Shear Wave Velocity Measurements
TR202403

Appendix B

Multichannel Analysis of Surface Waves (MASW) Manual

Provided by

SCI Engineering, Inc.

SCI ENGINEERING, INC.

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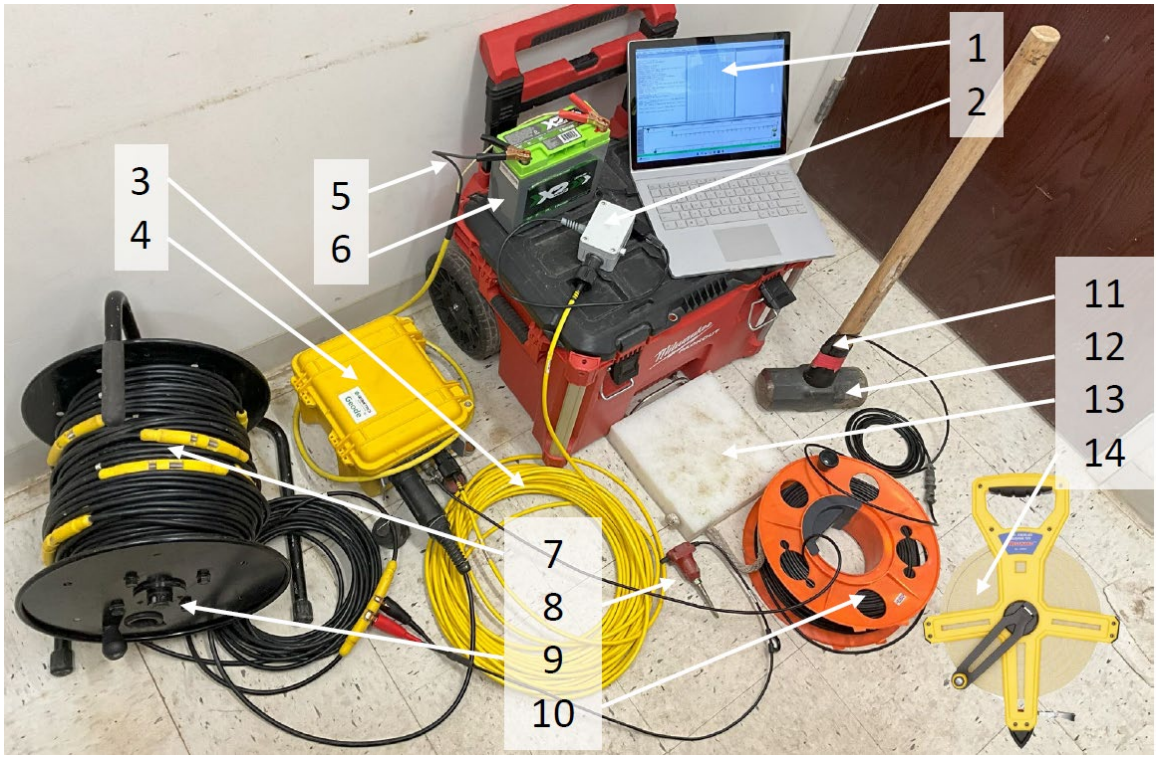
1.0 MASW Field Data Acquisition

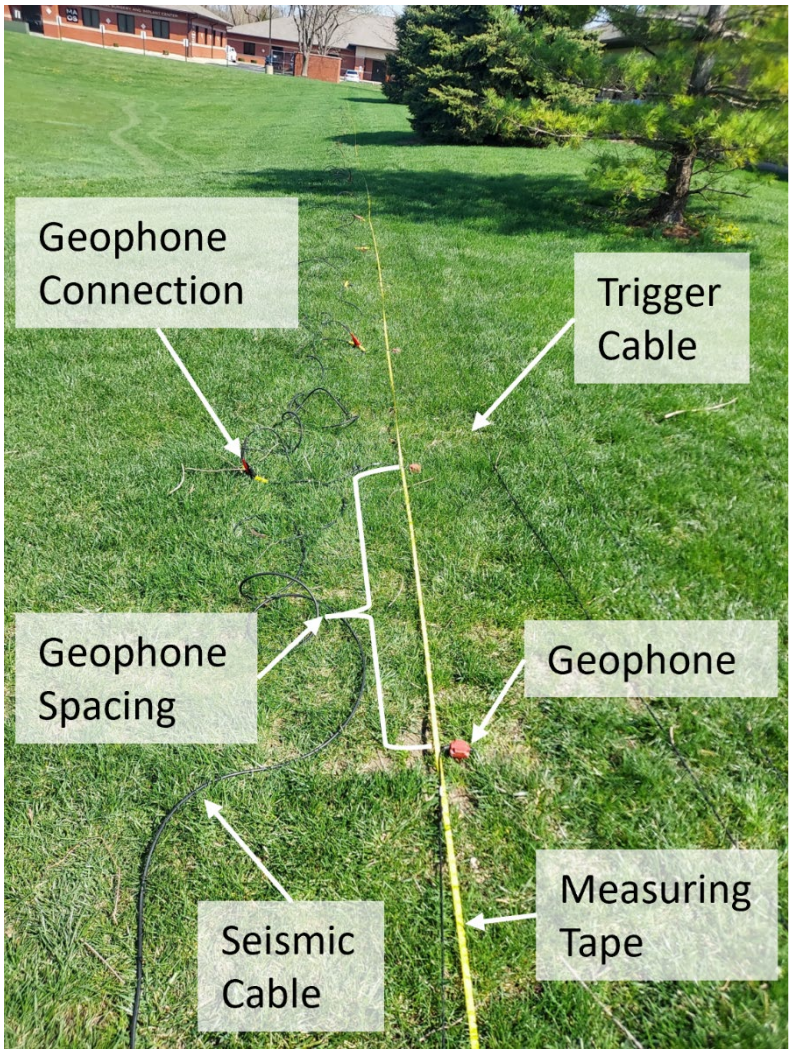
1.1 Field Equipment Setup

1.1.1 Component List for Standard MASW Setup



Photograph of the MASW equipment.

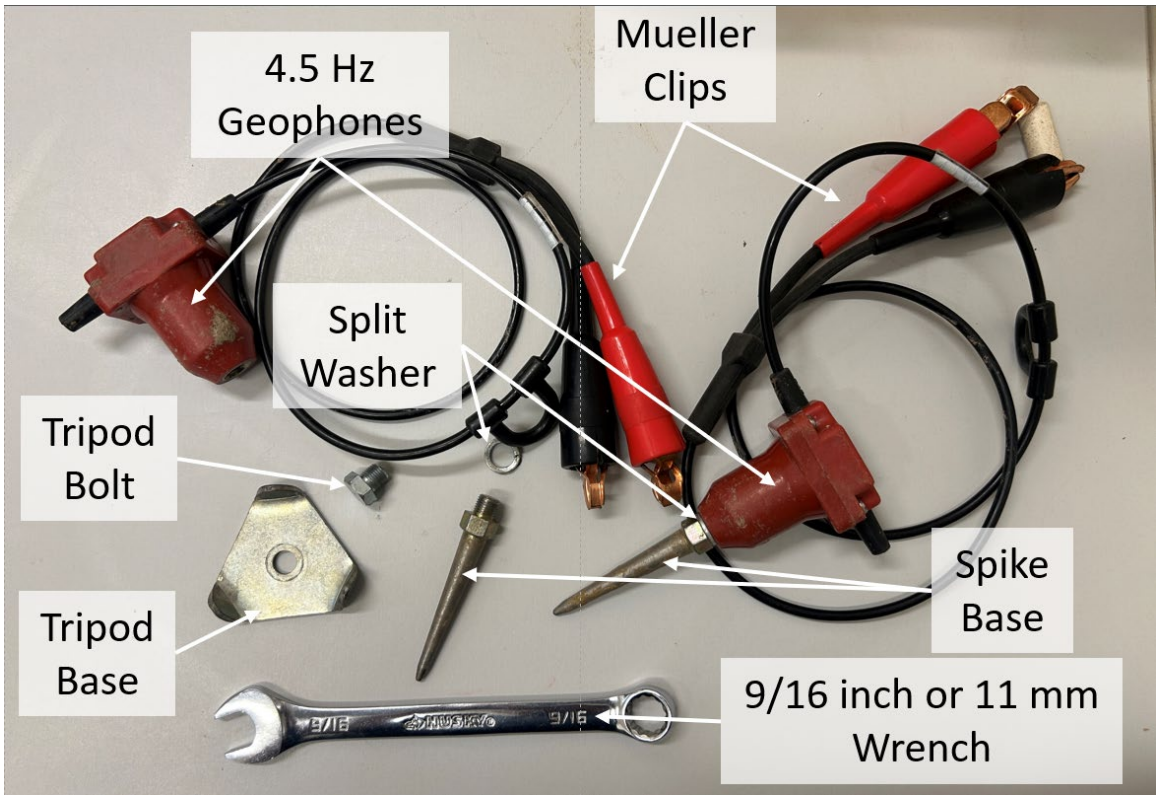
1 – Windows Laptop or Tablet with Single Geode Operating Software (Geometrics Seismodule Controller) installed.
2 – Geode Laptop Adaptor (with ethernet to USB connector, if necessary).
3 – Data Cable.
4 – Geode, 24-channel (seismograph).
5 – Geode (seismograph) Power Cable.
6 – Geode (seismograph) Power Source (12-V battery, AGM deep cycle or Lithium-Ion recommended).
7 – Geophone Spread (Seismic) Cable (with 24 channel connections and 61-socket connectors).
8 – Geophone, Vertical, 4.5Hz (with spike base and Mueller clip connectors).
9 – Free Standing Reel.
10 – Trigger Extension Cable.
11 – Hammer Switch (impact sensor, trigger).
12 – Seismic Source (20-pound sledgehammer recommended).
13 – Strike Plate (e.g., 6x6x1 inches aluminum/steel, and/or 10x10x2 inches polyethylene).
14 – 300-foot Measuring Tape.



Photograph of the seismic array in the field.

1.1.2 Standard Setup Steps

- Determine if using 5-foot, 10-foot, or both geode spacings for the array.
- Check traverse area for obstructions or possible sources of error such as adjacent utilities, large slope changes, pits, structures, etc.
- Use measuring tape to layout testing traverse.
- Layout Seismic Cable for the selected spacing.
- Place Geophones at the correct spacing and connect to Seismic Cable:
    - Geophones should be placed so they sit vertically and level with a little slack in the connecting cable;
    - Adjacent vegetation/debris should be removed so it does not “tap” the geophones in windy weather.
- Layout Trigger cable. Be sure to pull out enough cable to allow for moving the seismic source location to either end of the traverse.

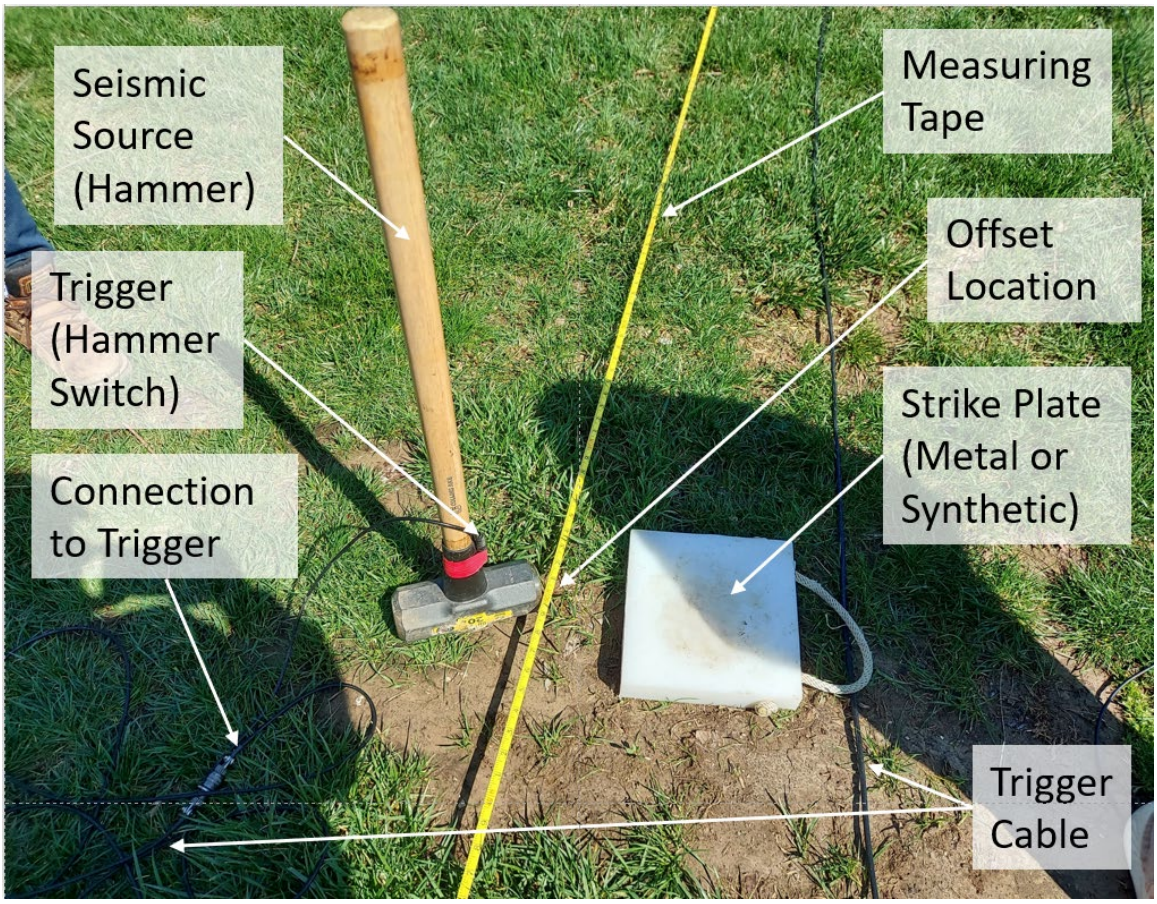


Photograph of 4.5-Hertz Vertical Geophone Setup.

- After confirming site conditions, you may need to adjust the bases on the geophones.
- It is preferred to use the spike bases as the collected data is generally of higher quality.
- Tripod bases are used in paved or areas of hardpan soil that will not take the spike bases.

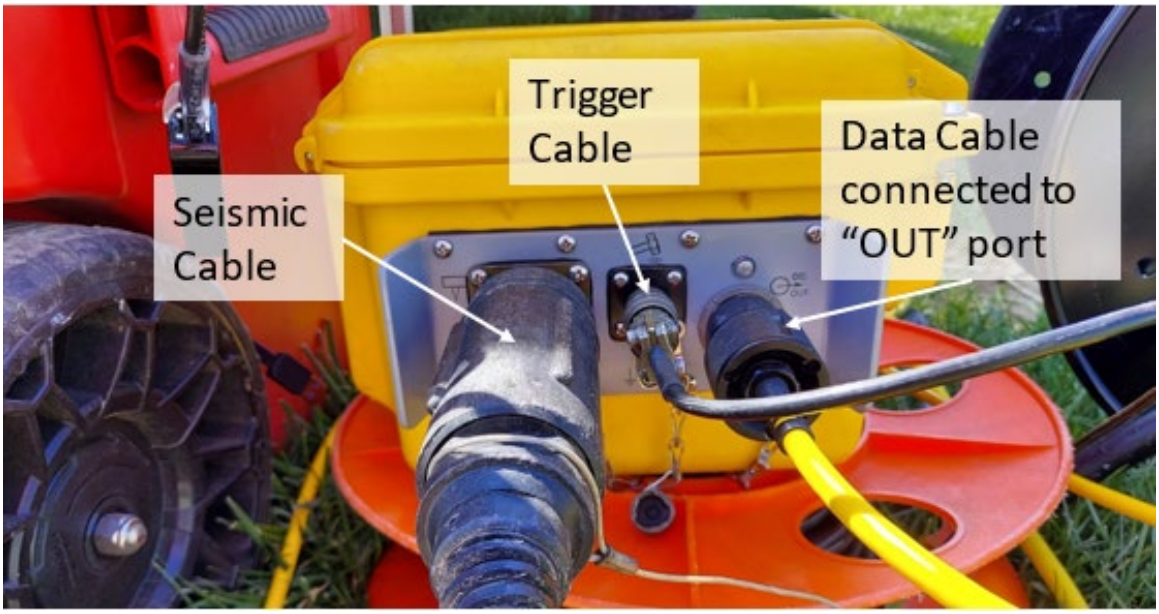
  IMPORTANT: If spike bases cannot be installed with gentle pressure do not use a sledgehammer or stomp/kick geophones with spike bases in an attempt to penetrate dense soils, switch to tripod bases.
- You can use a mix of spike and tripod bases depending on site conditions. Both base types can be installed/removed using a 9/16-inch or 14 mm wrench.
- When using spike bases also use a split ring washer and tighten until washer completely closes.
- When using tripod bases attach using a tripod bolt without a washer. Tighten until the tripod is firmly attached and does not move.
- It is recommended to use a wrench to tighten the bases as hand tightened bases may become loose during setup for testing.

  IMPORTANT: Do not overtighten the bases as this can cause geophone damage.

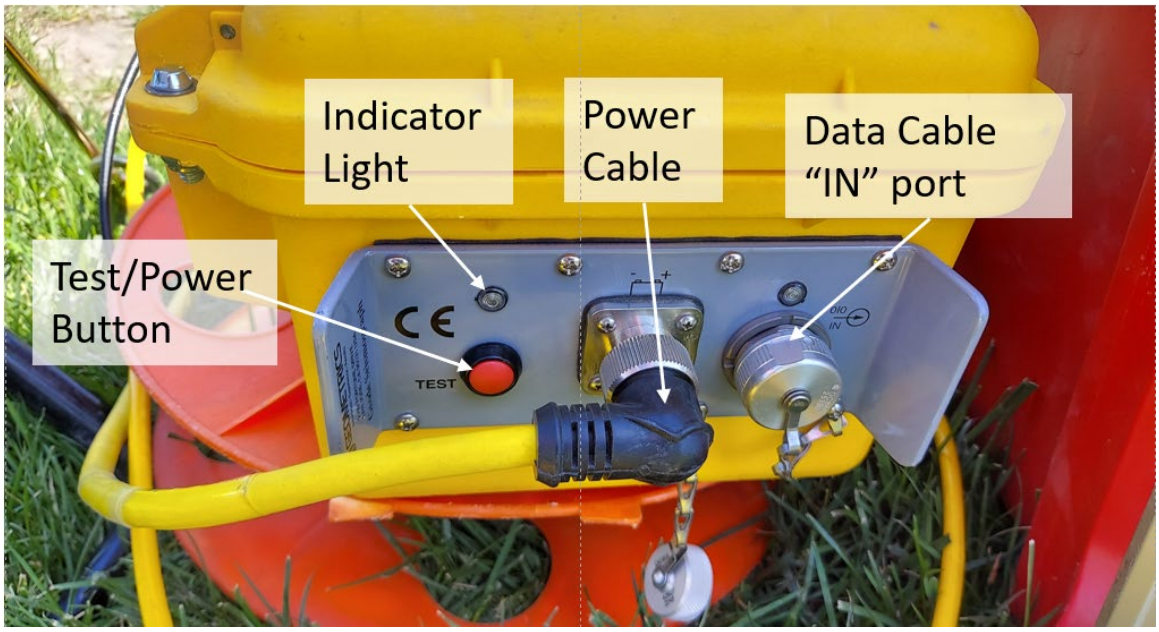


Photograph of seismic source setup

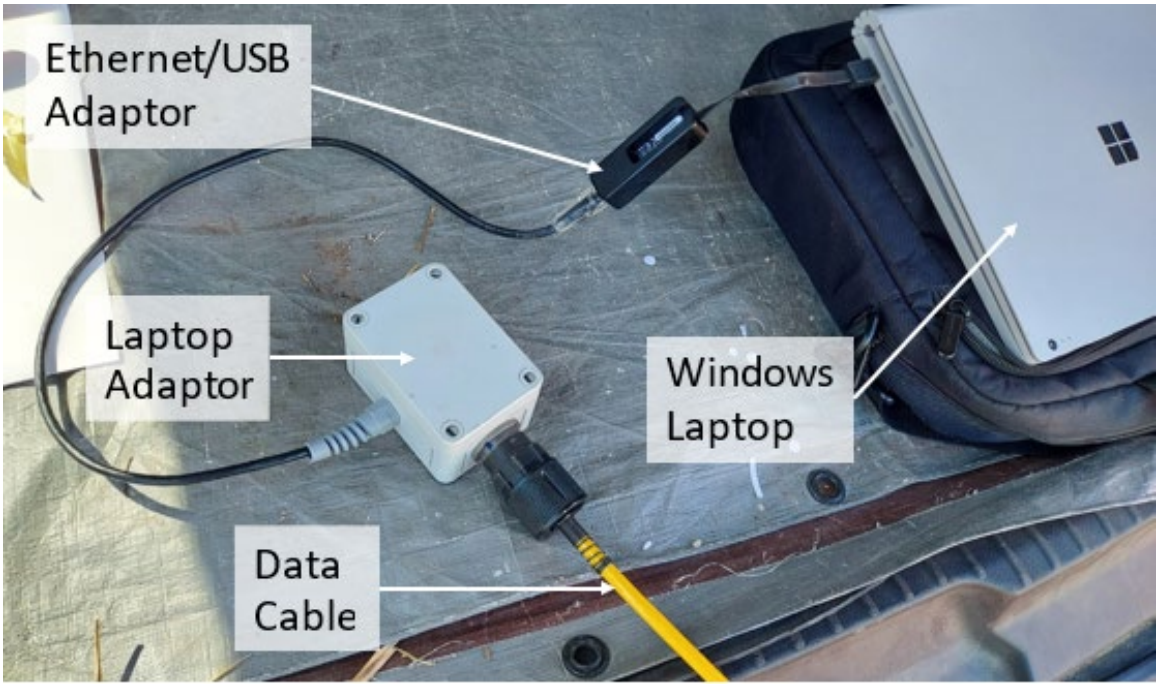
- Place strike plate and sledgehammer (seismic source) at initial offset location.
- If the trigger has not been attached to the sledgehammer, attach it to the sledgehammer on the shaft just below the sledgehammer head:
    - The trigger is directional and has a black dot indicating which side should be facing the sledgehammer;
    - When using the sledgehammer be sure that the trigger is always facing up.
- Connect trigger cable to the impact sensor attached to the sledgehammer.
- If there are multiple crew members setup for the seismograph can begin before the array setup is complete.
- After the array setup has been completed begin seismograph setup if it has not been started already.



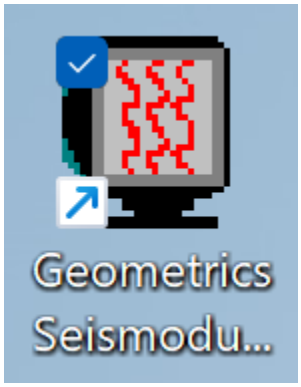
- Connect the Seismic Cable, Trigger Cable, and Data Cable on the left side of the seismograph and the power cable on the right side.



- Connect the power cable to the battery, and turn on the seismograph by pressing the red “Test” button:
    - The indicator light will begin flashing blue when it is powered on.
- Connect the data cable to the laptop adaptor and connect the adaptor to the PC:
    - Use an ethernet to USB connector if necessary.



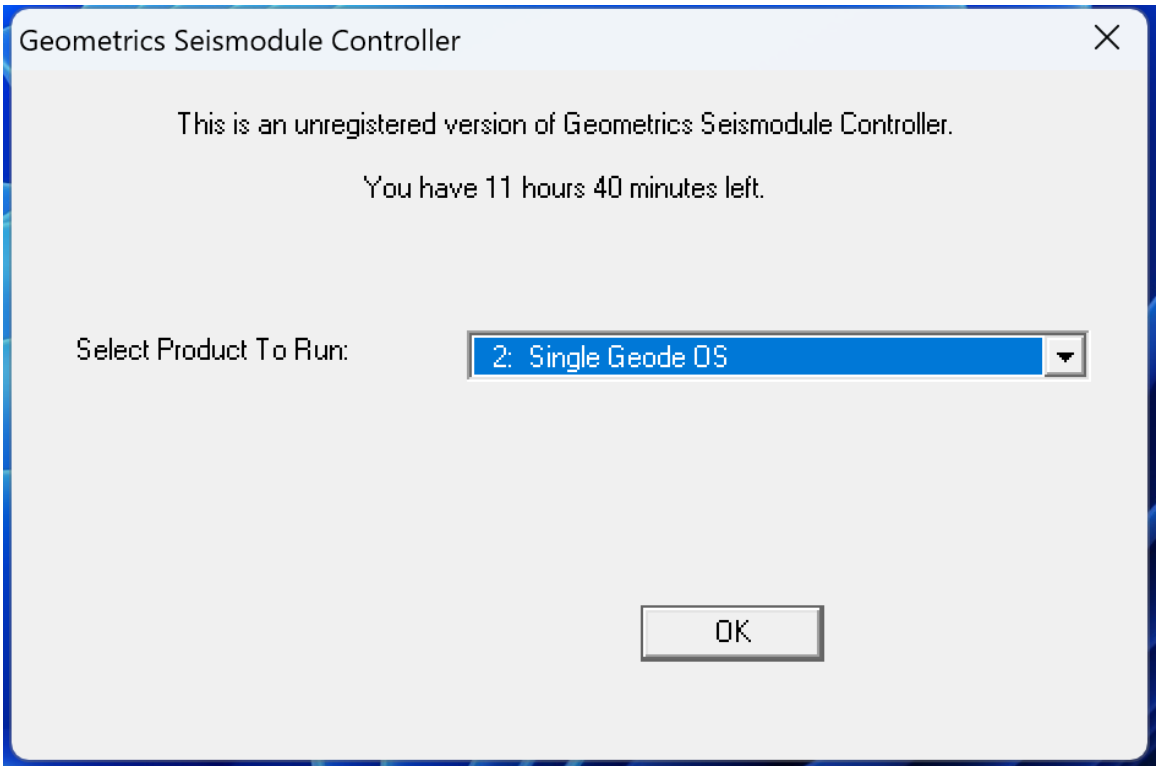
1.2 Data Acquisition: System Parameters and Project Setup



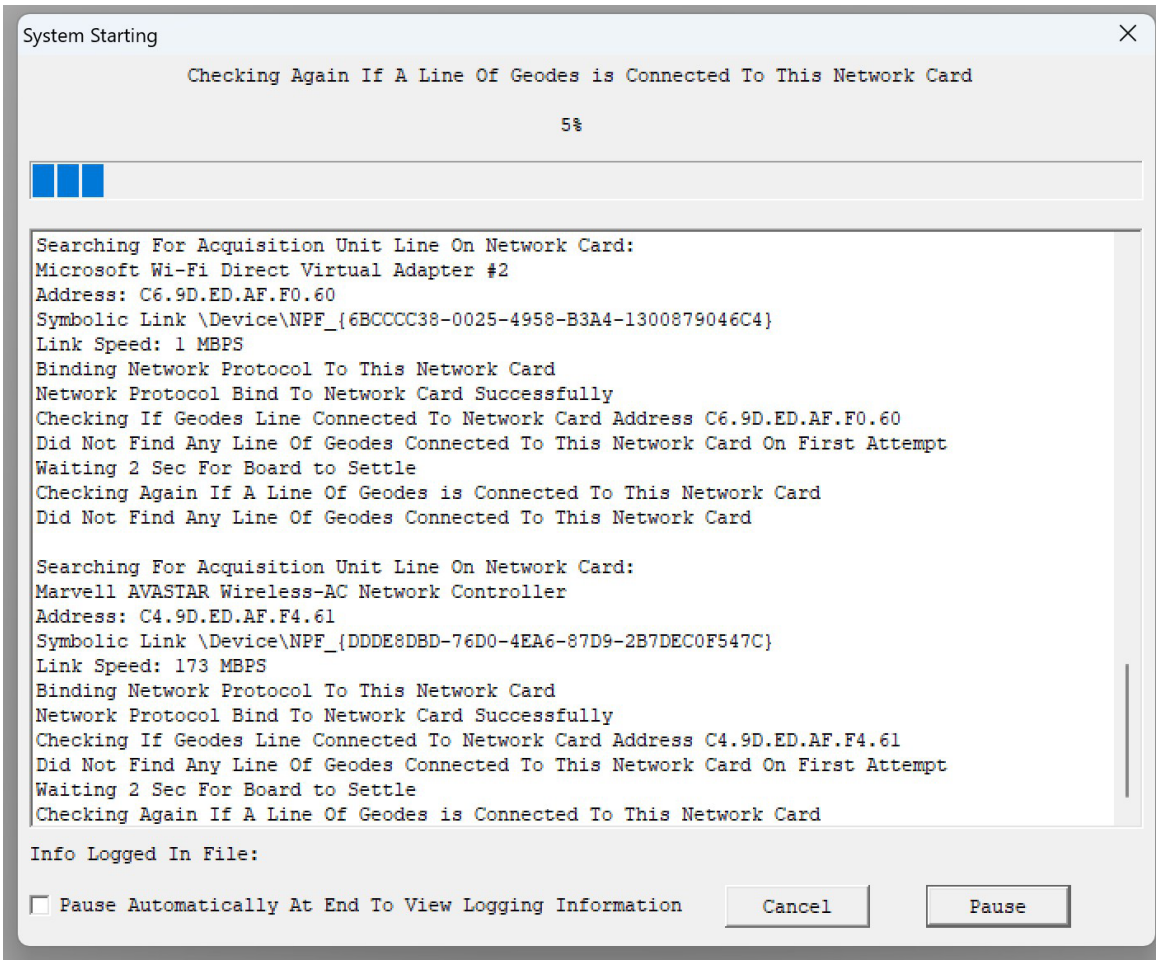
- All seismic data acquisition is conducted using Geometrics Seismodule Controller supplied with the seismograph.
- Verify the array setup is complete by double checking all sensors are installed and all connections are made:
    - Review the “Field Equipment Setup” if necessary.
- If not done already, turn on the seismograph by pressing the red “Test” button:
    - The indicator light will flash blue when it is on.
- Once the seismic array setup is complete and all the cable connections are made you are ready to boot up the PC and start the Geometrics Seismodule Program.

IMPORTANT: You must connect the seismograph and have it running (when the seismograph is on the indicator light will be flashing blue) before booting up your PC.

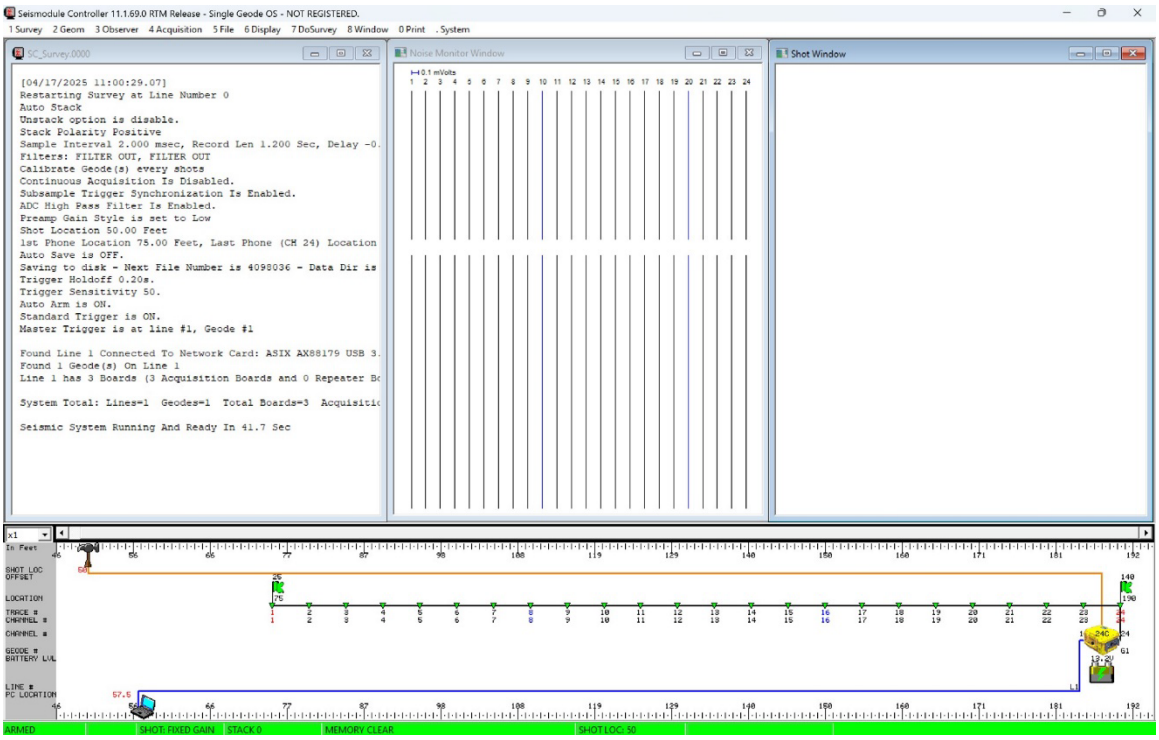
- Once the program starts, if you have not registered the program a Registration dialog box will popup.
- Register the program or select the “Cancel” button if you are not ready to register.
- You can run the program on a trial basis for up to 100 hours total before you must register the program to continue use.
- After you have registered on program startup it will go straight to the System Startup pop-up.



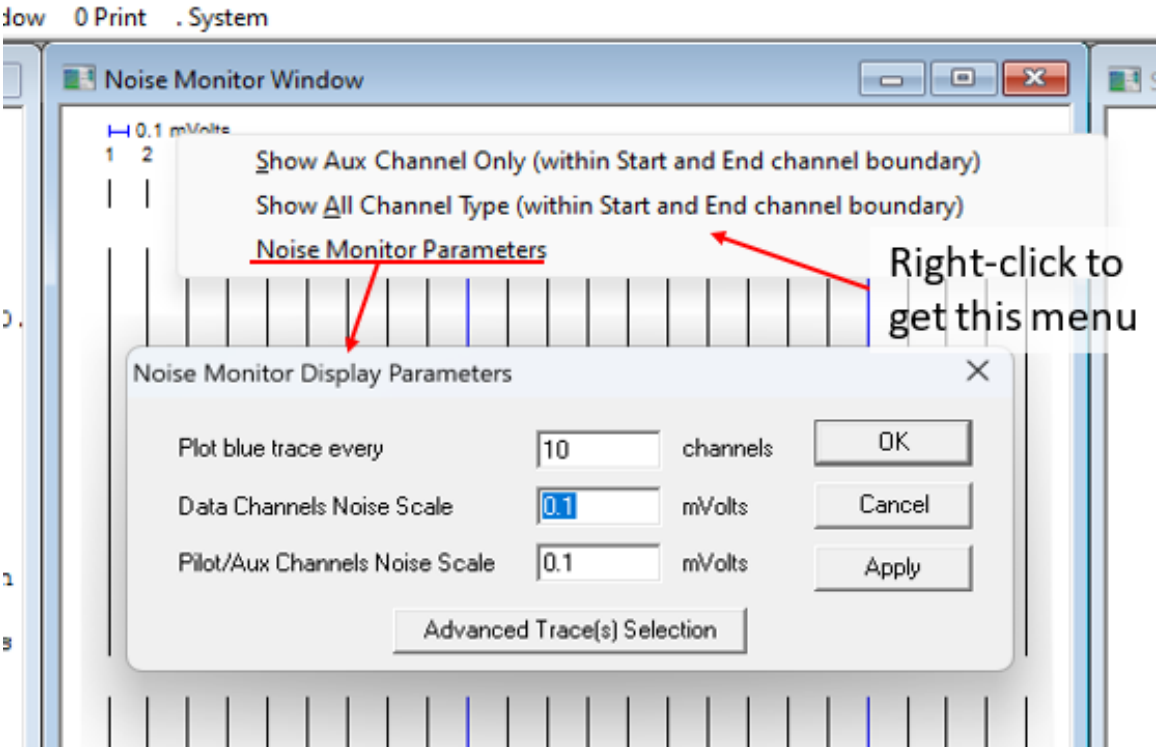
- If you do not register a second pop-up will appear.
- The remaining trial time will be displayed, and you will also be required to select your product.
- Select “2: Single Geode OS” from the drop-down menu and then select “OK”.



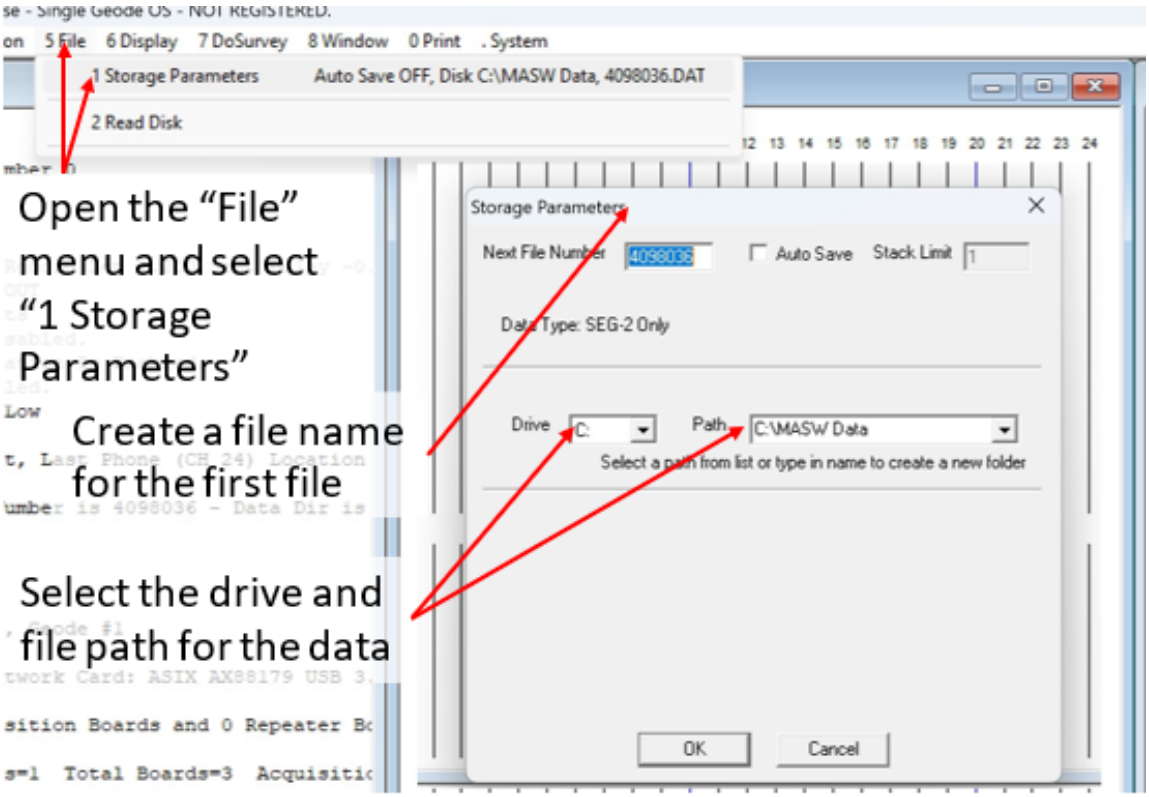
- The System Starting pop-up will appear each time the program is started.
- During the System Starting progress the first time you start the program a series of popups will appear each asking about a particular setting. Leave the default answer on each of them and select “OK”.
- Program Starting includes several system checks, including checking if a geode is connected. If there is a problem with the array setup an error message will show at the bottom of the pop-up and the program will retry several times. If it resolves the error, it will finish setup, if not it will ask if you want to retry, run without a seismograph, or exit the controller. If you are not running a test setup you can select “run without a seismograph” and the program will continue setup.
- If the problem cannot be resolved by the program, exit the controller, turn off the PC and double check all connections and that the Seismograph is on. Once everything is verified, restart the PC and the program.



- Once the system checks are complete the main program window will open up and setup for testing can begin.
- Here you can access all the submenus.
- The “SC_survey.0000” window is the system log. Here you can see any errors in data collection.
- The “Noise Monitor Window” shows real time data from each of the geophone gauges. It can be used to see how much background noise is present onsite and to double check that each gauge is installed and working correctly.
- The “Shot Window” displays the waveform of the recorded data for each geophone each time the trigger starts data recording.



- The Noise Monitor Window displays the real-time status of each gauge as a waveform display and is useful as a quick visual on the status of each gage:
    - You should be able to see each line distinctly;
    - If there is a lot of background noise onsite, the individual line scales may overlap;
    - If the noise scale is set too high, you will only see straight lines;
    - You can adjust the window sensitivity by adjusting the Data Channels Noise Scale.
- To adjust the Data Chanels Noise Scale, right click on window for the options menu pop-up.
- Click on “Noise Monitor Parameters” to open the Display Parameters menu.
- Adjust the “Data Channels Noise Scale”:
    - Typical values range from 0.1 to 0.3;
    - Lower values are generally preferred, but selection is based on user preference;
    - It is not recommended to exceed 0.5 unless there is excessive noise in the data.
- Once parameters are set select “OK” to save.

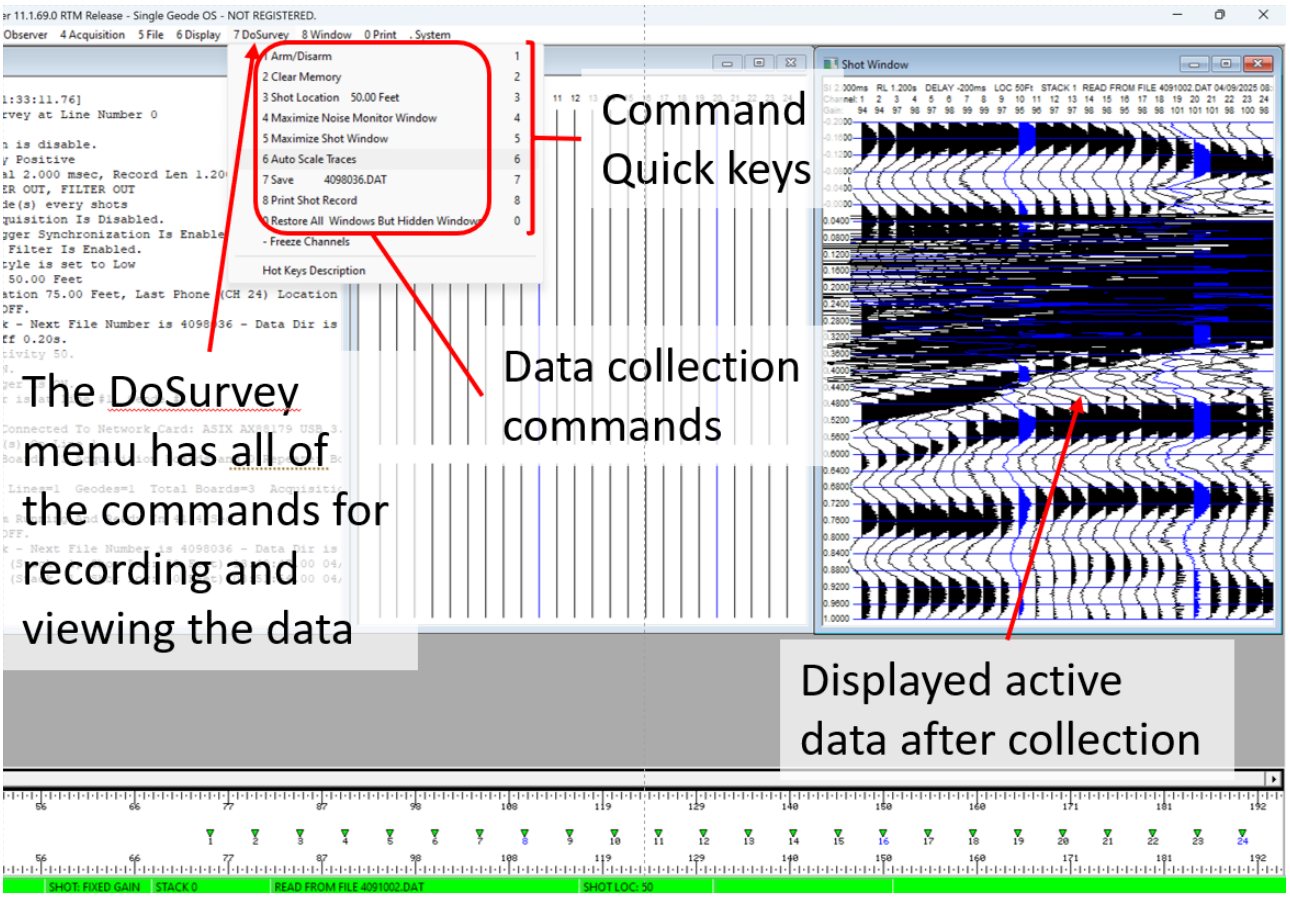


- To save the data files create a folder on the C: drive:
    - In this example we created a folder called "MASW Data".
- To select the file path, open the "File" menu at the top of the screen then select "Storage Parameters".
- In the pop-up select the file path to the folder you created and name the first file:
    - Each time a file is saved the program will incrementally increase the file name by one.

Note: the file name can be only a positive numerical value (no letters or special characters allowed). Some software packages, including SurfSeis have limitations on the file name lengths due to the allowed header size. SurfSeis allows names with the numbers between 0 and 32000. A file name with a higher number could be used, however may appear differently (e. g., as a negative number) during data processing.

- The "Auto Save" checkbox is generally unchecked during Active data collection to allow the user to review the data as it is collected:
    - If the test is being run by one person it is beneficial to leave this box checked so that the user can collect multiple data points while minimizing trips between the PC and the strike location ;

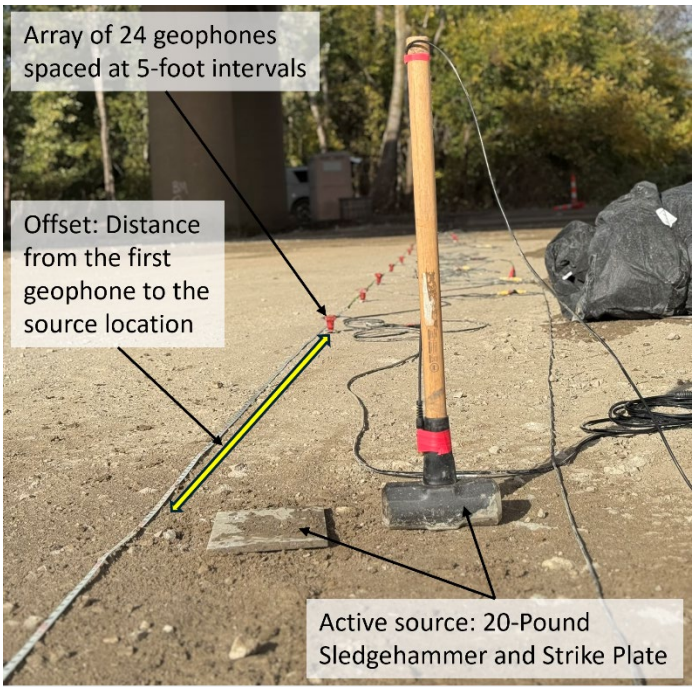
      If you are collecting Passive data this box needs to be checked.
- Once parameters are set select "OK" to save.



- Once all parameters are set you should be ready to begin setup for Active or Passive data collection.
- Commands for data collection are in the “DoSurvey” menu:
    - Each command also has a shortcut key denoted by the number to the right of each command in the menu.
    - These shortcuts save time by allowing the user to use the command without opening the menu.
- The most common commands and their shortcuts are Arm/Disarm (1), Clear Memory (2), Autoscale Traces (6), and Save (7).

1.3 Data Acquisition: Active MASW Data

Photograph of a field staff member prepared to generate acoustic energy for an Active data survey by striking the plate with a 20-pound sledgehammer.



Photograph of field setup for Active MASW survey.

- Active data collection is straightforward once the program is setup. Testing is generally performed with at least two people. One person uses the sledgehammer to create the seismic impacts by hitting the strike plate with the sledgehammer and moves the impact point to each offset location as necessary. The second person monitors the program, signals the first person to strike the plate, reviews the data, if necessary, adjusts the test procedure, saves the data, clears the saved data then repeats the process for the next data set.

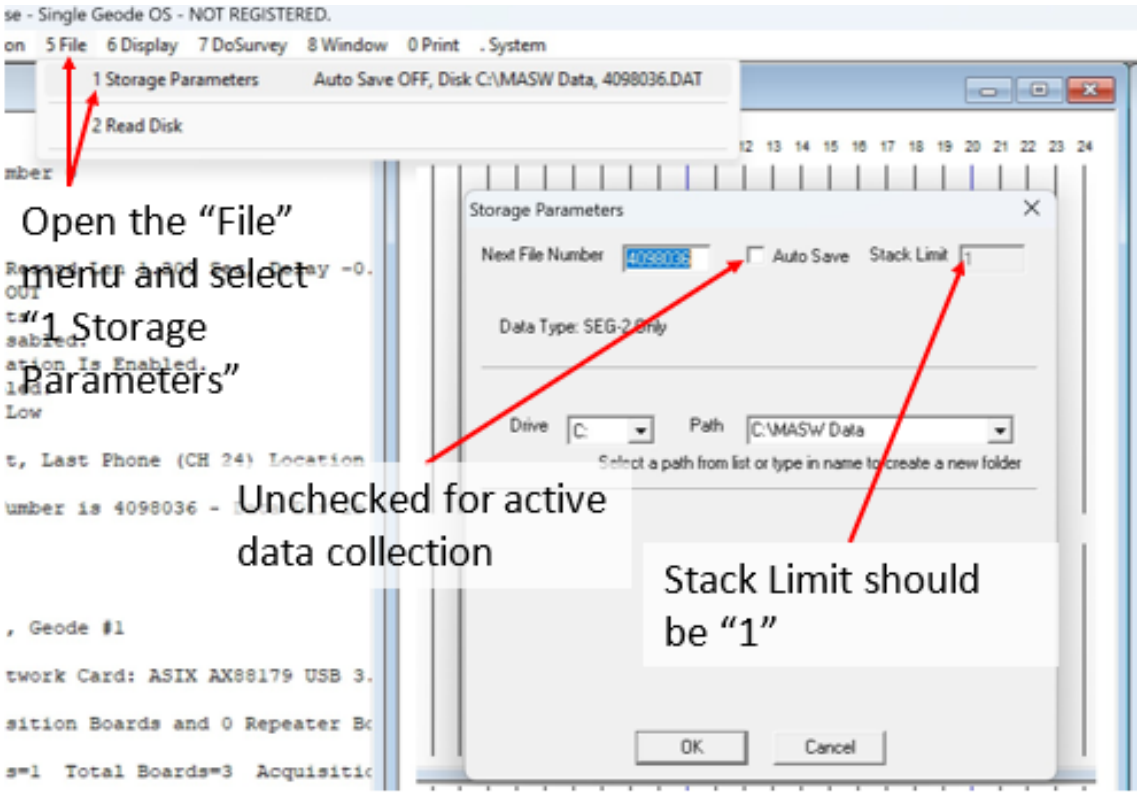
MASW Field Form

Project Name:	Shear Wave VelocityMeasurements TR202403			**Operator:**
Project No.:	2023-0680			**Assistant:**
Date:	5/15/2025			**Source:** 20-pound Sledgehammer
Delay:	-0.2	**Active**	**Passive**	**Site Notes:**
Sample Interval (msec):		0.2	0.2	*Temperature, wind, ground conditions, surface (soil, pavement, etc.)*
Record Length (s):		1	30	*Distances in feet*

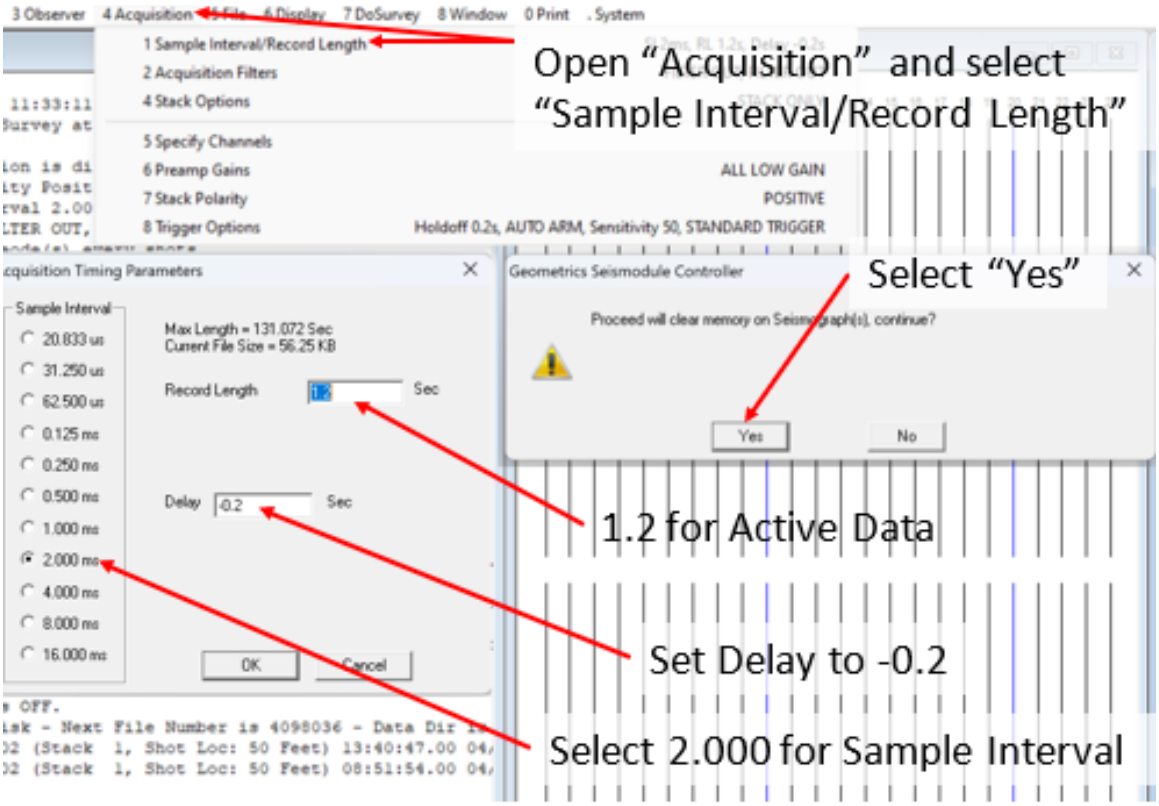
Traverse	File	Array Orientation	Geophone Spacing	Offset	Offset Location	Active	Passive	Notes
T-1	10001-10005	NW-SE	5	10	NW	☑	☐	
T-1	10006-10010	NW-SE	5	25	NW	☑	☐	
T-1	10011-10015	NW-SE	5	-25	SE	☑	☐	
T-1	10016-10020	NW-SE	5	-10	SE	☑	☐	
T-1	10100-10130	NW-SE	5	None	None	☐	☑	Distance to road 20 feet

Example of MASW Field Form used to takes notes during Active and Passive MASW surveys

- It is recommended to use a field data template for taking notes during Active and Passive MASW surveys. The Excel spreadsheet is included in the deliverable and can be modified as needed.

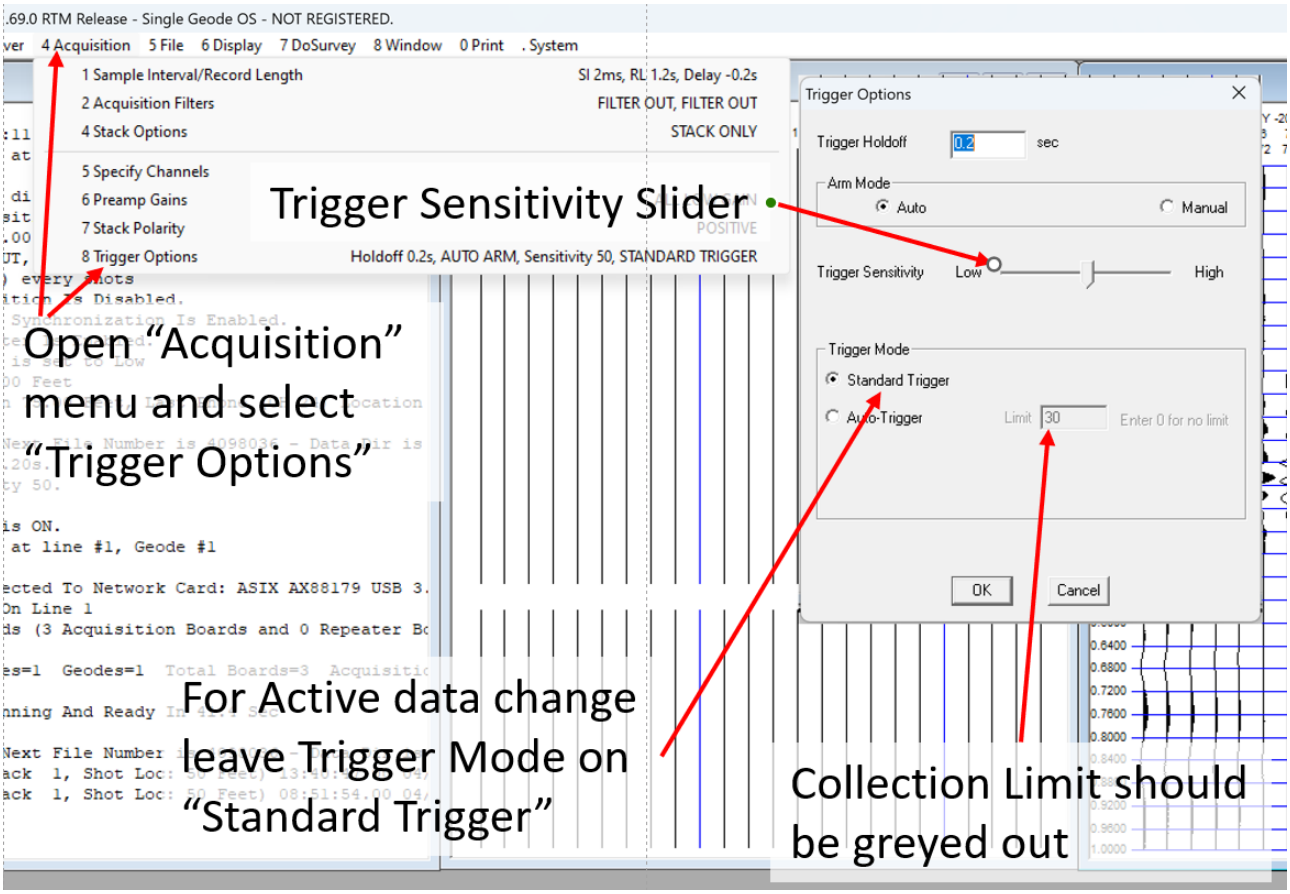


- Active data is generally saved manually.
- To ensure that the data can be saved manually the "Auto Save" needs to be disabled.
- To disable "Auto Save", open the "File" menu at the top of the screen then select "Storage Parameters".
- In the pop-up, leave the "Auto Save" checkbox unchecked to collect Active data.
- Double check that the Stack Limit is set to "1".
- Once parameters are correct, select "OK" to save.

