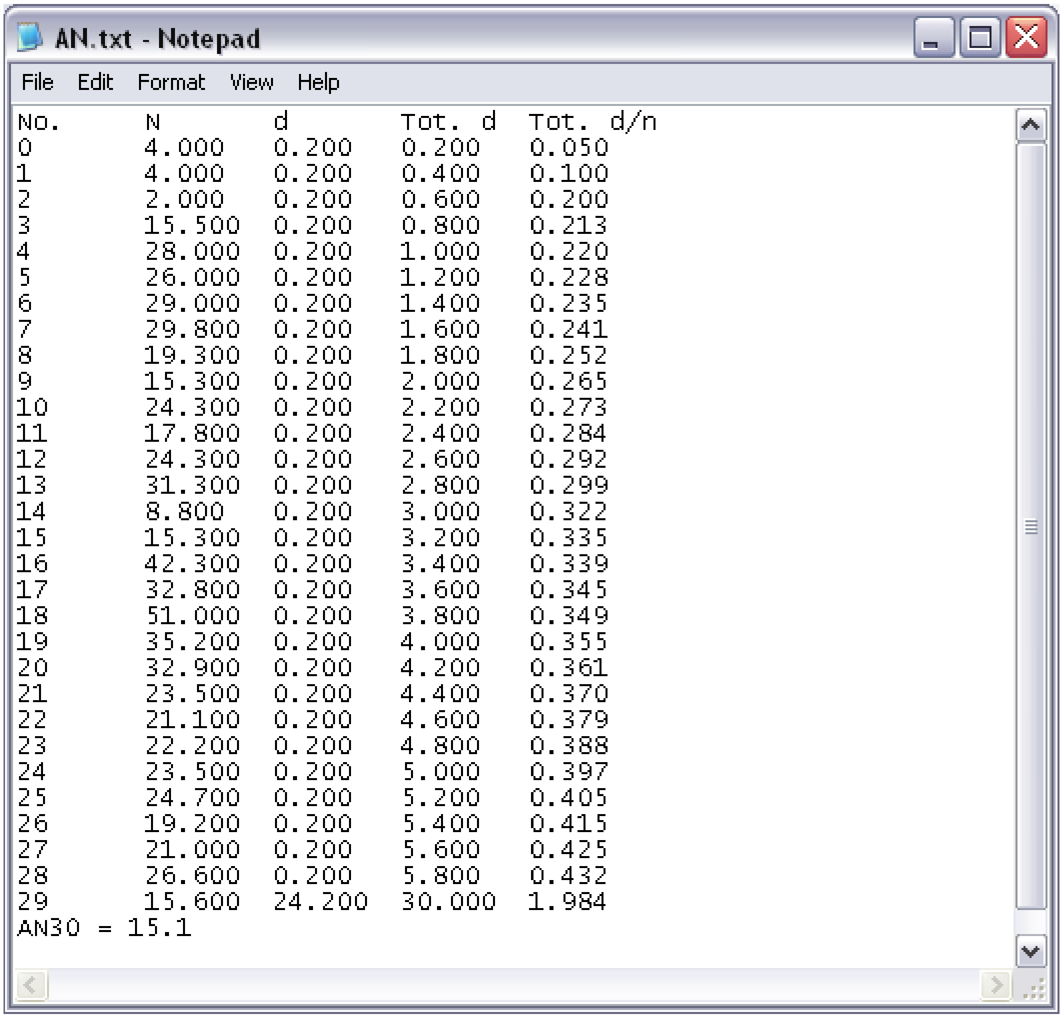
File Edit Format View Help

```
Unit=ft Depth=100.000001
No.     Vs      sl      d       Tot. Vs Tot. d
0       0.585   1.709   4.560   7.791   4.560
1       0.599   1.671   3.132   13.024  7.692
2       0.495   2.021   4.670   22.463  12.362
3       0.619   1.616   5.220   30.901  17.582
4       0.548   1.824   5.769   41.423  23.351
5       0.594   1.685   6.319   52.068  29.670
6       0.852   1.174   6.868   60.132  36.538
7       1.156   0.865   7.418   66.550  43.956
8       1.299   0.770   7.967   72.681  51.923
9       1.370   0.730   8.516   78.897  60.439
10      1.368   0.731   9.066   85.523  69.505
11      1.338   0.748   9.615   92.711  79.120
12      1.356   0.738   10.165  100.210 89.285
13      1.379   0.725   10.715  107.978 100.000
AVS100 = 930.1 ft/s
```

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.



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

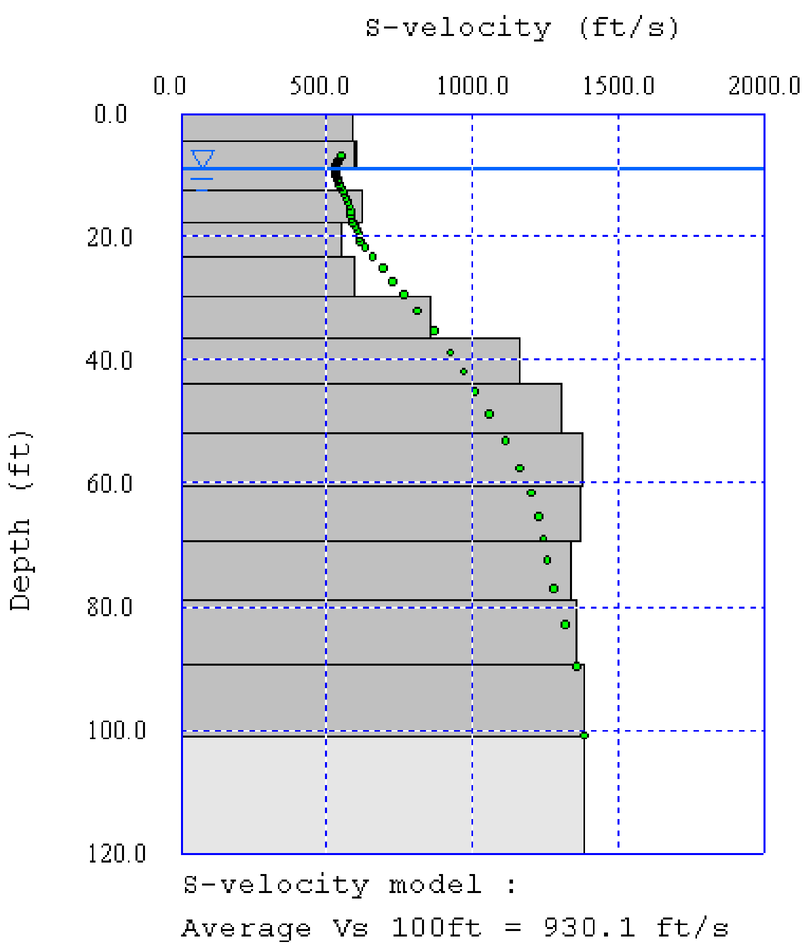
AN30 = 15.1

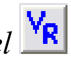
If the average V_s and N are to be calculated, it is recommend that there be reliable information to 30 m or 100 ft. Although the V_s model may extend to 30 m or 100 ft depth, the recorded surface waves may not have actually sampled to that depth. Refer to Section 6.3.9 on how to estimate the depth of penetration.

6.3.9 View Menu: Show Water Table Depth, Show Layer Boundary, Show Apparent Velocity Model (VR), Show Effective Depth (VR Max), and Show V_s and 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 6.5.3.

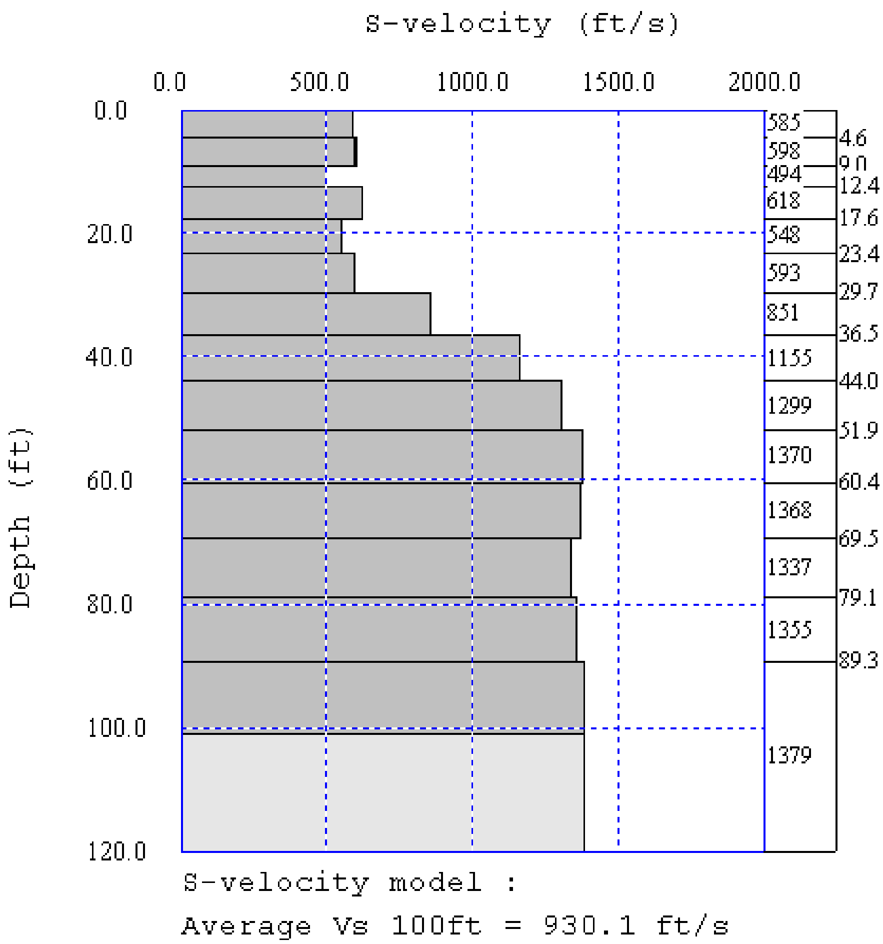
Selecting *Show layer boundary* or clicking the *Correct velocity model* button will outline the layers in the profile with horizontal black lines. Using the mouse, the vertical edge of any of the layers can be dragged to a new position to modify the V_s curve. In the dispersion curve view, the dispersion curve calculated for the altered model can be viewed by clicking on the *Comparison* button. The V_s curve can be manually fitted to the observed data in this manner.



Selecting *Show apparent velocity model (VR)* or clicking the *Apparent velocity model*  button will plot in green 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.

Show effective depth (VR max) shades the profile light gray from the deepest green point downward. This setting is on by default to call attention to the limits of the data.

Show Vs and depth overlays the layer information used to calculate the IBC V_s100/UBC V_s30 value.

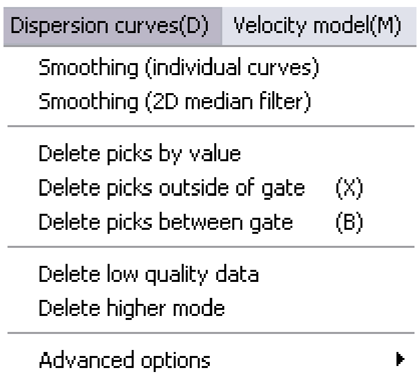


6.3.10 View Menu: Advanced Options: Show Regression Line

Show regression line is not active at this time.

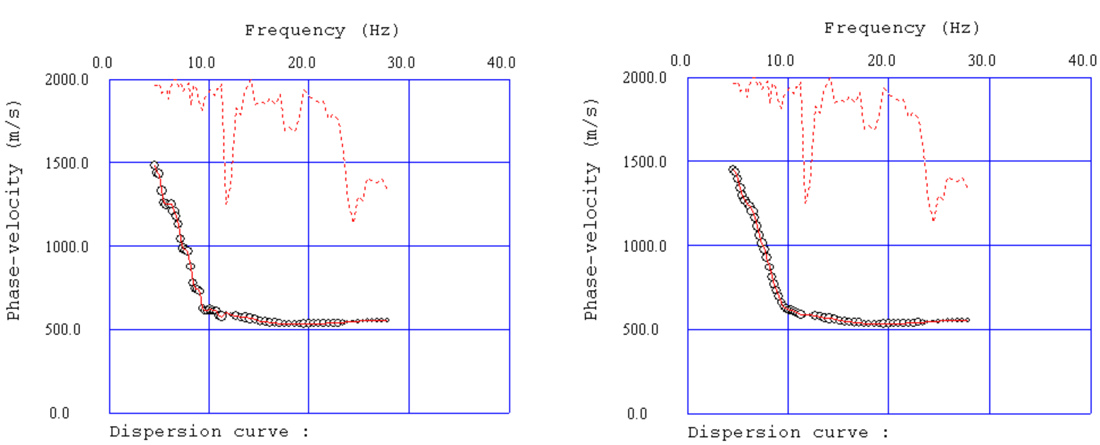
6.4 Dispersion Curves Menu

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, and 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.

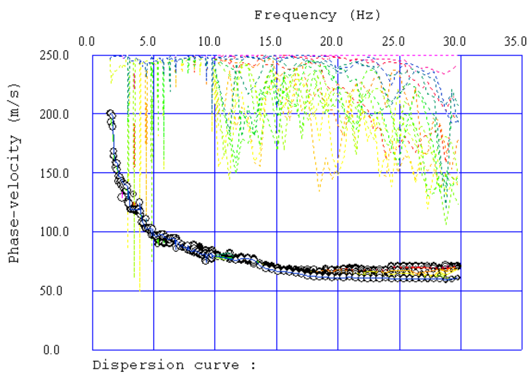


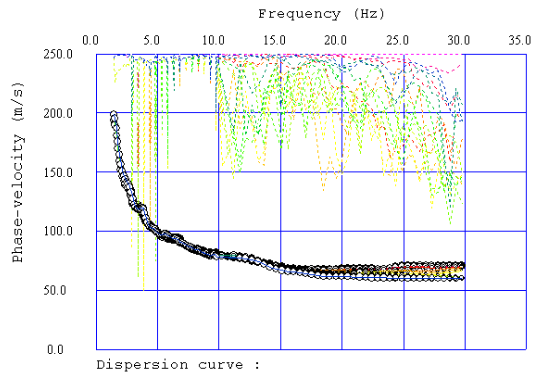
6.4.1 Dispersion Curves Menu: Smoothing (Individual Curves)

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).

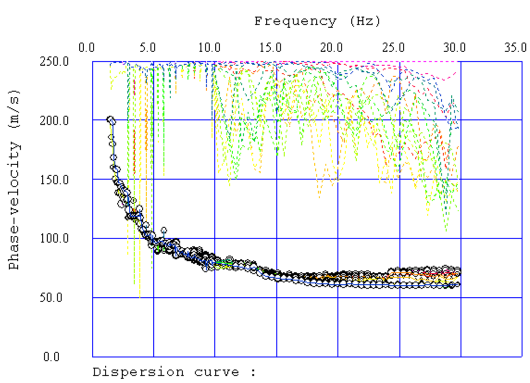


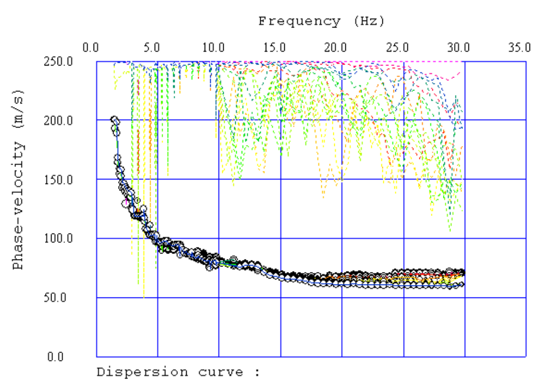


Because *Smoothing (individual curves)* is applied in the direction of frequency, you may find for some 2D datasets, that a smoothing function applied from curve to curve yields preferable results.

6.4.2 Dispersion Curves Menu: Smoothing (2D Median Filter)

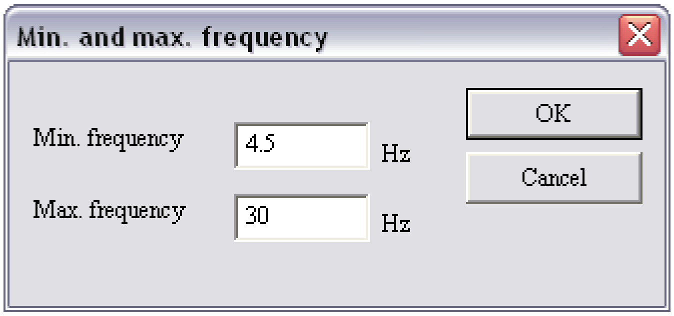
To smooth between dispersion curves in a 2D dataset, select *Smoothing (2D median filter)*. The process recalculates the set of dispersion curves using the median of five adjacent data points from curve to curve. The original dispersion curves (shown on left) are converted to smoother curves with fewer outlying data points and the relative difference between individual curves preserved (shown on right).





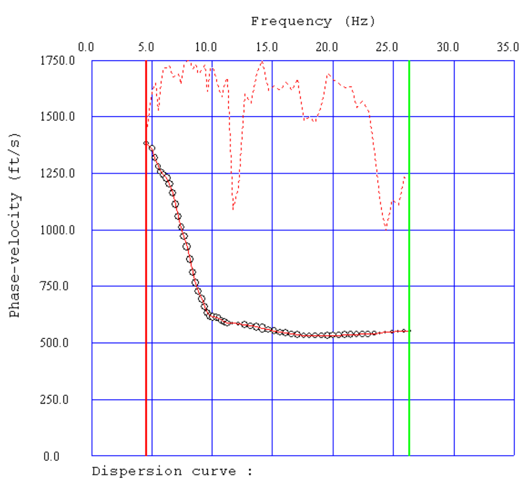
6.4.3 Dispersion Curves Menu: Delete Picks by Value, Delete Picks Outside of Gate, and Delete Picks Between Gate

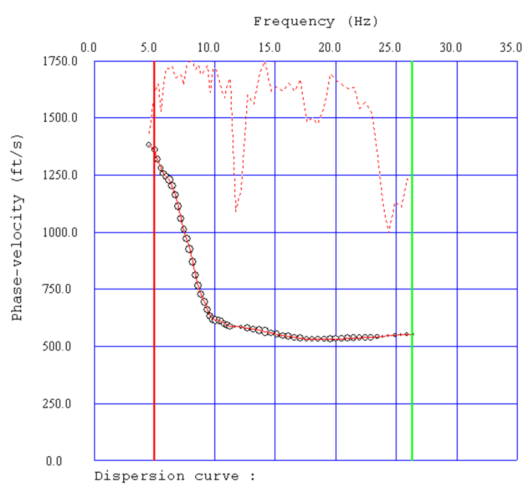
To set the minimum and maximum gate frequencies by entering specific values, select *Delete picks by value*.



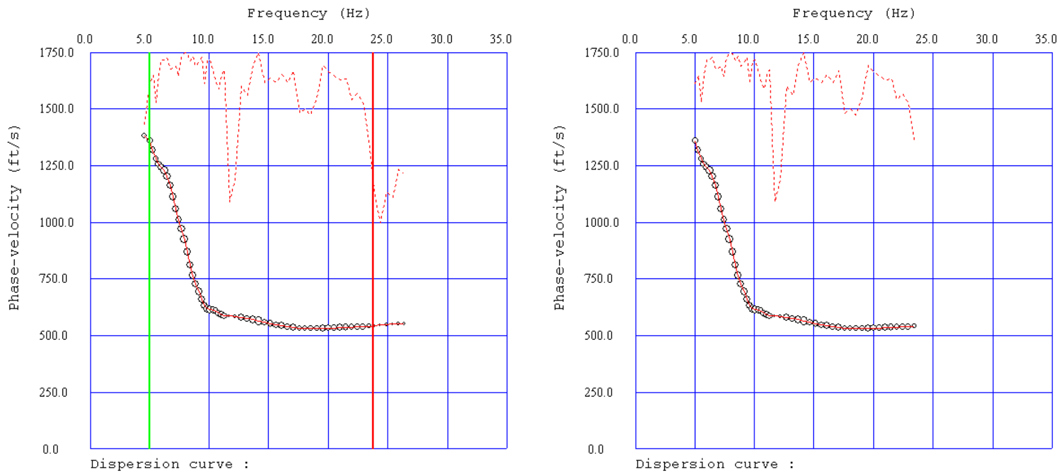
As an alternative, the frequency range can be set visually. Select *Delete picks outside of gate* and two gates will appear on the dispersion curve plot (shown on left). If needed, press the *Esc* key to exit.

The color red indicates which gate is active and the color green indicates which gate is inactive. Use the *right arrow* key to move the red gate to the new minimum frequency (shown on right).





