ELIOVSP®

PROCESSING AND ANALYSIS OF DOWNHOLE SEISMIC DATA
ALSO JOINTLY WITH THE HORIZONTAL-TO-VERTICAL SPECTRAL RATIO (HVSR)

RELEASE 2023

10 March 2023

Keywords: DownHole seismics; Vertical Seismic Profiling; HVSR; Vs30; body waves; surface waves; joint analysis; forward modelling

Remember that your goal ***is not*** to perform a DH (DownHole) survey **but to obtain a reliable and robust V_S profile**.

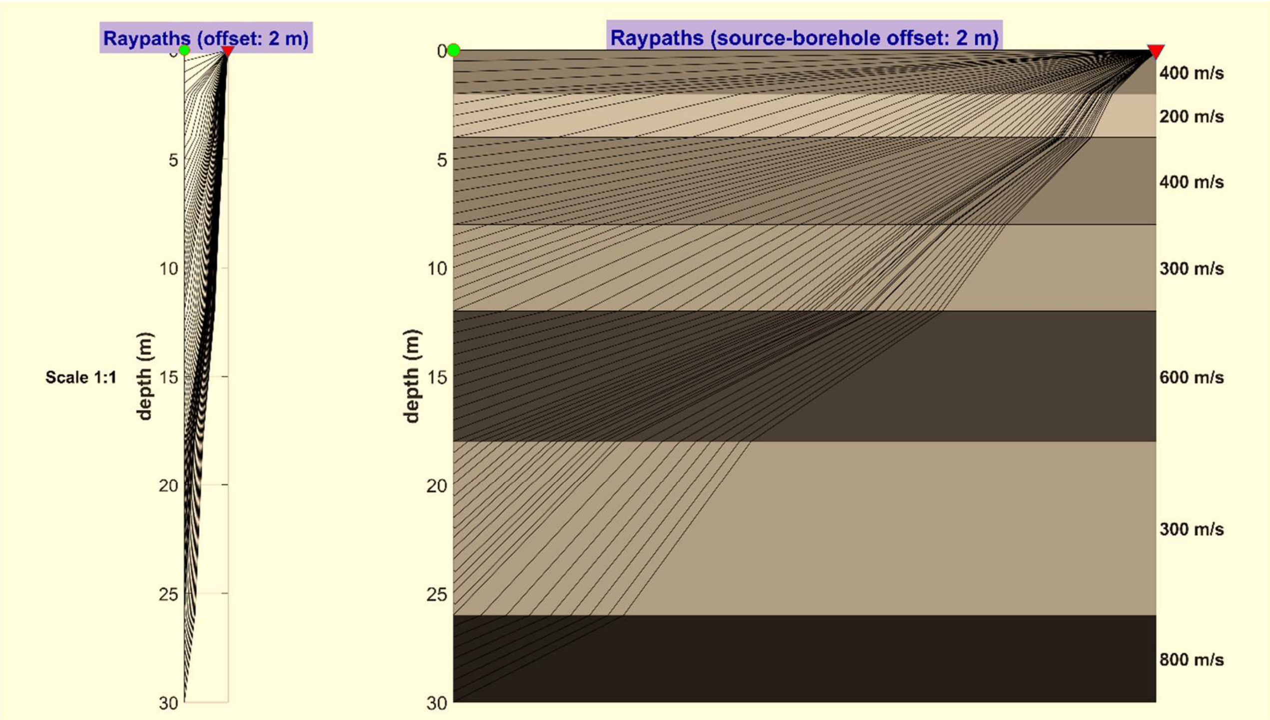
In order to do that, please, **strictly follow the recommendations provided in the following pages** and aimed at performing the **joint *modelling* of the DH data together with the HVSR curve**.

SOLVITUR AMBULANDO

SOFTWARE FOR THE ANALYSIS OF DOWNHOLE SEISMIC DATA

Joint modeling of P and SH-wave travel times [considering the *actual* ray paths – no simplification to linear ray paths!] also jointly with the HVSR curve (Horizontal-to-Vertical Spectral Ratio)

ELIOVSP also processes the data recorded by a twin borehole geophone (i.e. a borehole geophone with *two sensors* placed at two different positions within the case - in this way the field work is significantly reduced).



OUR SOCIAL MEDIA

https://www.facebook.com/HoliSurface/

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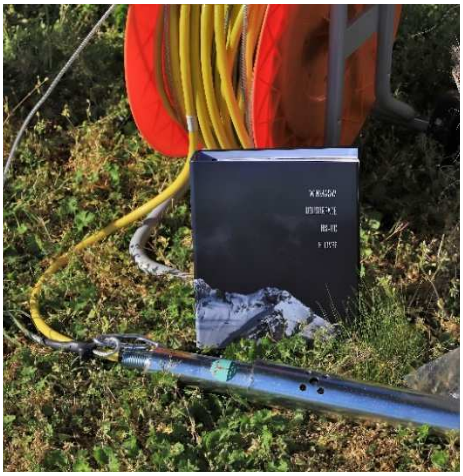
https://www.youtube.com/user/winMASW/videos

https://www.researchgate.net/profile/Giancarlo_Dal_Moro

Our *Facebook profile* is frequently updated with small case studies, news & tips

ELIOSOFT ALSO PROVIDES

ACQUISITION SYSTEMS OPTIMIZED FOR THE HOLISTIC ACQUISITION OF ACTIVE AND PASSIVE MULTI-COMPONENT SEISMIC AND VIBRATION DATA (SEISMOGRAPHS, SEISMIC CABLES, BOREHOLE GEOPHONES, SINGLE AND 3C GEOPHONES ETC.)



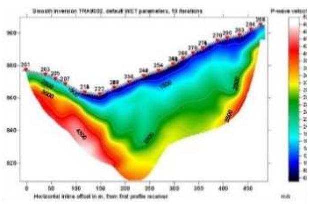
SOFTWARE

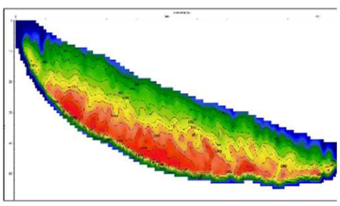
HoliSurface®
Holistic analysis of Surface waves and vibration data

winMASW®
Surface Waves and Beyond

VSP
ELIOSOFT
DownHole seismics

RayFract





ReflexW

DATA PROCESSING (see for example our ADAM2D service)


ELIOSOFT
geophysical software and services
www.winmasw.com
everything for your seismic surveys
VSP
ELIOSOFT
8 and 10-kg sledgehammer and polyethylene plate
In the beginning...
using the plate to generate Love waves
... after some months of hammering
HS

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MAIN NEWS IN ELIOVSP 2023

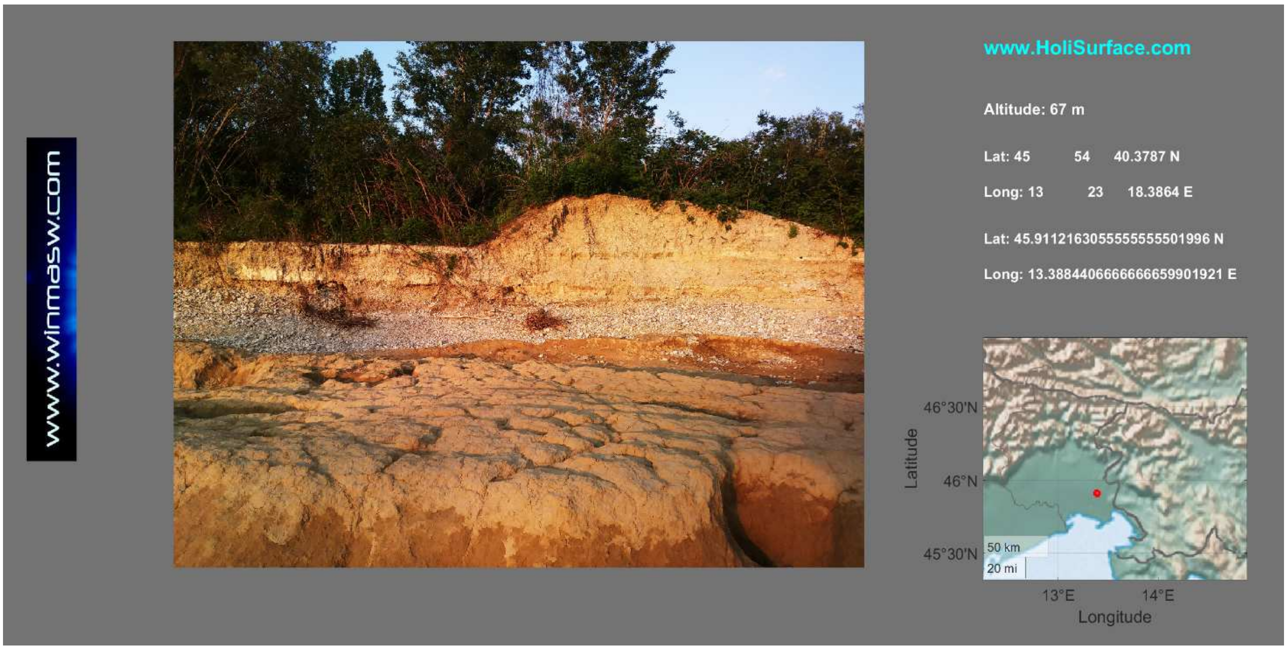
1) audio *warnings* during some crucial steps of the data *processing*

2) compatible with *Windows 11* [ELIOVSP does not require particularly powerful computers]

3) in order to avoid to process/upload oversampled data (i.e. data recorded with an unnecessarily-high sampling rate), an *automatic resamplig* option is now available: if activated, data are automatically resampled to 1000 Hz (1 ms) which, considering the actual frequency content (for ordinary geological projects/conditions), is more than sufficient

4) computation of the **seismic attributes** (**instantaneous frequency, phase and amplitude**) in order to better follow first arrivals in case of complex and noisy data

5) ***video tutorial*** available on *youtube*



1. ELIOVSP: a general overview

ELIOVSP is a software designed for the effective and advanced processing of downhole seismic data also jointly with the HVSR curve (*Horizontal-to-Vertical Spectral Ratio*).

MAIN FEATURES:

1. compatible with *Windows 11*

2. data processing (several tools) aimed at highlighting the first arrivals of body waves (P and SH) also in case of complex and noisy data (computation of the seismic attributes);

3. travel-time computation accomplished considering the detailed wave refraction (ray path is not approximated to a linear trajectory as most of other software applications do);

4. *audio warnings* during the data processing

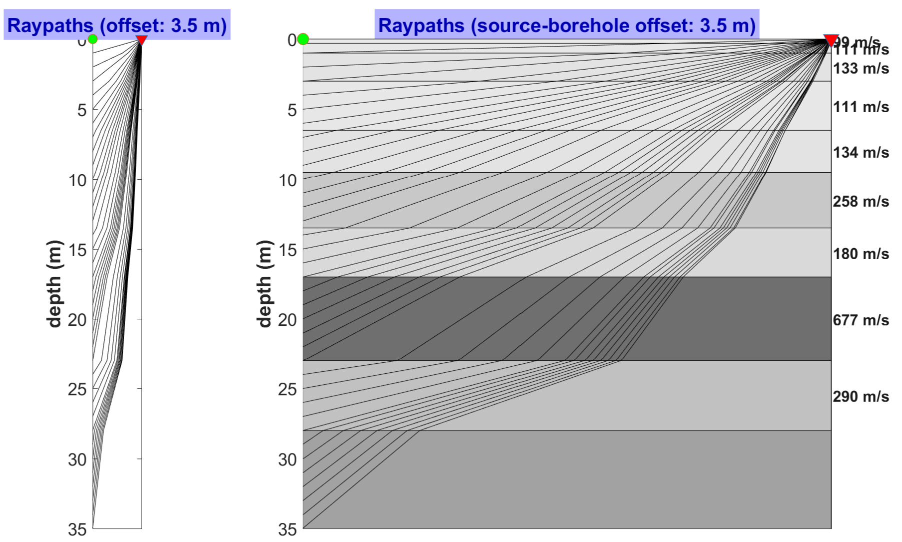
5. *forward modeling* (the user modifies the model and verify the agreement with the data – this is the recommended approach) and/or automatic inversion (picking and automatic inversion);

6. *forward modeling* (for P and SH waves) can also be performed together with the HVSR curve thus being able to achieve two results: on the one hand we obtain a more robust subsurface model (more *observables* allow you to better constrain the model - in practice this is the *holistic* approach widely used also in *winMASW*® and *HoliSurface*®), on the other hand we extend the investigated depth (i.e. the V_S profile) far deeper than the depth of the borehole.

Furthermore, thanks to the available processing tools, if you carefully follow our recommendations for the data acquisition, it is also possible to analyze the P-wave arrivals from the horizontal shots [HF]. **This will strongly reduce your fieldwork (no need to vertical-force [vertical sledgehammer] acquisitions).**

DATA UPLOADING is accomplished by means of a ***project file*** (a simple ASCII file which can be opened and modified with the simple *Notepad* software of your *Windows* operating system). You can then choose the components that best highlight the P and SH-wave arrivals and take advantage of the several data processing tools.

scale 1:1



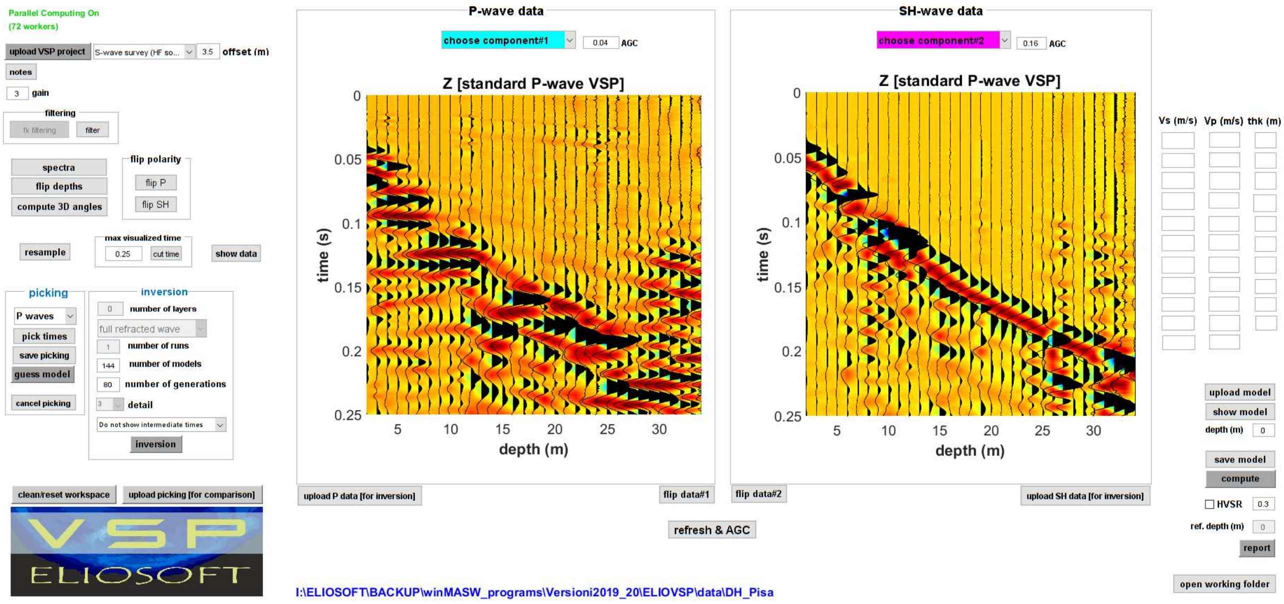
JOINT MODELING of P- and SH-wave travel times + HVSR

If you have previously computed the HVSR curve (.hv file) [see for instance our *HoliSurface®* and *winMASW®* software applications], you can upload it and model it together with the P- and SH-wave arrival times.
The HVSR curve (to upload in ELIOVSP) can be computed also with other/different software applications. The format is the standard one (.hv files - a simple ASCII file with a series of header lines and four columns with the frequencies, the average HVSR and the minimum and maximum standard deviations; see box below).

```
# version 1.1
# Number of windows = 139
f0 from average = 3.2219
Peak amplitude = 3.4084
# Number of windows for f0 = 139
# f0 from windows: -
# Frequency Average     Min    Max
0.688172 1.84976 1.31883 2.38069
0.719453 1.89829 1.36481 2.43177
0.750733 1.94364 1.42425 2.46303
0.782014 1.92659 1.4377 2.41548
0.813294 1.89056 1.37193 2.40918
0.844575 1.79461 1.34583 2.2434
0.875855 1.76489 1.3075 2.22229
0.907136 1.74703 1.28135 2.21271…
```

DEMO VERSION: Like many other geophysical investigations (please, see the introductory section in the *HoliSurface®* and *winMASW®* manuals from our web site), DownHole [DH] seismics often suffers from several misunderstandings and oversimplifications.
This is the reason why no *demo* is provided: we prefer to illustrate the use of our software applications while also providing the theoretical background necessary to understand *what* and *why*.
This is done during our webinar/workshops but can be also obtained through a careful reading of this manual.
Please, also consider that the software is provided together with a series of datasets useful for your own self-training (see final pages of this manual). So, fill your mug with your favorite tea or coffee and take some time to have a look at it!

