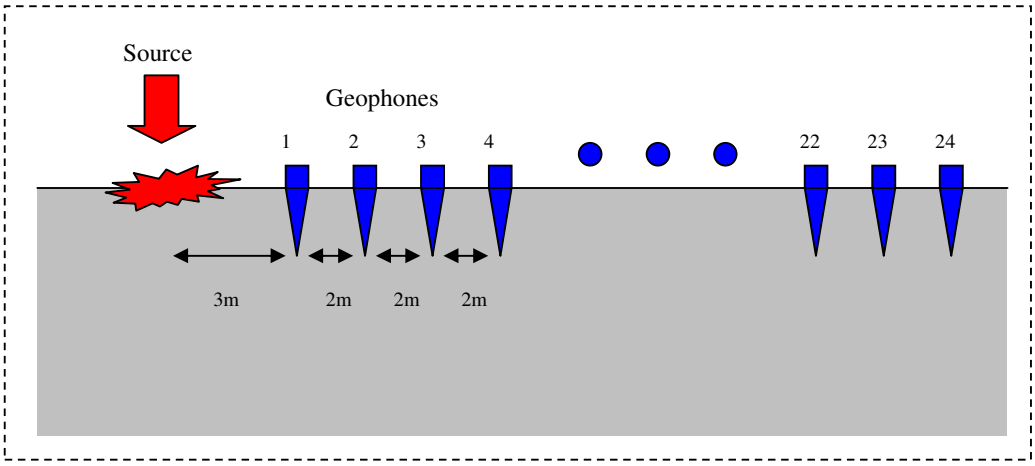
SWAN (Surface waves analysis)

This document contains detailed instructions to interpret appended MASW-SASW data through the software **SWAN**. Two examples are processed here and through this the user gets acquainted with most of the tools that **SWAN** includes.
Together with this document you find two set of *sg2* files:

- The folder *Sample1* contains the files *File1.sg2*, *File2.sg2*, *File3.sg2*, *File4.sg2* and *File5.sg2*. The data contained in these files needs to be cleaned before the spectrum calculation and inversion steps; in this some of the pre-processing tools available in **SWAN** can be used.
- The folder *Sample2* contains only the file *FileTot.sg2*. This file is the result from proper cleaning of the 5 in *Sample1*. By choosing this file to create a **SWAN** project the initial pre-processing step is avoided.

Raw data are related to MASW-SASW acquisition, and they are saved in *SEG-2* format. Acquisitions are done using an array made by 24 geophones, located with geophone step of 2 meters. The source is located at a distance of 3 meters from the first geophone, externally to the array.



The sampling interval is 1 millisecond (i.e. the sampling frequency is 1000Hz or 1KHz), and the length of the acquisition is 2 seconds.
Was acquired 5 shots, with the same configuration, every one saved on a different file.
The files are altered to simulate some of the possible problems that are connected to the acquisition step:

- In the file *File1.sg2* the geophones number 18 and 19 are connected to the instrument with inverted polarity.
- In the file *File1.sg2* the geophone number 23 is not working properly, e.g. due to a bad connection.
- In the file *File2.sg2* the pre-trigger time smaller than in the other files.
- In the file *File3.sg2* the geophone array has been reversed.
- In the file *File4.sg2* on the geophones number 9 to number 14 a continuous DC component is added to the signal.
- In the file *File5.sg2* there is a strong noise event added to the signal.

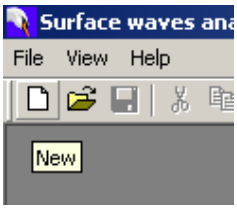
Elaboration steps:

To execute the processing of the data using **SWAN** the following operations should be executed in the given sequence:

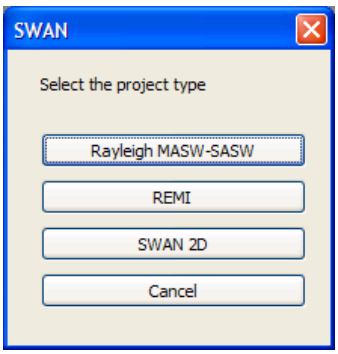
- Create a MASW-SASW project.
- Link the files that contains the raw data to be processed to the created project.
- Pre-process the data for better quality of the following spectrum calculations, dispersion curve extraction and inversion.
- Transformation of the seismogram to the spectral domain through FK or FV (fVph) transform.
- Extraction of the experimental dispersion curve from the transformed spectrum.
- Inversion, generation of a Vs model through fitting of this models respons (i.e. the synthetical dispersion curve) to the experimental dispersion curve.

Create a new MASW-SASW project:

- After that **SWAN** is installed, open it using the icon on the desktop or through the link in the start menu of Windows.
- Create a new project through the command *Menu>File>New*, or through the button on the toolbar.



- Select the right type of project, in this case press the button: rayleigh MASW-SASW.

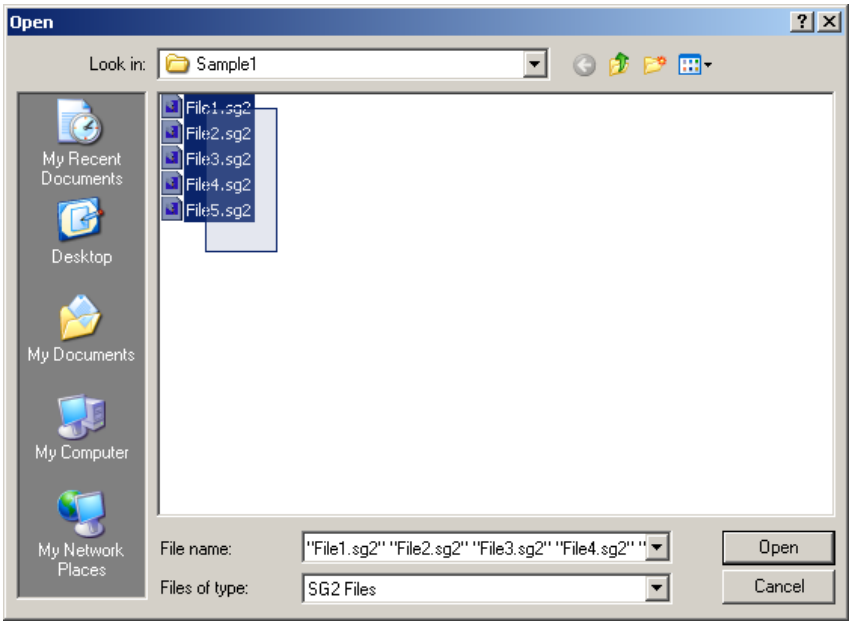


Link the data-files to the project:

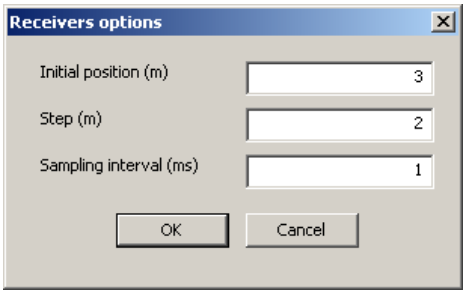
In the following you can find the description of the different procedures in the two different cases

Project using the raw data contained in the folder *Sample1*

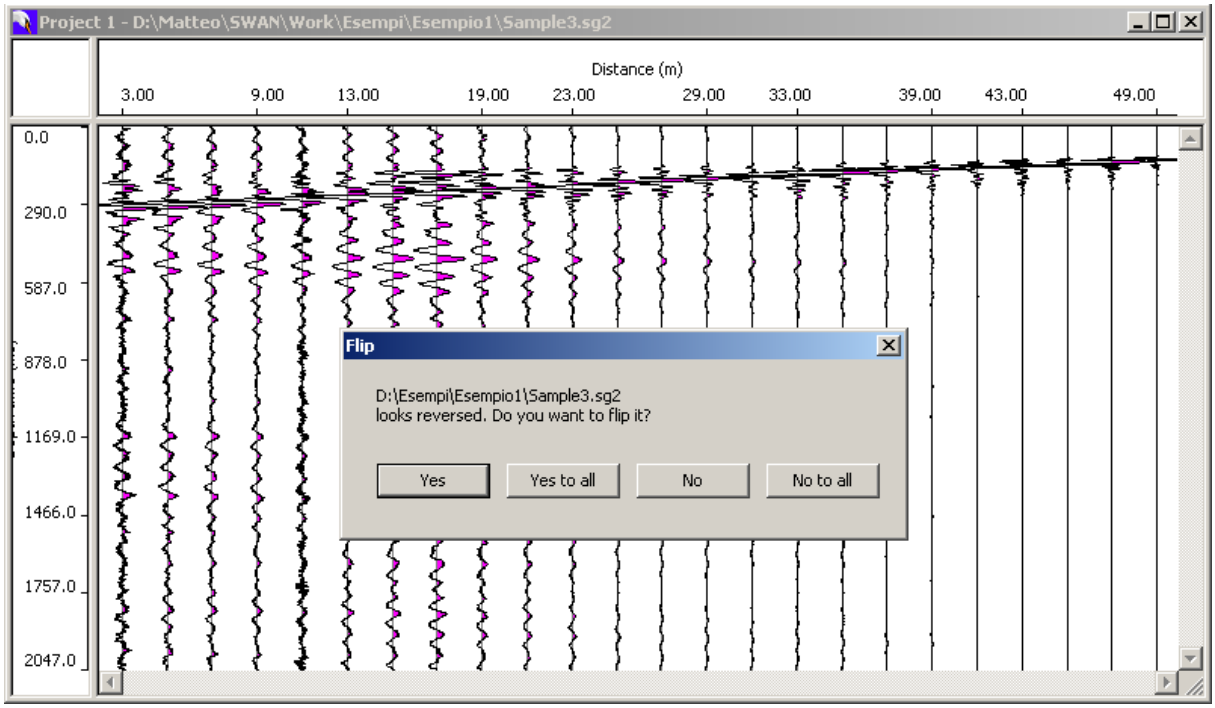
- After that the project type is selected, **SWAN** will open a dialog window. The five files *File1.sg2 ..File5.sg2* in the folder *Sample1* should be selected. The selection is done using the multi-selection tools in Microsoft, e.g. draw a rectangle with the mouse over the files or select the files separately while pressing the *CTRL* key.



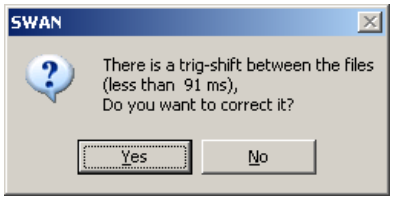
- After this a dialog window is opened, where the acquisition parameters should be inserted: the *initial position* is the distance from the first geophone to the source, in this case it is 3 meters; the *step* is the distance between two geophones, in this case 2 meters; and the *sampling interval* is in this case 1 millisecond. Then press the *OK* button to complete the data import step.



- **SWAN** automatically detects some of the possible problems the files that has been generated during acquisition. The file *File3.sg2* has been acquired with the channels numbered in the reversed order and automatically a window appears where the user is asked if it should be flipped or not. Press the button *Yes* to specify that is desired that **SWAN** corrects the problem.