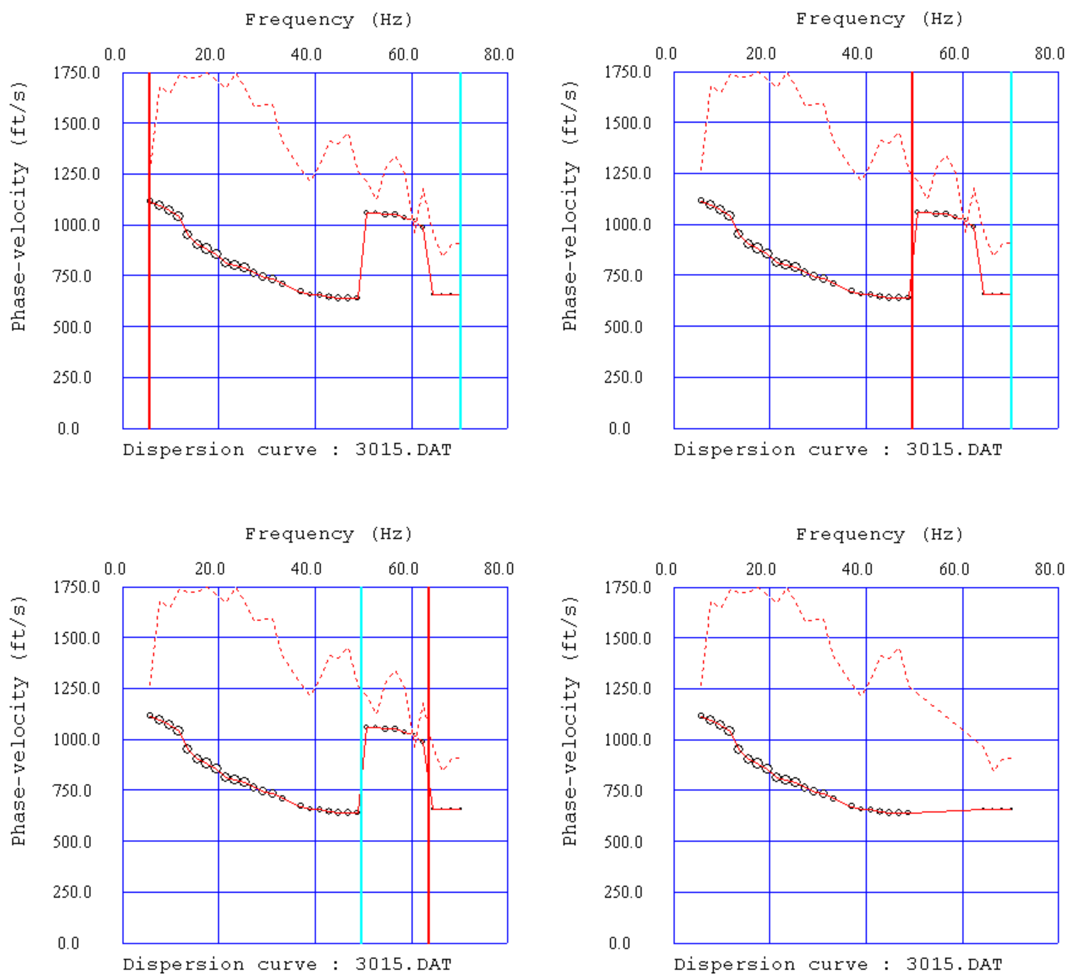
After the first gate is positioned, press the *Enter* key and the next gate will become active. Use the *left arrow* key to move the gate to the new maximum frequency (shown on left). Press the *Enter* key when done and the trimmed dispersion curve is displayed (shown on right).



In setting the gates, exclude only the points that are poor-quality or spurious. Commonly, on the low-frequency end, the phase velocity will start 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.

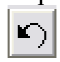
To determine where to set the new maximum frequency on the high-frequency end, the quality line can be used to assess where the quality starts to decrease (usually due to weak amplitudes at higher frequencies). In addition to quality, if the phase velocity starts to increase that is likely related to higher mode energy and those points should be deleted.

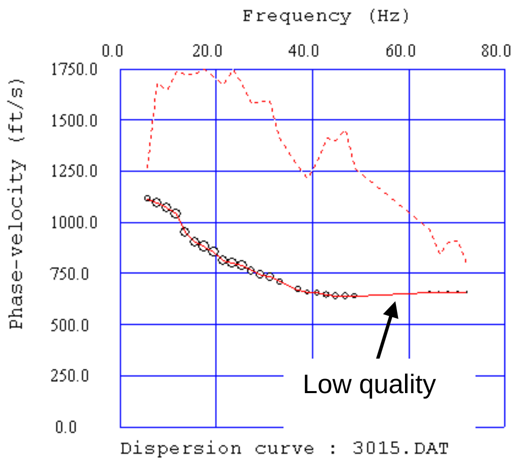
To remove points within a gate, select *Delete picks between gate*. The gates are positioned as described for *Delete picks outside of gate*, except that the inactive gate is indicated by the color teal blue. *Delete picks between gate* is useful for deleting higher modes. The editing sequence progresses below from left to right.

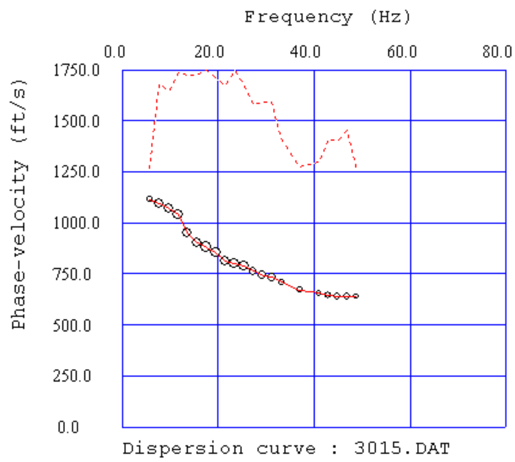


6.4.4 Dispersion Curves Menu: Delete Low Quality Data and Delete Higher Mode

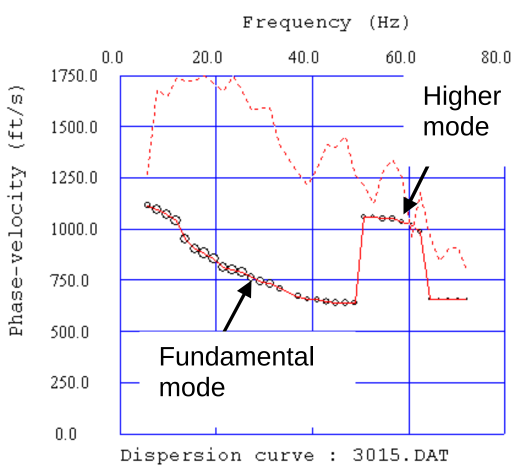
To automatically delete low quality picks, select *Delete low quality data*. Low quality tolerance is set in the *Advanced options* menu, *Setup low quality limit*. Refer to Section 6.4.5 on how to adjust the quality tolerance.

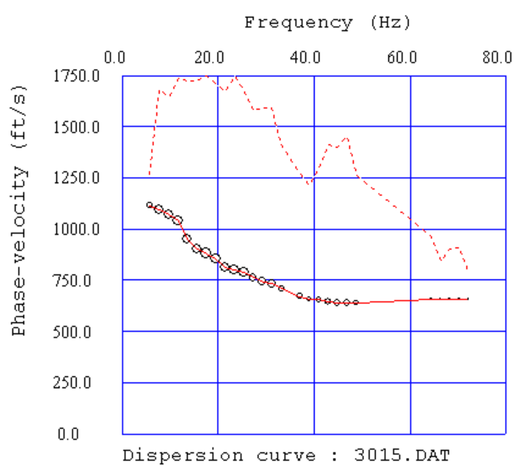
Upon selection, all the points that fall below the quality limit will be deleted (shown on right). To reverse the changes, click the *Undo*  button.





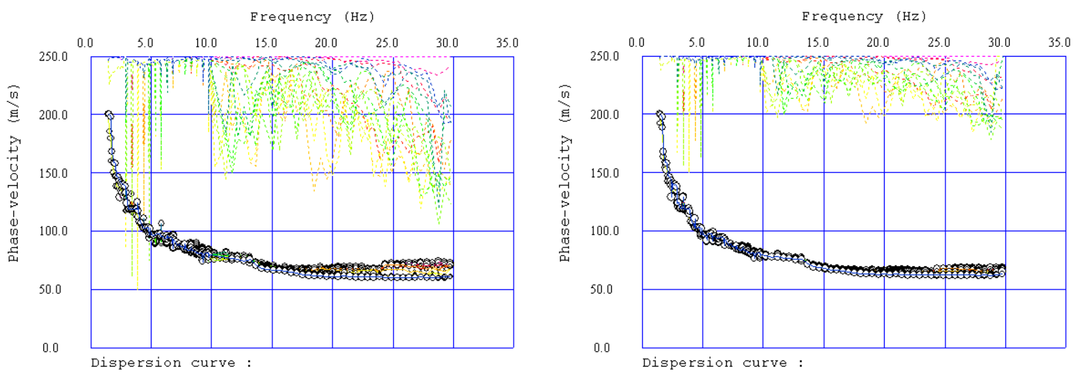
If higher mode picks appear in the dispersion curve (shown on left), select *Delete higher mode* to automatically delete the picks (shown on right). Higher mode tolerance is set in the *Advanced options* menu, *Setup higher mode selection*. Refer to Section 6.4.5 on how to adjust the higher mode tolerance.





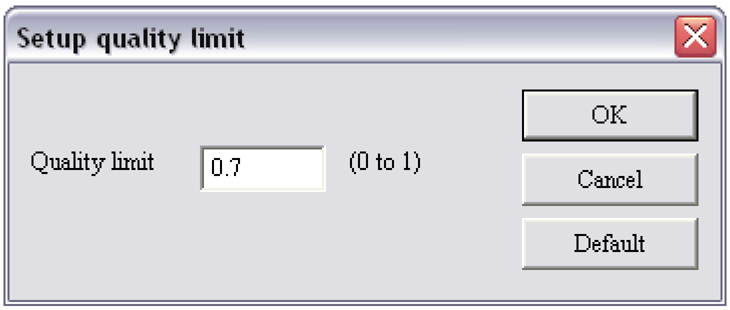
6.4.5 Dispersion Curves Menu: Advanced Options: Smoothing (Multiple Curves), Resampling (Every Other), Setup Low Quality Limit, and Setup Higher Mode Selection

To smooth between dispersion curves in a 2D dataset, select *Smoothing (multiple curves)*. The process is similar to *Smoothing (2D median filter)* (Section 6.4.2) except that the average of five adjacent data points is used instead of the median. The original dispersion curves (shown on left) are converted to smoother curves with fewer outlying data points but the relative difference between the individual curves is minimized (shown on right).

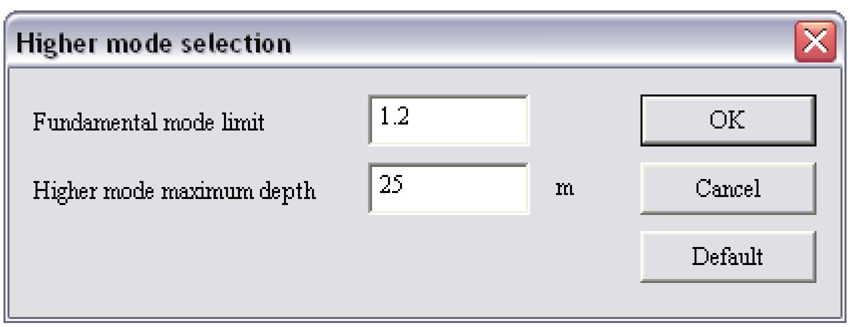


The function *Resampling (every other)* is used to speed up processing by decimating the dataset (removes every other sample).

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.

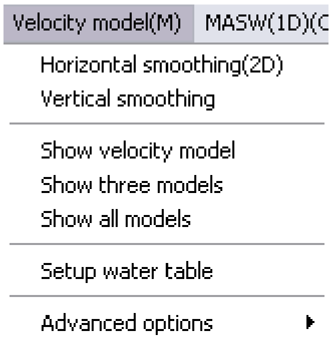


Setup higher mode selection allows the filter limits used when the function *Delete higher mode* is selected to be set. The default *Fundamental mode limit* value is 1.2, meaning that where the value of any data point is 20% more than adjacent values, those points are deleted. This value can be set between 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.



6.5 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.

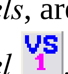


6.5.1 Velocity Model Menu: Horizontal Smoothing (2D) and Vertical Smoothing

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.

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.

6.5.2 Velocity Model Menu: Show Velocity Model , Show Three Models , Show All Models 

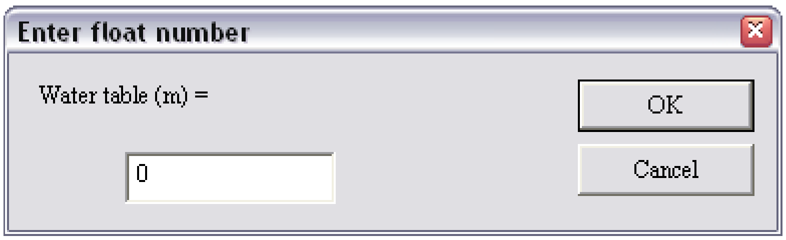
Once a velocity model exists, *Show velocity model*, *Show three models*, and *Show all models*, are used to control the display. These settings correspond to the *Show velocity model* , *Show three models* , and *Show all models*  buttons, respectively.

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 the overall trend that is meant to be discerned, not the individual models.

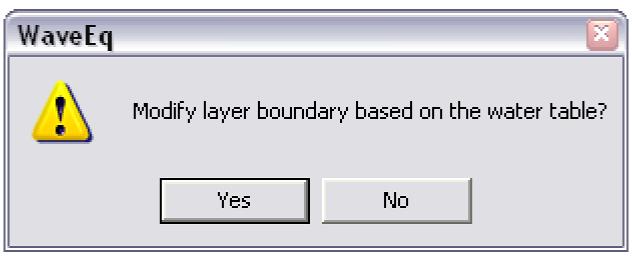
The *Show velocity model* button is useful for toggling from the dispersion curve to velocity model view.

6.5.3 Velocity Model Menu: Setup 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 click *OK*.

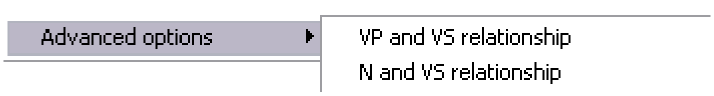


The model layer boundaries will be adjusted to place a boundary at the water table depth. Click *Yes* to confirm the change.



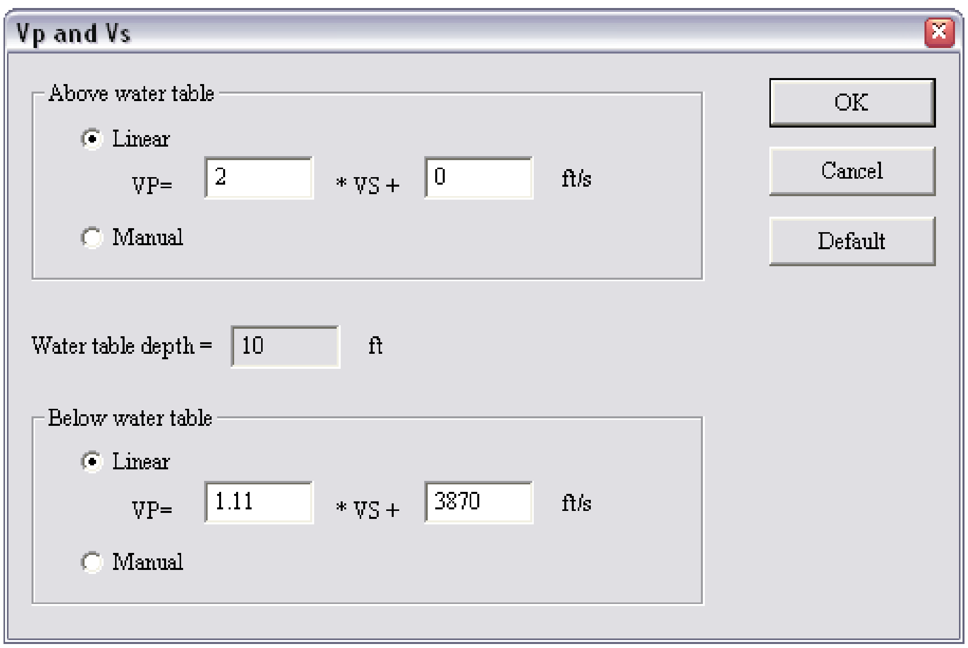
The water table is now set. Select the *View* menu, *Show water table depth* to display the water table as a blue line with the standard water table symbol on the velocity model.

6.5.4 Velocity Model Menu: Advanced Options: V_p and V_s Relationship and N and V_s Relationship



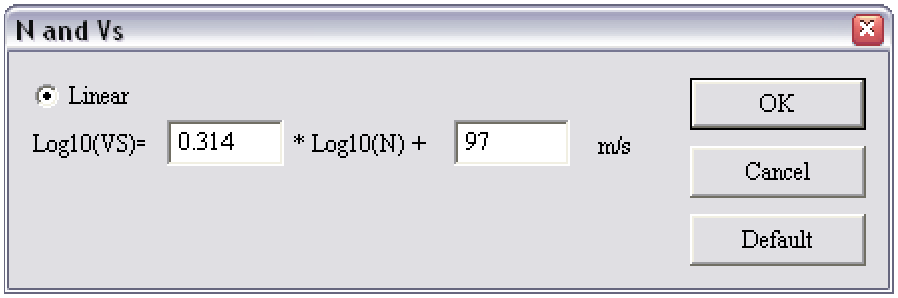
The *V_p and V_s relationship* and *N and V_s relationship* dialog boxes allow the equations used for calculating V_p from V_s and N from V_s to be customized.

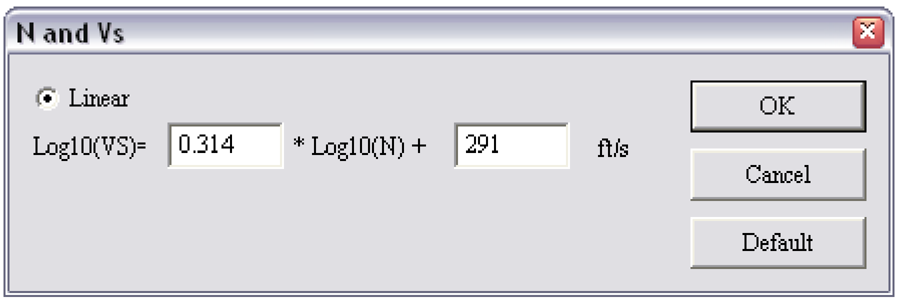
To modify the default equations for calculating V_p from V_s, select *V_p and V_s relationship* (dialog box with metric units selected shown on top, with English units selected shown on bottom). An equation may be defined for above and below the water table, with the water table depth set in the *Velocity model* menu, *Setup water table* dialog box (Section 6.5.3). The default equation for above the water table is simply two times V_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 choosing *Manual* and inputting V_p values through the *View* menu, *Open PS result file*.

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.



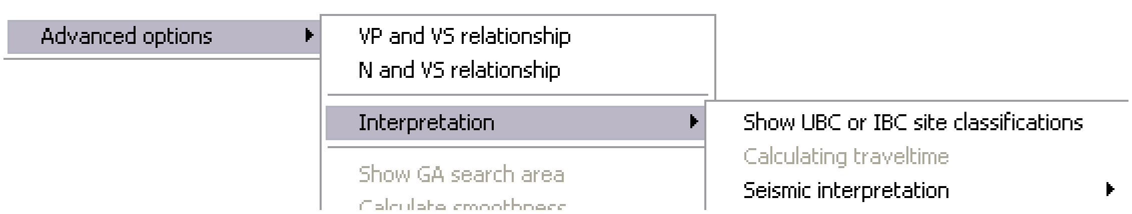


Where applicable, the equation used for calculating density is as follows from Ludwig *et al.* (1970).

$$\rho = 1.2475 + 0.399V_p - 0.026V_p^2$$

To revert back to the default values, click *Default*.

6.5.5 Velocity Model Menu: Advanced Options: Interpretation, Show UBC or IBC Site Classifications and Seismic Interpretation



In addition to calculating the average V_s as described in Section 6.3.8, 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 6).