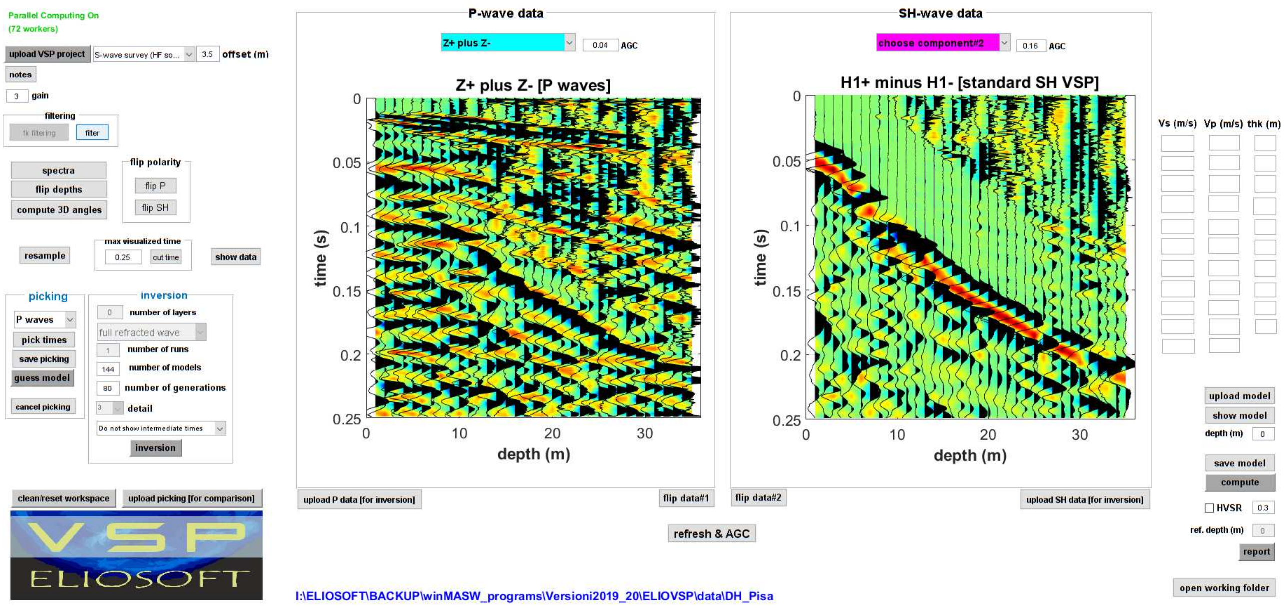
ELIOVSP® can be used in a simple and intuitive way. Once the data have been uploaded through the ***project file***, they are shown in two separate panels. The left one refers to P waves while the right one to SH waves.

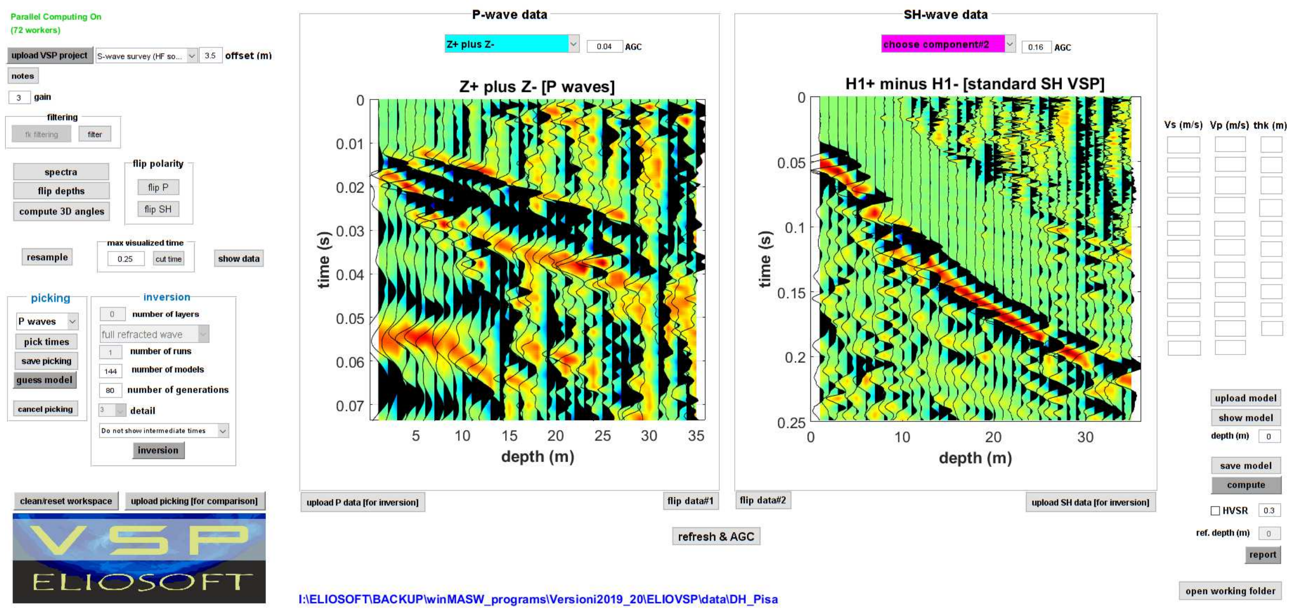


In the snapshot shown above, you can see the ELIOVSP® panel immediately after the data upload (before any processing). In fact, both the arrivals of SH (on the right) and P waves (left panel - first weak arrivals between about 0.01 and 0.03 seconds) are already apparent even without any processing.

Few simple processing operations (first of all the application of gain and AGC [*Automatic Gain Control*] by clicking the "**refresh & AGC**" button) will be enough to obtain what you can see in the next two snapshots, where P waves are emphasized and very clear.

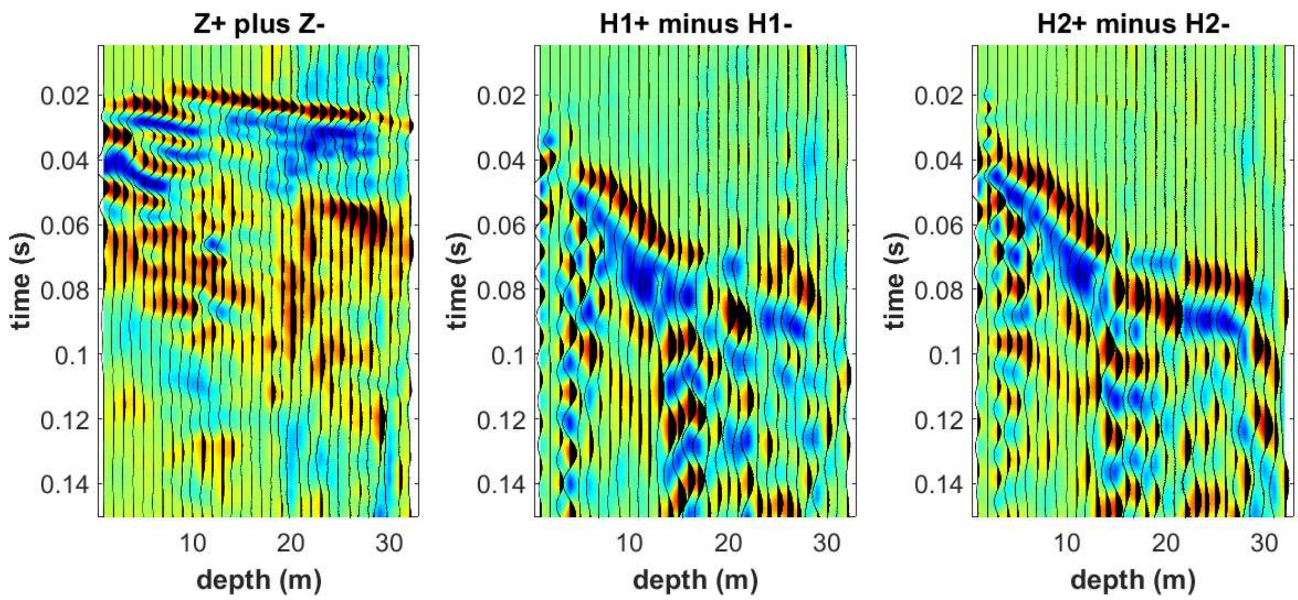
Please, consider that we are here considering the data collected from a standard HF+ and HF- 90° source. A shear source at about 70° would make the P waves further clear [see next section of the manual].





First arrivals of P (left) and SH waves (right) from a very simple processing of data collected by a standard (90°) shear source.

The figure below (from another survey) shows an HF+ / HF- dataset (again with a standard 90° source): P waves are perfectly identifiable (even more than in the previous example). ***So what is the point of performing also a VF (Vertical Force) acquisition (for P waves)?*** It is simply useless: we just need HF data, possibly considering a 60°-70° source (see following sections of this manual).