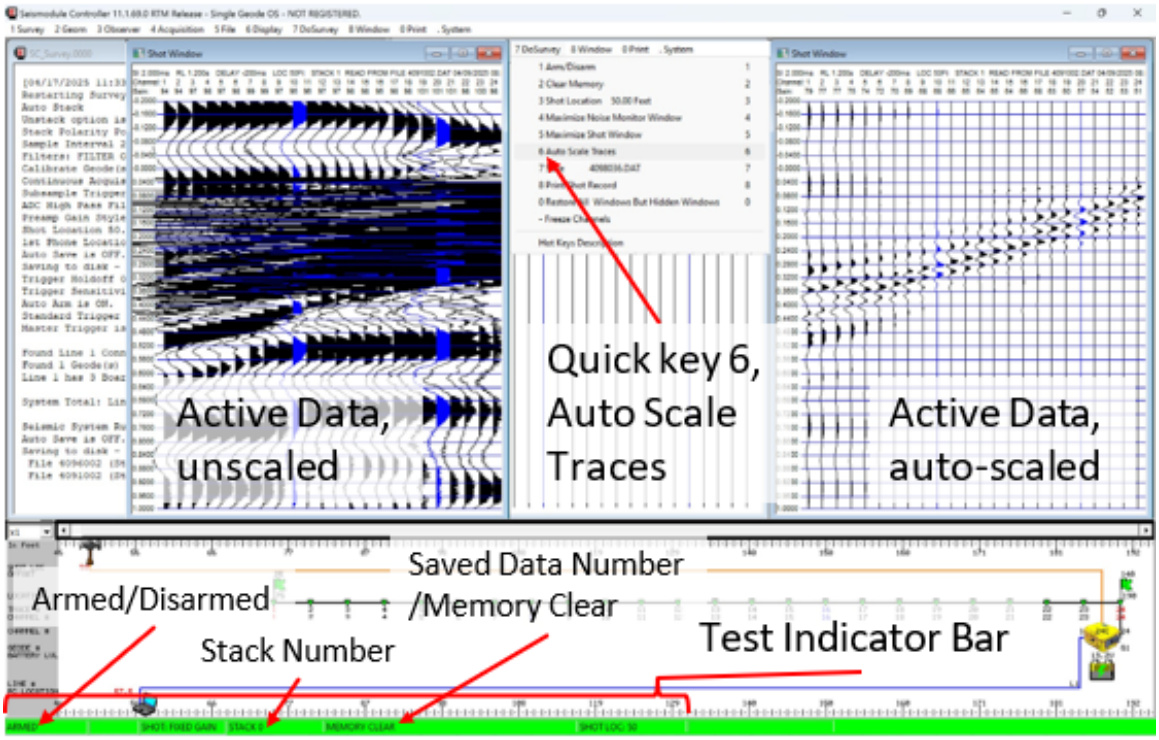


- To set up the recording parameters for data collection open the “Acquisition” menu and select “Sample Interval/Record Length”.
- When you open this a warning will pop-up informing you that collected data will be deleted. If data has not been saved, select no, save the data then re-open and select “Yes”.
- Once the parameters pop-up is open select the Sample Interval. We recommend a sample interval of 2.000 ms for all data.
- Input a Record Length of 1.2 s (seconds with a Delay of -0.2 s for Active data collection.
- Once parameters are set select “OK” to save.

Note: a record length may need to be increased to 2 seconds or more, if a larger geophone spacing is used and/or the shear wave velocities are expected to be relatively low at the test site.



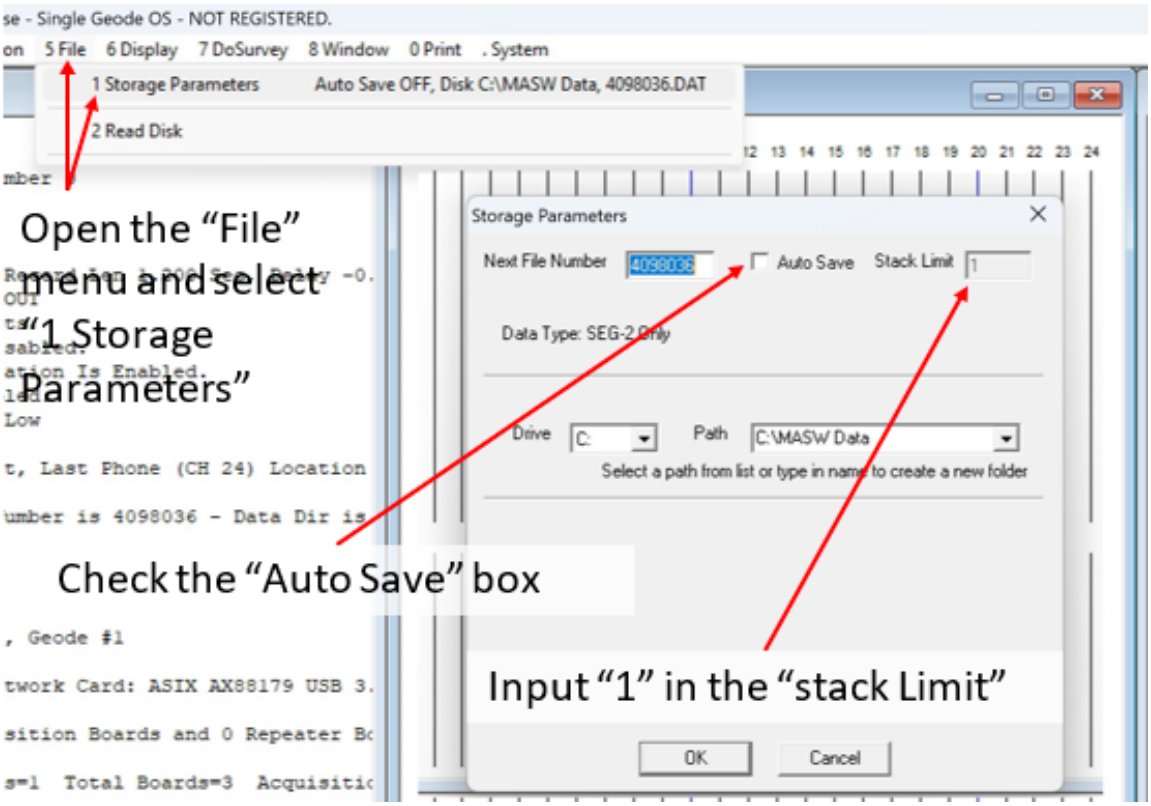
- The default Trigger Parameters are for Active data collection. To check Trigger Parameters for starting data collection open the "Acquisition" menu and select "Trigger Options".
- Trigger sensitivity can be adjusted using the Trigger Sensitivity slider:
    - Trigger sensitivity may need to be adjusted the first time testing is run on a new system or when the trigger sensor is replaced.
- If you are collecting Active data you should not need to change anything here.
- Ensure that under Trigger Mode "Standard Trigger" is selected.
- The "Limit" window should be greyed out.
- Once parameters are set, select "OK" to save.



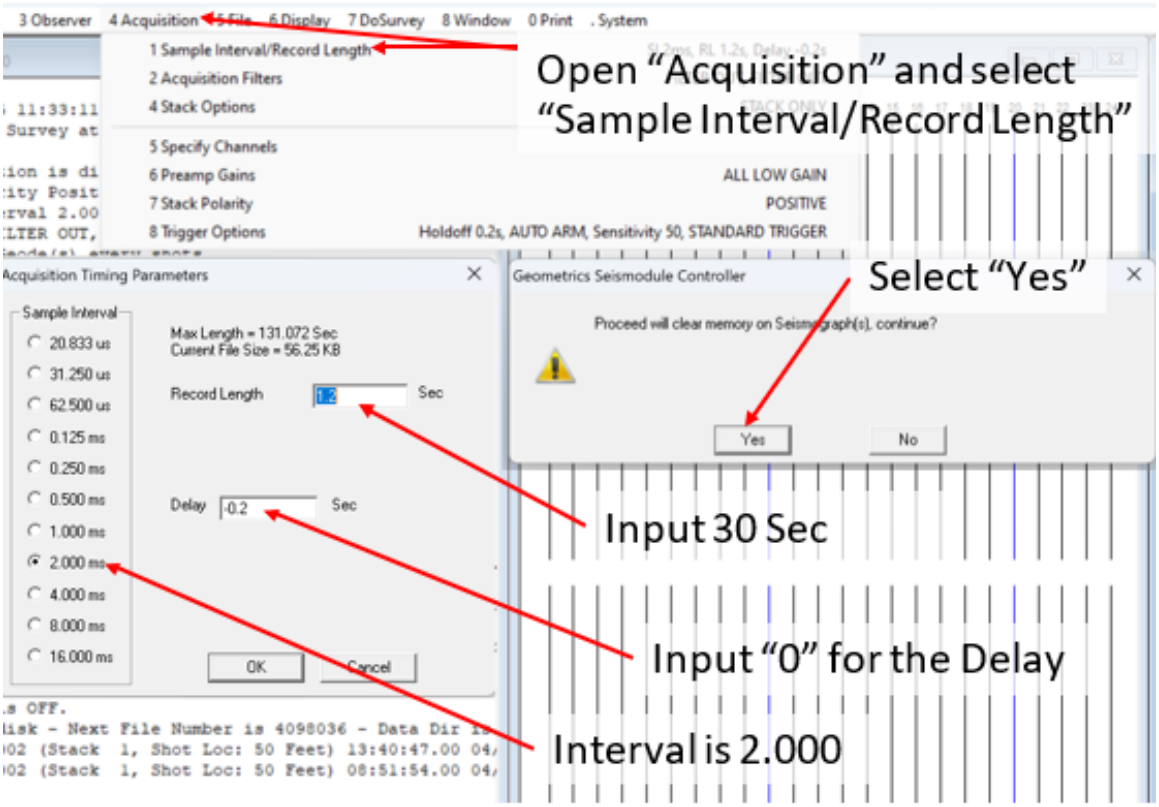
- It is recommended that the program operator double check settings for active testing before start of testing.
- Once the system is armed and the Test Indicator bar is green, signal sledgehammer operator to strike the strike plate:
    - To arm or disarm the system use the Arm/Disarm command (Shortcut key 1)
- When signaled, sledgehammer operator should create a seismic signal by swinging the sledgehammer onto the strike plate:
    - Sledgehammer operator should ensure that the trigger sensor attached to the sledgehammer is always facing the operator during testing, NOT toward the strike plate.
- Once the trigger sensor detects the seismic signal data collection will begin and the indicator bar will turn yellow.
- Once data recording is completed, the indicator bar will turn green again and the data will be displayed in the Shot Window.
- If the data is jumbled (left window above) Auto Scale Traces to rescale the data (right window above).
- If data is not acceptable, Clear Memory (hotkey 2) and repeat. If data is acceptable, Save (hotkey 7) then Clear Memory and repeat:
    - Typical testing at each offset consists of five (5) strikes.
- Once enough data is collected at the current offset, have the sledgehammer operator move the strike plate to the next offset and repeat. Do this for each offset location.
- Disarm the program after testing is complete.

1.4 Data Acquisition: Passive MASW Data

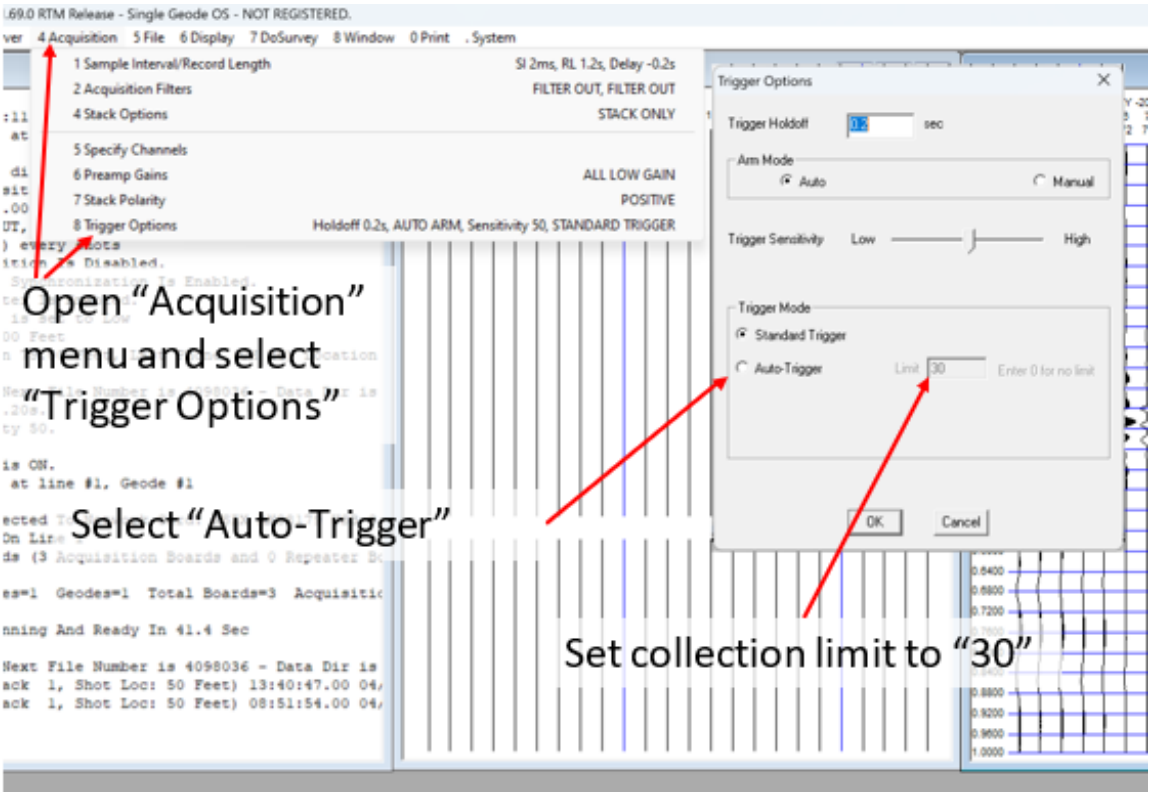
Passive data collection is also very straightforward. Once the program is setup and the testing is started it proceeds independently recording and saving the data automatically until the required number of data files have been completed. It is best practice to have someone monitoring the program as it collects data to ensure data collection is proceeding as planned and to make adjustments if any problems occur.



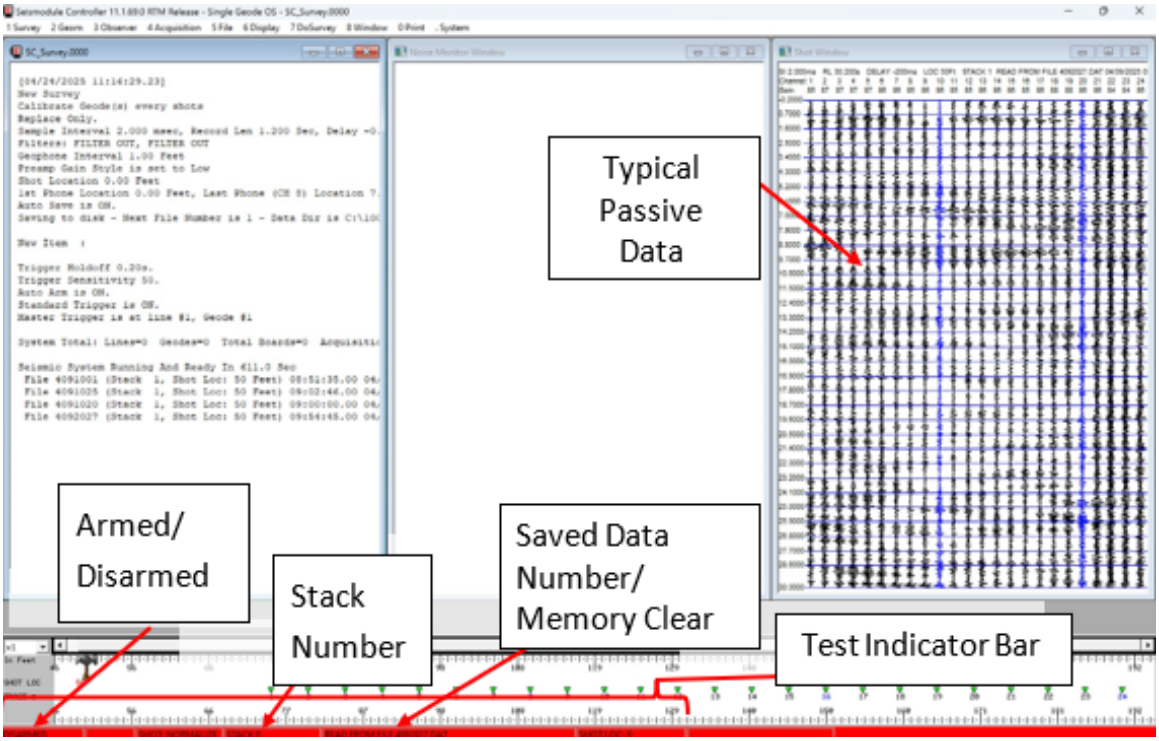
- Before changing setting for Passive data collection ensure that the program is Disarmed.
- Auto Saving is required for Passive data collection. To activate "Auto Save", open the "File" menu at the top of the screen then select "Storage Parameters".
- In the pop-up, select the "Auto Save" checkbox.
- Ensure that the Stack Limit is set to "1".
- Once parameters are set, select "OK" to save.



- To set up the recording parameters for Passive data collection open the "Acquisition" menu and select "Sample Interval/Record Length".
- When you open this a warning will pop-up informing you that collected data will be deleted. If data has not been saved, select no, save the data then re-open and select "Yes".
- Once the parameters pop-up is open select the Sample Interval. We recommend a sample interval of 2.000 ms for all data. The sample interval of 1.000 ms can be also used, however it will increase the data file size.
- Input a Record Length of at least "30" s with a Delay of "0" s.
- Once parameters are set select "OK" to save.



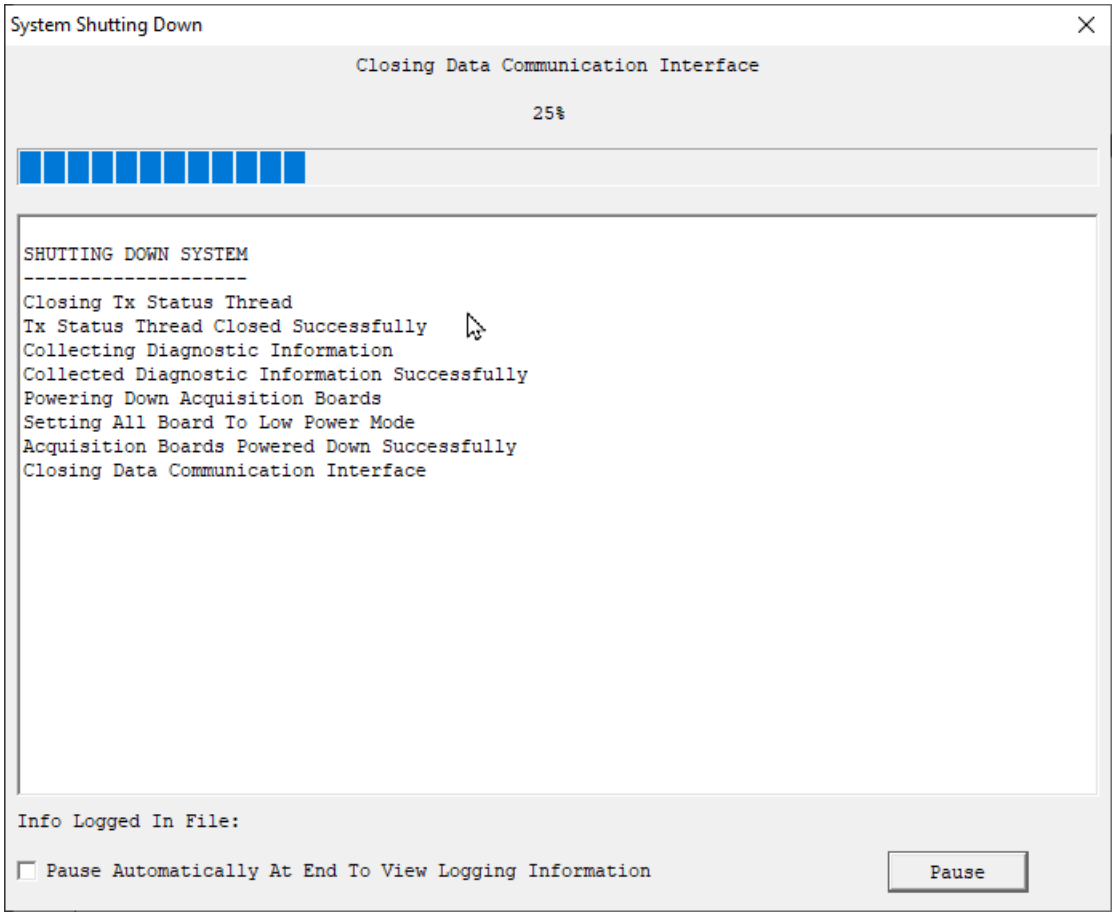
- To set up the trigger parameters for starting data collection open the “Acquisition” menu and select “Trigger Options”.
- Change the Trigger mode from “Standard” to “Auto” Trigger.
- Input the number of files to record in the “limit” window. We recommend 30.
- Once parameters are set select “OK” to save.



- If Active testing was performed prior to Passive testing, disarm the unit before changing settings for Passive testing to prevent premature starting of testing.
- Once settings are completed and double-checked, arm the system.
- If data collection does not start automatically, press the “T” key to manually trigger testing:
    - The indicator bar should turn yellow once testing begins.
- Observe the data during collection to ensure data quality and to make any adjustments or restart the testing if there are any problems.
- Testing should continue automatically saving each file and proceeding to the next test until the collection limit has been reached:
    - When testing is complete system will automatically disarm.

1.5 Data Acquisition: System Shutdown

- Once testing is complete, check the saved file folder to ensure that all required data is saved.
- Once saved data is verified shutdown the Seismodule Controller program by clicking the close program key in the upper right corner.
- When the program closes a shutdown popup will appear:
    - Do not unplug or turn off the Geode until the shutdown procedure for the Seismodule controller is completed.
    - You can up-plug the trigger and data collection cable while the program shuts down.

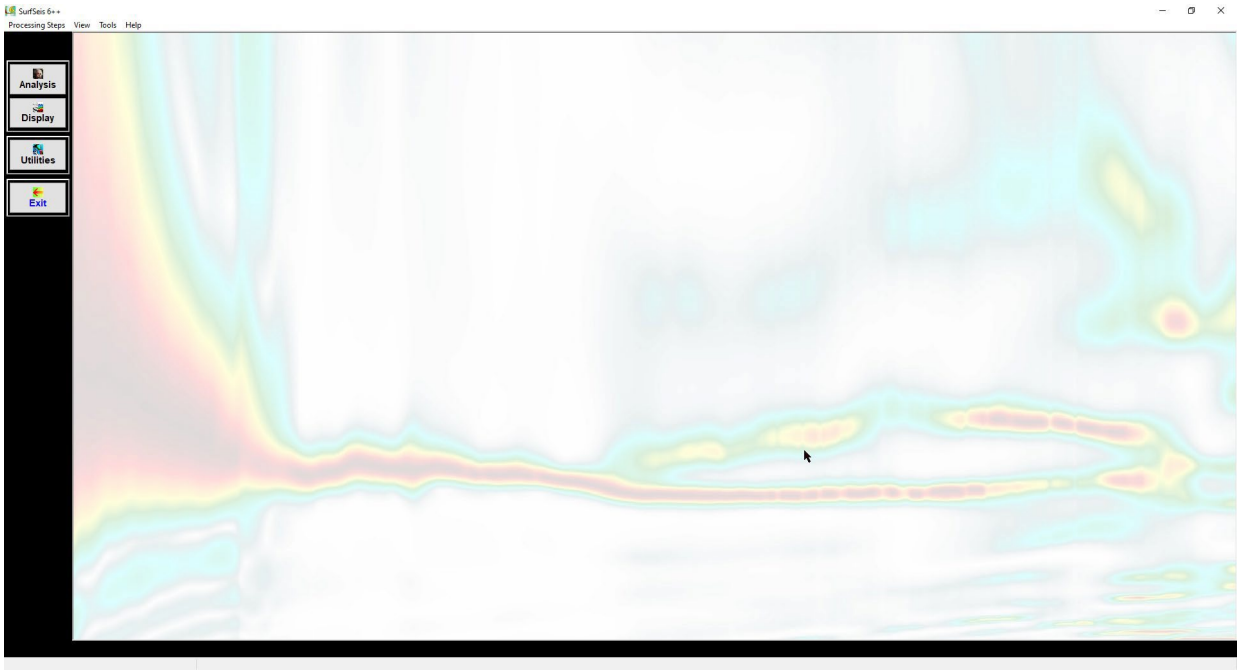


2.0 MASW Data Processing in SurfSeis

The fundamental data processing steps for both Active and Passive MASW surveys are outlined in this section. It is important to emphasize that the recommended workflow is provided for reference purposes only. This approach is based on the specific test data acquired during this project and may be adjusted or modified as needed to accommodate different site conditions or project requirements.

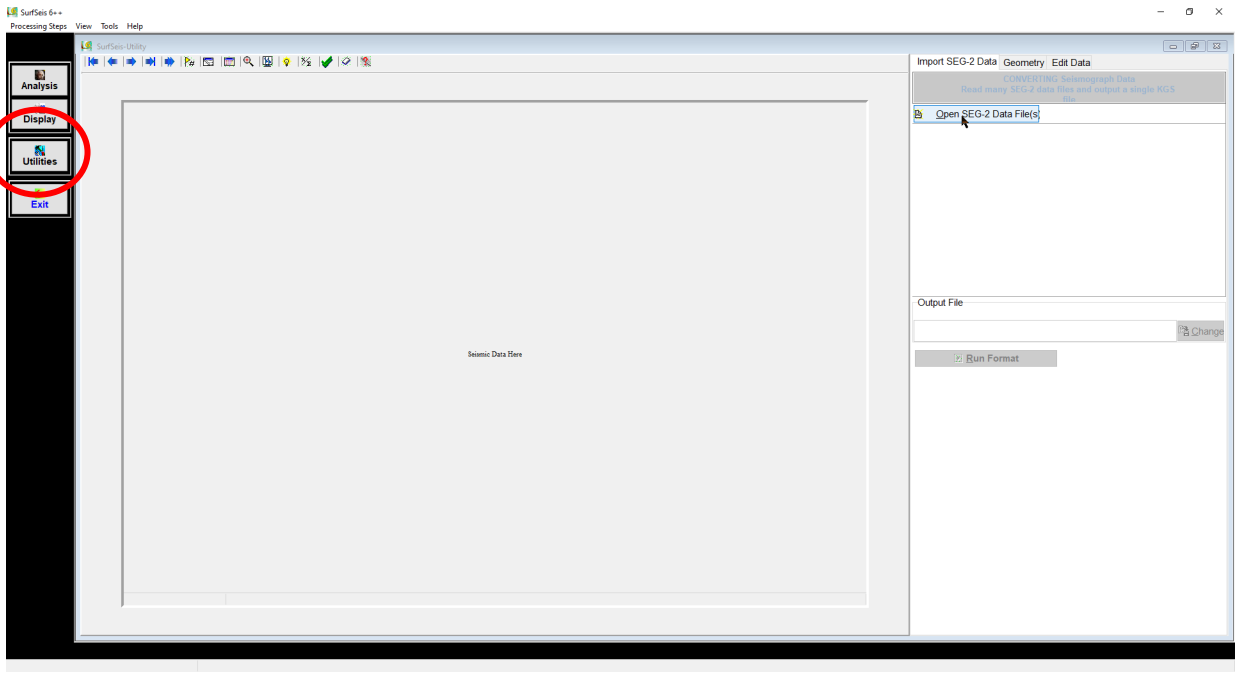
2.1 Active Data Processing

2.1.1 Data Import

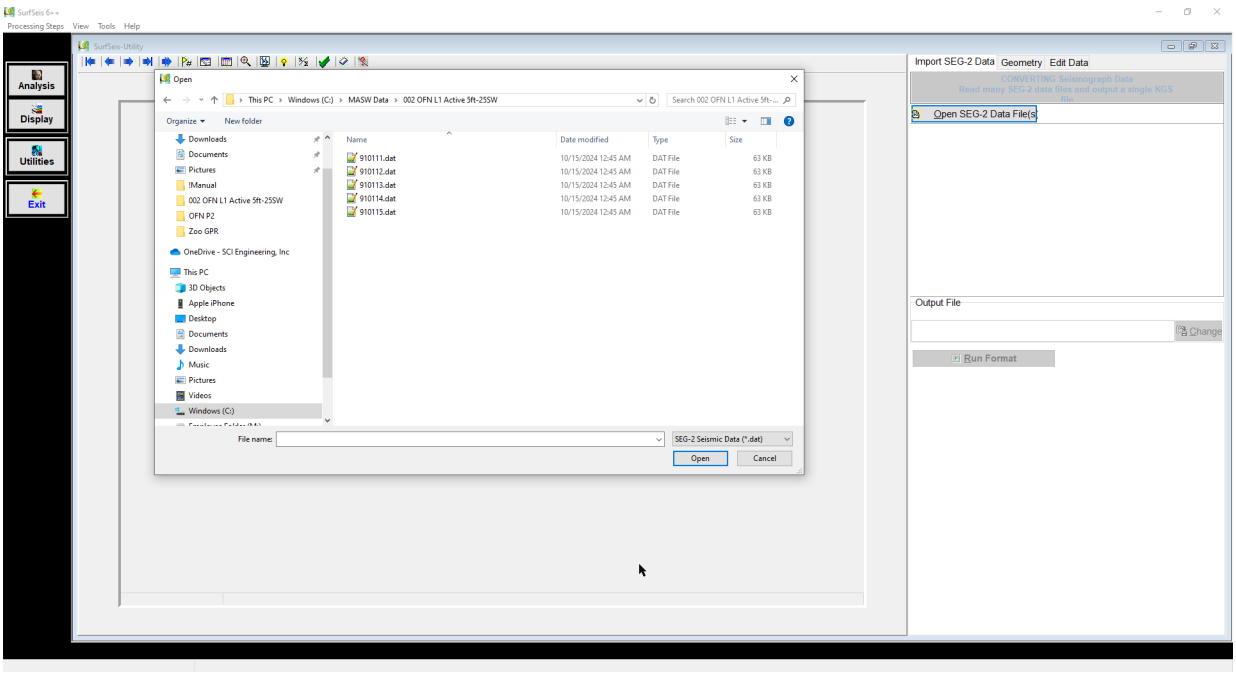


- Organize collected MASW field data (files in SEG2 format) in a local folder, ideally on your C: drive for easy access. Create subfolders for each line and acquisition type (Active or Passive).

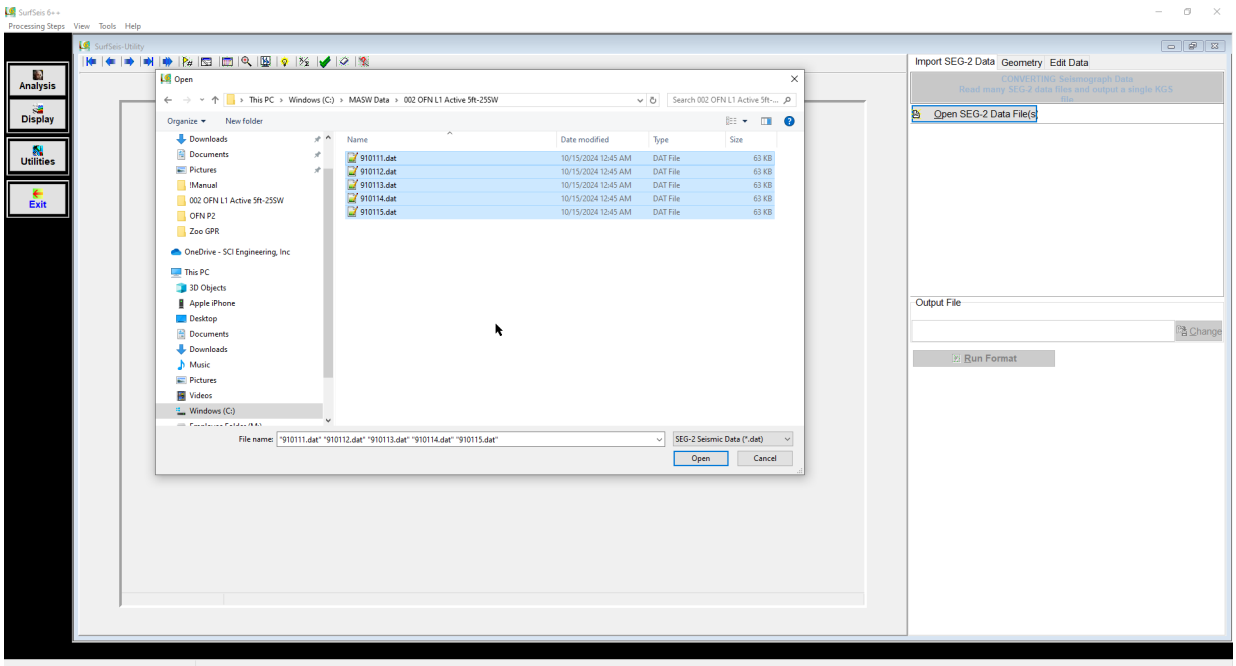
- Launch SurfSeis. Make sure the software USB dongle is plugged in before the software.



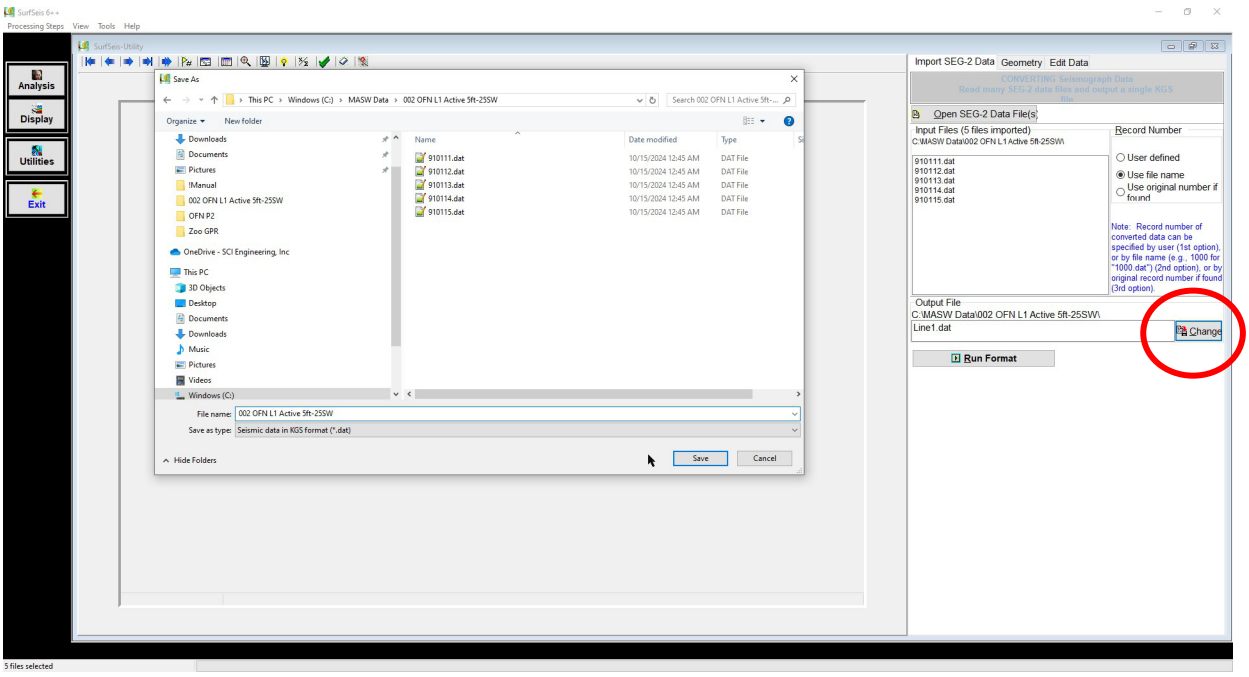
- Click **Utilities** tab on the left. Navigate to **Import SEG-2 Data Files(s)**.



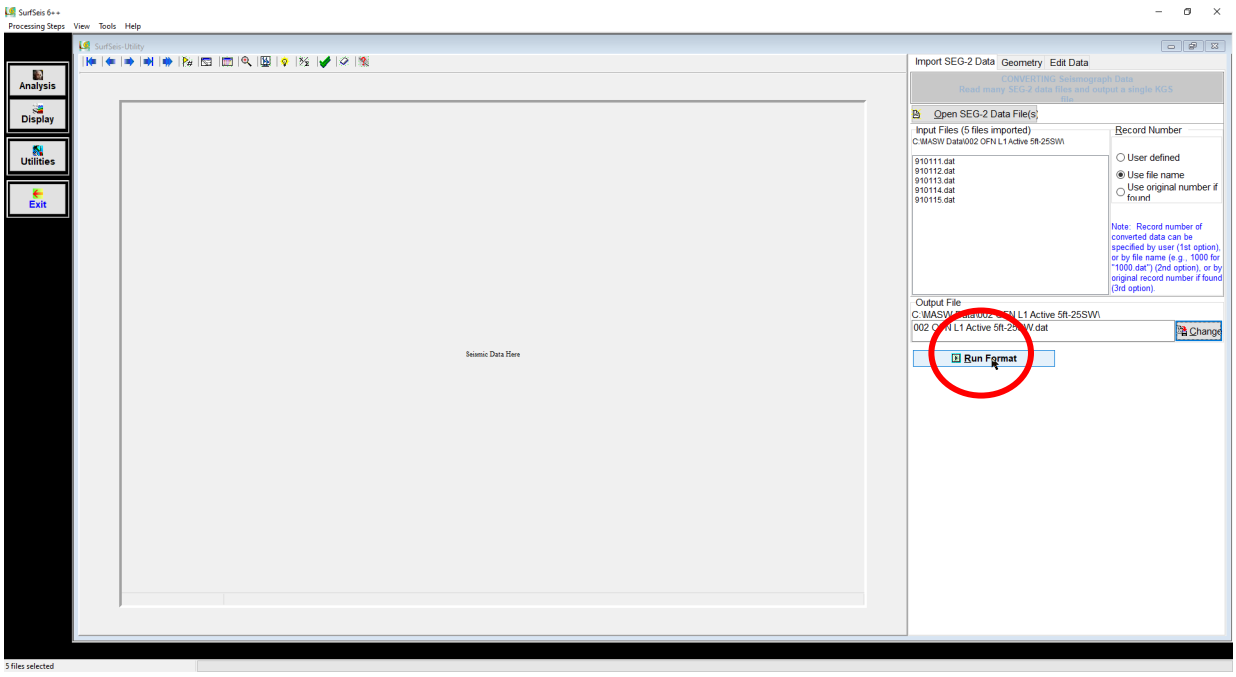
- Navigate to the folder with the data to be processed.



- Select and load your SEG2 files (5 files/records in this example).

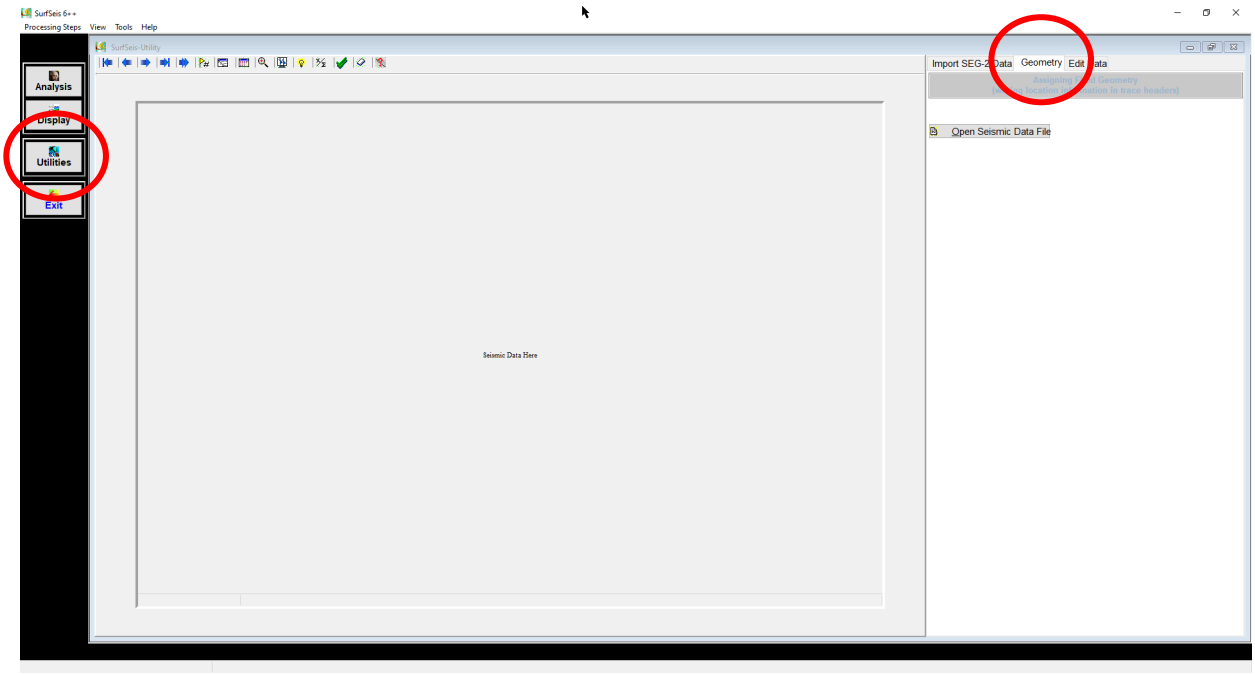


- In the **Output File** click **Change** and name the file logically (e.g., 'Line01_5ft_25ft_SW').

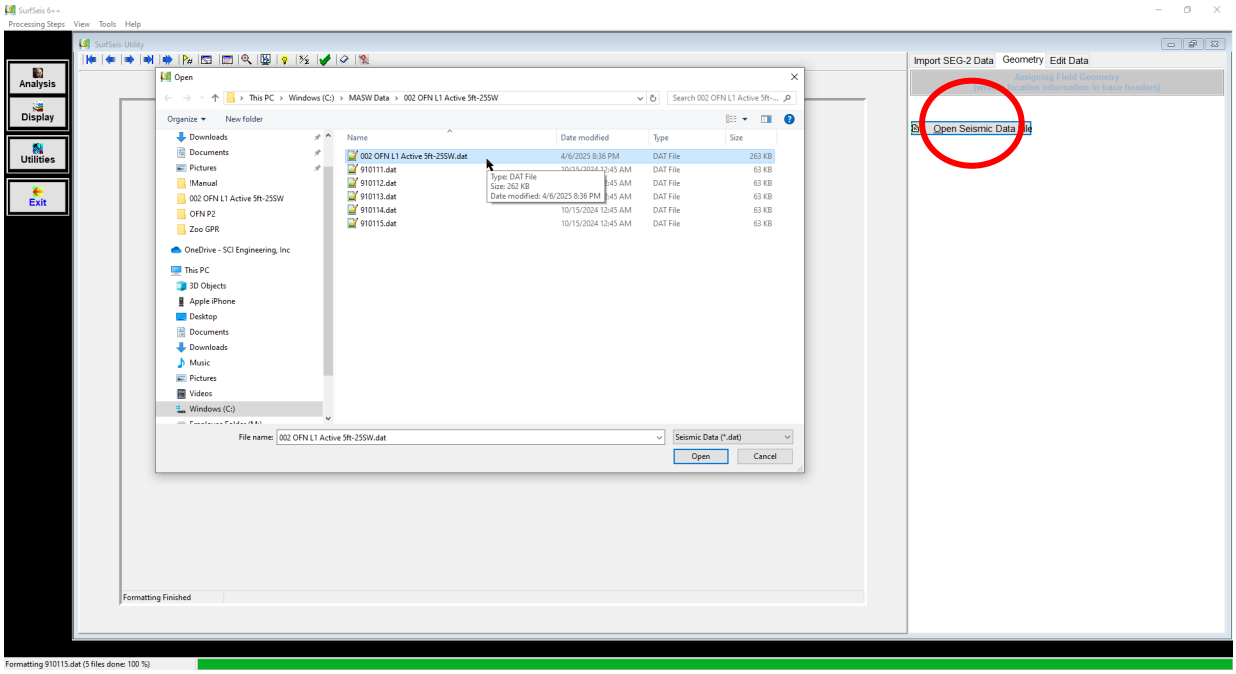


- Click **Run Format**. A new file will with all the converted data will be saved in the folder with the data.

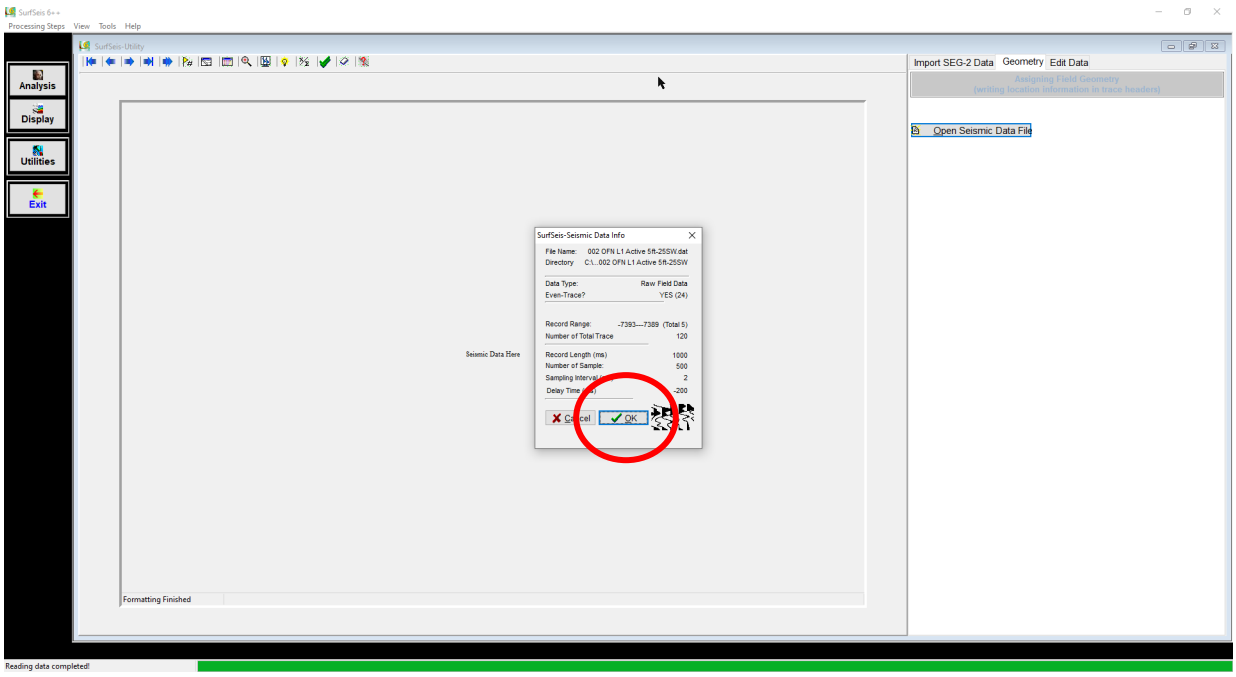
2.1.2 Geometry Assigning



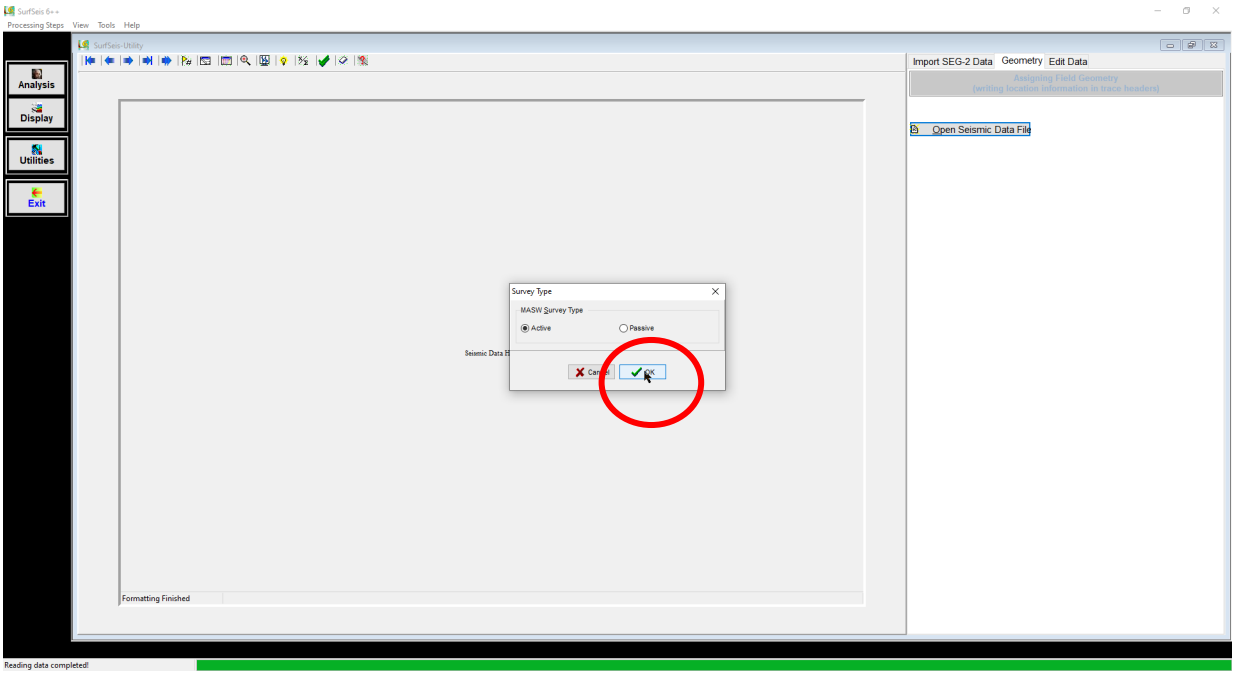
- Still in the **Utilities** tab. Navigate to **Geometry,** click **Open Seismic Data File**.



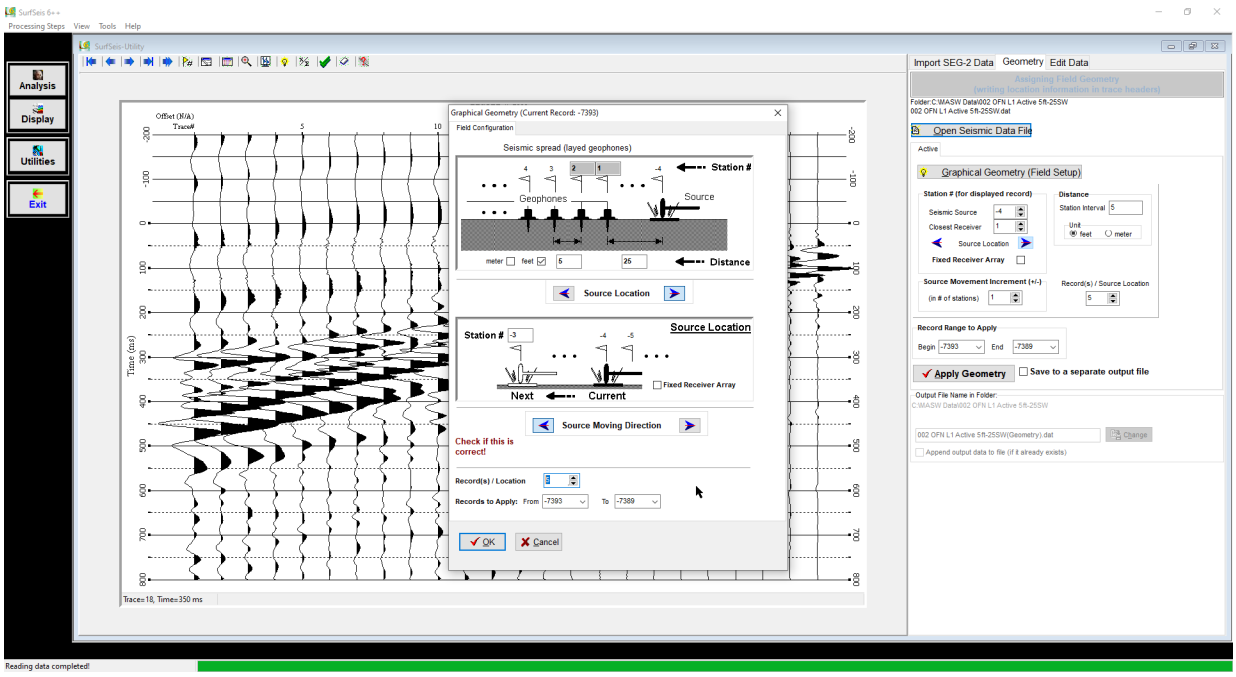
- Select the file that was created in the previous step and click **Open**.



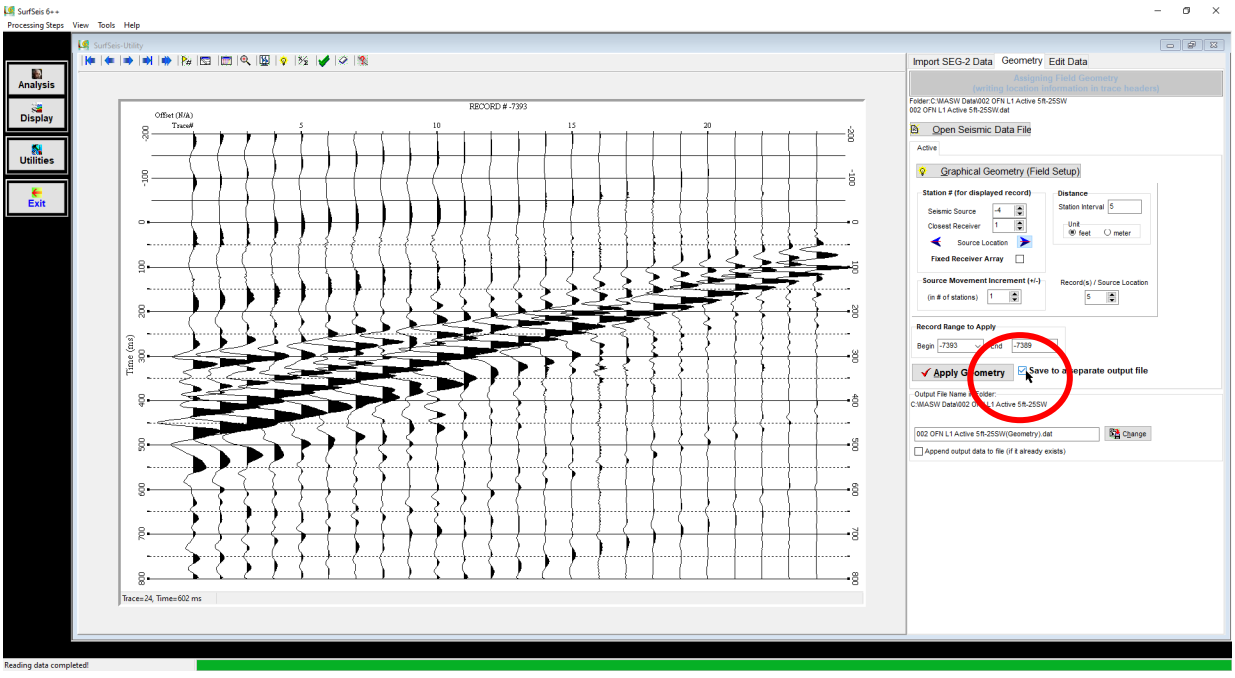
- A **SurfSeis-Seismic Data Info** window with information about the collected data will show. Click **Ok** to continue.



