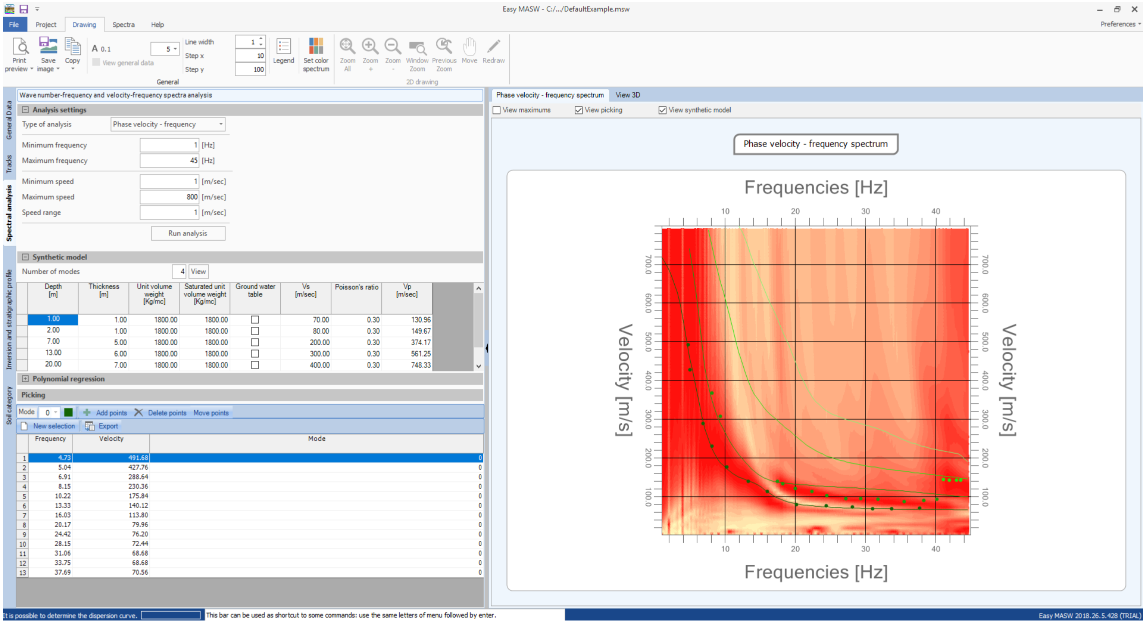
Easy MASW

1 Multi-Channel Analysis of Surface Waves -Easy MASW

Easy **MASW** is a new software for the interpretation and archiving of seismic data using the **MASW** method *(Multi-Channel Analysis of Surface Waves).* It is a very easy-to-use application that, with simple steps, performs the analysis of the shear waves velocities Vs



The software allows the inversion using more modes. During the spectral processing phase the user can view the dispersion of a customizable synthetic model and the results are plotted directly on the velocity-frequency spectrum.
The generation of the velocity-frequency spectrum has been improved to allow a more effective identification of modes. The user can select the points on which the inversion is performed directly on the velocity-frequency spectrum and assign to each point the mode to which it refers.

Importing Input Data

Data can be imported from files in **SEG2, SEGY and SU** standard format as well as from text files. After importing data, the design of the geometrical arrangement of springs and receivers will be processed. The design is a complete report which shows the altitude of the geophones positions and the depth scales. In addition to the geometric position are displayed field seismograms. At this stage the user can make operations on the signals deciding to exclude part of seismograms, move or add virtual arrays.

Signal analysis

The analysis of Rayleigh waves using **MASW** technique is performed with the spectral investigation of the signal, performing a double Fourier transform in the time and space domain. The transformed domain **(f-k)** is represented in both 2D and 3D and allows highlighting the signal produced by Rayleigh waves from other types of signals.
In the transformed domain, in fact, is well detectable the dependence of wave velocity on the frequency and the dispersion curve is easily traceable considering, for each frequency, the maximum amplitude of the spectrum. The experimental dispersion curve is extracted automatically by the program and the user can choose to approximate it to a polynomial function that can be adjusted by excluding the insignificant points.

Theoretical inversion curve

After assigning an initial geotechnical model characterized by some values as the number and thickness of the layers, weight per unit volume, Poisson’s ratio, etc., it is obtained the theoretical inversion curve and is compared with the experimental one. The process of variability of the parameters continues until is obtained the best superposition of the theoretical curve with the experimental inversion curve, in the range established during the picking phase. The process of matching was conducted with advanced statistical numerical methods. A series of additional features allow to have the direct control of the delicate inversion process: it is possible to determine the range of variability of the speed for each layer, impose known speed on the single layer, assign special conditions such as speed increasing with depth, etc.

Displaying Modes

For each processing it is possible to view, in addition to the fundamental mode, which is based on the process of curves matching, even the higher modes.

Geotechnical parameters

Easy Masw allows to determine in addition to the speed profile, the VS_{30}, the soil class and some geotechnical parameters such as : **Young’s Modulus, Shear Modulus, Edometric Modulus, Compressibility Modulus, tip resistance of the static penetrometer, Nspt correlation with dynamic penetrometer.**

Export

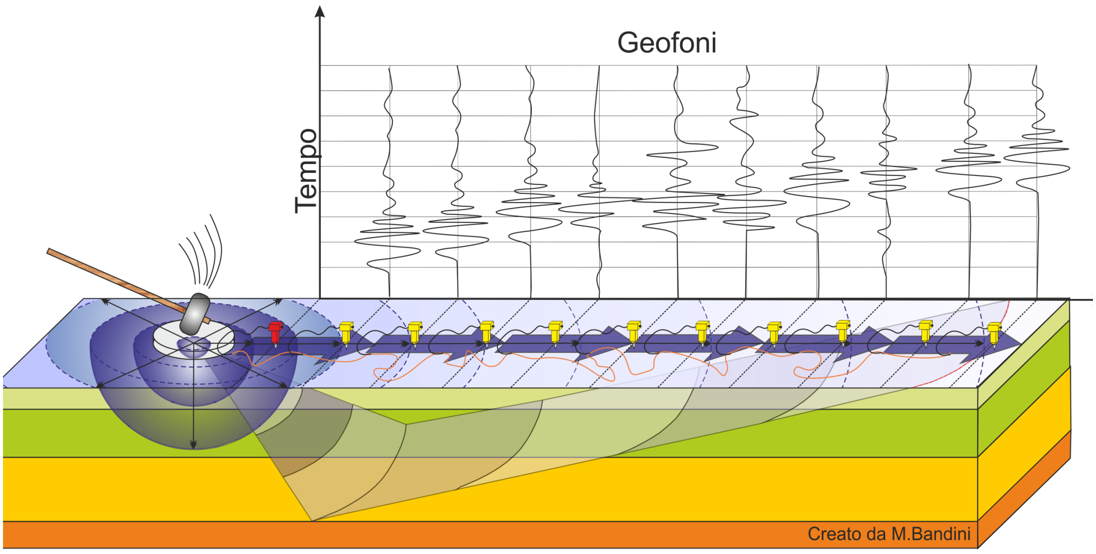
It is offered a detailed output report including numerical computation and graphics. The graphics can be exported in common formats such as **.DXF, .BMP, .JPG.**

Exchanging data between GEOSTRU applications

The seismic test can be exported to other GeoStru software such as Slope, Loadcap, Mp and Stratigrapher for the preparation of the stratigraphy.