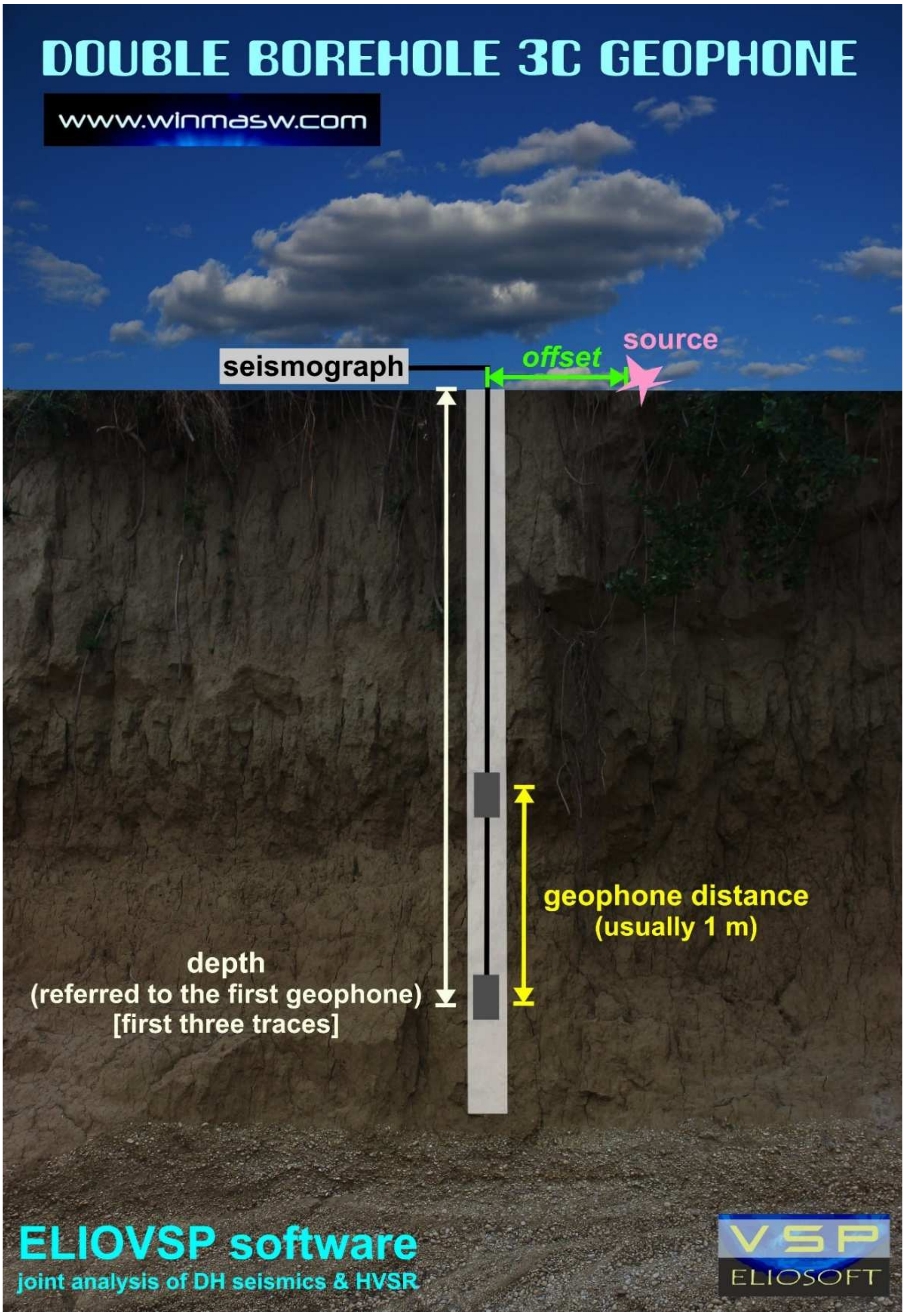


2. Data acquisition

Geometry

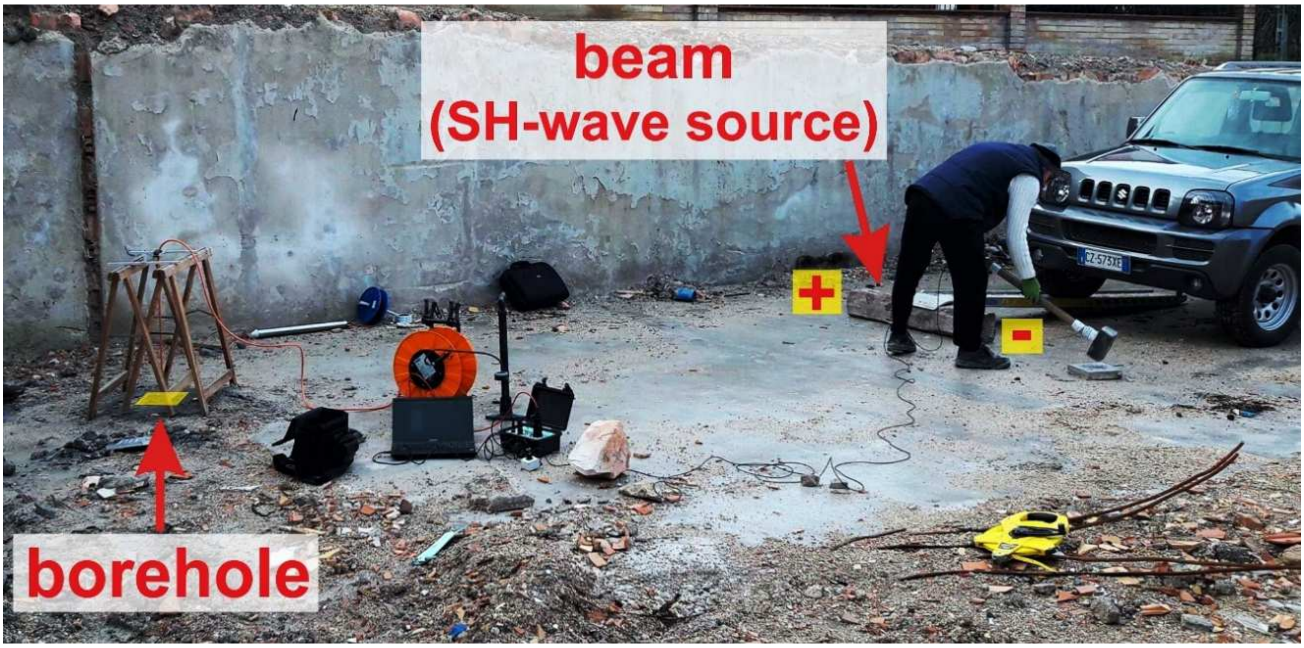
Start with the geophone at the maximum depth of your borehole and then pull it up. Usually the goal is to obtain a measurement each meter (e.g. 30, 29, 28 m and so on).

In case you are using our *twin borehole geophone* (see picture below), the field effort is halved since you will need to shoot your source just half the time (see the ***Data acquisition with our twin borehole geophone*** section of this manual).



Offset (distance between source and borehole)

Since our software rigorously models the wave propagation according to trajectories that consider the real path driven by the full wave refraction (other software applications approximate the path to a linear trajectory), it is theoretically possible to use large offsets that would not be manageable if your analyses (i.e. your software) does not consider the actual ray path. However, it must also considered that the seismic traces between the surface and a depth approximately equal to the offset are extremely complex (direct, reflected, scattered and refracted waves merge in a very complex fashion) and, for this reason, for ordinary surveys an **<u>offset value between 2 and 4 m</u> is suggested.**



Acquisition of the *left* and *right* (or *positive* and *negative*) HF (Horizontal Force) shots for the generation of the shear waves (as well as, to some extent, P waves – see next pages)

Recording length

It depends on the depth of the borehole but for the common 30-50 m, 0.5 s are usually sufficient (except for special cases, e.g. thick peat levels characterized by *very* low shear-wave velocities and that, for that reason, require a longer recording time)

Pre-trigger time

Zero [0] (in other words, no pre-trigger time should be applied, as for any type of active seismic)

Stack

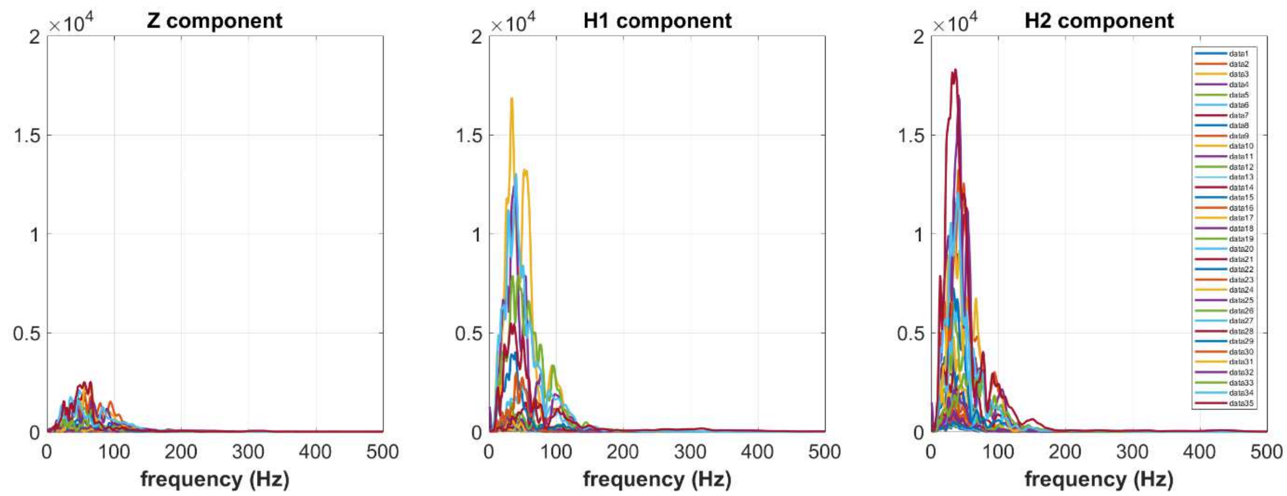
Never less than 3 (regardless of source, VF or HF).

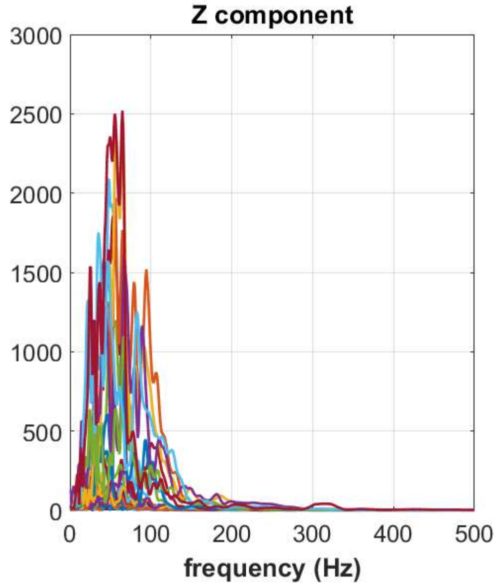
It is absolutely one of the most important and undervalued operations: **<u>the larger the stack, the better the data quality</u>**.

The amount of energy released into the ground is proportional to the number of shots used for the data stack. Large masses and complex energizing systems can be easily replaced by an adequate stack carried out using a common 8-10 kg sledgehammer.
Please do not be afraid to “exaggerate” with the stack (also considering that VF acquisitions are useless - see next pages).
In short, what we recommend is: a twin borehole geophone (in this way the amount of acquisitions is halved) and only HF60+ and HF60- shots (VF data are useless).
Stack: minimum 3 but in a very noisy environment and when the geophone is deep into the borehole, a larger amount of shots can be useful/necessary.

Sampling interval

0.5 ms (2000 Hz) are more than sufficient (*Nyquist frequency* equal to 1000 Hz).
In fact, considering the actual frequency content of the signal generated with the common sources and the signal attenuation, sampling at frequencies above 1000 Hz (1 ms) is usually pretty useless since the maximum frequency contained in the wave rarely exceeds 200-300 Hz (please, study the Nyquist-Shannon theorem and the practical consequences and attend our workshops/webinars).
The following figure shows the amplitude spectra of the three components (Z, H1 and H2) for a borehole dataset acquired using a standard shear-wave source (HF) [these amplitude spectra are automatically computed and shown when uploading the data into ELIOVSP and the figure is automatically saved in the *working folder* together with all the figures about the seismic traces of all the components].



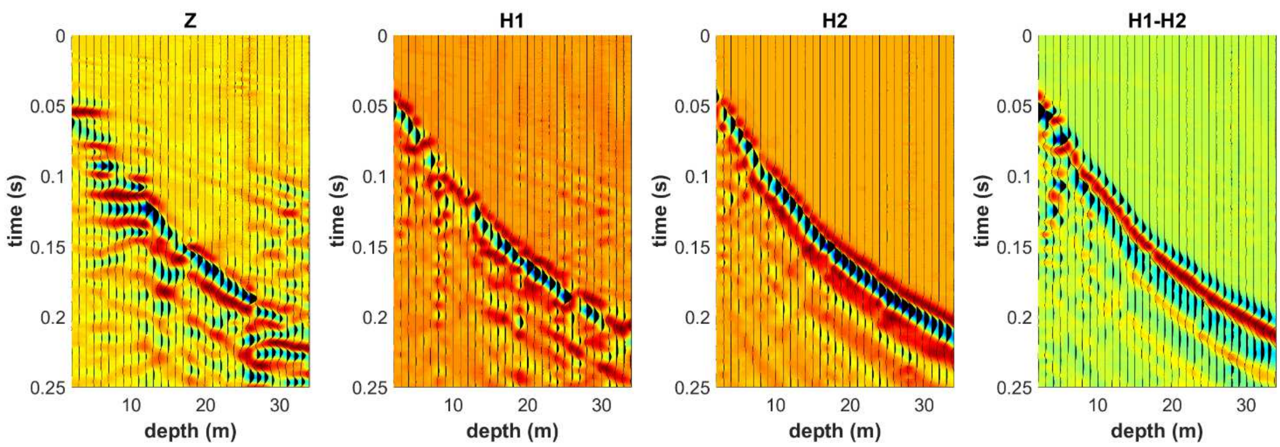


Two things are apparent:

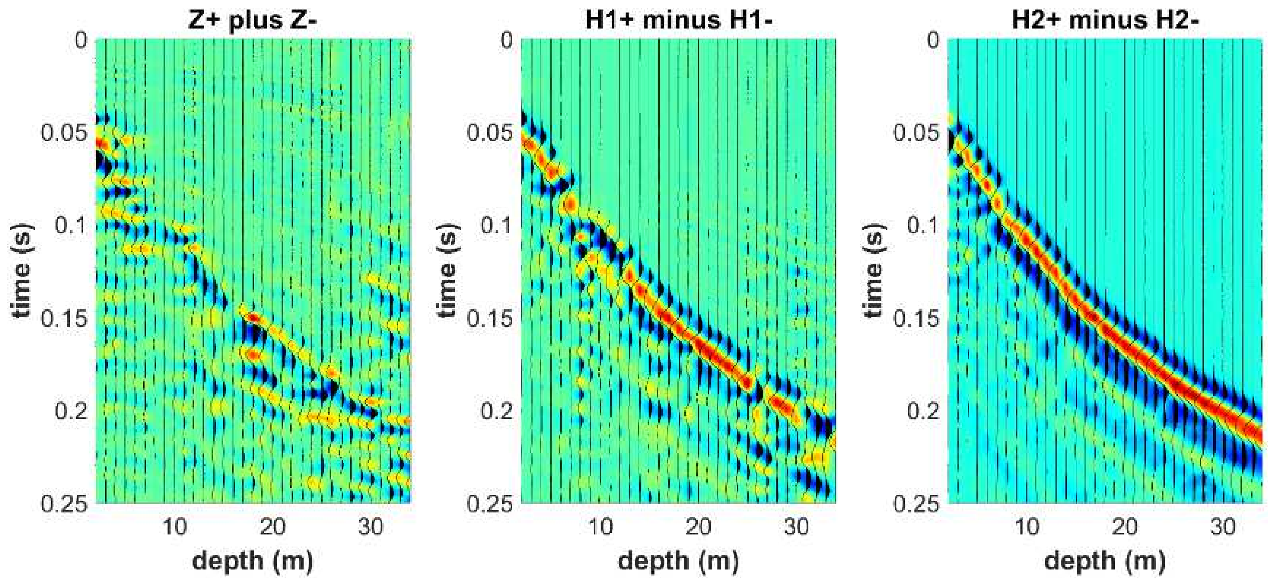
1) the maximum frequency is less than 200 Hz: therefore a sampling frequency of 400 Hz (2.5 ms) would be sufficient;

2) although these data were recorded using a standard ("pure") HF source (90°angle), the presence of a signal along the vertical (Z) component [i.e. about P waves] is also very clear. Using a 60°-70° source (see next sections of this manual) we would further emphasize this component (i.e. P waves), still keeping the SH waves clearly visible.

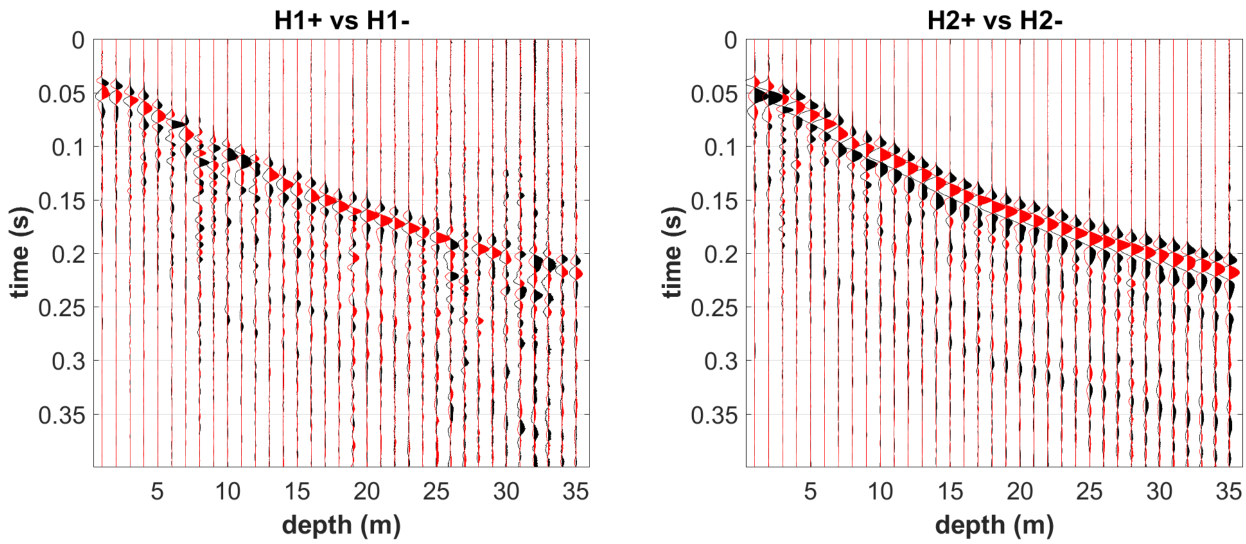
While uploading the data, the seismic traces of all the components are also shown. In the following figure (from a HF+ & HF- survey) are shown the Z, H1 (first horizontal), H2 (second horizontal) and the H1-H2 components.



A further series of possible combinations (useful to decide which one is the component or combination of components that better show the P and SH-wave arrivals) is reported in the following figure (automatically shown) [the titles tell everything about the meaning].



The very classical trace comparison for the H1 and H2 components from the *left* and *right* HF acquisitions is also presented.