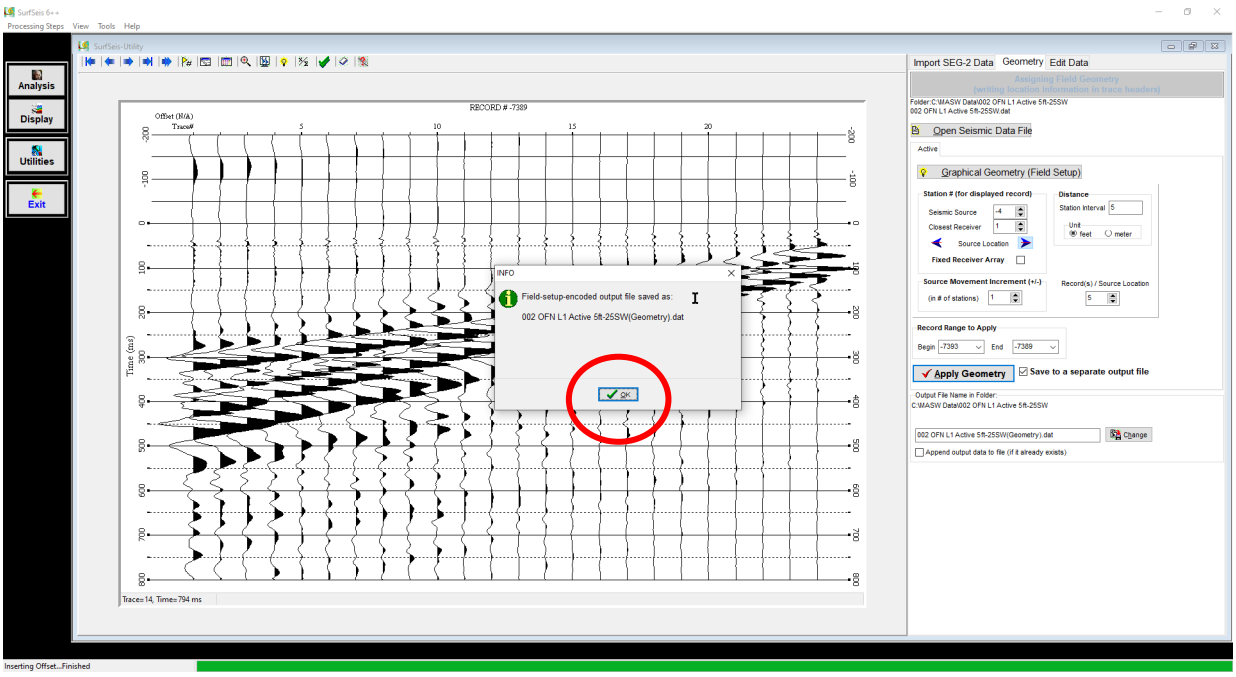
- **Survey Type** window will appear. Select **Active** and click **OK** to continue.



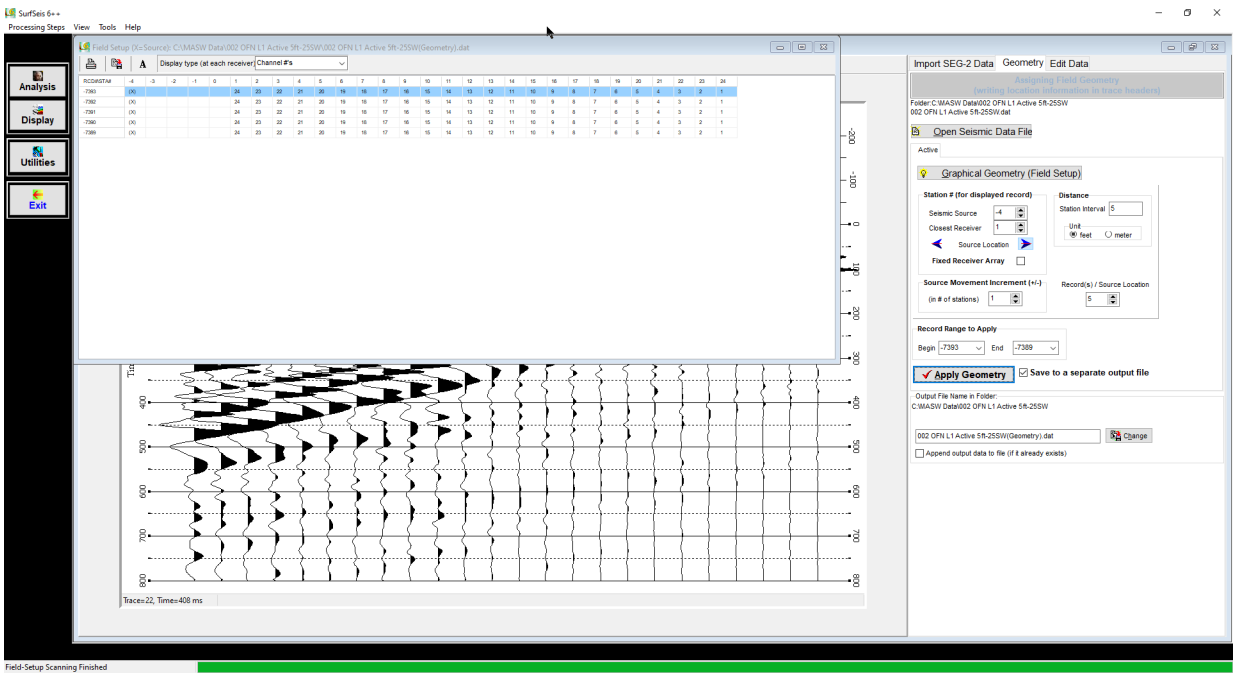
- Define **Station #** (1 for the first and 2 for the second geophone), **Source Distance** (25 feet in this example), and **Geophone Spacing** (5 feet in this example). Verify the **Source Location** is on the correct side (the source would be on the side with the shorter signal arrival time).
- Specify **Record(s)/Location** (5 files in this example).



- Click **OK**. Check the box **Save to a separate output file**. Click **Apply Geometry**.

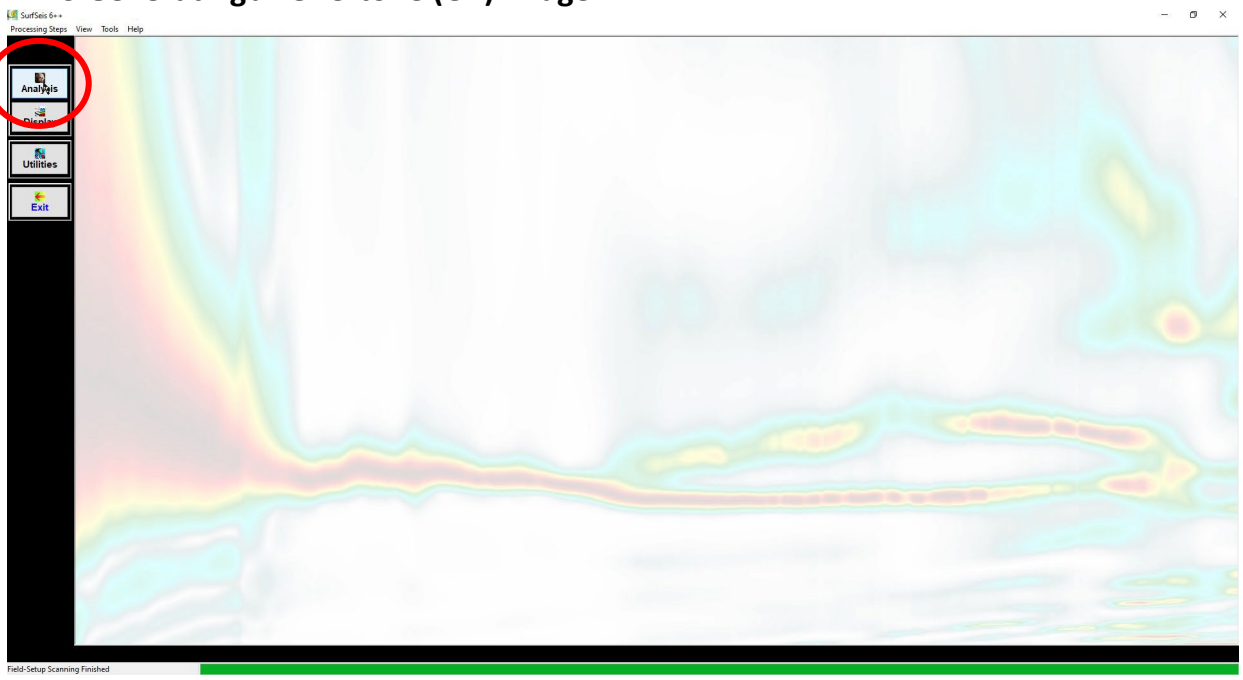


- An **INFO** window with information about the saved data will show. Click **OK** to continue.

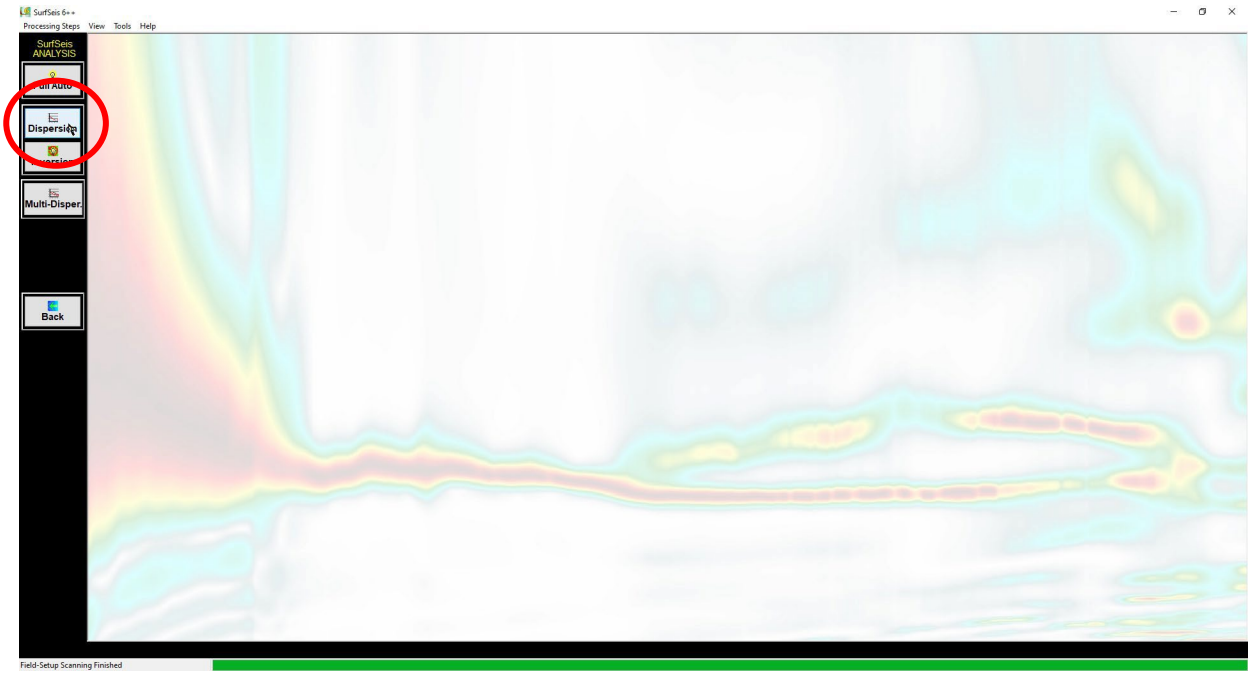


- A table with the assigned geometry for each file will appear for information purposes. The table window can be closed, this step is optional.

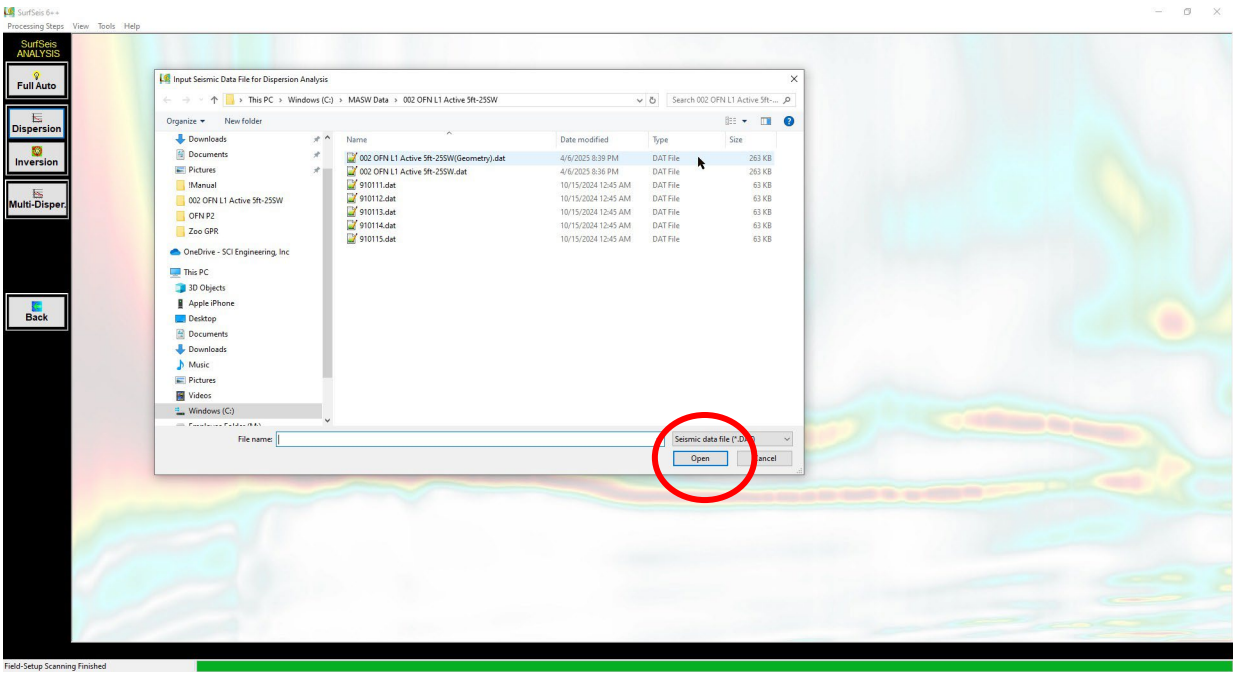
2.1.3 Generating an Overtone (OT) Image



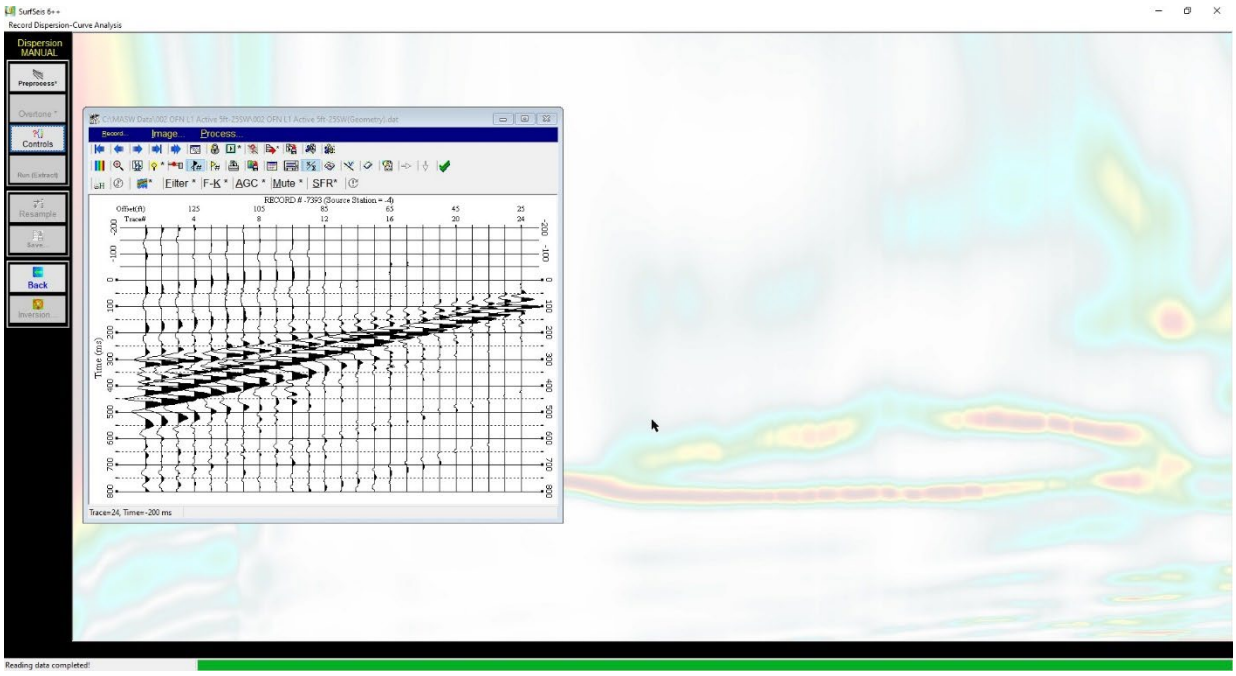
- Click **Analysis** tab on the left panel.



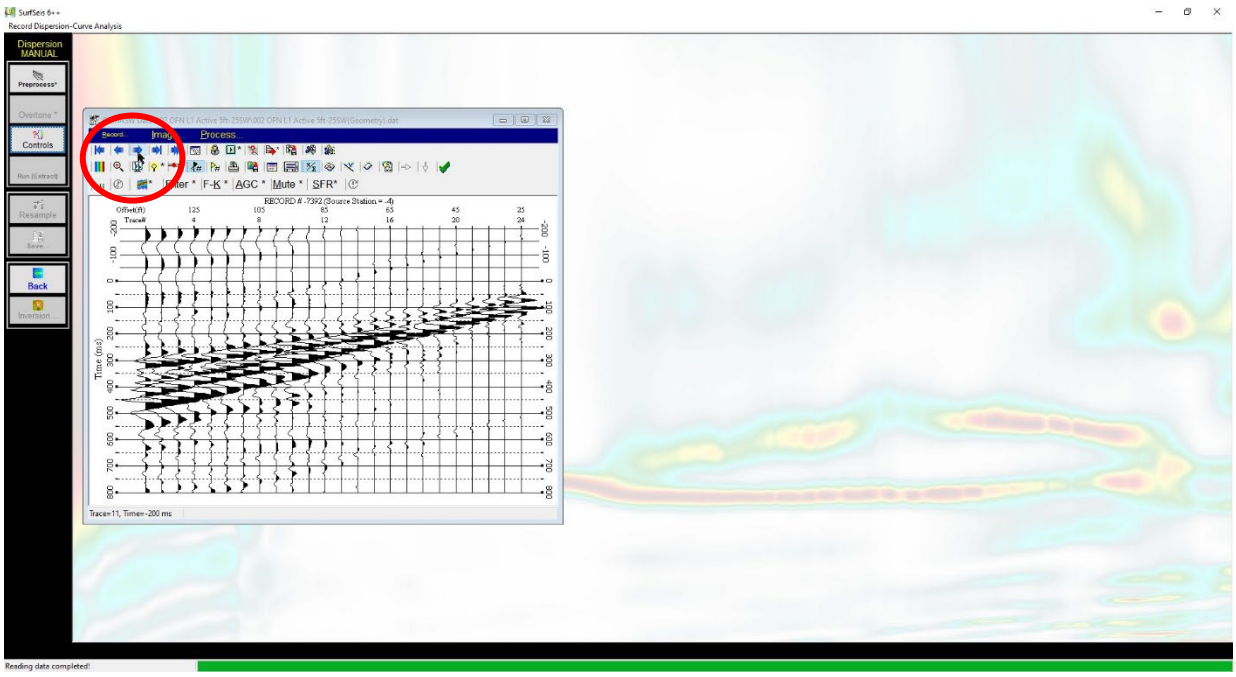
- The panel menu will change view. Click **Dispersion** tab**.**



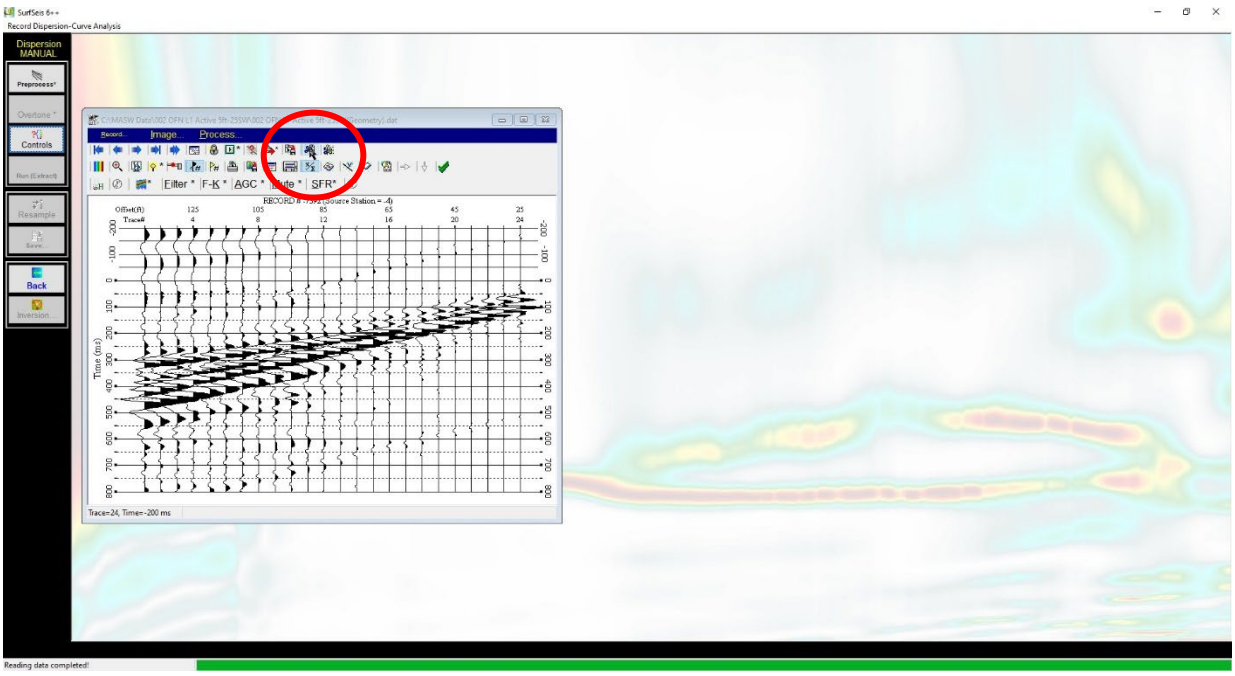
- Navigate to the folder where the file with assigned geometry was saved in the previous step. Click **Open**.



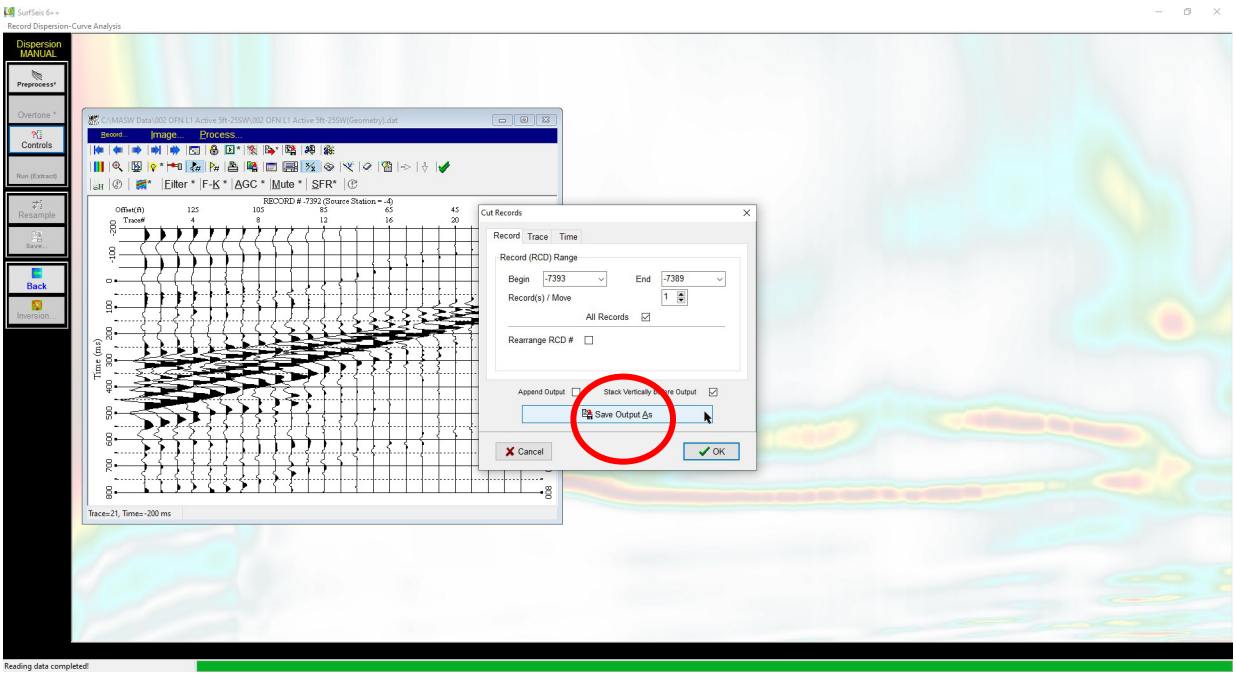
- A window with data will appear.



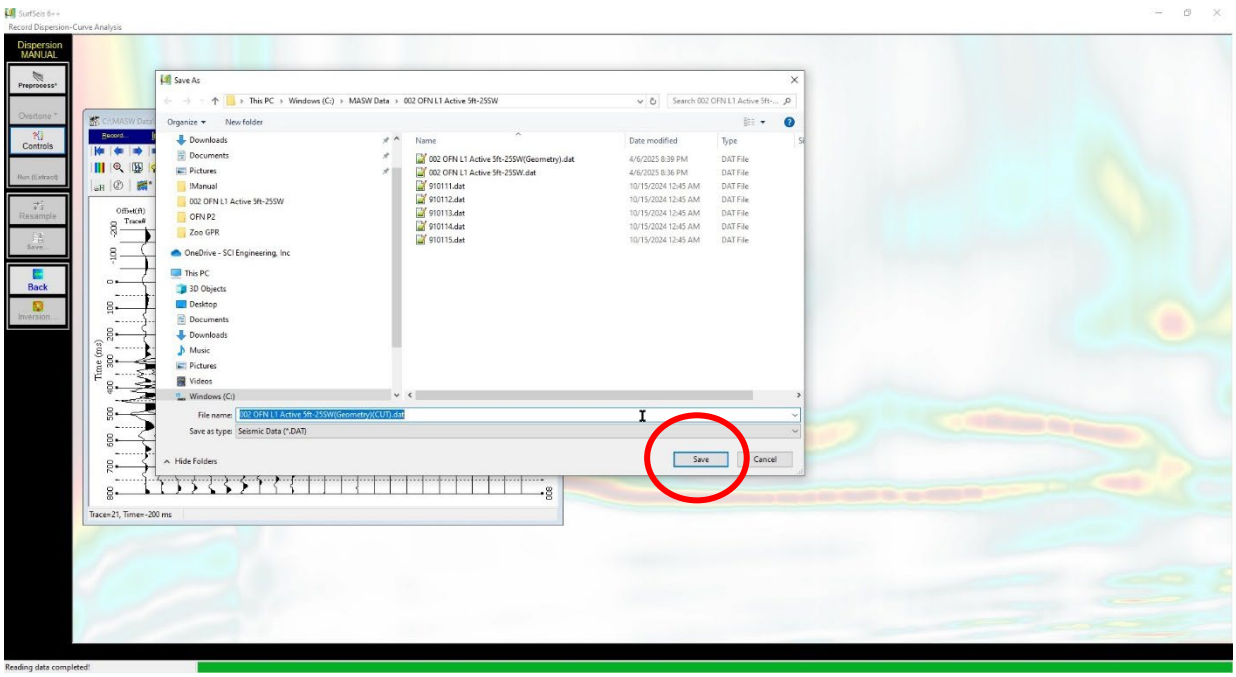
- To evaluate the quality and consistency of the collected data files click the right arrow button to view individual records. Ideally, they should look very similar.



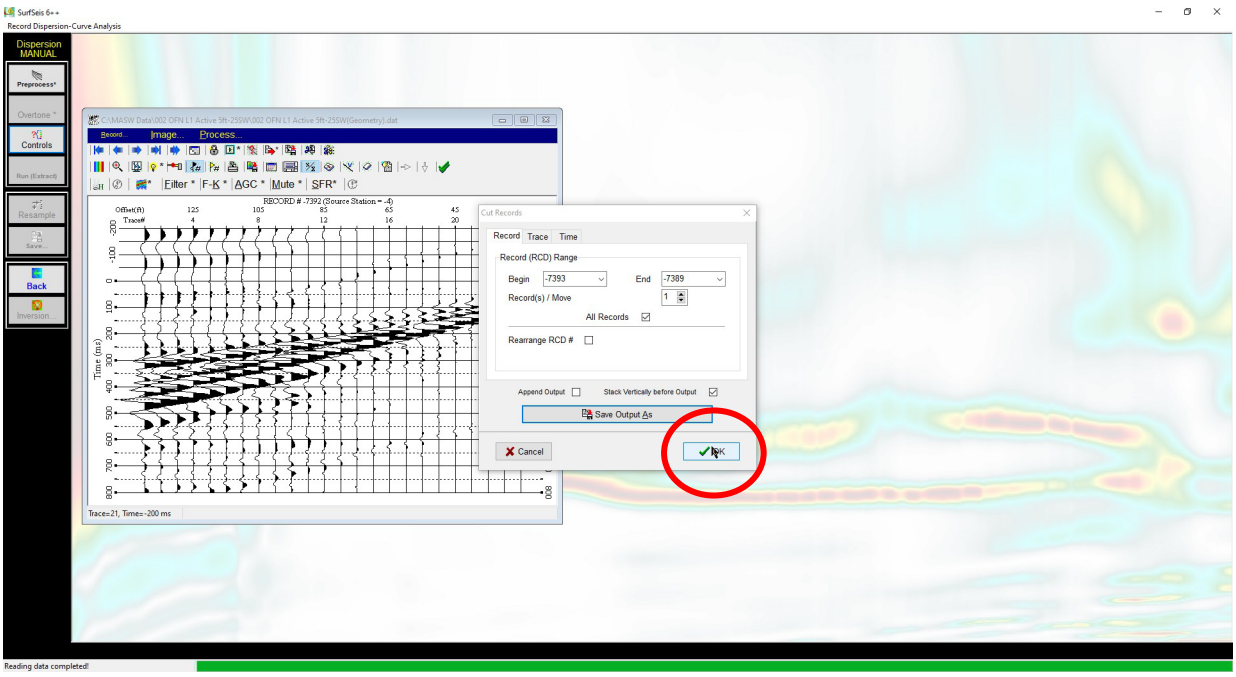
- To stack the data files (seismic records) click **Cut/Append Records** button in the menu at the top.



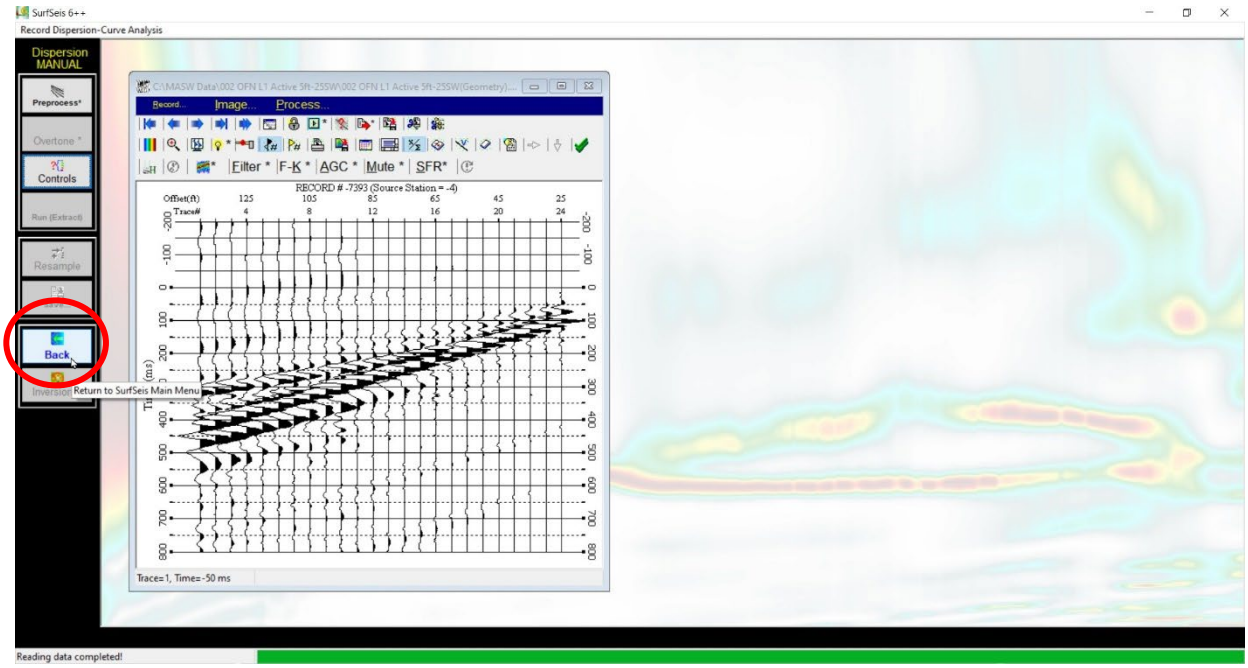
- Check the box **All Records** and click **Save Output As**.



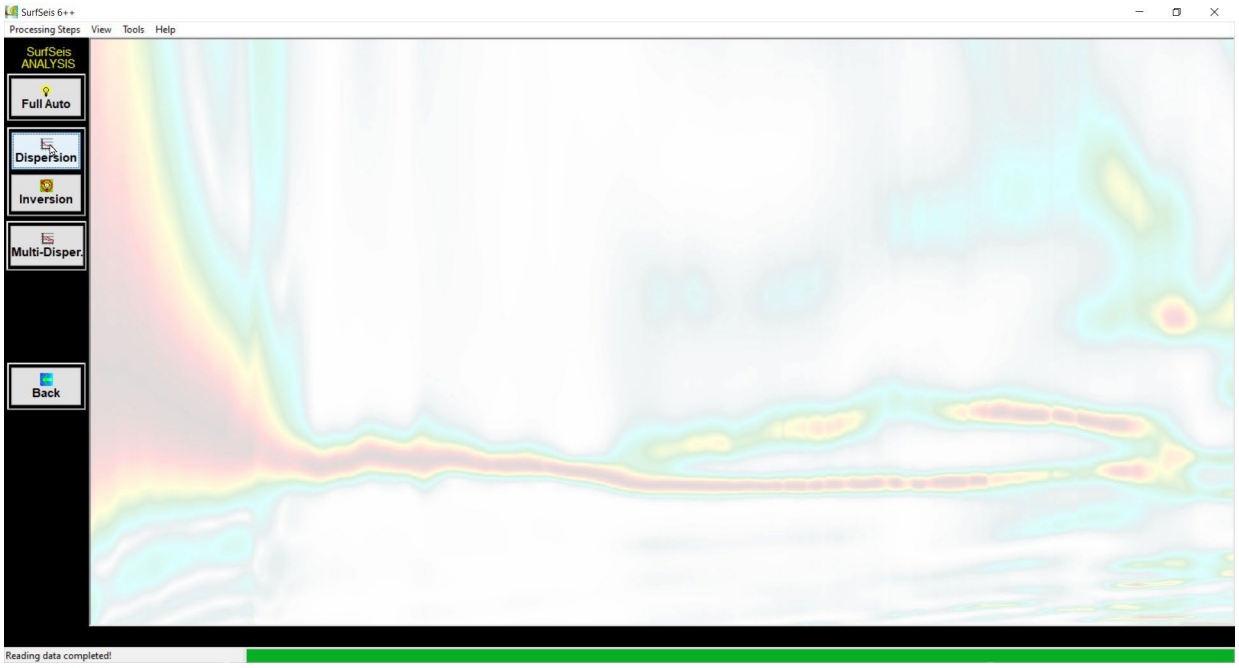
- A **Save As** window with an automatically generated new file name will appear. Click **Save**.



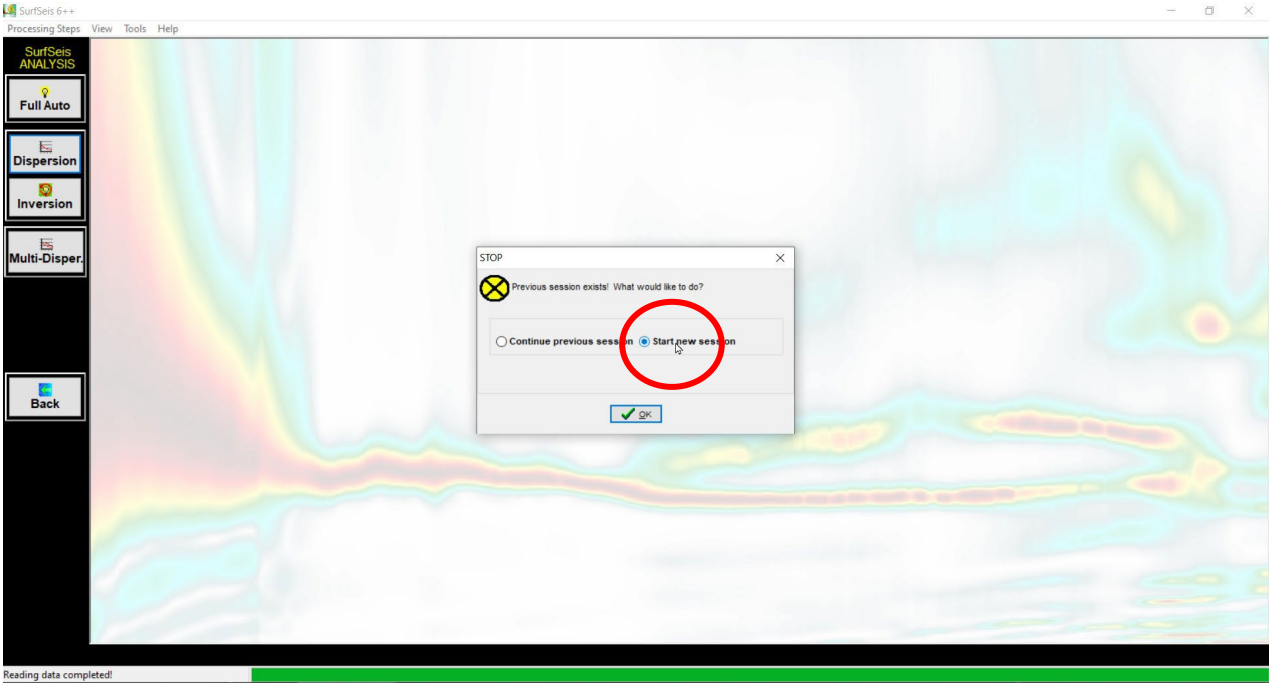
- Click **OK**.



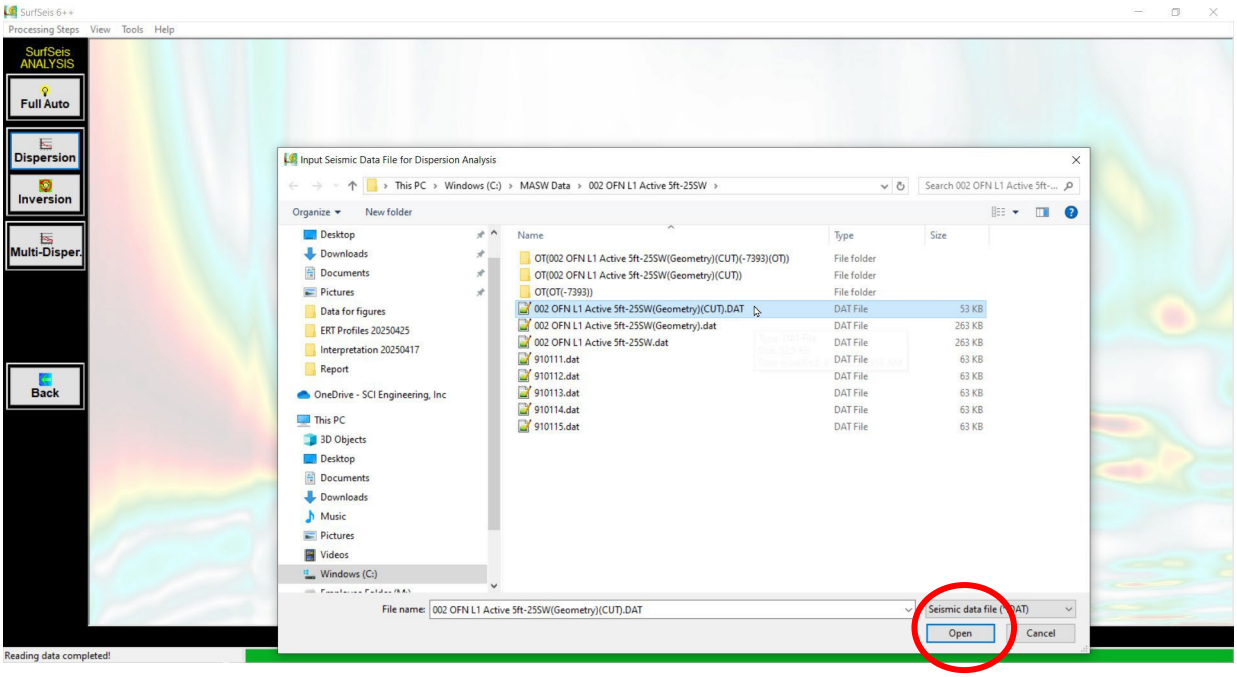
- Click **Back** to navigate to the main menu to reopen the stacked file.



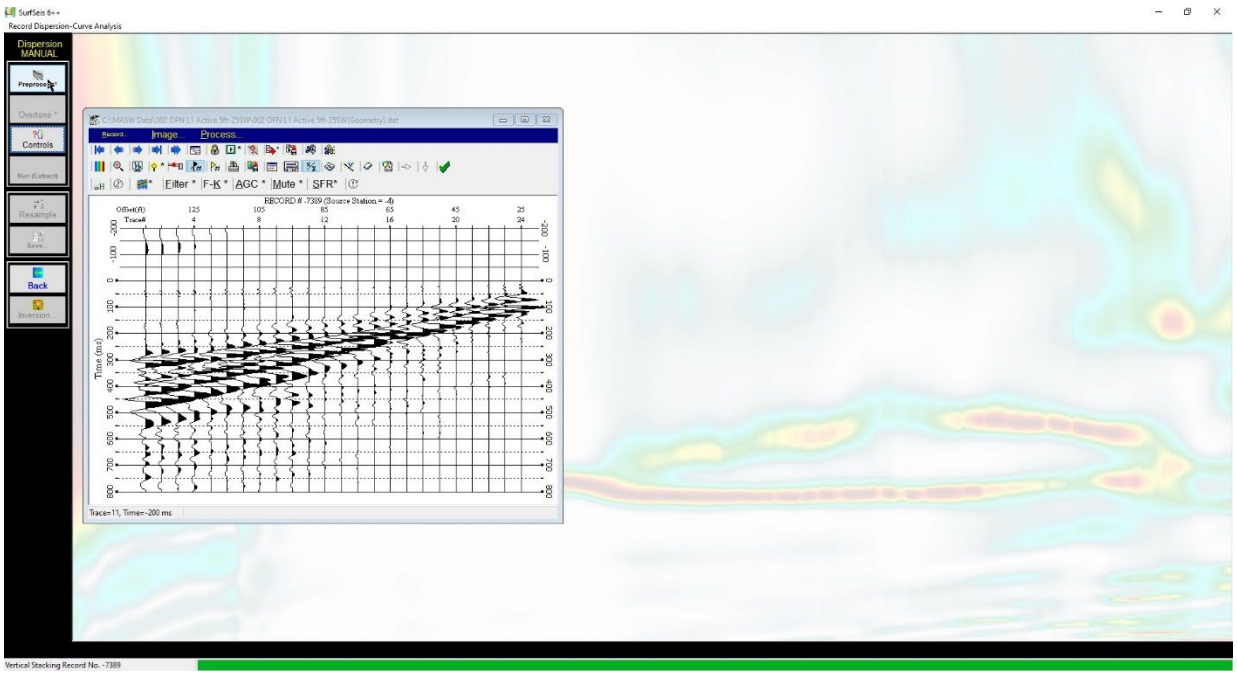
- The main menu view.



- A **STOP** window will appear. Select **Start new session** and click **OK**. Alternatively, you can close the software and follow the previous steps.

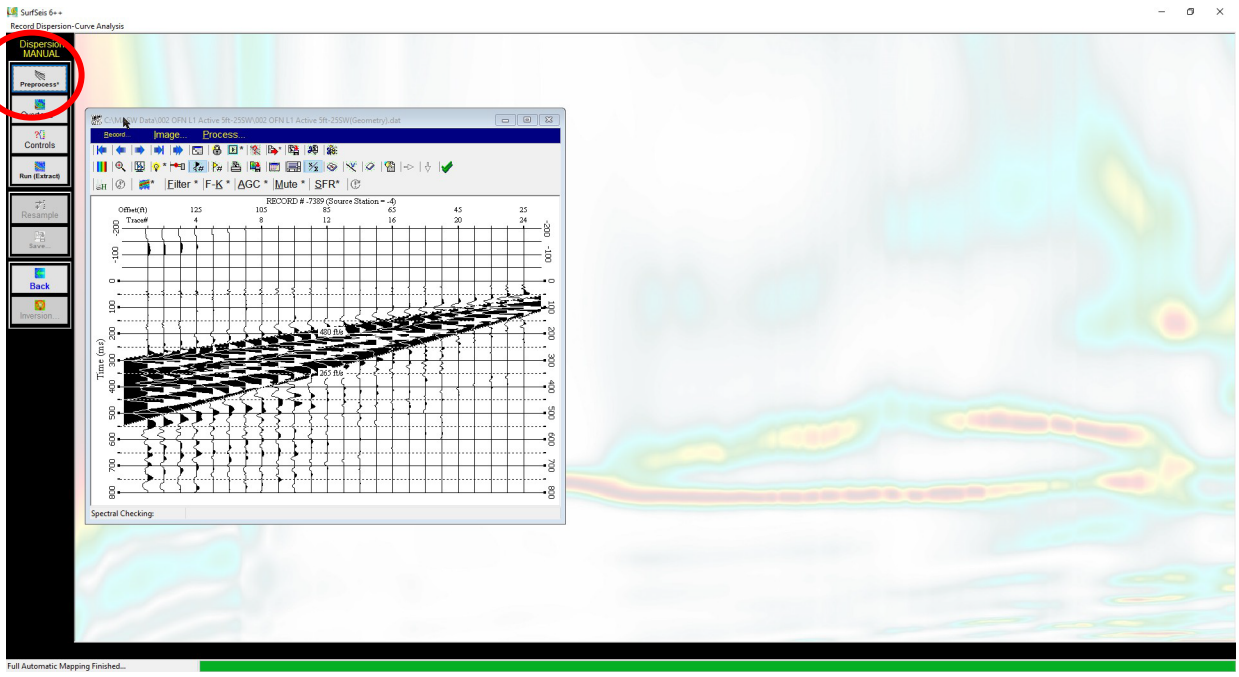


- Navigate to the folder where the stacked data file (with automatically added “(CUT)” to the file name by default) was saved in the previous step. Click **Open**.

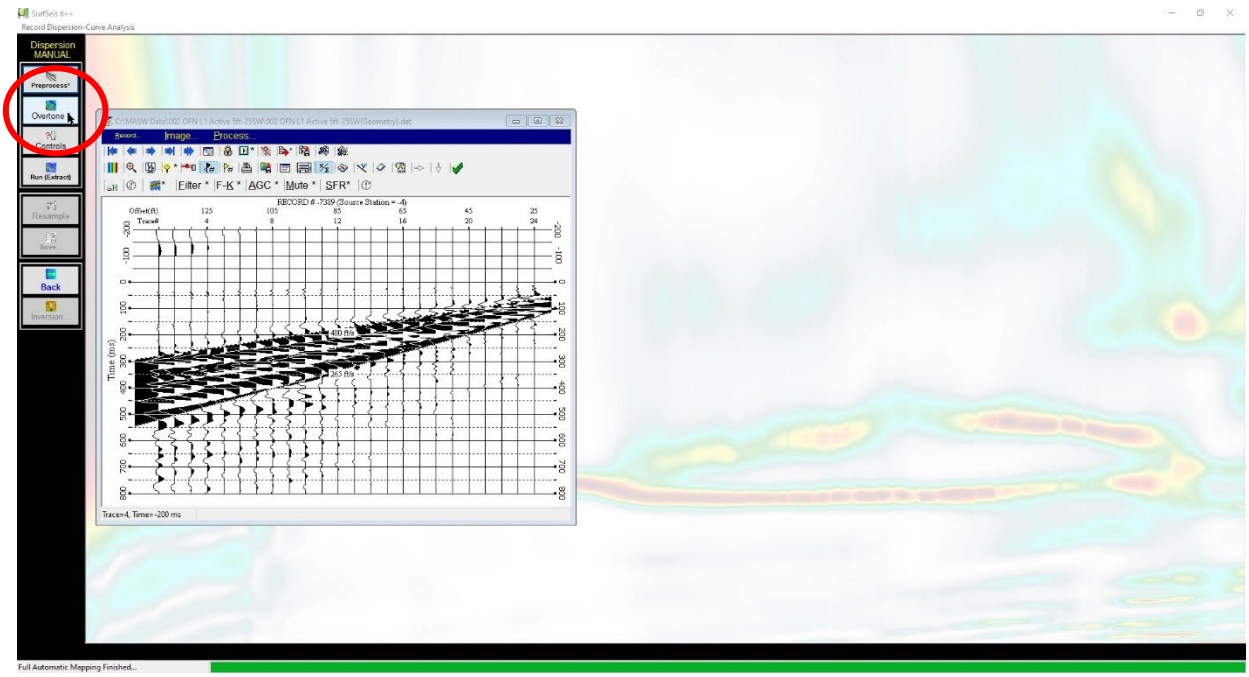


- A window with stacked records will appear.

Note: after the data are stacked there will be only one file/record.

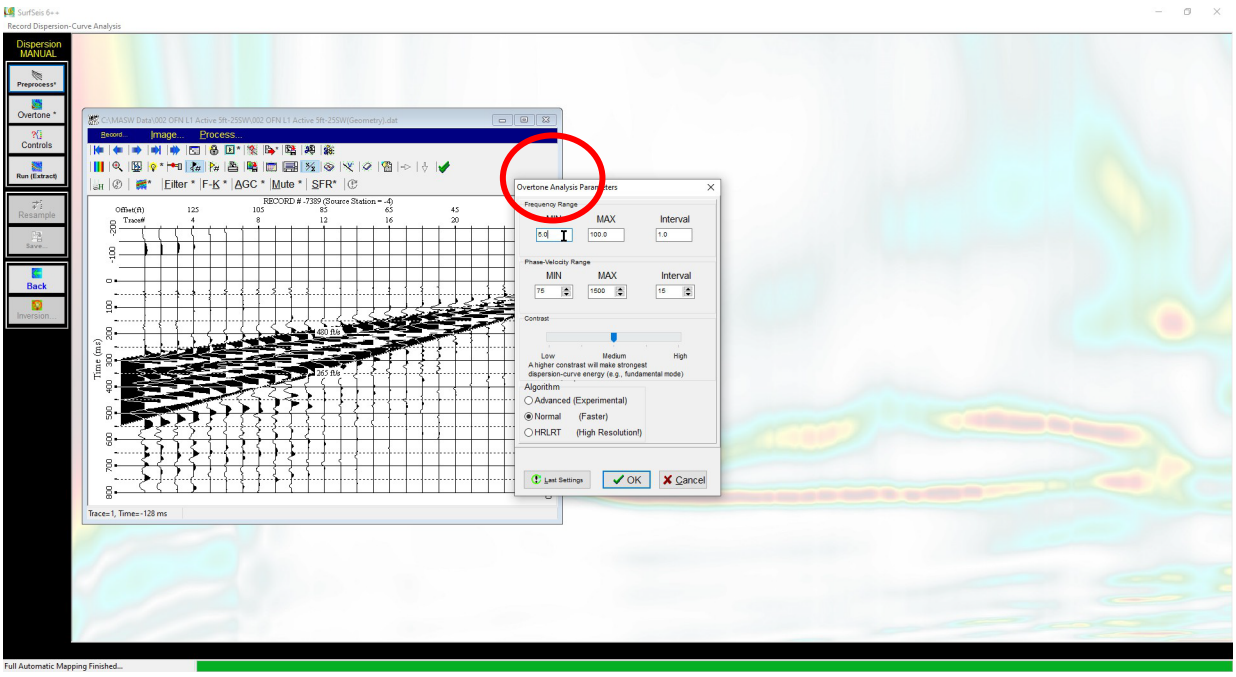


- Click on the **Preprocess** button. A section of the seismic record will highlight.

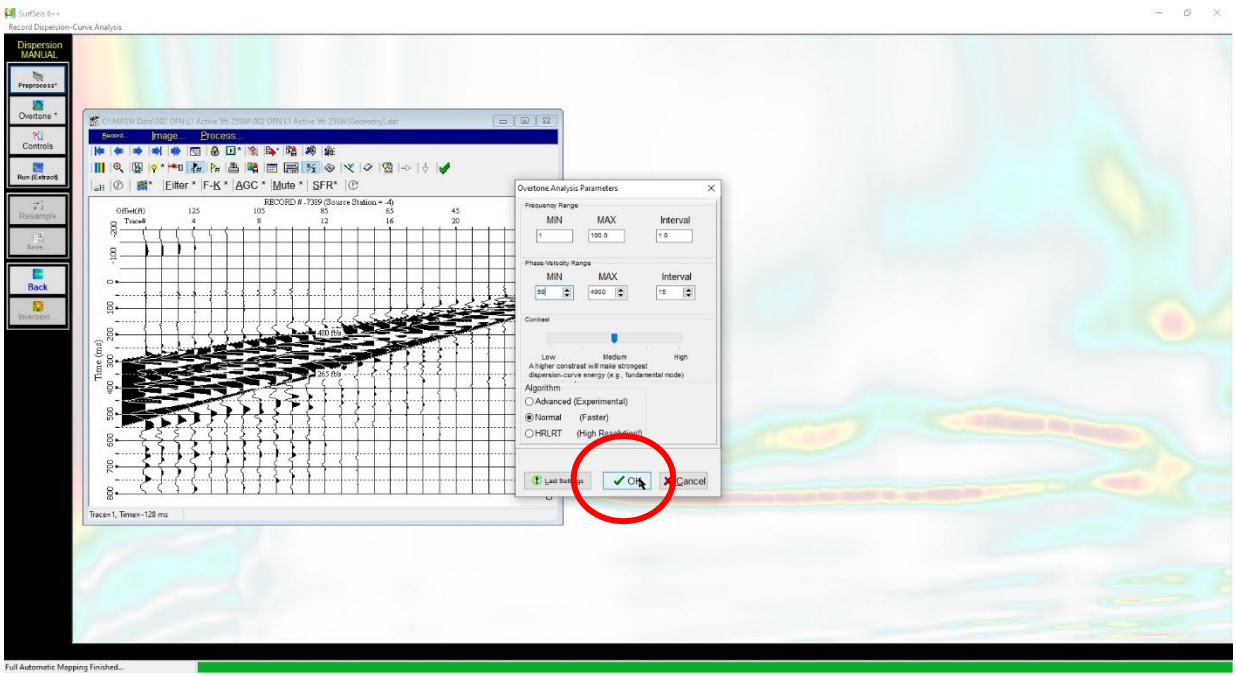


- Right click on the **Overtone** button to change the analysis parameters.

*Note: all the buttons marked with the asterisk ***** can be left clicked or right clicked for additional parameters.*

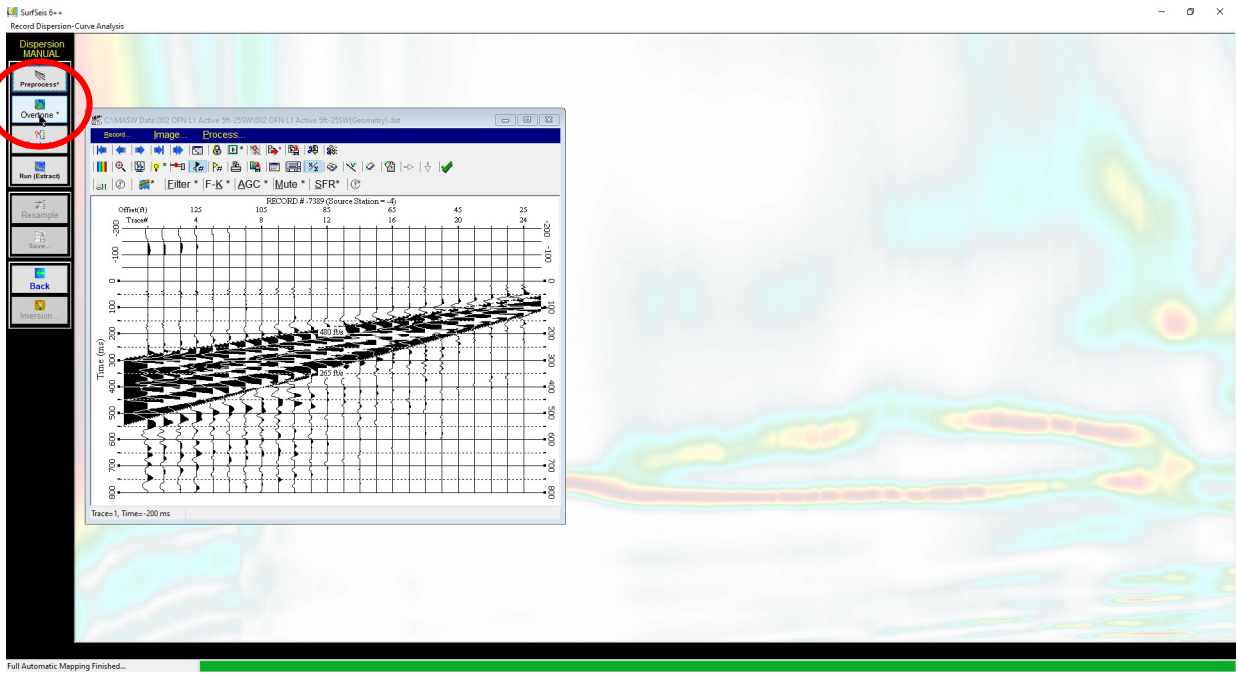


- A window **Overtone Analysis Parameters** will appear.