1.1 Introduction

Geophysics observes the behavior of waves propagating within a material. A seismic signal, in fact, changes according to the characteristics of the crossed environment. The waves can be generated artificially through the use of hammers, explosions, etc.



Motion of the seismic signal

The seismic signal can be decomposed into several phases, each of which identifies the movement of particles invested by the seismic waves. The phases are:

- *Longitudinal*-**P**: deep wave of compression;
- *Transversal*-**S**: deep wave of shear;

- *Love*-**L**: surface wave, composed of P and S waves;
- *Rayleigh*-**R**: surface wave consists of an elliptical and retrograde movement.

Rayleigh – "R" waves

In the past, studies on the spread of seismic waves have focused on the propagation of deep waves (P, S) considering surface waves as a disturbance of the seismic signal to analyze. Recent studies have allowed creating advanced mathematical models for the analysis of surface waves in environments with different stiffness.

Signal analysis with MASW technique

According to the fundamental hypothesis of the linear physics (Fourier's Theorem) signals can be represented as the sum of independent signals, called harmonics of the signal. These harmonics, for one-dimensional analysis, are trigonometric functions sine and cosine, and act independently, not interacting with each other. Focusing on each harmonic component, the final result in linear analysis will be equivalent to the sum of partial behaviors corresponding to different harmonics. The Fourier analysis (FFT spectral analysis) is the fundamental tool for the spectral characterization of the signal. The analysis of Rayleigh waves, using MASW technique is performed with the spectral treatment of the signal in the transformed domain, where you can, quite easily, identify the signal for the Rayleigh waves from other types of signals, observing in addition, the Rayleigh waves propagate with a velocity that is in function of the frequency. The velocity frequency link is called dispersion spectrum. The dispersion curve identified in the f-k domain is called the experimental dispersion curve, and in that domain represents the maximum amplitudes of the spectrum.

Modelling

From a synthetic geotechnical model characterized by thickness, density, Poisson's ratio, S and P wave velocity it is possible to simulate the theoretical dispersion curve, which links velocity and wavelength according to the correlation:

$$v = \lambda \times v$$

By changing the parameters of the synthetic geotechnical model, it can be obtained an overlay of the theoretical dispersion curve with the experimental one: this is called inversion and is used to determine the profile of velocities in environments with different stiffness.

Vibration modes

Both in the theoretical and experimental inversion curve it is possible to identify the different configurations of vibration of the ground. The modes for the Rayleigh waves can be: deformation in contact with the air, almost no deformation of the half-wavelength and zero deformation at high depths.

Depth of investigation

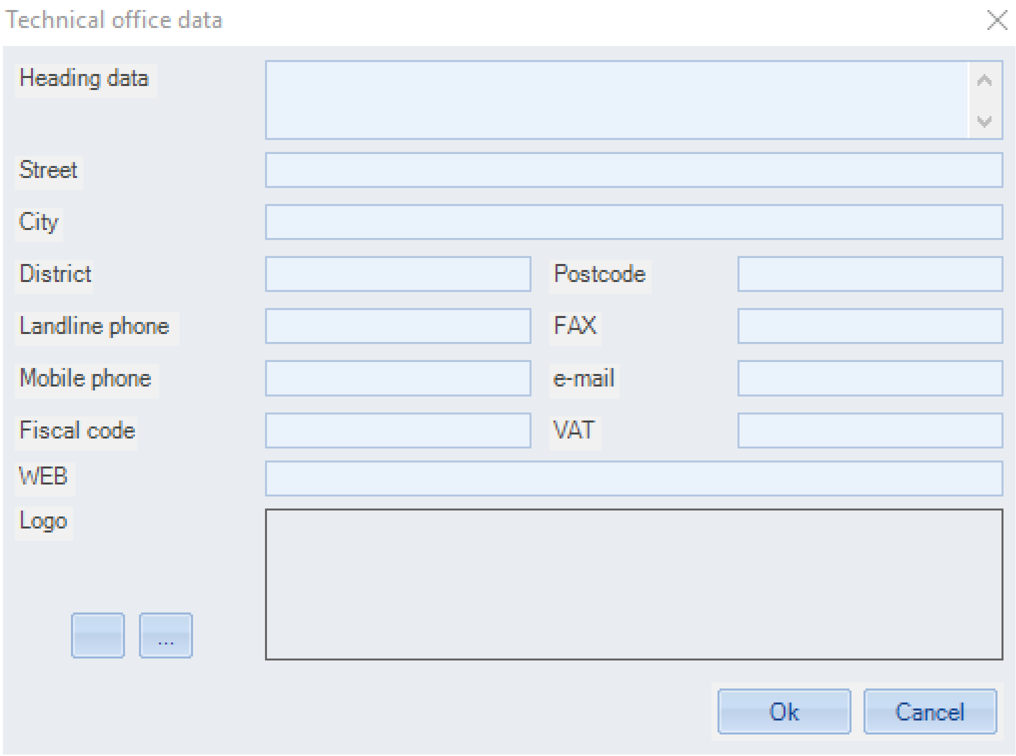
The Rayleigh waves decay at a depth approximately equal to the wavelength. Small wavelengths (high frequencies) are used to investigate superficial areas and large wavelengths (low frequencies) allow investigations to a greater depth.

1.2 Technical office data

Technical office data menu allows the input of information regarding the technical office that will be then included in the final report. The customizable fields are:

- *Address of residence;*
- *City;*
- *District;*
- *Postcode;*
- *Landline phone;*
- *FAX;*
- *Mobile phone;*
- *e-mail;*
- *Fiscal code;*
- *VAT;*
- *website;*

It is also possible to add the logo that will be appear on the cover of the final analysis report. .