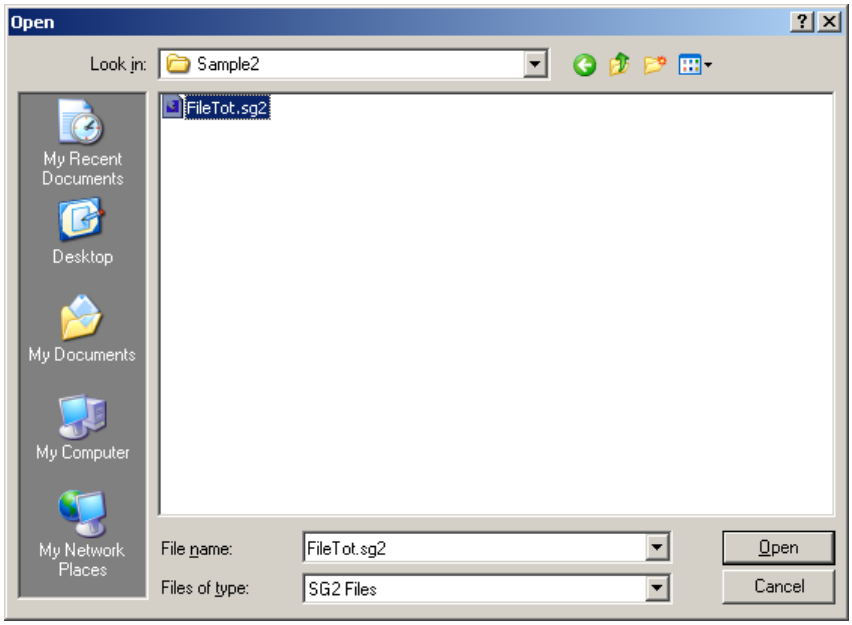


- **SWAN** also detects if there is a trig-shift between the separate files and if so an option to correct this is displayed. The file *File2.sg2* it is not well synchronized with the other data, with an offset about a tenth of second and it is a good idea to correct this. Press the button *Yes* present on the shown window.

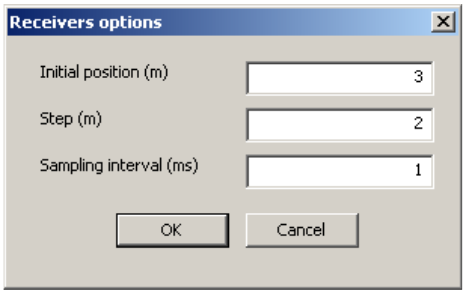


Project using the raw data contained in the folder *Sample2*

- In this case you use the same project type (Rayleigh MASW-SASW) and when **SWAN** opens the file select dialog window the file *FileTot.sg2* from folder *Sample2* should be selected.



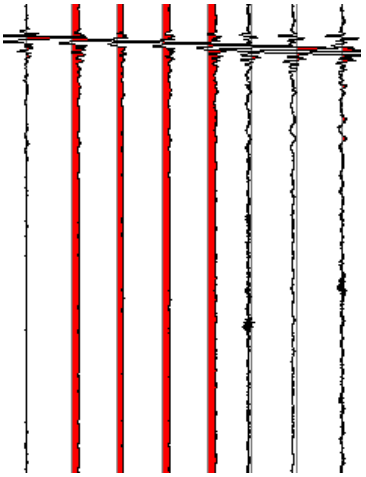
- The dialog window for acquisition parameters is displayed. The parameters in this case are the same as in the first case: *initial position* (the distance from the first geophone to the source) is 3 meters; the *step* (the distance between two geophones) is 2 meters; and the *sampling interval* is 1 millisecond. Then press the *OK* button to complete the data import step.

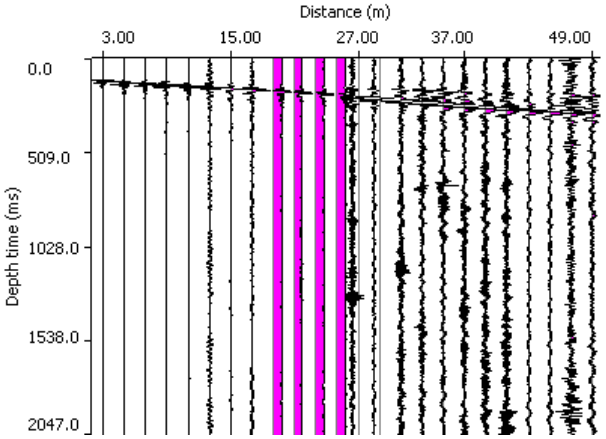


Independent of which of the 2 project that is created, **SWAN** opens a set of windows: one figure to show the seismogram of every linked file; one figure to show the mean seismogram; and one window that contains some text that describes the project history i.e. the operations that have been performed.

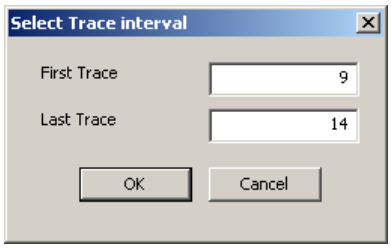
Pre-Processing:
This step needs to be done only in the *Sample1* project.

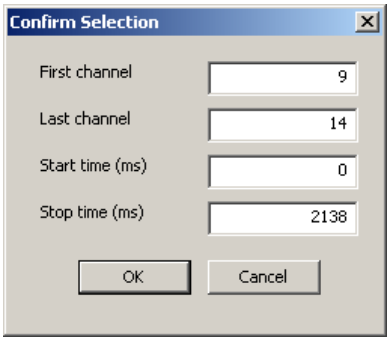
- Observing the mean seismogram it is possible to see that some channels are showing a signal that has got a mean value that is not exactly null, this can disturb the spectral analysis that need to be done.



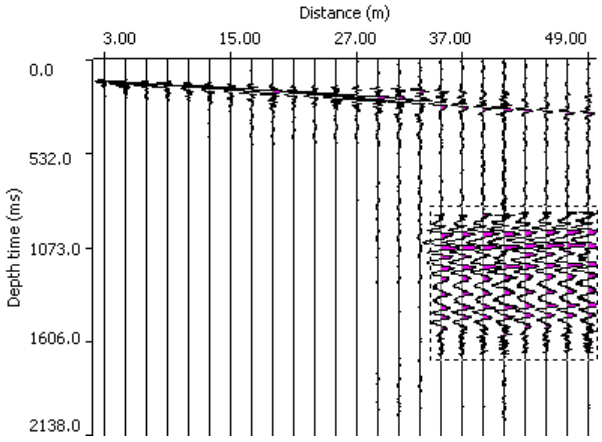


If the separate seismograms are viewed it can be seen that this problem is related to the file *File4.sg2*. Go on by activating the window with the seismogram related to *File4.*sg2. Select the disturbed channels (i.e. from the geophone number 9 to the geophone 14) through the command *Menu>Edit>Select Traces*. Then select *Menu>PreProcessing>DC Remove*, to specify this operation, and press *OK* in the window shown to confirm the area selection.