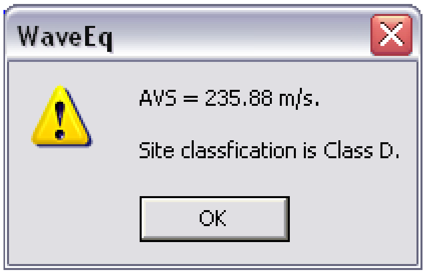
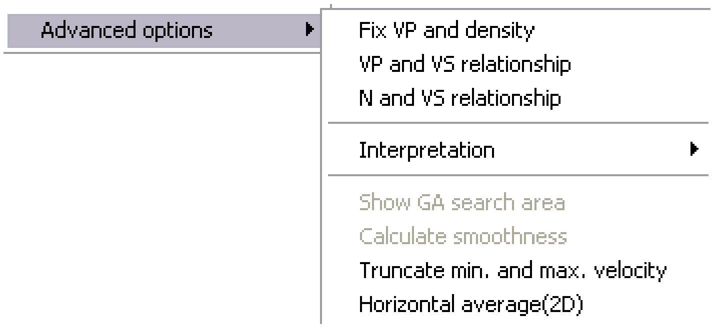


Table 6. UBC/IBC Site Classifications

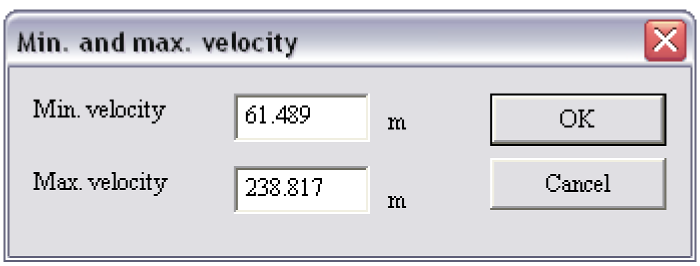
Site class	Soil type	UBC V_s30	IBC V_s100
Class A	hard rock	$V_s30 > 1,500$ m/s	$V_s100 > 5,000$ ft/s
Class B	rock	$760 < V_s30 \leq 1500$ m/s	$2,500 < V_s100 \leq 5,000$ ft/s
Class C	very dense soil, soft rock	$360 < V_s30 \leq 760$ m/s	$1,200 < V_s100 \leq 2,500$ ft/s
Class D	stiff soil	$180 < V_s30 \leq 360$ 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

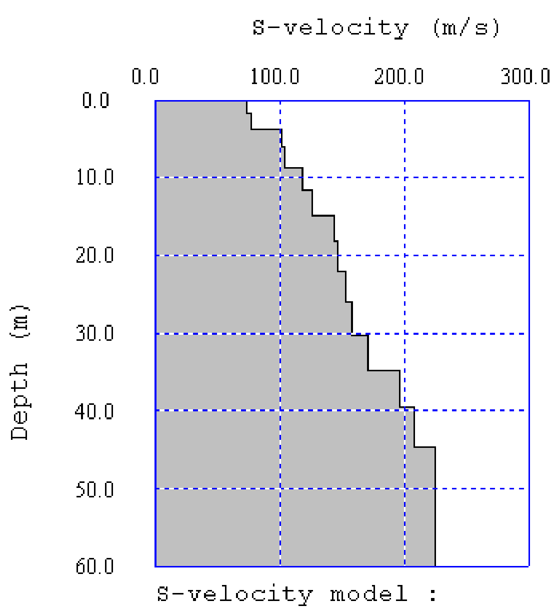
Calculating traveltime and *Seismic interpretation* are not active at this time.

6.5.6 Velocity Model Menu: Advanced Options: Truncate Min and Max Velocity and Horizontal Average (2D)

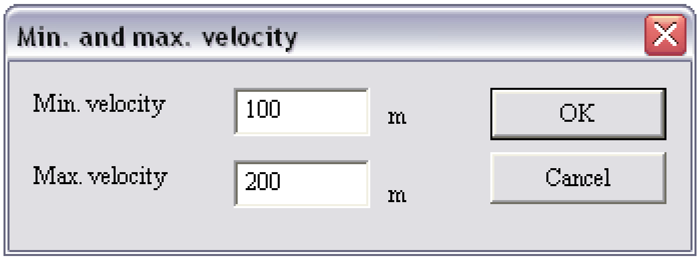


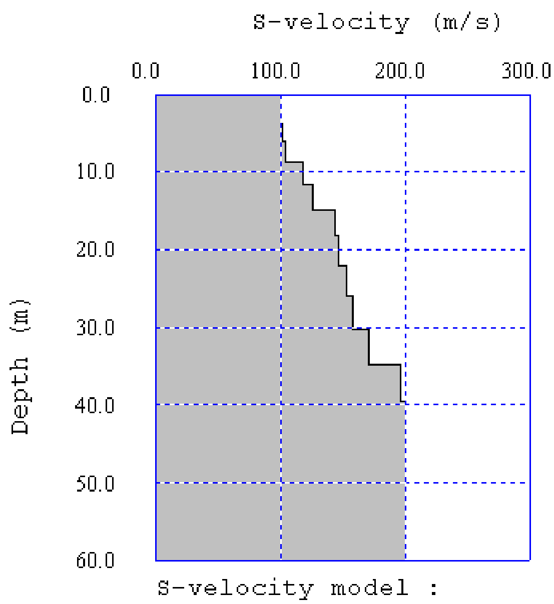
To set a minimum and maximum velocity for a given velocity model, select *Truncate min. and max. velocity*. The *Min. velocity* and *Max. velocity* reported are the actual minimum and maximum velocities for the current model. (Although m or ft is shown as the unit label, the values are actually velocities with the unit label of m/s or ft/s, respectively.)





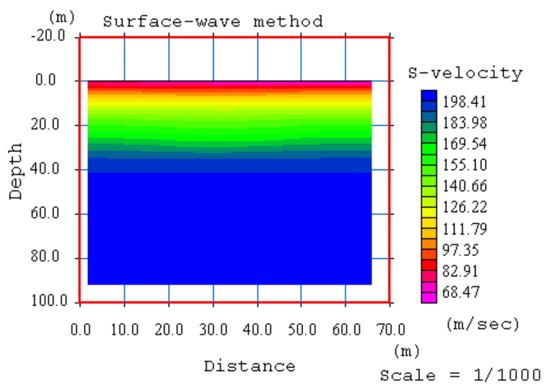
To set new boundaries, enter new values as desired and click *OK*. Note that the value entered for *Max. velocity* will be retained for the WaveEq session unless changed again or a new WaveEq instance is opened.

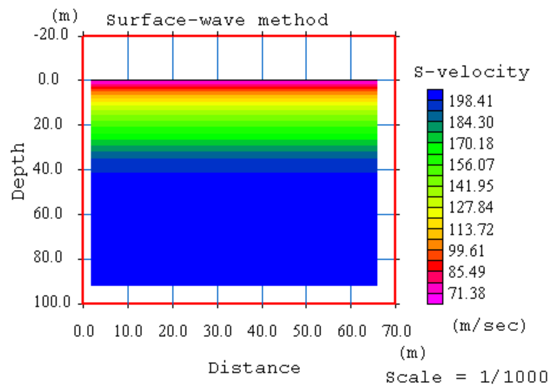




Typically, *Truncate min. and max. velocity* is used when building an initial model from scratch.

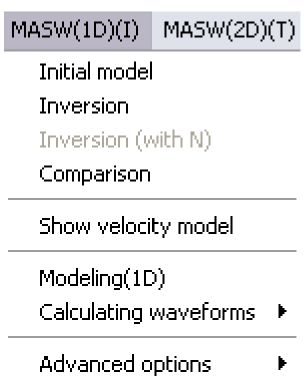
To make a cross-sectional velocity model uniform in the direction of distance, select *Horizontal average (2D)*. The process recalculates the velocity model using the average value at each depth. The original model (shown on left) with horizontal variation is converted to a simplified, horizontally uniform model (shown on right).





6.6 MASW (1D) Menu

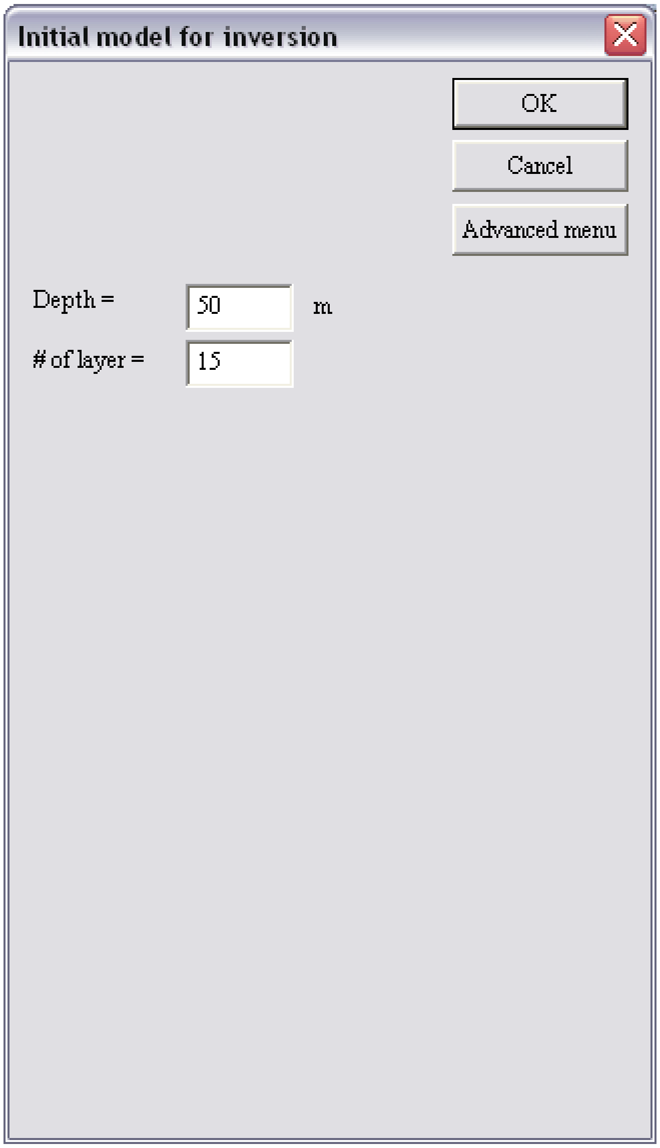
The *MASW (1D)* menu primarily includes functions for calculating an initial model for a 1D dataset and running the inversion to find the best fit of the initial model with the observed data. Other modeling functions are also included. Although the term MASW refers to active source surveys, the same functions apply for analysis of MAM datasets.



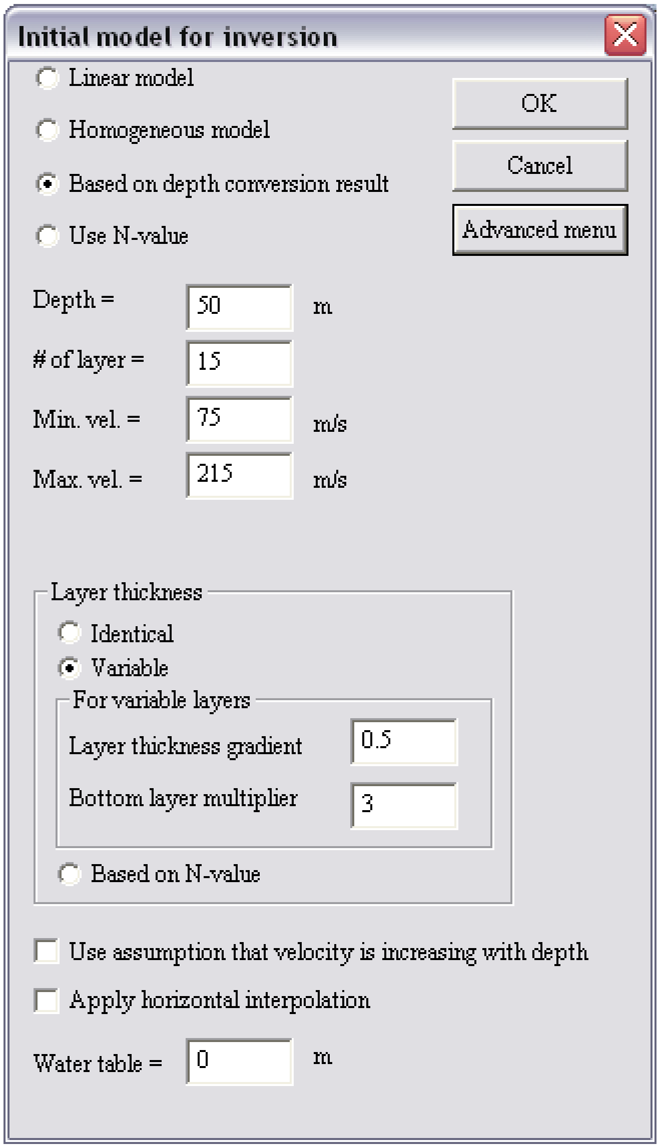
The *Advanced options* are not available at this time.

6.6.1 MASW (1D) Menu: Initial Model

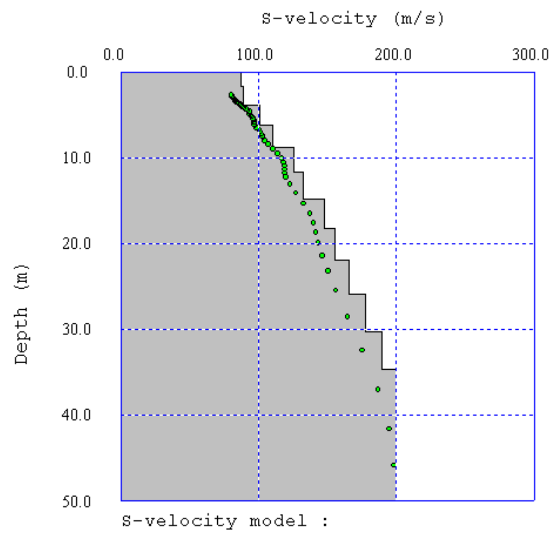
The initial V_s model is the starting point for the inversion. To generate an initial model for a single dispersion curve, select *Initial model*. The *Initial model for inversion* dialog box shows only the *Depth* and *Number of layers* by default. In most cases, only the maximum *Depth* of the model needs to be entered and the default value of 15 for the *Number of layers* is suitable.

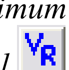


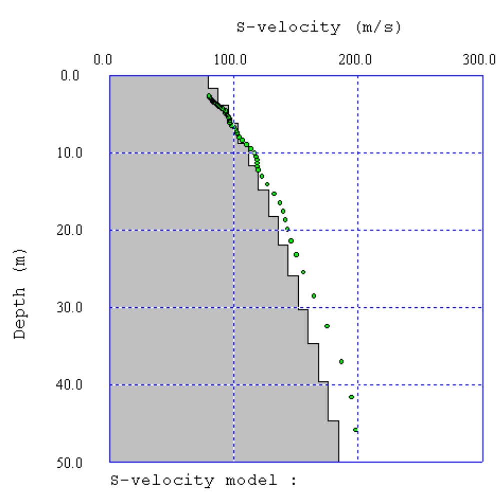
Clicking on *Advanced menu* reveals the rest of the parameters with default values. Typically, none of these settings need to be changed.

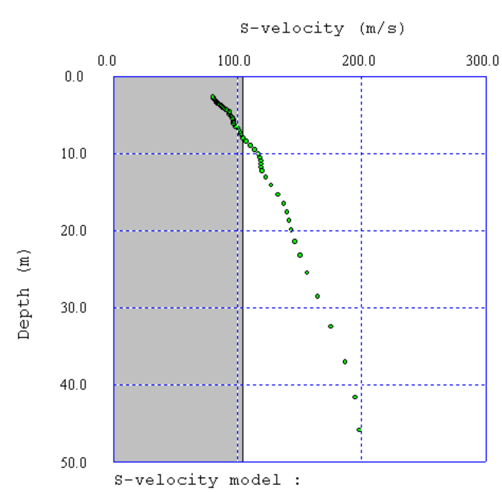


Initial models are calculated *Based on depth conversion result* by default. This method uses 1.1 times the phase velocity for an estimate of V_s and the one-third-wavelength approximation for an estimate of depth. The *Minimum* (phase) *velocity* and *Maximum* (phase) *velocity* are automatically assigned corresponding directly to the low and high values observed on the dispersion curve. The *Maximum velocity* is automatically assigned to the deepest layer.



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) 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) has no velocity variation with depth; the *Minimum* and *Maximum velocity* have the same value. The *Show apparent velocity model*  button overlay provides a visual comparison of the *Based on depth conversion result* model with the *Linear model* and the *Homogeneous model*.





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, *Open N-value* file. If it is not open, you will be notified. Click *OK*, open the N-value file, and then come back to *Initial model*.

Layer thickness applies to all models. Selecting *Identical* sets all layers equal in thickness. By default, the layer thickness is set to *Variable*, and thus, layers increase 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, *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, is it 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.

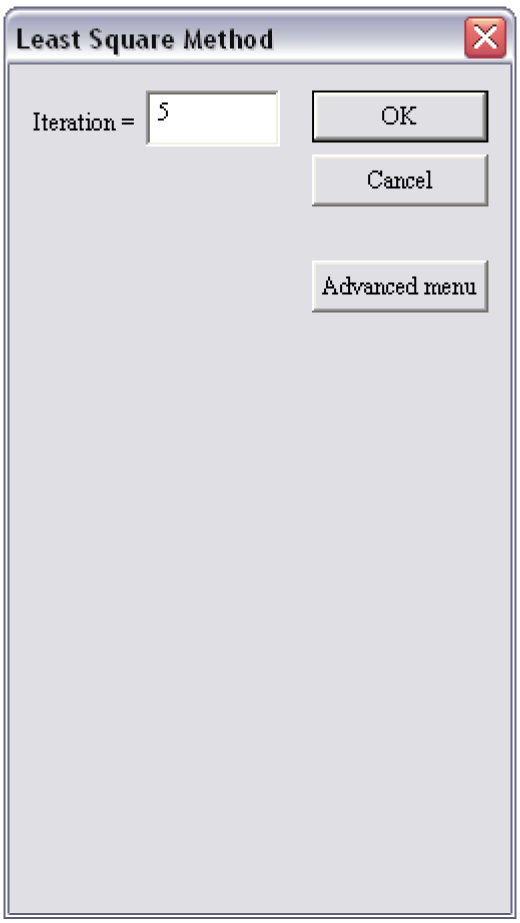
The *Initial model for inversion* dialog box settings revert back to the default values each time the dialog box is opened.

6.6.2 MASW (1D) Menu: Inversion and Inversion with N

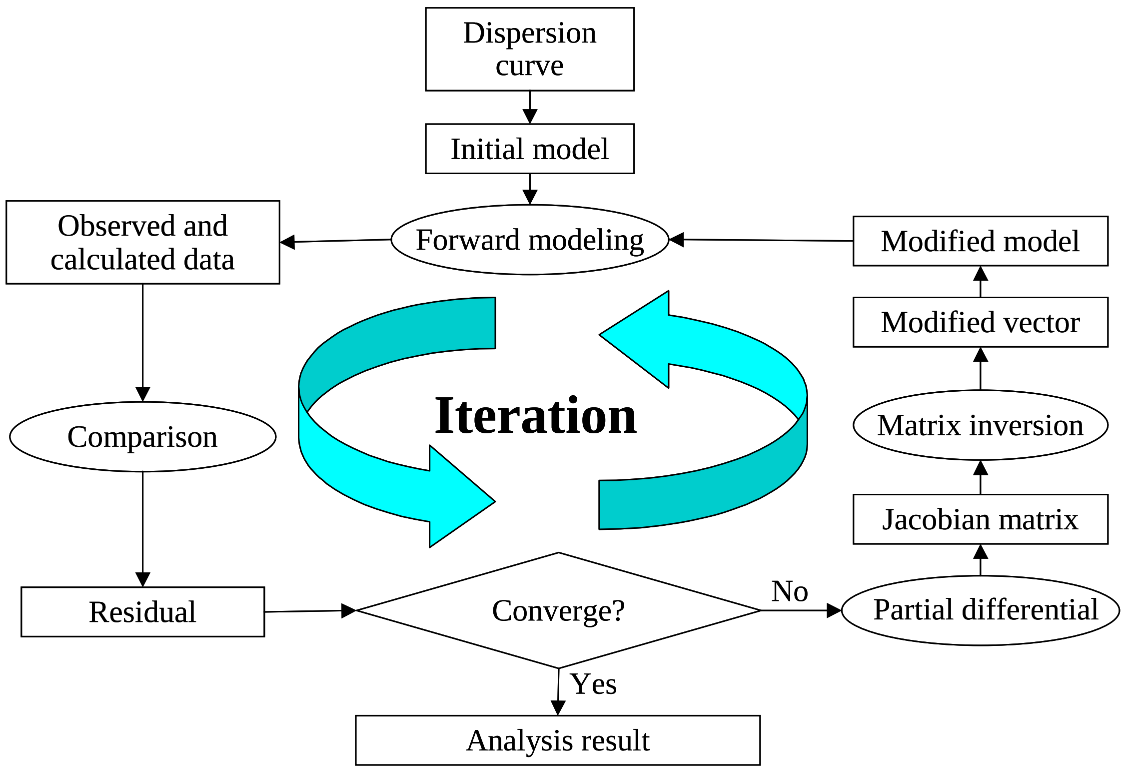
6.6.2.1 MASW (1D) Menu: Inversion

To calculate the V_s curve that best matches the observed data, select *Inversion*. The mathematical process is based on the Least-Squares Method and simply stated, iteratively modifies the initial model to minimize the difference from the observed data. After running through a number of iterations, the modified initial model is output as the final model. Refer to Hayashi (2003) for a complete explanation.