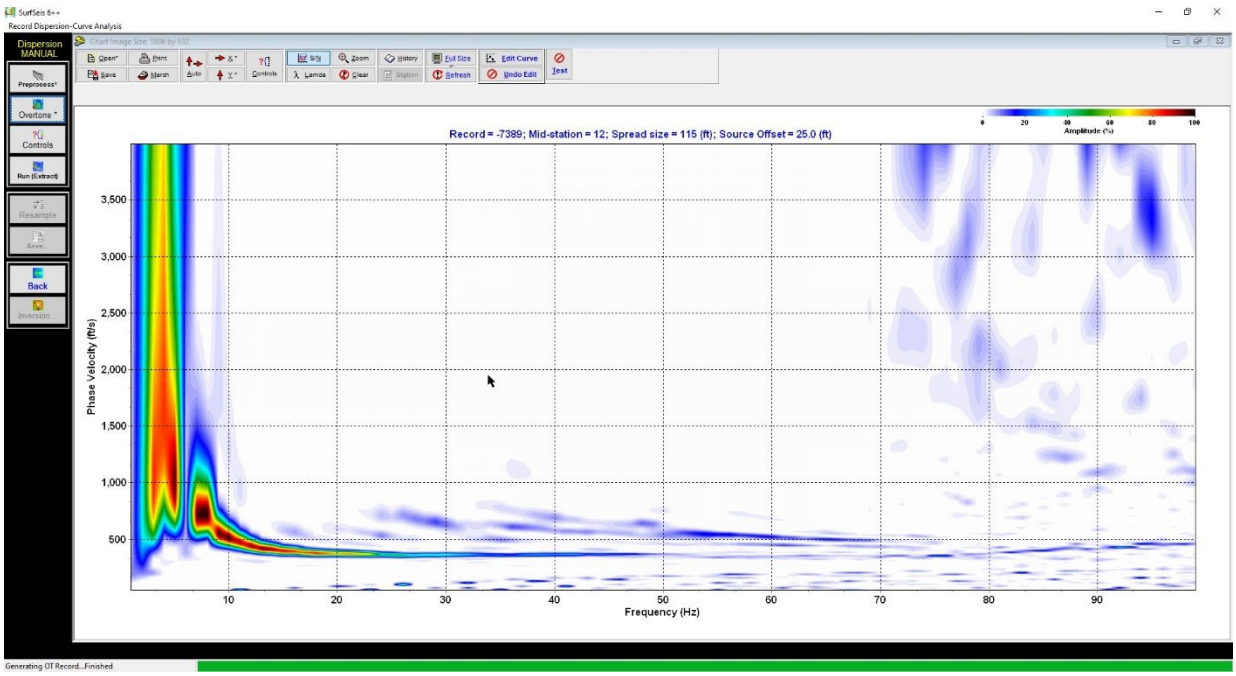


- Select the **Frequency Range** for data processing (1 to 100 Hertz in this example) and **Phase-Velocity Range** from 50 to 4000 feet per second in this example. The **Interval** values can be left by default.

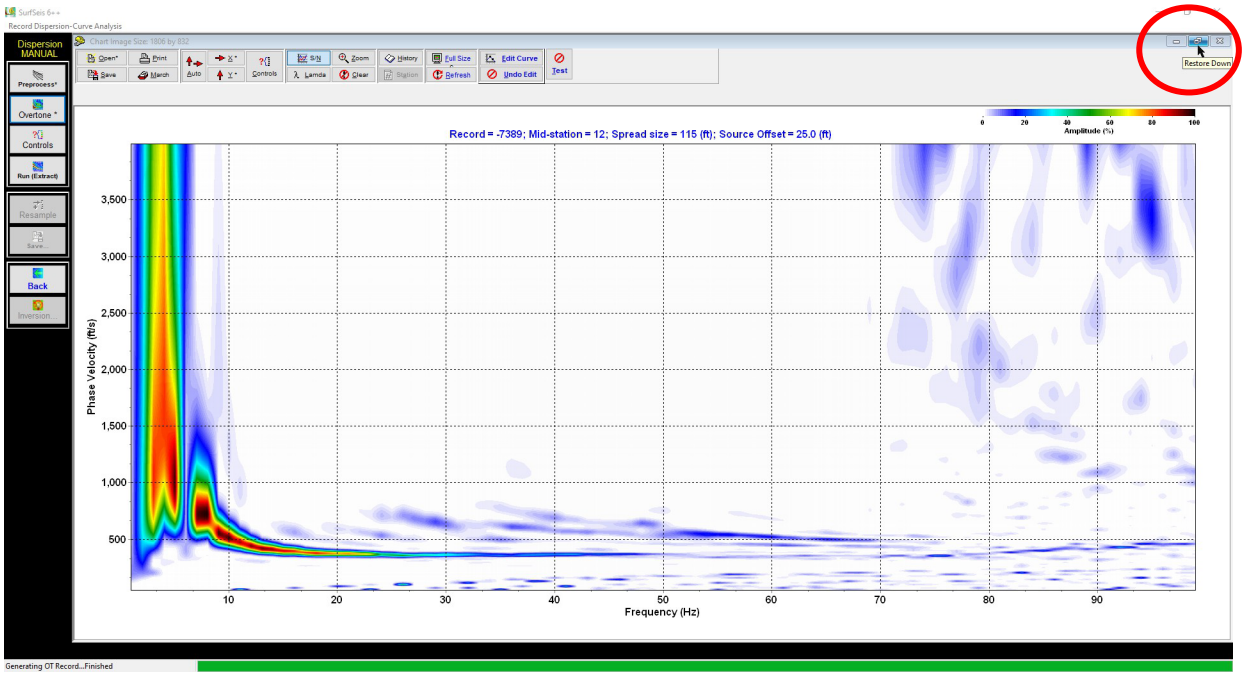
  Note: typically, a "useful" range of velocities and frequencies present in MASW data is 100 to 2,000 ft/s and 4 to 50 Hz, accordingly. However, the range is site specific and should be evaluated during data processing for individual data sets.



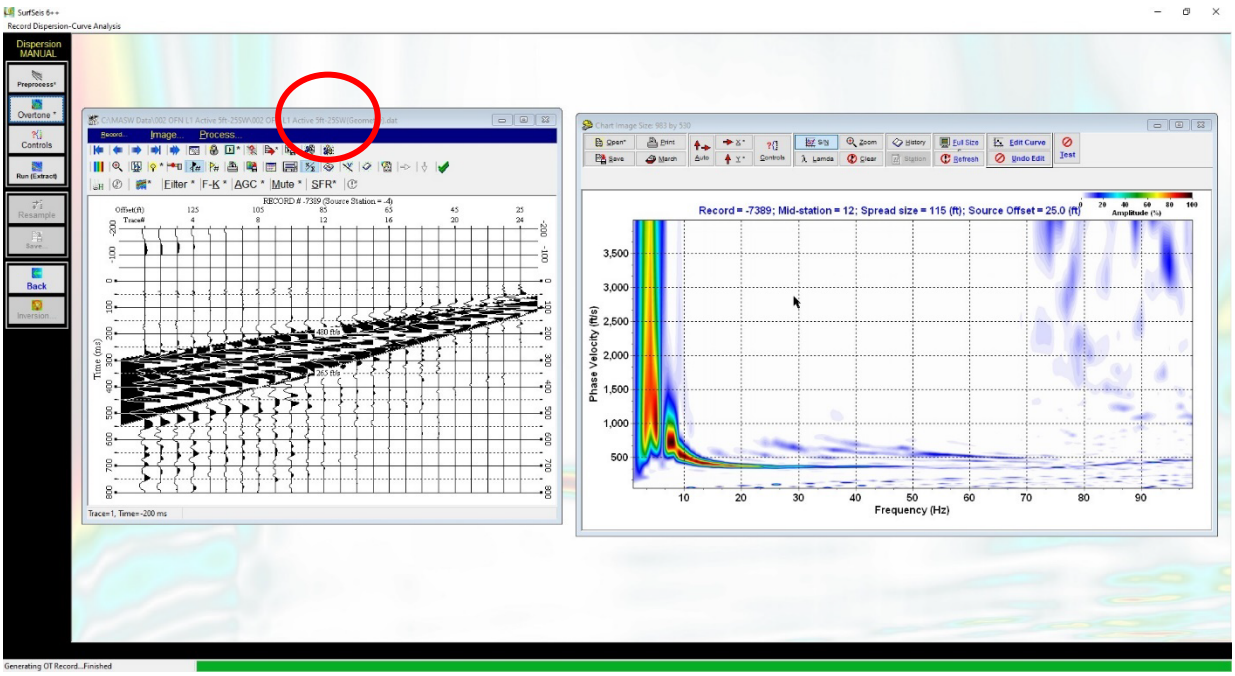
- Click the **Preprocess** button again. A section of the seismic record will highlight. Click the **Overtone** button**.**



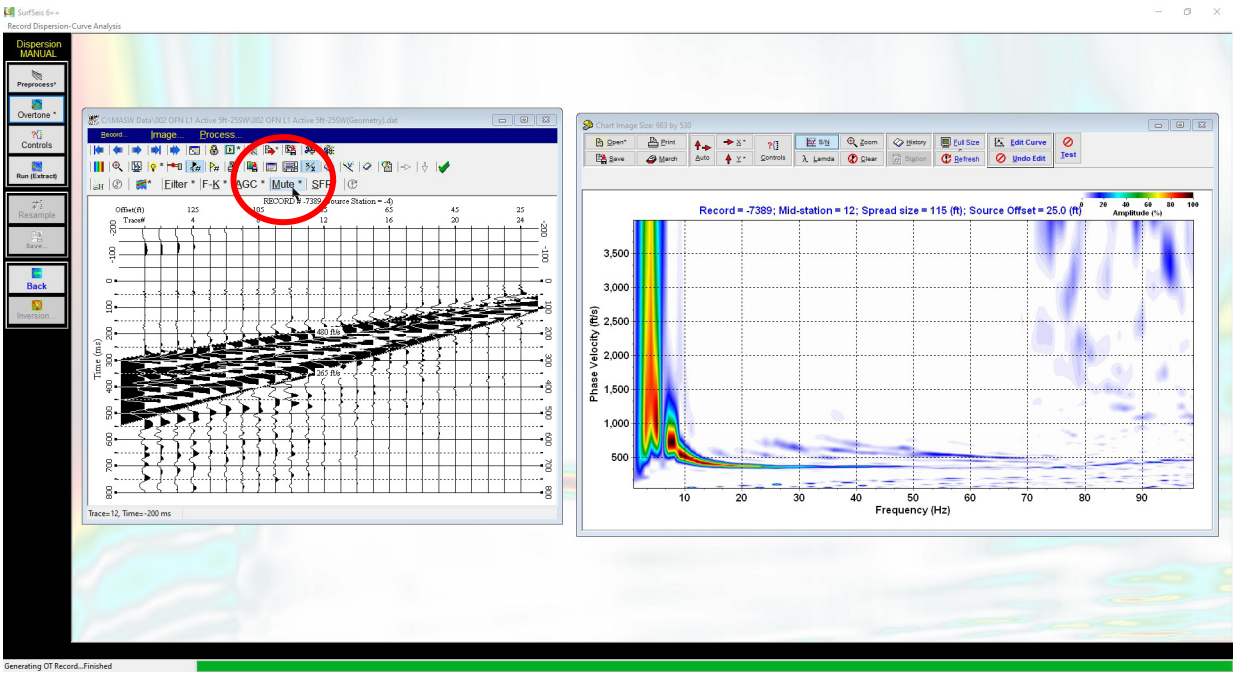
- An Overtone image will be automatically generated. The bottom axis represents frequencies, and the vertical axis represents phase velocities in the data set.



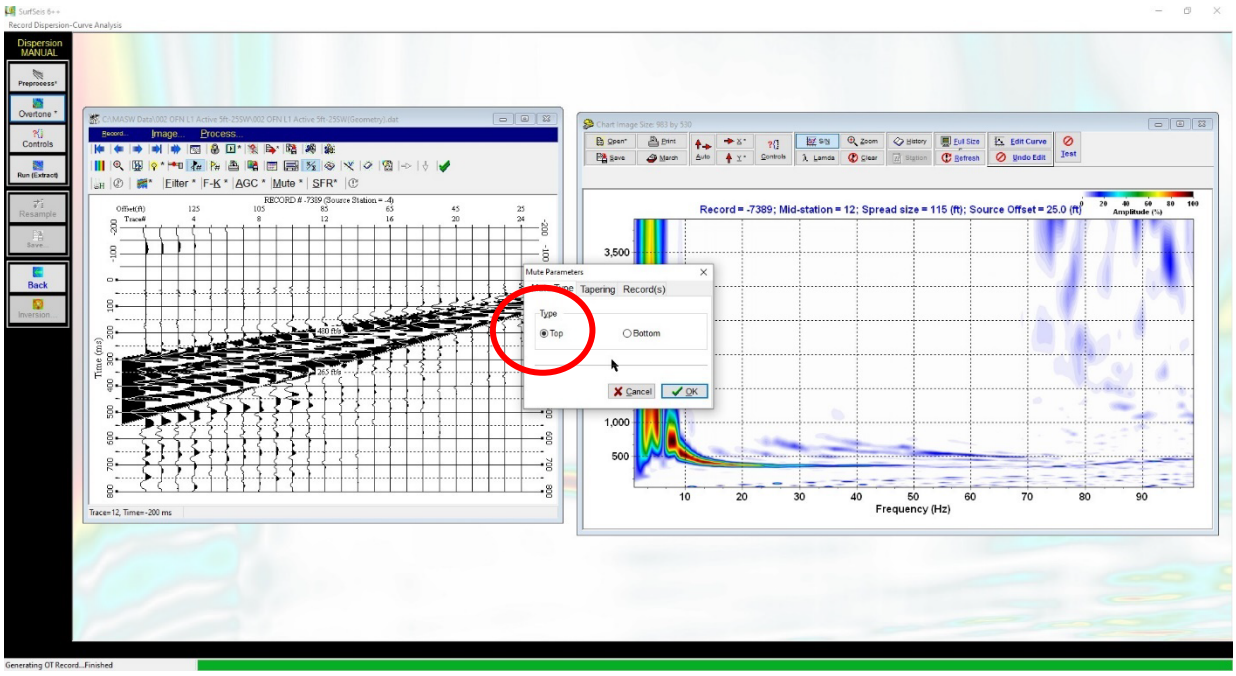
- Click **Restore Down** so both seismic record and the Overtone image can be viewed in one screen.



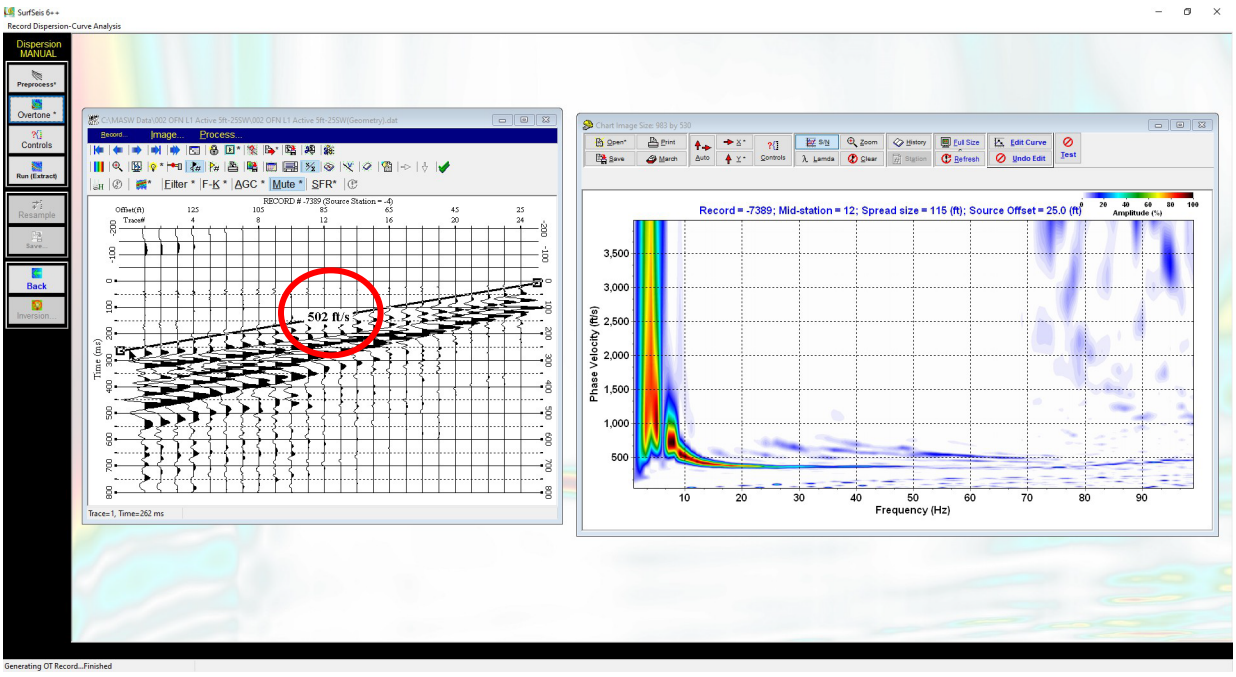
- Click on the seismic record window to make it active.



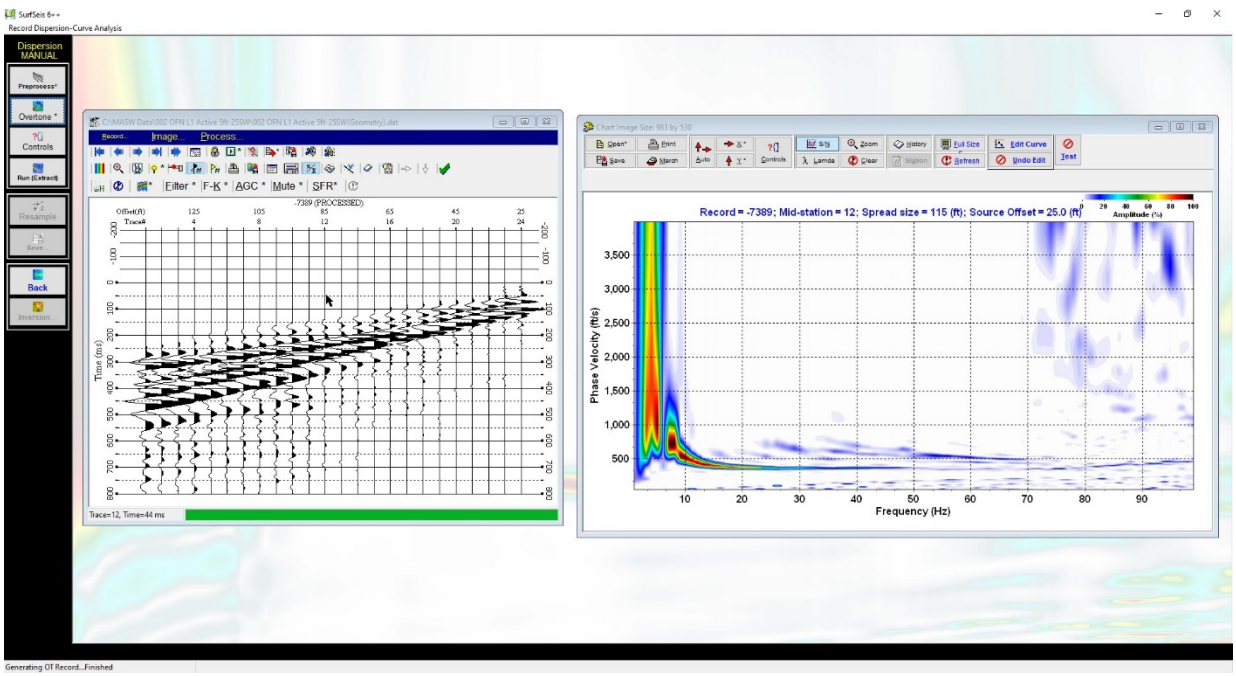
- To improve the overtone image the seismic record may have to be filtered. The most effective filter is **Mute.** Right click on the **Mute** button to select the parameters.



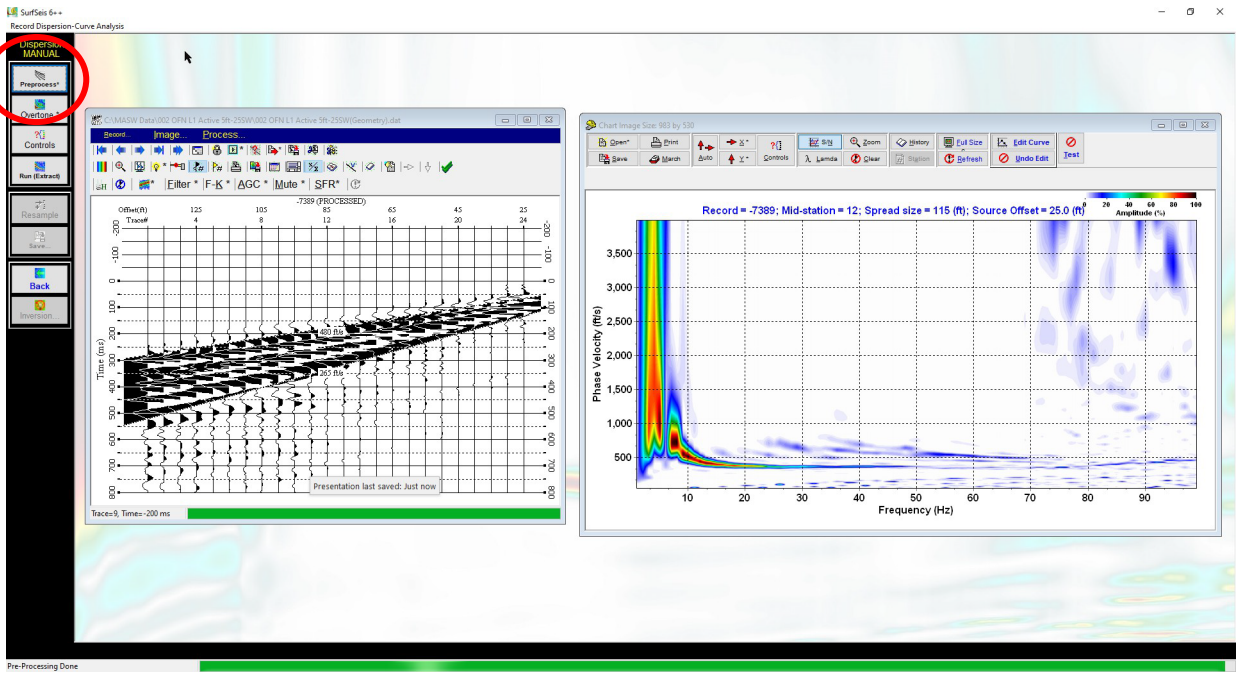
- In the **Mute Parameters**, **Mute Type** tab select **Top**.



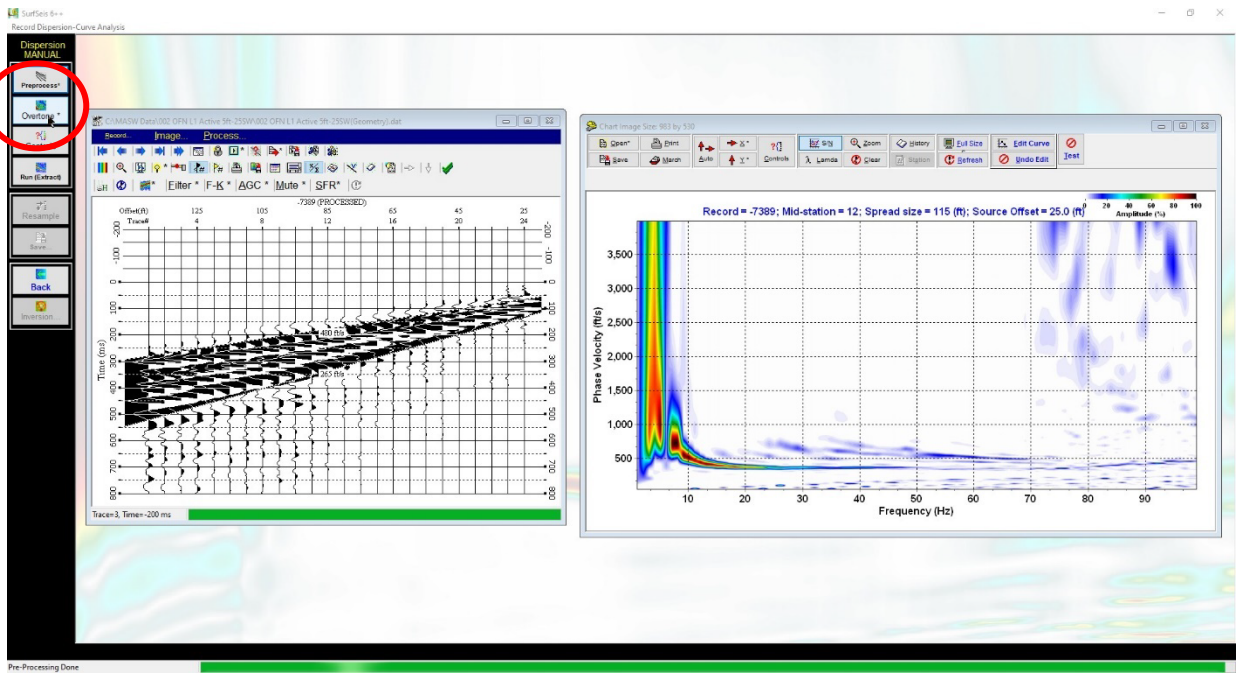
- Select the start point on the right (Trace 24) and approximately 0 milliseconds (ms) on the vertical axis, left click and drag the mouse to the left side of the record (Trace 1), and approximately 250 ms and release the mouse button. A line with estimated velocity will appear. Double click anywhere within the seismic record window.



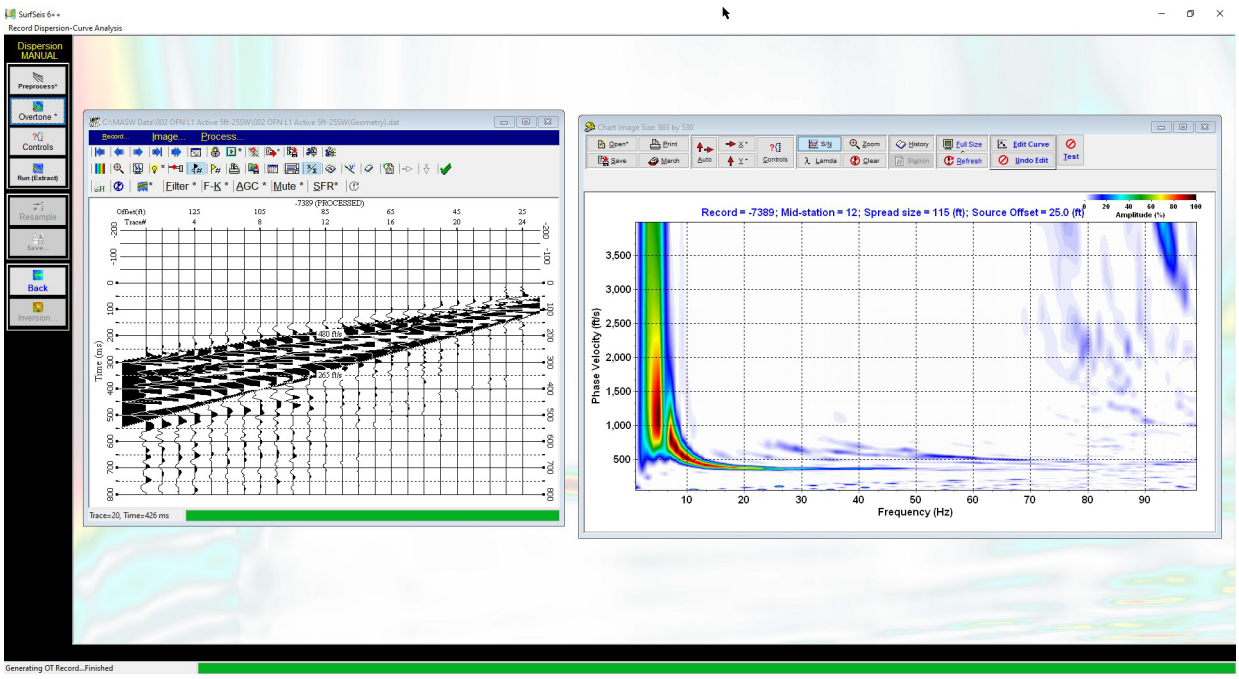
- The seismic record will be updated: the top portion of the data, above the line, will be muted.



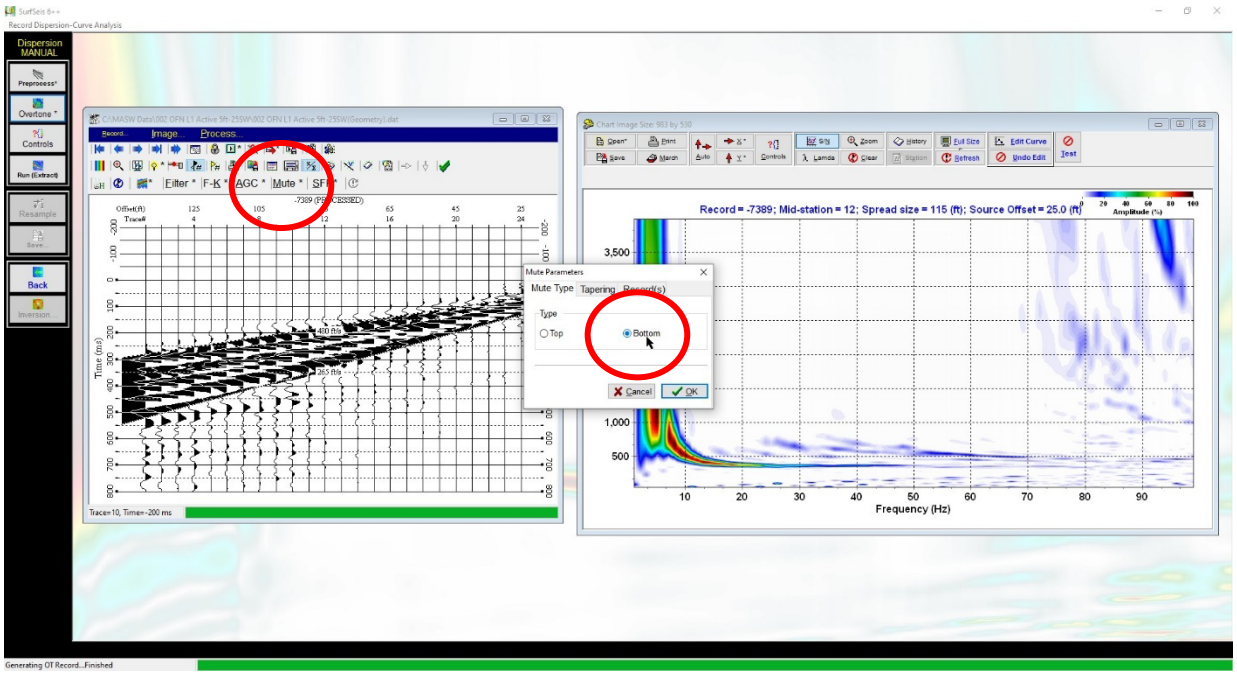
- Click the **Preprocess** button again. A section of the seismic record will highlight.



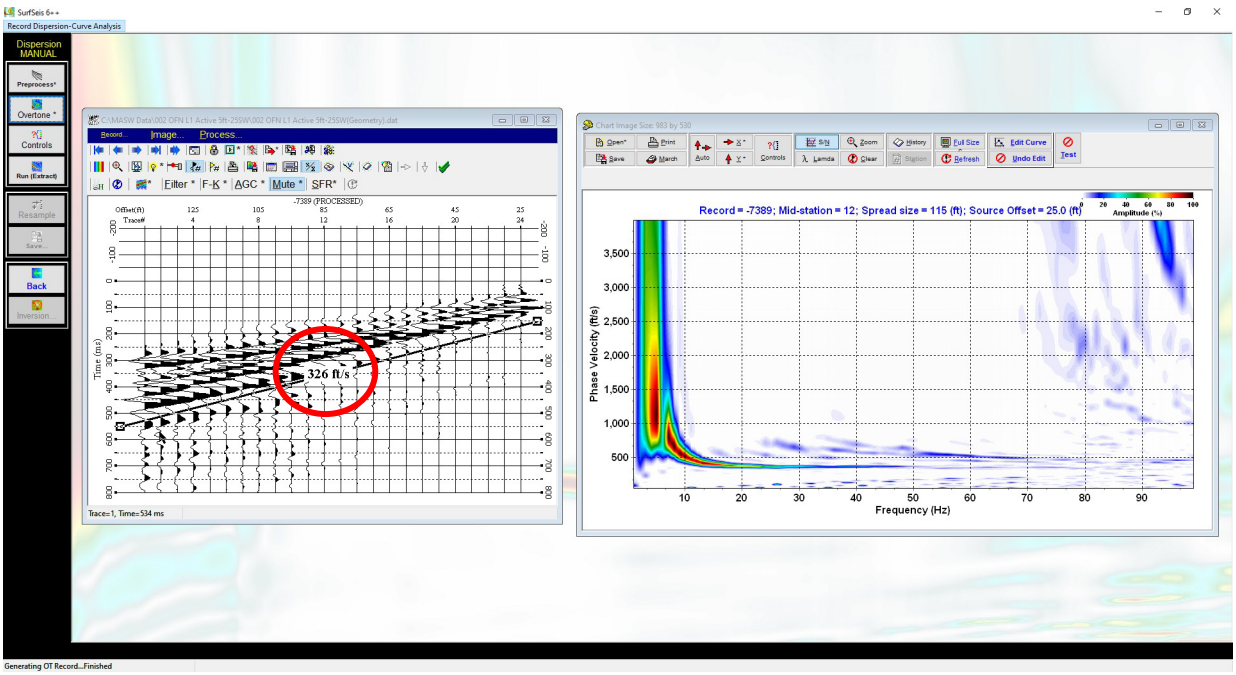
- Click the **Overtone** button.



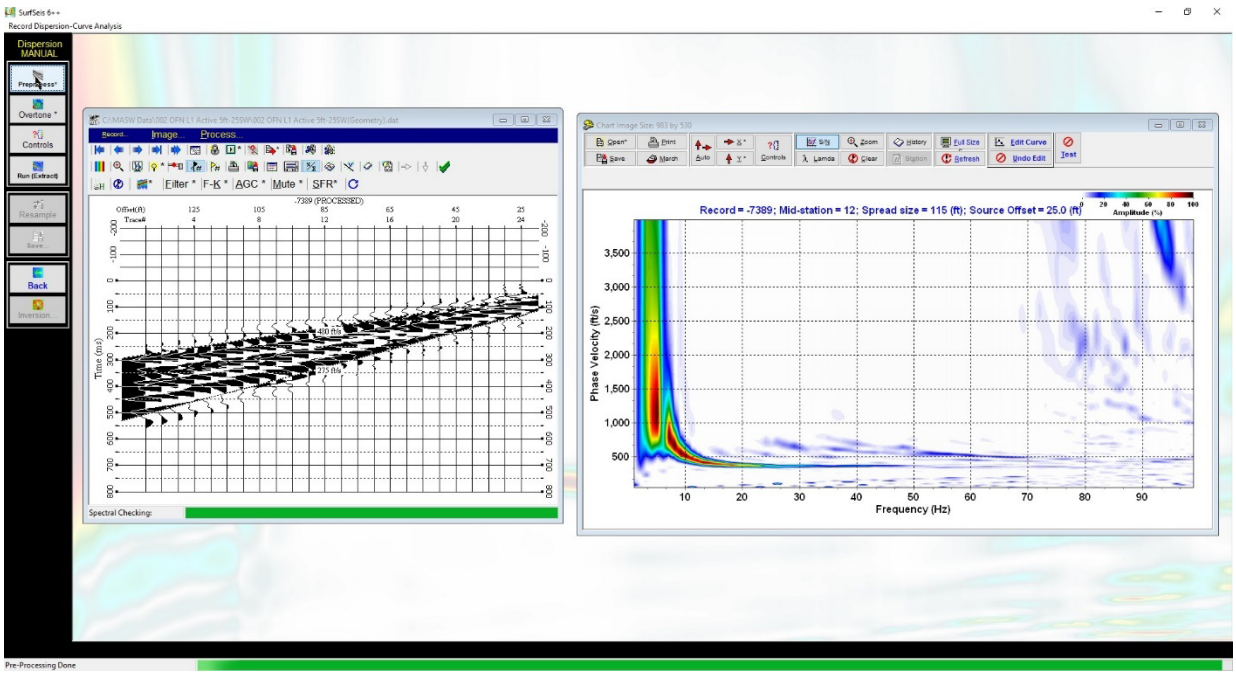
- An Overtone image (the window on the right) will be automatically updated.



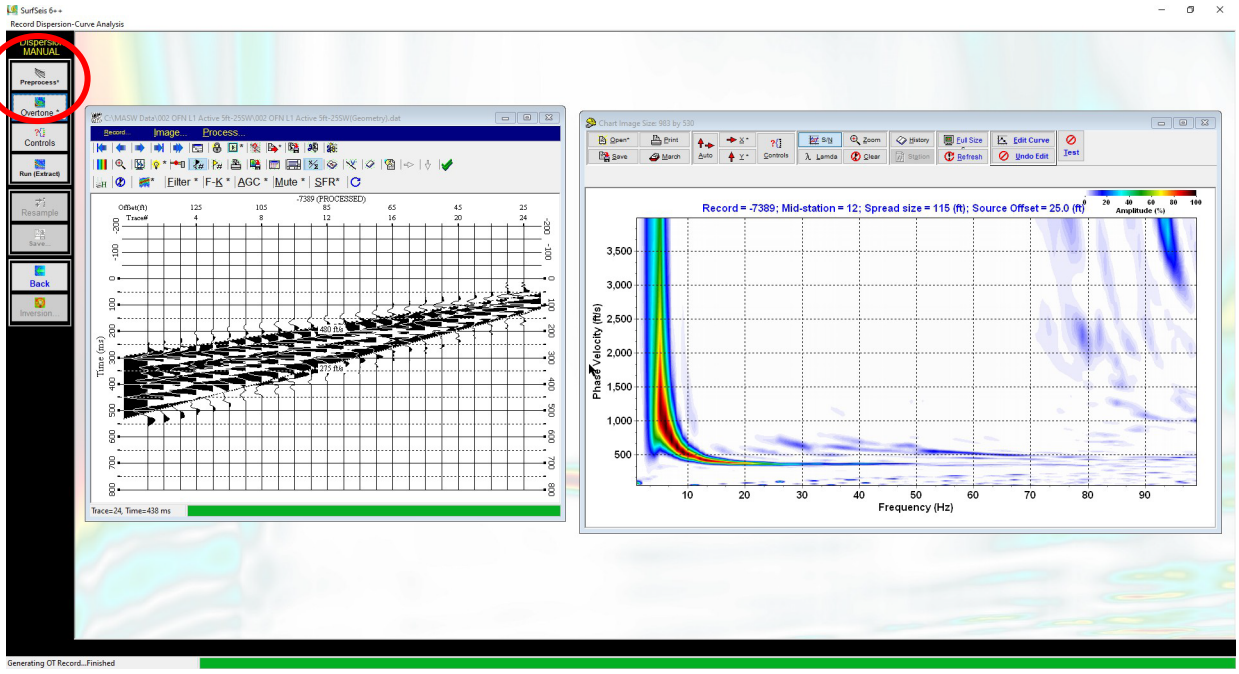
- To further improve the Overtone image right click on the **Mute** button to select the parameters. In the **Mute Parameters**, **Mute Type** tab select **Bottom**.



- Select the start point on the right (Trace 24) and approximately 150 ms on the vertical axis, left click and drag the mouse to the left side of the record (Trace 1), and approximately 550 ms and release the mouse button. A line with estimated velocity will appear. Double click anywhere within the seismic record window.

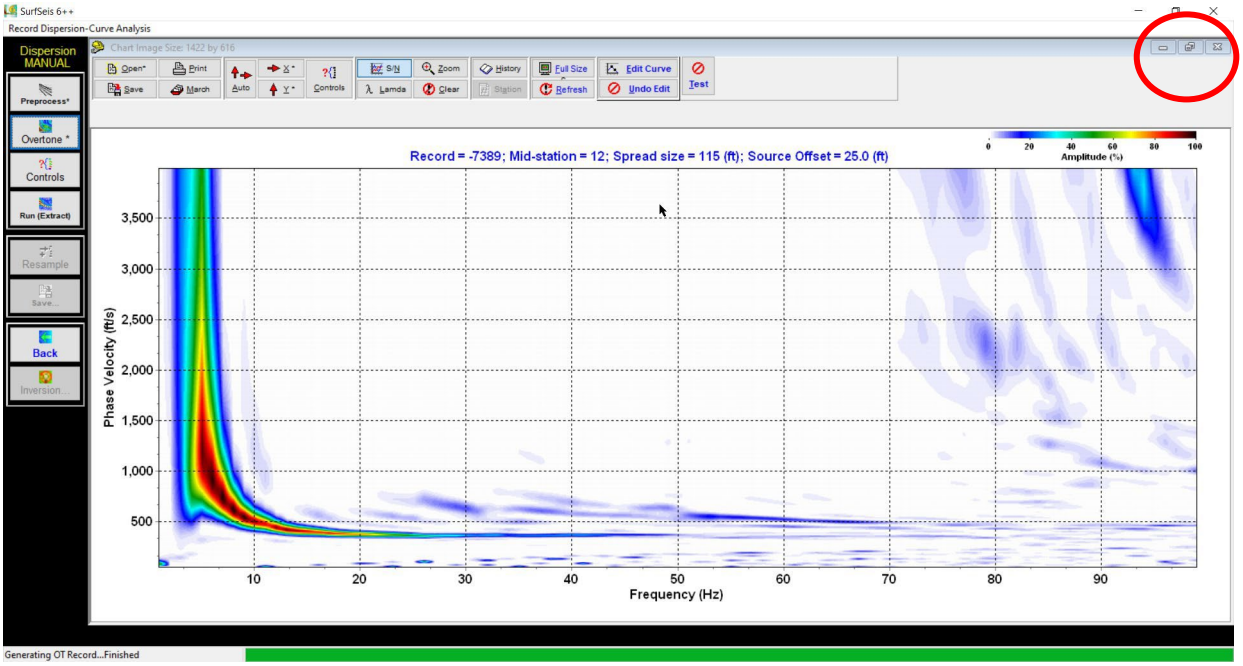


- The seismic record will be updated: the top portion of the data, below the line, will be muted.

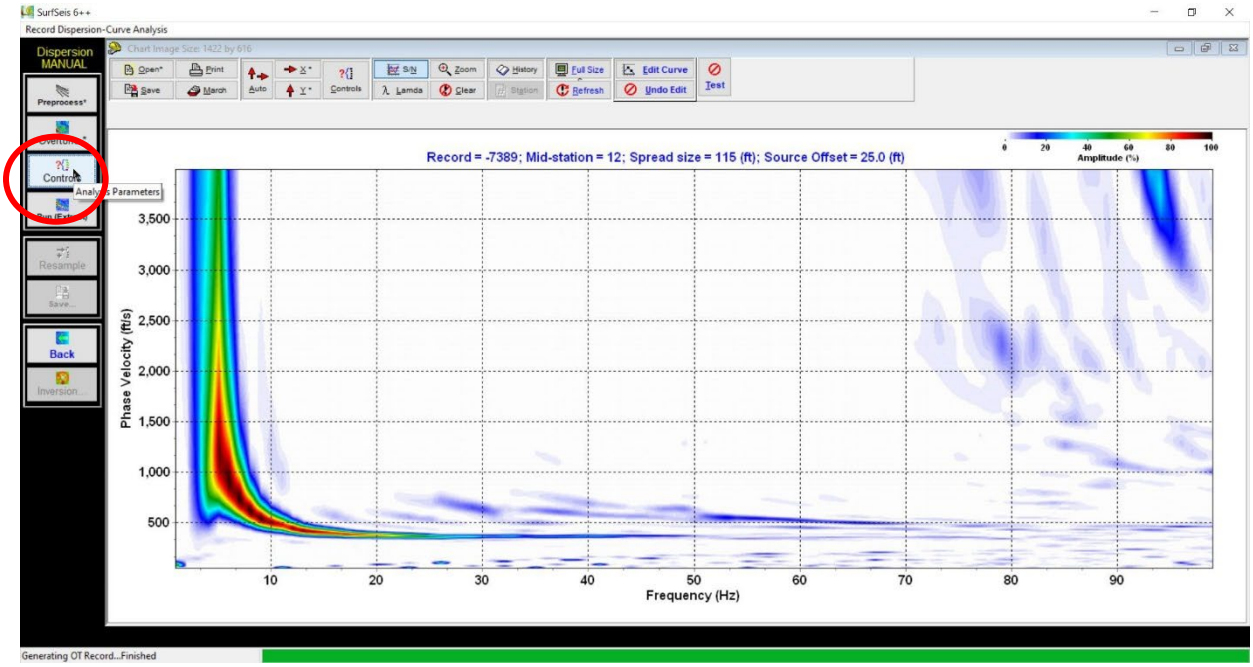


- Click the **Preprocess** button again. A section of the seismic record will highlight. Click the **Overtone** button**.** An Overtone image (the window on the right) will be automatically updated.

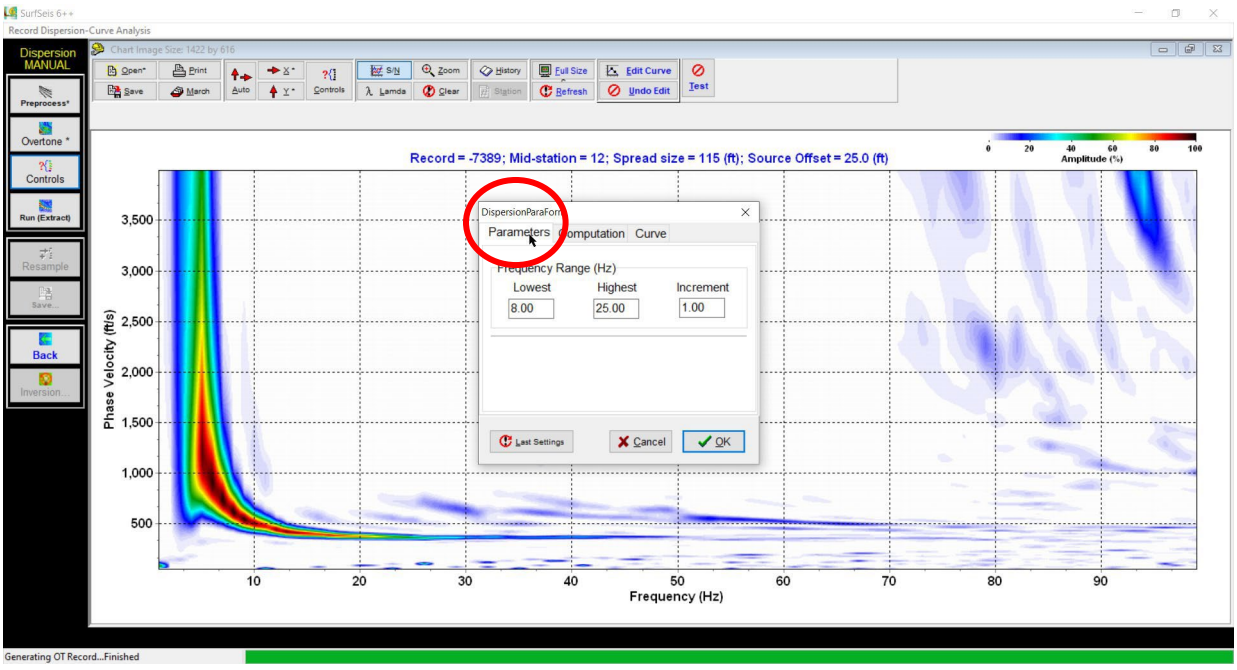
2.1.4 Picking a Dispersion Curve (DC)



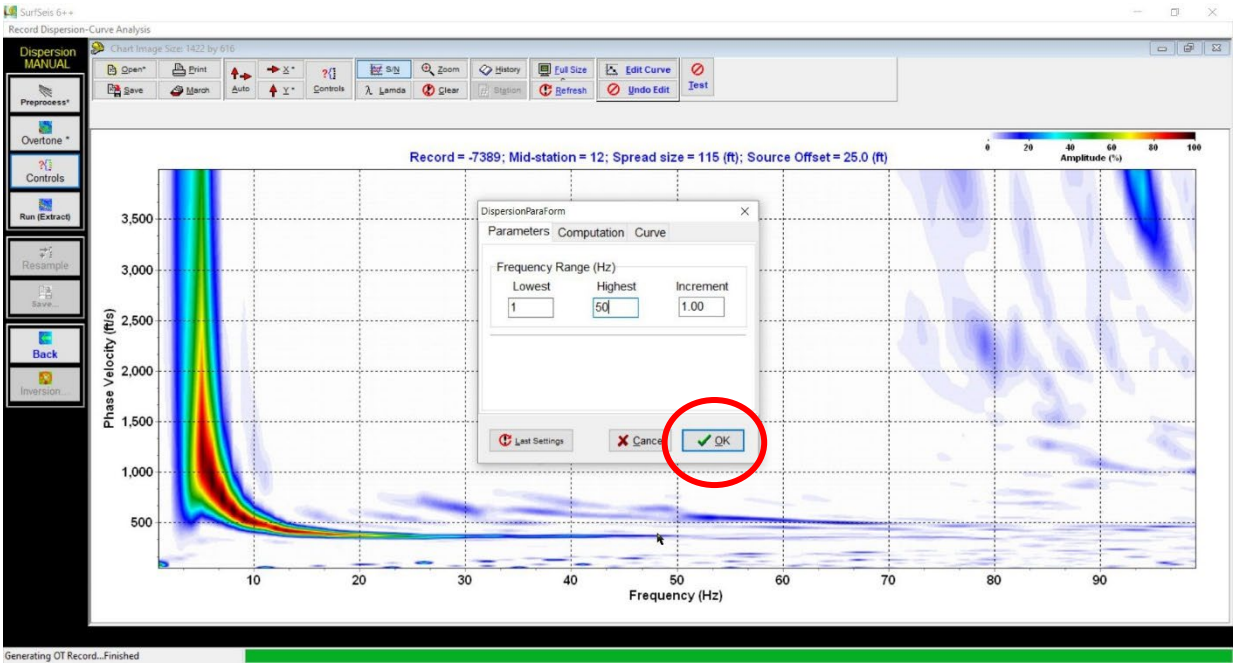
- Click **Maximize** the Overtone image window.



- Right click on the **Control** button.

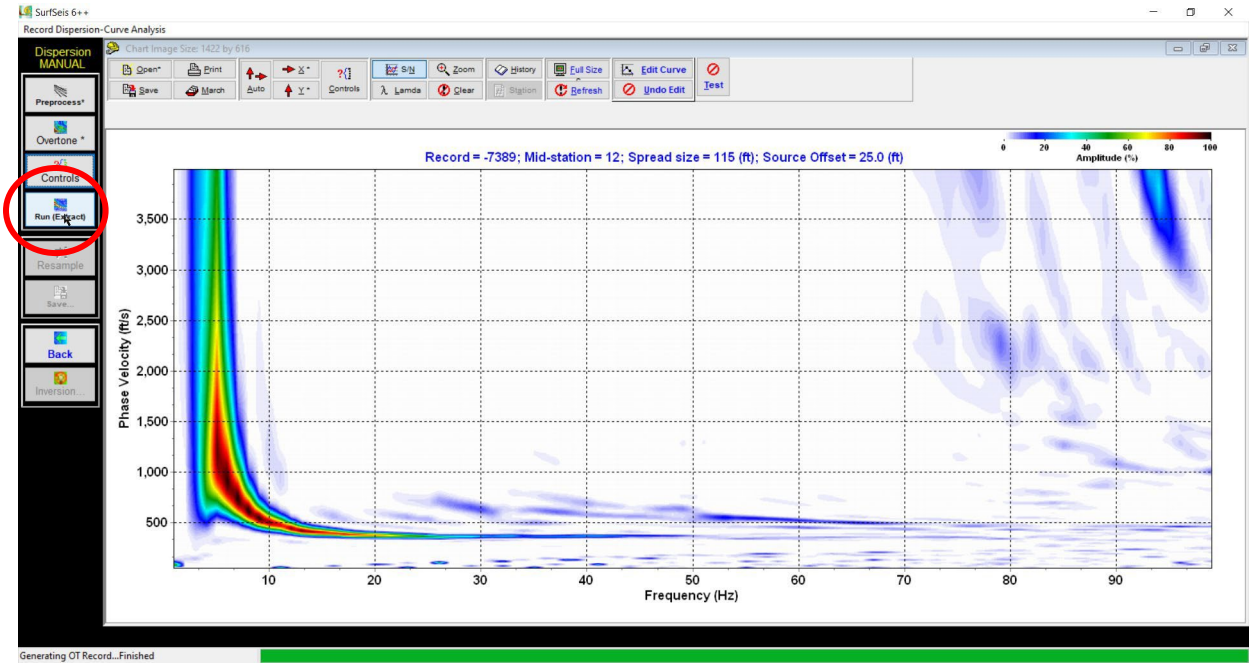


- A **DispersionParaForm** window will appear.

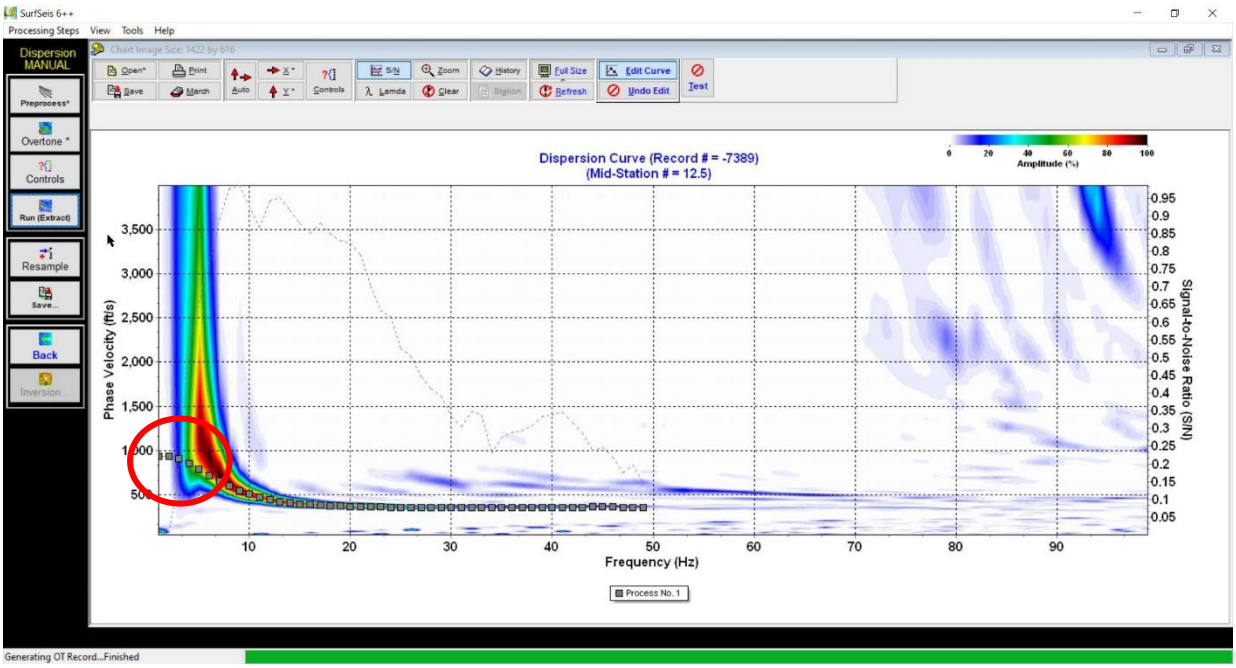


- In the **Parameters** tab select the frequency range for processing. In this example 1 to 50 Hertz with the increment of 1 are selected. Click **OK**.