P waves

Usually obtained using a vertical-impact (VF) source <u>but read carefully the next sections of this manual</u> since they can be easily identified also in the HF data (no need for VF shooting).

SH waves

The "rule" requires that the acquisition be made by hitting right (+) and left (-). In fact, if you work with care and attention this is not always strictly necessary (it is often easy to identify the SH wave - without confusing it with the P wave - even with a single SH shot, indifferently left or right).

It is strongly recommended to use a *<u>beam with an impact surface of about 60°-70° (see photos)</u>*. The purpose is twofold: on the one hand, it allows the input of more energy (because of mere ergonomic reasons) and on the other hand, it allows you to generate a balanced and useful amount of both P and SH waves. **Therefore you can avoid carrying out the VF acquisitions since P waves will be very clear (along the Z component) from the shots recorded using this sort of source.**

This type of shear source is also useful for the acquisition of SH and Love waves (for refraction and surface-wave studies - see our *winMASW*® and *HoliSurface*® products).

In order to avoid damaging the wooden beam and to produce large amplitudes at high frequencies (useful in the analysis of body waves), we recommend to use the polyethylene striking plate as shown in the following photo.

We could define this source as HF60 (the angle does not have to be defined too precisely: an angle between about 55°and 75° is surely fine).

Borehole geophone with single and twin (double) sensors

ELIOVSP can process the data recorded with a standard single borehole geophone as well as with a twin borehole geophone (that we recommend and provide).

A **standard (single) borehole geophone** is simply a 3-component (3C) geophone (i.e. there are two horizontal and one vertical geophones – more or less like a 3C geophone used to record the data used to define for instance the HVSR curve or the HS [HoliSurface] data).

On the other side, a **twin borehole geophone** is a "case" where two 3C geophones are installed (usually 1 m one from the other - see photos in the **"*Geometry*"** and "***Project file***" sections).

By using a borehole geophone with two 3C geophones (*twin borehole geophone*), data acquisition is clearly much more efficient compared to the effort required to record the data with a standard single borehole geophone.

In fact, a twin borehole geophone records the data at two (2) different depths and, consequently, it is be possible to "skip" a shot. If the two geophones of the twin geophone are, for example, at 30 and 29 m, in order to obtain the data at 28 and 27 m the geophone must be pulled up by 2 m, thus **halving the number of shots necessary to obtain the data at each single position**.

To keep it simple: if you need to collect the data each 1 m for a 30 m borehole and you are using a standard single borehole geophone, you need to move the geophone at each single position (30, 29, 28 m and so on – altogether 30 positions and shootings).

On the other side, if you are using our **twin borehole geophone**, you can halve the number of shootings since for each shot you will obtain the data at two different positions (30 & 29, 28 & 27, 26 & 25 and so on).

Please, remember that ELIOSOFT provides you all the necessary equipment for a correct and efficient acquisition of seismic data with a qualified technical support on both the hardware and software products.

Borehole geophones with more than 2 horizontal sensors?

In the *project file* (see pertinent section of this manual) it is necessary/possible to define the *components* that you want to consider

If your standard borehole geophone has more than two (2) horizontal components, when you upload the data by means of the *project file*, you must specify the two components you want to consider to identify the first arrivals of the SH waves (please, consider that this type of geophones pretty useless, as shown during our webinars/workshops and, to some extent, in this manual). It is clearly possible to compile different versions of your *project file* while considering different components/traces (and see if different horizontal components are more or less clear and useful for your purpose).

WARNING

The correctness of the acquisition procedures is always a key point. Too many people underestimate such a point and do not keep in mind the well-known **GIGO** acronym:

Garbage In, Garbage Out

If the data quality is garbage, the analyses/results will also be garbage.

Naming the data files effectively

As we always recommend also when dealing with surface-wave analysis, it is crucial naming the files in a rational way, so to easily understand what those files concretely represent.

The easiest thing is to report in the file name the information about the type of source (Vertical or Horizontal Force) and the depth of the geophone. In the case of HF data (*Horizontal Force* source used to generate *shear waves*), it is important to report also the information about the *verse* of the shot (right/left or positive/negative, as you wish).

Here some examples of *files* where the meaning is clear (imagine the geophone at a depth of 30 m):

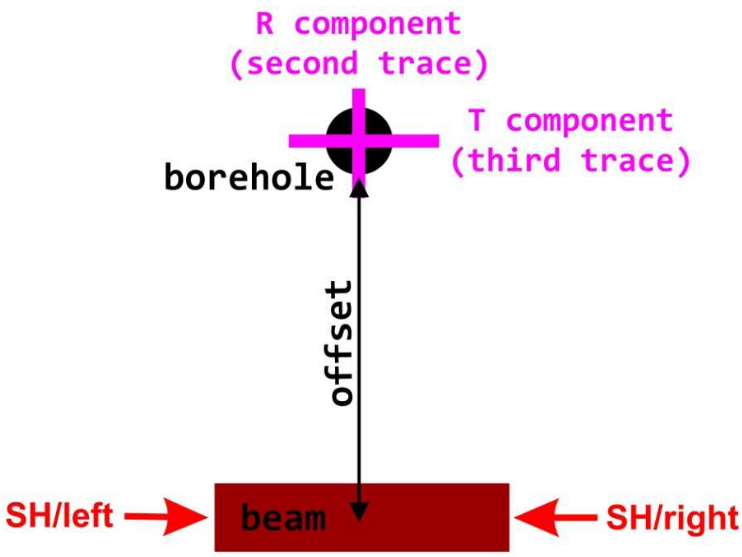
	Example#1	**Example#2**
vertical shot (for P waves) - not necessary [see next sections of this manual]	VF_30.seg2	VF_30m.seg2
left **horizontal shot (for SH and P waves)**	30_HFleft.seg2	HFpos_30m.seg2
right **horizontal shot (for SH and P waves)**	30_HFright.seg2	HFneg_30m.seg2

Important note: if you always use the same file names and the same acquisition procedures and parameters, the ***project file*** [see next sections] will be always the same and you will never need to modify it.

Orientation of the borehole geophone [a key point]

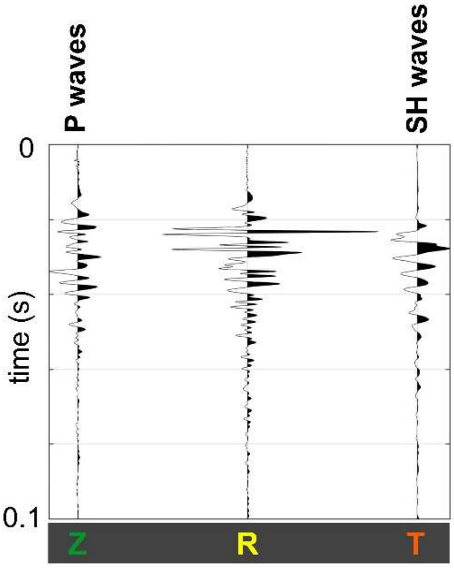
During the data acquisition, it is important to try to keep the **transversal component/trace** parallel to the beam used as source (see figure below - *map view*, i.e. from above), thus obtaining a final file that **<u>strictly follows the following standard convention</u>:**

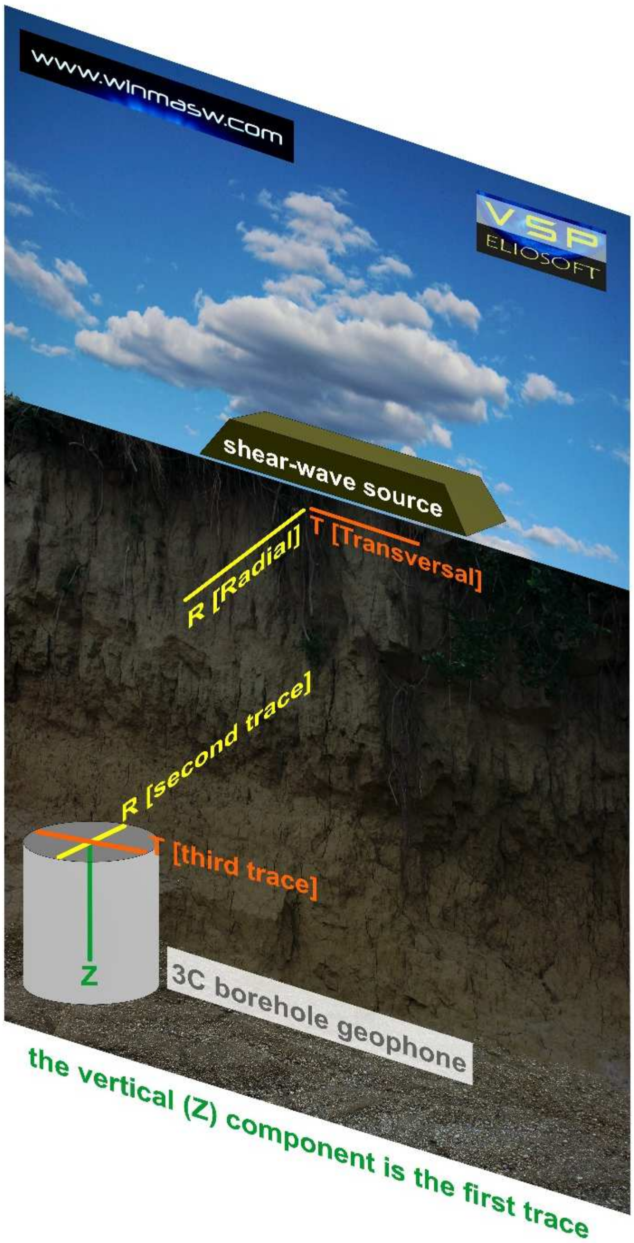
trace#1: vertical component (Z)
trace#2 (H1): horizontal <u>radial</u> component (R)
trace#3 (H2): horizontal <u>transversal</u> component (T)



Likely, during the field operations, the geophone can rotate but it is important to try to maintain the orientation as in the above scheme (see also the scheme shown in the next page).

While uploading the data (see *project file*), it is however possible (and necessary) to specify the sequence of the traces (i.e. where are the traces pertinent to the Z R and T components) and different orientations/conventions/formats can therefore be easily managed (depending on your *acquisition system*).
If your *acquisition system* works in such a way to obtain a dataset with the R, T, Z sequence (the first trace refers to the radial component, the second to the transversal and the third to the vertical), in the *project file* you simply need to specify the sequence **3 1 2**. This means that you are telling the software that the Z trace is the third one, the Radial trace is the first one and the Transversal trace is the second one.





Data acquisition with our *twin borehole geophone*

To ensure maximum results with the minimum field effort, ELIOSOFT provides flexible and useful *acquisition systems* to deal with a wide range of acquisition techniques (see our *HoliSurface® system*). The borehole geophone we provide (together with the seismograph, software etc.) is a **double (twin) borehole geophone**. In other words, in the borehole case there are two 3C (3-component) geophones placed at a distance of 1 m from each other. This way, with a single shot you will record the arrivals at two different depths, thus halving the fieldwork.
The twin geophone is positioned at a depth of, for instance, 30 m, and the data will be obtained at a depth of 30 and 29 m. The geophone will be then pulled up by 2 meters in order to have the two sensors at 28 and 27 m and so on (in this way, in order to obtain the data at each meter, you will just need to perform 15 shootings).

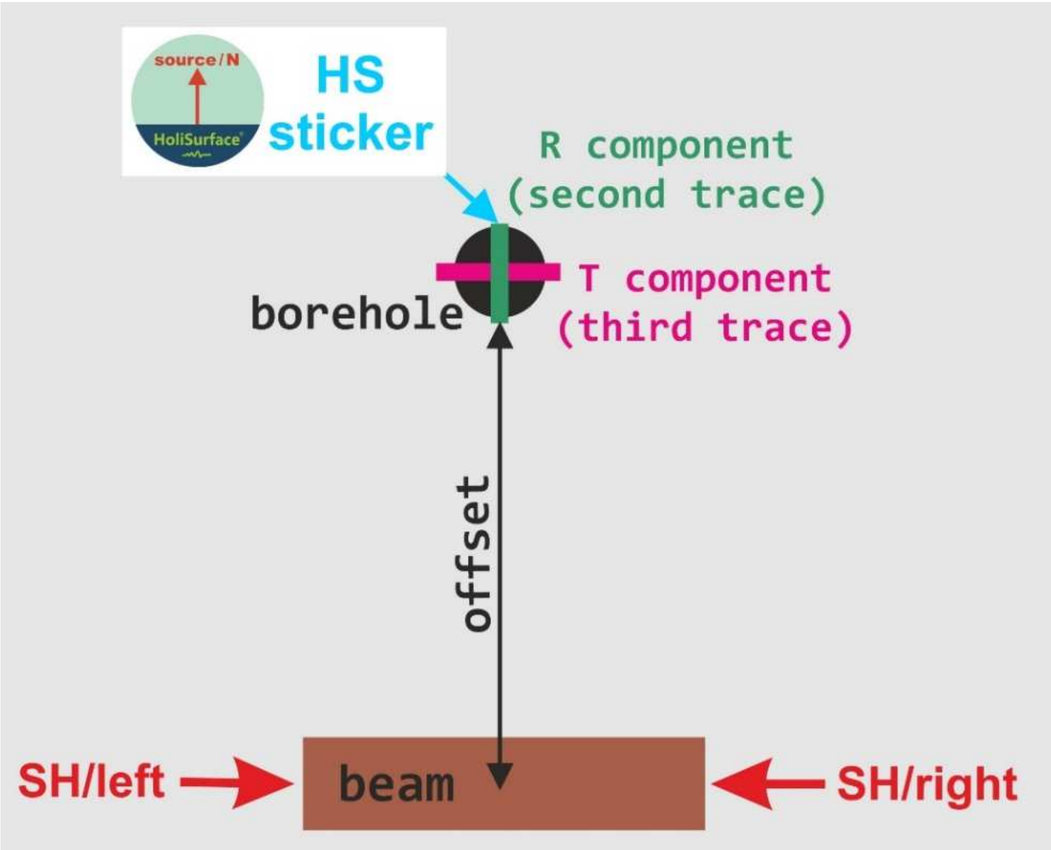
Thanks to ELIOVSP you will then upload (see *project file*) all the data in just a few seconds.
In case you are using our *system*, you must connect the **twin borehole geophone** to the 13-24 connector of the seismograph and activate (through the acquisition software) the **channels 13-14-15-16-17-18.**
When lowering the geophone into the borehole, try to keep the radial direction of the geophone (indicated by the **HoliSurface sticker**) in the correct position: the sticker must be diametrically opposite with respect to the source (see the two following images).

In this way, the <u>six seismic traces</u> you obtain represent (in sequence):

the traces of the Z R and T components of the deep geophone

&

the Z R T traces of the second geophone (1 m above the previous one)



Correct orientation of the borehole geophone (top view): the HS sticker (see also next photo) must be in a position diametrically opposite to the source point.

The top of the twin (double) borehole geophone we provide. The HS sticker is used to properly orientate the geophones in the borehole (see also previous image)

The diameter of the borehole geophone we supply is 50 mm and, consequently, the internal **diameter of the borehole should be at least 60 mm**. The most common tube has a **diameter of 2.5 inches (2 and a half inches)**.