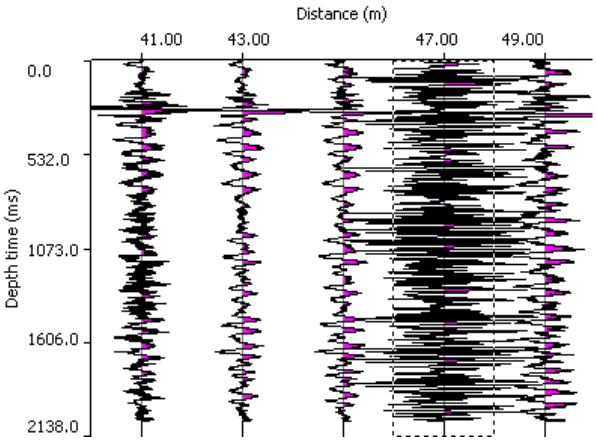


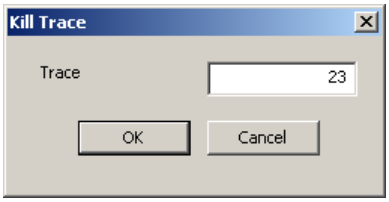


- The strong noise event present late in the last eight traces is related to the file *File5.sg2*. To delete this noise select the area of the seismogram between the channel 17 and 34 and between 800 and 1700 milliseconds by drawing a rectangle with the mouse while pressing the right mouse button. After the area is selected press the *Del* key on the keyboard, or use the command *Menu>Edit>Delete*.

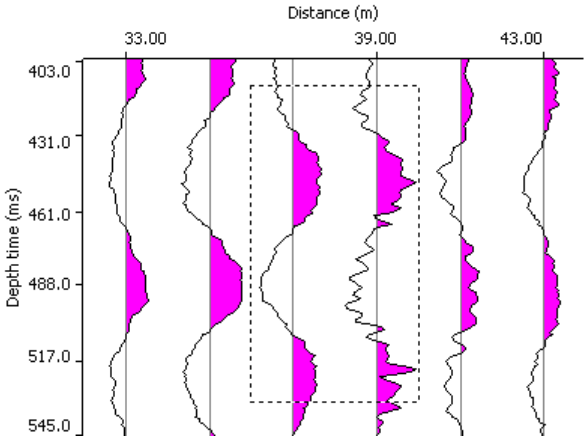


- In the file *File1.sg2* it is possible to see that the geophone number 23 hasn't recorded a good signal. This channel should be deleted from this seismogram so that the noise is not left to disturb the analysis. Activate the window relative to that file and select the command *Menu>Pre Processing>Kill Trace*. In the dialog window that **SWAN** opens, specify trace number 23 and then press *OK*.

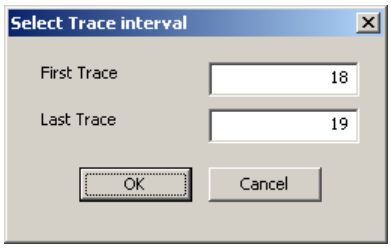


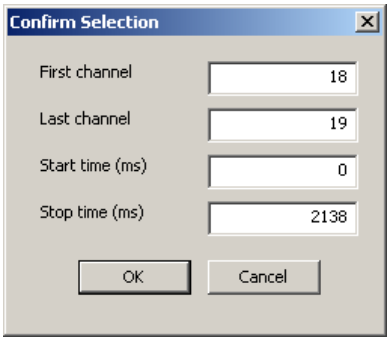


- To magnify a region of the seismogram draw a rectangle using the mouse while pressing the right mouse button, then select the command *Menu>View>Zoom Area* or press the magnifying glass button on the toolbar. To againg view the entire seismogram select the command *Menu>View>Zoom Out* or double click with the right mouse button on the window.
- An interesting area to view is on the seismogram related to the file *File1.sg2*, between the geophone 16 and 21 and between 400 and 600 ms. While zooming this area it becomes clear that geophones 18 and 19 have reversed polarity, they have probably been connected to the instrument with the connectors in the wrong way.

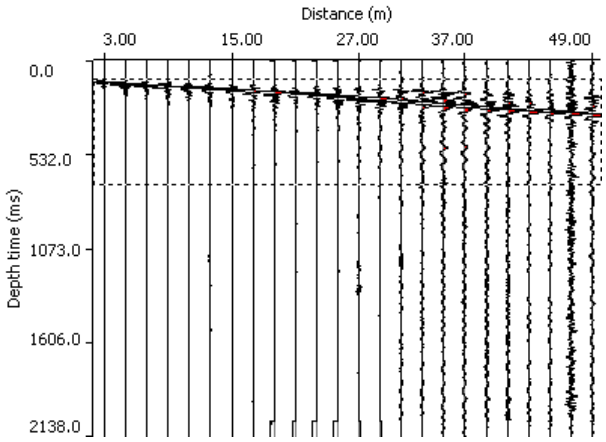


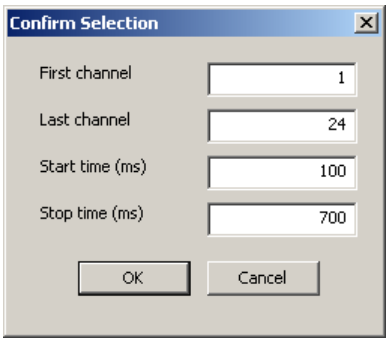
- To correct this problem activate the seismogram related to *File1.sg2*, select the command *Menu>Edit>Select Traces* and specify geophones 18 to 19. After this select the command *Menu>Pre-Processing>Polarity*, and press the *OK* button to confirm the area to be processed.