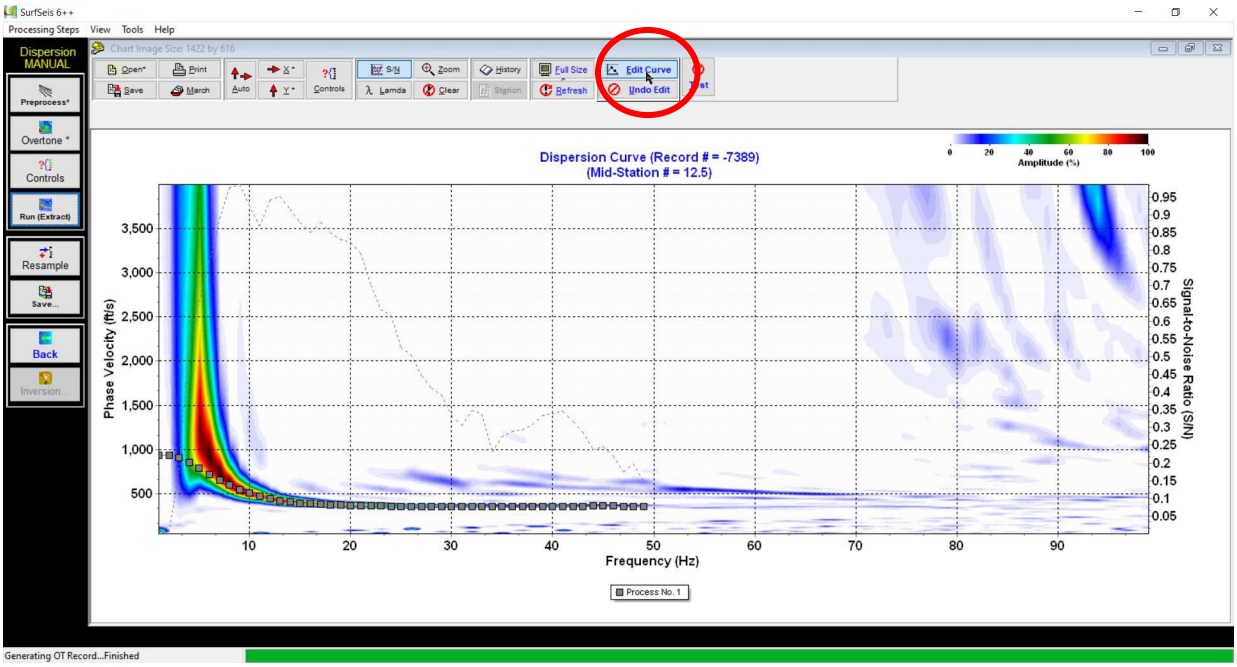
  Note: Processing data with lower Increment values (e.g., 0.1) can help produce smoother OT images and, but can also slightly increase data processing time.



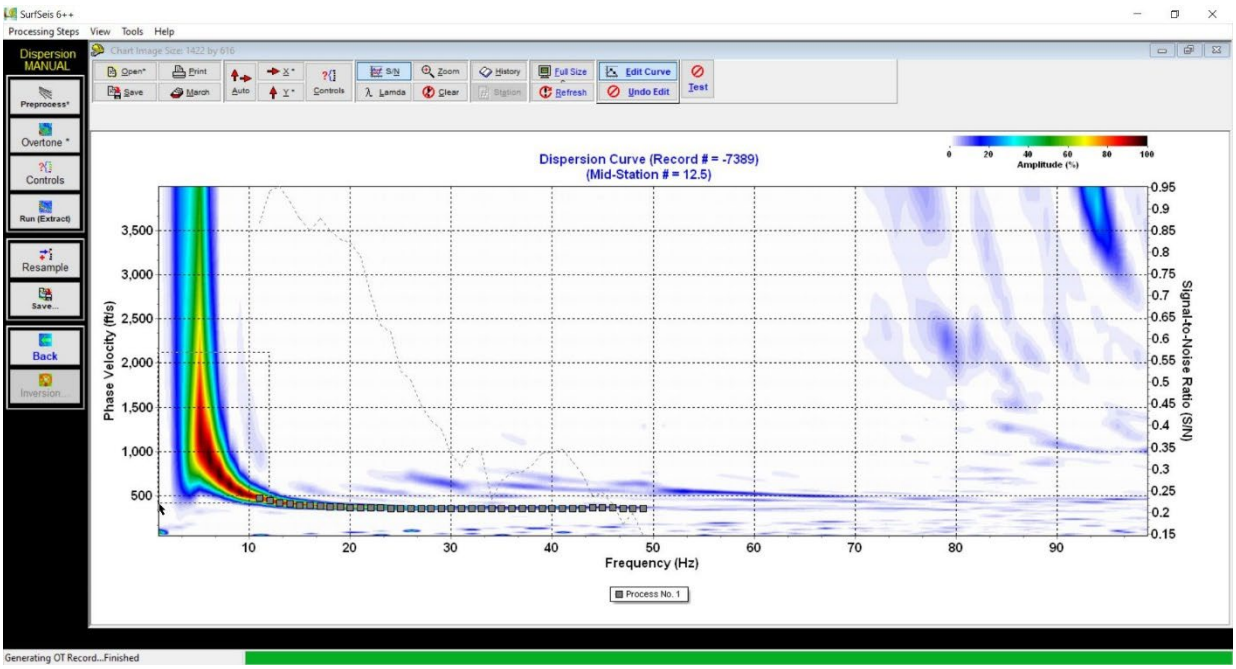
- Click **Run (Extract)** button.



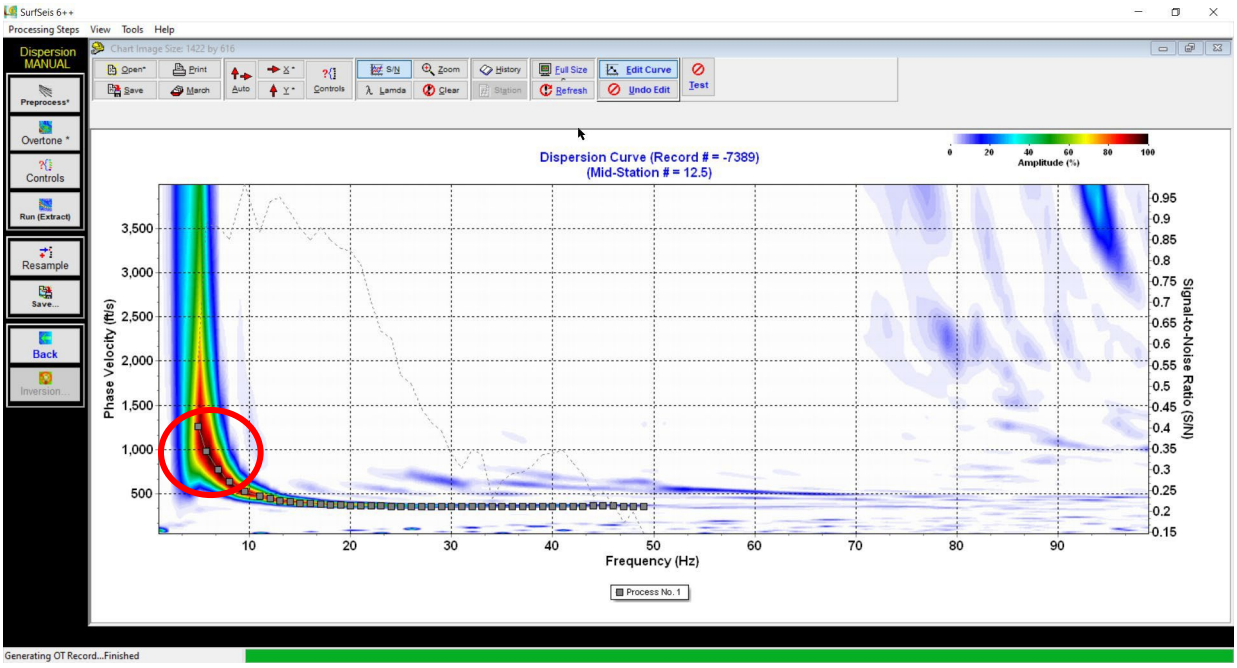
- An automatically picked **Dispersion Curve (DC)** within the frequency range defined will appear on the overtone image.



- **Dispersion Curve (DC)** points (shown as squares connected by a line) can be manually edited by clicking the **Edit Curve** button (highlighted in blue when active) on the top panel.

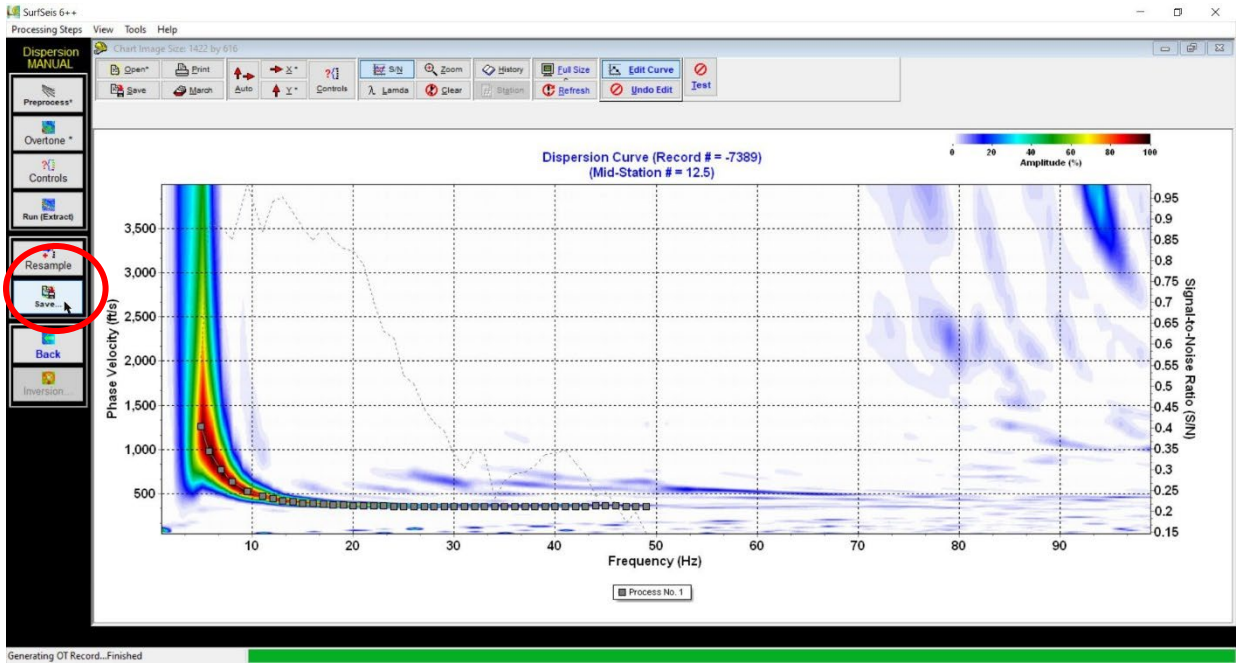


- Points can be added by left clicking anywhere on the OT image or deleted by left clicking on the existing point. A section of the DC could be removed by holding left button and dragging it over to highlight the region where the points will be deleted.

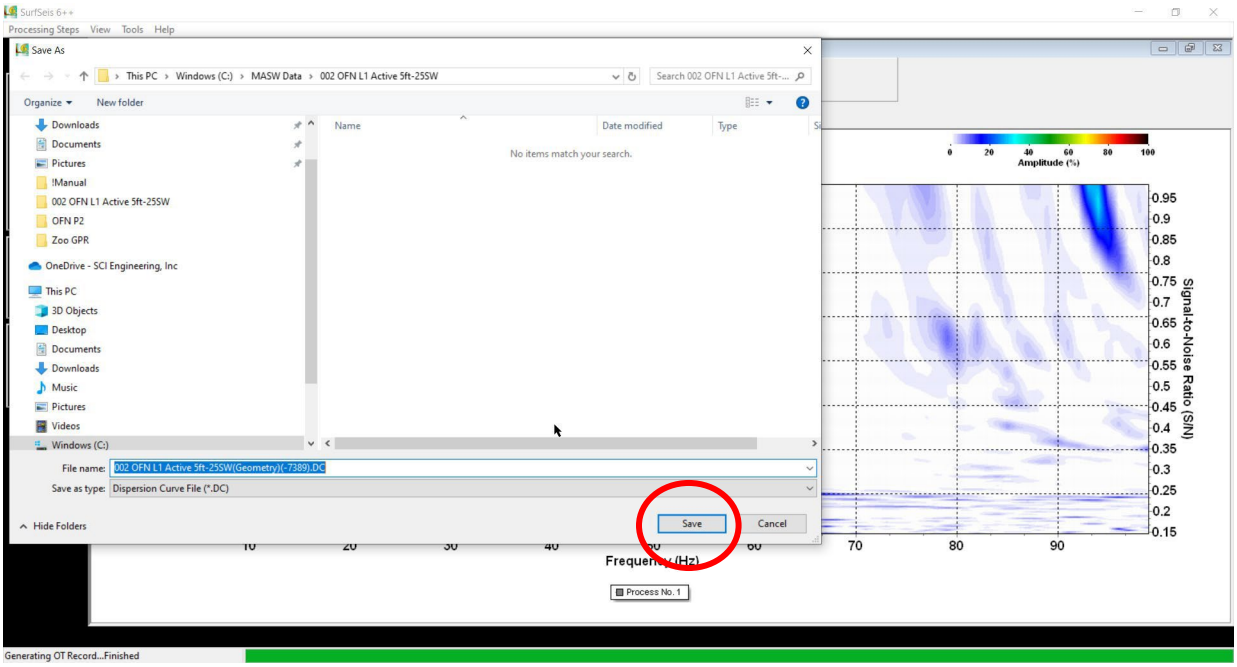


- New points can be added by left clicking on the **Overtone** image with the maximum signal amplitude.

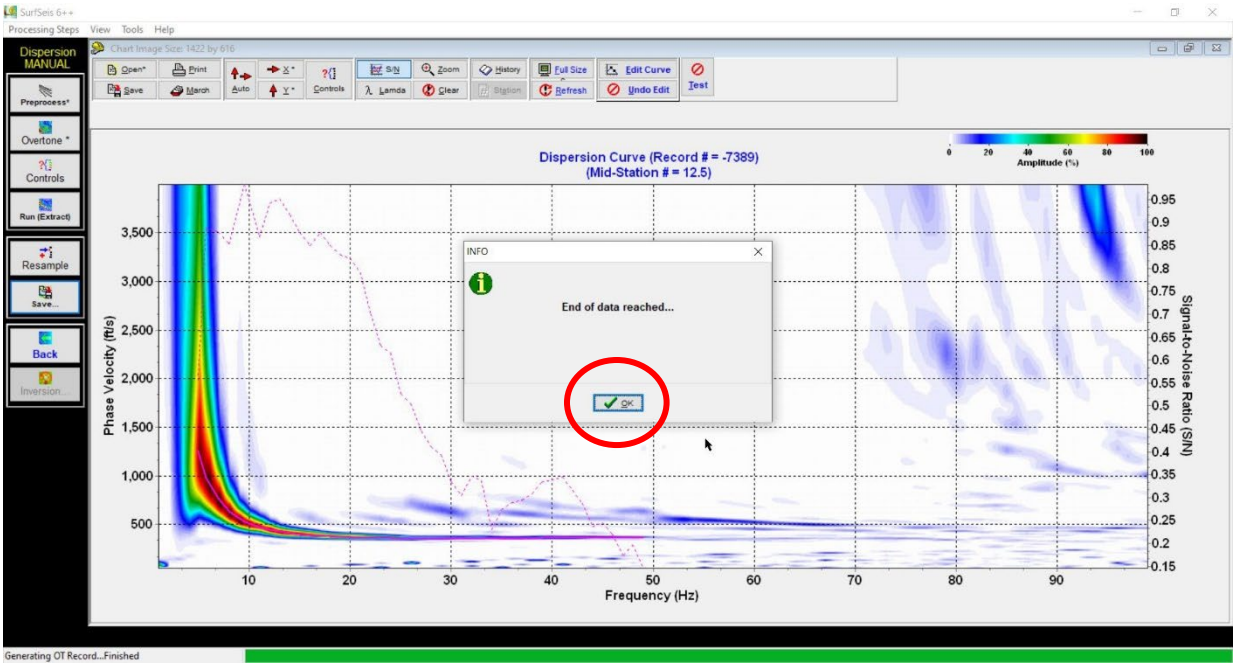
  Note: The point with the lowest frequency (on the left side of the window) controls the maximum depth of the shear wave velocity profile generated. Care should be exercised when picking the points in the lower frequency range (i.e., below 4 Hz) – placing a DC point in regions where OT signal is unclear, such as areas where the curve rises sharply, can introduce model instability and potentially lead to misinterpretation of the subsurface conditions.



- Click **Save** button on the left menu panel.

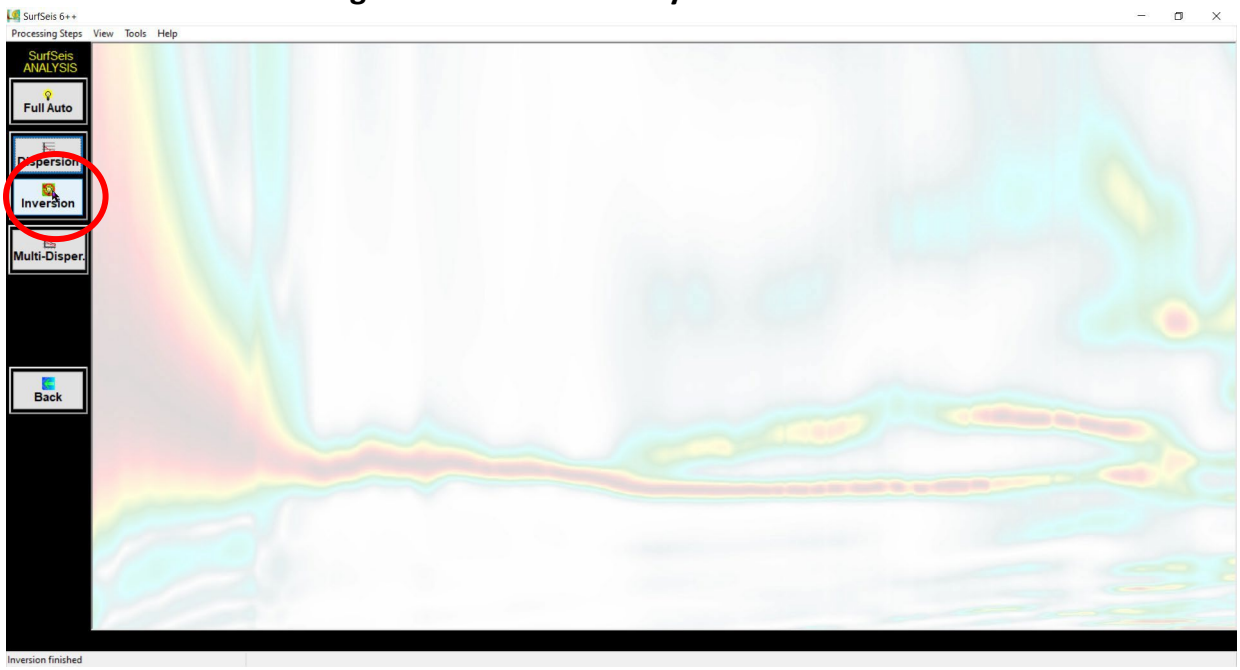


- Click **Save** to save the DC file.

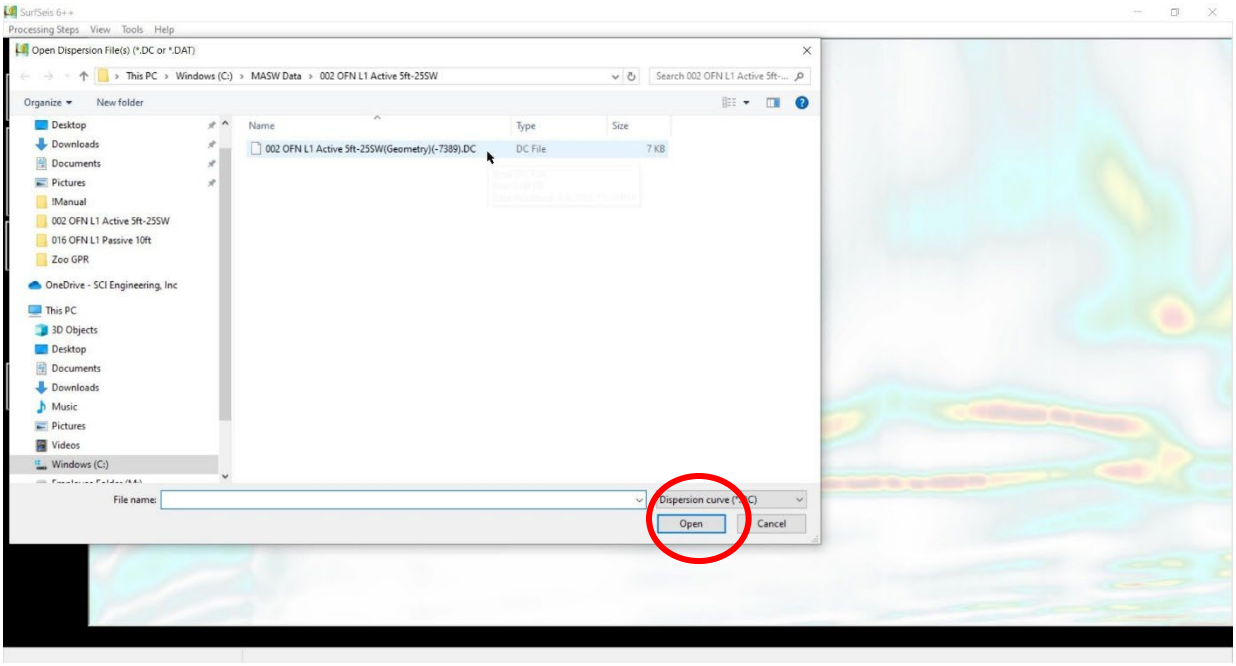


- Click **OK** to proceed.

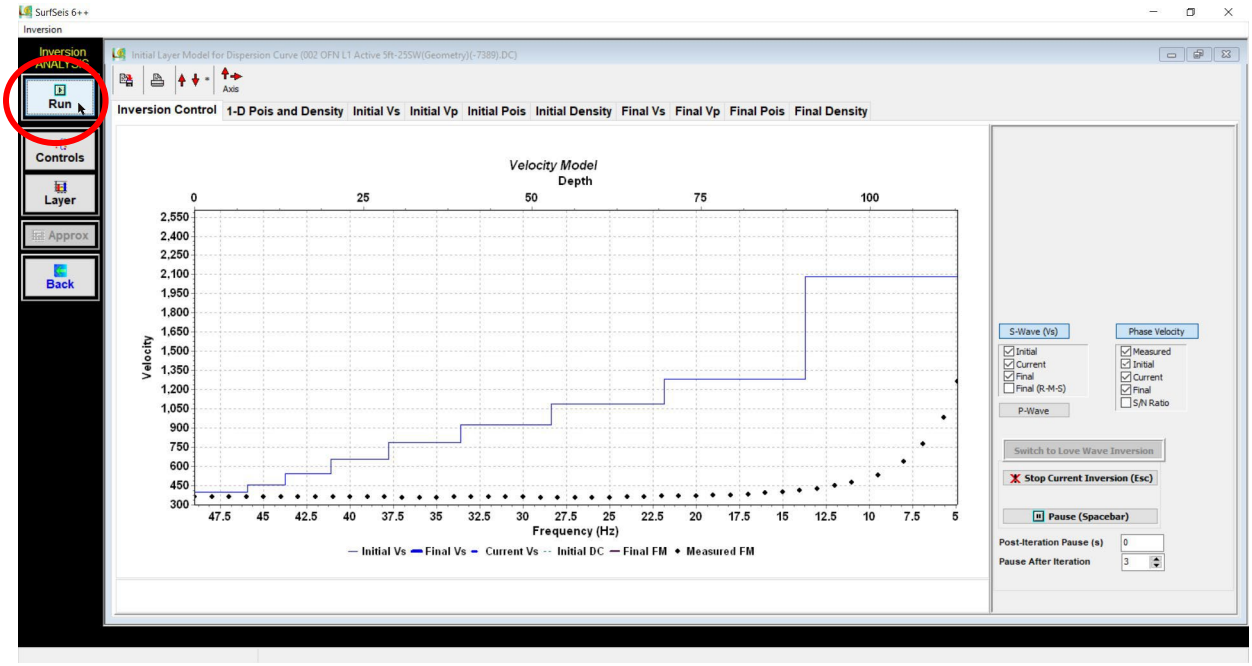
2.1.5 Inversion: Generating a Shear Wave Velocity Profile



- Click **Inversion** tab on the left panel. If the software is re-launched Click **Analysis** and then select **Inversion** tab on the left panel.

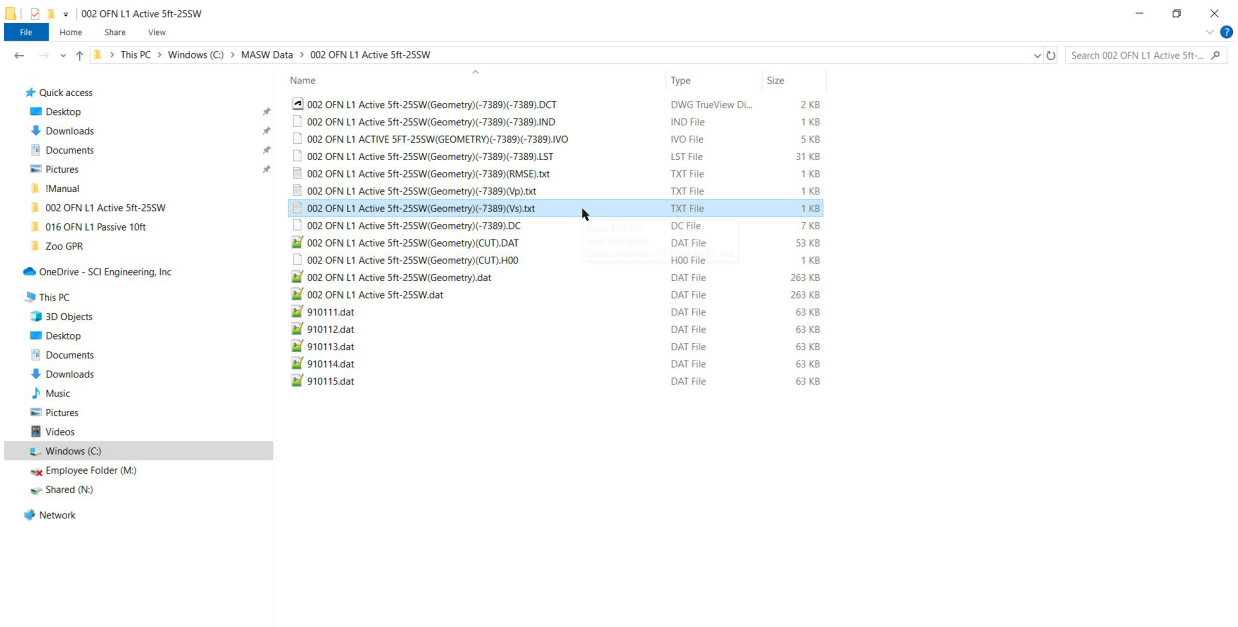


- To the saved DC file, select it and click **Open**.

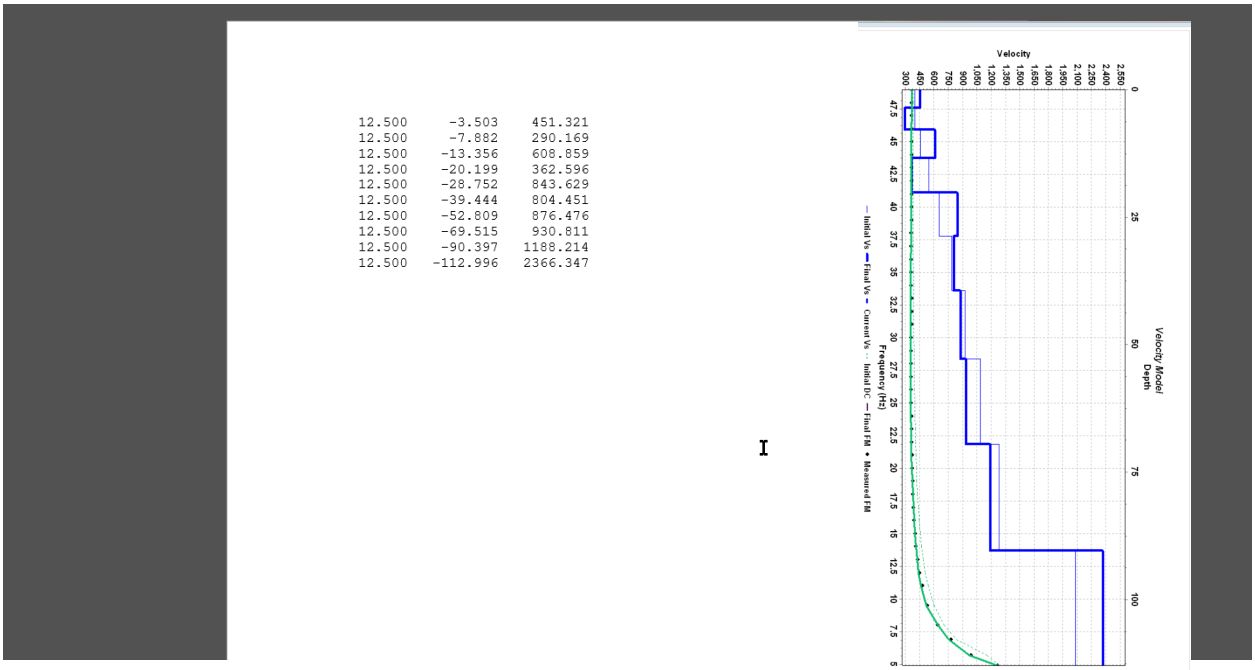


- An inversion window will appear. Click **Run** button on the left panel. The software generates a 10-layer velocity model by default. If more advanced data processing is required, the number of layers can be changed by the processor.

- The software will automatically generate a share wave velocity profile with 10 velocity layers. In this example the inversion process stopped after 9 iterations.



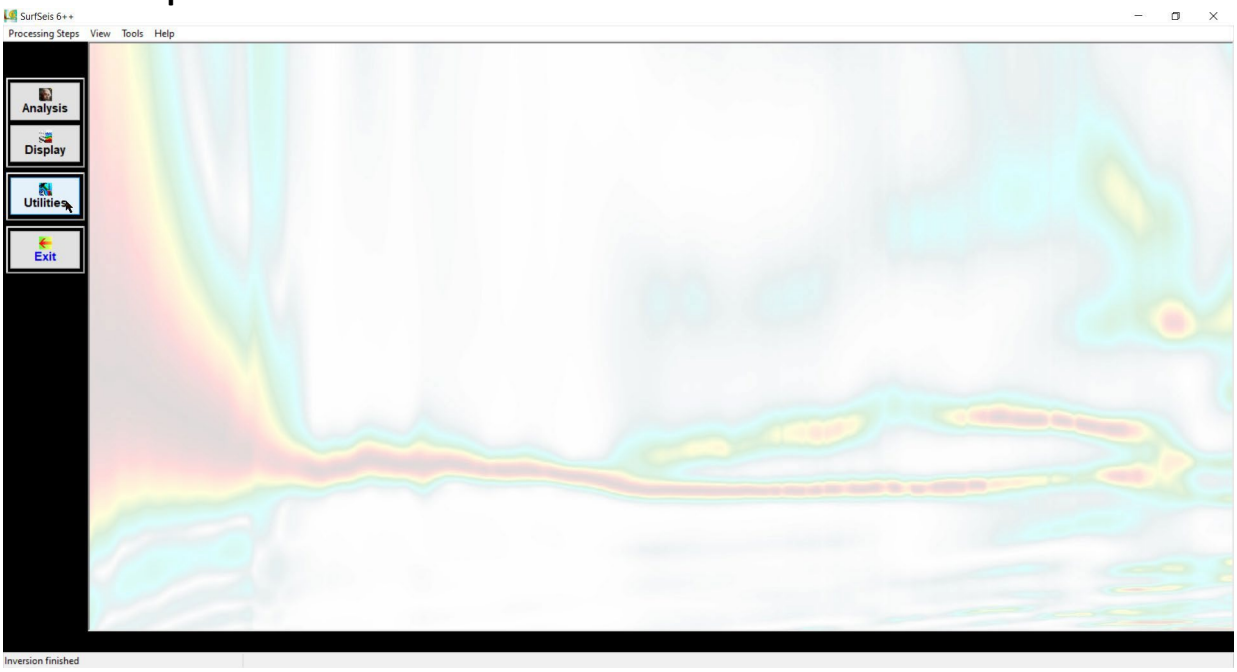
- The results of the inversion are saved in the text format in the folder with the rest of the data. This file could be opened and reviewed in a Microsoft Notepad, Excel or Word program.



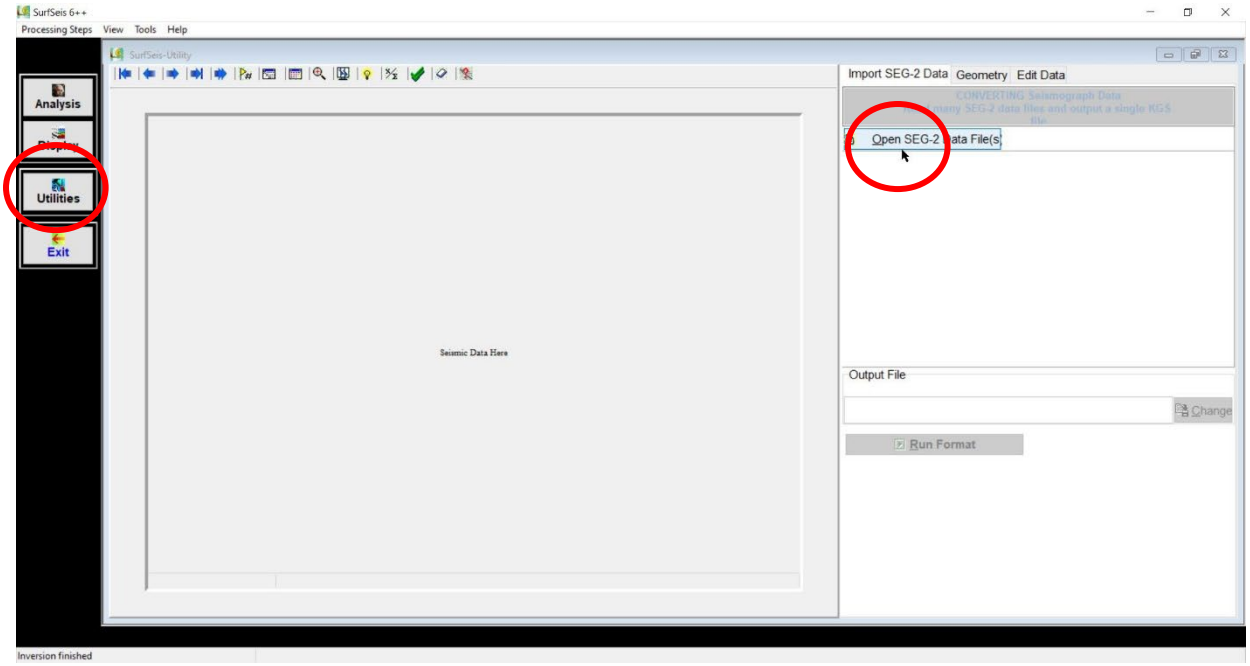
- The output file has 3 columns. The first column is the middle station (calculated from the record geometry), the second column is the depth relative to the surface and the third column is the shear wave velocity. Visually check the correlation between the table (left) and the profile (right). The data can be imported in Excel or other software for further calculations.

2.2 Passive Data Processing

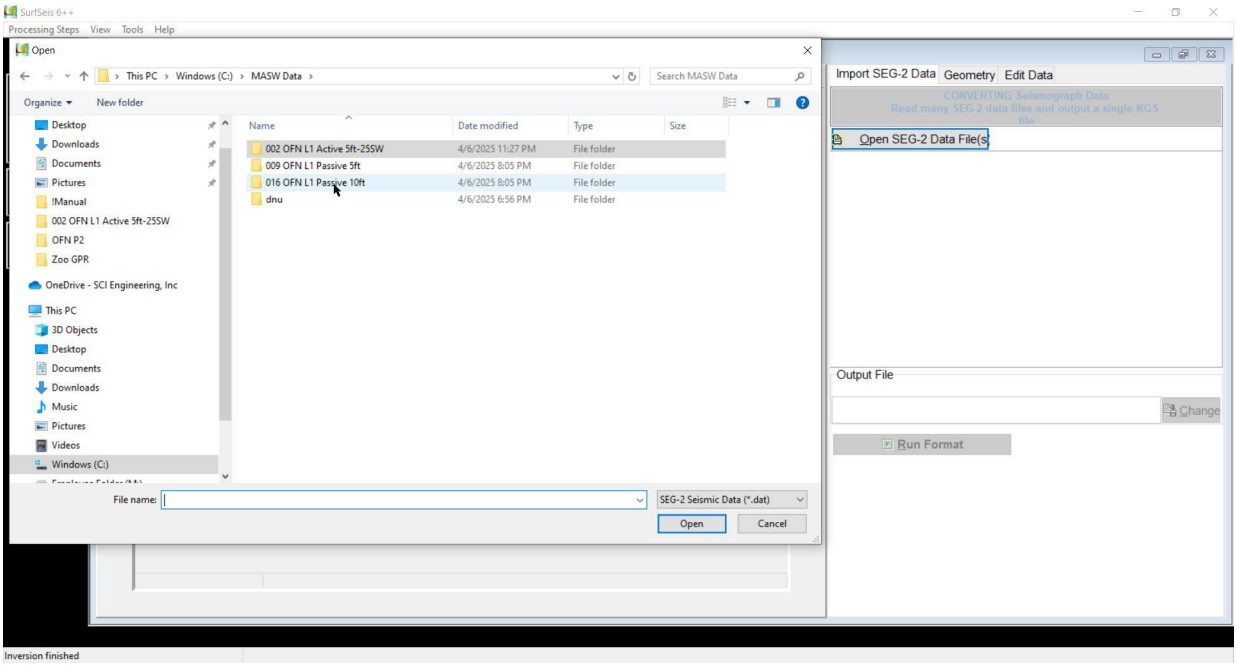
2.2.1 Data Import



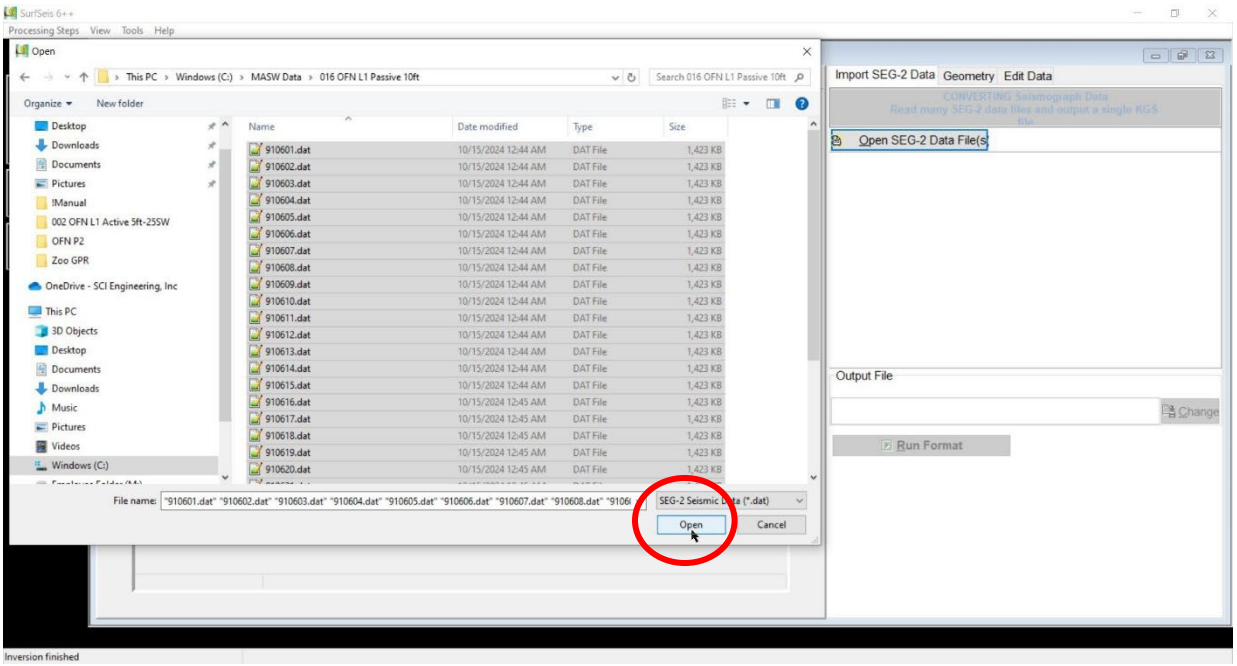
- Launch SurfSeis. If processing Passive data after Active data, it is recommended to close and relaunch the software.



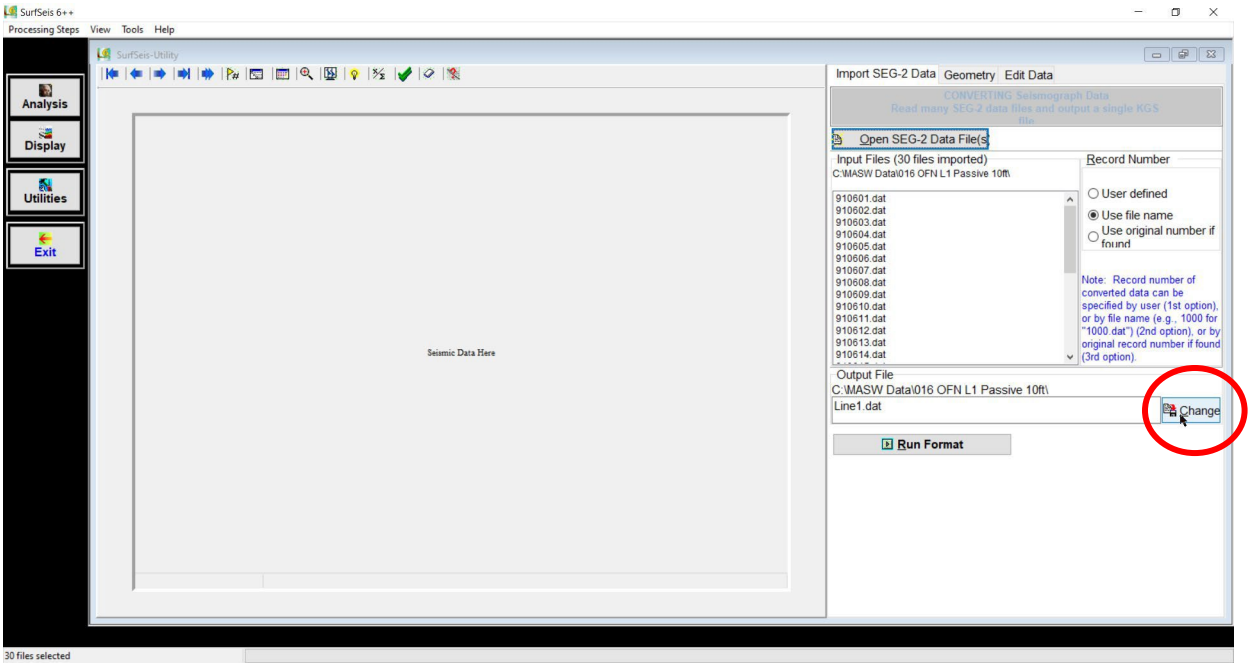
- Click **Utilities** tab on the left. Navigate to **Import SEG-2 Data Files(s)**.



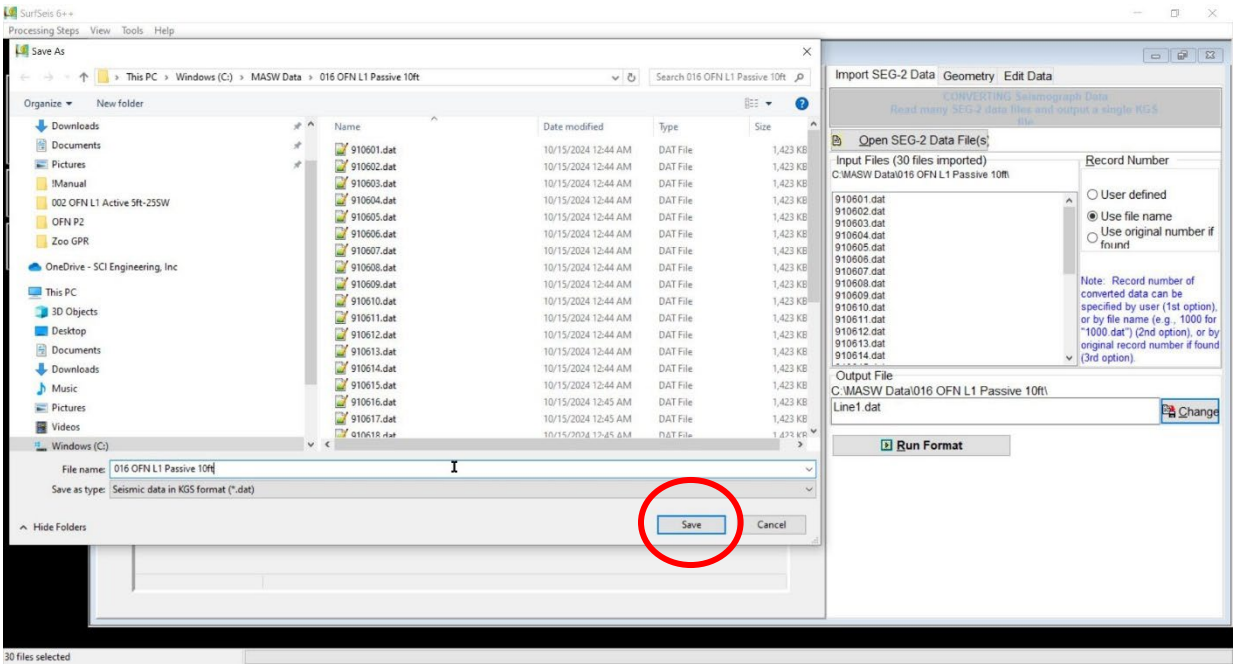
- Navigate to the folder with the data to be processed.



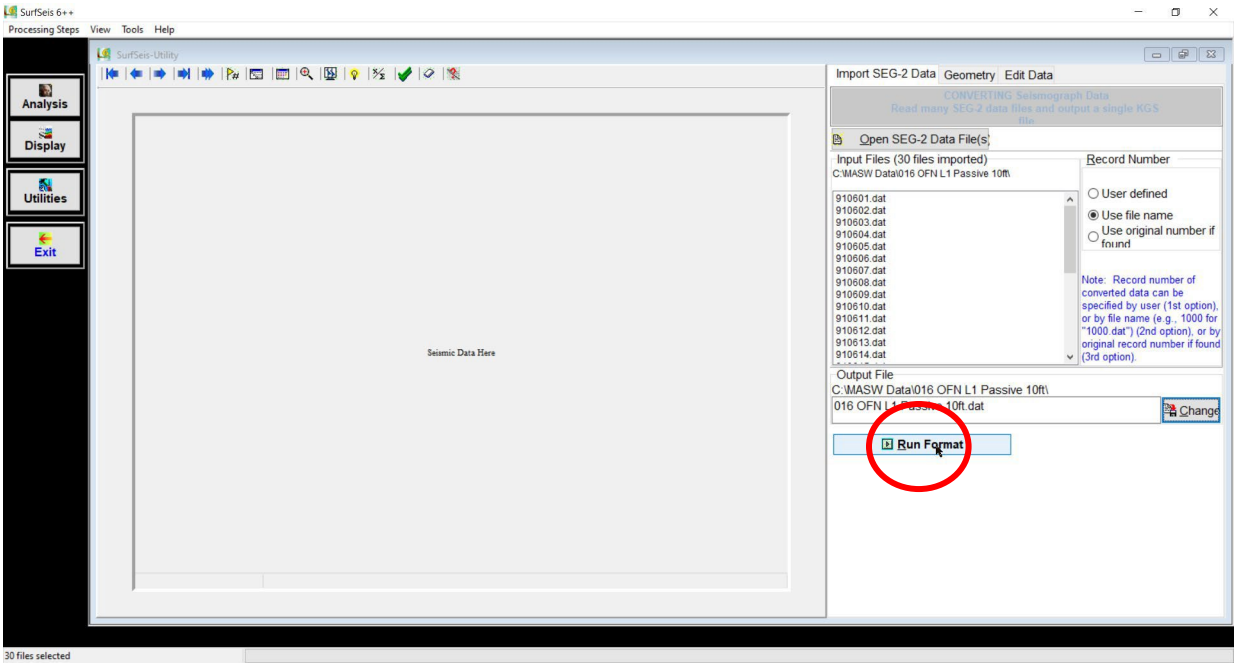
- Select and load the SEG2 files (30 files/records in this example).



- In the **Output File** click **Change**.

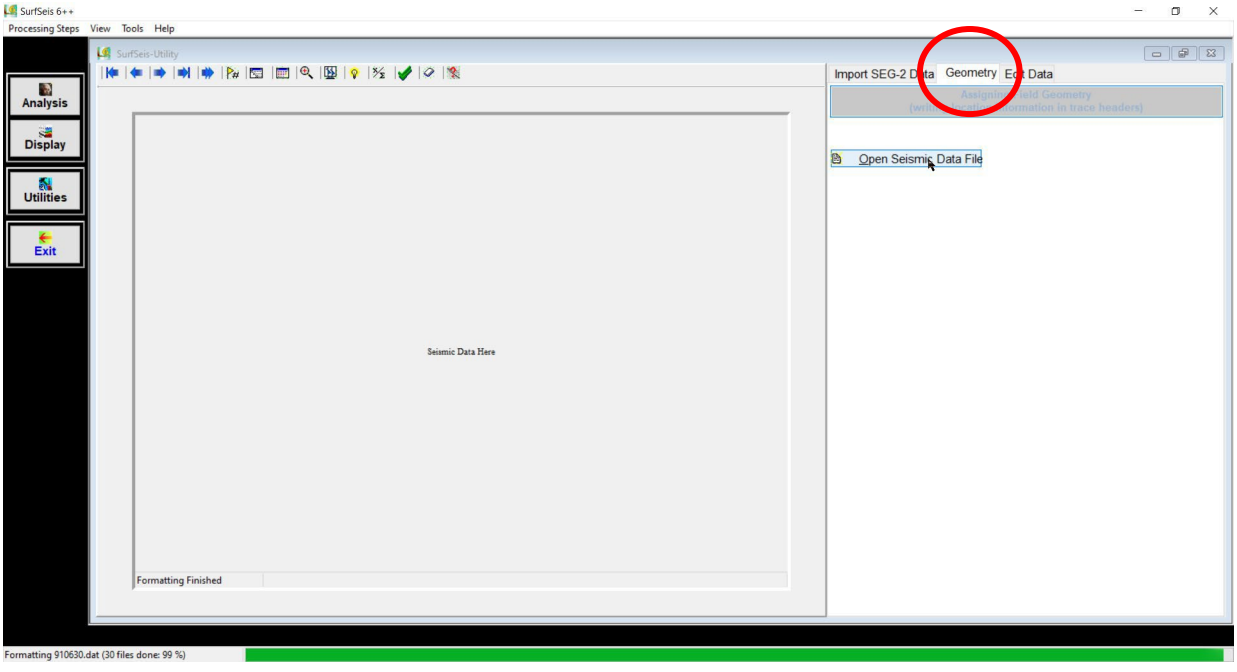


- Name the file logically (“016 OFN L1 Passive 10ft’ in this example) and click **Save**.

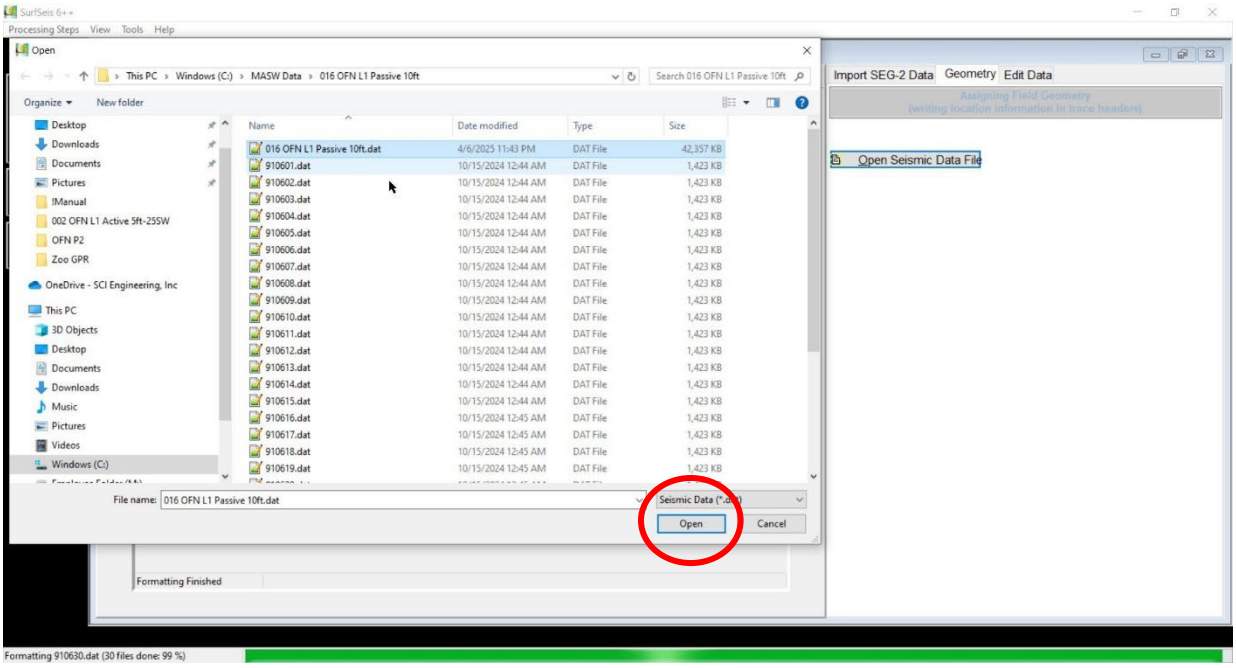


- Click **Run Format**. A new file will with all the converted data will be saved in the folder with the data.

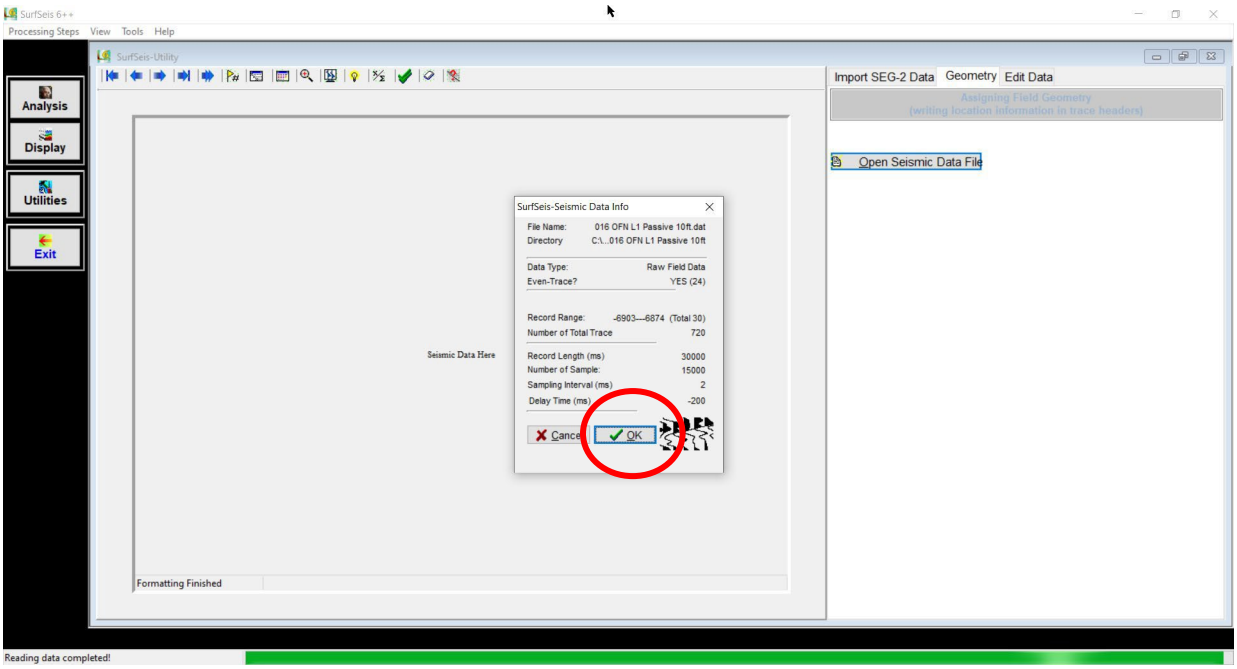
2.2.2 Geometry Assigning



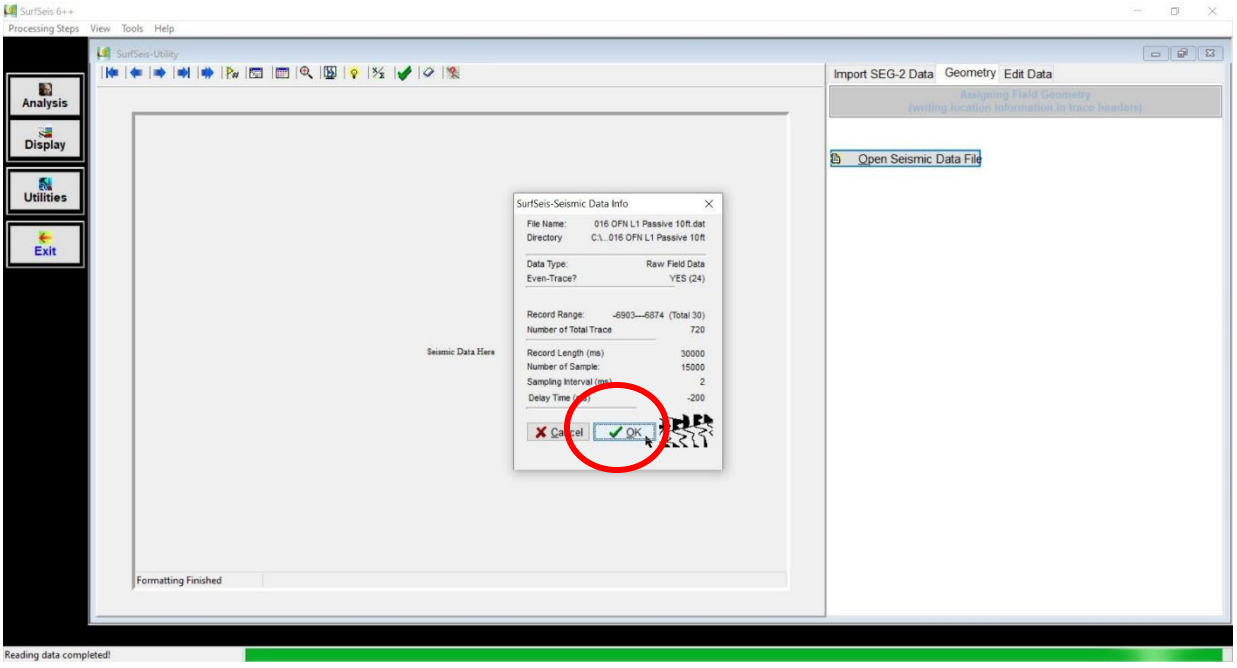
- Still in the **Utilities** tab. Navigate to **Geometry**, click **Open Seismic Data File**.