Gain

If you also want to estimate the *damping* values, it is important that the gain value (if any) is the same for all the traces/channels/shoots.

Scheda di campagna

Nella seguente pagina è riportata una possibile scheda di campagna utile per tenere traccia dei dati acquisiti. Ricorda che, in generale, è utile usare come nome file la profondità alla quale si trova il geofono, aggiungendo poi un suffisso che indica il tipo di energizzazione (**VF**, **HF** o, come da noi consigliato, ***inclinata***).

www.winMASW.com

SITE:	
OFFSET (m):	
DAY/TIME:	
NOTES:	

#	FILE NAME	DEPTH (m)	SOURCE (VF, HF, INCLINED)	NOTES
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
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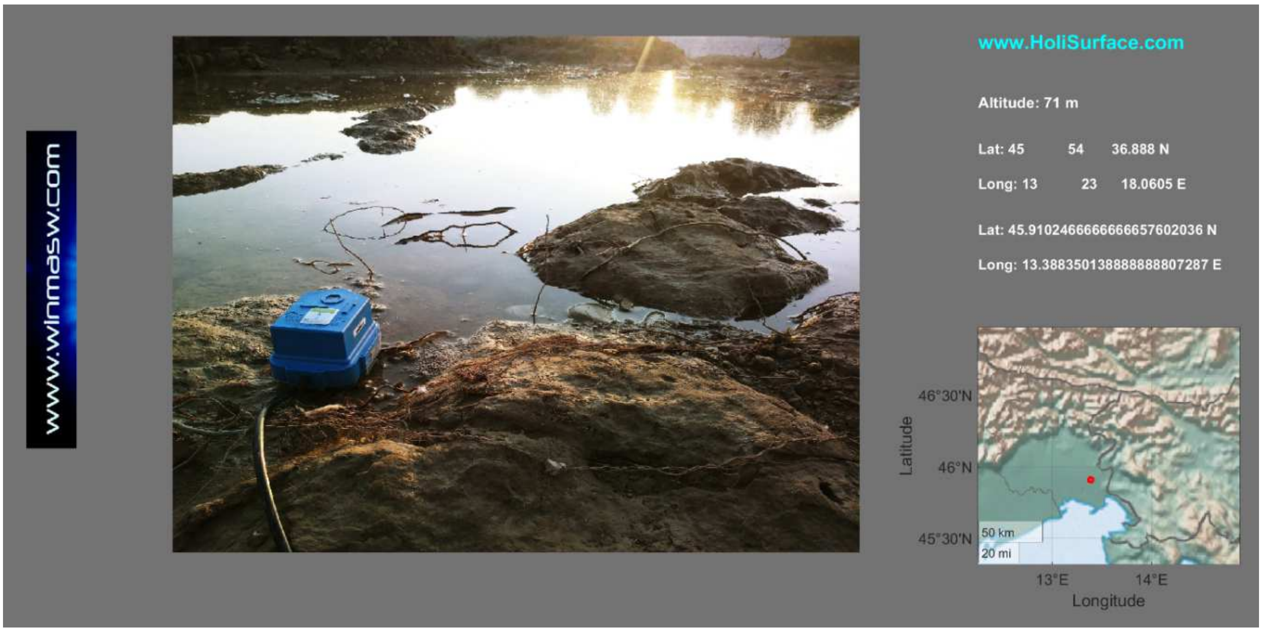
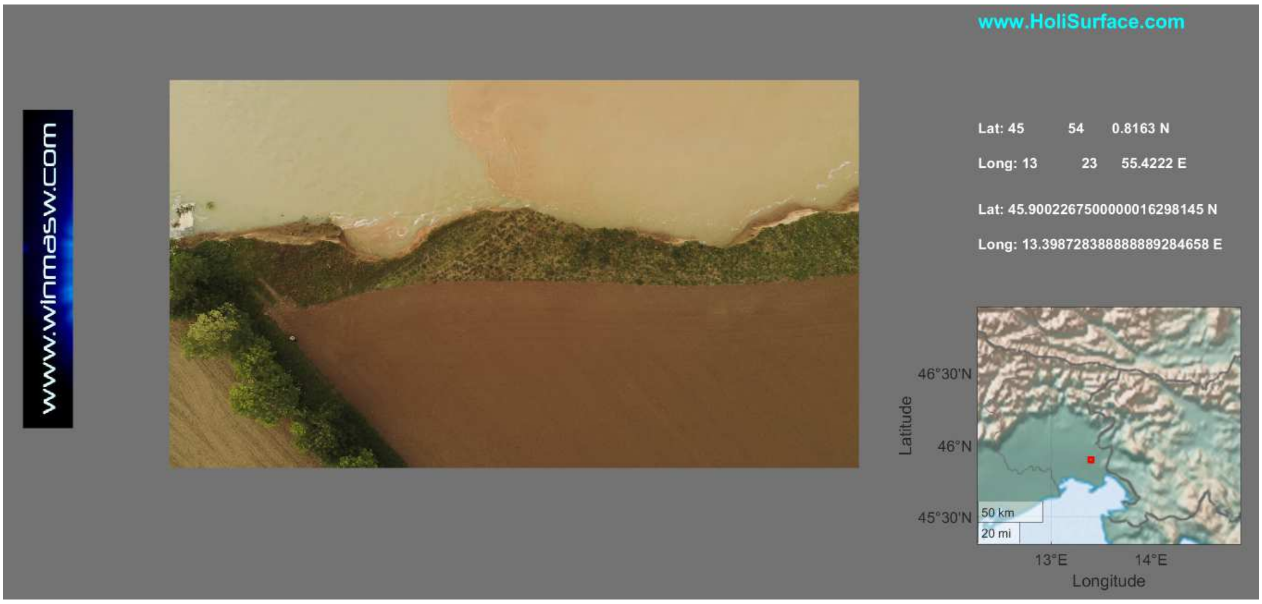
30				

Photo documentation of the survey site

It is also possible to upload an image (to include in the report) and, in case such an image contains GPS information (several APPs of your smartphone can do that [e.g. *MapCam* or *GPS Map Camera*] as well as all the *Action Cameras* [e.g. GoPro] and *drones*), **the GPS information (Latitude, Longitude, Altitude and number of satellites) will be shown.** Of course, it is possible to upload any photo you want to insert in your report, even without GPS information.

MapCam **GPS Map Camera** **Action cameras** **Drones**





Two examples of what you get by uploading a photo according to the mentioned procedure (the first photo was taken by a common *Smartphone* while the second by a popular *drone*).

HVSR

Since **ELIOVSP** also allows you to jointly model the HVSR (together with the SH and P-wave arrival times from your borehole data), **it is useful to record a couple of HVSRs in the surroundings of the borehole (at two different points around the borehole - please, remember that recording a single HVSR is very risky).**

Two advantages: on the one hand we will obtain a better-constrained model (the more *observables* we have, the more robust the solution – see our *Elsevier* and *Springer* books in the Reference section), on the other hand we will be able to extend the V_S subsurface model much deeper than the maximum depth of the borehole.

The map shown in the following is a summary of the data acquisition in case you are interested in the comparison between borehole and surface data. Around the borehole you need to record a couple of HVSRs (at two different positions). If you want to analyze surface-wave dispersion you have **several** possible active and passive options (see the *Elsevier* and *Springer* books).

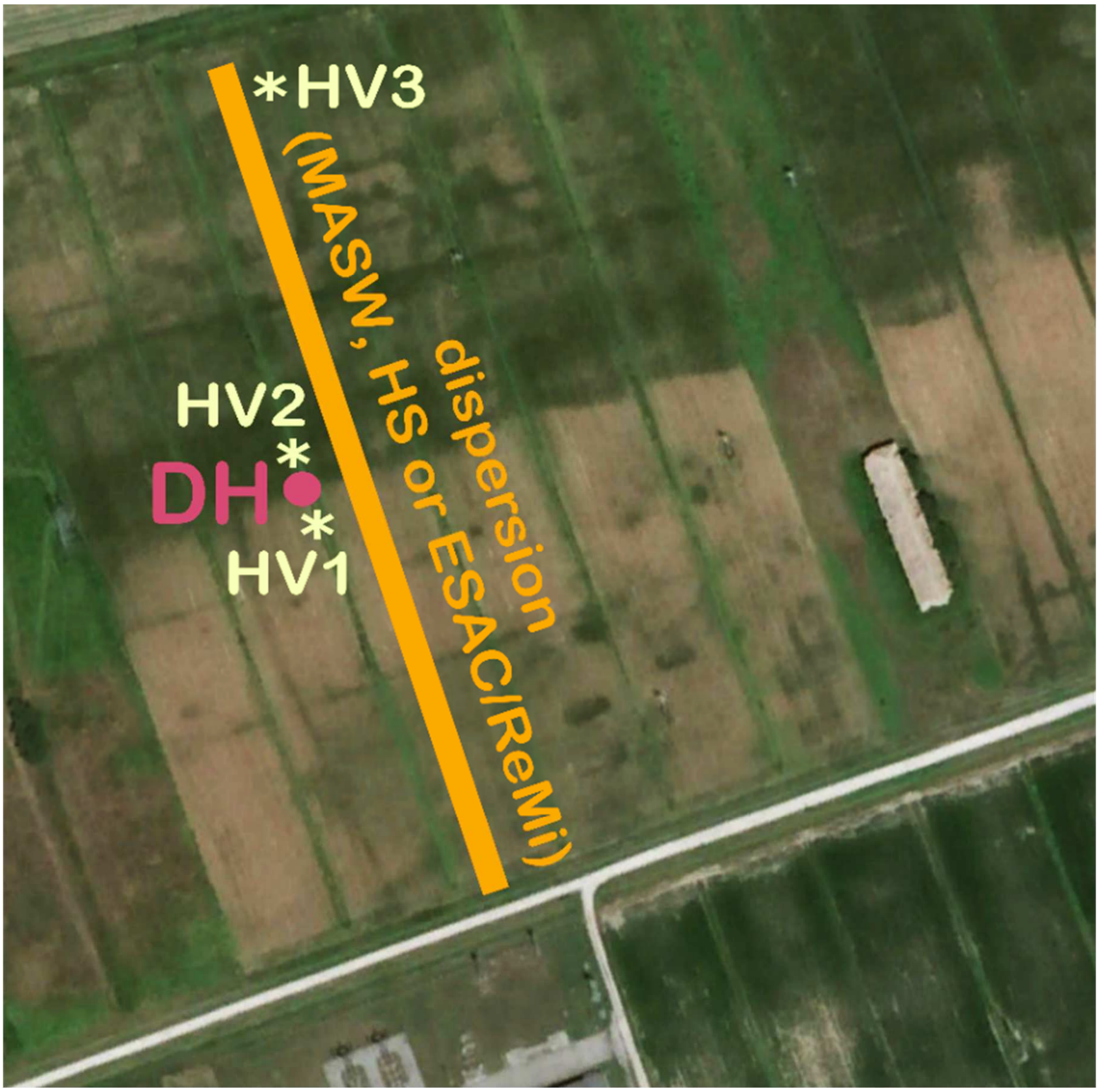
Be aware that if the site is characterized by porous sediments (e.g. sands or gravels), the cement used for the borehole can leak into the sediments, thus altering its properties and, therefore, the velocities.

In case some disagreement is observed, please consider that:

1) several problems and pitfalls are possible for any methodology both during data acquisition and analysis (results depend on several subjective choices made by the user);

2) borehole data provide very local information while surface waves provide average information about a wider area (MAAM [Miniature Array Analysis of Microtremors] is the only surface technique capable of providing information about very local conditions – see our *HoliSurface*® software application).

An additional cause of possible disagreement between borehole and surface-wave measurements is the material anisotropy ($V_{SH} \neq V_{SV}$). Please, consider that if you want to highlight possible anisotropies from surface-wave analysis, it is necessary to record and properly analyze all the components (Z, R & T).



Example of data acquisition aimed at verifying the consistency between DownHole (DH) and surface-wave data (different methodologies are possible: multi-component MASW, HoliSurface, ESAC/SPAC/ReMi, MAAM etc.). Even if you do not intend to carry out this type of "comparative" analyses, it is strongly recommended to record a couple of HVSRs to use in the joint modeling with the DH data.

2.1 Data acquisition: is VF necessary? Going beyond the legends to work effectively

Is it really necessary to record VF, HF+ and HF- data in order to produce and record P and SH waves? [consider that for each point and type of acquisition we have to stack several shots and therefore DowhHole [DH] seismics can become a relatively-heavy task].

During our webinars/workshops, we show that VF data acquisition (i.e. a vertical source used to produce P waves) is not necessary. **HF+ and HF- data acquisition (with a 60-70° source - see previous sections of this manual) is more than sufficient** (and, if we have a robust theoretical background and a good field experience, a simple HF+ **or** HF- dataset alone can be enough).

To keep it short: you record the HF+ and HF- shots (*stack* at least 3 - depending on the depth of the geophone, the background noise and the type of source more stack might be necessary) and, thanks to the ELIOVSP processing tools, from these data you will be able to obtain both the V_P and V_{SH} (see “Modelling/inversion: possible and recommended approaches” section).

The analysis of the vertical component will allow you to identify the P waves even just from the HF+ / HF- data. P waves will be easily identifiable along the vertical component of the traces obtained by means of a 60° shear source (no need for vertical-impact sources – VF). Therefore:

We strongly recommend acquiring HF data using a source inclined by about 60° for both the *left* and *right* shots

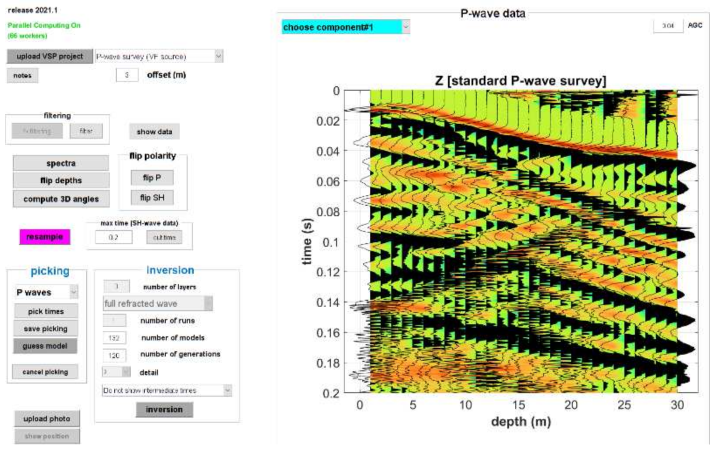
The two HF+ and HF- datasets (that we could also define as HF60+ and HF60-) will be excellent for the identification of both P (Z component) and SH (horizontal components) waves

About the HVSR: at least two measurements (around the borehole - see scheme in the previous figure)

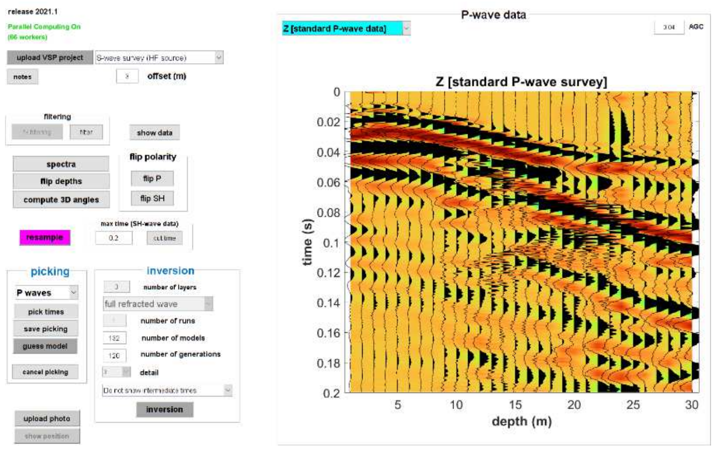
An example/comparison of data (vertical component) recorded with a vertical source (VF) and with a standard HF (90° Horizontal Force) source is shown below. Do you see that P waves are clearly visible and identifiable even in the HF data (panel below)?