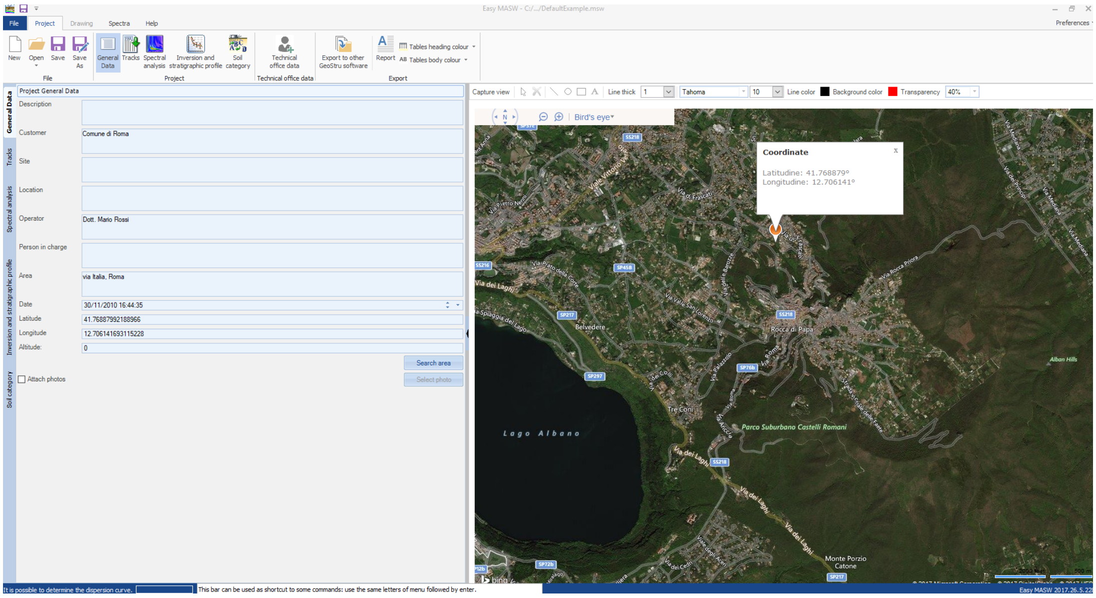


1.3 General data

General data menu allows the input of general information for the test:

- *Description;*
- *Customer;*
- *Site;*
- *Location;*
- *Operator;*
- *Person in charge;*
- *Date.*

By introducing the latitude and longitude or the zone, it will be displayed on the right side of the screen the location of the test on Google Maps. By selecting the image using the "Capture view" button you can customize the graphic representation that will be included in the final report.
In the image it is possible to insert objects: line, rectangle and ellipse customizing the transparency of the shape and the color of lines and background.

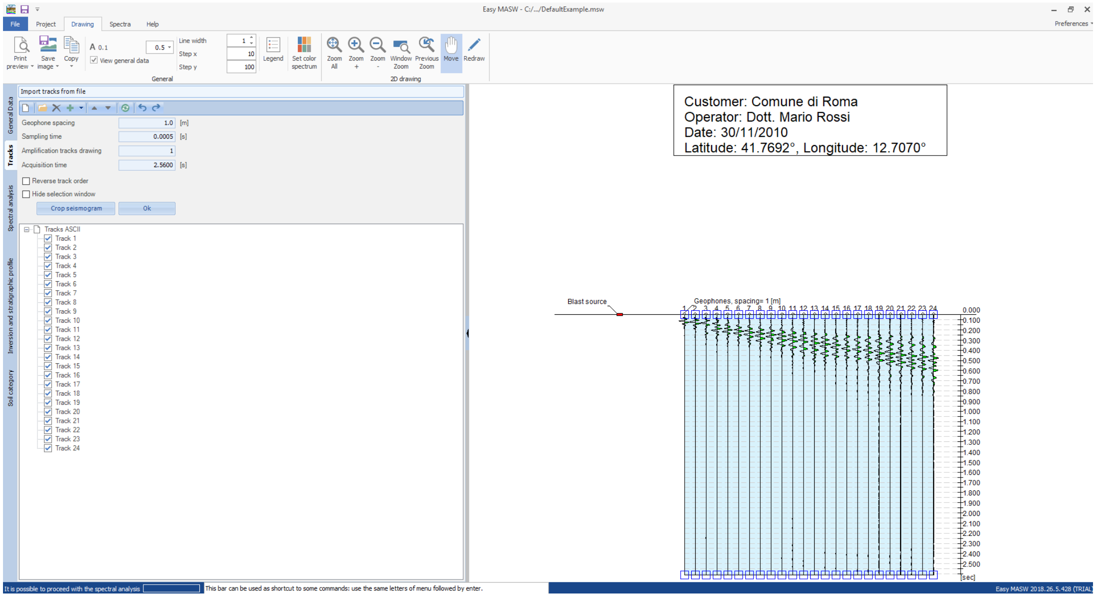


Note
To use this function it is necessary that the computer is connected to the Internet.

It is possible to attach the photo of the geophones positions that will be included in the final report using the "Attach photo" button and selecting the file containing the picture.

1.4 Tracks import

In this section the data to process is imported into the program. It is possible to import tracks from standard files SEG-2 (both with the extension. Sg2 and Dat) or from text files.



It is possible to import multiple tracks in the same project and shift their order depending on the needs. If necessary you can also automatically reverse the order of the tracks using the appropriate option. The import of multiple files can be done by:

- *inserting the new tracks in the queue of existing ones;*
- *inserting the new tracks before the existing ones;*
- *interposing the new tracks among the existing ones.*

If you are importing tracks from a SEG2 file, in the control list on the left side of the window you can find all information recorded by the instrument in acquisition phase including the sampling time.
To import the tracks from one or more text files it is necessary that the data contained to follow a convention. If each file contains a single track, it should consist of lines each of which has the datum associated with the acquired sample. If a file contains more tracks, they must be organized in columns in which the default separator is the character ";". It is possible to set a different character to consider as tracks separator using the appropriate summary window that appears after opening the file.

Once the import of the tracks was concluded and they were represented on the diagram, you can select the tracks to exclude from the computation acting on the control list on the left side of the screen. You can also limit the acquisition time and find the useful part of the acquired signals to cut the tracks to analyze. To perform a cut, just select the useful part of the track directly on the diagram and confirm the selection by pressing the Ok button. The cut is applied to the area selected using a logarithmic law of decay that extends to a maximum of 20 samples.

The buttons **"Cancel"** and **"Restore" in** the toolbar of the selection panel on the left, allow to operate with more flexibility.

To perform the computation you must set the spacing of the geophones and the sampling period of the tracks. If the tracks were imported from a SEG-2 file, the sampling period is automatically determined and set by the program.

Other operations that can be made at this phase are:

- *export the displayed image;*
- *fit the size of texts;*
- *operate on the graph with tools such as zoom, pan etc.*

Offset

By offset we are referring to the distance between the energization point and the first geophone of the same seismic. Even though its position is represented graphically, the offset does not affect the interpretation and for such reason, in Easy Masw, it is not required in the input fields. In other words, varying the offset does not alter the spectrum.
The offset is very important in the signal acquisition phase: acquisitions with different offsets on the same seismic line provide more-or-less different spectrums, depending on the lithological complexity between the beating point and the last geophone inserted on the seismic line.
In principle, it can be said that by increasing the offset we lose information on the first layer for the benefit of the deeper ones. If the offset and the stringing are low (< 40-50m) we risk losing information in depth, during acquisition phase.
Multiple experiments for this case (offset proximity to first geophone) demonstrated the presence of signal disturbances due to overlapping of P, S and R waves.
It is advisable to achieve acquisitions with “minimum offset”. We usually adopt the formula:

offset= (3-4 volte) x interdistanza dei geofoni (non minore di 4 m)

It is also recommended to carry out acquisitions by varying the offset from the minimum to a distance equal to half of the stringing. The processing of the signals acquired by varying the offset provides a better general representation to portray.