- Finally, the spectral analysis should be limited only to the part of the seismogram containing useful data. Activate the window related to the mean seismogram and select the area between 100 and 700 milliseconds, from the first to the last geophone (as displayed in picture), then select the command *Menu>Pre-Processing>Resize*, and press *OK*. This reduces the active part of the window to that selected which in turn reduces the time it takes to perform spectral calculations. This operation also removes all noise present outside the portion of the signal generated by the source.

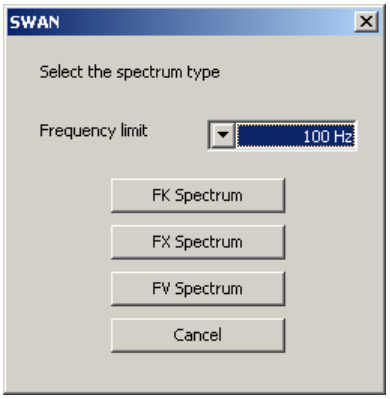




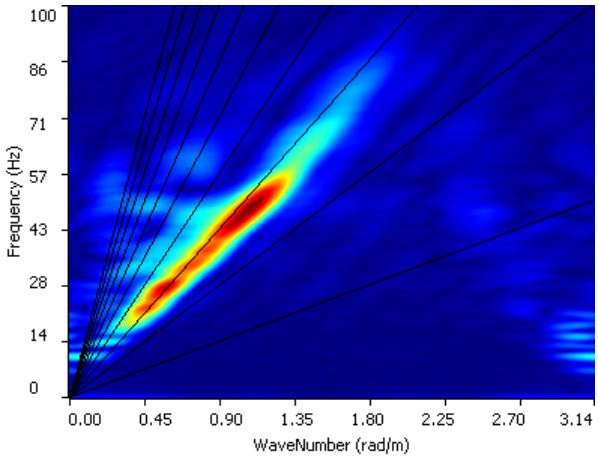
FK spectrum:

When the mean seismogram is correctly cleaned it is necessary to perform a Fourier transform, bringing the data to the FK domain. In the FK domain the energy distribution between different modes of propagation can then be viewed. Before executing this operation the bandwidth in the signal can be observed:

- Activate the window with the mean seismogram. When this window is activated **SWAN** enables the command *Menu>Processing>Spectrum* (and at the same time it enables the corresponding buttons on the toolbar). When selecting that command a dialog window appears where it is possible to indicate the value of the maximum frequency that limits the spectrum. In this example, and most often in geological conditions, the wanted information is present below 100Hz. In this case select this value.



- Press the *FK Spectrum* button to start the processing. After a few seconds the FK spectrum appears.



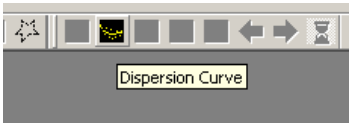
Extraction of the experimental dispersion curve:

The MASW-SASW theory teaches that the fundamental dispersion curve must be search on the maxima of the FK spectrum. In **SWAN** this can be done automatically or manually. However, before this step it is necessary to do some simple observations:

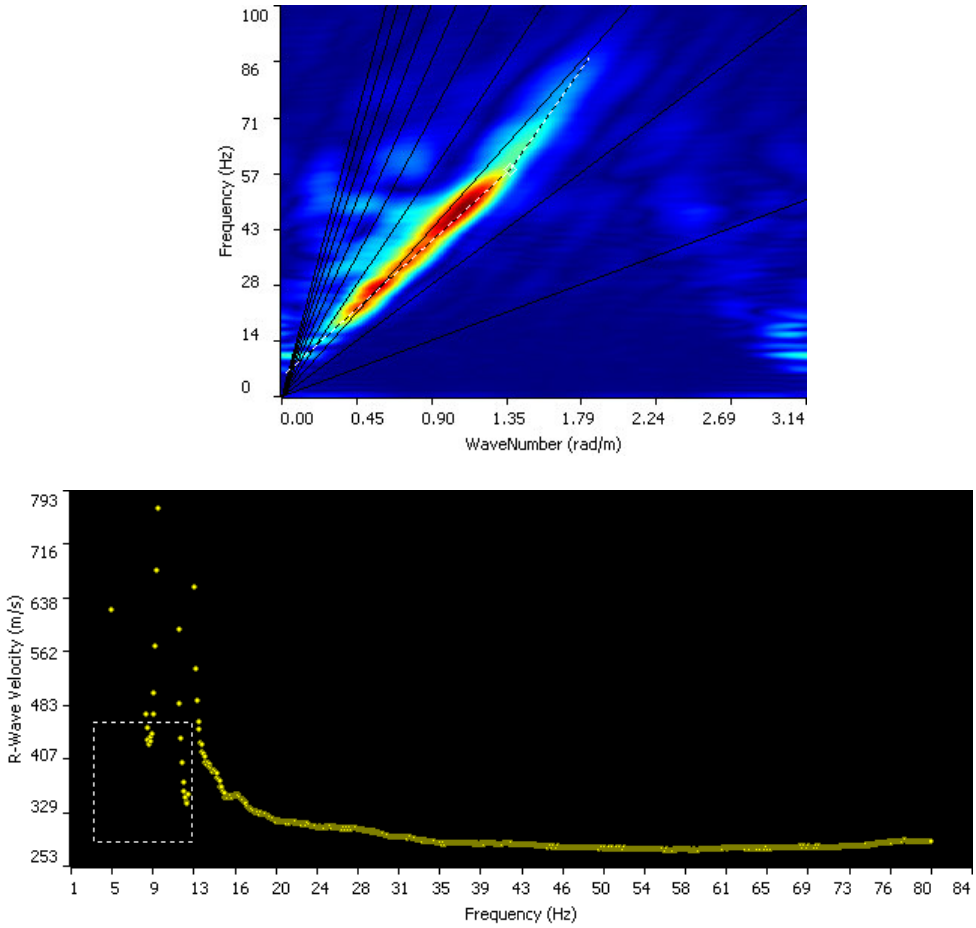
Geophones used in surface wave seismic acquisition normally has a cut off frequency of 4.5 Hz, therefore it is not advisable to work with lower frequency than this. It can be seen here that the value of the maximum frequency, in this example, where the dispersion curve can be searched is 80 Hz.