Vertical component (i.e. traces recorded along the vertical component of the borehole geophone).

P wave arrivals using VF source (vertical impact) [raw data shown before any cleaning and *gain* operation].
Compare these traces with those reported below (from the HF acquisition).



P waves arrivals using standard HF source (shear source) with a vertical surface (i.e. not using a 60* shear source as suggested)
[raw data before any cleaning and *gain* operation].



The uselessness of the VF acquisitions is apparent since P waves are apparent even in the HF data.
Using, as suggested, an inclined source (about 60°) we will further emphasize the P waves (the SH-wave arrivals along the H1 and H2 components remaining very clear).

Few key points to emphasize and consider

1) in case of data recorded using an **inclined source (about 60-70°),** P and SH waves are extremely clear: so we strongly recommend not to record the P waves using a vertical hammering and the SH waves with a horizontal force. **Produce and record P and SH wave using just a inclined source (data acquisition and processing will be quicker)**;

2) V_P values have little or no importance for most of the common geotechnical and/or seismic-risk applications (in unconsolidated sediments they often simply indicate the depth of the water table and, because of this, have little/no geotechnical meaning/value);

3) even when you are asked to perform just a downhole survey, **please do not forget to record a couple of HVSR datasets around the borehole so that you can jointly model with ELIOVSP**. This way your V_S values will be much more robust (joint analysis). Remember that your goal **is not** to perform a DH survey **but to obtain a reliable and robust V_S profile** (same things applies also with surface-wave surveys);

4) we strongly recommend you not to follow the "pick-and-invert" approach, but the ***forward model approach***. If you pick the data you will not invert the data but your subjective (possibly working) interpretation. On the other side, if you work with the *forward model* approach, you will keep under control the whole process and realize how many theoretical facts reflect on the practical level.

Few recommendations for the data acquisition

1) Photo documentation with the *MapCam* app (**geo-referenced photos – remember to activate the GPS of your smartphone**). The photos must help to understand/remember ***what*** has been done and ***how*** it has been done.

2) Carefully **place the geophone** so that the **radial direction R** and the **transversal direction T** are clear [see photos and schemes in the previous pages of the manual].

3) Use an **inclined shear source** (*right* and *left* acquisitions) [no need of VF acquisitions to generate P waves].

4) **Stack:** at least three (when the geophone is deep in the borehole you can increase the stack depending on the source you are using and the background noise of the area).

5) Usually it is better to start with the geophone at the bottom of the borehole and then pull it up.

6) **File names** should clearly indicate the depth (remember that if you use always the same file names, the project file will be always the same); for instance, if you are using a twin borehole geophone and produce the *right* and *left* shear shots, you obtain the following files: HFright_30.sg2, HFleft_30.sg2; HFright_28.sg2, HFleft_28.sg2; etc. [the depth reported in the file name refers to the deepest geophone while the second geophone (more superficial) will be at a depth of 29 and 27 m, respectively].

7) Record **a couple of HVSRs** around the borehole.

What is right accords with principle

Robert Fripp

3. The project file

The format of the *project file* should not be changed or altered in any way. You cabn take one from the datasets provided with the software for your training and modify it with your data without changing spacing, etc.

Under no circumstances should tabulations ⭾ be used. Blank spaces are created solely by means of the *space bar*.

In the *project file*, never use the comma (",") for the numbers: always use the dot "."

Since VF acquisitions are not necessary, (P waves are easily identified form the HF data) we strongly recommend to record only HF+ and HF- data and compile just the HF project file. **A *project file* is a simple ASCII file with the .vsp extension (see examples shown in the following pages and provided together with the self-training data in the ELIOVSP USB sick).**

Important note: if you always use the same file names and the same acquisition procedures, the ***project file*** will remain always the same (so you do not have to modify it).

```
Project name: DH - Amatrice [quake area]
NOTES: inclined shear source (+/-)
offset (source-borehole distance, in meters): 8
pre-trigger (s): 0.0
geophone components [Z R T]: 1 2 3
double geophone - distance [meters]: 0
type of source (VF [for P waves] or HF [for SH waves]): HF
subfolder: \Somme\
==================================================================
file | geophone depth (in meters) | source polarity (for HF source) | channel sequence (Z R T)
==================================================================
***source: HF+
30d.sg2   30  + 1 2 3
29d.sg2   29  + 1 2 3
...
```

MEANING OF THE FIELDS TO BE FILLED IN THE .VSP FILE

- **Project name:**
  The name of the Project (which will be reported in the output files)

- **NOTES:** any information useful to remember/consider during the processing

- **offset (source-borehole distance, in meters)**

It is the distance between the source and the borehole: enter the value in meters (if necessary, use the dot, never the comma)

- **pre-trigger (s):** 0

If larger than 0 (zero), the specified amount of data are removed. For instance: if pre-trigger (s) is 0.1, the first 0.1 seconds will be removed from the data.
We **strongly discourage the application of any pre-triger time for any kind of active methodology.**

- **geophone components [Z R T]:**

How to indicate the seismic components [very important]

First of all, consider that the software is extremely flexible and can be used to process data collected using both a standard single borehole geophone, both a twin borehole geophone. Since different manufacturers can adopt different formats/conventions, the user can (actually *must*) define the meaning of each trace.
In simple terms: the user must tell the software which trace(s) is/are the vertical component and which traces the horizontal components.

We need to tell the software which traces are the Z R T components.

Let us image we are dealing with a standard single borehole geophone with 3 geophones (1 vertical and 2 horizontal). If your acquisition system records the traces as Z, R (H1) and T (H2), you simply have to specify the **1 2 3** order.
On the other side, if your system records the data as H2 (transversal), H1 (radial) and Z (i.e. the vertical component is the third trace), you must specify **3 2 1**.
Such values/information must be specified both in the “geophone components [Z R T]:” field as well as along the 4, 5 and 6 columns of the seismic data characteristics (see examples in the following pages).

On the other side, if you are using our acquisition system and its **twin borehole geophone** (properly connected and oriented – see previous pages of the manual), the traces are following the following format/convention: the first three traces are the Z R T components of the deep geophone while the traces 4, 5 and 6 are the Z R and T components of the second geophone (1 m above the previous one).
This means that you need to specify the following lines:

“geophone components [Z R T]: 1 2 3 4 5 6”

and in the file characteristic section (for instance) **[see examples in the following box]**:

…
30right.sg2   30 + 1 2 3 4 5 6
…

and

…
30left.sg2   30 + 1 2 3 4 5 6
….

At the beginning this could sound complicated but it is just a matter of understanding the meaning and the fact that this ensures you to analyze any sort of dataset, recorded with whatever equipment.
In the end, your *acquisition and analysis system* should be considered as the racket for a tennis player: you need to know each single detail. You must *feel it* as part of your brain and master the whole thing. Only this way you can become a champion!

- **double geophone - distance [meters]**

If you are using a *twin borehole geophone* (see previous sections), this is the distance between the two geophones (usually 1 m). If we are using a standard single borehole geophone, just set the value to 0 (zero).

- **type of source (VF [for P waves] or HF [for SH waves])**

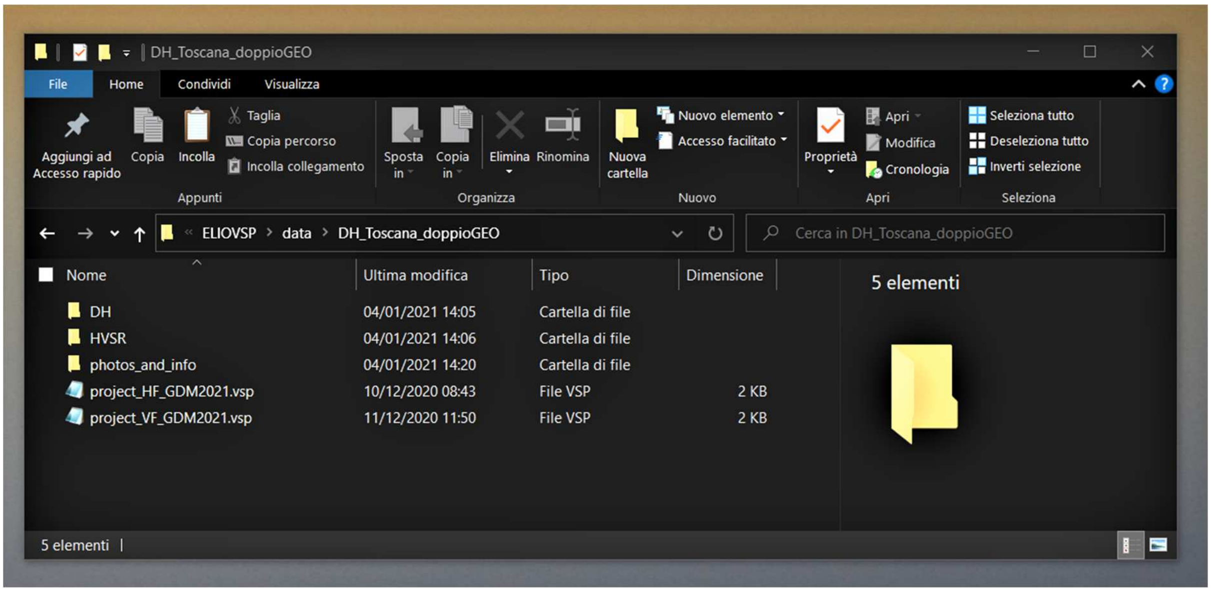
VF (Vertical Force) for acquisitions with a vertical-impact source (to produce P waves [not mandatory!]).
HF (Horizontal Force): to produce shear waves (it is recommended to shoot on both sides of the beam – files are usually named as *left*/*right* or *positive*/*negative*).

For HF data, in the VSP project file, it is necessary to specify both the **HF+** and **HF-** shots (see box with the examples in the following pages).

- **subfolder**

it is the folder where the DH data files are stored (all the DH files must be saved in such a folder). **The *project file* must be in a folder outside such a folder**. In the following snapshot you can see an example of how folders/data should be organized: the two project files (for the HF and VF acquisitions - **but remember that the VF is not necessary!**) are saved in the ***working folder*** where three *subfolders* are present: one containing the DownHole data (DH subfolder), a further one with the HVSR data (remember to record a couple of HVSRs at two different points around the borehole) and a third one with photos and other documents/information.

In this case, the *subfolder* to report in the *project file* is simply "/DH/", therefore the lines of the project file are [consider that in this case we used a twin borehole geophone (i.e. we are dealing with 6 traces) – see next pages]:
…
geophone components [Z R T]: 1 2 3 4 5 6
double geophone - distance [meters]: 1
subfolder: \DH\
…



Do not use folder names with special characters and/or blank spaces such as, for instance, "*C:\Users\Lou\Desktop\DH\DH San Severino\Today Data*".

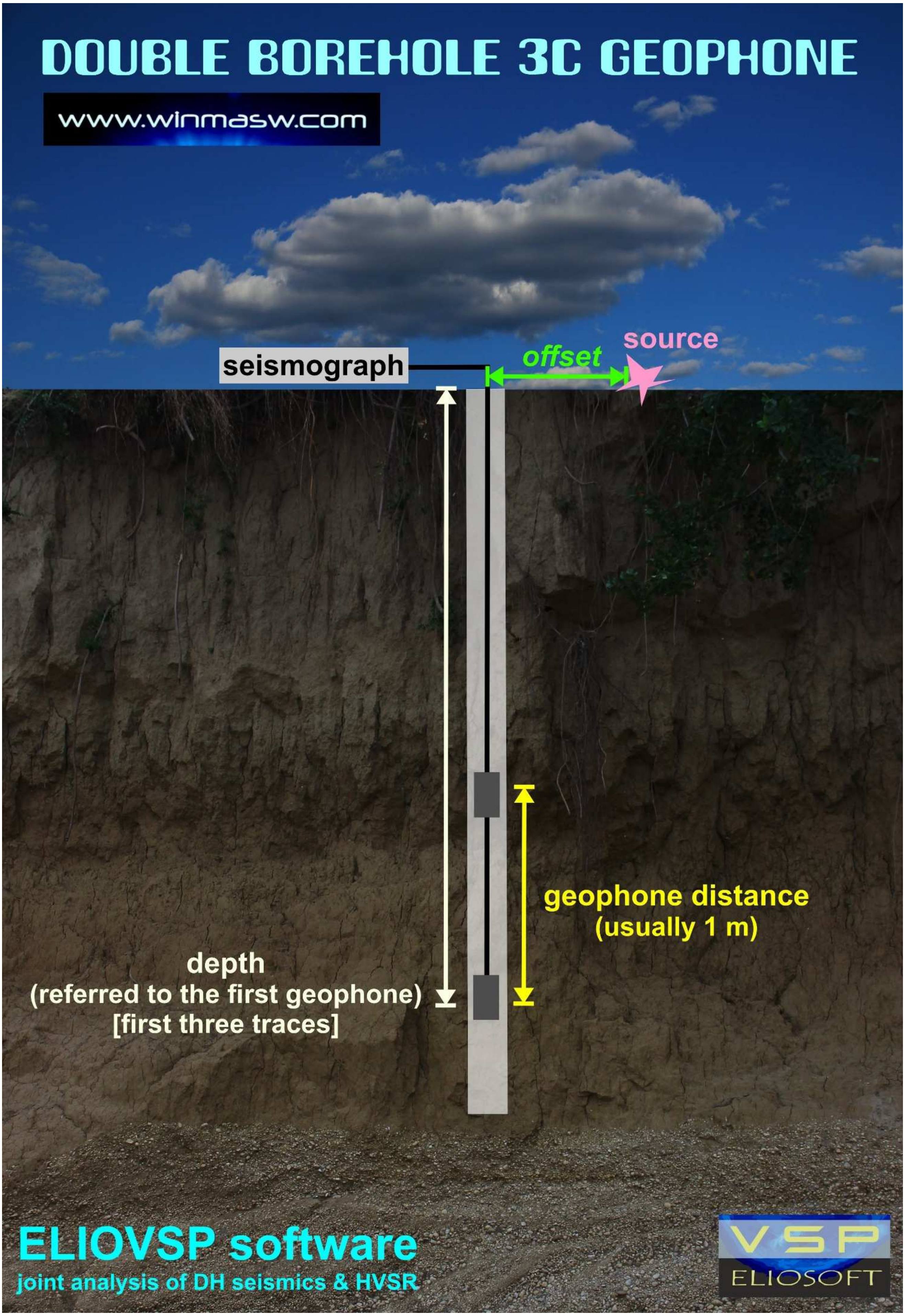
Also avoid mathematical symbols such as the minus ("-"). Folder (or file) names such as "C:\Users\Lou\Desktop\DH\DH-Data\" can generate problems/errors.