The data that the user must provide as input to the program are:

- **intergeophonic distance (m)**: the default being 1m;
- **sampling period (s)**: usually read from the acquisition file (0.001s order of magnitude);
- **acquisition time (s)**: read from the acquisition file (approximately 2.0480s).
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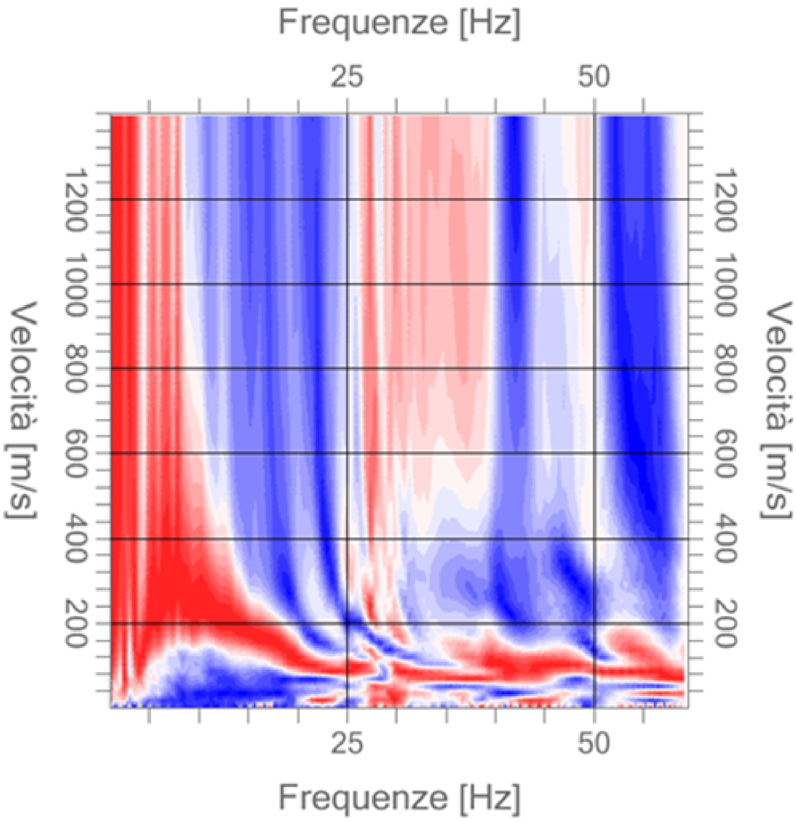
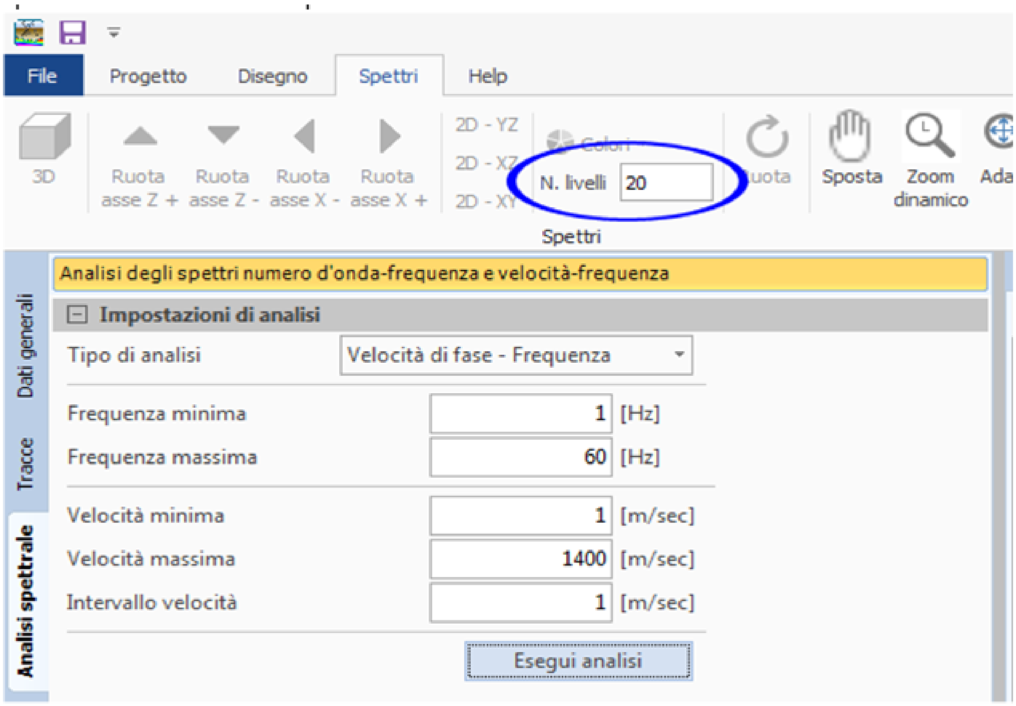
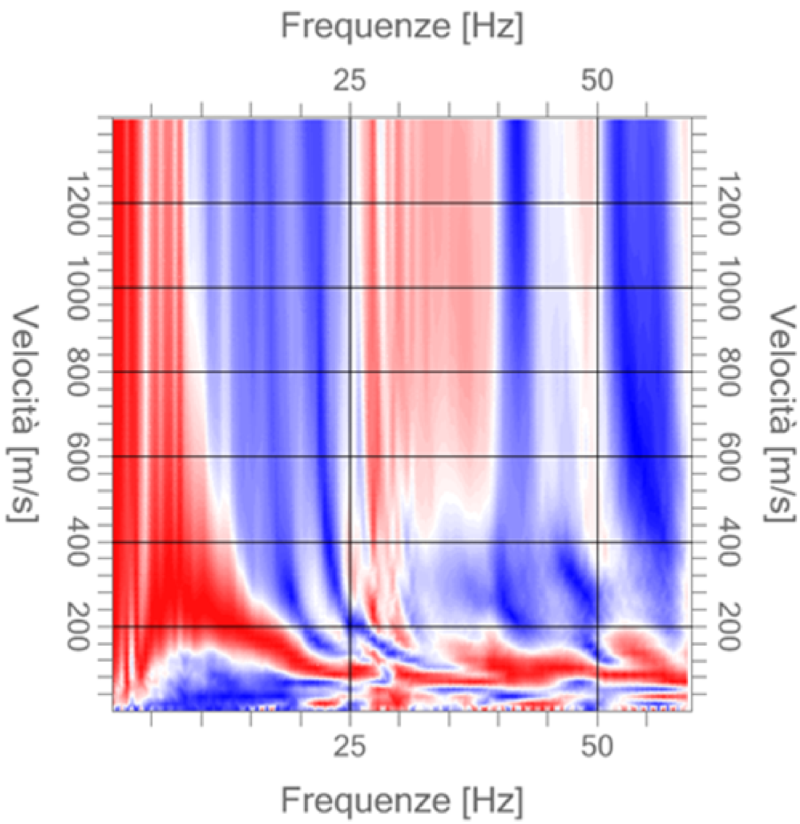
The following image represents the frequency-velocity spectrum of an acquisition:



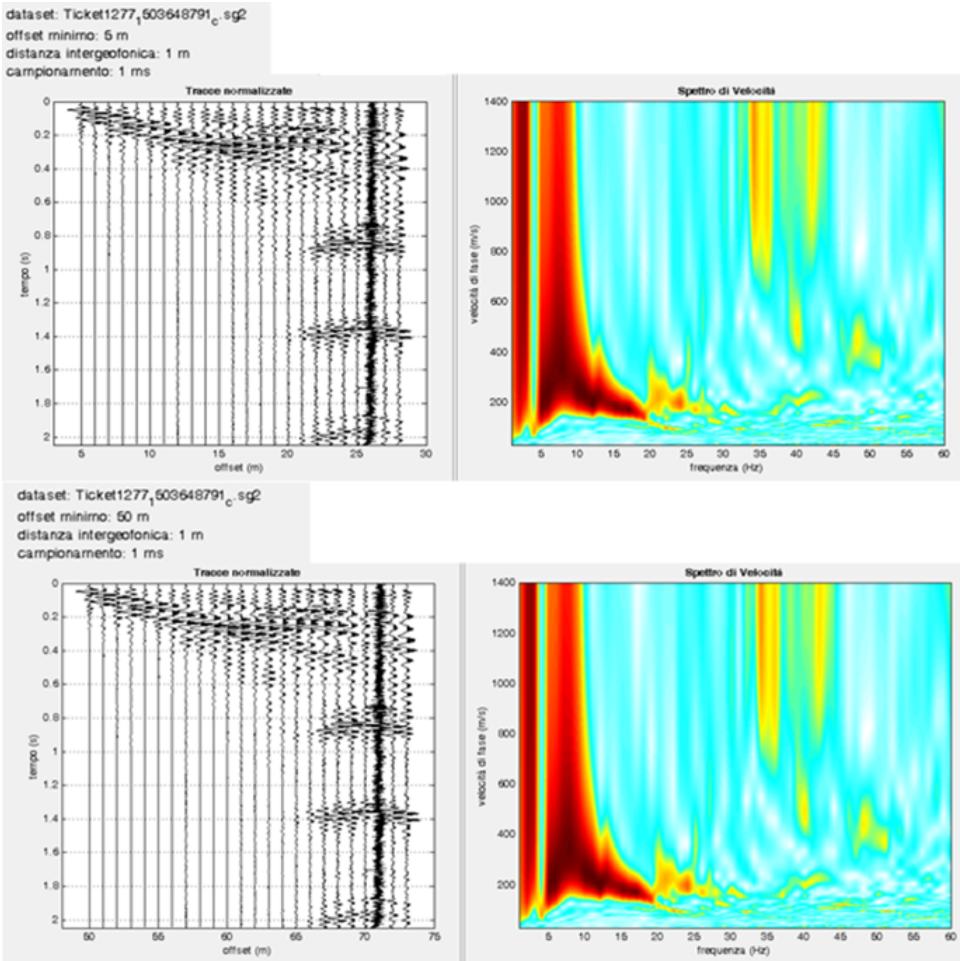
By vividly examining the above image, we can see a variation in passing bands between the maximum area (red) and the minimum area (blue), due to the number of layers the software uses to draw the spectrum, which by default is 20.



If the number of levels is set to 60, we obtain a more shaded spectrum. The layer number variation only produces a graphical effect and does not affect the computation.

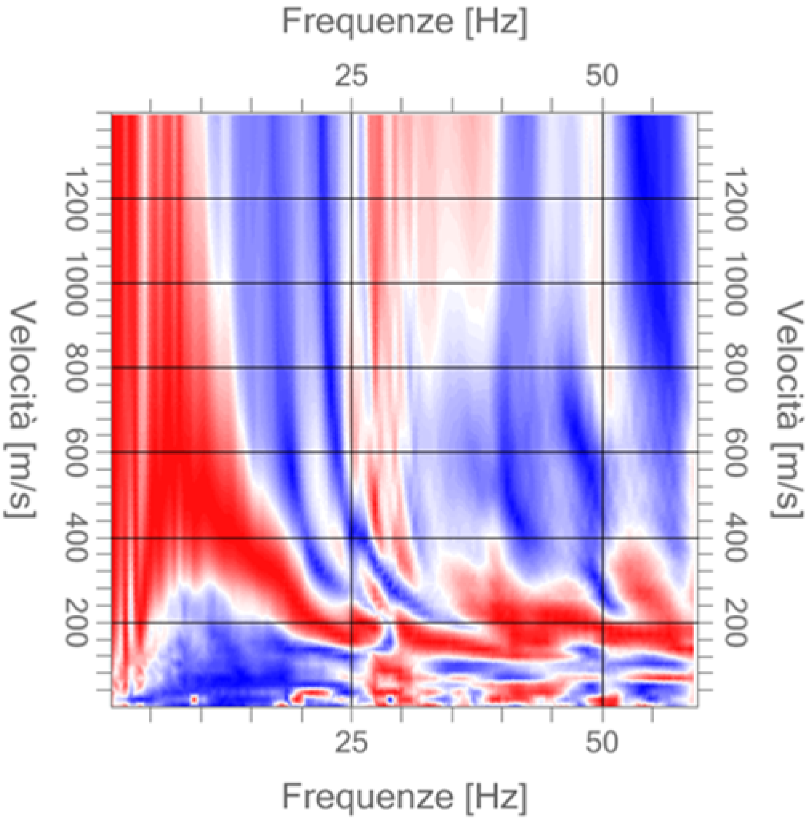


In order to demonstrate the above, we follow with the same process done by a different software that allows to vary the offset position.



By varying the offset from 5 to 50 meters, the spectrum does not change. The only difference between the outputs of the two software is graphical. By comparison, Easy Masw provides a very well-defined spectrum, even in case of high frequencies.
The data that must not be modified is the following: intergeophonic distance, sampling period, acquisition time. Manipulating this data will distort the interpretation.

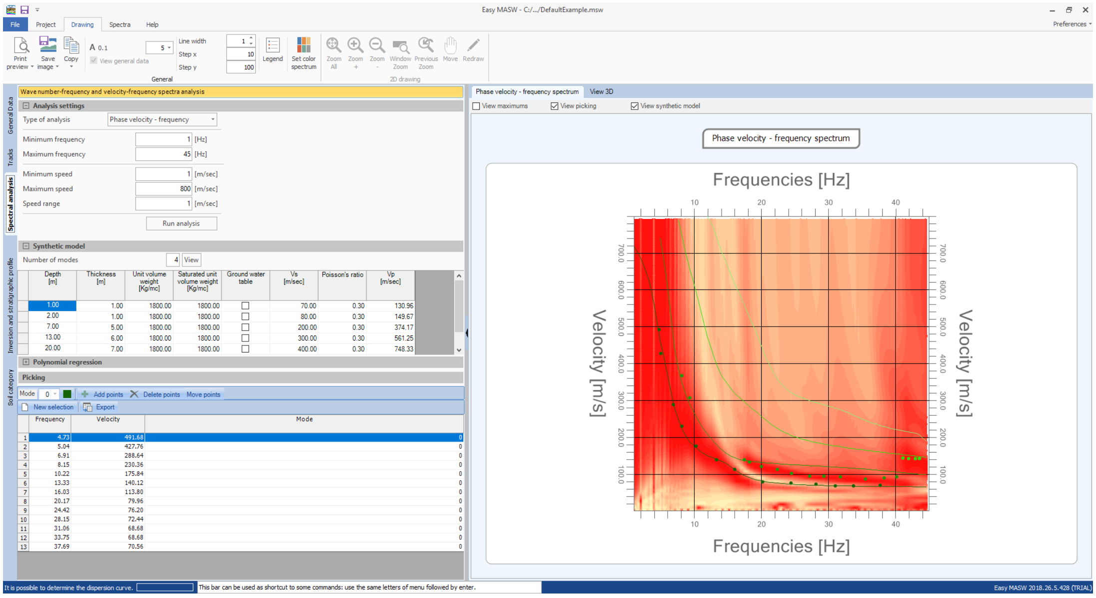
The following image shows how varying the intergeophonic distance from 1 meter (acquisition parameter) to 2 meters (inserted by the user in Easy Masw) affects the spectrum. This parameter affects the computation.