Upon selecting *Inversion*, the *Least Squares Method* dialog box shows the *Iteration* parameter with a default value of 5.

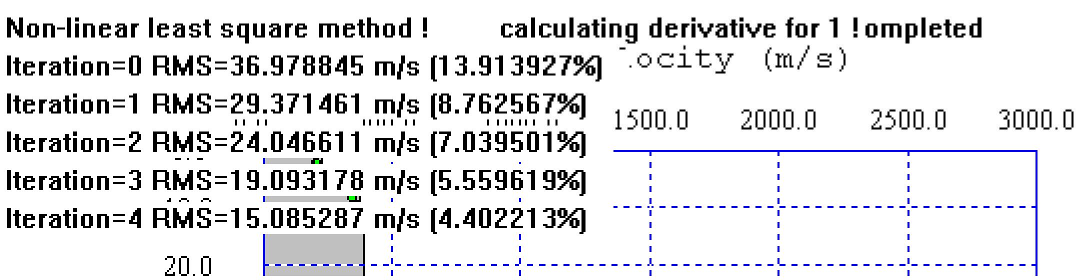


Iteration is the number of times the initial model will be compared and modified to converge on the best match with the observed data. In between iterations, the improved model is used as the new starting point so the error or mismatch should decrease. The iteration concept is conveyed by the flowchart below.

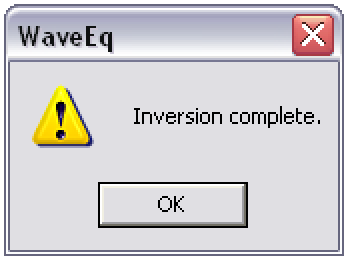


The default *Iteration* value of 10 is suitable for most cases. Increasing the *Iteration* value may occasionally be necessary; this will allow the process additional attempts to minimize the mismatch between the initial model and the observed data.

Upon clicking *OK*, the inversion process begins and the error in velocity (m/s or ft/s) and percent (%) is displayed. The error should decrease after each iteration and the final error should be less than about 5% but will depend on the dataset.



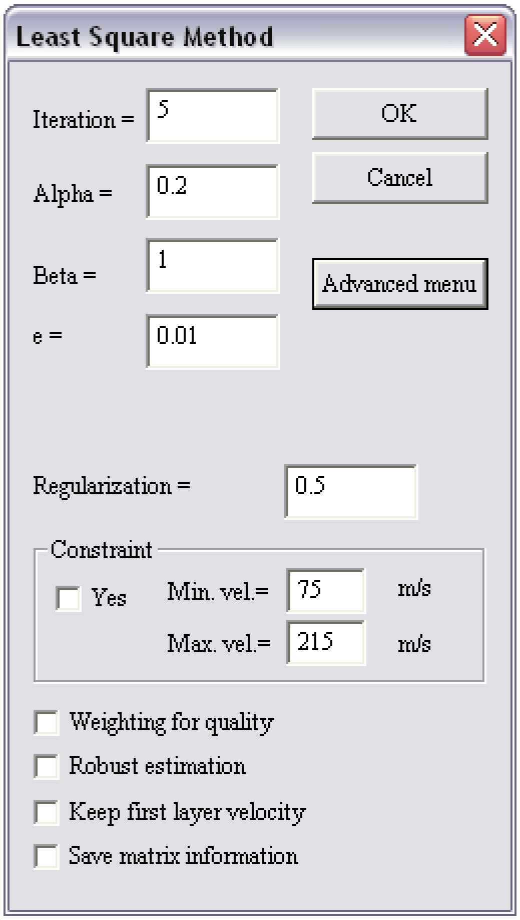
Once the inversion is complete, click *OK*.



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 corrected if necessary before running the process again.

Clicking 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 of 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 error. *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 back to the default values each time WaveEq is opened.

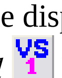
6.6.2.2 MASW (1D) Menu: Inversion with N

If N-values are used to construct the initial model, select *Inversion with N* instead of *Inversion*. The *Least Square Method* dialog box settings are the same as those explained in Section 6.6.2.1, except that the default value for *E* equals 0.1 and for *Regularization* equals 0.5.

6.6.3 MASW (1D) Menu: Comparison or Calculate Theoretical Dispersion Curves 

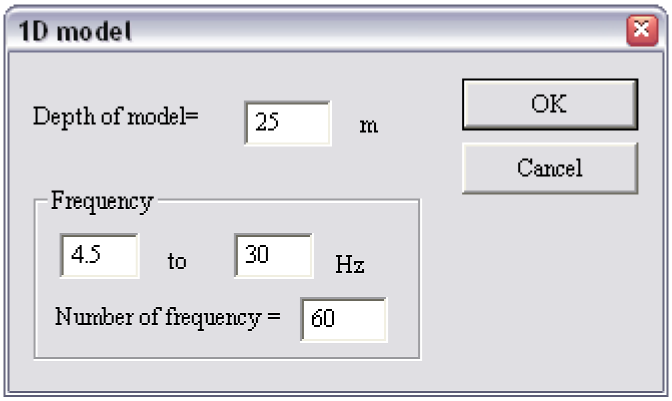
To calculate and overlay a theoretical dispersion curve over an observed dispersion curve, select *Comparison* or click the *Calculate theoretical dispersion curves*  button. The calculated curve is shown as a black line. To remove the calculated dispersion curve from the display, unclick the *Calculate theoretical dispersion curves* button.

6.6.4 MASW (1D) Menu: Show Velocity Model 

To toggle to the velocity model display from the dispersion curve display, select *Show velocity model* or click the *Show velocity model*  button.

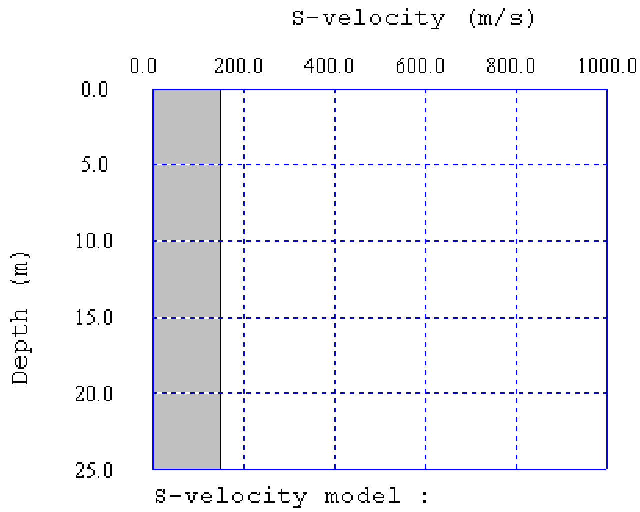
6.6.5 MASW (1D) Menu: Modeling (1D) or Creating a New Velocity Model for Modeling

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 click the *Creating a new velocity model for modeling* button.

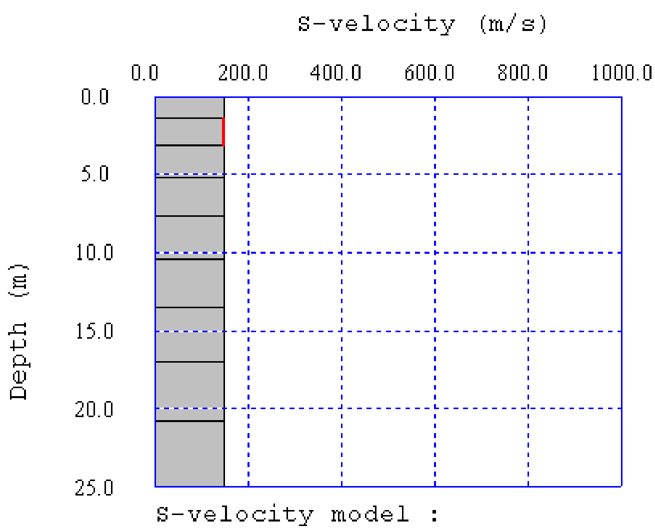


Depth of model is used to indicate the maximum depth of the model. The default *Frequency* range is suitable to simulate depth of penetration from an active source. If the *Depth of model* is greater than 30 m or 100 ft, correspondingly, the lower end frequency should be set to 2 Hz to simulate a greater sampling depth.

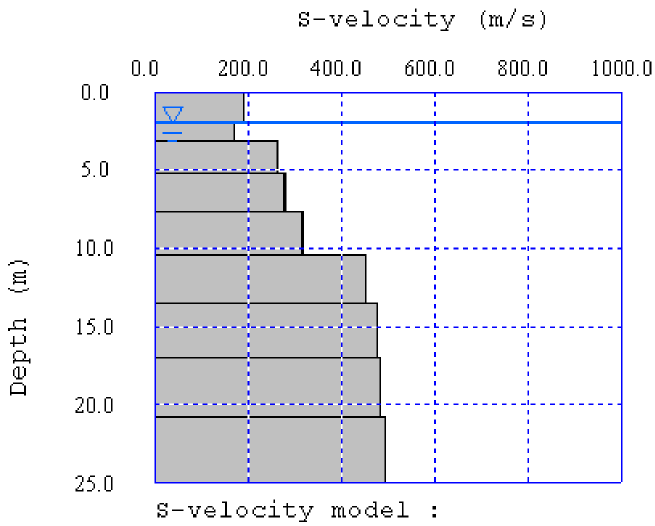
The frequency range is divided by the *Number of frequency* and sets the resolution of the dispersion curve. The *Number of frequency* default value of 60 is suitable for the default frequency range. If the frequency range is widened significantly, the *Number of frequency* should also be scaled up accordingly. Upon clicking *OK*, the following homogeneous model appears; the associated dispersion curve does not yet exist.



To modify the velocity model, click 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.



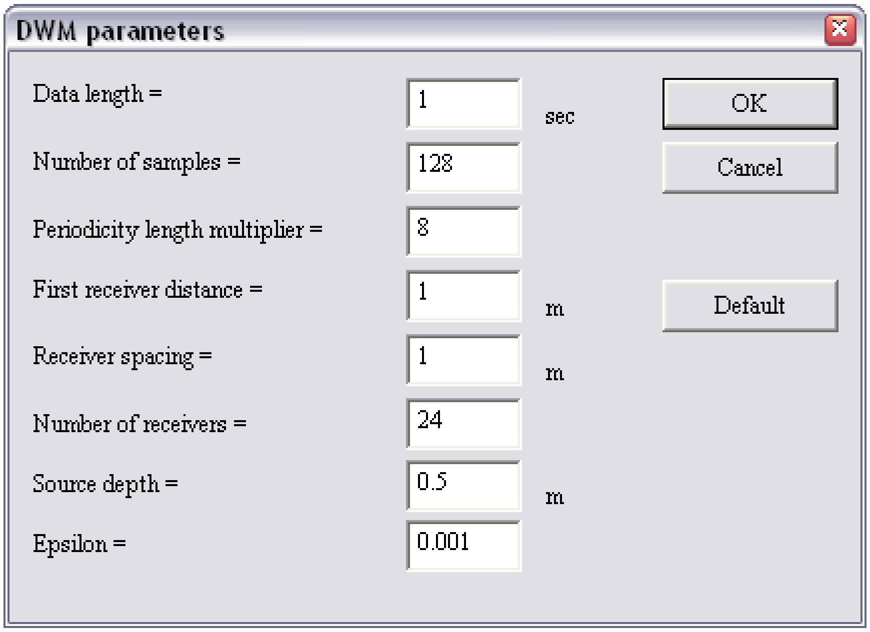
Position the rest of the layers and set the water table if desired.



Refer to Section 6.6.6 to continue modeling by simulating a survey and generating a dispersion curve.

6.6.6 MASW (1D) Menu: Calculating Waveforms, Discrete Wave-number Method (3D)

Once a synthetic velocity model exists, to calculate the dispersion curve, first a synthetic waveform file must be generated. Only active source waveform files can be simulated. To generate the waveform file, select *Calculating waveforms*, *Discrete wave-number method (3D)*. The *DWM parameters* dialog box settings determine how the waveform record is calculated.

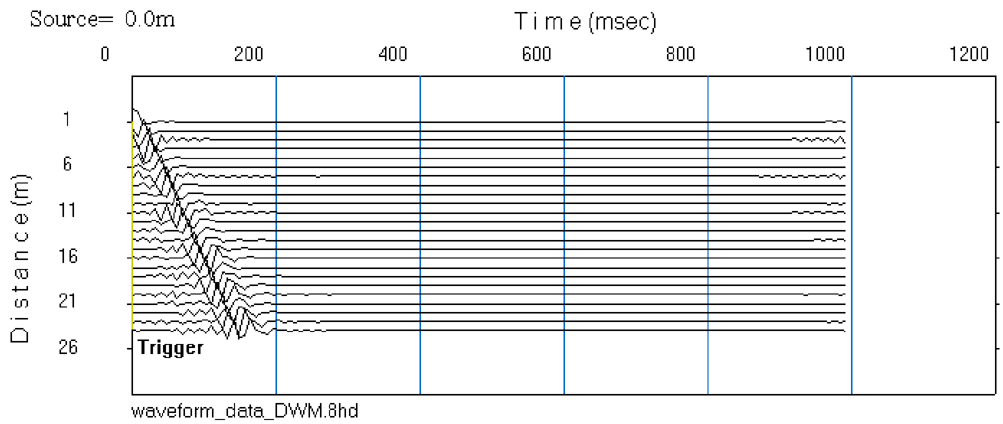


The *Data length* is the record length in time. *Number of samples* relates to the sample interval used in field acquisition; 1 second divided by 128 samples equals a sample interval of 7.8 milliseconds. Although this is much larger than what is commonly used in the field for a 1D MASW survey, a value 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 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.

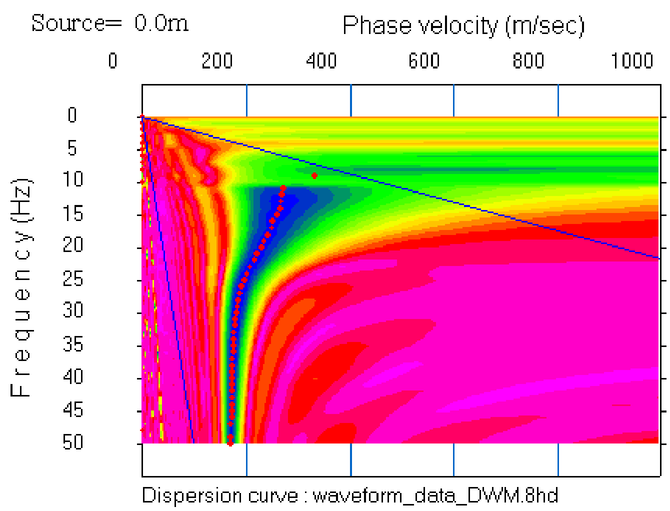
To revert back to the default values, click *Default*.

Click *OK* and the corresponding waveform file is calculated and automatically displayed in Pickwin.



The waveform file is automatically saved to the current directory with the file name *waveform_data_DWM.8hd*.

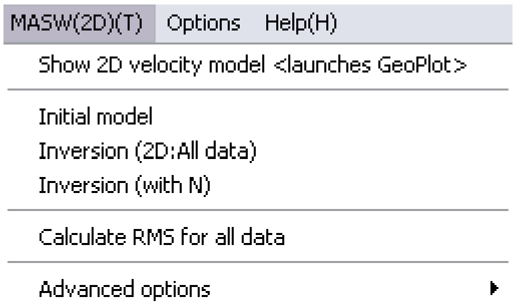
Proceed with calculating phase velocity and picking the dispersion curve as if the synthetic waveform file was a field record.



Import the dispersion curve picks into WaveEq, set-up an initial model, and run the inversion. Refer to Section 6.10.7 for explanation of additional modeling functions.

6.7 MASW (2D) Menu

The *MASW (2D)* menu includes functions for calculating an initial model for a 2D dataset and running the inversion to find the best fit of the initial model with the observed data. For purchases of SeisImager/SW-1D, this menu is not active.



The *Advanced options* are not available at this time.

6.7.1 MASW (2D) Menu: Show 2D Velocity Model

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 for more information on setting display parameters in GeoPlot.

6.7.2 MASW (2D) Menu: 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 6.6.1 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.

6.7.3 MASW (2D) Menu: Inversion (2D: All Data) and Inversion (with N)

The *Inversion (2D: 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.

6.7.3.1 MASW (2D) Menu: Inversion (2D: All Data)

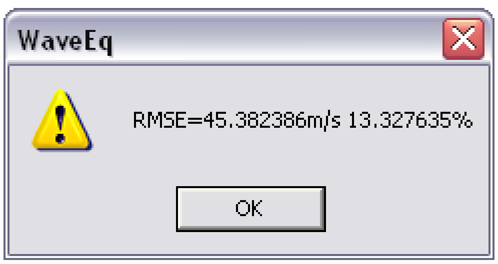
To calculate the V_s cross-section that best matches the observed data, select *Inversion (2D: All Data)*. The *Least Square Method* dialog box settings are the same as those explained in Section 6.6.2.1, except that the default value for *E* equals 0.1 and for *Regularization* equals 0.5.

6.7.3.2 MASW (2D) Menu: Inversion (with N)

If N-values are used to construct the initial model, select *Inversion (with N)* instead of *Inversion (2D: All Data)*. The *Least Square Method* dialog box settings are the same as those explained in Section 6.6.2.1, except that the default value for *E* equals 0.1 and for *Regularization* equals 0.5.

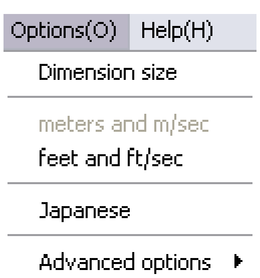
6.7.4 MASW (2D) Menu: Calculate RMS for All Data

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 percent (%). It is preferable for the error to be less than about 15%, but it will depend on the dataset.



6.8 Options

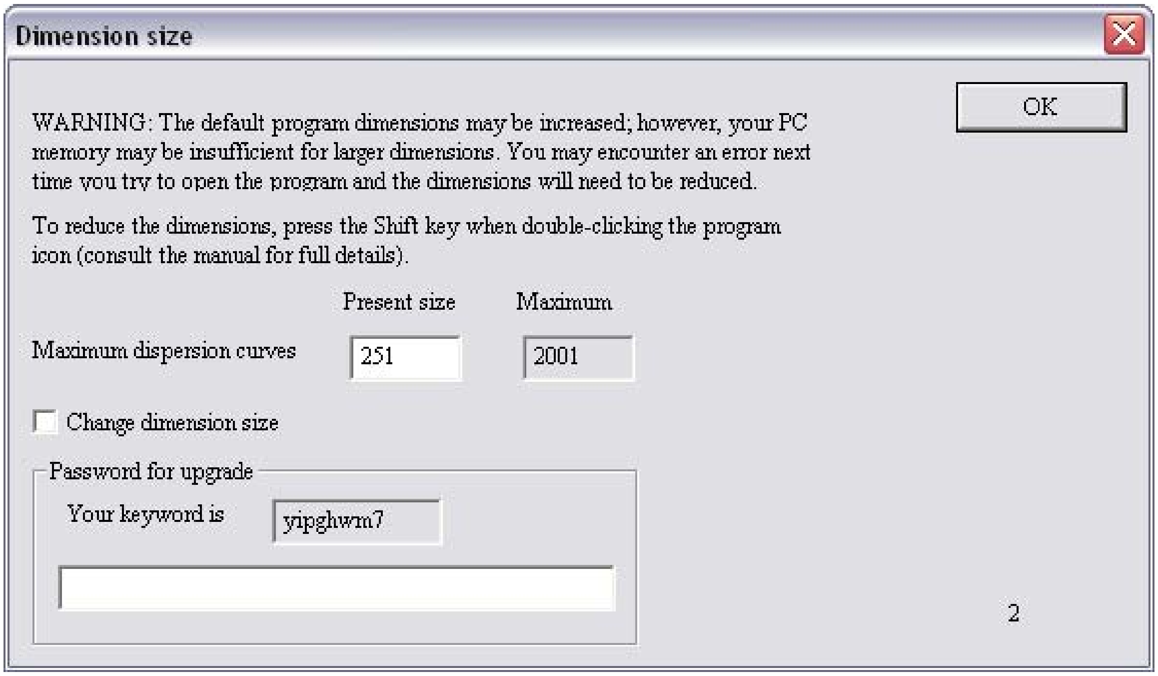
The *Options* menu includes program controls and display settings.



6.8.1 Options: 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 click *OK*.



Click *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.

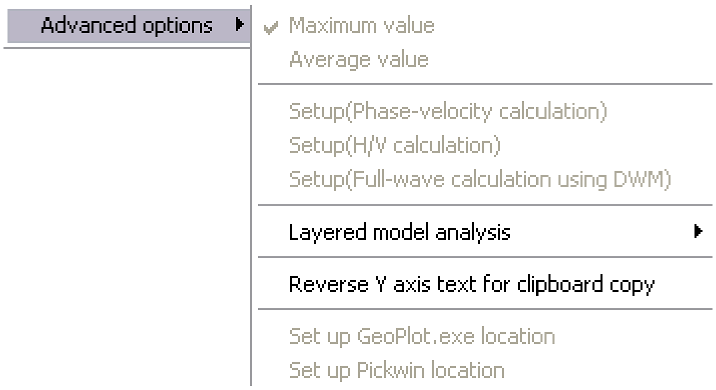
6.8.2 Options: Meters and m/sec and Feet and ft/sec

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.