Use instead something simple and compact like for instance: *C:\Users\Lou\Desktop\DH_San_Severino\Data*

Remember that the software is ***case sensitive*** (i.e. upper and lower cases have a different "meaning"): "NOTES", "notes" or "Notes" is different (incorrect cases lead to *error messages*).

So please take some time to see how the *project file* works from the following examples and be sure to know the format/convention of your *acquisition system* (seismograph and borehole geophone).

For your self-training, you can use the data provided in the ELIOVSP USB stick ("DATA_DISSEMINATION" folder).


DOUBLE BOREHOLE 3C GEOPHONE
www.winmasw.com
seismograph
offset
source
geophone distance
(usually 1 m)
depth
(referred to the first geophone)
[first three traces]
ELIOVSP software
joint analysis of DH seismics & HVSR
VSP
ELIOSOFT

EXAMPLE OF VSP PROJECTS
USING A BOREHOLE GEOPHONE WITH SINGLE 3C GEOPHONE

PAY ATTENTION

Do not modify the keyword of the *project file*. Just report the value for your data.

Example of vsp file (HF+ e HF- data) for a standard borehole geophone (with a single 3C geophone) that provides the data according to the Z R T sequence (the first trace is from the vertical geophone, the second trace is from the first horizontal geophone [set radially with respect to the source point] and the third trace is the second horizontal geophone [perpendicular to the previous line and therefore representing the T component]):

```
#################################
########### ELIO-VSP ###########
#################################
## Vertical Seismic Profiling ##
####### www.winmasw.com ########
#################################
type of source (VF [for P waves] or HF+ [for SH waves] and HF- [for SH waves])
#################################
Project name: DH - Amatrice [quake area]
NOTES: inclined shear source (+/-)
offset (source-borehole distance, in meters): 8
pre-trigger (s): 0.0
geophone components [Z R T]: 1 2 3
double geophone - distance [meters]: 0
type of source (VF [for P waves] or HF [for SH waves]): HF
subfolder: \Somme\
=================================================================
file | geophone depth (in meters) | source polarity (for HF source) | channel sequence (Z R T)
=================================================================
***source: HF+
30d.sg2   30  + 1 2 3
29d.sg2   29  + 1 2 3
28d.sg2   28  + 1 2 3
27d.sg2   27  + 1 2 3
26d.sg2   26  + 1 2 3
25d.sg2   25  + 1 2 3
24d.sg2   24  + 1 2 3
23d.sg2   23  + 1 2 3
22d.sg2   22  + 1 2 3
21d.sg2   21  + 1 2 3
20d.sg2   20  + 1 2 3
19d.sg2   19  + 1 2 3
18d.sg2   18  + 1 2 3
17d.sg2   17  + 1 2 3
16d.sg2   16  + 1 2 3
```

```
15d.sg2   15  + 1 2 3
14d.sg2   14  + 1 2 3
13d.sg2   13  + 1 2 3
12d.sg2   12  + 1 2 3
11d.sg2   11  + 1 2 3
10d.sg2   10  + 1 2 3
9d.sg2   9 + 1 2 3
8d.sg2   8 + 1 2 3
7d.sg2   7 + 1 2 3
6d.sg2   6 + 1 2 3
5d.sg2   5 + 1 2 3
4d.sg2   4 + 1 2 3
3d.sg2   3 + 1 2 3
2d.sg2   2 + 1 2 3
1d.sg2   1 + 1 2 3
=================================================================
***source: HF-
30s.sg2   30  - 1 2 3
29s.sg2   29  - 1 2 3
28s.sg2   28  - 1 2 3
27s.sg2   27  - 1 2 3
26s.sg2   26  - 1 2 3
25s.sg2   25  - 1 2 3
24s.sg2   24  - 1 2 3
23s.sg2   23  - 1 2 3
22s.sg2   22  - 1 2 3
21s.sg2   21  - 1 2 3
20s.sg2   20  - 1 2 3
19s.sg2   19  - 1 2 3
18s.sg2   18  - 1 2 3
17s.sg2   17  - 1 2 3
16s.sg2   16  - 1 2 3
15s.sg2   15  - 1 2 3
14s.sg2   14  - 1 2 3
13s.sg2   13  - 1 2 3
12s.sg2   12  - 1 2 3
11s.sg2   11  - 1 2 3
10s.sg2   10  - 1 2 3
9s.sg2   9 - 1 2 3
8s.sg2   8 - 1 2 3
7s.sg2   7 - 1 2 3
6s.sg2   6 - 1 2 3
5s.sg2   5 - 1 2 3
4s.sg2   4 - 1 2 3
3s.sg2   3 - 1 2 3
2s.sg2   2 - 1 2 3
1s.sg2   1 - 1 2 3
```

In the following an example of vsp file for VF data (again with a standard single borehole geophone) [not necessary!]

```
################################
########### ELIO-VSP ###########
################################
## Vertical Seismic Profiling ##
####### www.winmasw.com ########
################################
type of source (VF [for P waves] or HF+ [for SH waves] and HF- [for SH waves])
################################
Project name: DH - Amatrice [quake area]
NOTES: vertical-impact source
offset (source-borehole distance, in meters): 8
pre-trigger (s): 0.0
geophone components [Z R T]: 1 2 3
double geophone - distance [meters]: 0
type of source (VF [for P waves] or HF [for SH waves]): VF
subfolder: \Somme\
=================================================================
file | geophone depth (in meters) | source polarity (for HF source) | channel sequence (Z R T)
=================================================================
***source: VF+
30v.sg2   30  + 1 2 3
29v.sg2   29  + 1 2 3
28v.sg2   28  + 1 2 3
27v.sg2   27  + 1 2 3
26v.sg2   26  + 1 2 3
25v.sg2   25  + 1 2 3
24v.sg2   24  + 1 2 3
23v.sg2   23  + 1 2 3
22v.sg2   22  + 1 2 3
21v.sg2   21  + 1 2 3
20v.sg2   20  + 1 2 3
19v.sg2   19  + 1 2 3
18v.sg2   18  + 1 2 3
17v.sg2   17  + 1 2 3
16v.sg2   16  + 1 2 3
15v.sg2   15  + 1 2 3
14v.sg2   14  + 1 2 3
13v.sg2   13  + 1 2 3
12v.sg2   12  + 1 2 3
11v.sg2   11  + 1 2 3
10v.sg2   10  + 1 2 3
9v.sg2   9 + 1 2 3
8v.sg2   8 + 1 2 3
7v.sg2   7 + 1 2 3
6v.sg2   6 + 1 2 3
5v.sg2   5 + 1 2 3
4v.sg2   4 + 1 2 3
3v.sg2   3 + 1 2 3
2v.sg2   2 + 1 2 3
1v.sg2   1 + 1 2 3
```

EXAMPLES OF VSP PROJECTS
USING A TWIN BOREHOLE GEOPHONE (TWO 3C GEOPHONES)

Example of vsp file (HF+ e HF- data) from a twin borehole geophone (two 3C geophone 1 m one from the other) (the first three channels are about the deepest geophone (Z R T sequence) while the 4 5 and 6 traces are from the 2nd geophone (1 m above the previous one) and follow the same convention [Z R T]):

```
################################
########### ELIO-VSP ###########
################################
## Vertical Seismic Profiling ##
####### www.winmasw.com ########
################################
type of source (VF [for P waves] or HF+ [for SH waves] and HF- [for SH waves])
################################
Project name: Fauglia (IT)
NOTES: shear sources (+/-)
offset (source-borehole distance, in meters): 3
pre-trigger (s): 0
type of source (VF [for P waves] or HF [for SH waves]): HF
geophone components [Z R T]: 1 2 3 4 5 6
double geophone - distance [meters]: 1
subfolder: \j19090_09_10_Fauglia_DH\
======================================================================
file | geophone depth (in meters) | source polarity (for HF source) | channel sequence (Z R T)
======================================================================
***source: HF+
02.sg2 30 + 1 2 3 4 5 6
05.sg2 28 + 1 2 3 4 5 6
08.sg2 26 + 1 2 3 4 5 6
11.sg2 24 + 1 2 3 4 5 6
14.sg2 22 + 1 2 3 4 5 6
17.sg2 20 + 1 2 3 4 5 6
20.sg2 18 + 1 2 3 4 5 6
23.sg2 16 + 1 2 3 4 5 6
26.sg2 14 + 1 2 3 4 5 6
29.sg2 12 + 1 2 3 4 5 6
32.sg2 10 + 1 2 3 4 5 6
35.sg2 8 + 1 2 3 4 5 6
38.sg2 6 + 1 2 3 4 5 6
41.sg2 4 + 1 2 3 4 5 6
44.sg2 2 + 1 2 3 4 5 6
======================================================================
***source: HF-
03.sg2 30 + 1 2 3 4 5 6
06.sg2 28 + 1 2 3 4 5 6
```

09.sg2 26 + 1 2 3 4 5 6
12.sg2 24 + 1 2 3 4 5 6
15.sg2 22 + 1 2 3 4 5 6
18.sg2 20 + 1 2 3 4 5 6
21.sg2 18 + 1 2 3 4 5 6
24.sg2 16 + 1 2 3 4 5 6
27.sg2 14 + 1 2 3 4 5 6
30.sg2 12 + 1 2 3 4 5 6
33.sg2 10 + 1 2 3 4 5 6
36.sg2 8 + 1 2 3 4 5 6
39.sg2 6 + 1 2 3 4 5 6
42.sg2 4 + 1 2 3 4 5 6
45.sg2 2 + 1 2 3 4 5 6

Example of correct vsp file for VF data (remember that this is useless) from a twin borehole geophone:

```
#################################
########### ELIO-VSP ###########
#################################
## Vertical Seismic Profiling ##
####### www.winmasw.com ########
#################################
type of source (VF [for P waves] or HF+ [for SH waves] and HF- [for SH waves])
#################################
Project name: Fauglia (IT)
NOTES: vertical-impact source (VF)
offset (source-borehole distance, in meters): 3
pre-trigger (s): 0
type of source (VF [for P waves] or HF [for SH waves]): VF
geophone components [Z R T]: 1 2 3 4 5 6
double geophone - distance [meters]: 1
subfolder: \j19090_09_10_Fauglia_DH\
==========================================================================
file | geophone depth (in meters) | source polarity (for HF source) | channel sequence (Z R T)
==========================================================================
***source: VF
01.sg2 30 + 1 2 3 4 5 6
04.sg2 28 + 1 2 3 4 5 6
07.sg2 26 + 1 2 3 4 5 6
10.sg2 24 + 1 2 3 4 5 6
13.sg2 22 + 1 2 3 4 5 6
16.sg2 20 + 1 2 3 4 5 6
19.sg2 18 + 1 2 3 4 5 6
22.sg2 16 + 1 2 3 4 5 6
25.sg2 14 + 1 2 3 4 5 6
28.sg2 12 + 1 2 3 4 5 6
31.sg2 10 + 1 2 3 4 5 6
```

```
34.sg2   8  + 1 2 3 4 5 6
37.sg2   6  + 1 2 3 4 5 6
40.sg2   4  + 1 2 3 4 5 6
43.sg2   2  + 1 2 3 4 5 6
```

IMPORTANT NOTE for data recorded with a twin borehole geophone:
the depth (second column) refers to the deepest geophone. The second is at a depth given by such a depth minus the “double geophone - distance [meters]:” field. For example, in the case considered here, the second geophone is located 1 m above the first (i.e. above the deepest one).

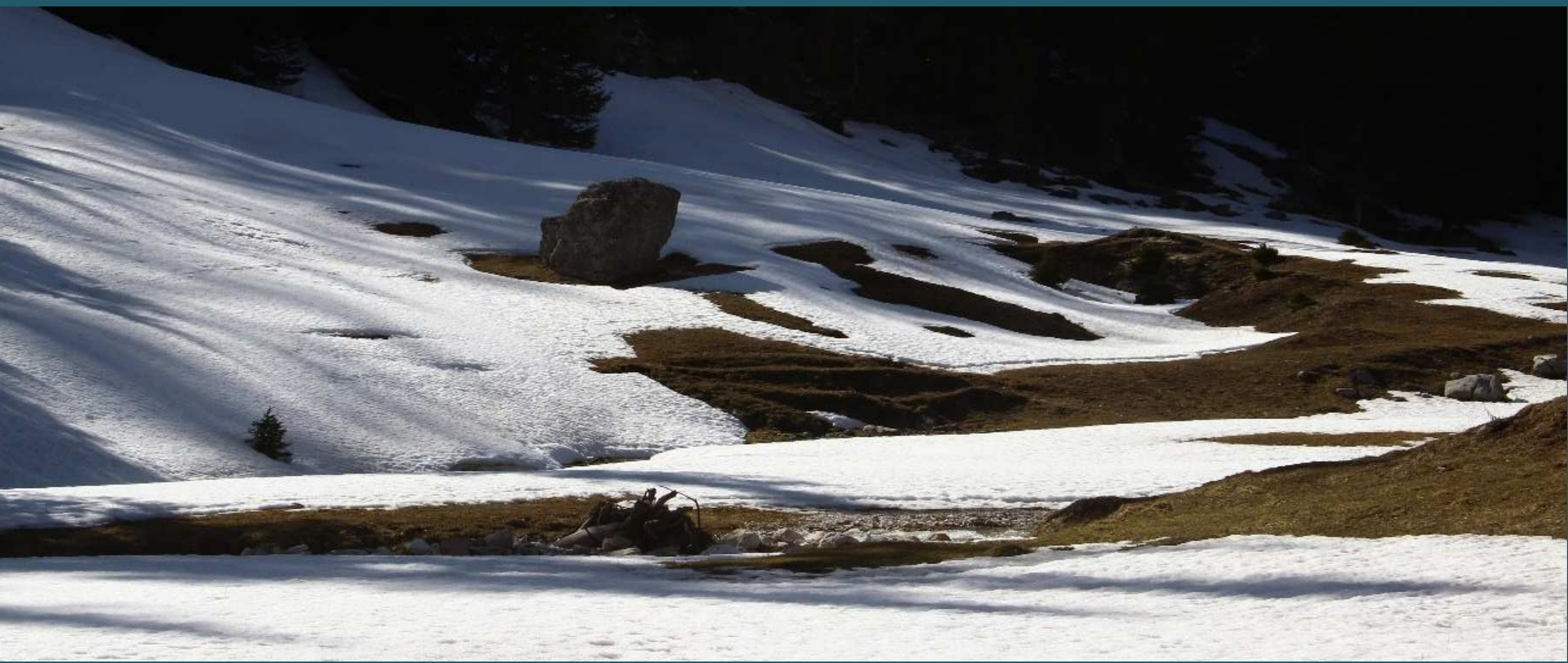
Please, avoid *empty/blank spaces* or *special characters* (@, # * etc.) in the file and folder names.

In the project file *do not* use the tabulator (Tab ⇆): use the space bar.

The sign - (minus) must be considered as mathematical *minus*, not as a hyphen

The ELIOVSP DVD contains a series of datasets with the complied *project files* that you can analyze in order to get familiar with the software (see "DATA_DISSEMINATION" folder).