1.5 Spectral analysis

The phase of the spectral analysis is needed to determine the experimental dispersion curve. The software performs this analysis using the double discrete Fourier transform, applied to the variables of time and space.
It allows two types of analysis:

- *generation of the phase velocity-frequency spectrum;*
- *generation of the wave number-frequency spectrum.*



To perform the analysis with the phase velocity - frequency spectrum the following parameters can be set:

- *minimum frequency of research;*
- *maximum frequency of research;*
- *minimum speed of research;*
- *maximum speed of research;*
- *speed range to consider in the analysis.*

A note about the maximum frequency of research

The maximum frequency of the research is fixed according to Nyquist's theory on the discrete Fourier transform by the relation

$$f_{\max} = \frac{f_c}{2} = \frac{1}{2T_c}$$

where fc is the sampling frequency of the instrument that corresponds to the inverse of the sampling period Tc

To conduct a thorough analysis, the program allows the user to define a preliminary model of the terrain through which it is possible to visualize the dispersion curve directly on the processed spectrum of velocity-frequency. In the preliminary model, the last layer is always considered as infinite half-space, therefore the thickness can also be set to zero.

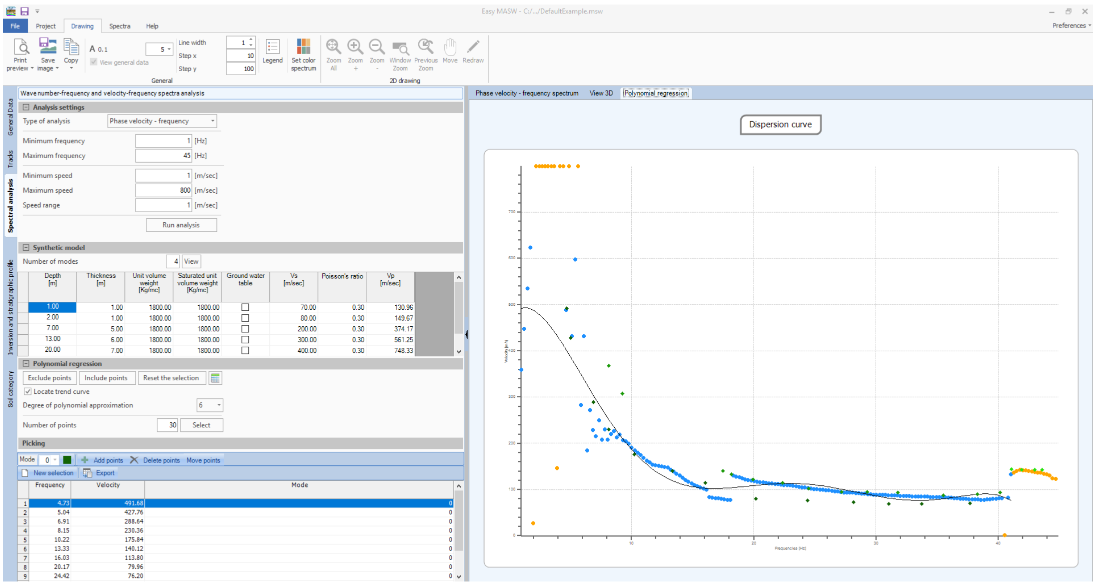
On this spectrum are identified also a set of points for the fundamental mode (mode 0) and for the higher modes (up to mode 4). The selection can be made only for the modes clearly ascertainable from spectral analysis.

The result of the selection is always summed up in the grid where all the results of identified modes are gathered.

The selection phase is being started by pressing the **"Add points"** button and ends by deselecting it. The points then can be moved and deleted by acting on the diagram or data grid. On the chart you can plot the maximums determined for each frequency of the processed spectrum.

When you move the mouse on the diagram the information related to the corresponded point is shown.

The "Polynomial regression" section can be a convenient tool in the phase of discovering points to use for the inversion. Enabling this menu, the maximums processed in spectral curve are plotted on the diagram with the trend curve that they identify. The user can choose the degree of the polynomial regression and the points to include in the computation. To exclude some points from the computation is enough to select the "Exclude points" button and draw on the diagram a window to confine the points to discard. Similarly, using the "Add points" button you can insert some excluded points in the regression computation.



Using the regression curve, the software can choose a set of values to use during the inversion. It is good to note that the selected points are considered as points of the fundamental mode.
The values automatically identified are plotted on the spectrum so that the user can refine the selection both by inserting points related to higher modes as well as changing or deleting the ones already identified.

Other operations that can be made at this phase are:

- *export the displayed images;*
- *fit the size of texts;*
- *operate on the charts with tools such as zoom, pan etc..;*
- *adapt graphics in full screen;*
- *display the three-dimensional graph of the spectra and apply the desired rotations;*
- *set the chart grid of spectra with a customized step.*

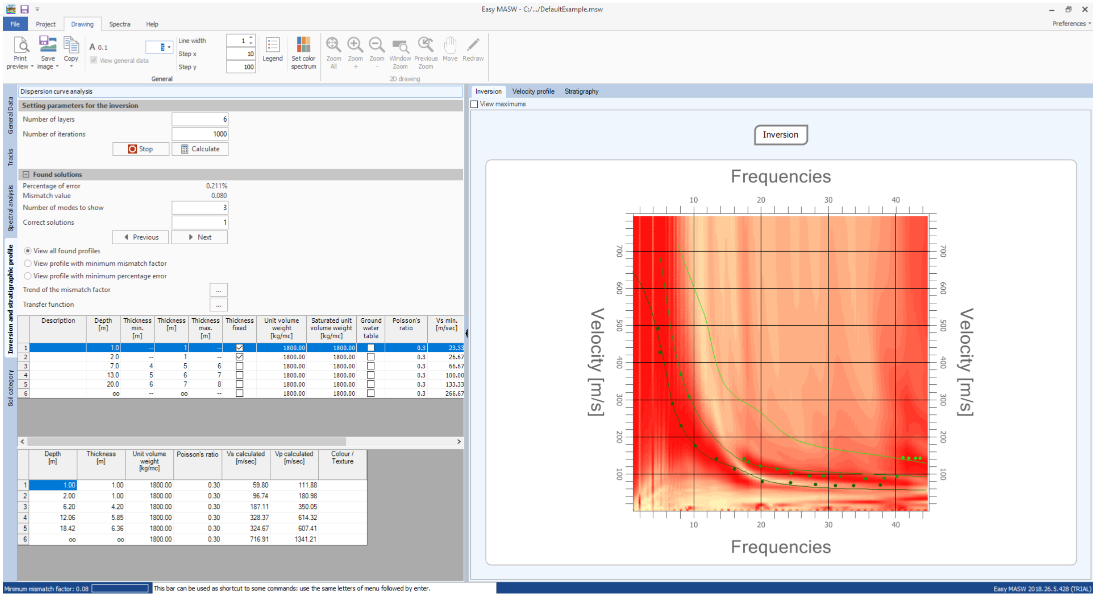
1.6 Inversion and determination of the velocity profile of the waves