6.8.3 Options: Japanese

The program language can be converted between English and Japanese. To convert from English, check *Japanese*. Obviously, this is not recommended unless you want to use the software in Japanese and have the necessary version of Windows. If symbols appear in various places, it is likely that the language is not set to English and Windows is unable to render the program in Japanese.

6.8.4 Options: Advanced Options: Reverse Y-Axis Text for Clipboard Copy

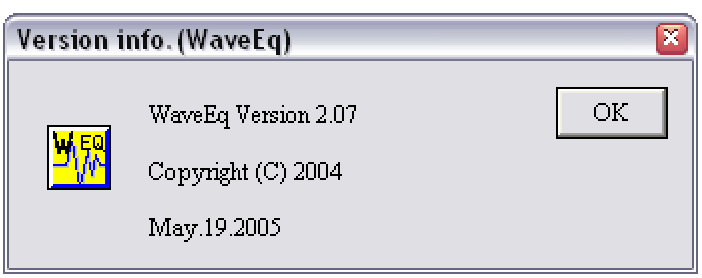


Layered model analysis is not active at this time.

Reverse Y-axis text for clipboard copy controls how the label for the vertical axis appears when the *Edit* menu, *Copy to clipboard* is selected. 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.

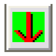
6.9 Help

The *Help* menu or *Version info* button reports the software version information.

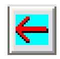
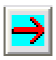


6.10 Button Bar Functions

The WaveEq button bar functions not already discussed in association with specific menu functions are explained in this section.

6.10.1 Button Bar: Enlarge Waveform Amplitude  and Reduce Waveform Amplitude 

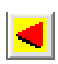
The *Enlarge waveform amplitude* and *Reduce waveform amplitude* buttons have no meaning in WaveEq.

6.10.2 Button Bar: Reduce Horizontal Scale  and Enlarge Horizontal Scale 

To reduce or enlarge the horizontal scale of plots of dispersion curves, geometry, and velocity models, click the *Reduce horizontal scale* and *Enlarge horizontal scale* buttons. The associated keyboard shortcuts are the left arrow and right arrow keys, respectively.

6.10.3 Button Bar: Enlarge Vertical Scale  and Reduce Vertical Scale 

To enlarge or reduce the vertical scale of plots of dispersion curves, geometry, and velocity models, click the *Enlarge vertical scale* and *Reduce vertical scale* buttons. The associated keyboard shortcuts are the up arrow and down arrow keys, respectively.

6.10.4 Button Bar: Show Previous  and Show Next 

To scroll through individual dispersion curves or velocity models, click 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.

6.10.5 Button Bar: Home  and End 

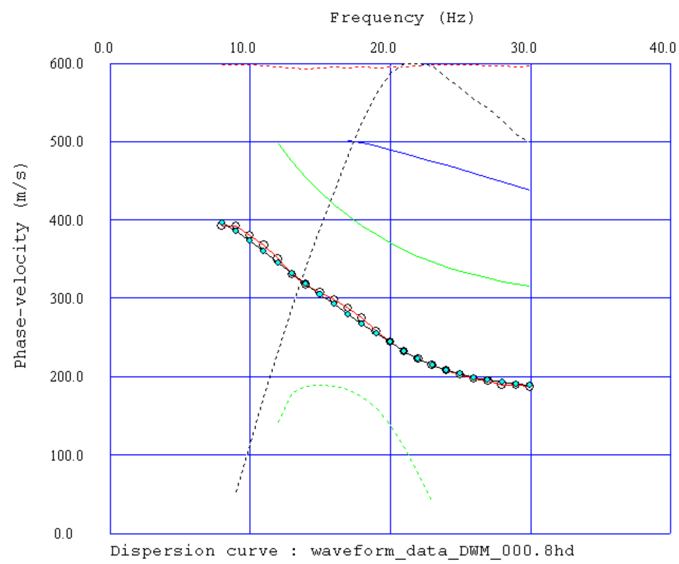
To jump to the first or last of a set of dispersion curves or velocity models, click the *Home* and *End* buttons.

6.10.6 Button Bar: Calculate Theoretical Dispersion Curve by Fundamental Mode 

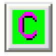
The *Calculate theoretical dispersion curve by fundamental mode* button toggles off *Calculate theoretical dispersion curve by harmonic mode*.

6.10.7 Button Bar: Calculate Theoretical Dispersion Curve by Harmonic Mode 

For synthetic modeling, in the dispersion curve view, higher modes can be modeled by first clicking on the *Calculate theoretical dispersion curve by higher mode* button, then clicking 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.

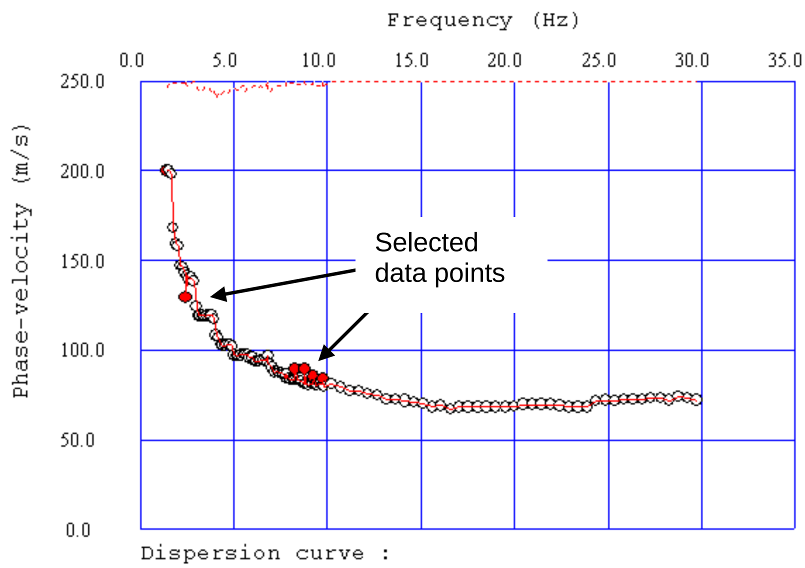


To toggle off the higher mode dispersion curves, click the *Calculate theoretical dispersion curves* button again. To return to the fundamental mode, click the *Calculate theoretical dispersion curve by fundamental mode*  button.

6.10.8 Button Bar: 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, click on the *Undo*  button.

Click on 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.



When done selecting points, hit the *Delete* key or select the *Edit* menu, *Delete*. If you change your mind and do not want to delete the selected points, click 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, click the *Correct dispersion curve* button. Click the left mouse button 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.

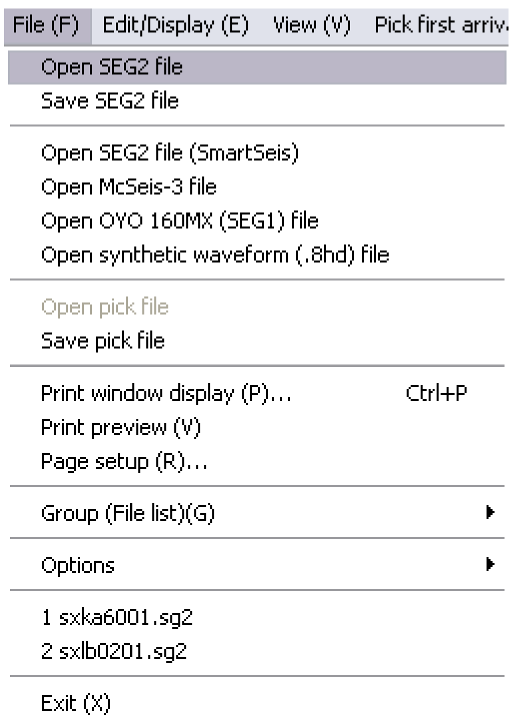
The *Undo* button can be clicked after any deletion or repositioning to reverse the effect.

7 – Basic Processing Flows

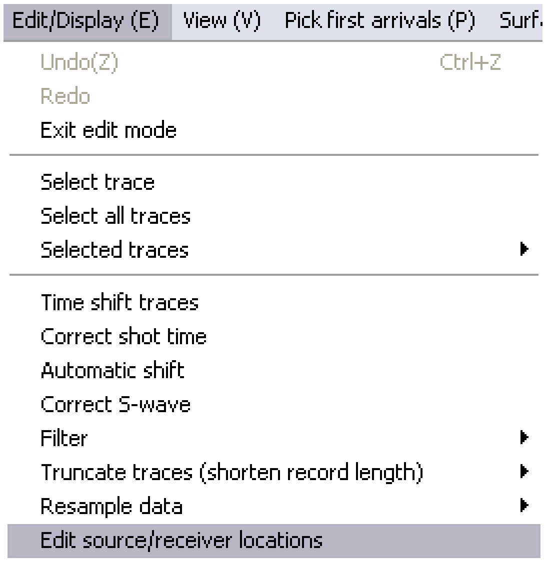
The basic processing flows for 1D MASW, MAM, and 2D MASW datasets are summarized in this section. In Sections 7.1, 7.2, and 7.3, the functions automatically run by the wizard are listed in order, with exceptions noted. Section 7.3.1 describes the processing flow to individually edit 2D MASW dispersion curves in the Pickwin phase velocity-frequency plot view.

7.1 Active Source 1D MASW

1. In Pickwin, open a waveform file.

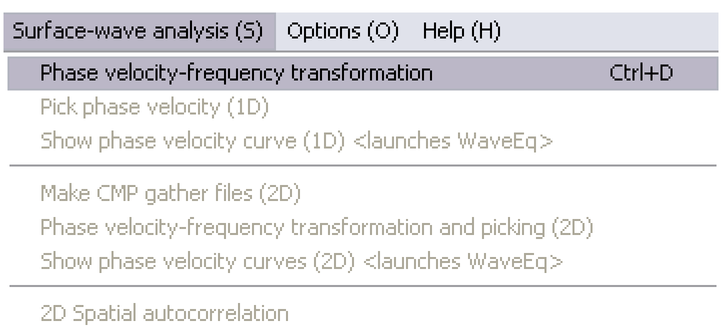


2. In Pickwin, set the unit labels to *meters* or *feet* by selecting the *Edit/Display* menu, *Edit source/receiver locations*. (This is not an automatic part of the wizard, but should be done if there is a change from the unit labels used last.)



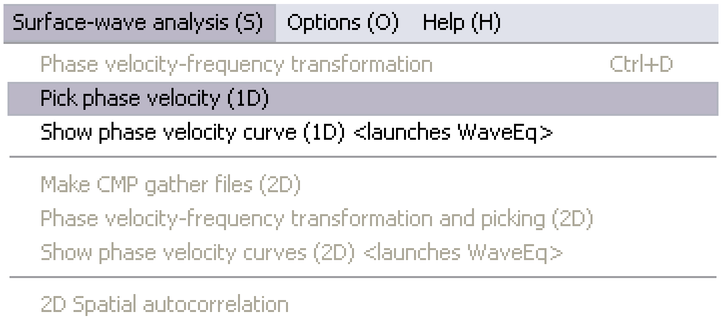
Alternatively, the unit labels may be set by selecting the *Options* menu, *meters and m/sec* or *feet and ft/sec*.

3. In Pickwin, calculate phase velocity.

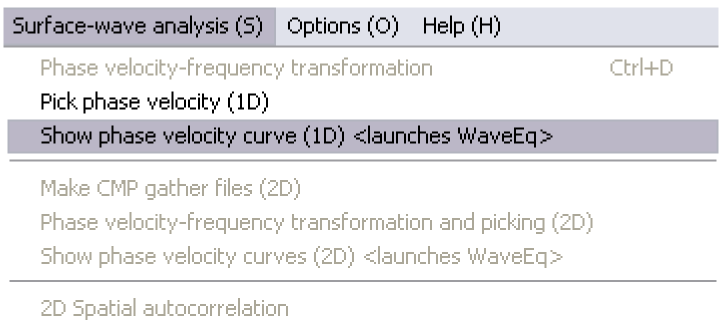


Upon viewing the phase velocity-frequency plot, if the calculation parameters need to be changed, click the *Undo* button and re-run the process. (This is not an automatic part of the wizard.)

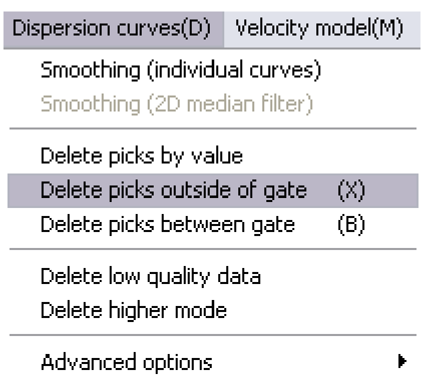
4. In Pickwin, pick the dispersion curve.



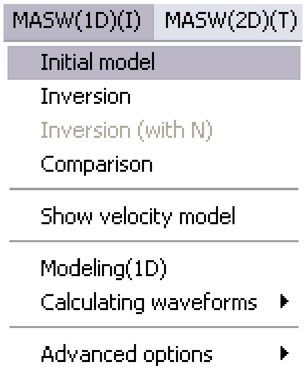
5. In Pickwin, import the picks into WaveEq.



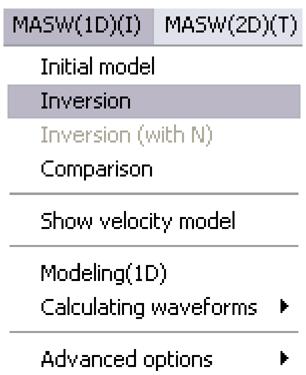
6. In WaveEq, edit the dispersion curve.



7. In WaveEq, calculate the initial model.

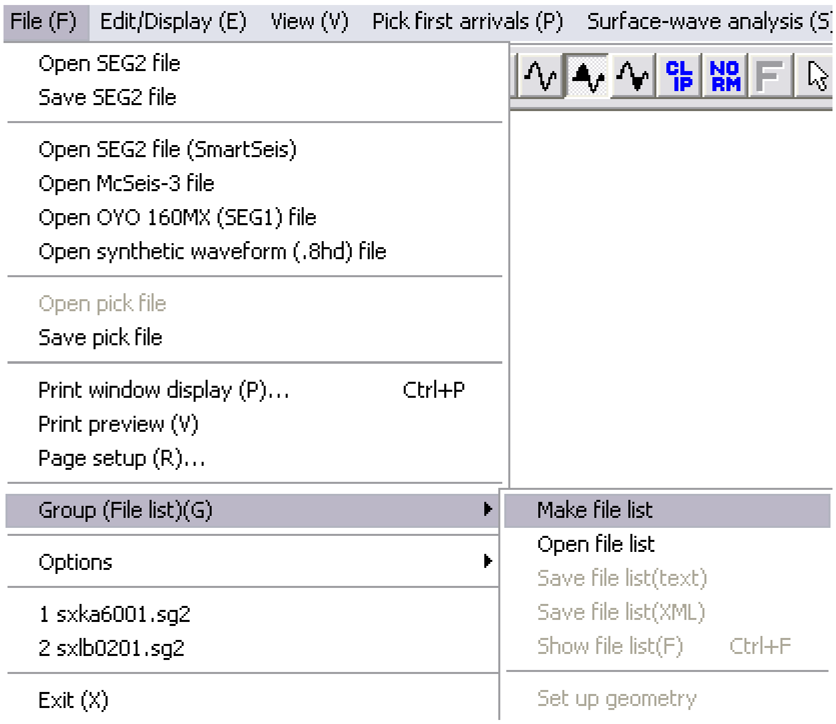


8. In WaveEq, run the inversion.

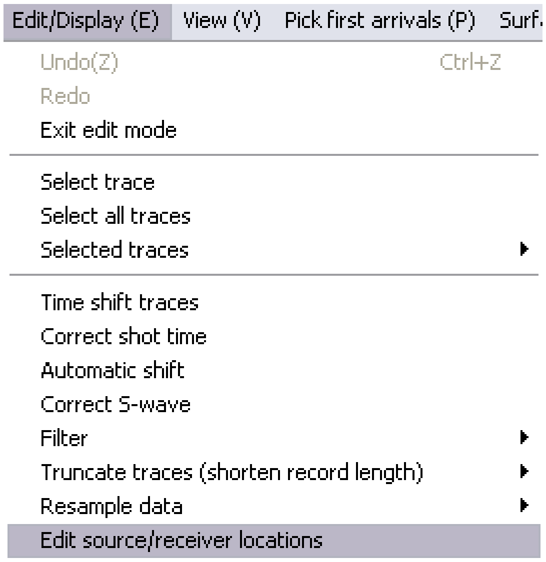


7.2 Passive Source MAM

1. In Pickwin, make a list of the waveform files in the dataset.

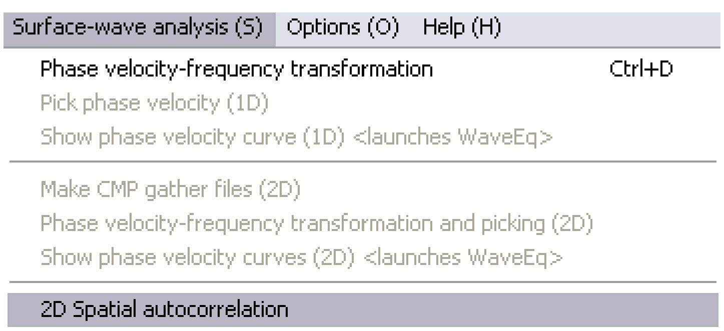


2. In Pickwin, set the unit labels to *meters* or *feet* by selecting the *Edit/Display* menu, *Edit source/receiver locations*. (This is not an automatic part of the wizard, but should be done if there is a change from the unit labels used last.)

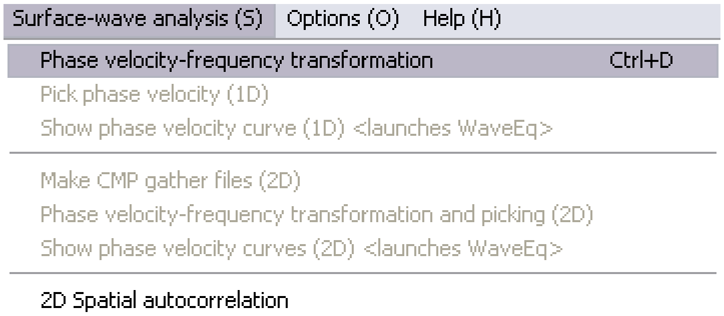


Alternatively, the unit labels may be set by selecting the *Options* menu, *meters and m/sec* or *feet and ft/sec*.

3. In Pickwin, run the spatial autocorrelation.

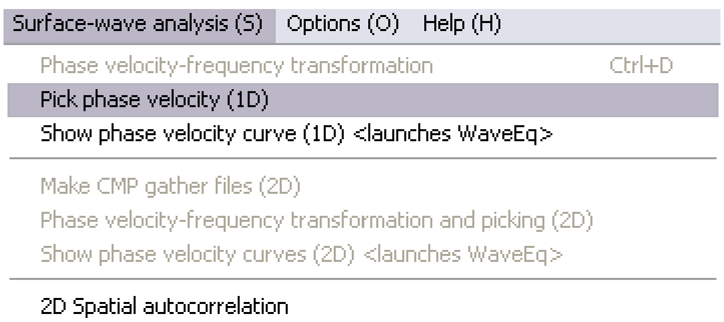


4. In Pickwin, calculate phase velocity.

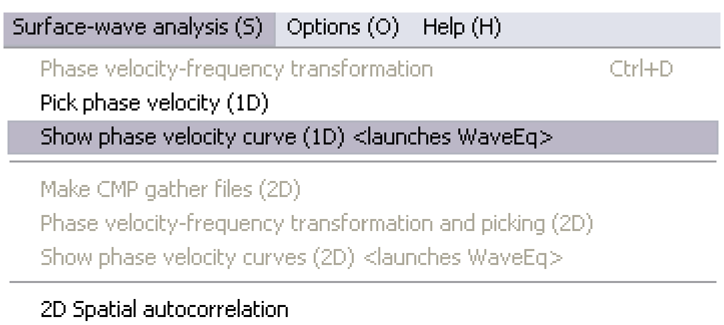


Upon viewing the phase velocity-frequency plot, if the calculation parameters need to be changed, click the *Undo* button and re-run the process. (This is not an automatic part of the wizard.)

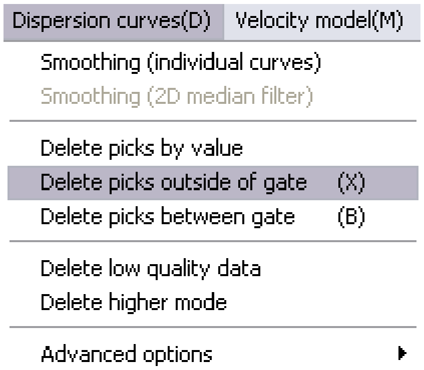
5. In Pickwin, pick the dispersion curve.