Observing the spectrum finally it is possible to see that, in this case, the main part of the energy (red and yellow color in the seismogram) is limited between 200 and 400m/s (the oblique black lines that are exiting from the origin of the FK axes each represent a velocity starting with 100 m/s in the bottom and the increasing with 100 m/s for each line). This area is where the dispersion curve should be searched.

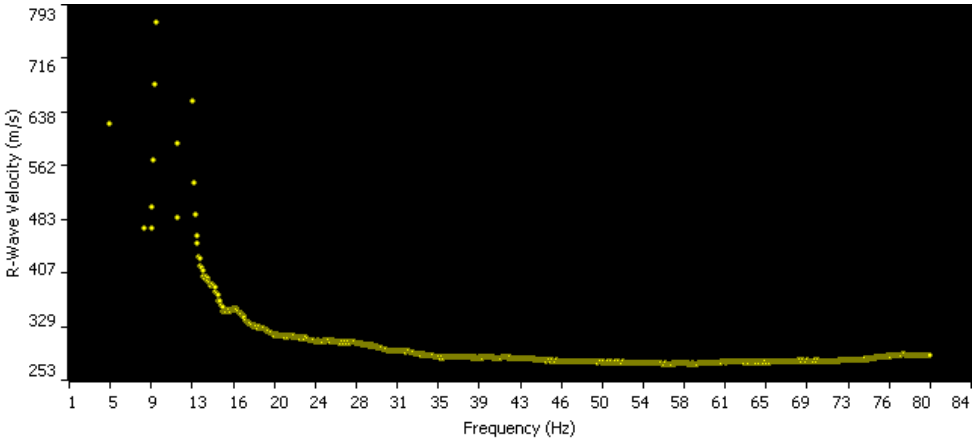
- Activating the window of the FK spectrum, **SWAN** will enable the command *Menu>Processing>Dispersion Curve* the corresponding buttons on the tool bar.



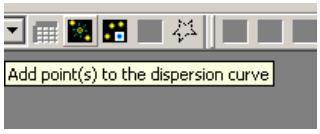
- First the approximate position of the experimental dispersion curve has to be selected. This is done by drawing a line connected by a few points on the spectrum. Usually it is enough with 2 or 3 clicks on the image of the spectrum to obtain a result similar to what is shown in the picture below. Press the button on the toolbar again or press *Enter* on the keyboard to let **SWAN** extract the experimental dispersion curve. A similar image to what is show in the picture below will appear.

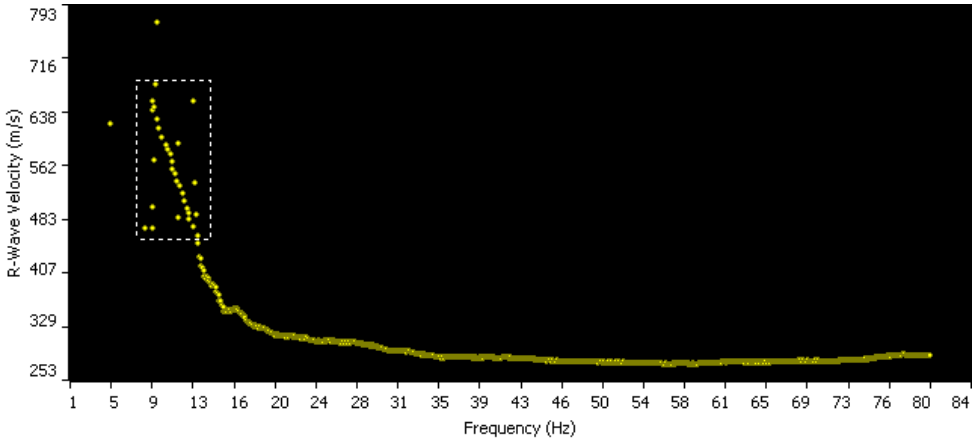


- The points describes the experimental dispersion curve and correspond to the energy maxima in the spectrum. This curve now need a fast clean before the inversion. Draw a rectangle, as shown in the picture, to select the points that are not following the dispersion curve, then press *Del* on the keyboard to remove this data.



- The dispersion curve can be interpolate in the frequency range below 15 Hz where a lot of scatter is evident. Activate the window with the experimental dispersion curve (in the domain frequency-velocity), **SWAN** will then enable the command *Menu>Edit>Add Points* and the corresponding button on the toolbar. Select it and add some points to the dispersion curve with some clicks with the left mouse button. When end disable this tool pressing again the button on the toolbar.





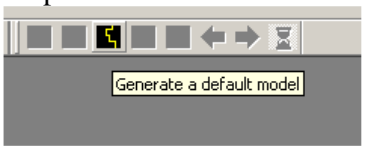
Inversion:

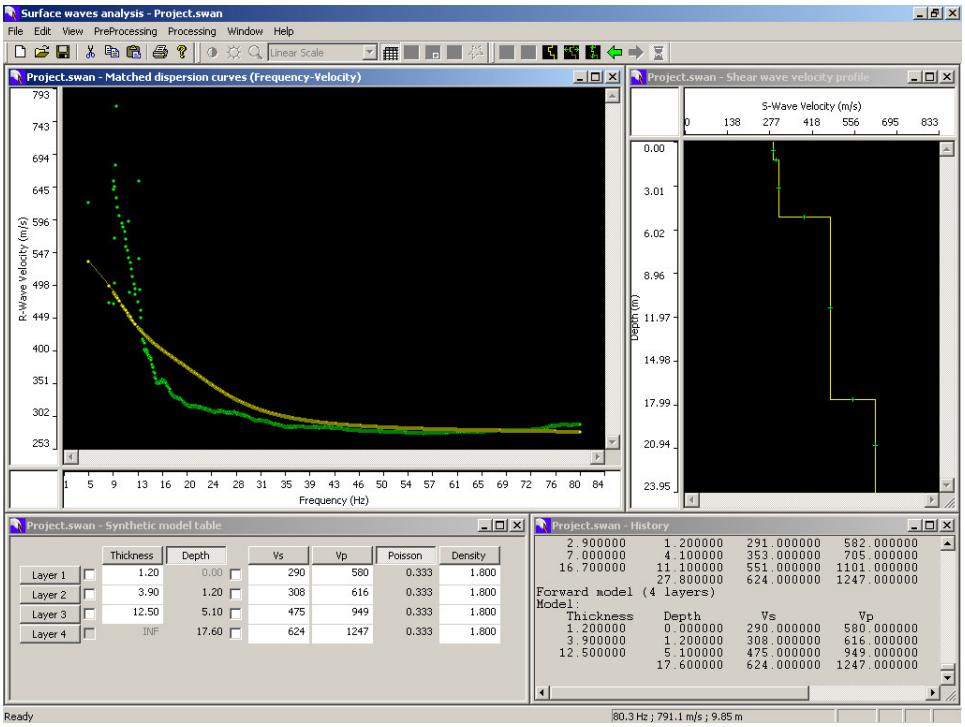
The inversion aims to find a shear wave velocity profile of the ground that is linked to the experimental dispersion curve. Basically this is done by comparing the theoretical dispersion curve from a Vs model with the experimental one. After this the Vs model is updated based on the difference between the two curves. Experimental data is what you have retrieved from the processing, i.e. the measured data. Theoretical data is numerically calculated based on the assumed Vs model.

Initially **SWAN** creates a start model based on the experimental data. As mentioned above this model must now be updated so that the experimental and theoretical curves superimpose. The Vs model can be changed through automatic inversion or through simple manual operations. The window with the Vs model has to be activated. Then, the velocity and thickness of each layer in the Vs model can be easily changed by dragging the corresponding line with the mouse

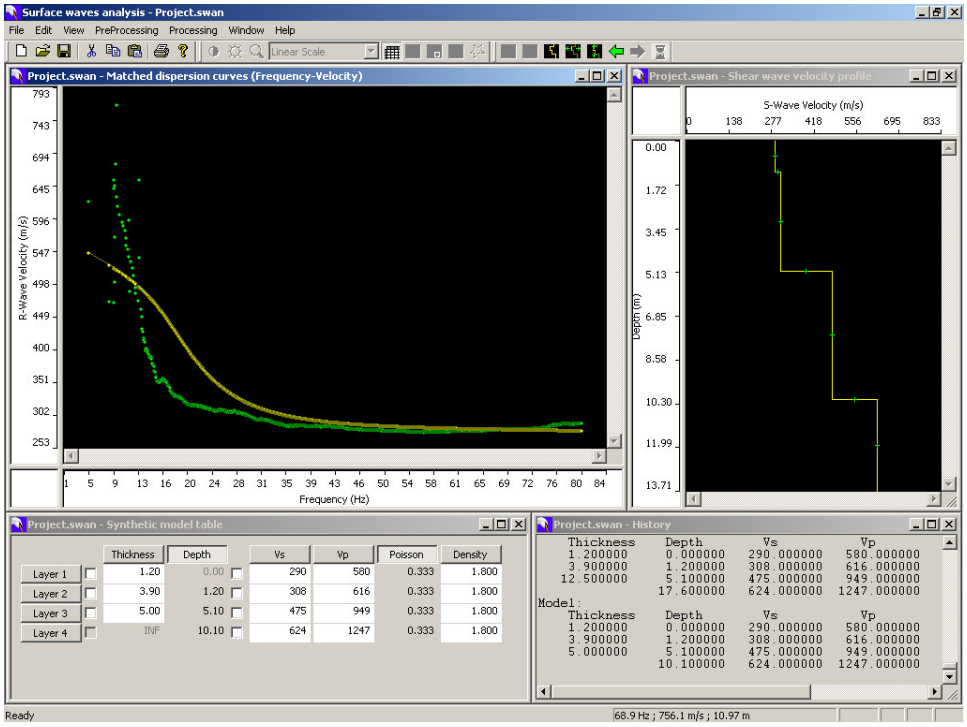
pointer while the left mouse button is pressed. Immediately when this operation is done the theoretical dispersion curve is updated.
Based on scaling properties between the dispersion curve and the Vs model it is also possible to move the theoretical dispersion curve to search a better fit with the experimental dispersion curve. This is done by dragging the curve with the mouse pointer keeping the left mouse button pressed. When letting go of the left mouse button the Vs model is immediately updated. During these operations the data error (i.e. some measure of the difference between the experimental and theoretical dispersion curves) can be viewed in the project history window.

- An inversion can be started with the command *Menu>Processing>Forward Model>4 Layers* or the corresponding button on the toolbar, that is enabled by **SWAN** when the experimental dispersion curve window is activated. When doing this a group of windows, as in the figure below, appears. (Depending on how the dispersion curve is cleaned during the execution of this sample data processing, the start model can appear a little bit different from what is showed here. Follow the procedures described before to reach the same start point).