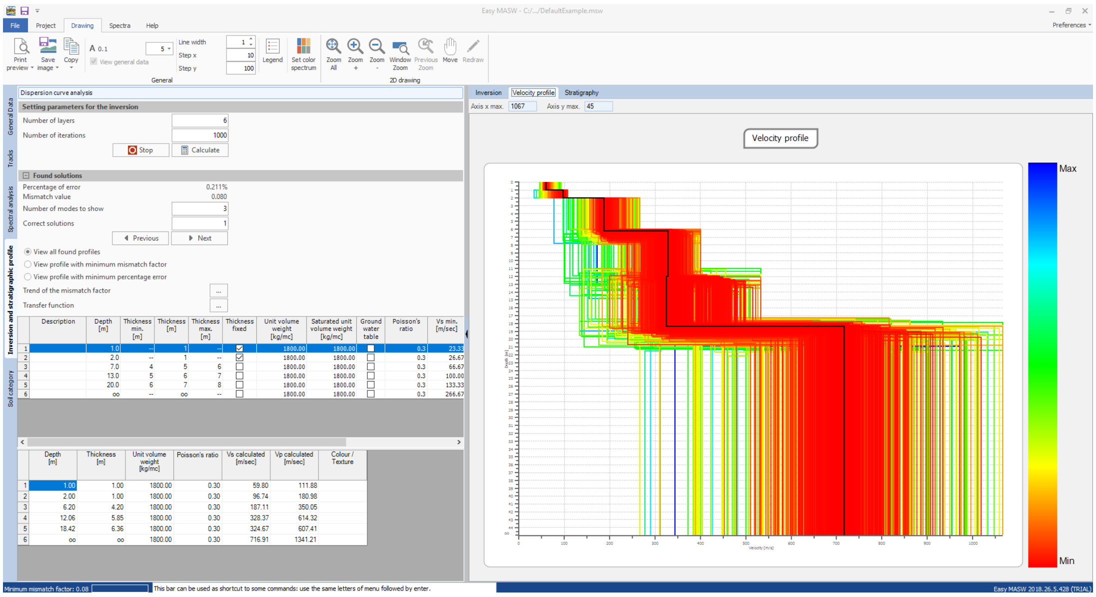
The phase of inversion can only be executed after completing the spectral analysis. The window shows the points on which the inversion will be carried out and the velocity-frequency spectrum graph. As a first step is necessary to set the ground model on which the processing will be based. If you have defined a preliminary model in the process of spectral analysis, it is automatically copied.

The parameters to define are:

- *number of layers;*
- *minimum thickness of research;*
- *initial thickness of research;*
- *maximum thickness of research;*
- *weight per unit of volume;*
- *saturated weight per unit of volume;*
- *presence of water;*
- *Poisson's ratio;*
- *minimum speed of the wave permissible for layer;*
- *wave velocity for the first attempt;*
- *maximum speed of the wave permissible for layer;*

The result of inversion is strongly dependent on the settings chosen for the model so that the user should modify as needed the setup parameters.





To determine the soil stratigraphy model that generates a dispersion curve similar to that obtained from the survey experiment, the software applies a heuristic algorithm. From the model set by the user, the solver builds a set of compatible models and for each of them compares the dispersion curve generated with that of the experimental test. The generation of models is formulated to minimize the value of an objective function that evaluates the efficiency of the solution given by the model. The maximum number of patterns to generate is selectable by the user and should be chosen so that they are processed a sufficient number of attempts. It is possible to directly assess the performance of the value of the objective function; this parameter may prove to be a good indicator for choosing the number of models to generate.

The software displays the model that has the lowest mismatch factor, the model with the minimum value of percentage error and provides the parallel evaluation of all the models examined by allowing the user to choose which to use among those surveyed.

It is possible, finally, to impose calculation constraints to the solver. It is possible, finally, to impose constraints to the solver calculation. In fact, you can choose, for each layer, a fixed rate or a thickness that will not be optimized in the calculation and use models of the stratigraphy which does not allow the velocity inversion between the layers.

The graphic output can also highlight the higher modes, identified as a solution for the model chosen, while the calculation results are summarized in the lower grid.

Other operations that can be made at this stage are:

- *export the displayed images;*
- *fit the size of texts;*
- *operate on the charts with the tools to zoom, pan etc.*.

Theoretical notes

F-k spectrum

The data elaboration method is based on Fourier's transform formula and consists of transforming sample data of the space-time domain to different domains, in which the dispersion curve is obtained from the spectral maximums.
By applying Fourier's transform formula twice on field data, the dispersion curve can be identified as the highs in the frequency-velocity chart (f-c) or in the frequency-wave number one (f-k) in which the wave number (k) corresponds to the reciprocal of the wave length.
In theory, Fourier's transform formula allows us to identify the different propagation methods of the Rayleigh waves, or rather the ways in which an energized terrain can oscillate.
By extrapolating from the f-k spectrum through an interpolation algorithm, we can obtain the dispersion curves of campaign for every method.