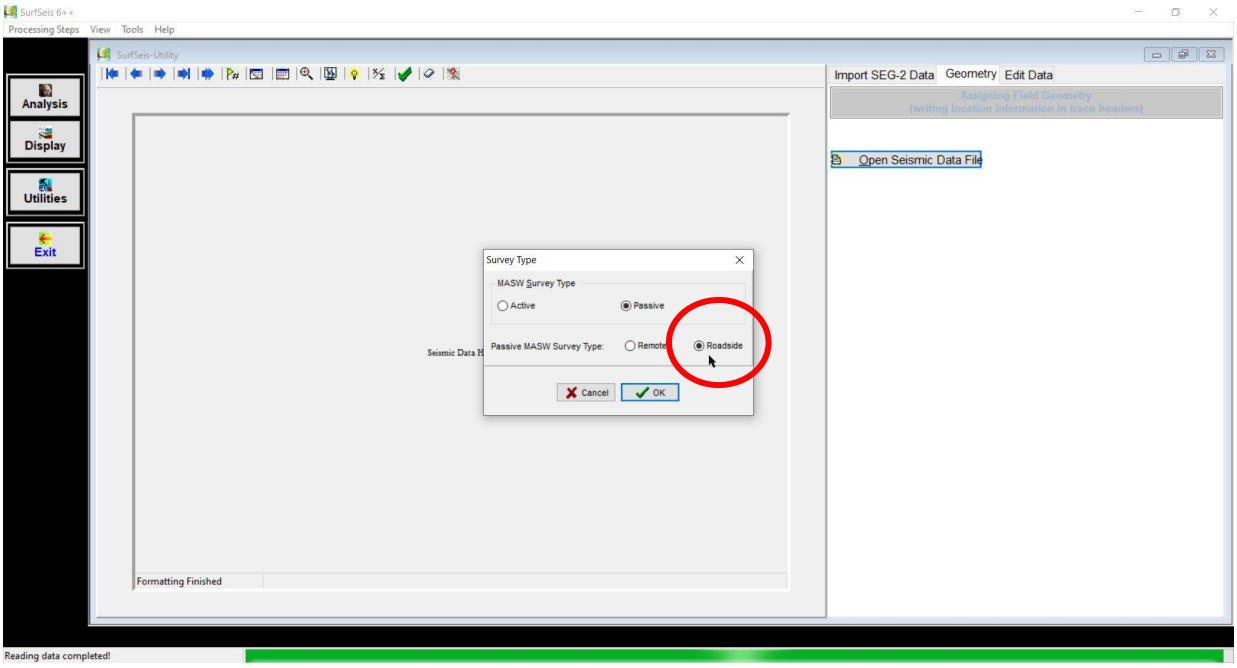
- Select the file that was created in the previous step and click **Open**.



- A **SurfSeis-Seismic Data Info** window with information about the collected data will show.

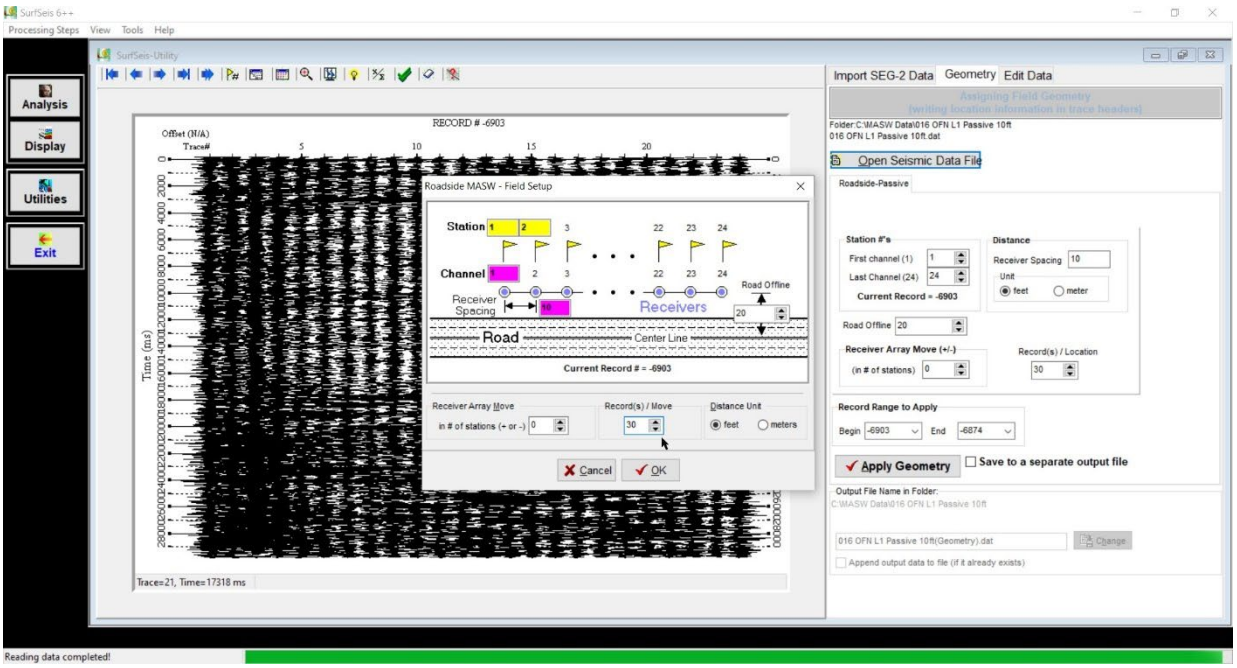


- Click **OK** to continue.

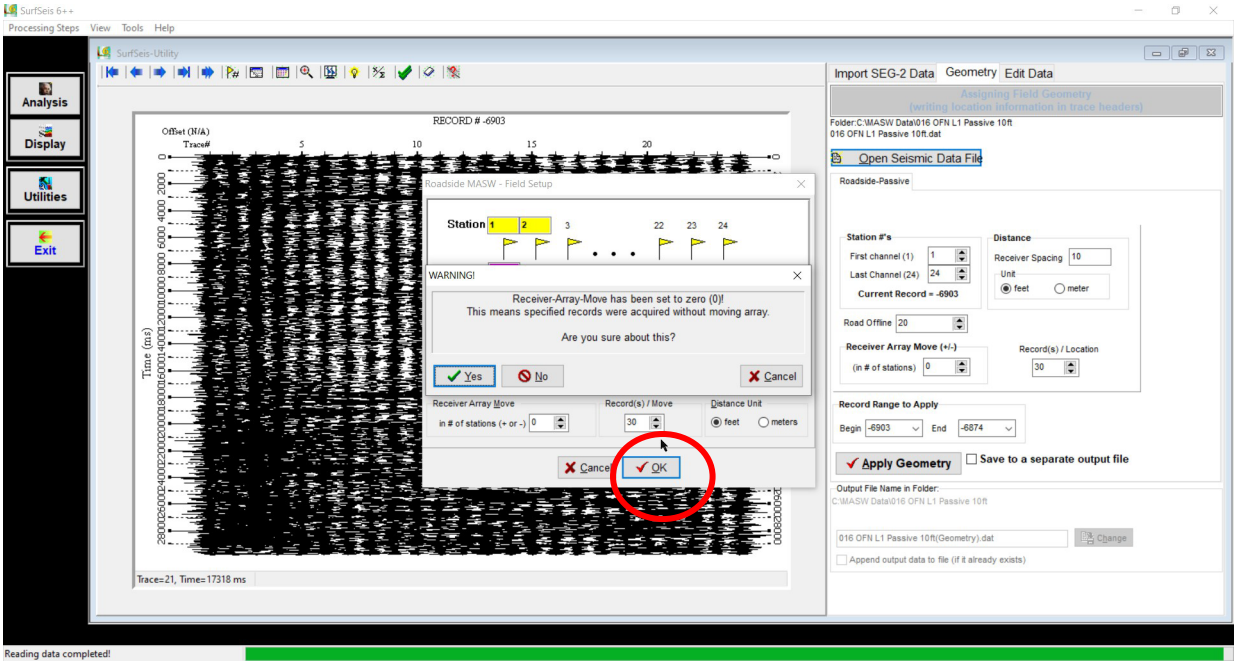


- **Survey Type** window will appear**.** Select **Passive** and then **Roadside.** Click **OK** to continue.

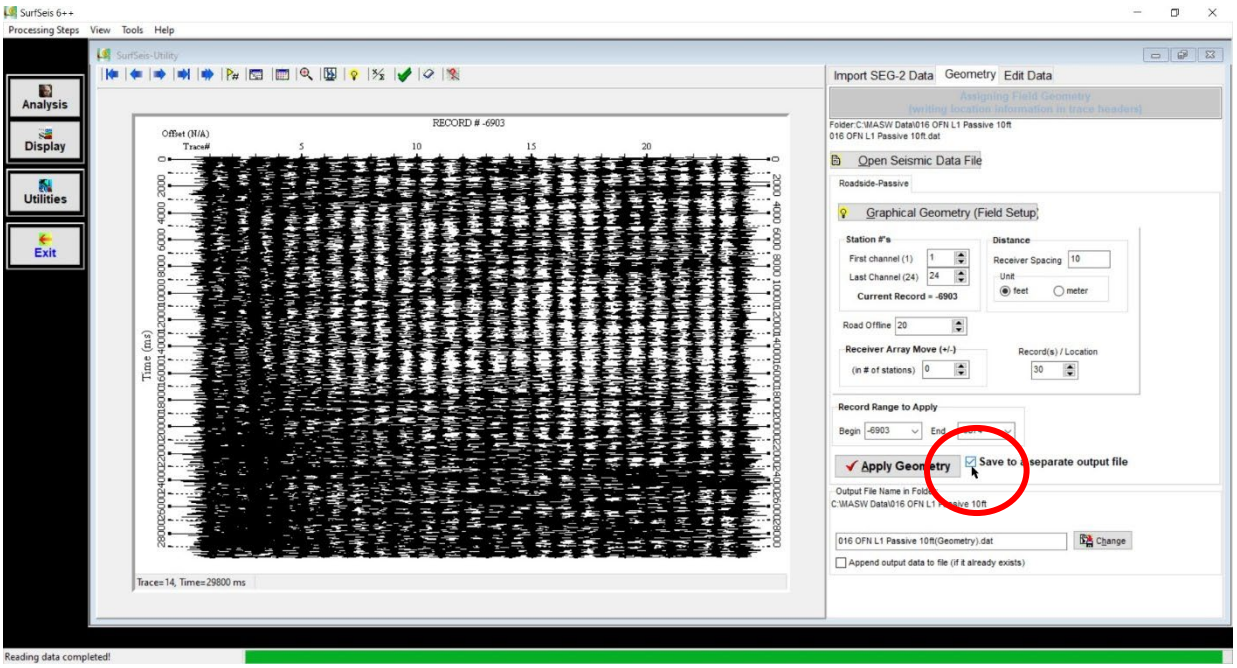
Note: for linear Passive array Roadside is used. If a 2-dimensional array (e.g., circle, L-shape, etc.) is used, then Remote option should be selected in Passive MASW Survey Type.



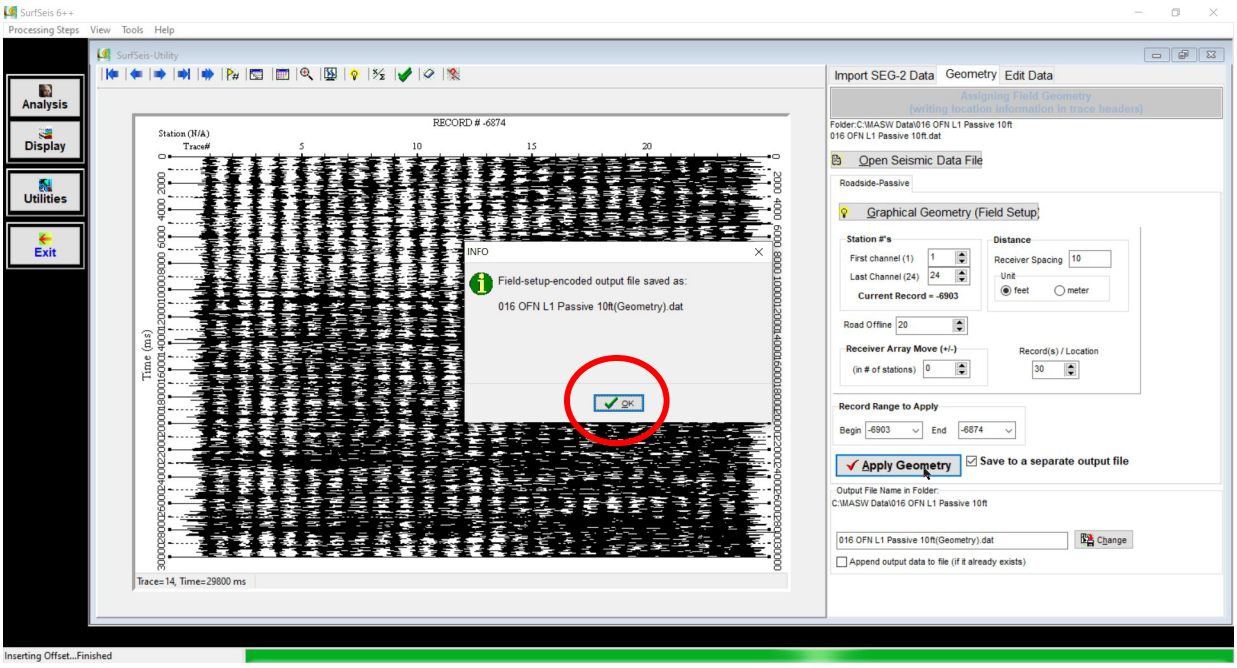
- Define **Station** (1 for the first and 2 for the second window works in most cases), **Channel** (1 for the first, the rest will be automatically assigned), **Receiver Spacing** (i.e., Geophone Spacing) (10 feet in this example), **Road Offline** (distance from the road, 20 feet in this example), and **Record(s)/Move** (30 files in this example). Select correct **Distance Units**.



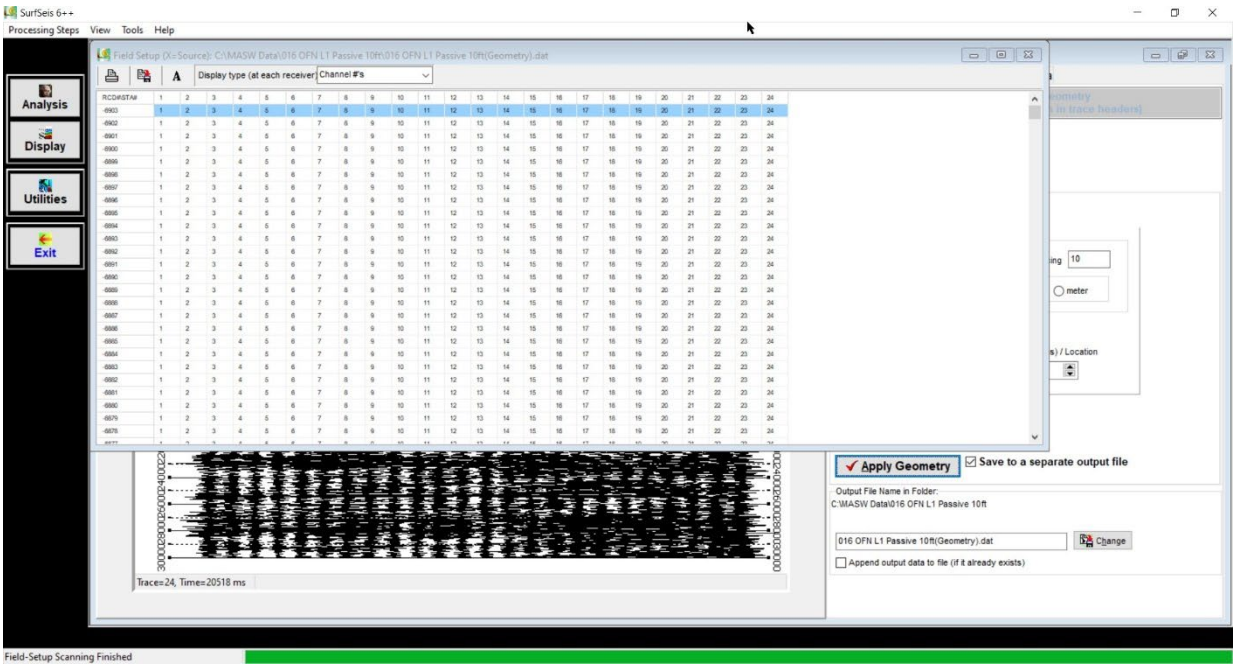
- A **Road MASW-Field Setup** window will appear, with a warning message to confirm that all 30 records were collected at one location. Click **OK**.



- Check the box **Save to a separate output file**. Click **Apply Geometry**.

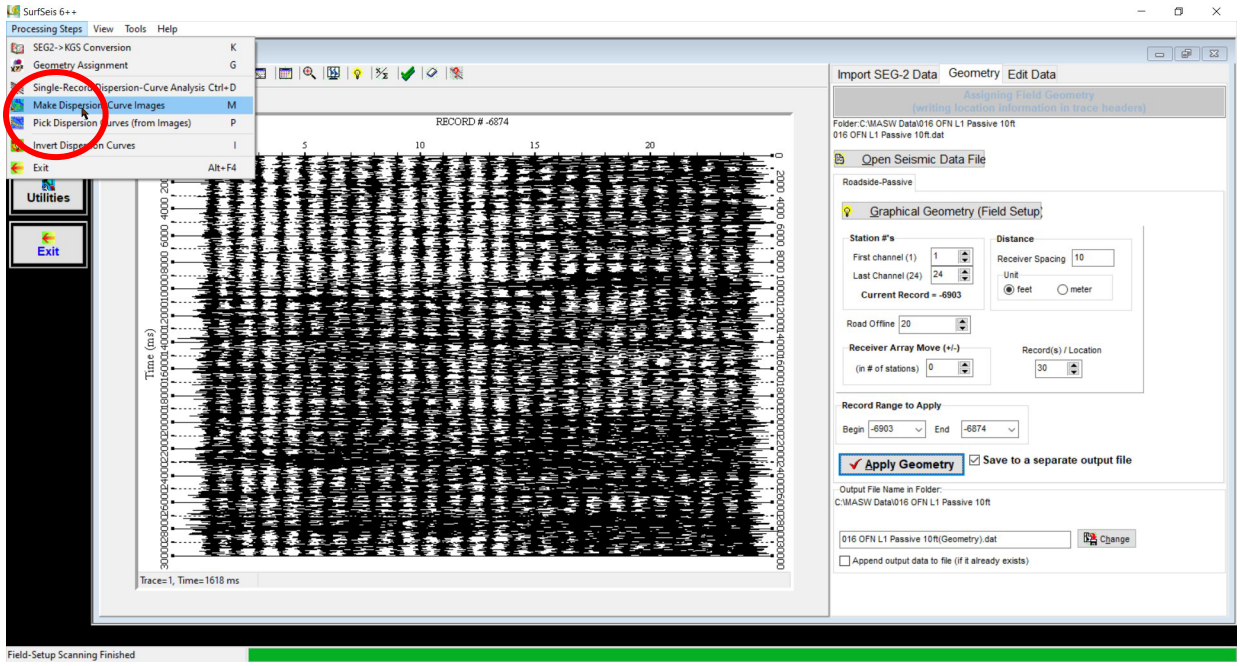


- An **INFO** window with information about the saved data will show. Click **OK** to continue.

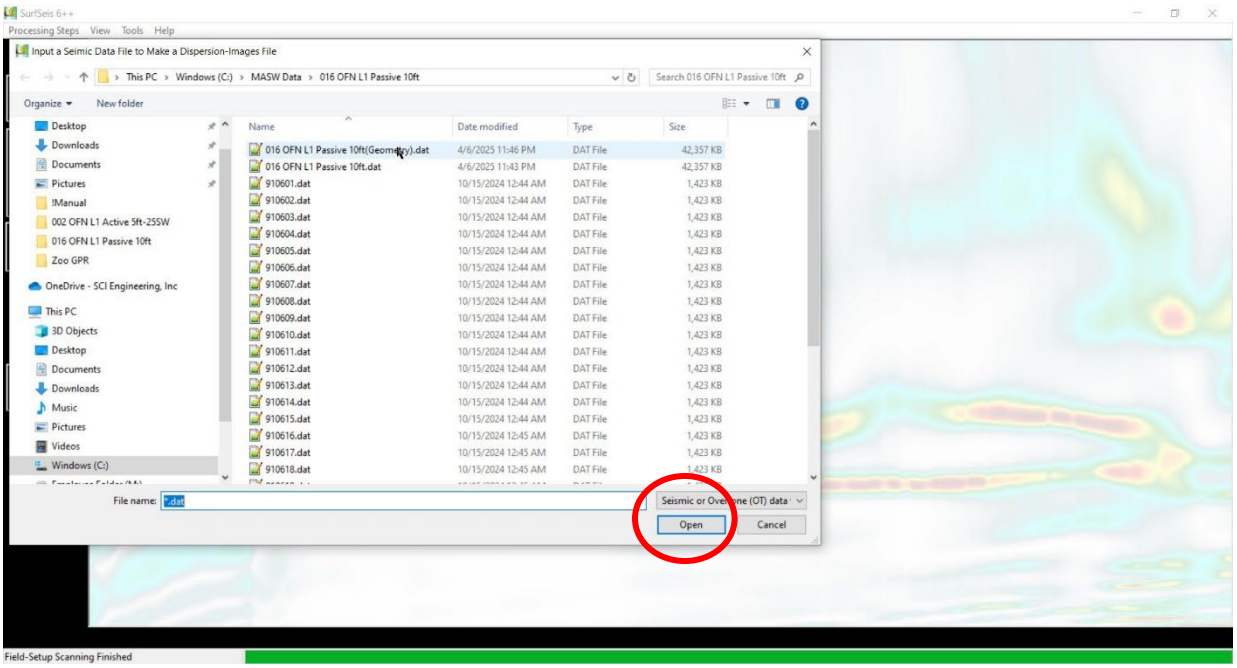


- A table with the assigned geometry for each file will appear for information purposes. The table window can be closed, this step is optional.

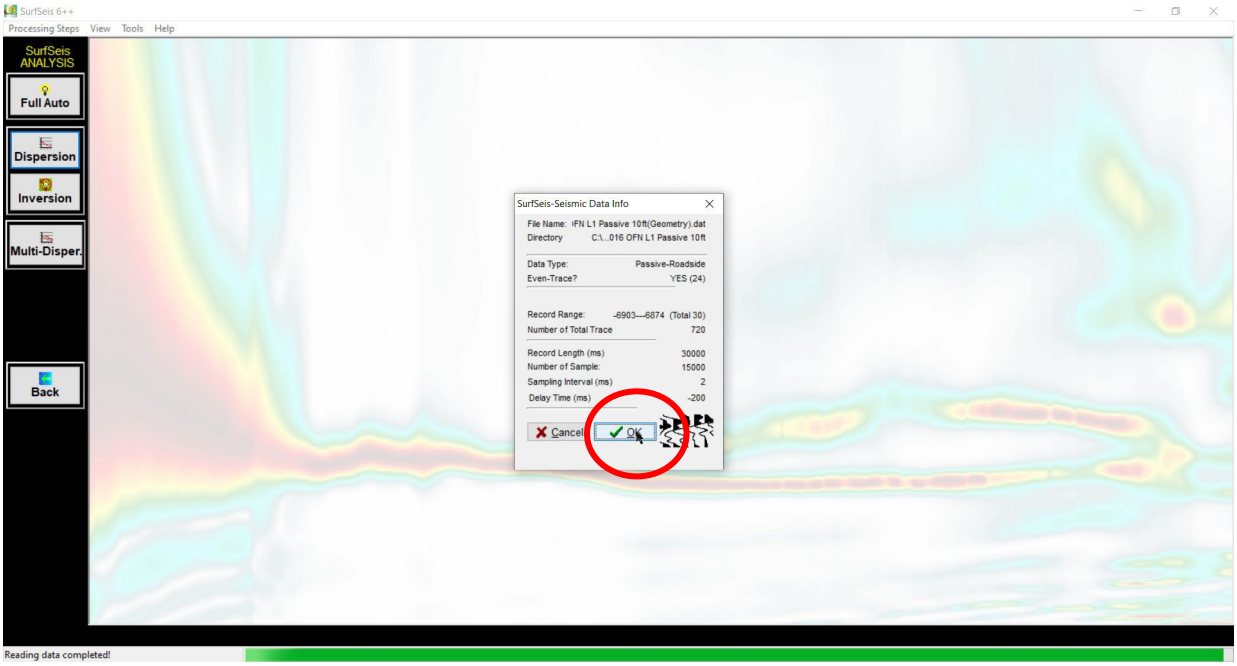
2.2.3 Generating an Overtone (OT) Image



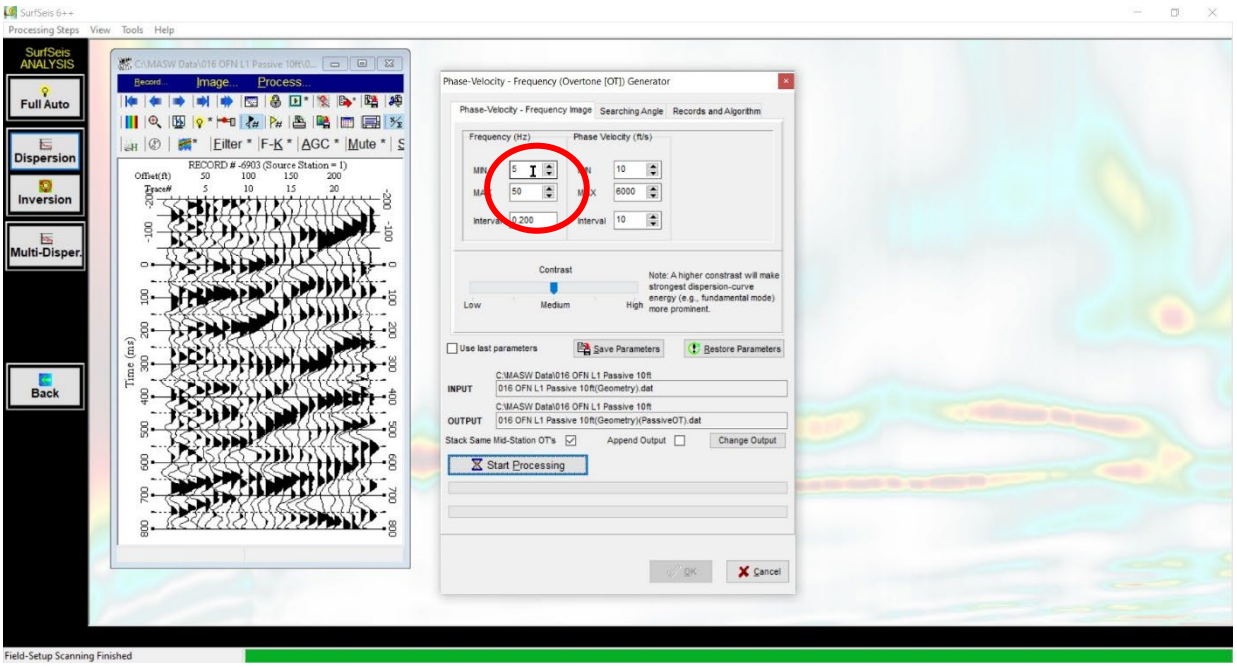
- Click **Processing Steps** at the software window top. If it is visible close and re-launch SurfSeis.
- Click **Make Dispersion-Curve Images.**



- Navigate to the folder where the file with assigned geometry was saved in the previous step. Click **Open**.



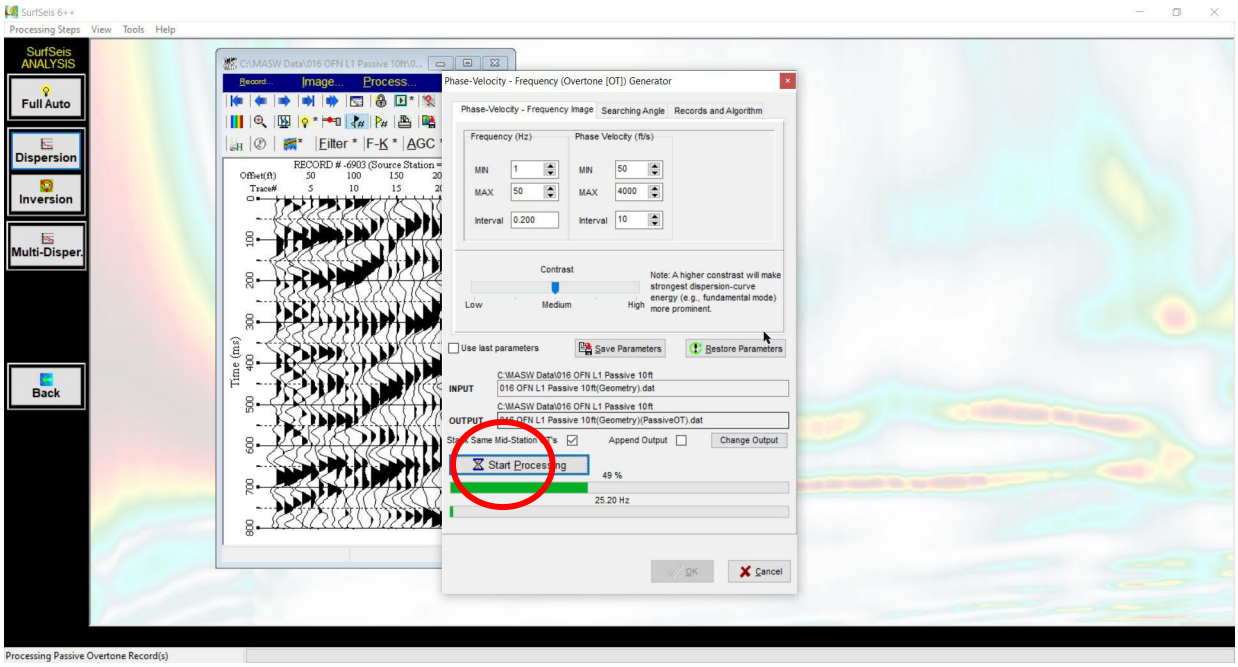
- A **SurfSeis-Seismic Data Info** window with information about the collected data will show.



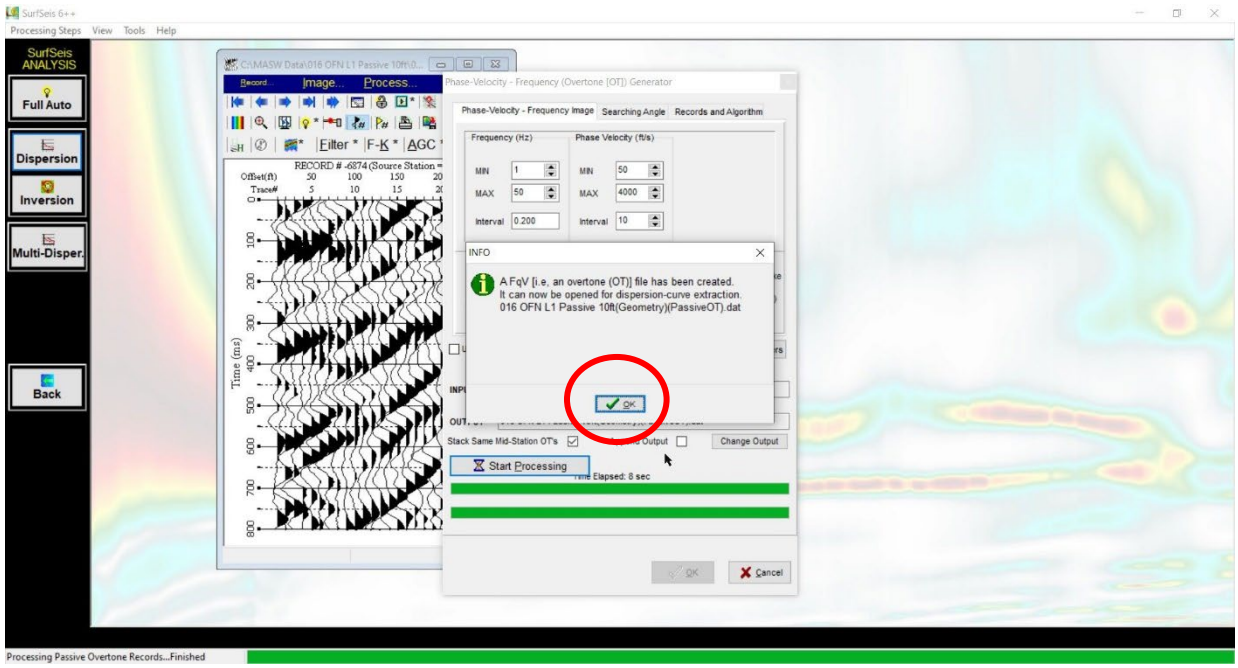
- A seismic record window and the Phase-Velocity – Frequency Overtone [OT]) Generator window will appear.

  Note: typically, a "useful" range of velocities and frequencies present in MASW data is 100 to 2,000 ft/s and 4 to 50 Hz, accordingly. However, the range is site specific and should be evaluated during data processing for individual data sets.

  If Active and Passive data will be combined later, it is recommended to use the same frequency and velocity range and the interval values for both data sets.



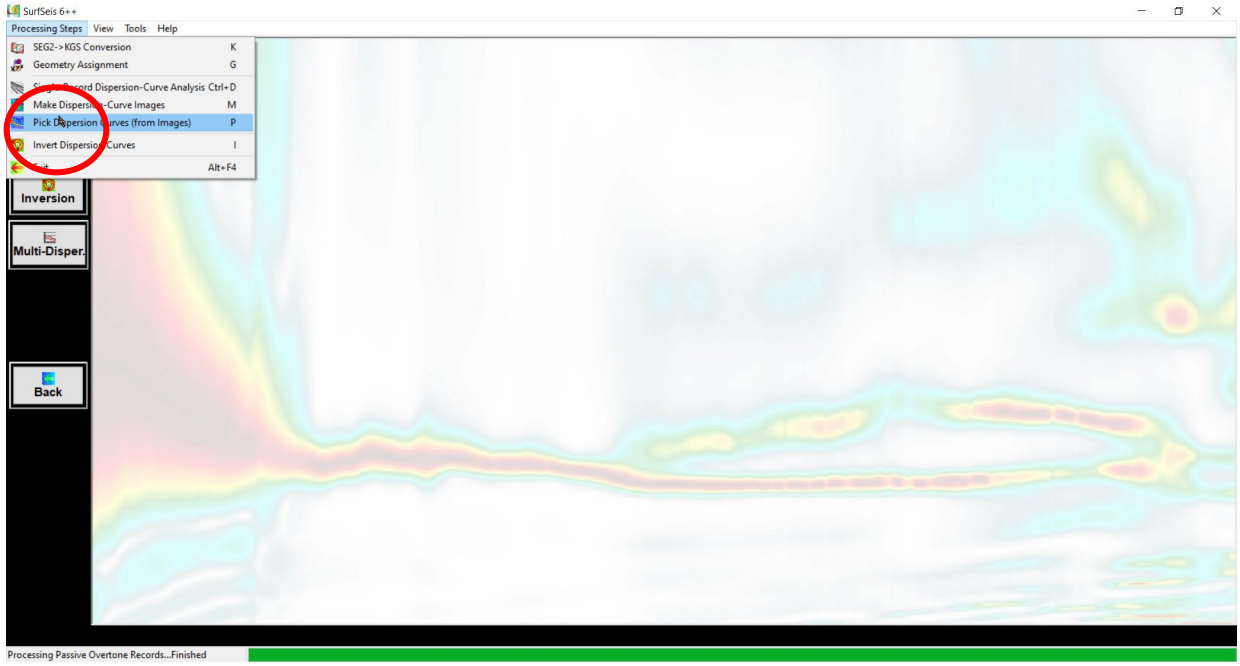
- In the **Phase-Velocity – Frequency Overtone [OT]) Generator** window select the **Frequency Range** for data processing (1 to 50 Hertz in this example) and **Phase-Velocity Range** from 50 to 4000 feet per second in this example. The **Interval** values can be left by default. The **Stack Same Mid-Station** must be checked. Click **Start Processing** button.



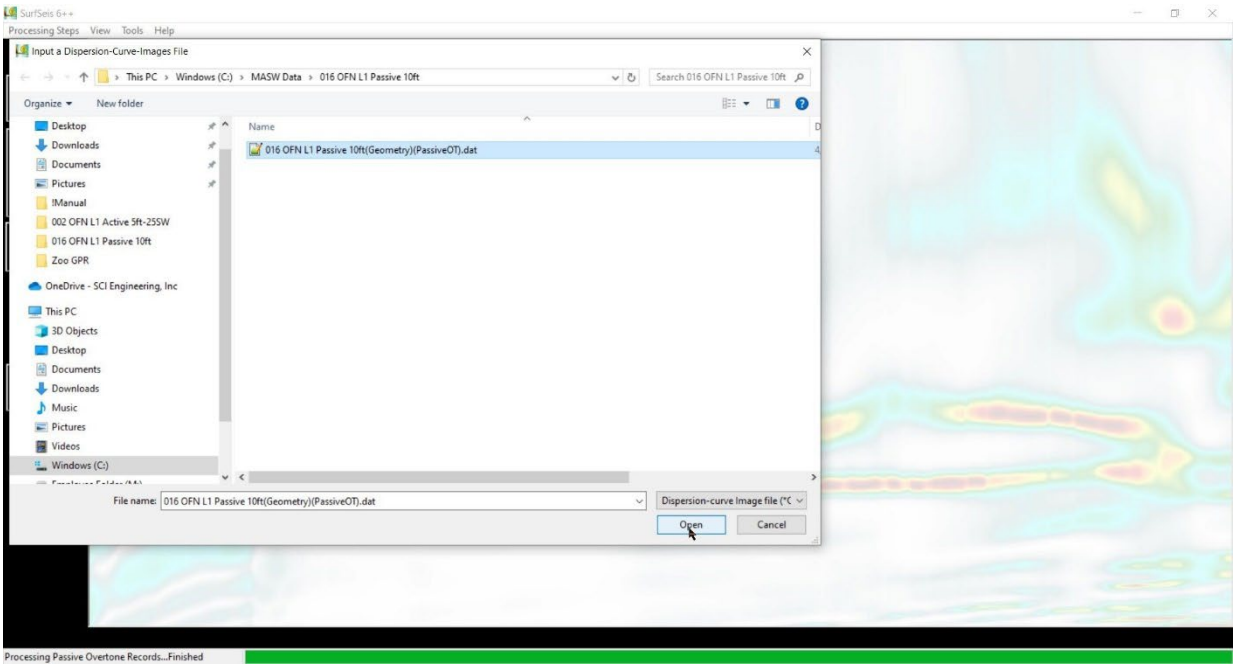
- The Software will automatically start processing all 30 files. An **INFO** window will appear with a message that the overtone image is generated.

  Note: Overtone image is saved as a file but is not shown in the software during this step.

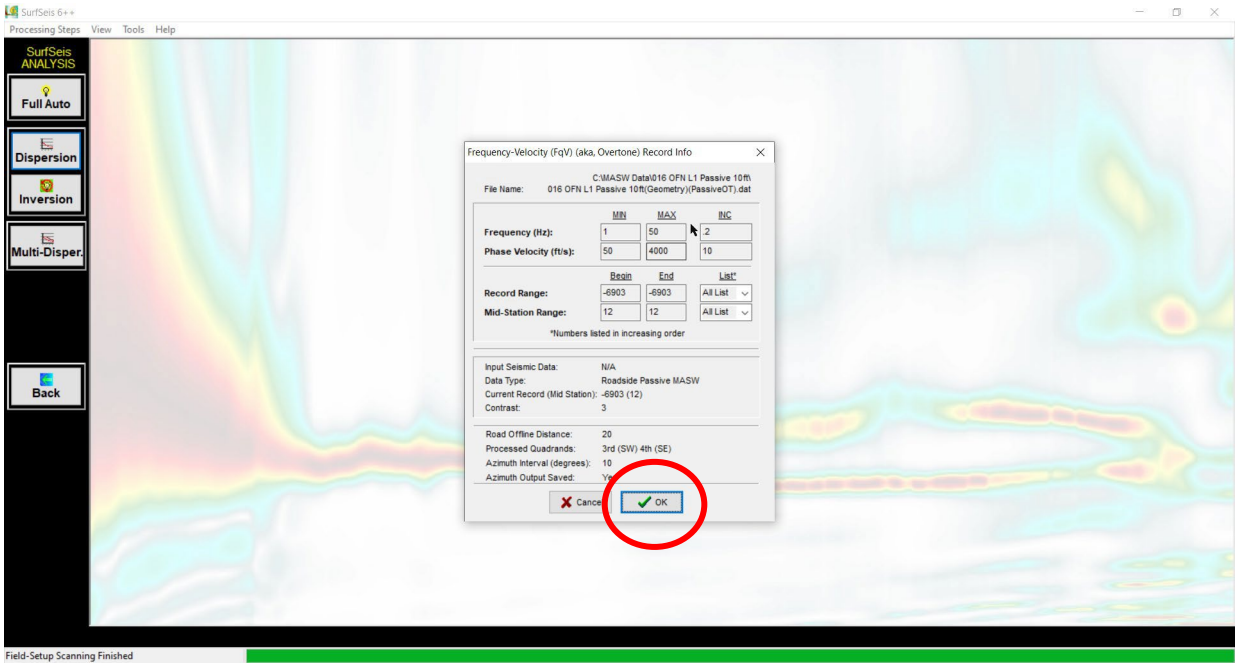
2.2.4 Picking a Dispersion Curve (DC)



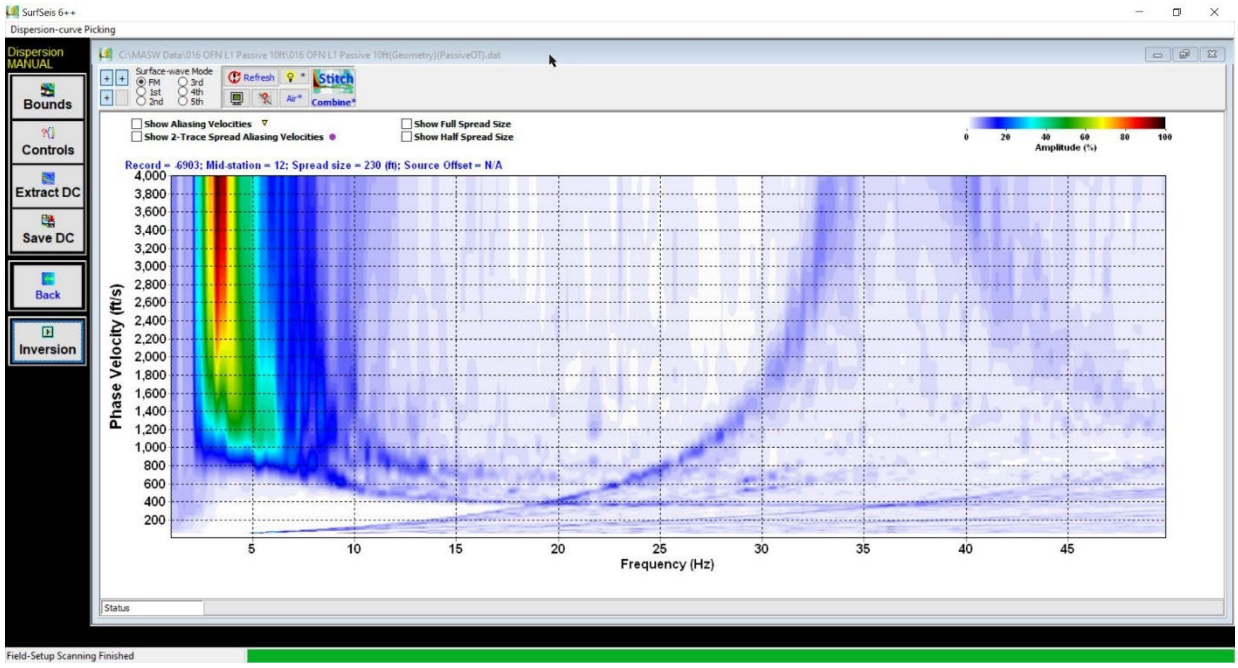
- Click **Processing Steps** at the software window top. If it is visible close and re-launch SurfSeis.
- Click **Pick Dispersion Curves (from images).**



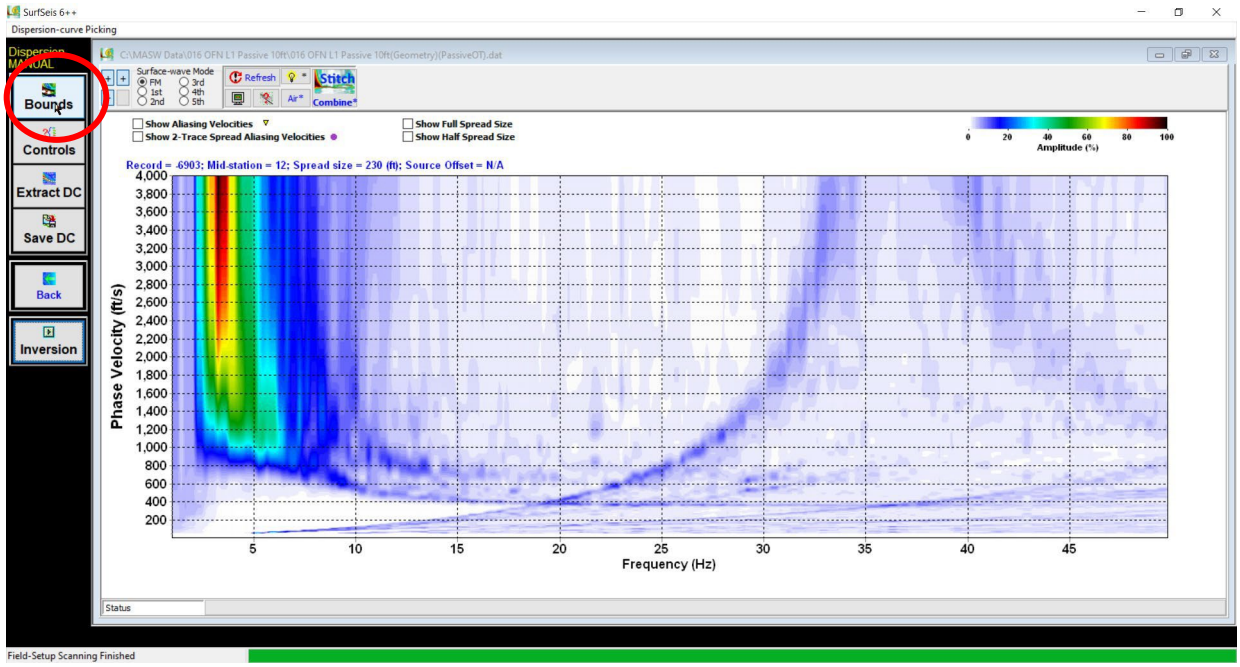
- Navigate to the folder with the data to be processed and open the Overtone image generated in the previous step.



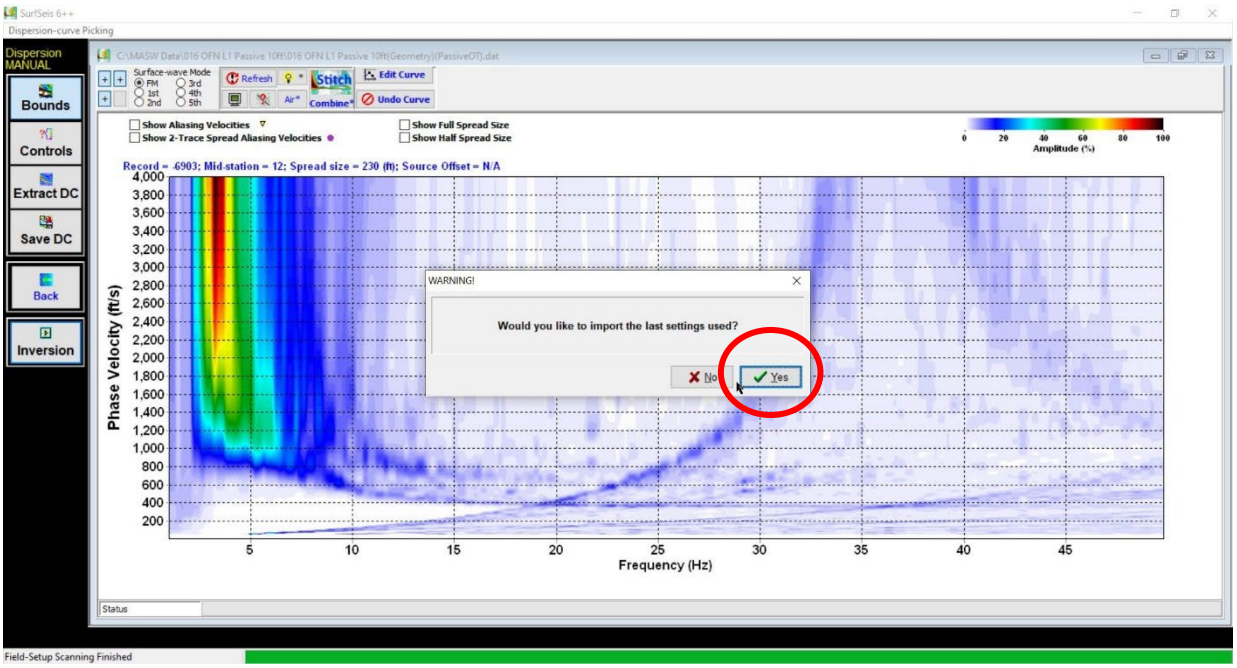
- A **Frequency-Velocity (fqV) (aka, Overtone) Record Info** window with information about the saved data will show. Click **OK** to continue.



- An Overtone image generated from stacked 30 Passive MASW files will appear.

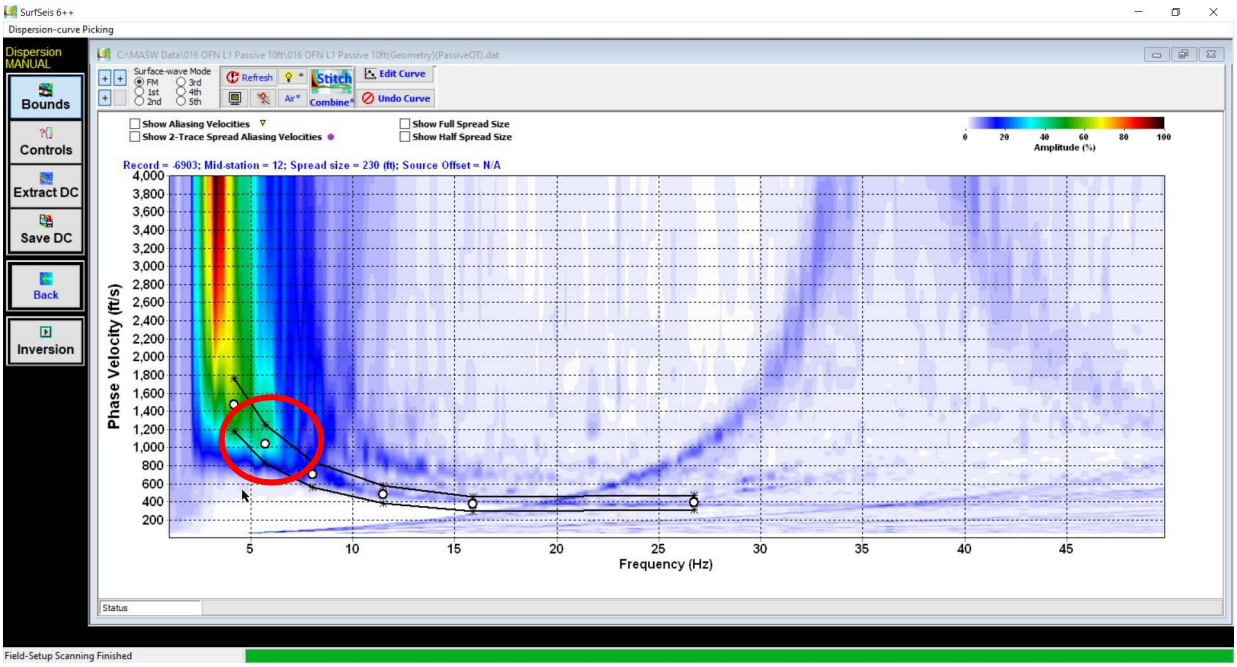


- Click **Bounds** on the left panel.

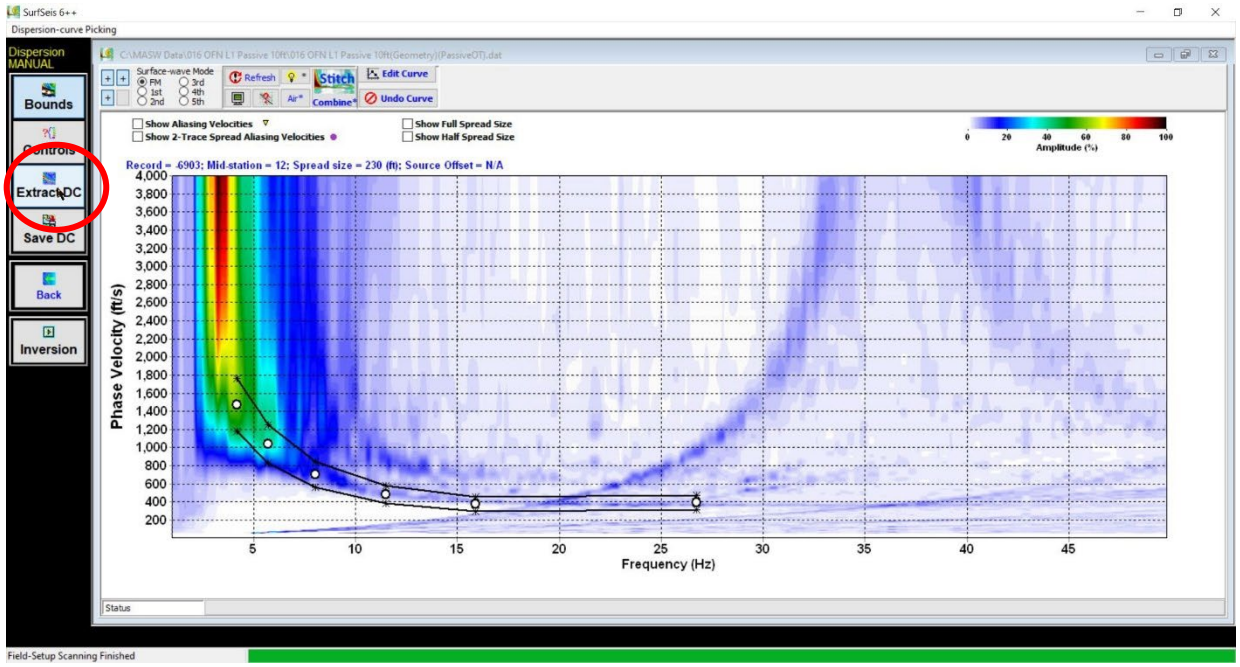


- A **WARNING!** window will appear. Click **No**.