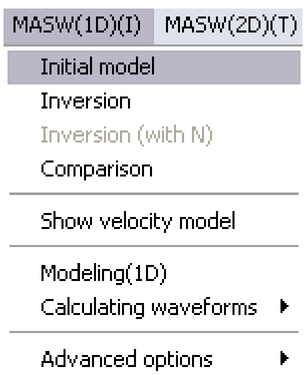
6. In Pickwin, import the picks into WaveEq.



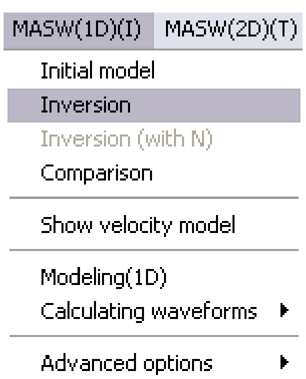
7. In WaveEq, edit the dispersion curve.



8. In WaveEq, calculate the initial model.

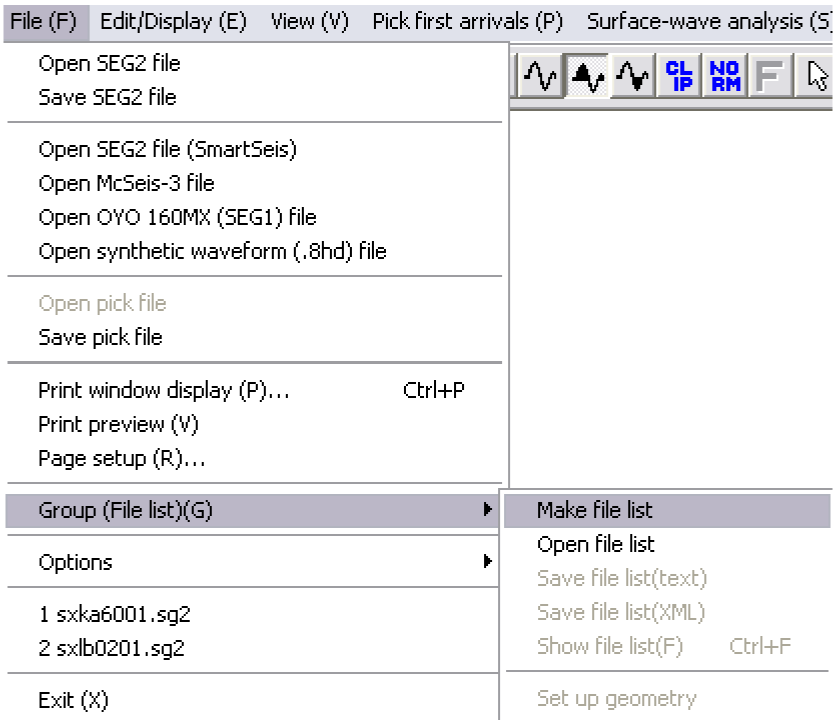


9. In WaveEq, run the inversion.

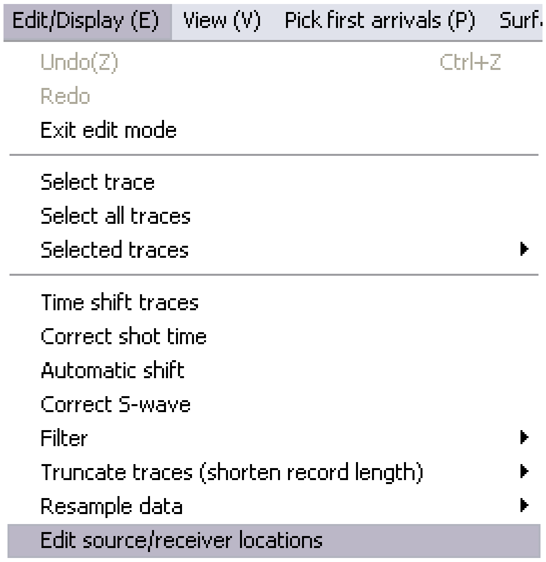


7.3 Active Source 2D MASW

1. In Pickwin, make a list of waveform files in the dataset.

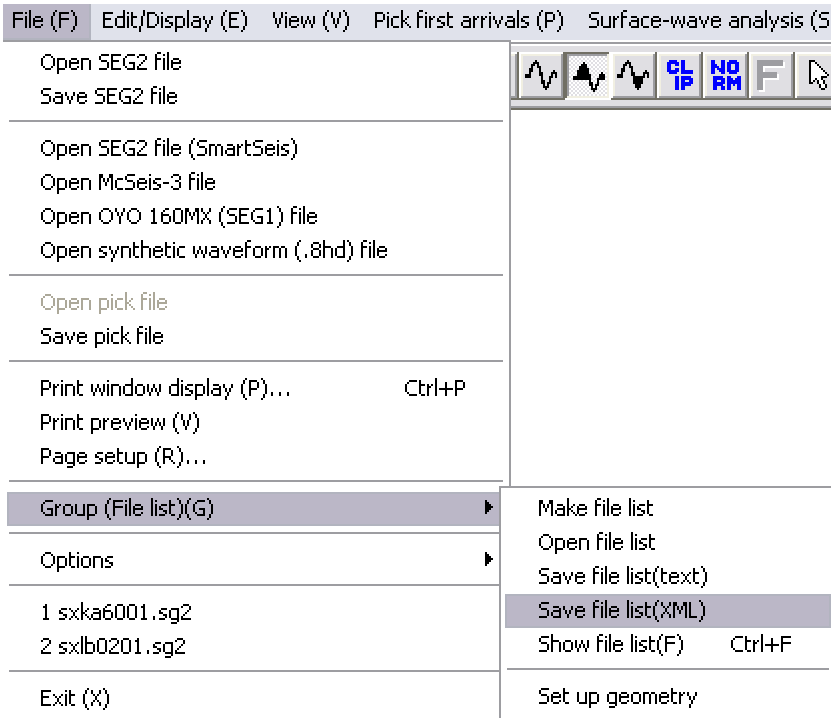


2. In Pickwin, set the unit labels to *meters* or *feet* by selecting the *Edit/Display* menu, *Edit source/receiver locations*. (This is not an automatic part of the wizard, but should be done if there is a change from the unit labels used last.)

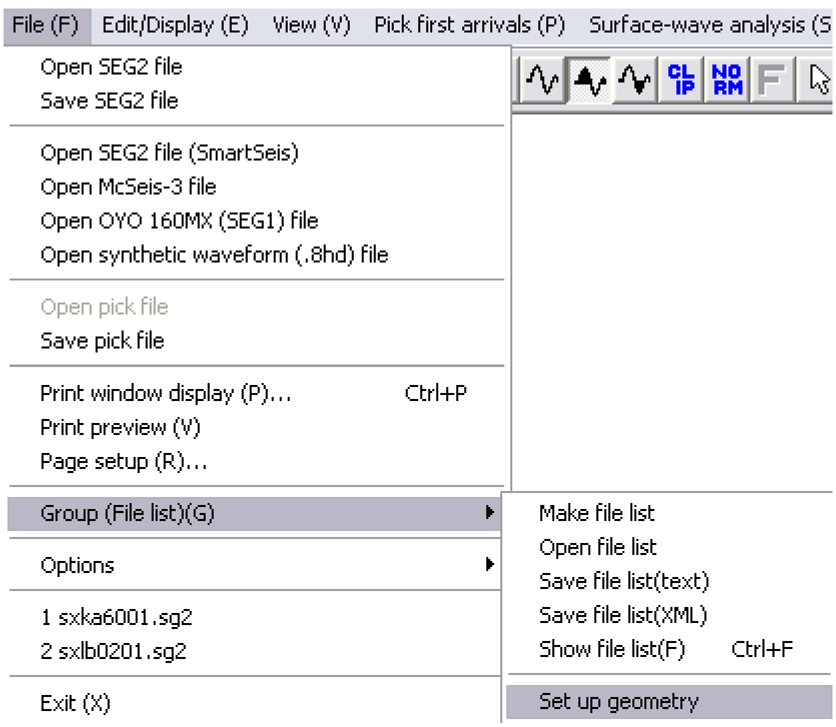


Alternatively, the unit labels may be set by selecting the *Options* menu, *meters and m/sec* or *feet and ft/sec*.

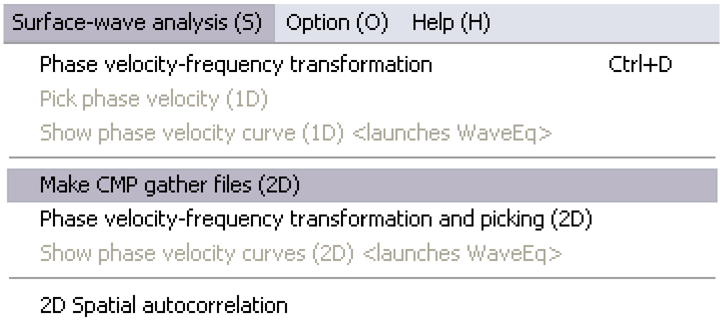
3. In Pickwin, save the file list for future use.



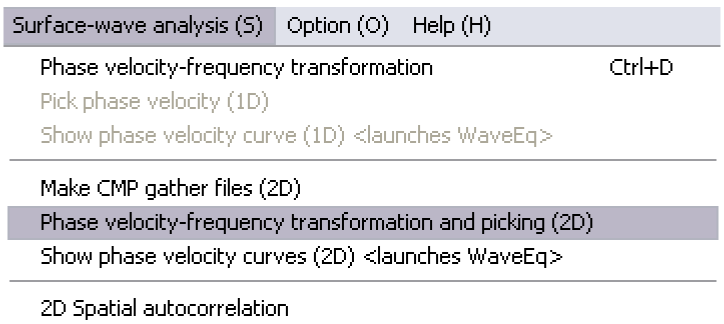
4. In Pickwin, set up the source-receiver geometry.



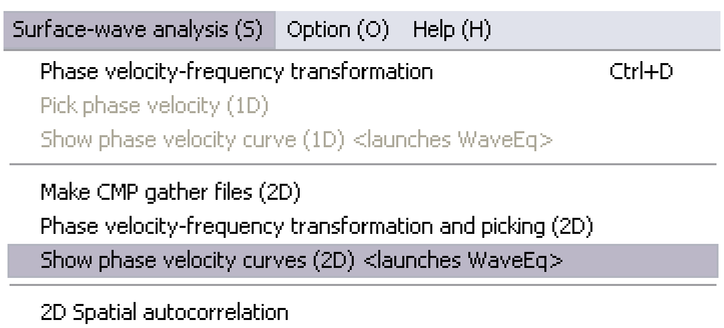
5. In Pickwin, calculate and assemble the CMP cross-correlation gathers.



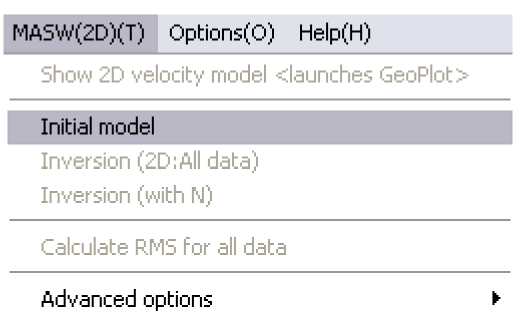
6. In Pickwin, calculate phase velocity for the CMP cross-correlation gathers and automatically pick the dispersion curves.



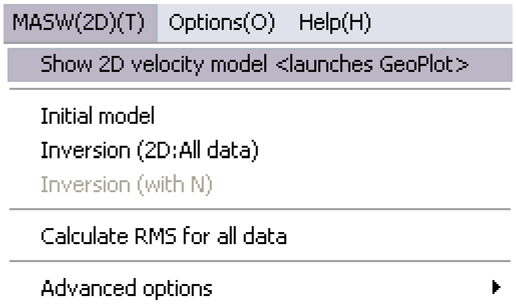
7. In Pickwin, import the dispersion curves into WaveEq.



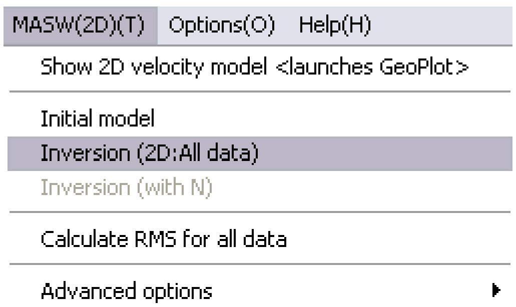
8. In WaveEq, calculate the initial model.



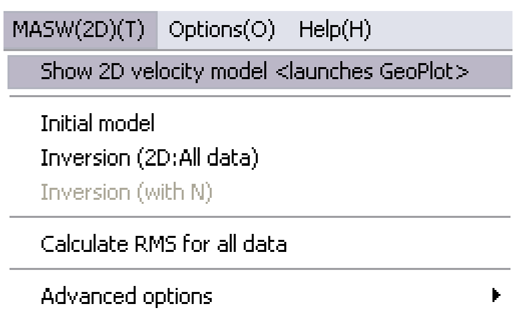
9. In GeoPlot, view the initial model.



10. In WaveEq, run the inversion.

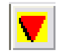


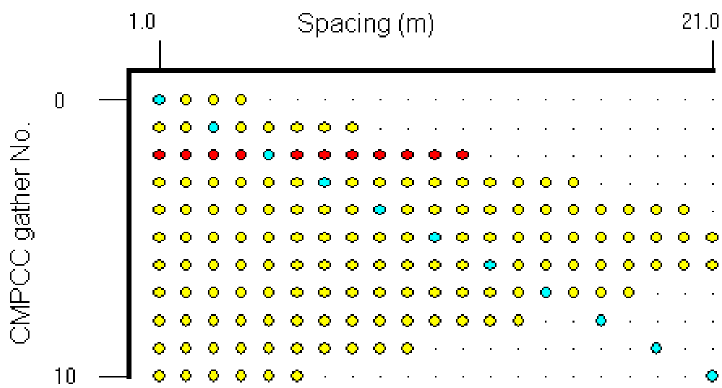
11. In GeoPlot, view the final model.



7.3.1 Viewing and Editing Individual Dispersion Curves in Pickwin

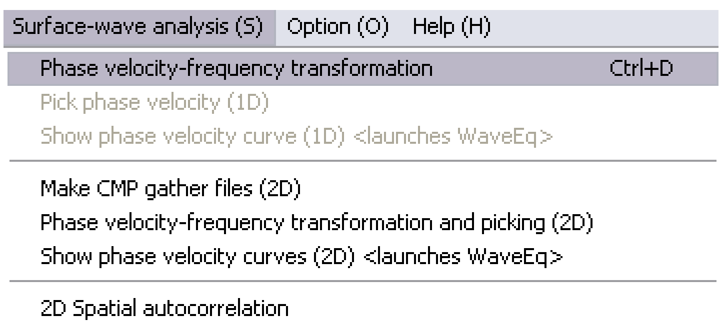
In Pickwin, prior to launching WaveEq, dispersion curves from a 2D MASW dataset may be individually edited in the phase velocity-frequency plot view. Usually with 2D MASW datasets, there are too many curves to pick manually and the automatic picker is more precise than the human eye. Occasionally, however, 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 in Section 7.3.

1. In Pickwin, click 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 its dispersion curve.

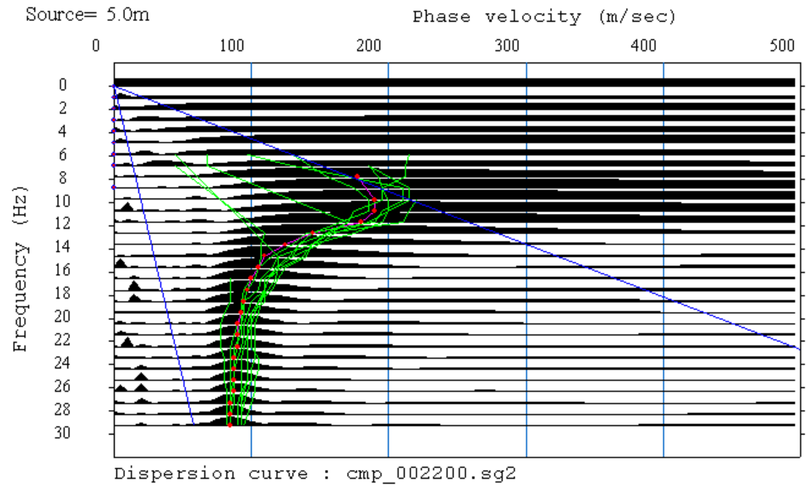


2. Click the *Waveform*  button to display the waveform file for the selected CMP cross-correlation gather.

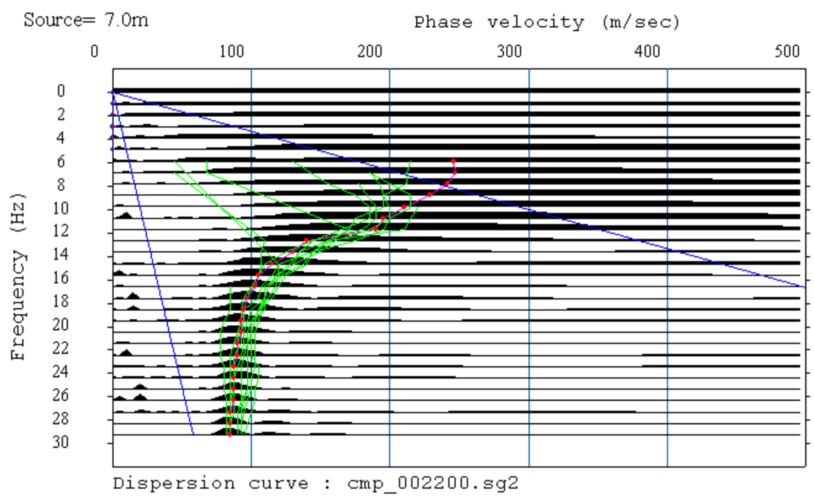
3. Calculate phase velocity for the CMP cross-correlation gather.



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 of Section 7.3. 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.

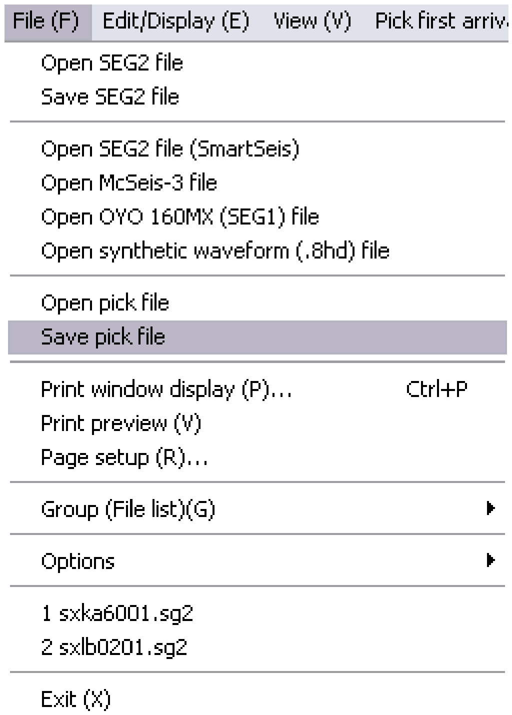


Adjust the dispersion curve picks as desired and use the *Update*  button to register the new picks.

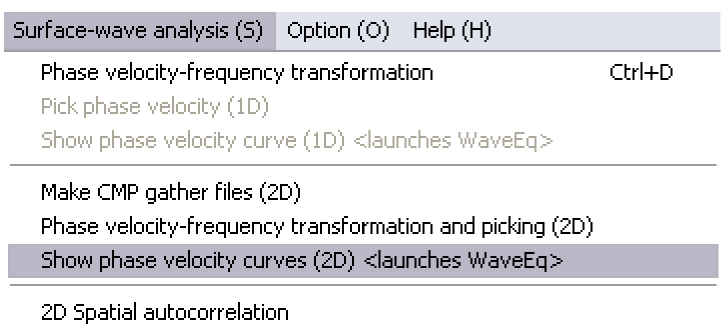


5. To edit other dispersion curves, repeat the process from Step 1.

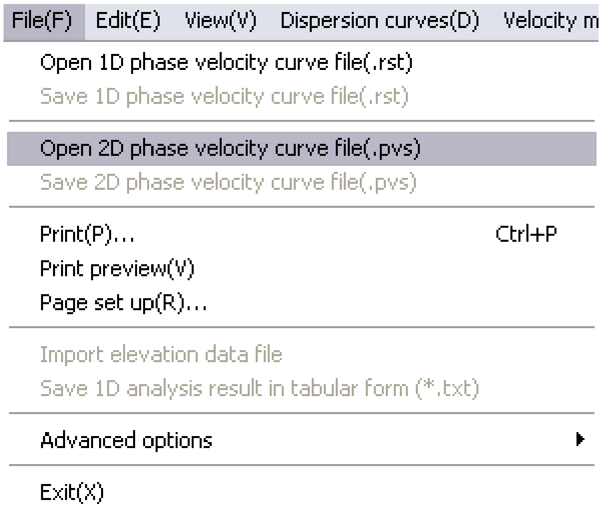
6. Once editing is complete, save the revised dispersion curves.