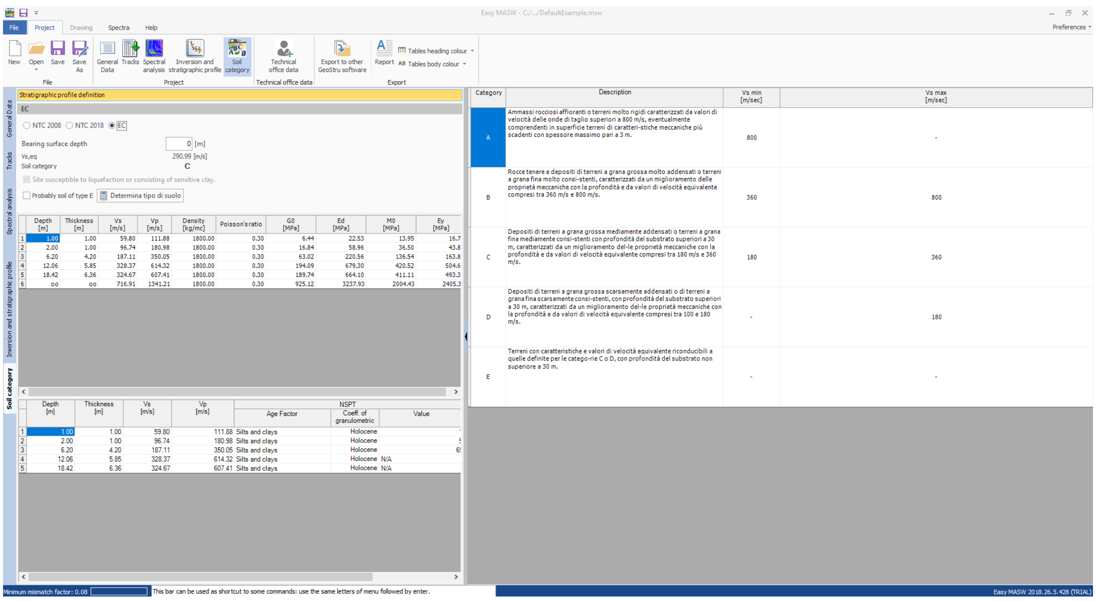
Inversion

The process of sample data inversion is the last step to follow and it provides the velocity profiles of the cutting waves derived from the dispersion characteristics observed in the sample data.

The inversion, in fact, consists in a process meant to determine the subsoil model that seems to have a dispersion curve nearest to the one obtained from the campaign data.
To do so it is necessary to solve a direct problem: we simulate the response of a hypothetical terrain of which we know beforehand some parameters in order to reconstruct the so-called theorical dispersion curve.
Subsequently, we perform a calibration operation, also called optimization, in which we minimize in an iterative manner a misfit function between the experimental dispersion curve and the theorical one to identify the model parameters.

1.7 Soil category and determination of other geotechnical parameters

The last component of the processing phase is the one that allows the determination of the soil category and geotechnical parameters using the results obtained during the computation.
Here is shown the average of the velocity Vs in the first thirty meters, weighed on the thickness of the layers defined in the model. From this data and using some additional definitions, is determined the category to which the examined soil belongs.



Finally, are also calculated:

- ***Shear deformation modulus;***

$$G = \rho \cdot V_S^2$$

- ***Edometric modulus;***

$$E_d = \rho \cdot V_P^2$$

- ***Volumetric compressibility modulus;***

$$M_0 = \rho \cdot (V_P^2 - \frac{4}{3} V_S^2)$$

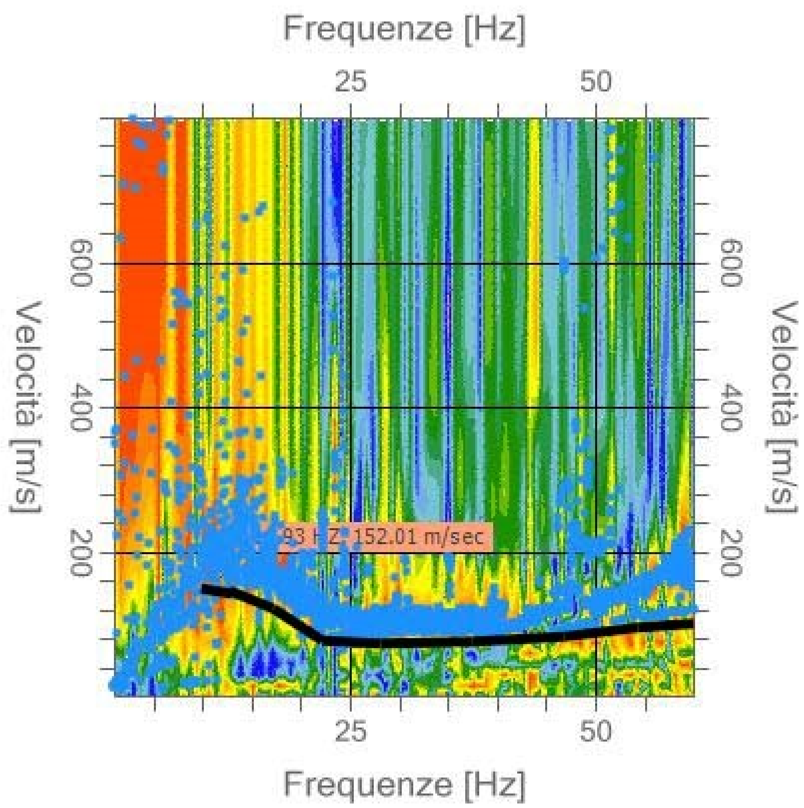
- ***Young's modulus;***

$$E = 2 \cdot \rho \cdot V_S^2 (1 + \nu)$$

- ***NSPT ,Qc.***

1.8 REMI

It is possible to interpret a **REMI** test with Easy Masw by using a picking maneuver: instead of doing it on the maximums (dark-colored areas), we do it on the minimums, or the part where the light-colored shade starts.



As shown in the picture, it would be required to perform the picking immediately below the point cloud which determines the maximums'

section. The stringing used to derive the spectrum in the above picture is probably short, so the same figures of a masw are valued.
In the REMI test the stringing length is important – good results are obtained with lengths higher than 80m.
To understand the behavior of the two techniques, it is enough to string out 24 geophones spaced by at least 2 or 2.5 meters in an area of sharp signal, such as a clay formation thicker than 50 or 60 meters.
The steps are the following:

- we perform the MASW and **REMI** registration on the same stringing;
- we do the MASW picking;
- we overlap the REMI picking.

We can see in the picture how the picking on **REMI** up to frequencies higher than 10Hz is positioned lower than the maximums.

The **MASW** provides a better resolution than the **REMI** up to approximately 15-20Hz, but the **REMI** should be more accurate up to approximately 5Hz.

A good precaution in a **REMI** test is to extend the signal to at least 2 seconds. The downside is that of not reaching high depths on particularly soft terrains.

However, the technical practice highlighted that a one-second-long signal is enough to investigate 90% of the cases. To stabilize the signal it would be opportune to have tracks longer than a minute, add up multiple files and perform the analysis.

1.9 Geoapp

Geoapp: the largest web suite for online calculations

The applications present in Geostru Geoapp were created to support the worker for the solution of multiple professional cases.
Geoapp includes over 40 applications for: Engineering, Geology, Geophysics, Hydrology and Hydraulics.

Most of the applications are **free**, others require a monthly or annual **subscription**.

Having a subscription means:

- access to the apps from everywhere and every device;
- saving files in cloud and locally;
- reopening files for further elaborations;
- generating prints and graphics;
- notifications about new apps and their inclusion in your subscription;
- access to the newest versions and features;
- support service throught Tickets. Enter topic text here.

1.9.1 Geoapp Section

General and Engineering, Geotechnics and Geology

Among the applications present, a wide range can be used for Easy MASW. For this purpose, the following applications are recommended:

➢ Sismogenetic zone
➢ Soil classification SMC
➢ Seismic parameters

2 Contact

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