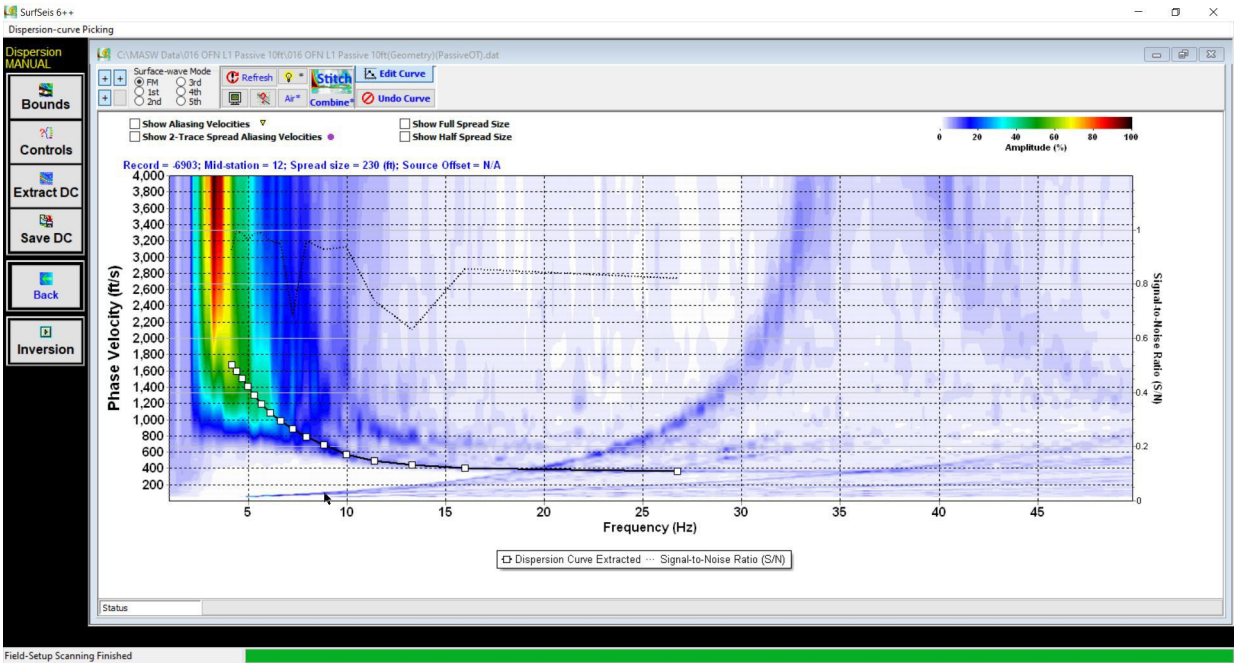
Note: if multiple data sets are processed in the same session, importing the last setting used could be selected.



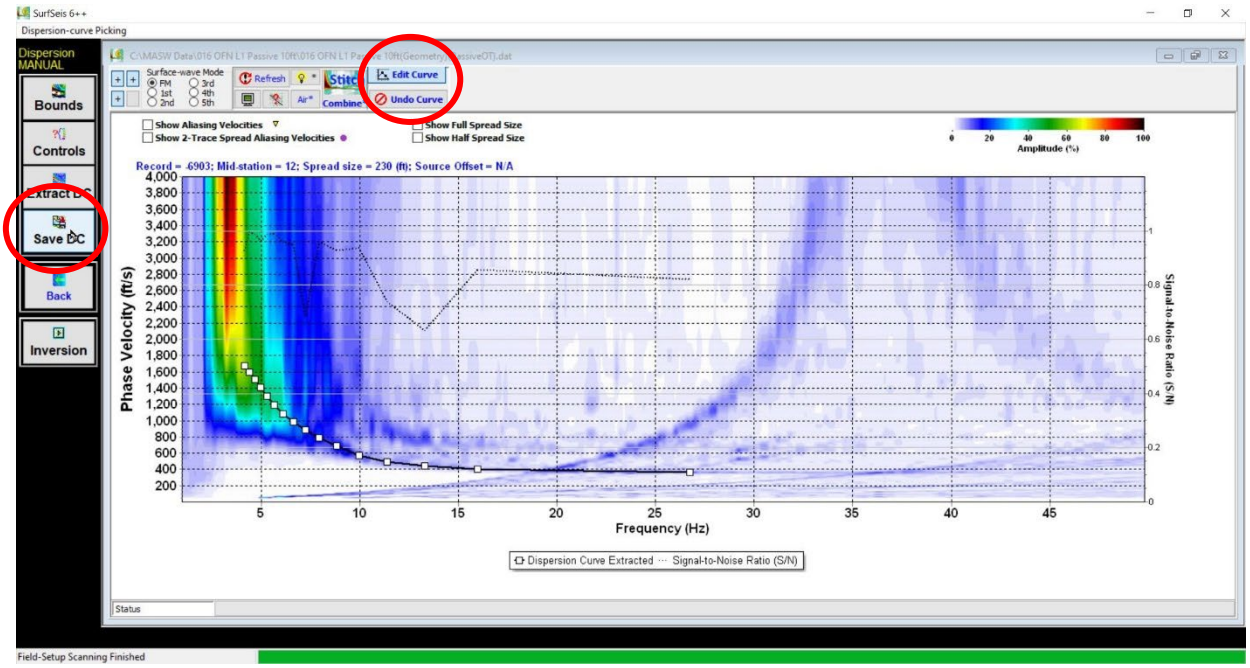
- Using left click pick the proximate locations for the dispersion curve based on the maximum signal amplitude in the Overtone image. The Fundamental Mode (lowest velocity) must be picked.



- Click **Extract DC** button on the left panel.

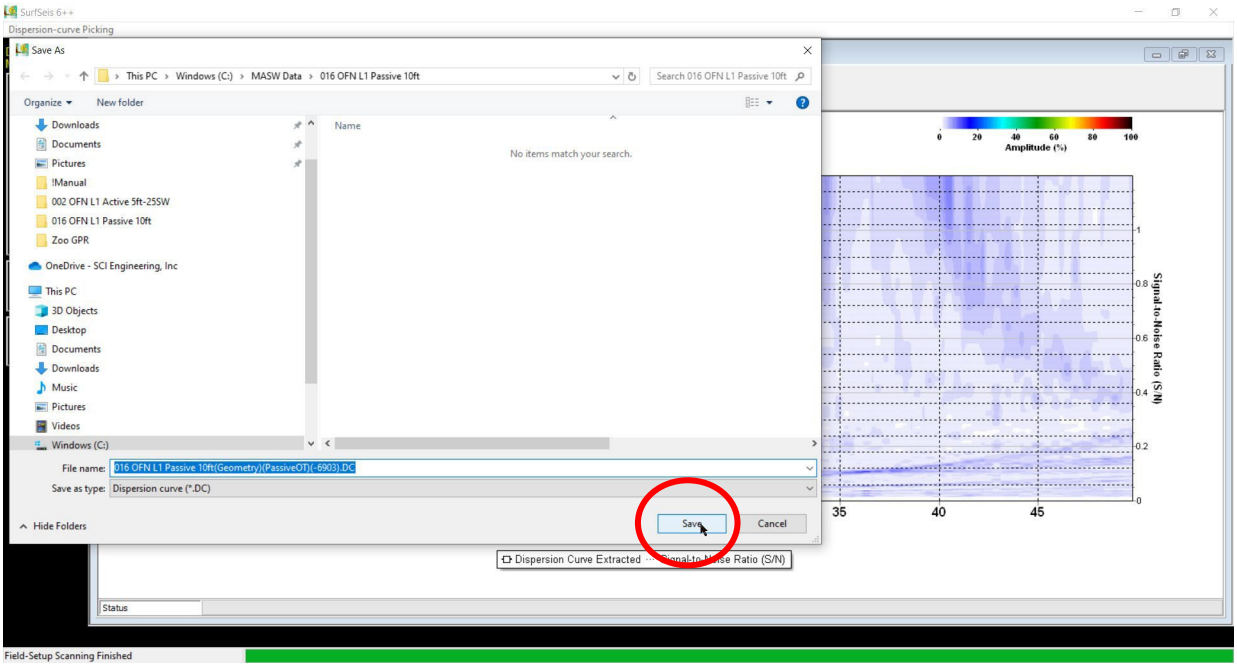


- A dispersion curve will be automatically generated within the limits picked in the previous step.

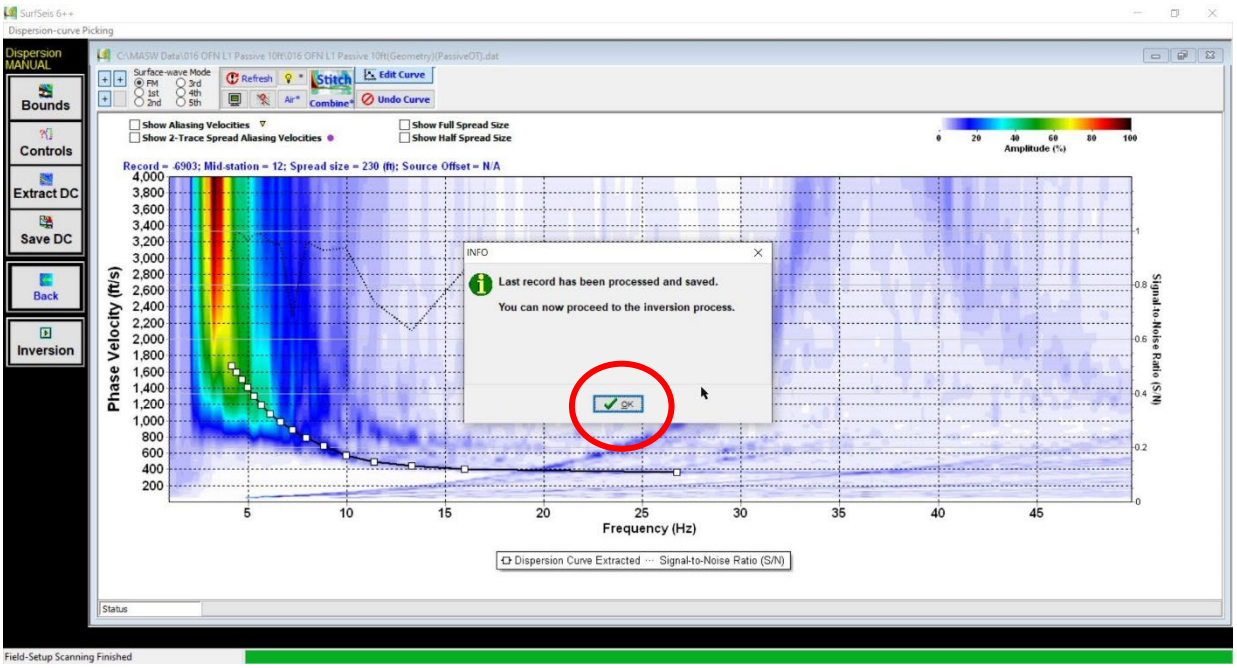


- Click **Save DC** button on the left panel to save the current dispersion curve.

*Note: the dispersion curve can be edited by clicking **Edit Curve** button on the top panel.*

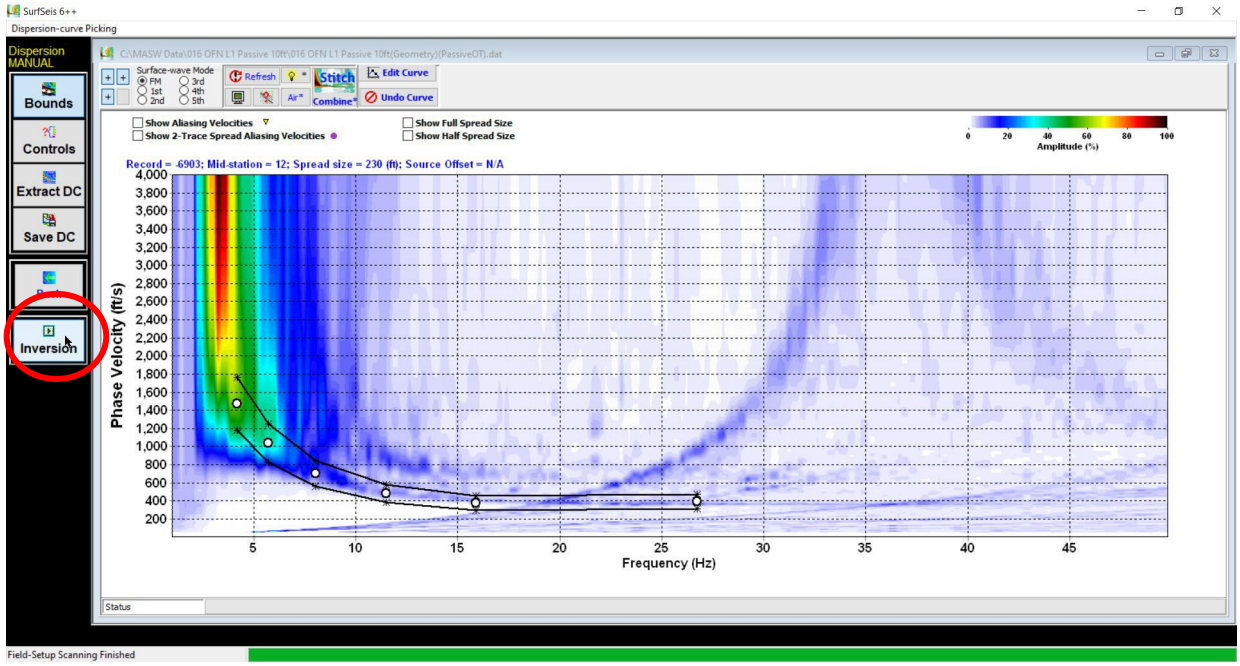


- Save the dispersion curve file in the data folder.

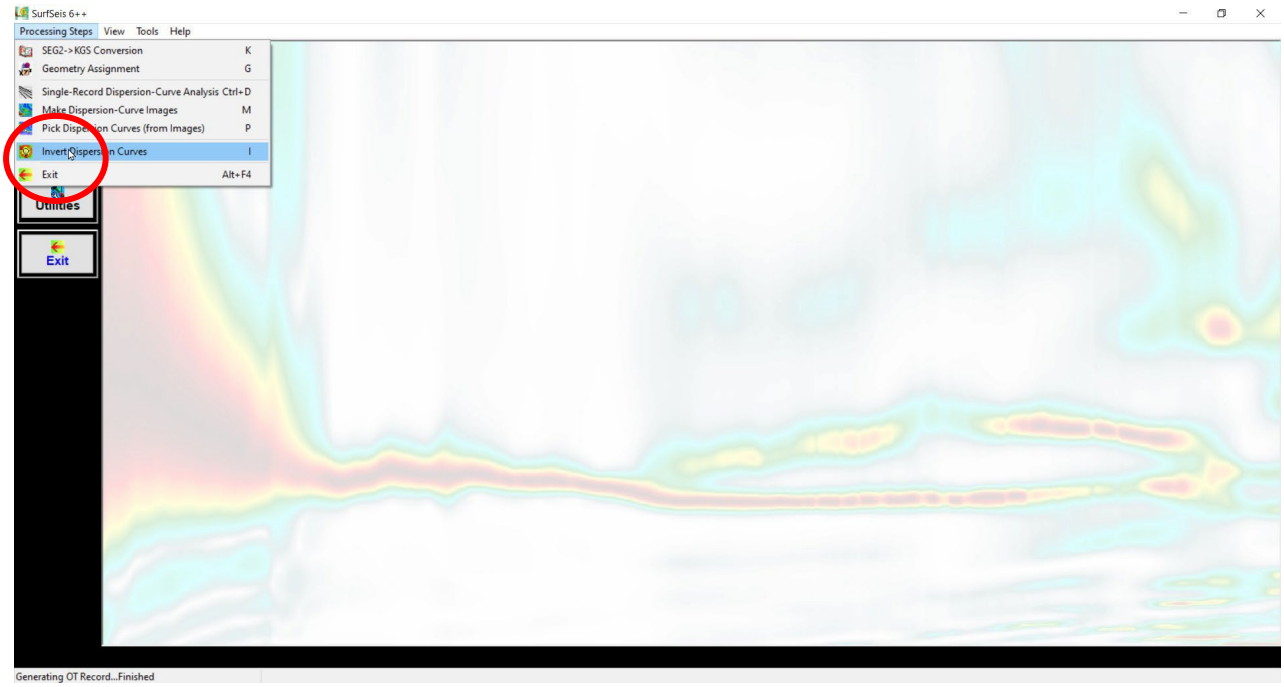


- An **INFO** window will appear. Click **OK** to proceed.

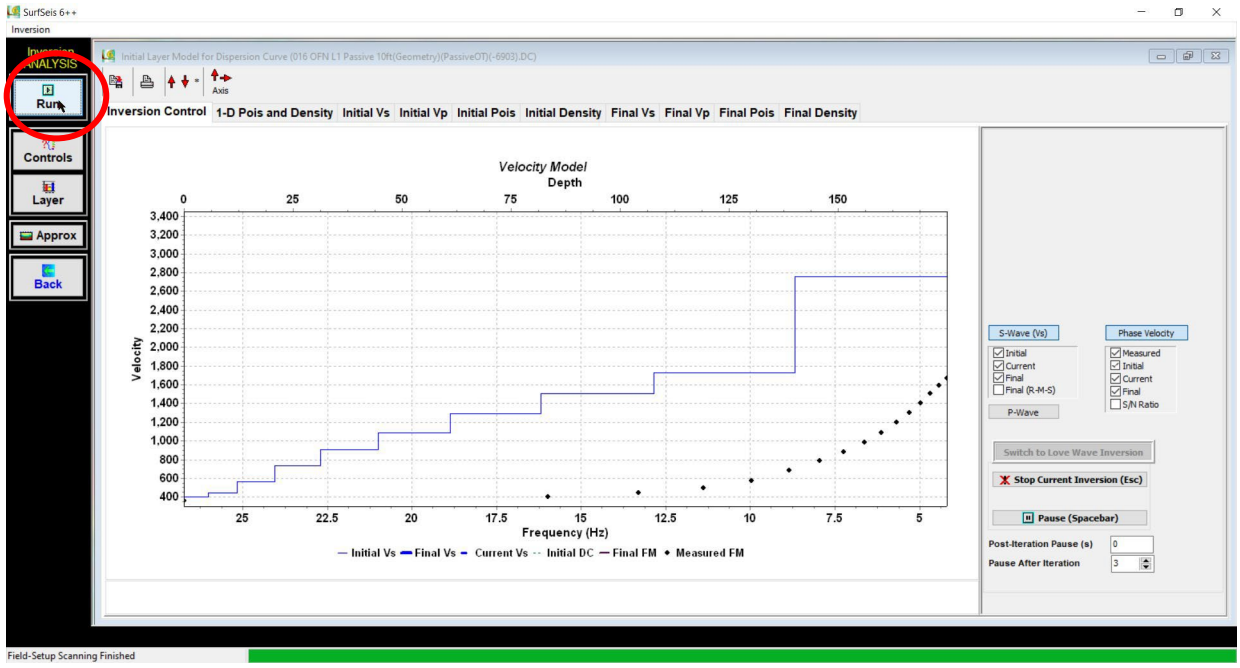
2.2.5 Inversion: Generating a Shear Wave Velocity Profile



- Click **Inversion** tab on the left panel to continue from the previous step.

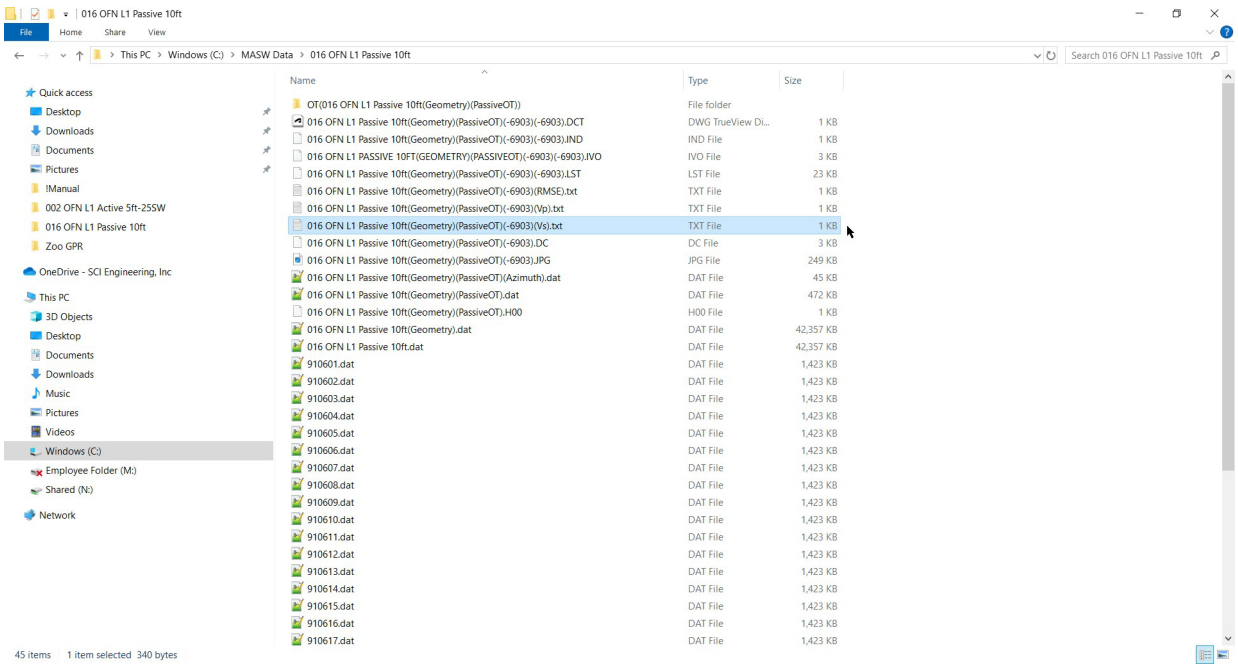


- Alternatively, If the software is re-launched the **Inversion** can be started by clicking **Processing Steps** button on the top panel from the main menu and then **Invert Dispersion Curves**.

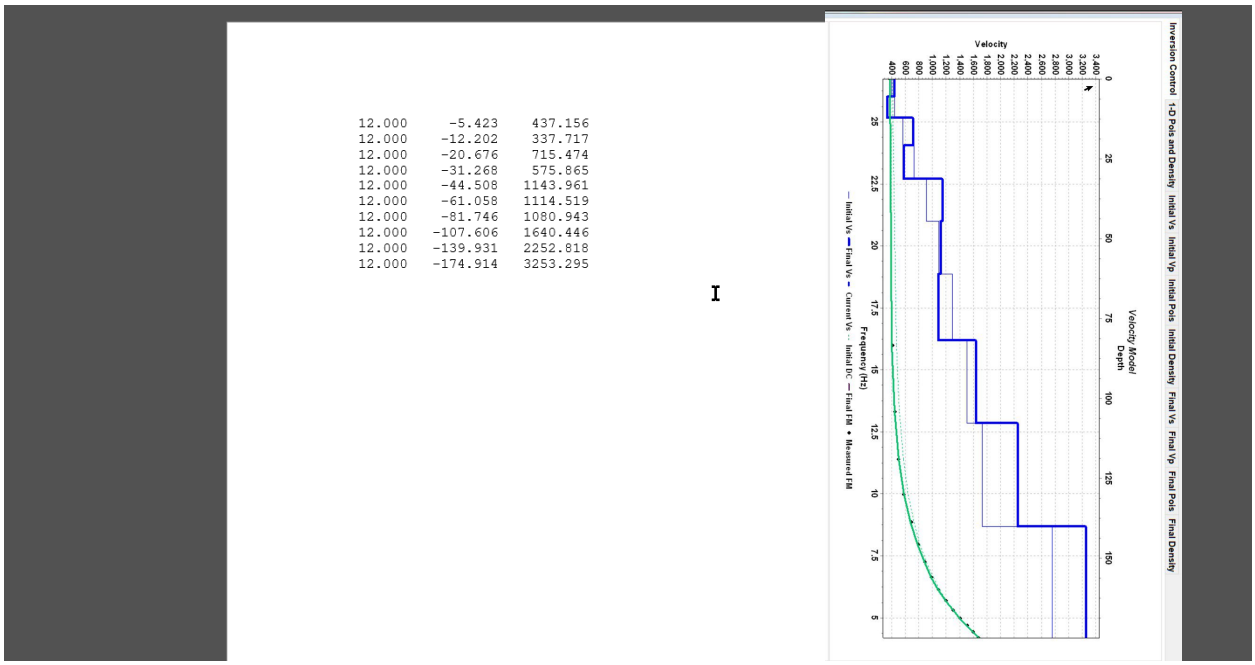


- An inversion window will appear. Click **Run** button on the left panel. The software generates A 10-layer velocity model by default. If more advanced data processing is required, the number of layers can be changed by the processor.

- The software will automatically generate a share wave velocity profile with 10 velocity layers. In this example the inversion process stopped after 12 iterations.

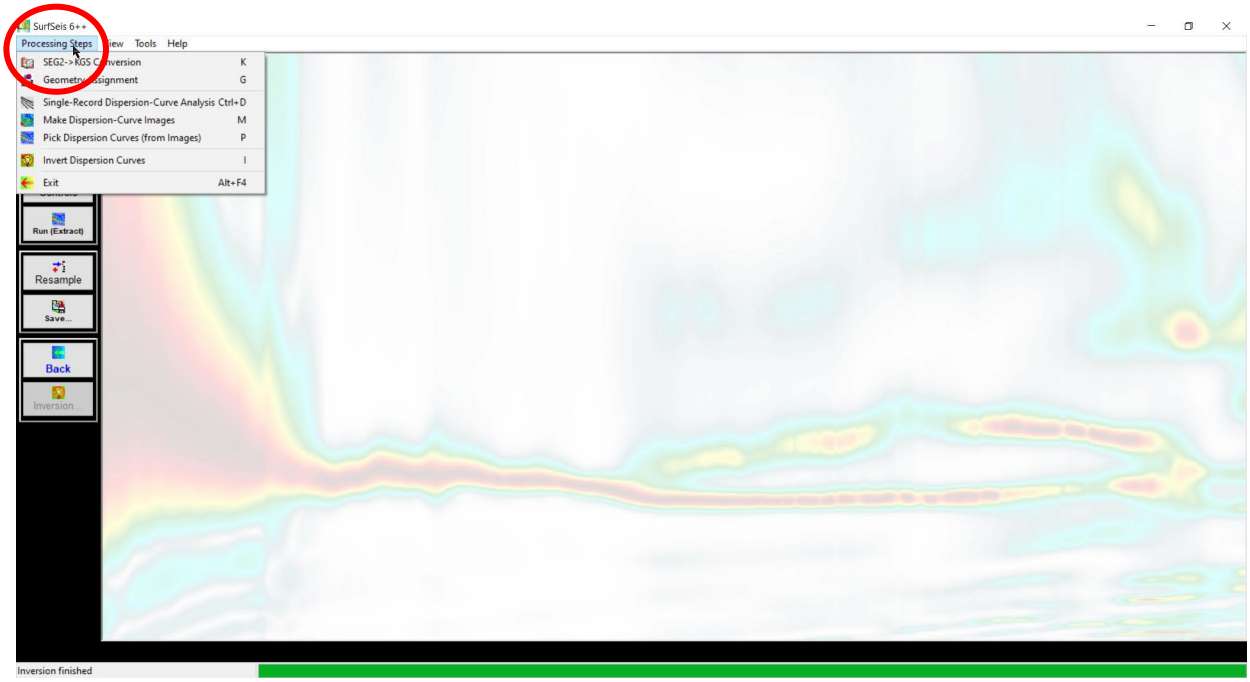


- The results of the inversion are saved in the text format in the folder with the rest of the data. This file could be opened and reviewed in Microsoft Notepad, Excel or Word program.

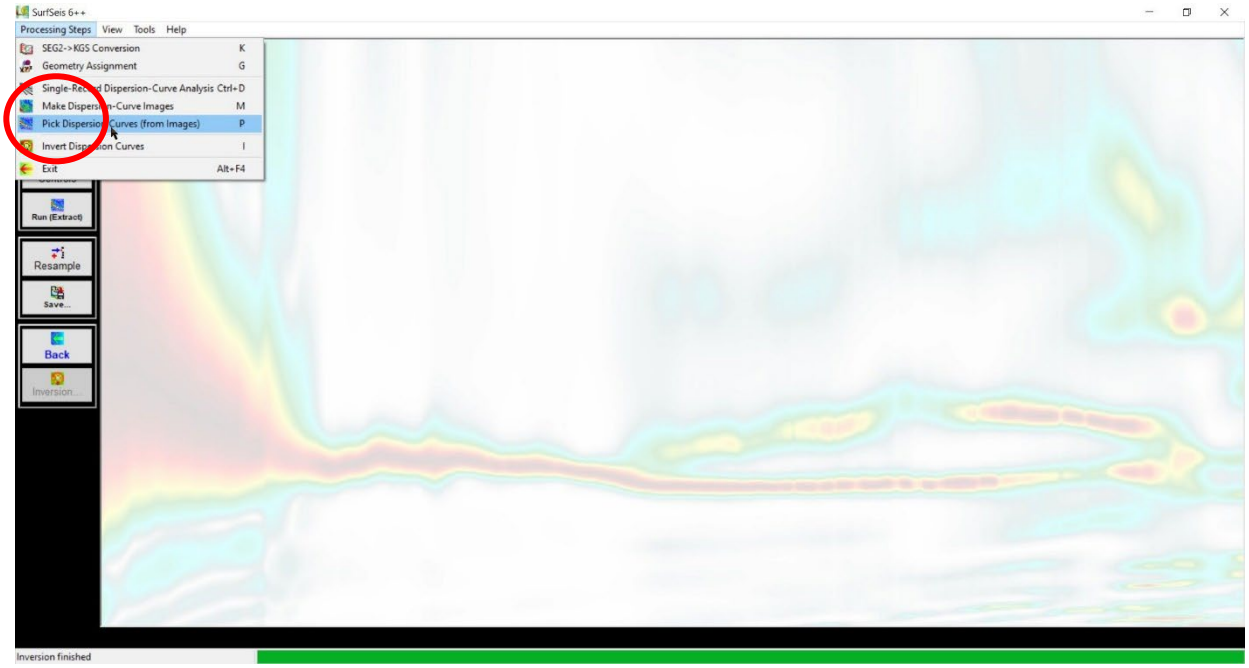


- The output file has 3 columns. The first column is the middle station (calculated from the record geometry), the second column is the depth relative to the surface and the third column is the shear wave velocity. Visually check the correlation between the table (left) and the profile (right). The data can be imported into Excel or other software for further calculations.

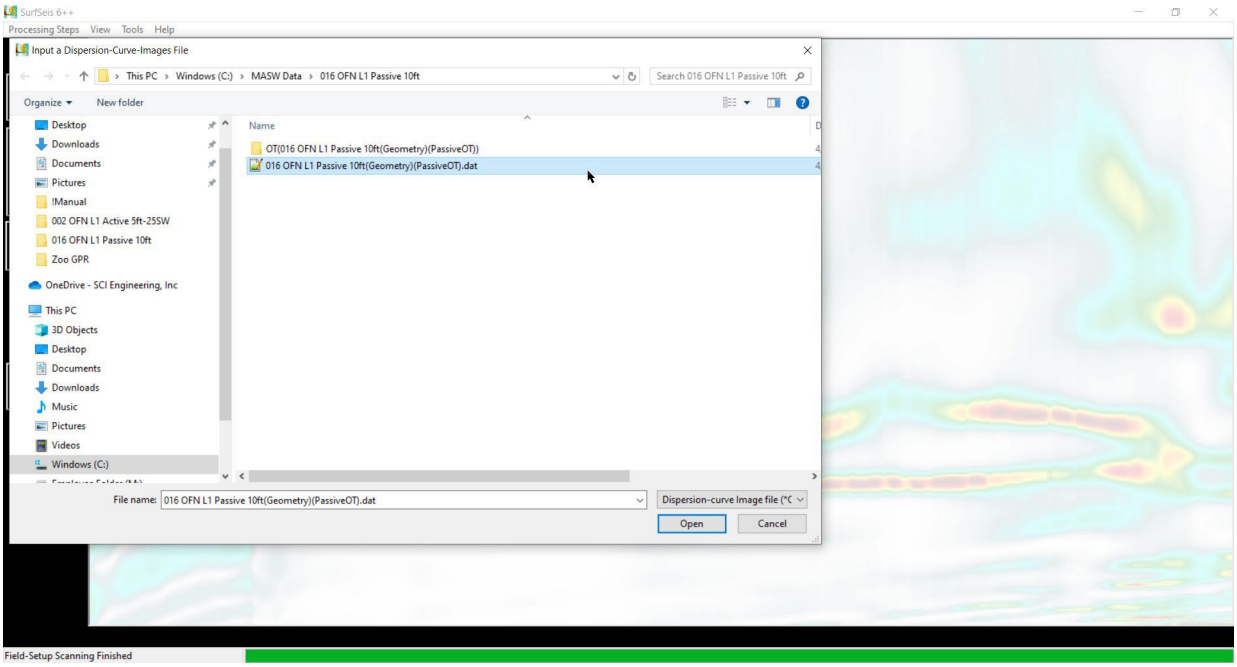
2.3 Combining Active and Passive Data



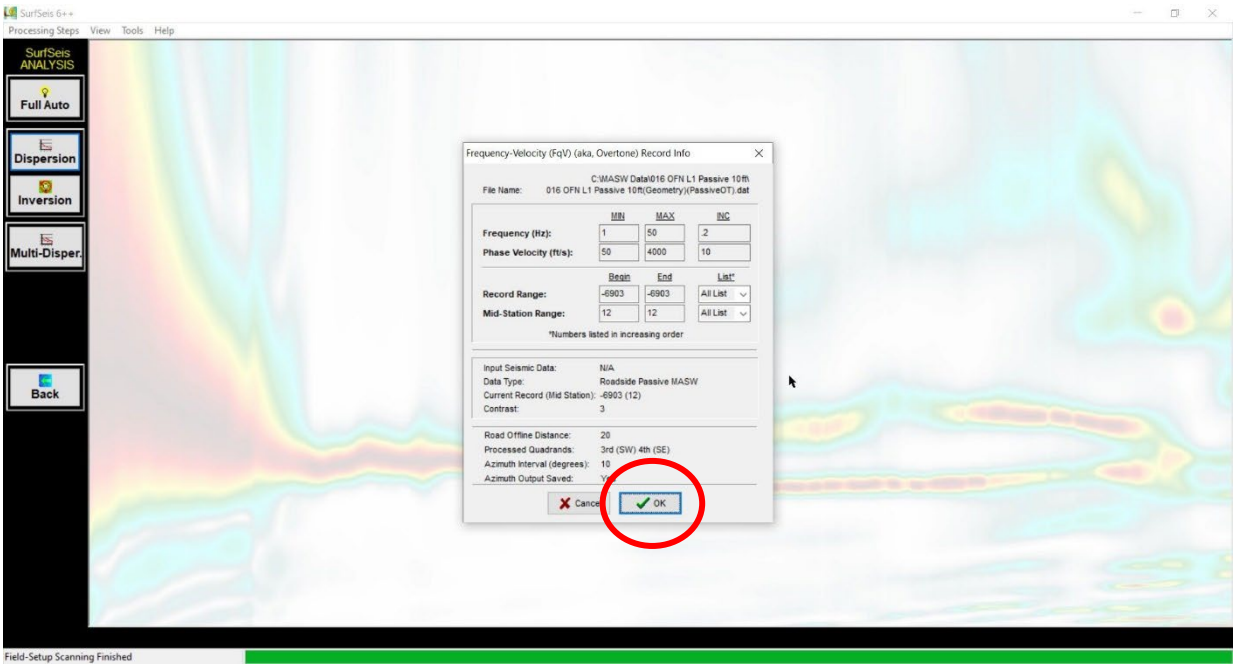
- Click **Processing Steps** at the software window top. If it is visible close and re-launch SurfSeis.
  Click **Pick Dispersion Curves (from images).**



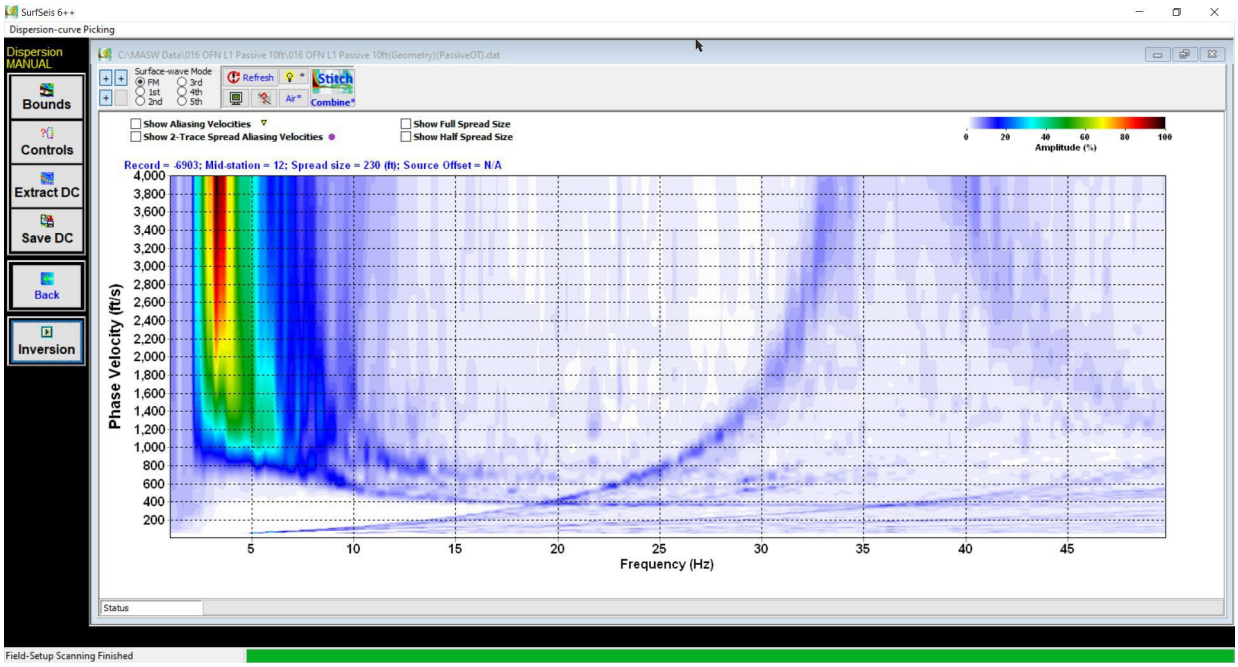
- Click **Pick Dispersion Curves (from images)**.



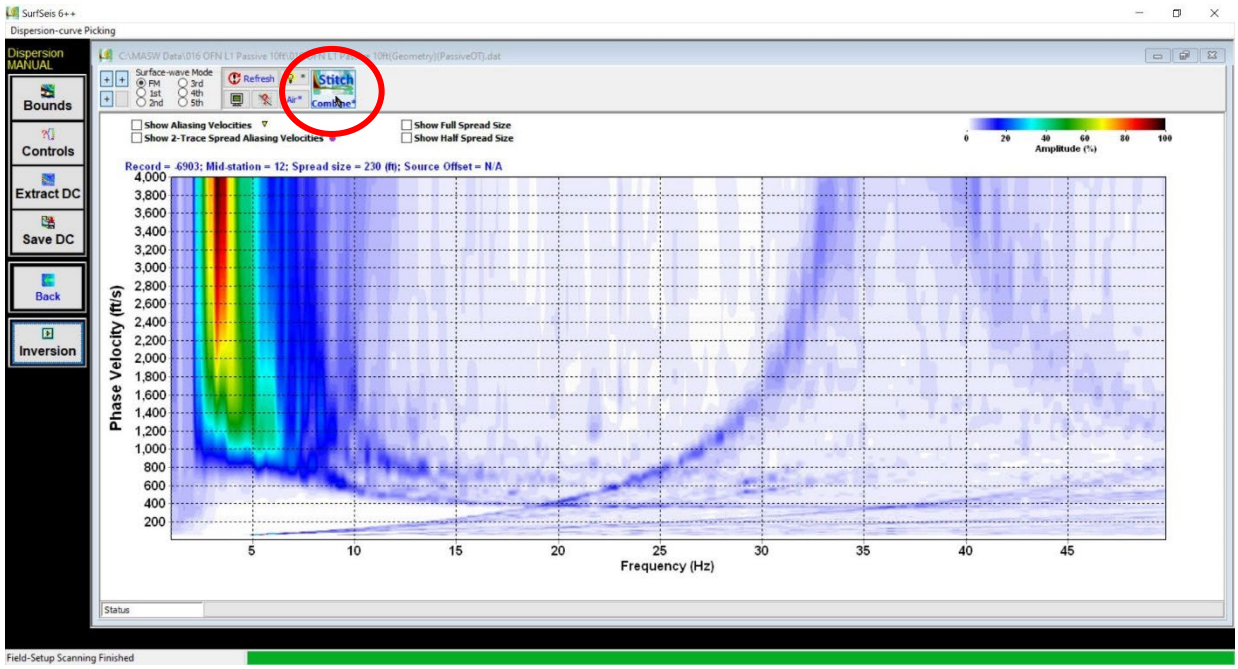
- Navigate to the folder with the Passive Overtone image generated in the previous steps and open the file.



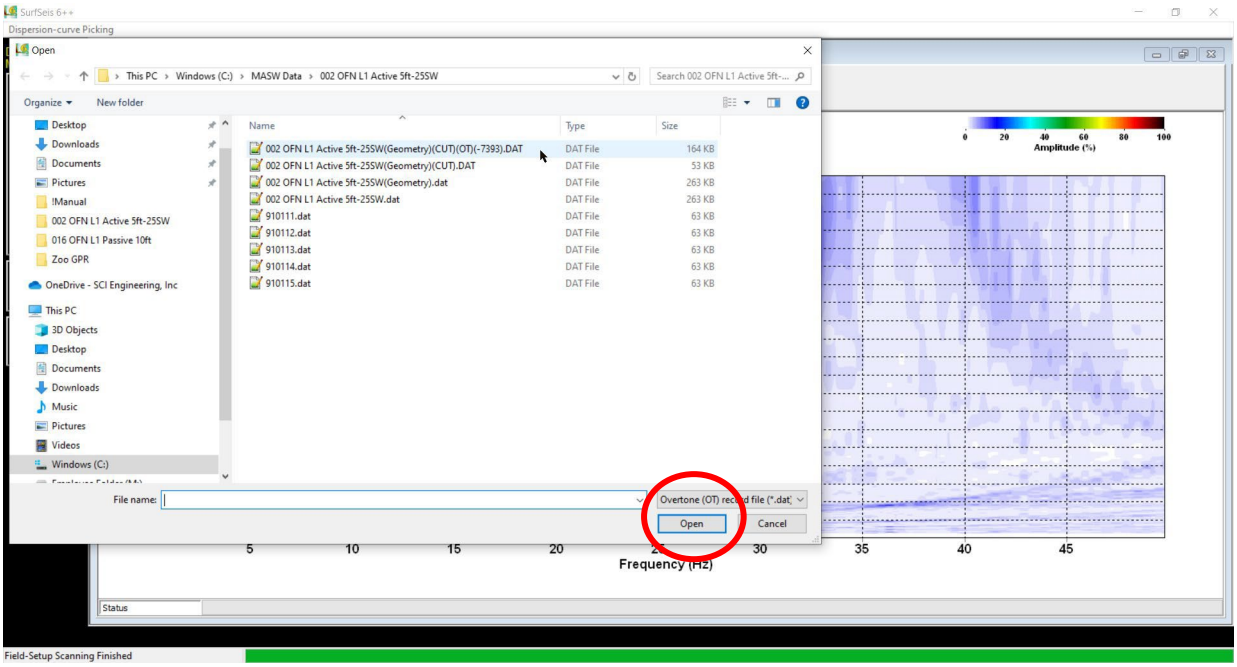
- A **Frequency-Velocity (fqV) (aka, Overtone) Record Info** window with information about the saved data will show. Click **OK** to continue.



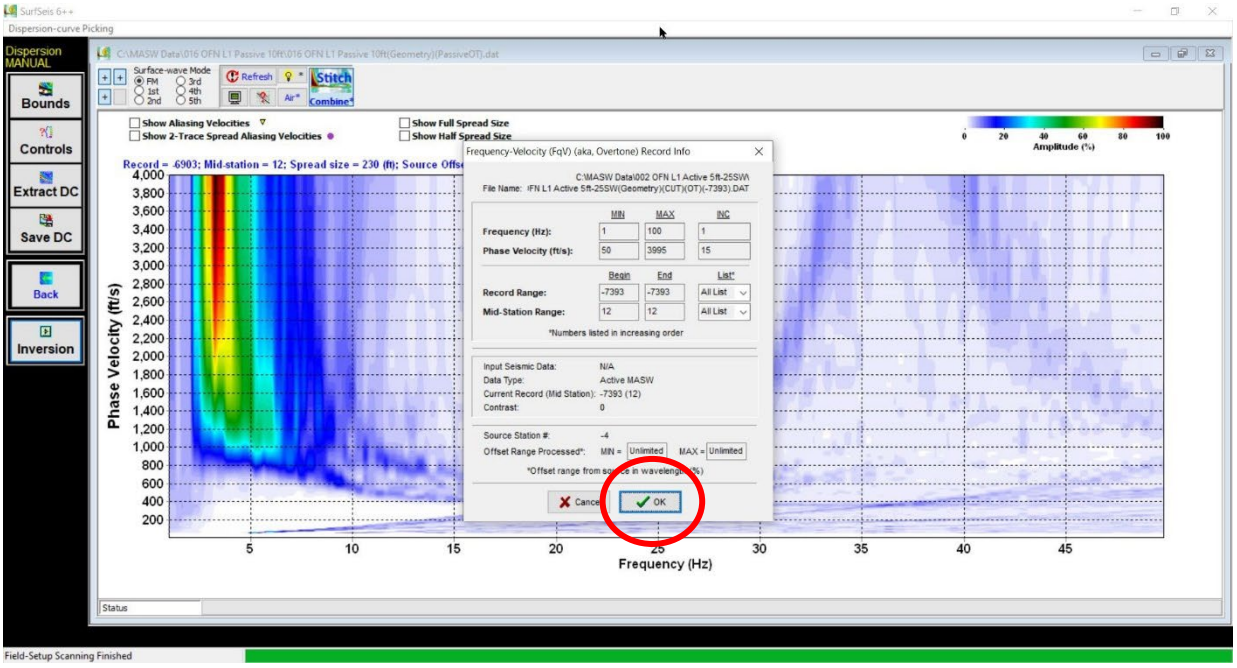
- An Overtone image generated from stacked 30 Passive MASW files will appear.



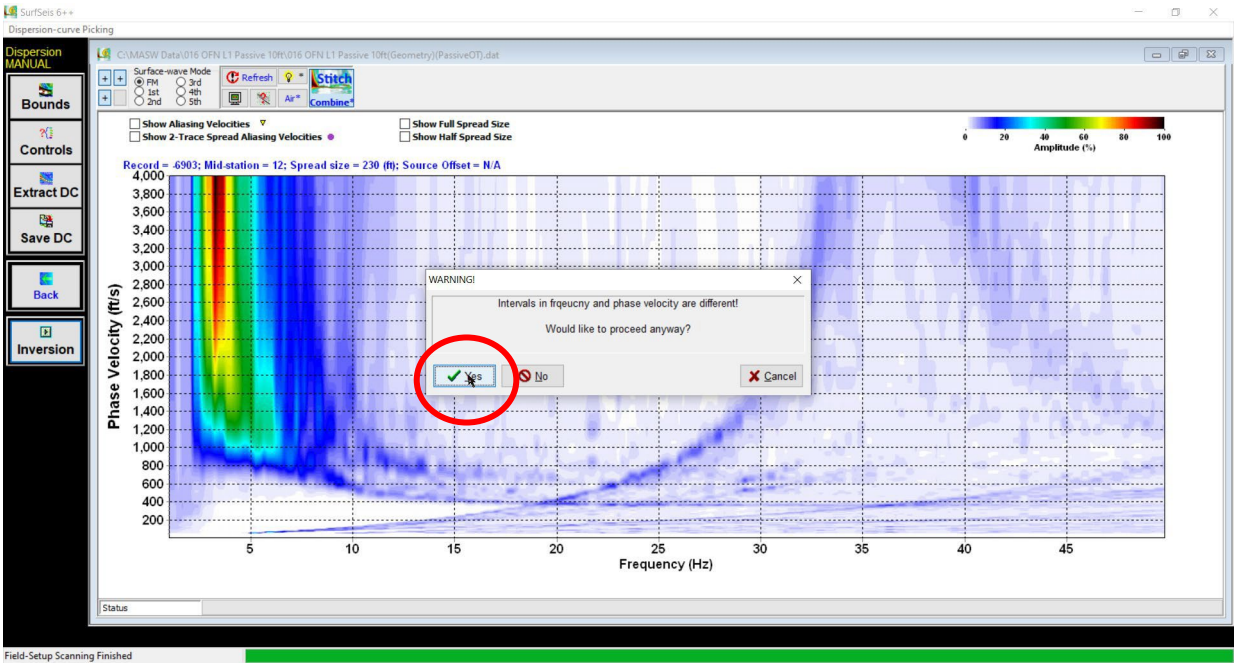
- Click **Stitch Combine*** button on the top panel.



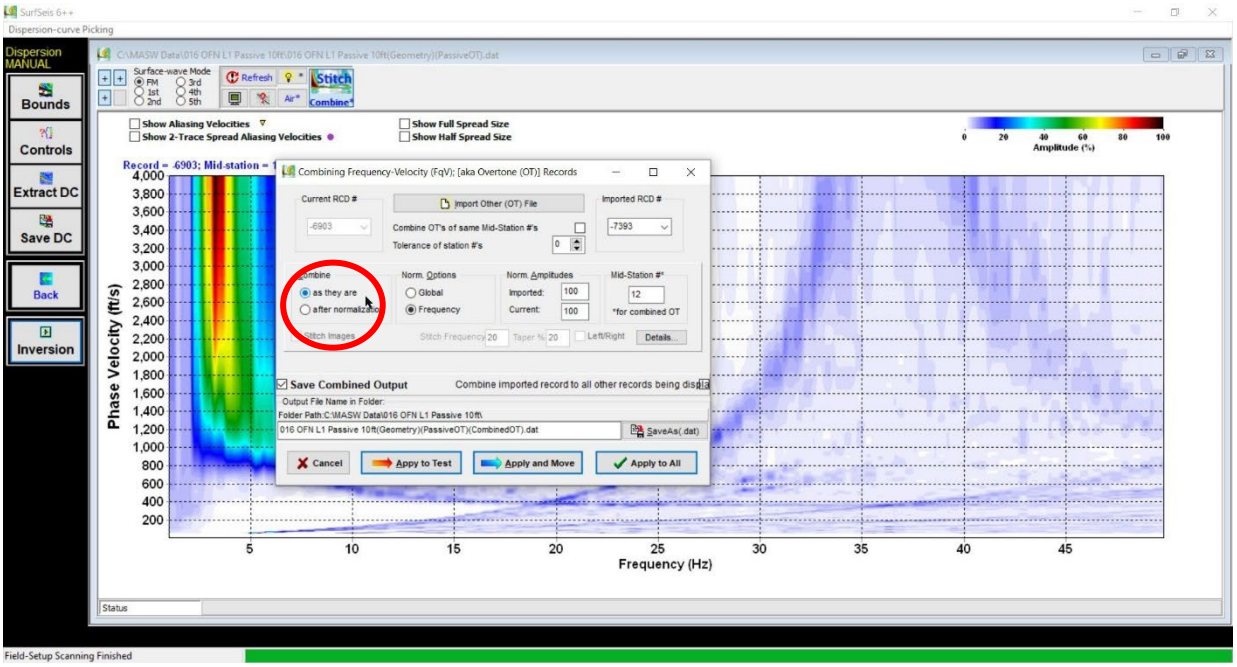
- Navigate to the folder with the Active Overtone image generated in the previous steps and open the file.



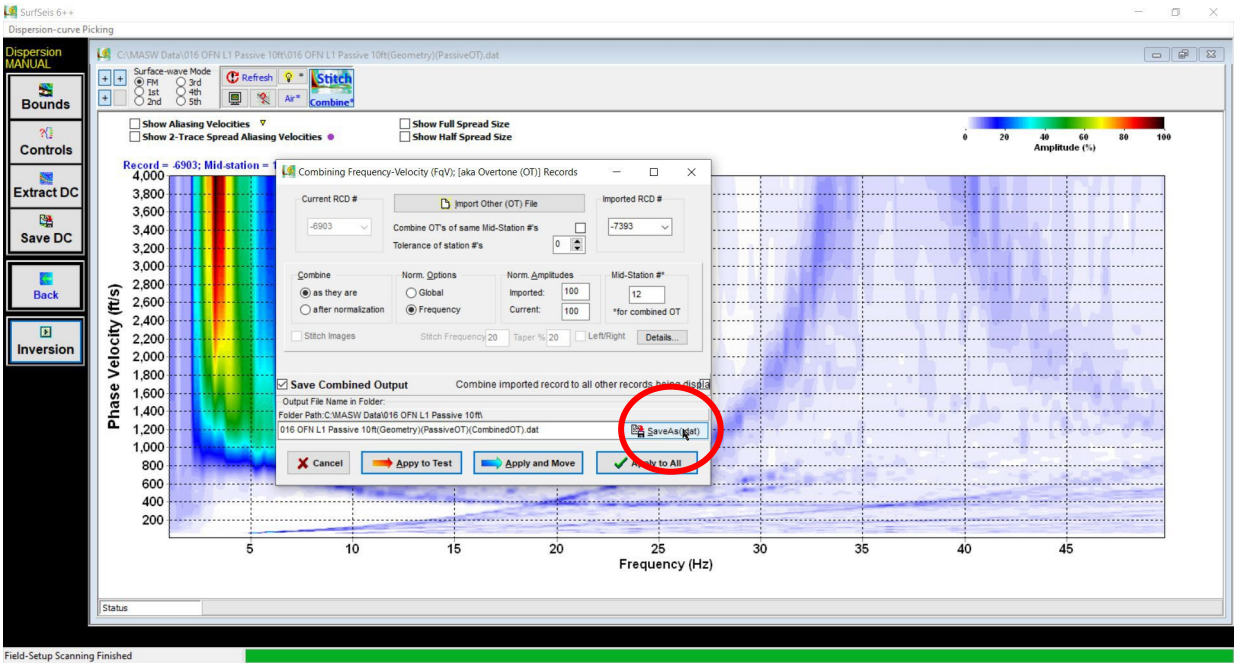
- A **Frequency-Velocity (fqV) (aka, Overtone) Record Info** window with information about the saved data will show. Click **OK** to continue.



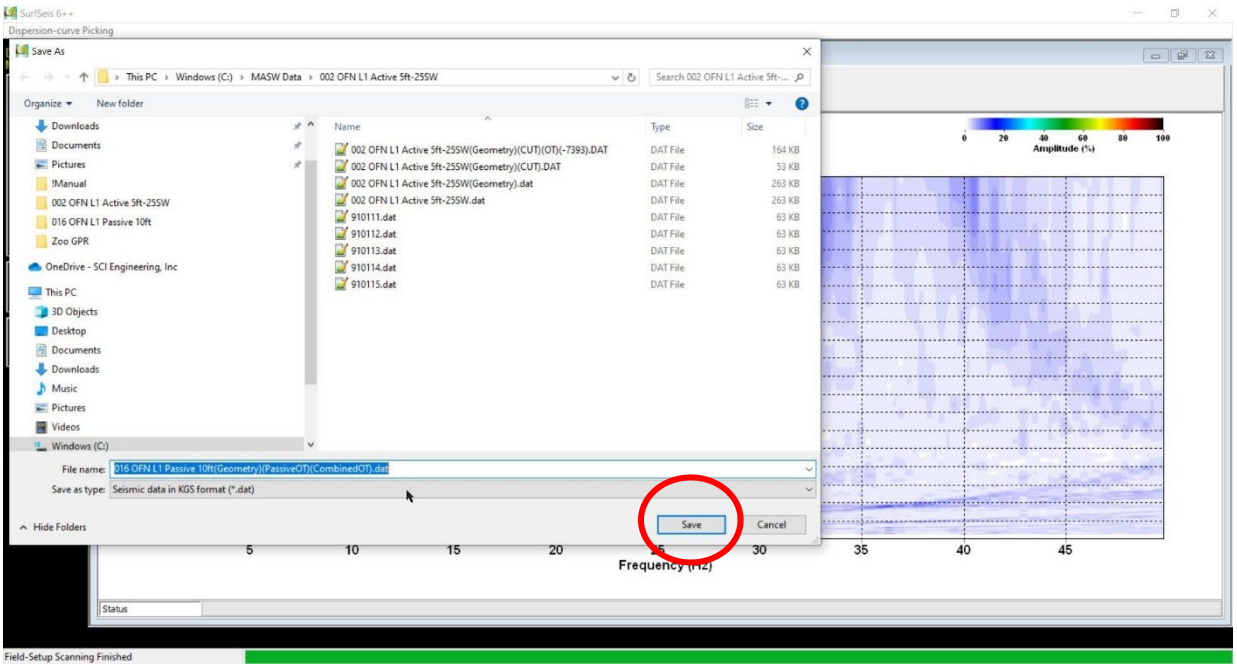
- A **WARNING!** indicating that intervals and phase velocities are different may appear. Click **OK** to continue.