7. Import the revised dispersion curves into WaveEq.



As an alternative, the saved dispersion curve file can be opened in WaveEq.

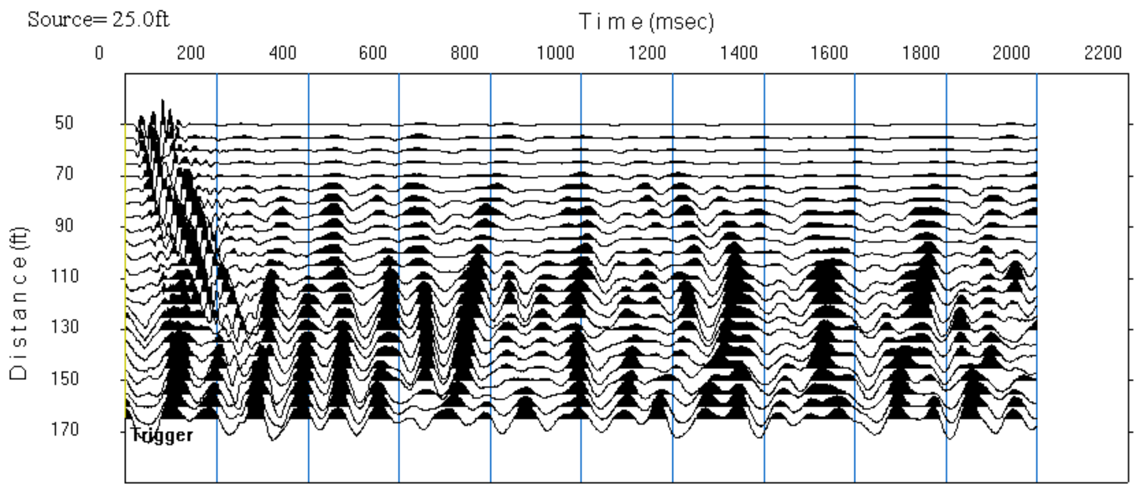


8 – Examples

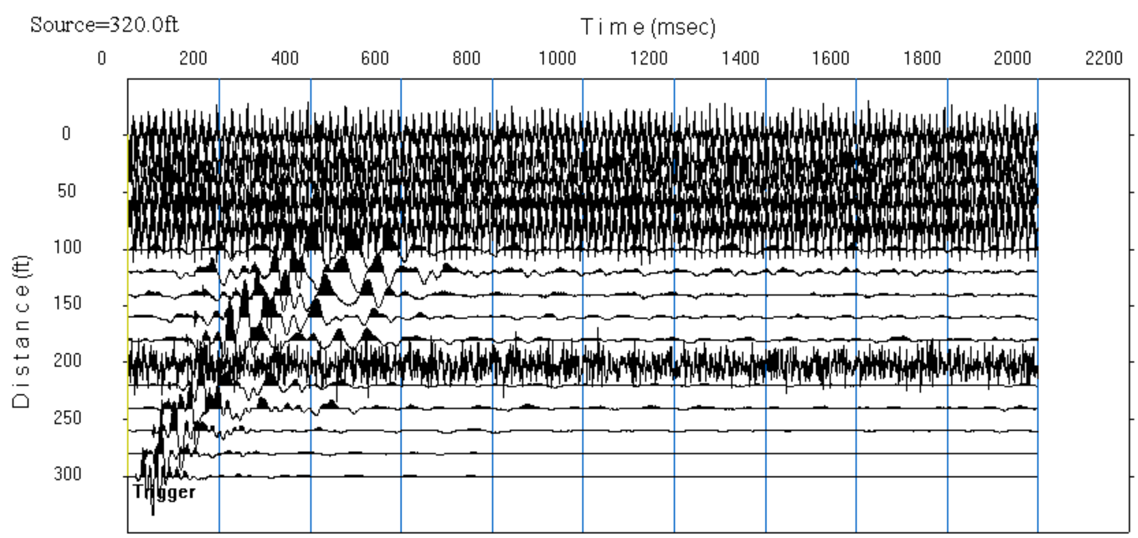
8.1 Active Source Waveform Data

8.1.1 Lower Quality

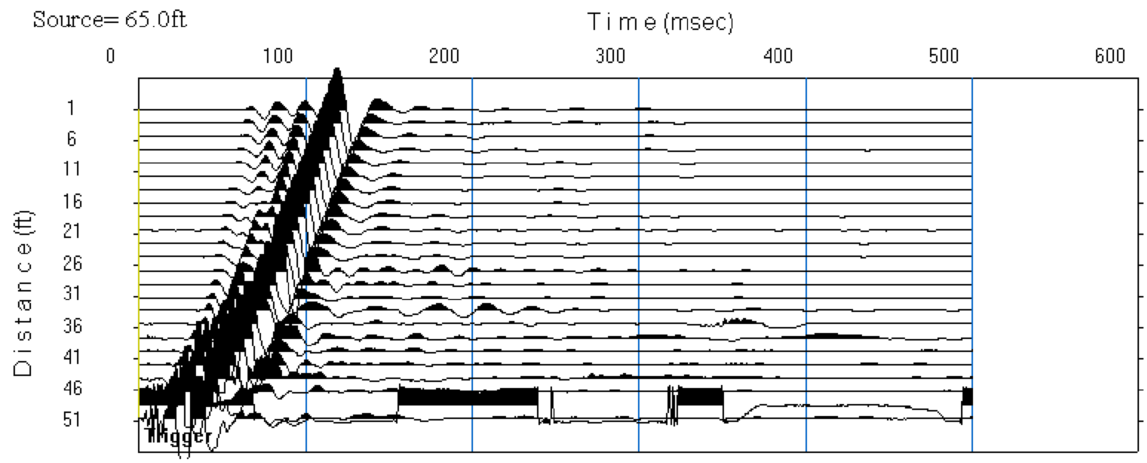
The shot record below lacks coherent surface wave signal from the near to far traces and is heavily contaminated with relatively lower frequency noise, particularly from 75 to 170 feet. Shot stacking or a larger source, and also waiting for a quieter recording period, would probably help.



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.

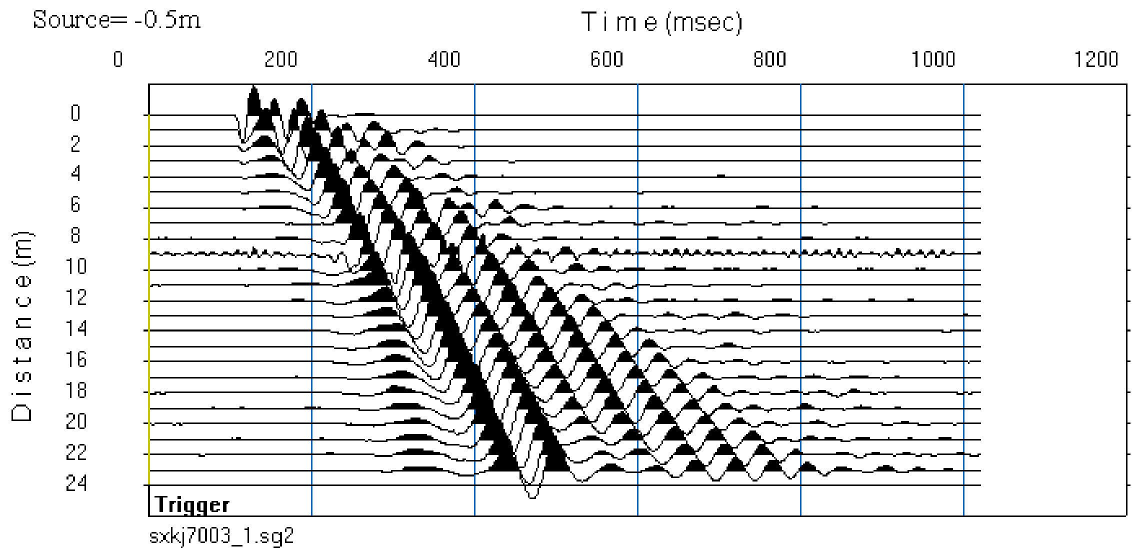


Due to a small near offset, in this shot record, the signal on the geophone at 51 feet was clipped. A few overdriven channels can be tolerated but it is best practice to not record clipped signal.



8.1.2 Higher Quality

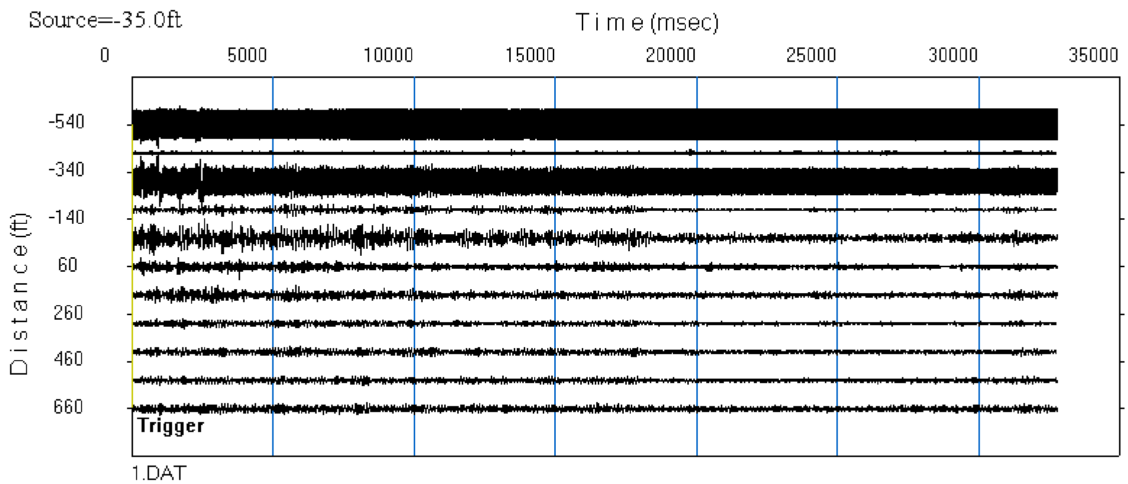
The shot record below displays high signal-to-noise ratio, no clipped traces, and coherency from trace-to-trace.



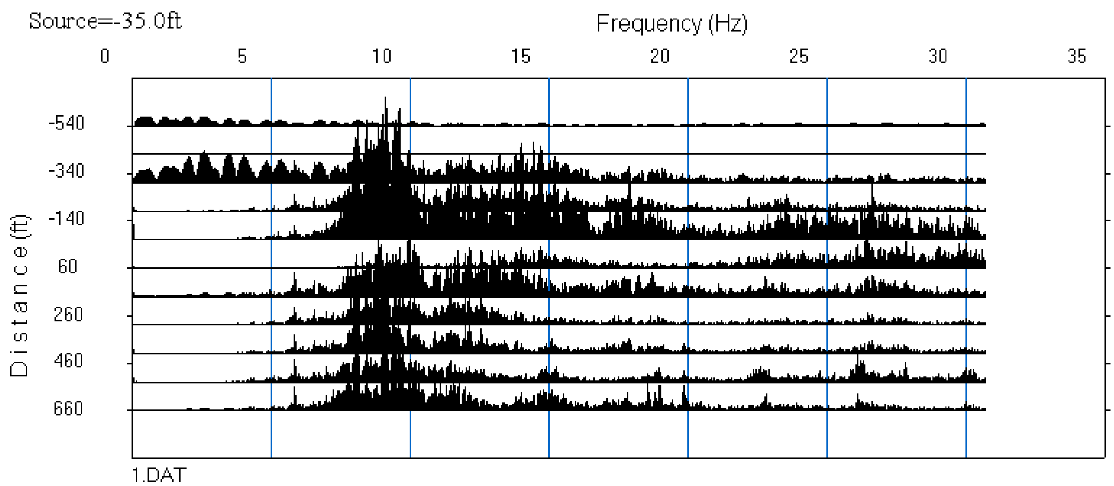
8.2 Passive Source Waveform Data

8.2.1 Lower Quality

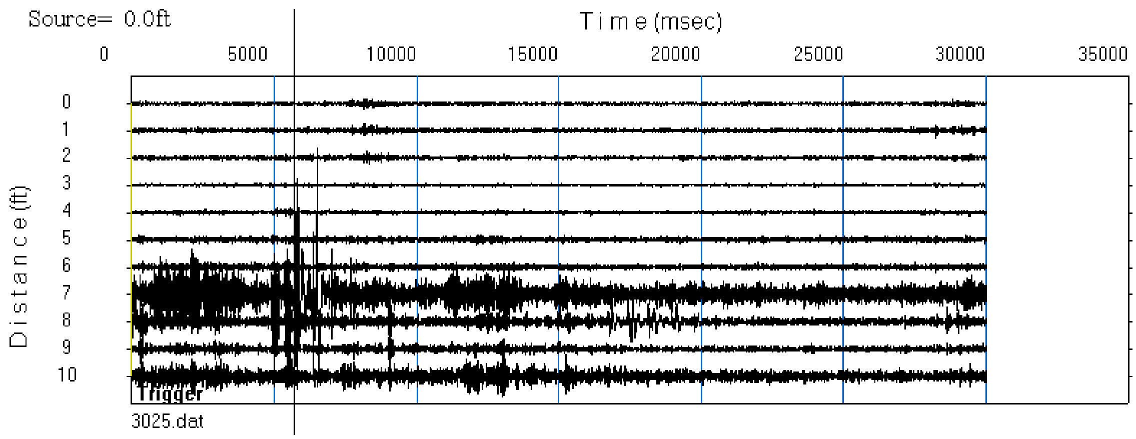
The record below shows wide variation in trace amplitude from trace-to-trace.

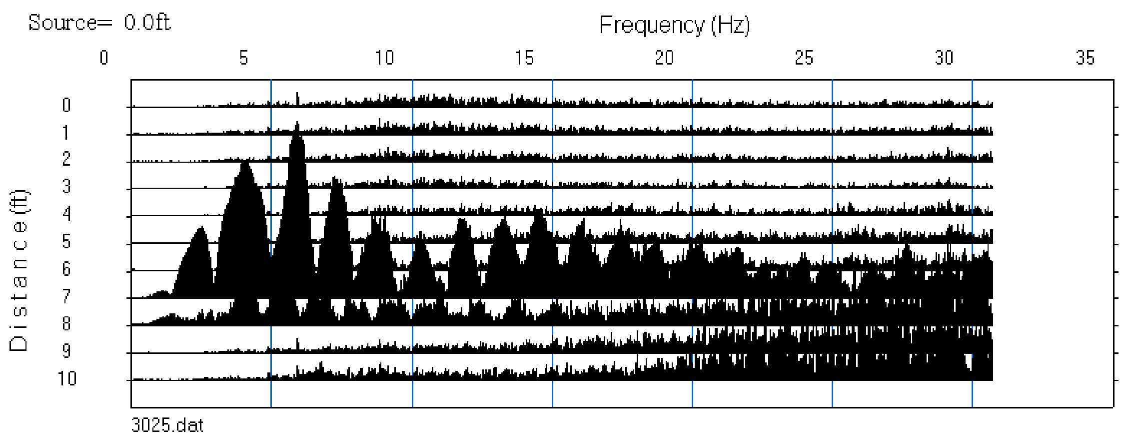


Upon viewing the spectrum, it is clear that the frequency content is uneven.

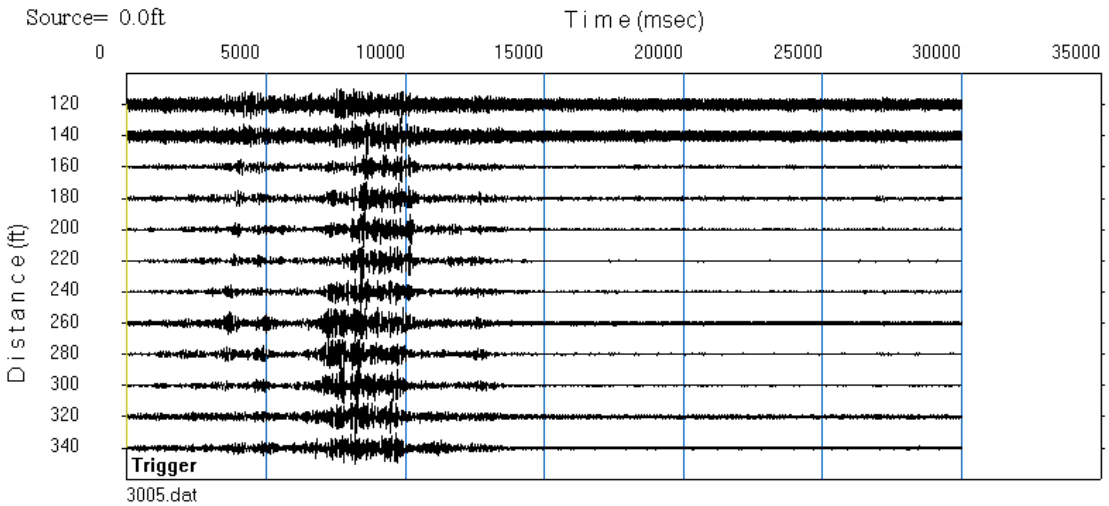


A similar condition is evident in this record and associated frequency spectrum.

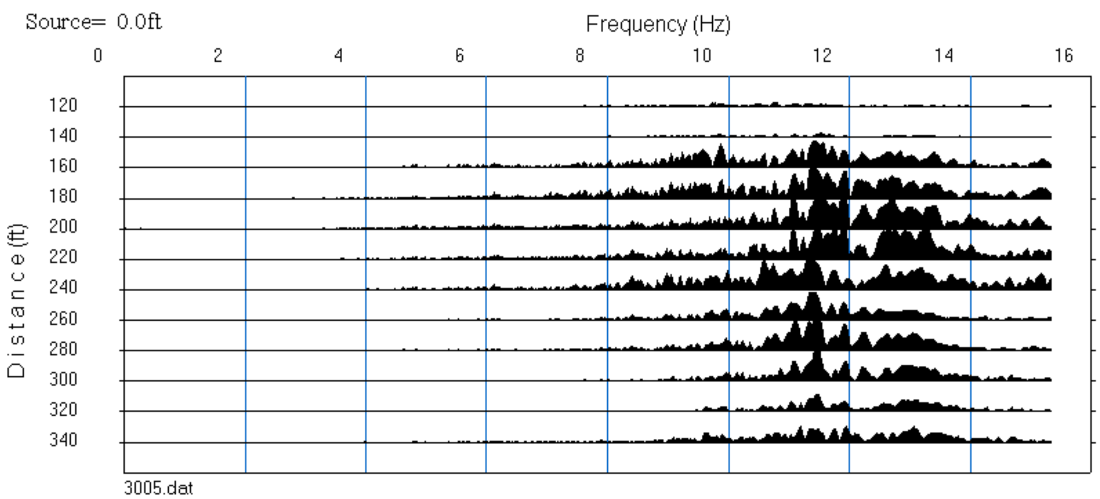




In this record, the traces are similar to each other, but over time, there is wide range in amplitude.

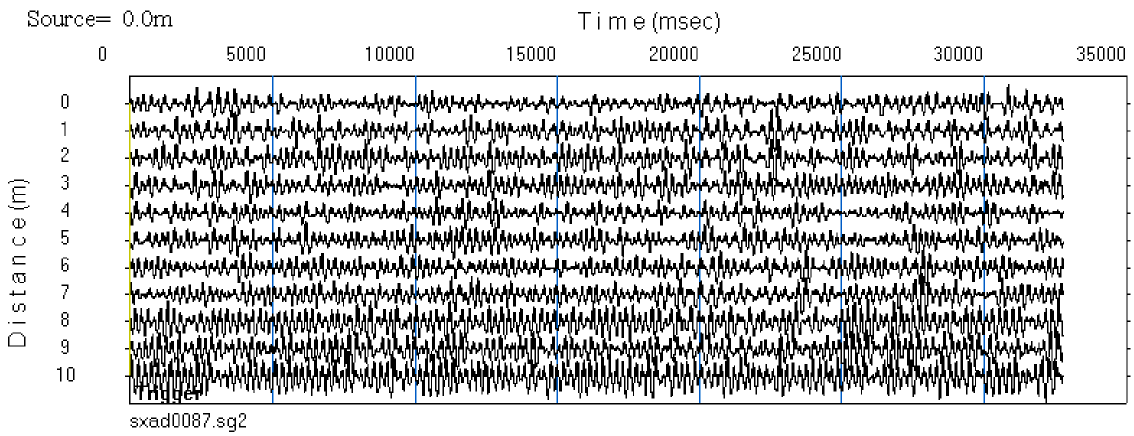


The spectrum shows fairly consistent frequency content from trace-to-trace, but not as tight as it could be.