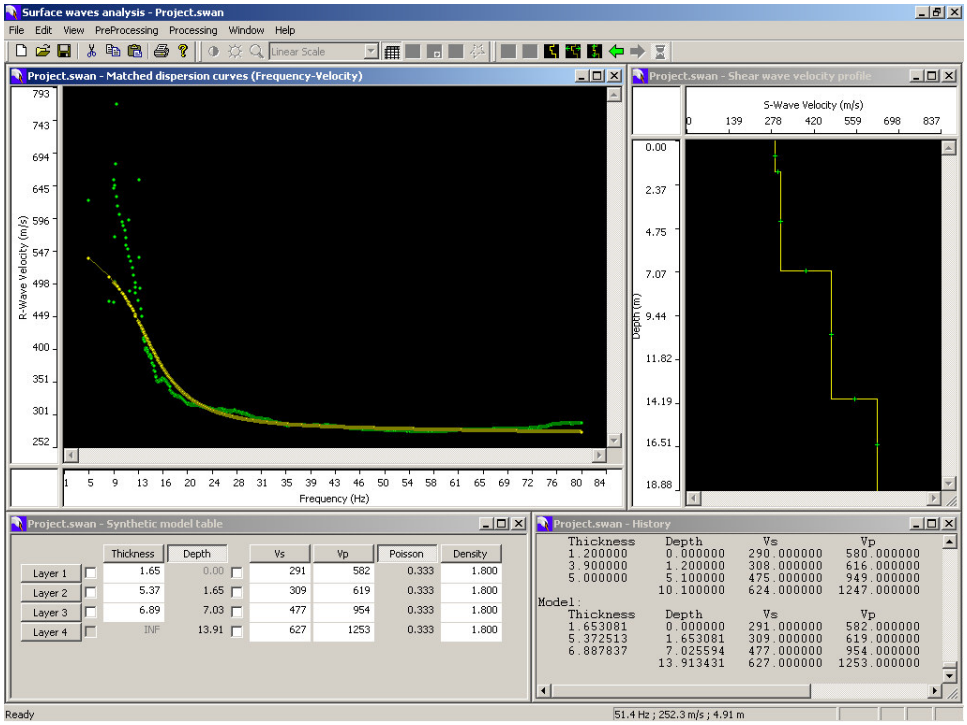




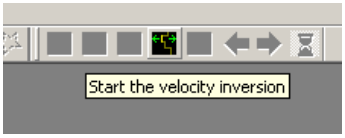
- Use the mouse to reduce the thickness of the third layer to 5 meters (using the procedure described before) by moving the depth of the fourth layer from 10 meters to about 17 meters.



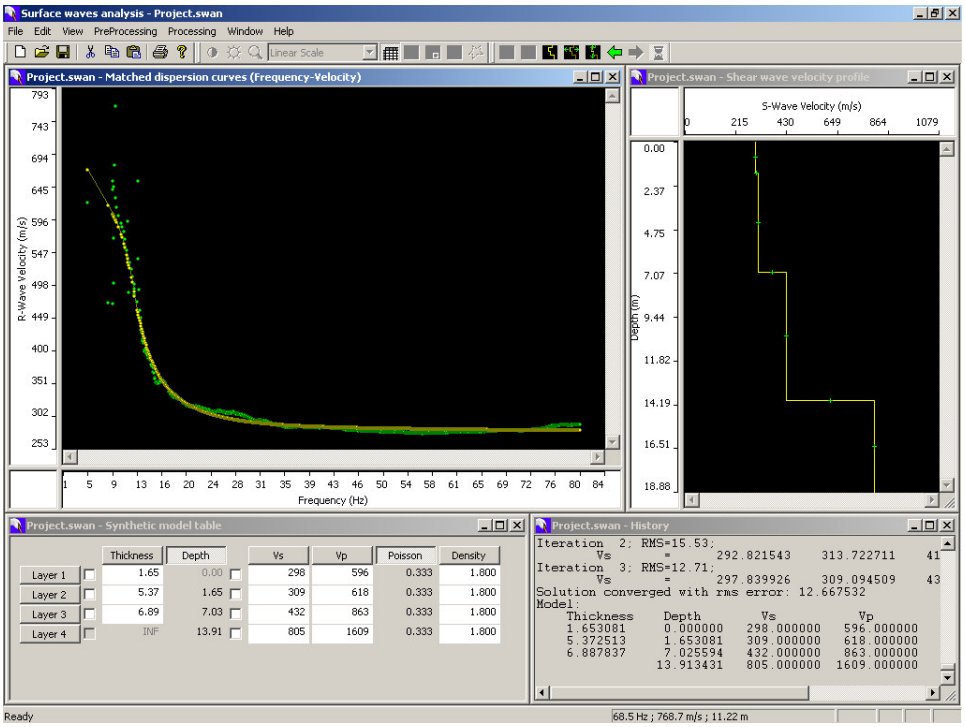
- After that you have created a model similar to the one above you should have a shape on your theoretical dispersion curve that is similar to the experimental dispersion curve. Now try to drag the theoretical curve to get a better fit with the experimental curve.



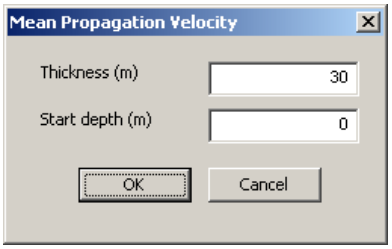
- Finally, increase the fitting between the curves through the execution of an automatic inversion on the velocity of the layers. This is done through the command *Menu>Processing>Velocity Inversion* or by pressing the corresponding button on the toolbar.

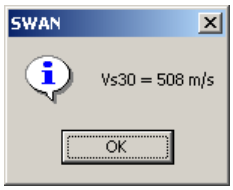






- If after this step the data fit is sufficient (normally it can be considered sufficient when you can't easily improve it further) the inversion step is finished. Through the command *Menu>Processing>Mean Propagation Velocity* (enabled if the window that show the Vs profile is active), you can now compute the value of the parameter *Vs30* (useful index to classify the site according to the design and engineering standards and regulations). Insert the values as shown in the picture: the *Thickness* of the part of the profile to be considered is 30 meters, and the depth of the foundations (*Start depth*) is located at 0 meters (i.e. on the ground surface). Press the OK button to retrieve the value of the parameter *Vs30*.





GeoStudi Astier s.r.l.

eng. Matteo Russo