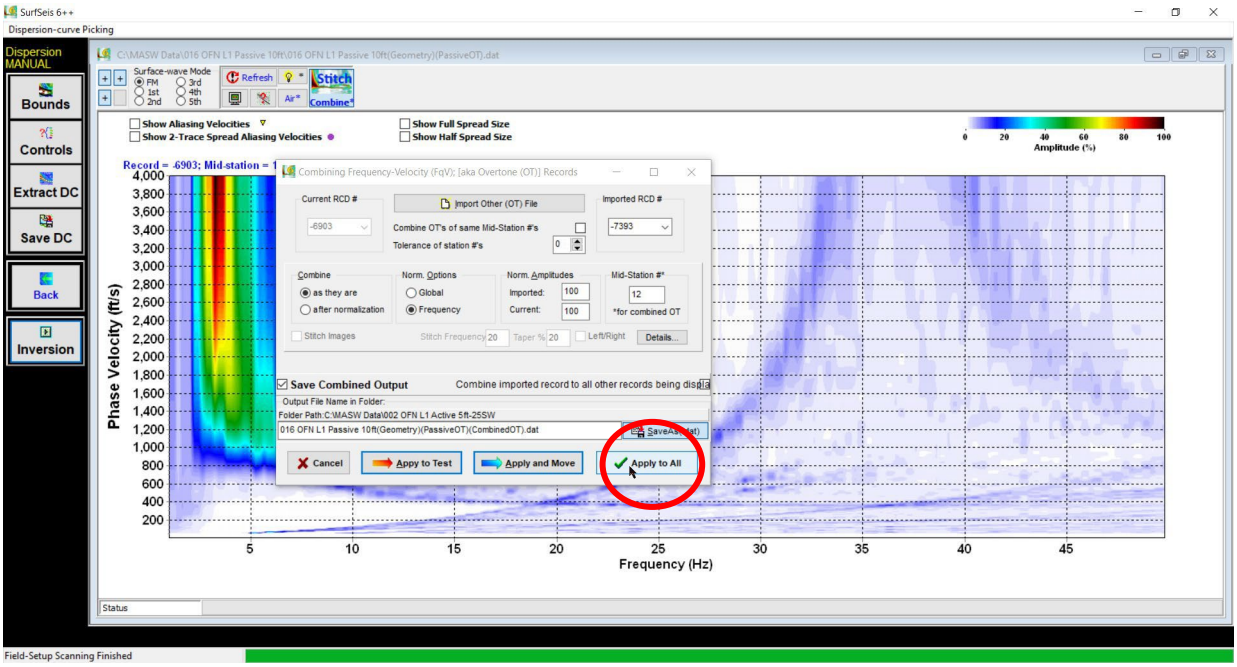
- Select **as they are** under **Combine** option.



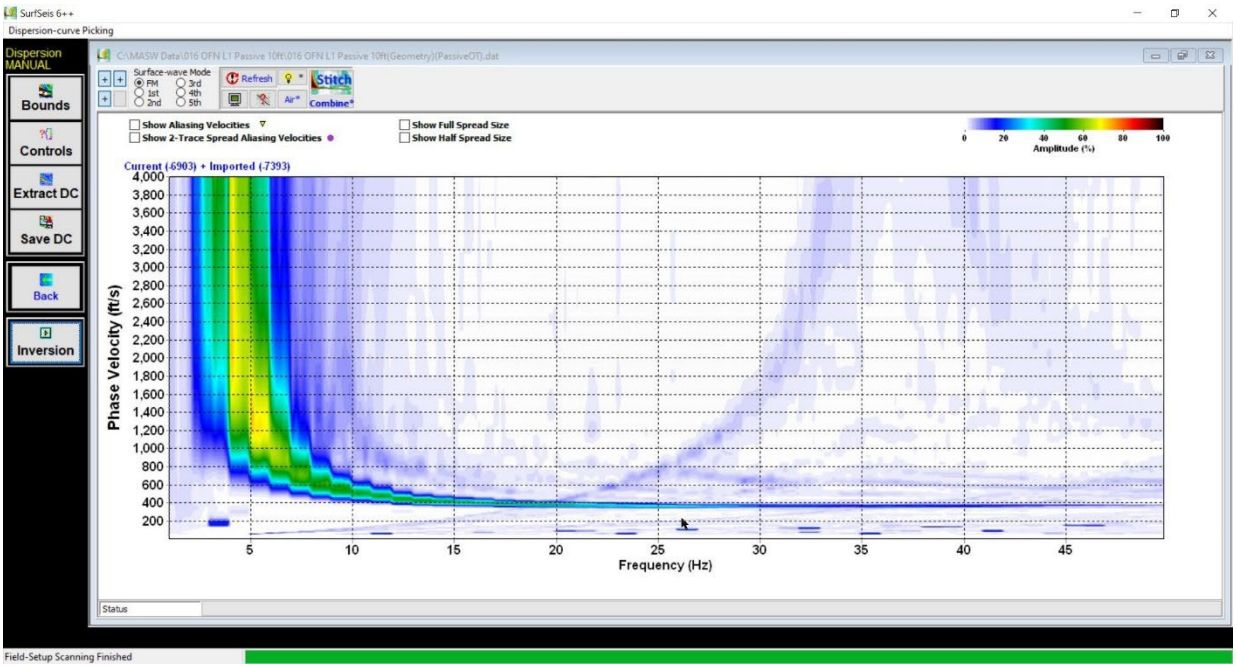
- Click **Save As (.dat)**.



- Select a file name (or leave the default name) for the combined Overtone image file. Click **Save**.

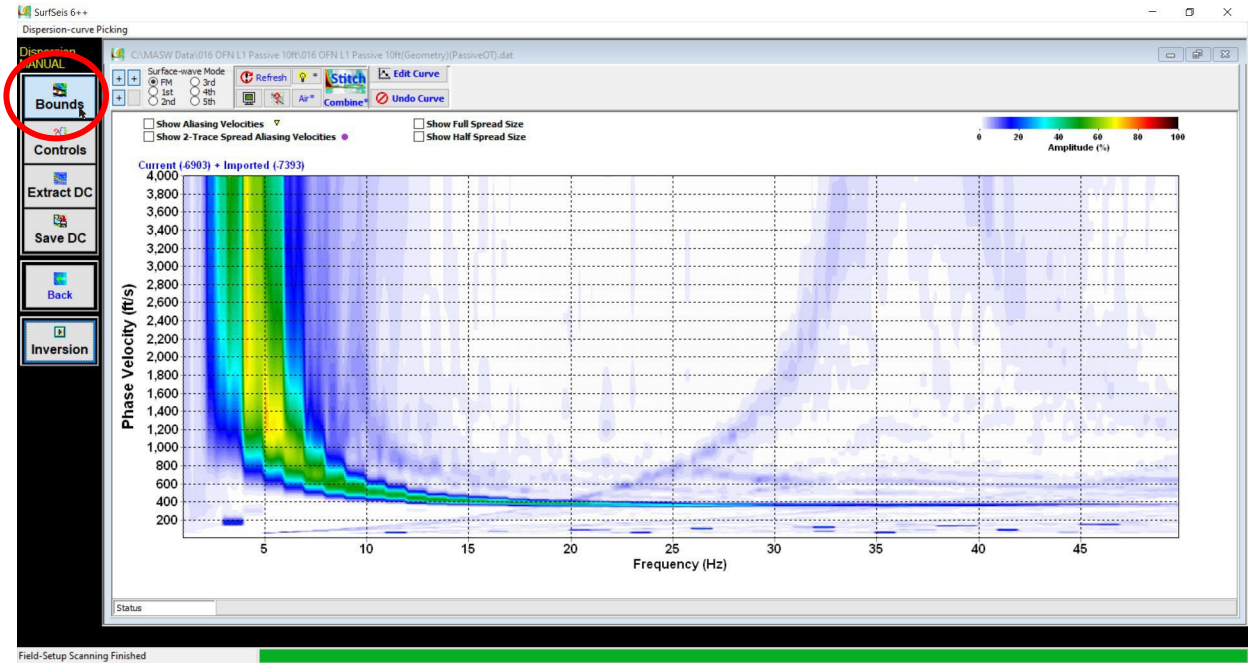


- Click **Apply to All**.

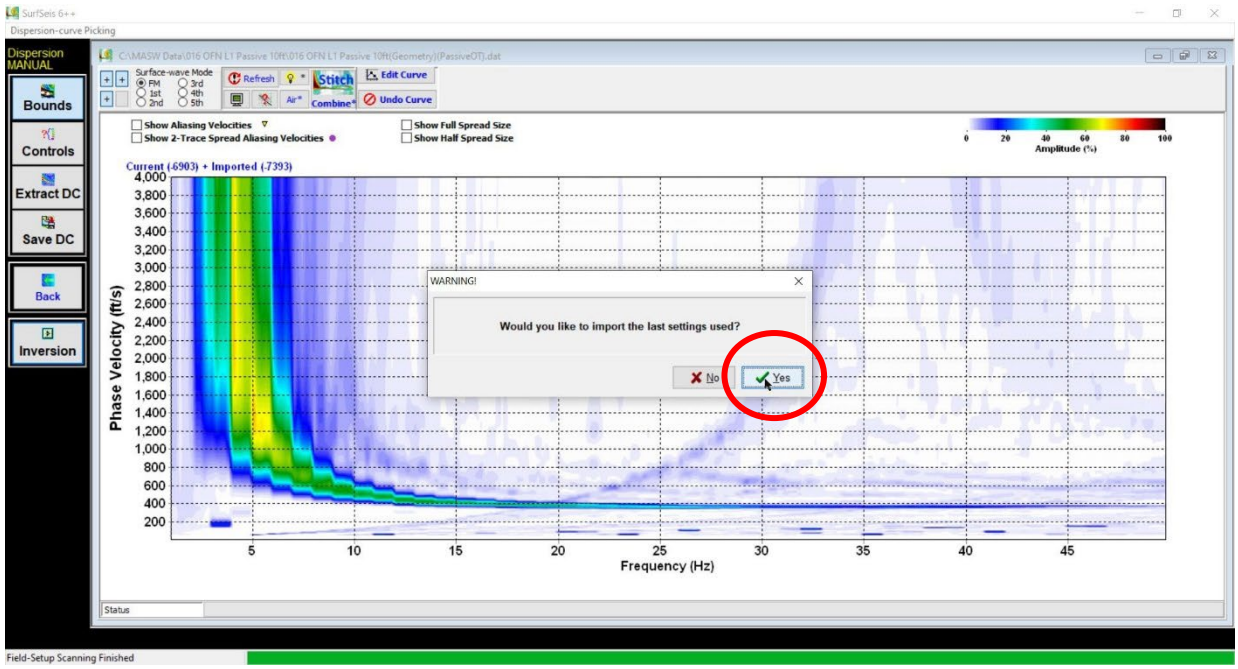


- An updated Overtone image containing both Active and Passive data will appear.

Note: any overtone images can be combined (e.g., Passive and Active, Passive and Passive, Active and Active). Only two images can be combined at once. Alternatively, Stitching option can be used to combine records using specific data ranges (e.g., 4-15 Hz from Passive data and 15-50 Hz from Passive data).

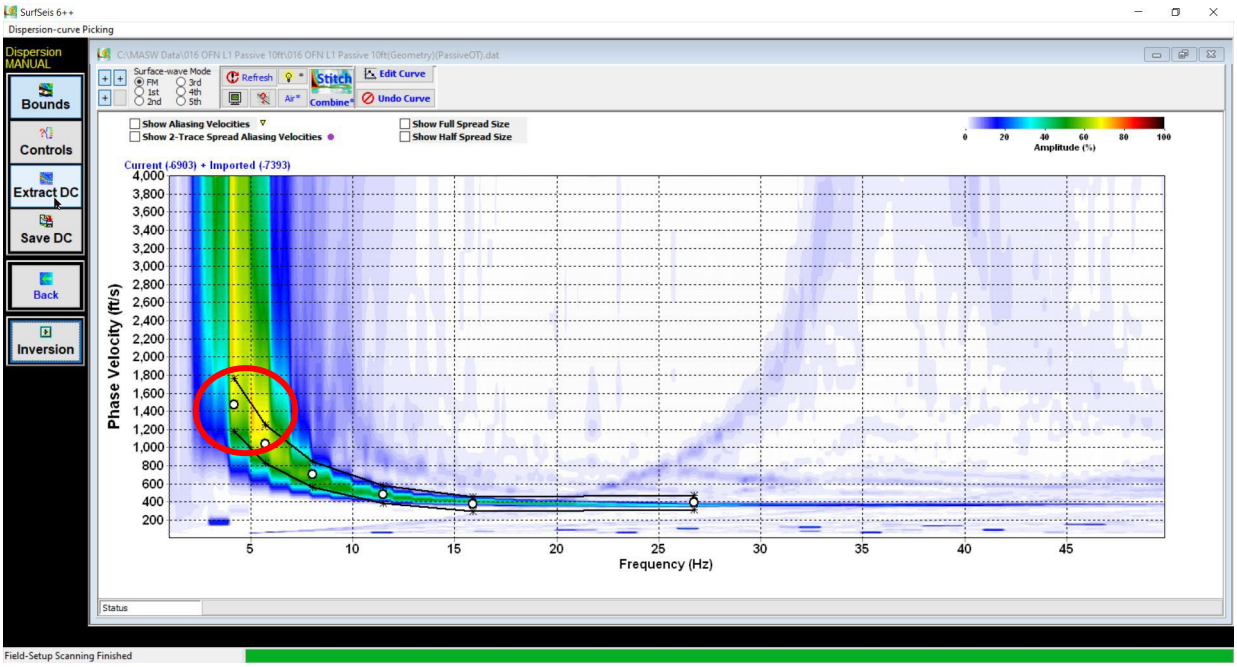


- Click **Bounds** on the left panel.

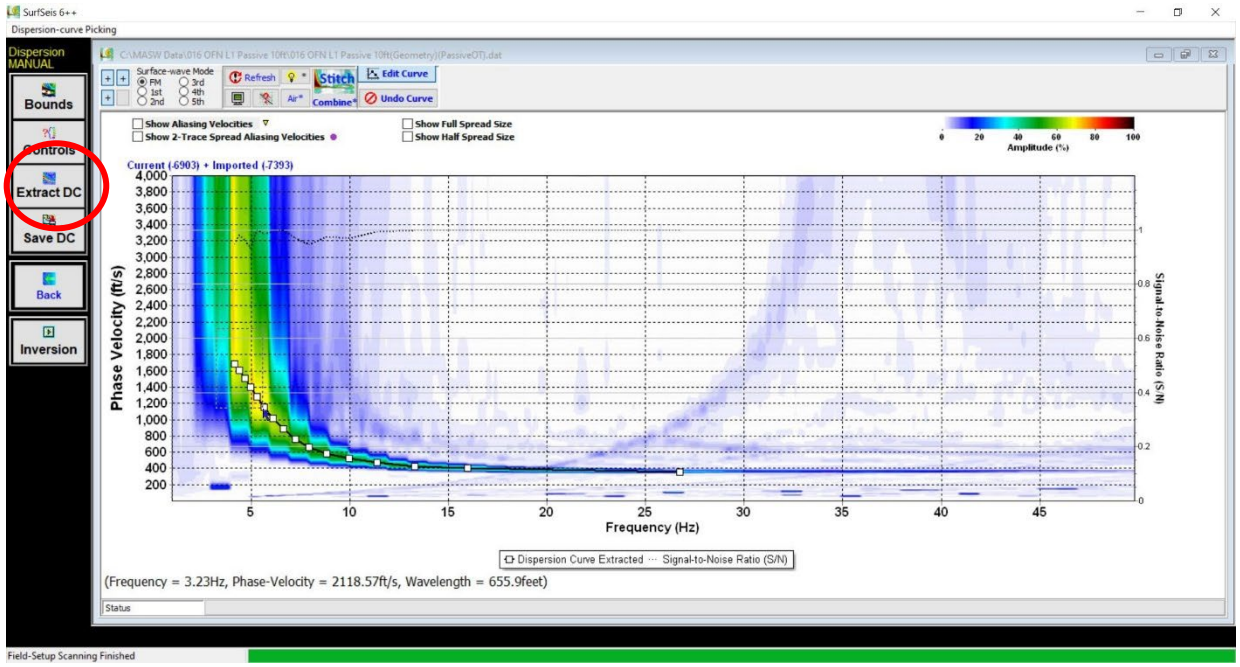


- A **WARNING!** window will appear. Click **No**.

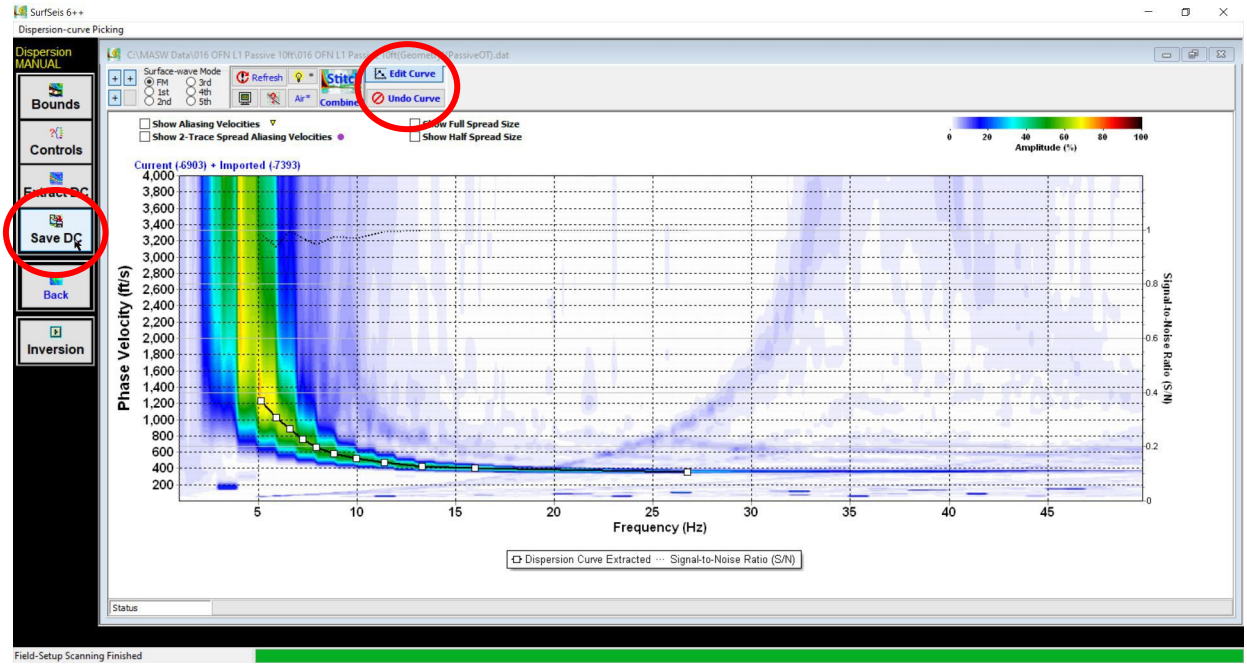
Note: if multiple data sets are processed in the same session, importing the last setting used could be selected.



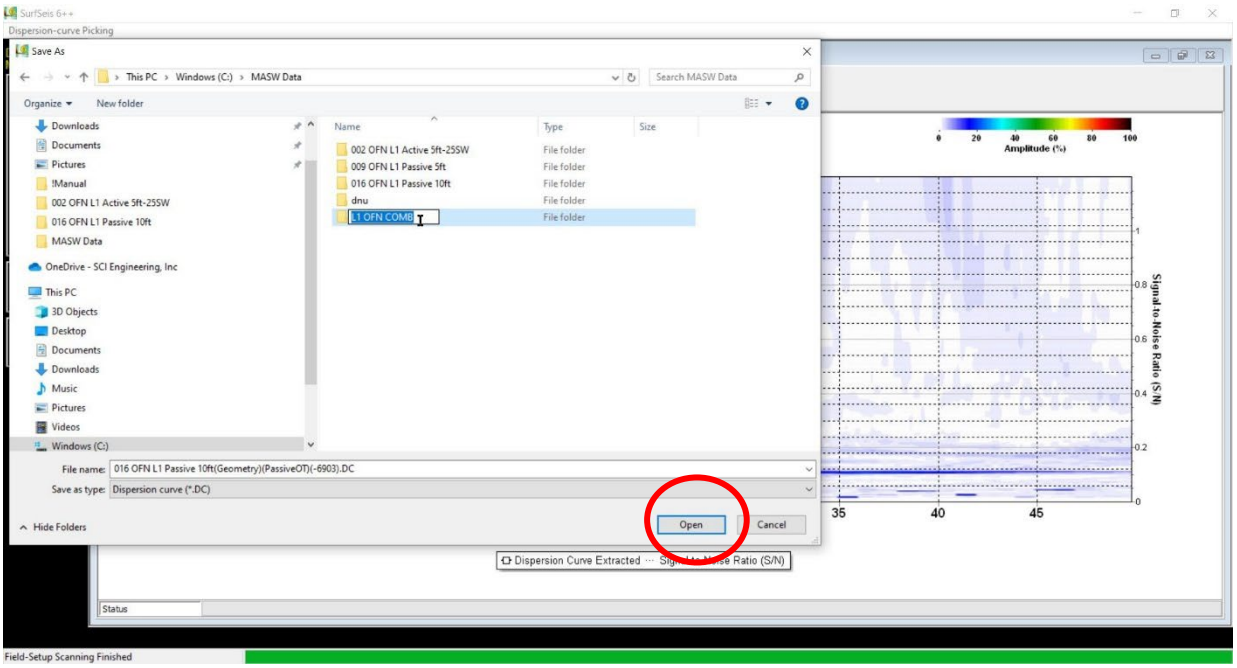
- Using left click pick the proximate locations for the dispersion curve based on the maximum signal amplitude in the Overtone image. The Fundamental Mode (lowest velocity) must be picked.



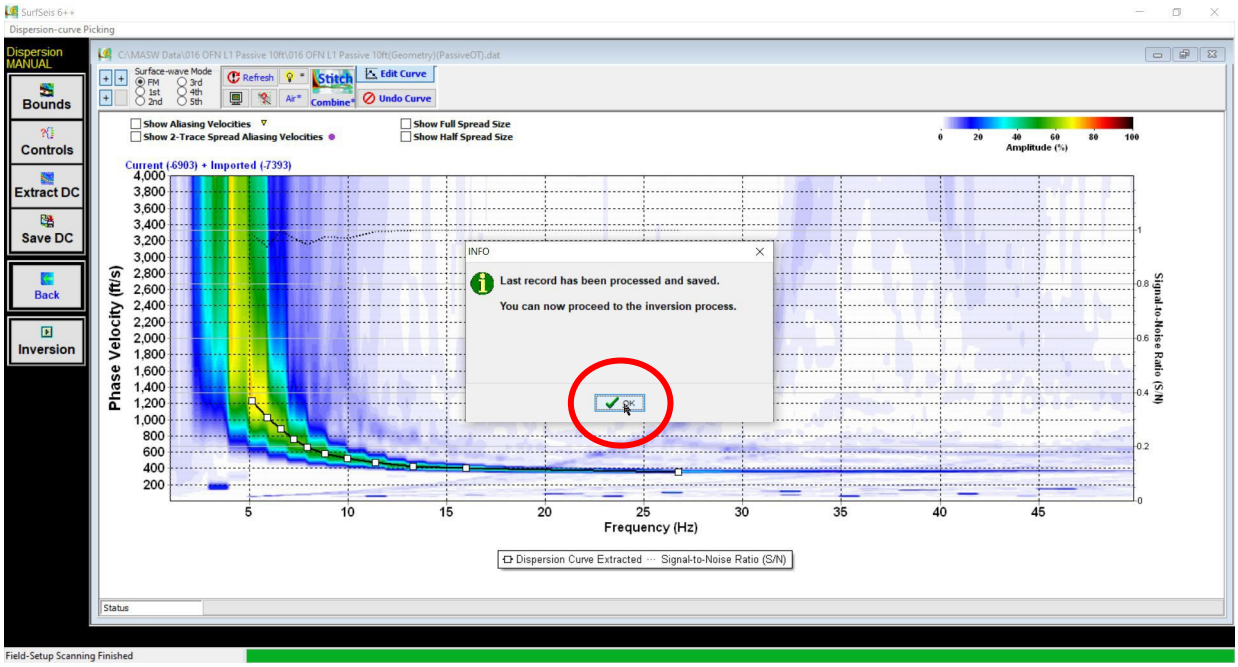
- Click **Extract DC** button on the left panel. A dispersion curve will be automatically generated within the limits picked in the previous step.



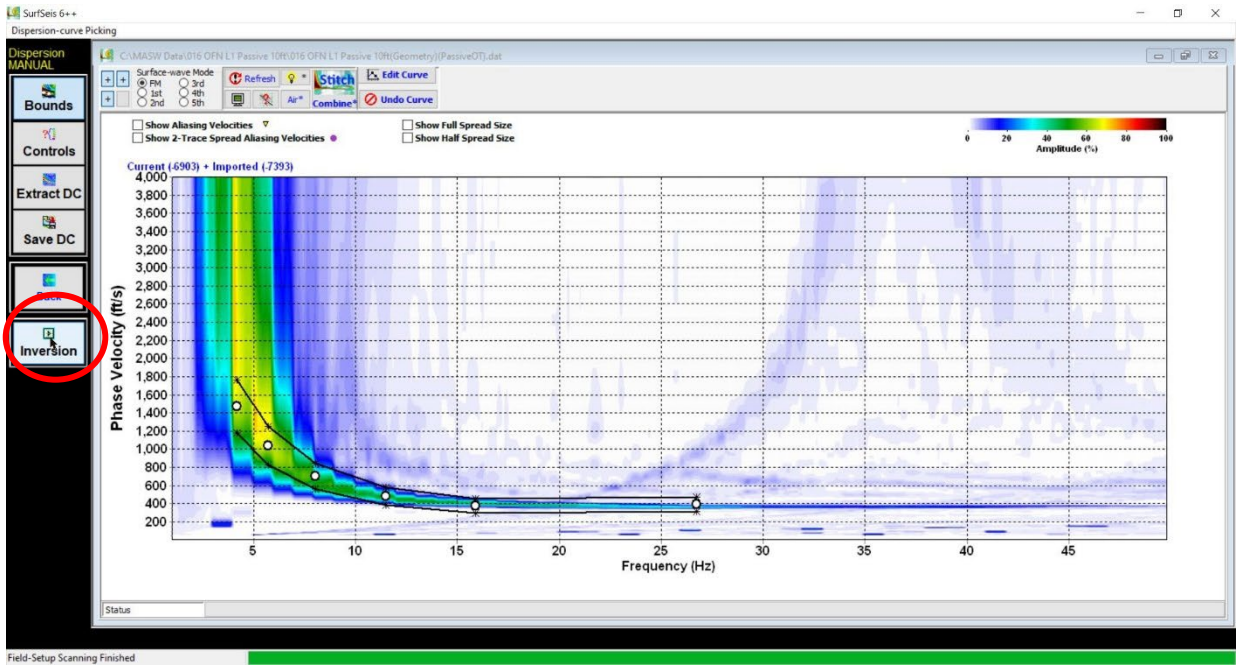
- The dispersion curve can be edited by clicking **Edit Curve** button on the top panel.



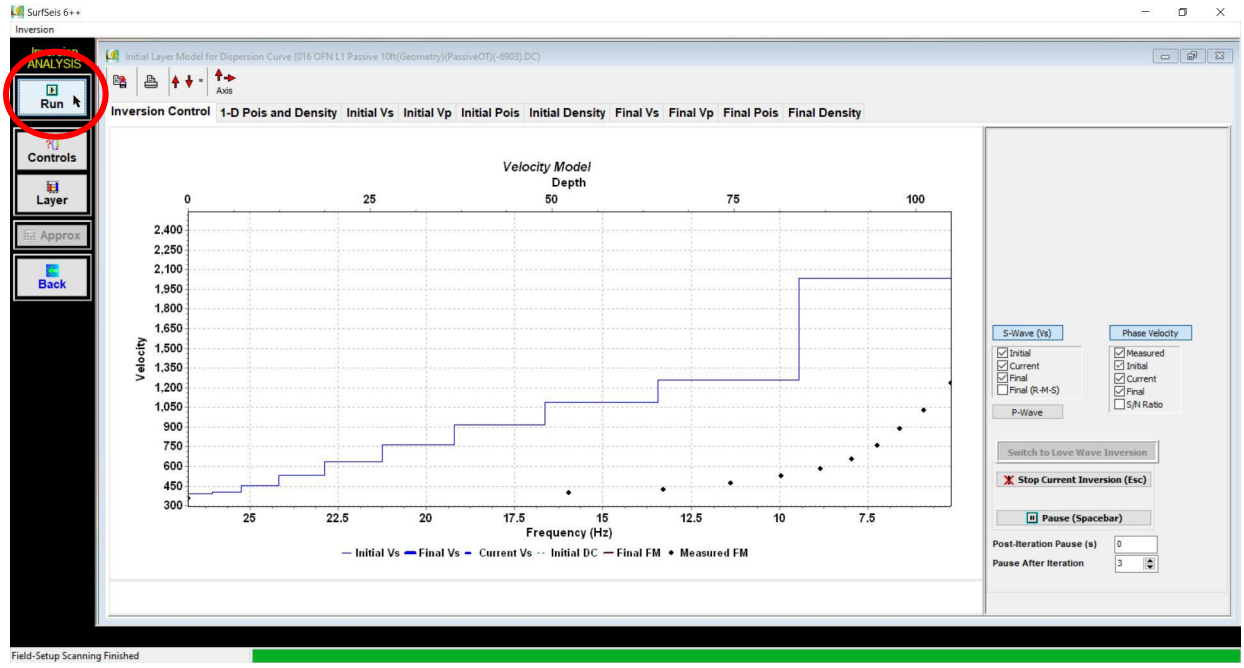
- Click **Save DC** button on the left panel to save the current dispersion curve. Creating a new folder for combined data is recommended (right click New->Folder), click **Open** the created folder and **Save** the file.



- An **INFO** window will appear. Click **OK** to proceed.

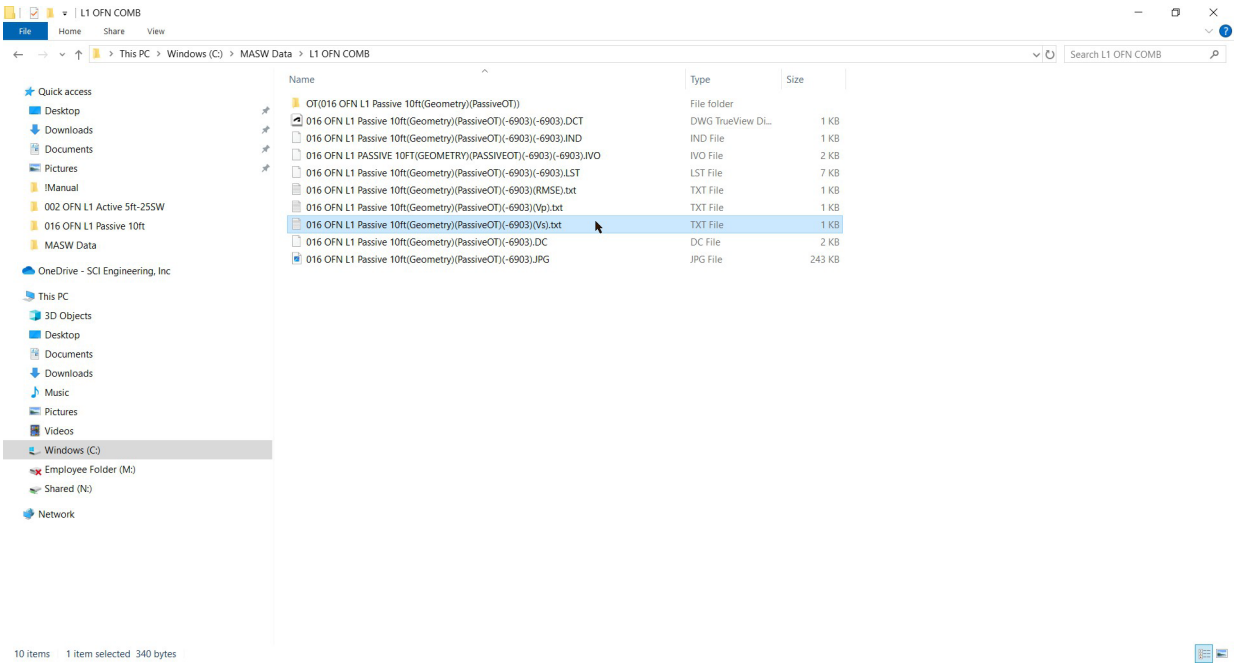


- Click **Inversion** tab on the left panel to continue from the previous step. Alternatively, If the software is re-launched the **Inversion** can be started by clicking **Processing Steps** button on the top panel from the main menu and then **Invert Dispersion Curves**.

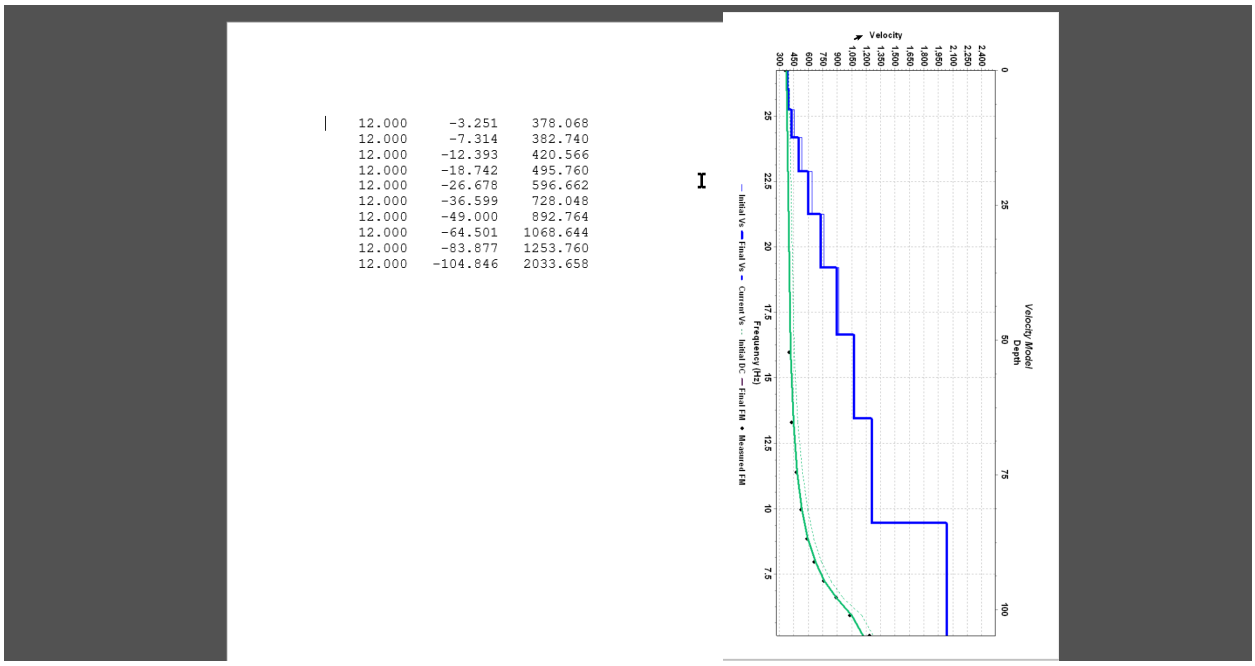


- An inversion window will appear. Click **Run** button on the left panel. The software generates a 10-layer velocity model by default. If more advanced data processing is required, the number of layers can be changed by the processor.

- The software will automatically generate a share wave velocity profile with 10 velocity layers. In this example the inversion process stopped after 1 iteration.



- The results of the inversion are saved in the text format in the folder with the rest of the data. This file could be opened and reviewed in Microsoft Notepad, Excel or Word program.

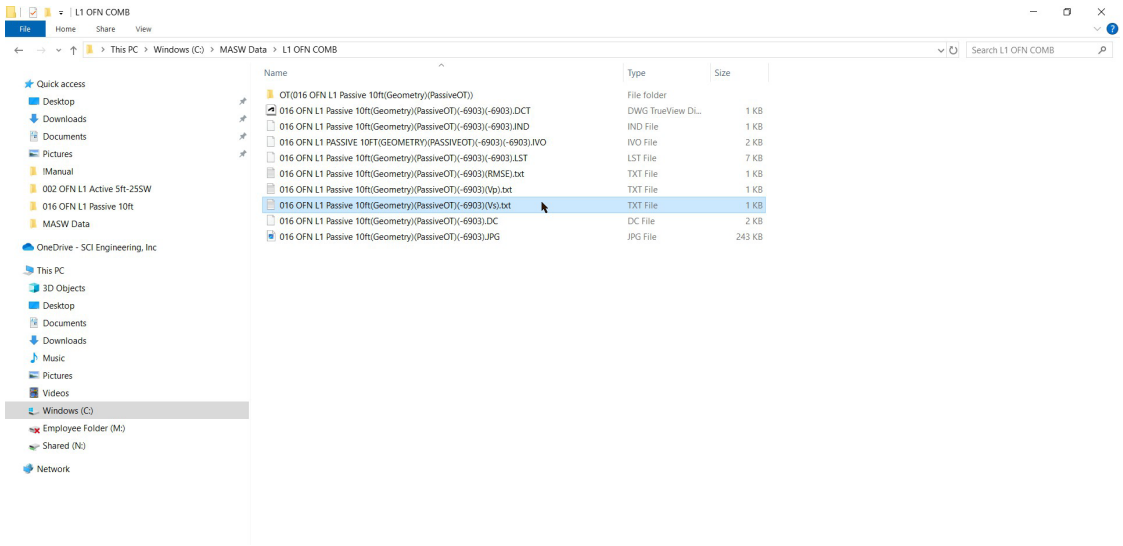


```
   12.000     -3.251    378.068
   12.000     -7.314    382.740
   12.000    -12.393    420.566
   12.000    -18.742    495.760
   12.000    -26.678    596.662
   12.000    -36.599    728.048
   12.000    -49.000    892.764
   12.000    -64.501   1068.644
   12.000    -83.877   1253.760
   12.000   -104.846   2033.658
```

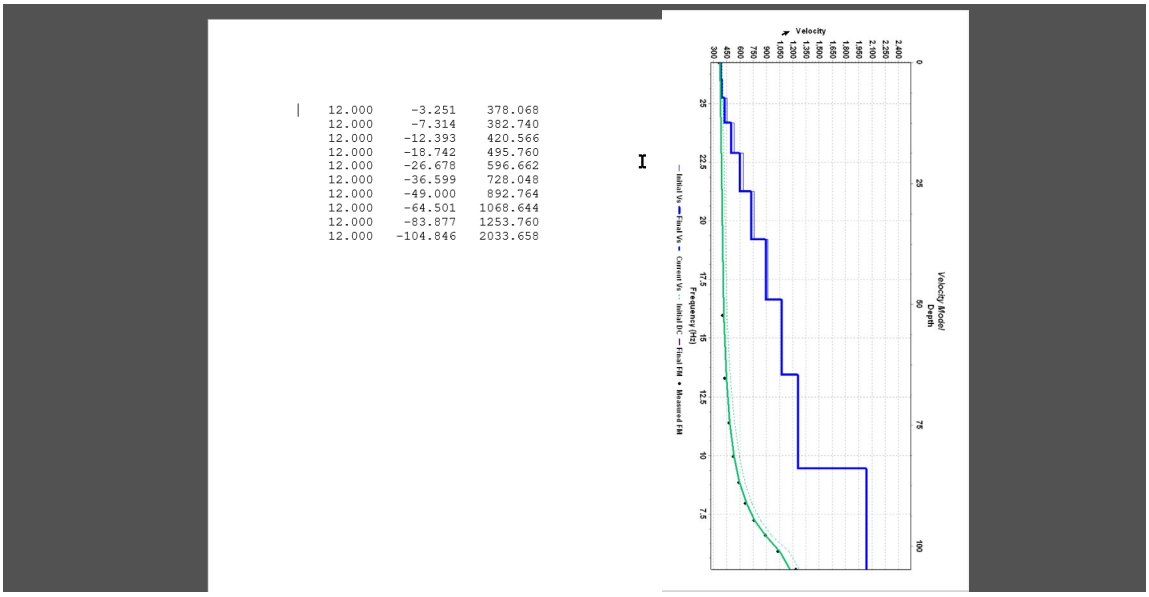

- The output file has 3 columns. The first column is the middle station (calculated from the record geometry), the second column is the depth relative to the surface and the third column is the shear wave velocity. Visually check the correlation between the table (left) and the profile (right). The data can be imported in Excel or other software for further calculations.

3.0 MASW Data Interpretation

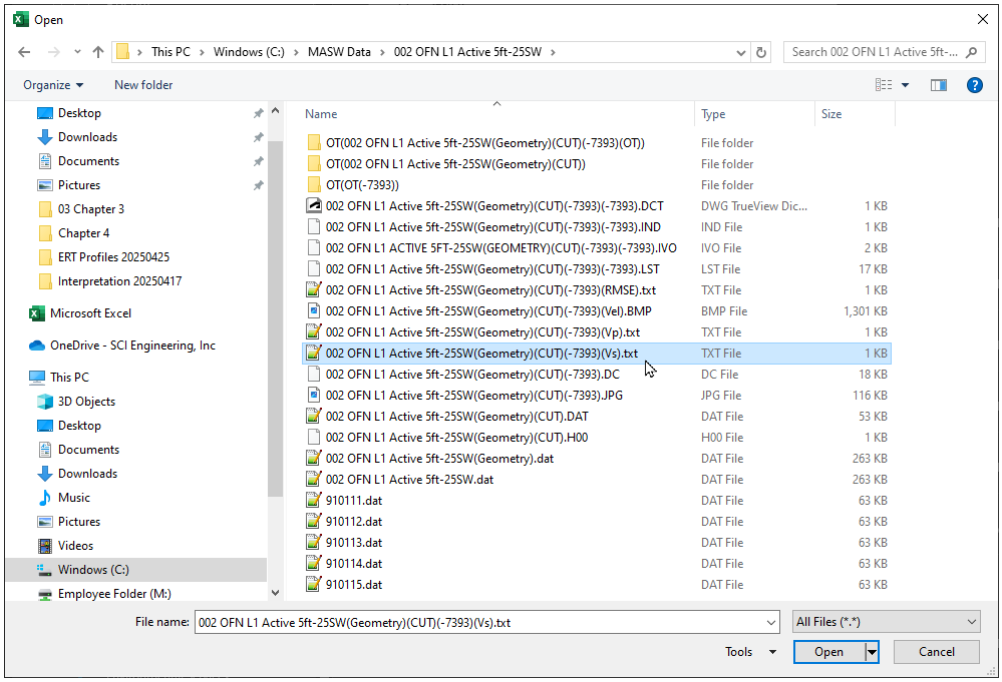
3.1 Data Import in Excel



- The results of the data inversion in SurfSeis software are saved in the text format in the folder with the rest of the data, in a file with a name ending with "… **(Vs)**.txt". This file could be opened and reviewed in Microsoft Notepad, Excel or Word program.



- The one-dimensional share wave velocity (1D SWVP) profile is saved as a file with 3 columns. The first column is the middle station (calculated from the record geometry), the second column is the depth relative to the surface and the third column is the shear wave velocity. Microsoft Excel can be used for calculation of an average shear wave velocity in the upper 100 feet of the subsurface (Vs 100).



- To open the SurfSeis output file in Excel: launch Excel, click **Open->Browse**, navigate to the folder with the processed data and select **All Files** to see files with the extension **TXT**.

- The MASW data inversion results in a layered shear wave velocity (Vs) model. A standard output is a 10-layer model, where each modeled velocity layer is characterized by a thickness (di) and a corresponding shear wave velocity (Vsi). The weighted average shear wave velocity Vs_{100} can be calculated using the following formula:

$$\mathbf{Vs_{100} = H / (\Sigma\ (di / Vsi))}$$

Where:

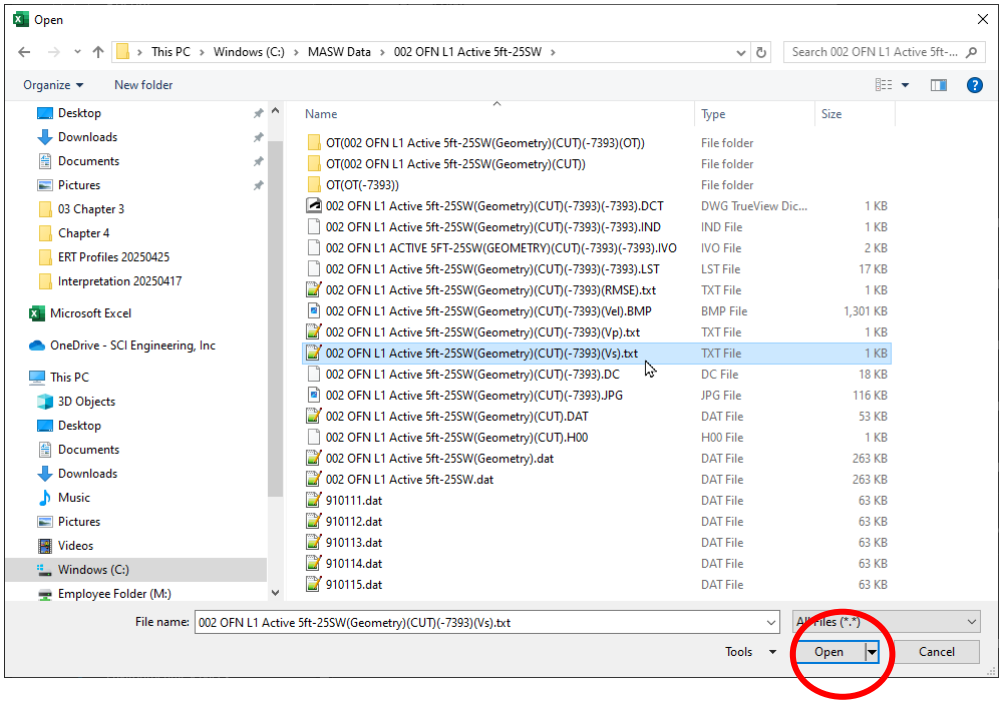
Vs_{100} is average shear wave velocity over depth H (feet/second, or meters/second)

H is total thickness (sum of all di) (typically 100 ft, or 30 m)

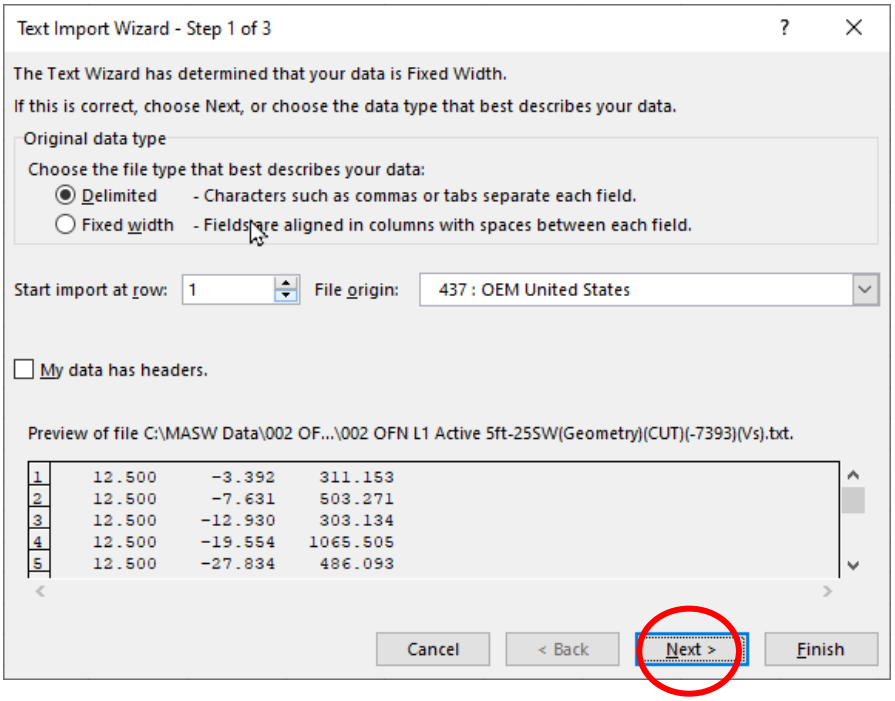
di is thickness of the i-th layer (ft or m)

Vsi is shear wave velocity of the i-th layer (ft/s or m/s)

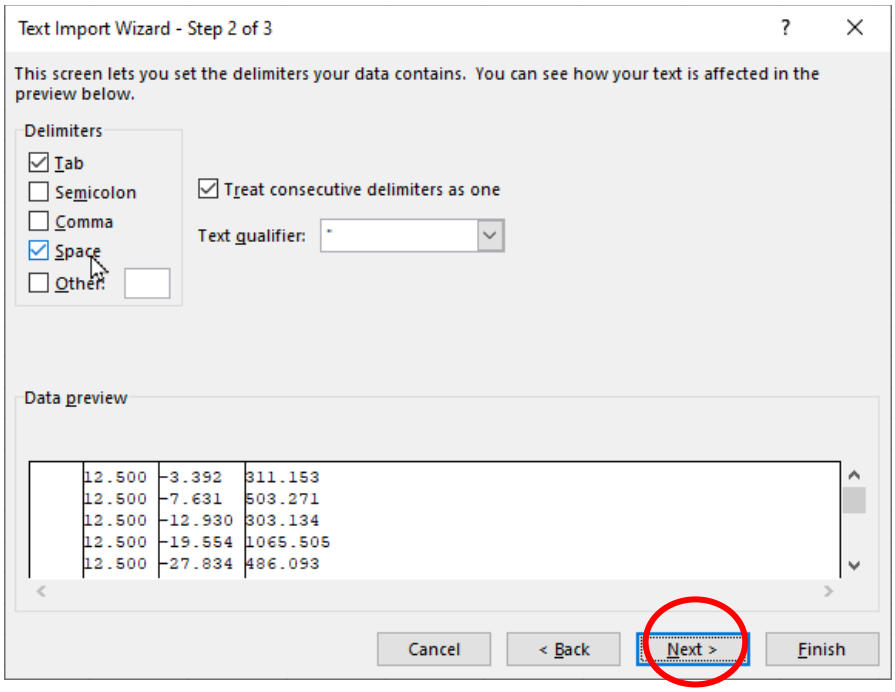
n is number of layers (in this case, 10)



- To open the SurfSeis output file in Excel: launch Excel, click **Open->Browse**, navigate to the folder with the processed data and select **All Files** to see files with the extension **TXT**.



- Select **Delimited** and click **Next**.

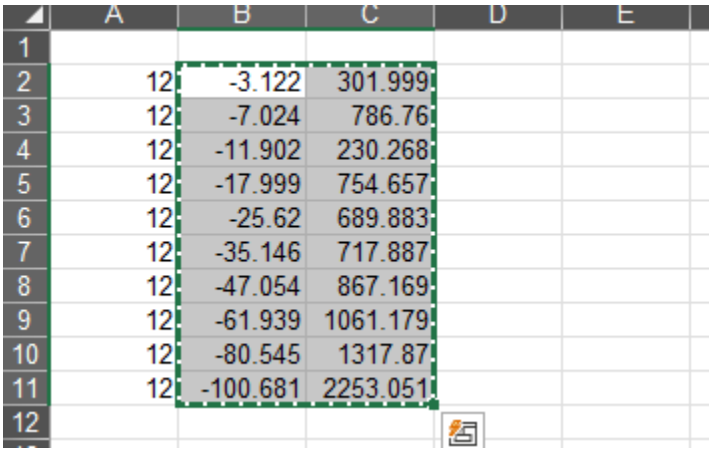


- Check box **Space** and click **Finish**.

	A	B	C	D	E
1					
2	12	-3.122	301.999		
3	12	-7.024	786.76		
4	12	-11.902	230.268		
5	12	-17.999	754.657		
6	12	-25.62	689.883		
7	12	-35.146	717.887		
8	12	-47.054	867.169		
9	12	-61.939	1061.179		
10	12	-80.545	1317.87		
11	12	-100.681	2253.051		
12					
13					
14					
15					
16					
17					
18					

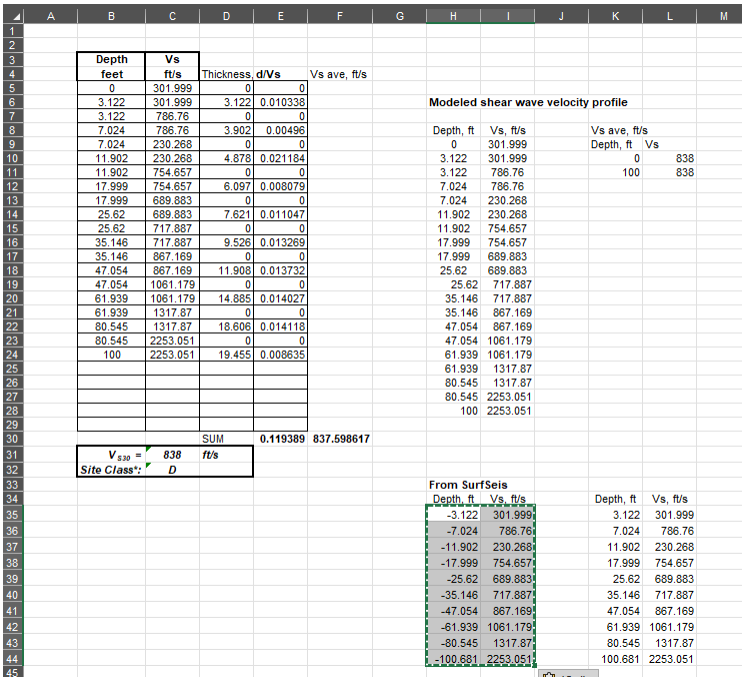
- The SurfSeis output file with modeled layer depths and corresponding velocities will open in the table format.

3.2 Calculating Average Shear Wave Velocity



	A	B	C	D	E
1					
2	12	-3.122	301.999		
3	12	-7.024	786.76		
4	12	-11.902	230.268		
5	12	-17.999	754.657		
6	12	-25.62	689.883		
7	12	-35.146	717.887		
8	12	-47.054	867.169		
9	12	-61.939	1061.179		
10	12	-80.545	1317.87		
11	12	-100.681	2253.051		
12					

- Copy the right two columns (depths and velocities) and insert in the **SWVP Graph.xlsx** file (provided for the demonstration purposes).



Depth feet	Vs ft/s	Thickness,	d/Vs	Vs ave, ft/s
0	301.999	0	0	
3.122	301.999	3.122	0.010338	
3.122	786.76	0	0	
7.024	786.76	3.902	0.00496	
7.024	230.268	0	0	
11.902	230.268	4.878	0.021184	
11.902	754.657	0	0	
17.999	754.657	6.097	0.008079	
17.999	689.883	0	0	
25.62	689.883	7.621	0.011047	
25.62	717.887	0	0	
35.146	717.887	9.526	0.013269	
35.146	867.169	0	0	
47.054	867.169	11.908	0.013732	
47.054	1061.179	0	0	
61.939	1061.179	14.885	0.014027	
61.939	1317.87	0	0	
80.545	1317.87	18.606	0.014118	
80.545	2253.051	0	0	
100	2253.051	19.455	0.008635	
		SUM	0.119389	837.598617
V_{S30} =	838	ft/s		
Site Class*:	D			

Modeled shear wave velocity profile

Depth, ft	Vs, ft/s
0	301.999
3.122	301.999
3.122	786.76
7.024	786.76
7.024	230.268
11.902	230.268
11.902	754.657
17.999	754.657
17.999	689.883
25.62	689.883
25.62	717.887
35.146	717.887
35.146	867.169
47.054	867.169
47.054	1061.179
61.939	1061.179
61.939	1317.87
80.545	1317.87
80.545	2253.051
100	2253.051

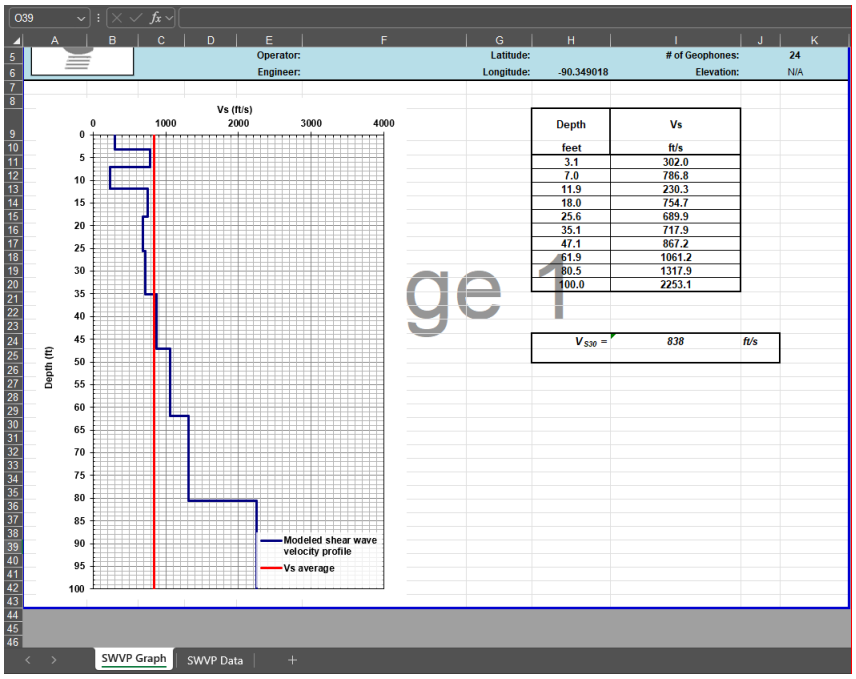
Vs ave, ft/s	
Depth, ft	Vs
0	838
100	838

From SurfSeis

Depth, ft	Vs, ft/s
-3.122	301.999
-7.024	786.76
-11.902	230.268
-17.999	754.657
-25.62	689.883
-35.146	717.887
-47.054	867.169
-61.939	1061.179
-80.545	1317.87
-100.681	2253.051

Depth, ft	Vs, ft/s
3.122	301.999
7.024	786.76
11.902	230.268
17.999	754.657
25.62	689.883
35.146	717.887
47.054	867.169
61.939	1061.179
80.545	1317.87
100.681	2253.051

- An average shear wave velocity to a depth of 100 ft (30 m) will be calculated.



- Navigate to "**SWVP Graph"** tab to view a shear wave velocity profile and the calculated Vs_{100}. In the provided example the Vs_{30} (Vs_{100}) = 838 ft/s.

  Note: the calculations in this example are based on the 10-layer velocity model, generated by the software, and are used for the preliminary Vs average value estimating only. This model does not represent a true geologic model, which typically consists of fewer layers. The final Vs_{30} (Vs_{100}) is determined by an engineer and incorporates multiple datasets, including site geology and ground truth data.