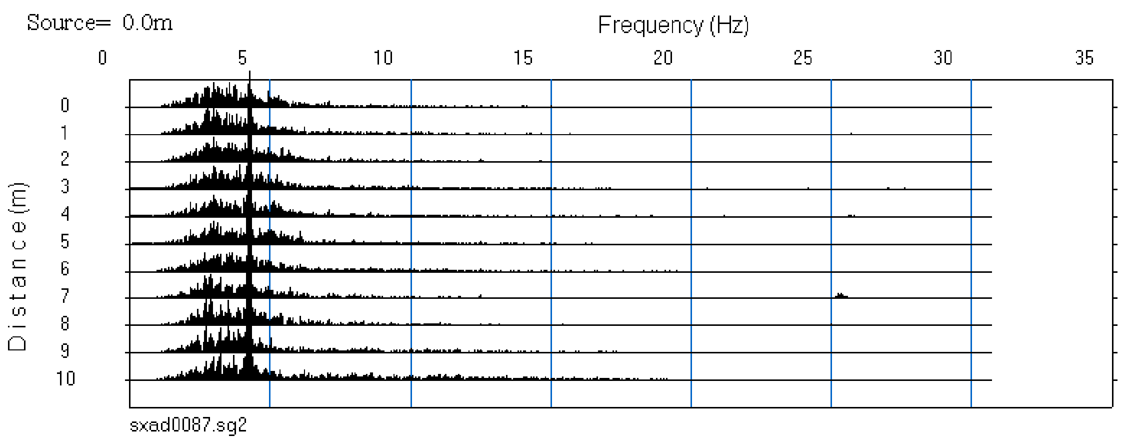


8.2.2 Higher Quality

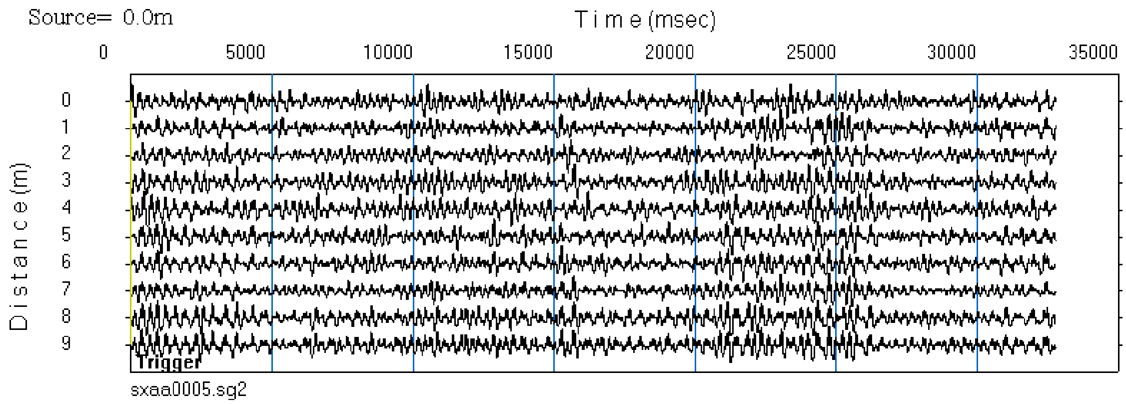
The record below is ideal showing even signal amplitude from trace-to-trace and in time.



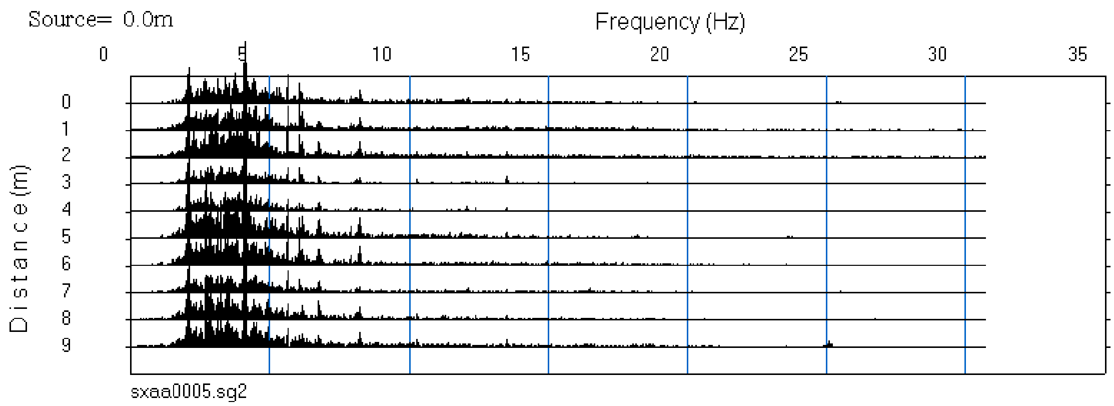
The corresponding frequency spectrum shows the energy contained in a neat envelope from approximately 2 to 7 Hz.



This record has some intermittent higher-amplitude noise from passing cars (between 21 and 26 seconds).



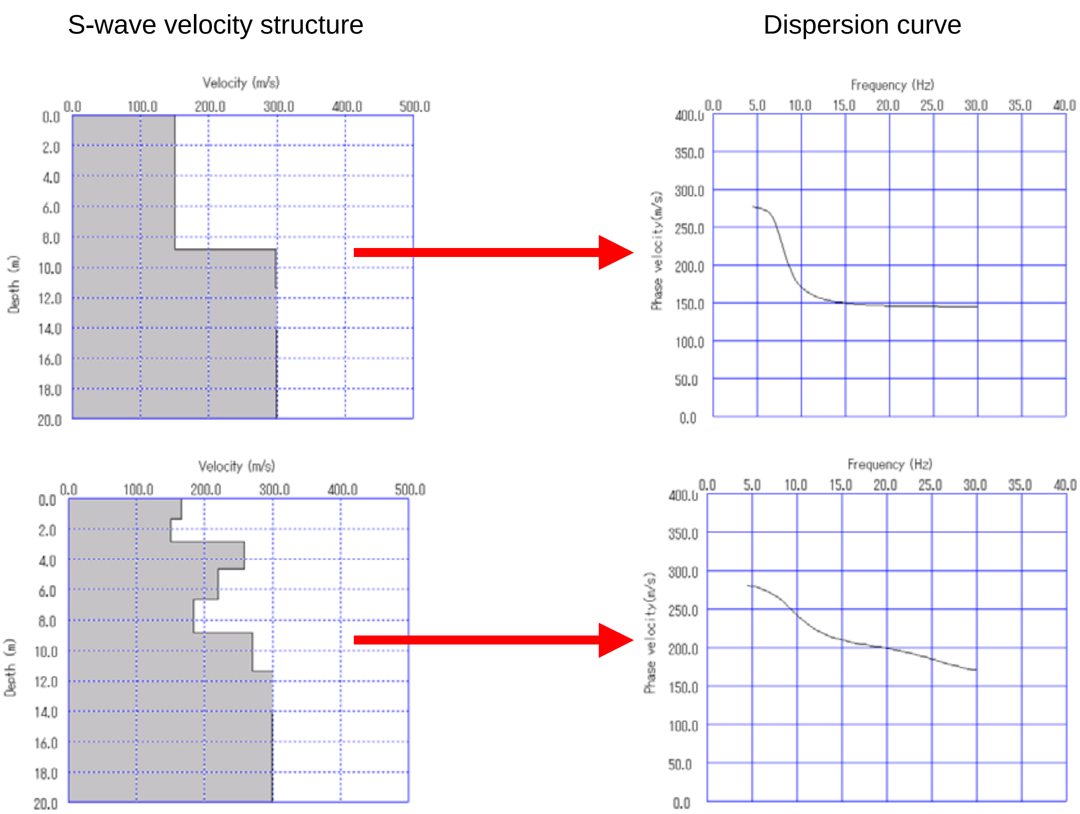
The frequency spectrum shows the car noise has relatively little impact on the record quality since it comprised a relatively short period compared to the total recording time.



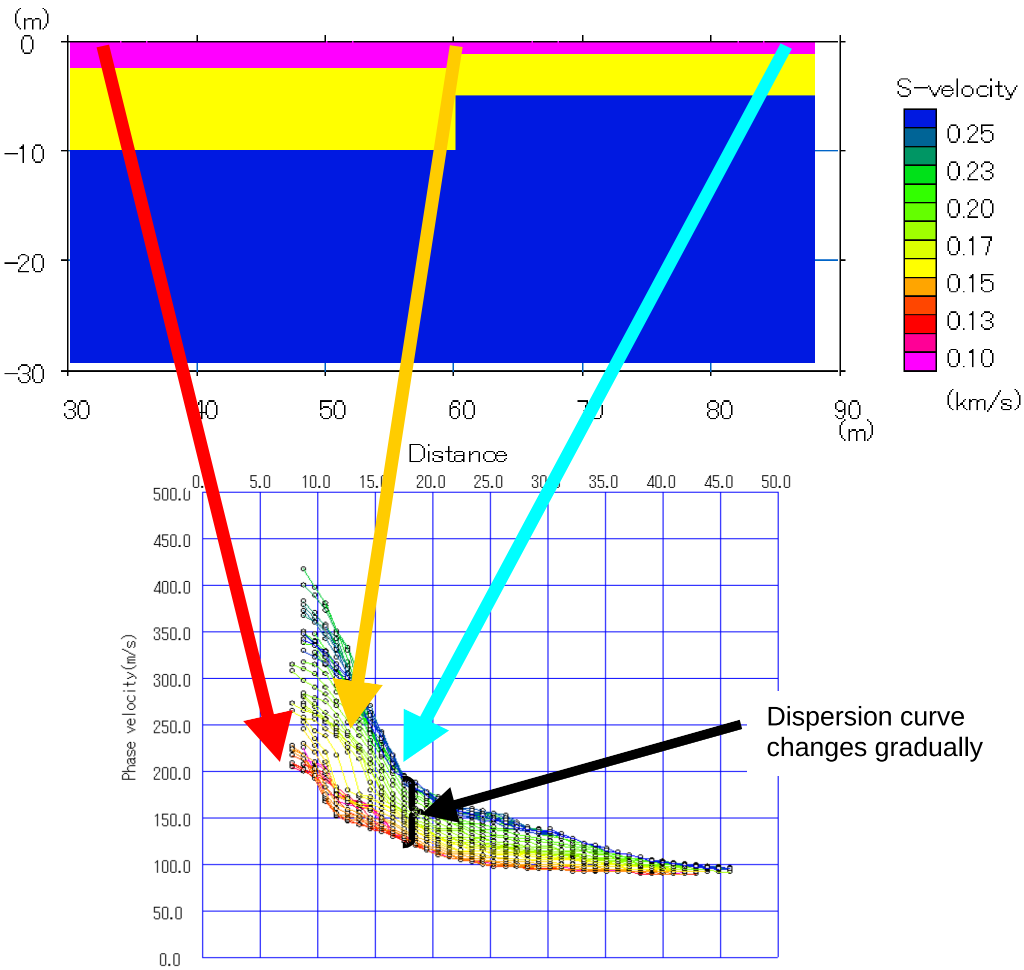
8.3 Dispersion Curves

8.3.1 Characteristics

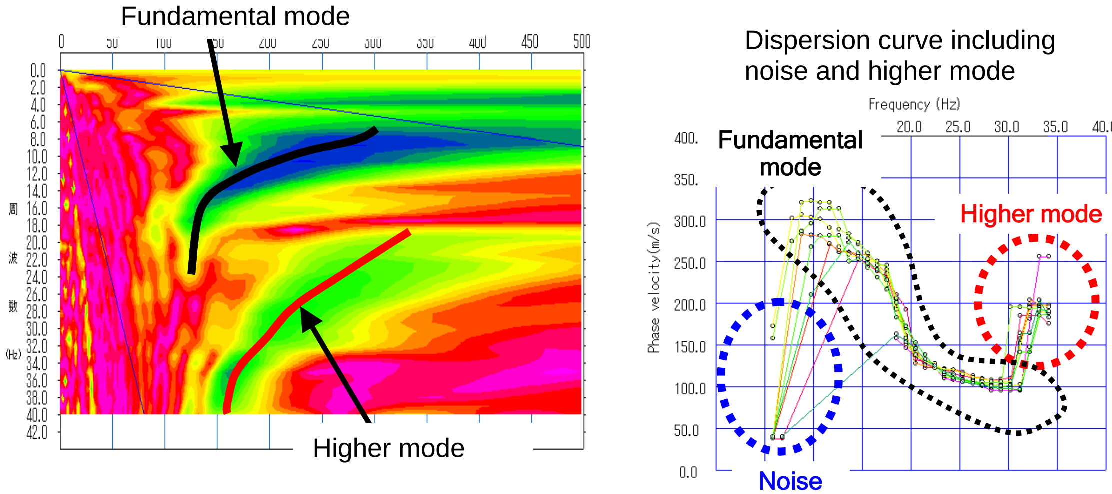
Dispersion curves are smooth, curved or straight lines.



Dispersion curves reflect the *average* velocity model beneath the geophone spread.

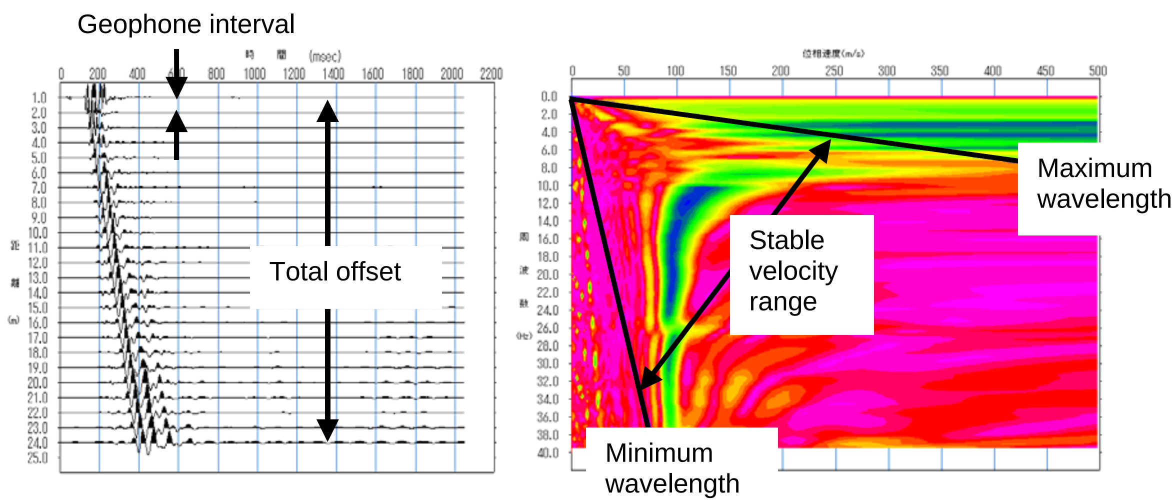


Only the Rayleigh wave fundamental mode is used for analysis, although higher modes are present and often visible.

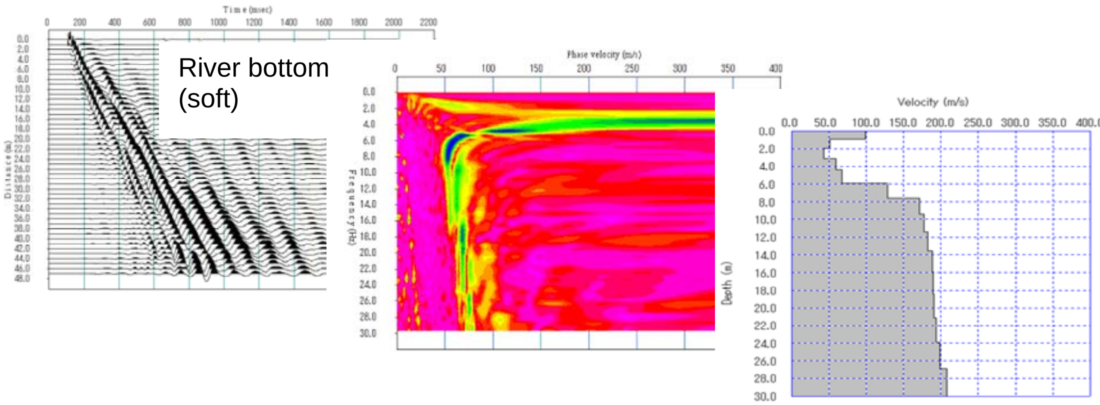


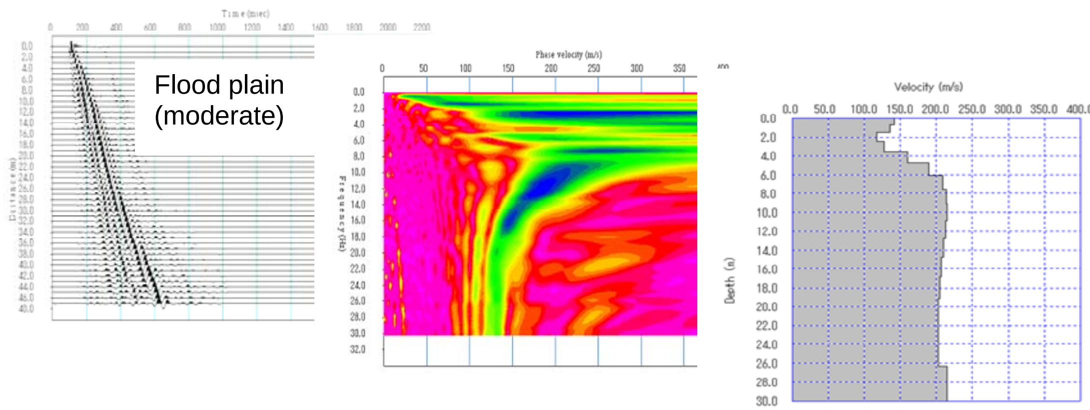
The frequency range within which phase velocity is considered stable corresponds to the minimum and maximum wavelengths recorded, and there is generally a one-to-one relationship between the minimum and maximum wavelength and the geophone interval and total offset (spread length), respectively.

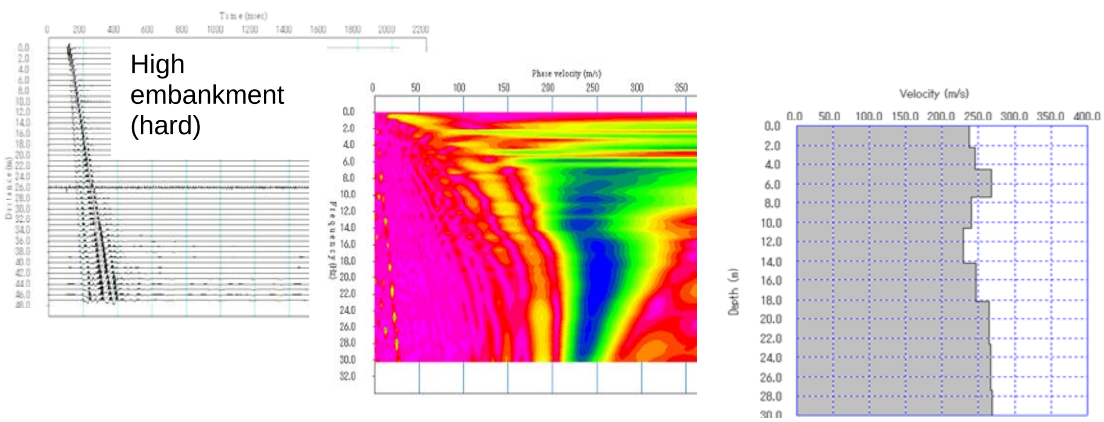
The bounds of the stable frequency range are depicted on the phase velocity-frequency plot by blue lines (shown above and by bold black lines shown below) with slopes that correspond to the minimum and maximum wavelengths.



8.3.2 Comparison of data from ground with variable stiffness







9 – References

9.1 Theory and Methods

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. 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.

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), Multichannel analysis of surface waves, *Geophysics*, 64(3): 800-808.
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.
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.

9.2 Land Streamers

Bay Geophysical, www.baygeo.com/html/the_land_streamer.html.
Dolena, T.M., Speece, M.A., Link, C.A., and Duaime, T.E. (2005), A land streamer aided, three-dimensional (3-D) seismic reflection system, *Journal of Engineering and Environmental Geophysics*, ?.
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.
GeoStuff, www.georadar.com/LSdatasheet.pdf.
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. (?), *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.
Kansas Geological Survey, www.kgs.ku.edu/Geophysics/swave.html.
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.
OYO Corporation, www.oyo.co.jp/english/index.html.
Ploug, C., www.geometrics.com/Geoprofiles/LandStreamer/CarstenLS/carstenls.html.
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*, ?-?.
Tyrens Infraconsult, www.tyrens.se/.
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.

Geometrics, Inc. takes no responsibility for any interpretation of data or effects resulting from use of the SeisImager software package or its support of the SeisImager software package.