4. Processing tools



➢ Max visualized time

By changing this value you can reduce/modify the maximum time visualized in the two panels (about the P and SH waves).
By changing this "max visualized time" and then clicking on "**refresh & AGC**" (in the center of the panel), the data will be displayed up to the indicated time and with the gain values (amplification and Automatic Gain Control) set by the user.
If you click the "**cut**" button the data currently not visualized (times larger than the “max visualized time”) will be definitely removed. It is useful to remove useless data (you just need to see the first arrivals) which can slow down the processing

➢ Filter

Low pass, high pass or band pass filtering is applied to **the two selected components**

➢ Gain

Multiplication factor (gain) applied to the data to increase the amplitude

➢ AGC (Automatic Gain Control)

AGC gain applied to the data (the effect is completely different with respect to the simple “multiplicative gain”). Since the characteristics of P and SH waves are significantly different, the AGC values are different for the two components

➢ “show data” button

It shows the uploaded data with the true amplitudes (i.e. not normalized) and the phase-velocity spectra (which can be useful for a quick estimate of the velocities)

➢ “flip P” e “flip SH” buttons

Flip the polarity of the traces for the two chosen components. It can be useful for improving the identification of the first arrivals

➢ “refresh & AGC” button”

Refreshing the data shown in the two (P and SH) panels and application of the gain and AGC values. Use different gain values so to better highlight the first arrivals

➢ HVSR curve import

You can import the HVSR curve (previously computed with any software – ***winMASW***® or ***HoliSurface***® or any software that provides the HVSR in the standard **.hv format**). At this point, the "HVSR option" (see right side of the panel) is automatically activated. Now, together with the P and SH theoretical arrivals of the model you are currently evaluating, the theoretical HVSR will be also computed and shown together with the experimental curve.

• HVSR curve cutting

A previously-uploaded HVSR curve can be "cut" (for example to remove high frequencies – usually frequencies higher than about 15 Hz are pretty useless for common geological goals) by clicking the ***scissor icon*** on the toolbar.

Note about the HVSR (average of *n* HVSR curves)

It is always recommended to record at least two (2) HVSR datasets (at two different points around the borehole) and then compute the average curve to be used in the joint analysis with P and SH-wave arrivals. Having two or more HVSRs at different positions around the borehole is necessary to verify that data are consistent and reliable. In *winMASW*® and *HoliSurface*®, it is possible to upload a series of HVSR curves, visualize all of them and compute the mean curve (which is automatically saved as *averageHVSR.hv* file in the working folder). Do it and, during the modelling, work with the average curve.

***Modelling* tools**

On the right side of the panel, you can find all the tools for the ***fprward modeling*** of the P and SH-wave arrivals (possibly jointly with the HVSR). Their meaning and use is quite intuitive (and should be already quite familiar to the *winMASW*® and *HoliSurface*® users).

- **The α (alpha) parameter**

By means of the α parameter (see the book published for Springer in 2020 or the *HoliSurface*® manual) it is possible to modify the amount of Love waves in the microtremor field. Generally this value is around 0.3 (*default value*) but it is possible to modify it (common values range from 0.2 to 0.5).

- **Reference depth**

It is the depth from which the Vs30 (or the **equivalent** $\mathbf{V_S}$) is computed. Usually this is the depth of the foundation (in meters) of the structure you are assessing.

V_S equivalent (VsE) [the mean Vs down to the bedrock depth]

The V_S equivalent (VsE or VsH) is defined according to the following formula:

$$V_{S,eq} = \frac{H}{\sum_{i=1}^{N} \frac{h_i}{V_{S,i}}}$$

where the depth H is the depth where V_S is equal or higher than 800 m/s (*seismic bedrock*). Maximum considered H is 30 m so that, in case the seismic *bedrock* is deeper than 30 m, VsE equals Vs30.

- **Upload *picking* (for comparison)**

You can upload a previously-picked set of data to compare them with the seismic traces currently visualized. It can be useful for different goals: comparing borehole data acquired in different sites and moments, verifying the uselessness of the VF data/acquisitions for the identification of the P-wave arrivals, etc.

In order to avoid uploading data with an exceedingly-high sampling rate (this would slow data the data pre-processing), an **automatic re-sampling option** is now available. If activated (by default), during the project/data upload, seismic data are automatically resampled at 1000 Hz (1 ms) which, considering the actual frequency content of ordinary DH seismic data, is more than sufficient (just remember and consider the Nyquist-Shannon theorem).

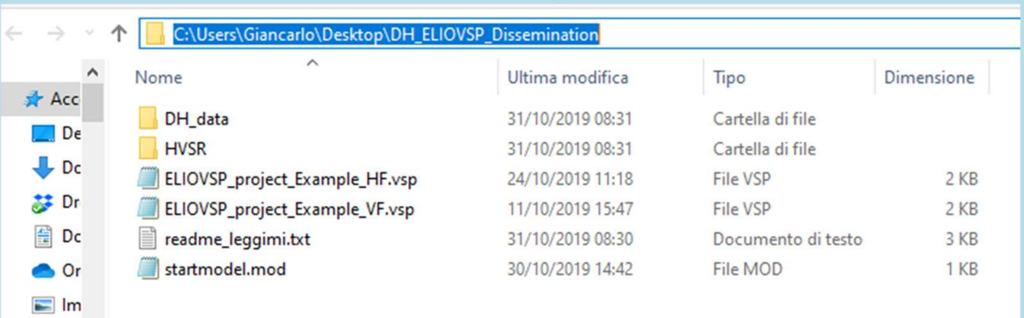
The working folder

After you launch ELIOVSP, you need to set the *working folder*.

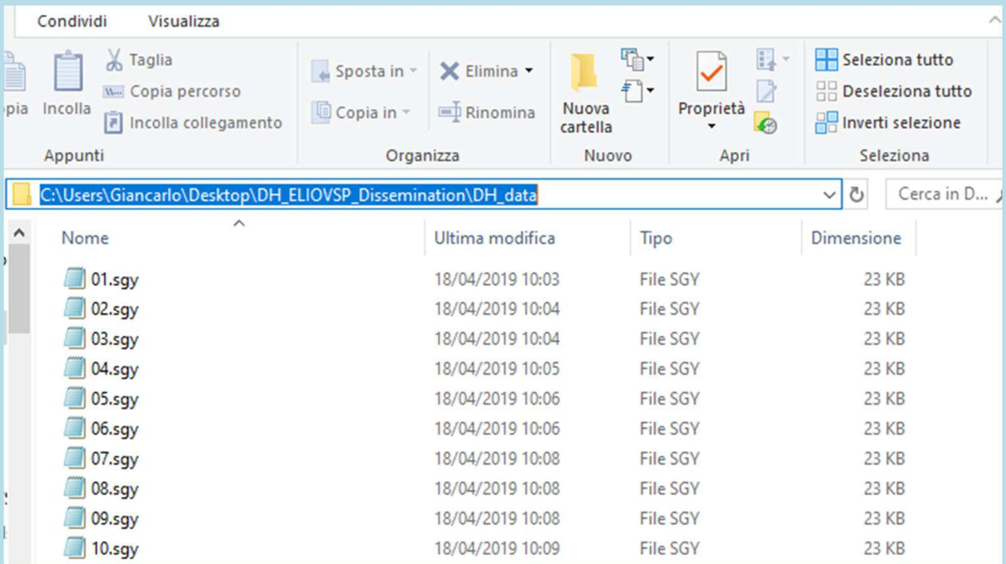
Here for instance the working folder is:

"C:\Users\Giancarlo\Desktop\DH_ELIOVSP_Dissemination" and the two subfolders contain the HVSR and DH data, respectively.

The *project files* (for VF and HF data) are the two .vsp files.



It is important that all the HF (and VF) files are in the same subfolder [see snap below]



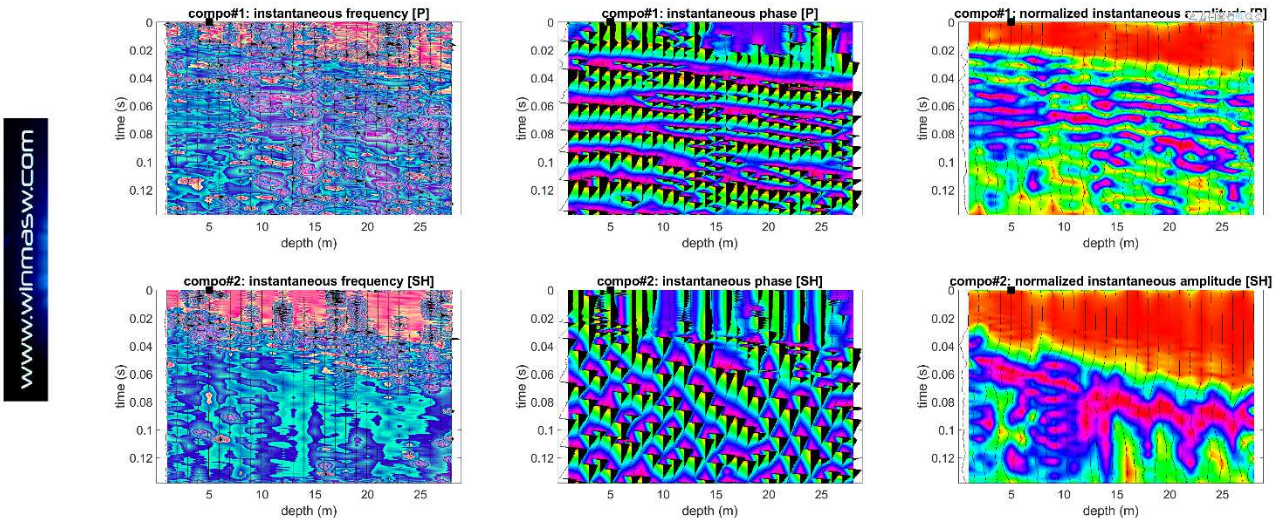
Seismic attributes: Instantaneous Frequency, Phase and Ampllitude

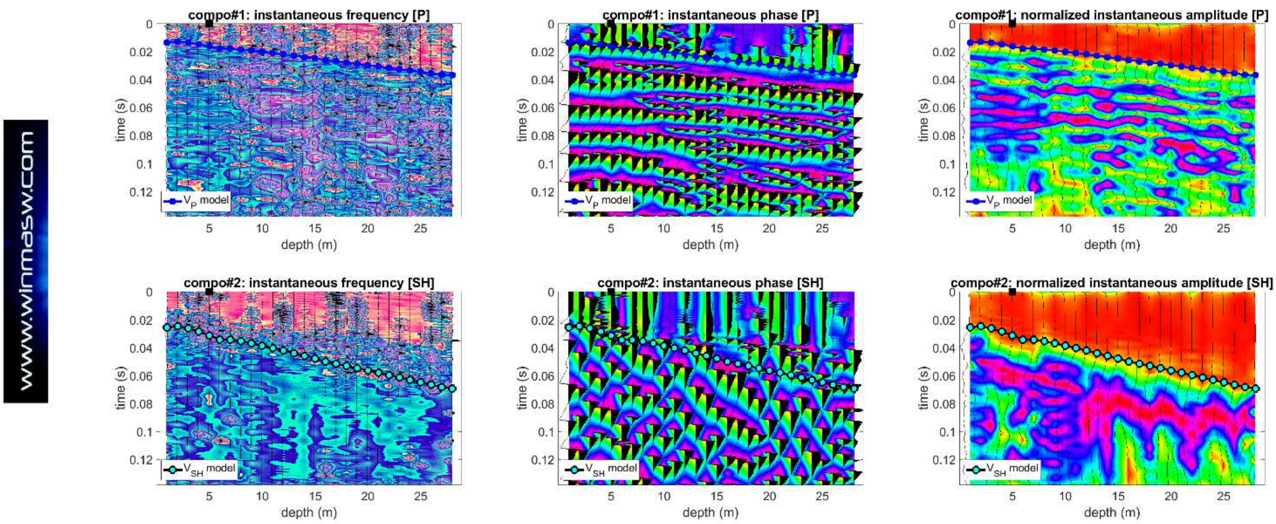
What are the ***seismic attributes***?
Here an introductory paper: https://spgindia.org/2008/398.pdf

Once the data have been uploaded, the **ATTRIBUTES button** can be used to compute *seismic attributes* (instantaneous frequency, phase and amplitude) which, especially in the case of complex and dirty data, can help to better track the body wave first arrivals.

In the case you are performing a forward modelling session, a dialogue box will ask whether you wish to plot also the arrival times of the current model.

In the two images shown below, an example of computed seismic attributes for the data of the **example#4** presented in this manual (see the “Examples of data processing” section). Above the attributes plotted without the P- and SH-wave arrival times of the current model and below with the model arrival times.





5. Modeling/inversion: possible and recommended approaches

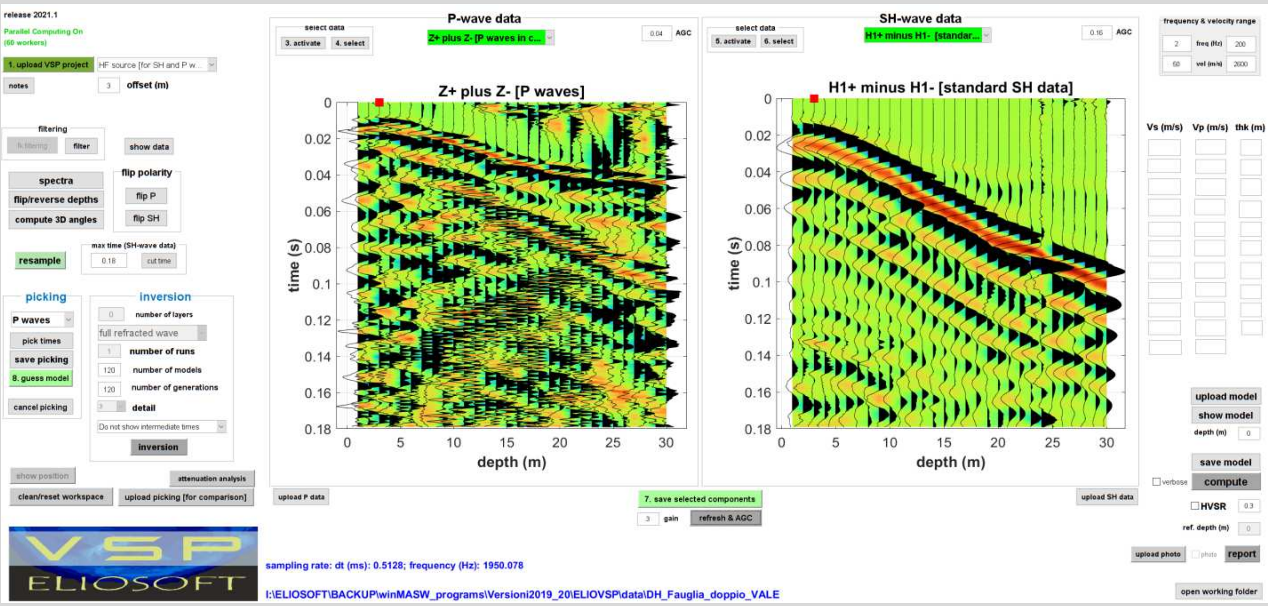
Forward modeling (the recommended approach)

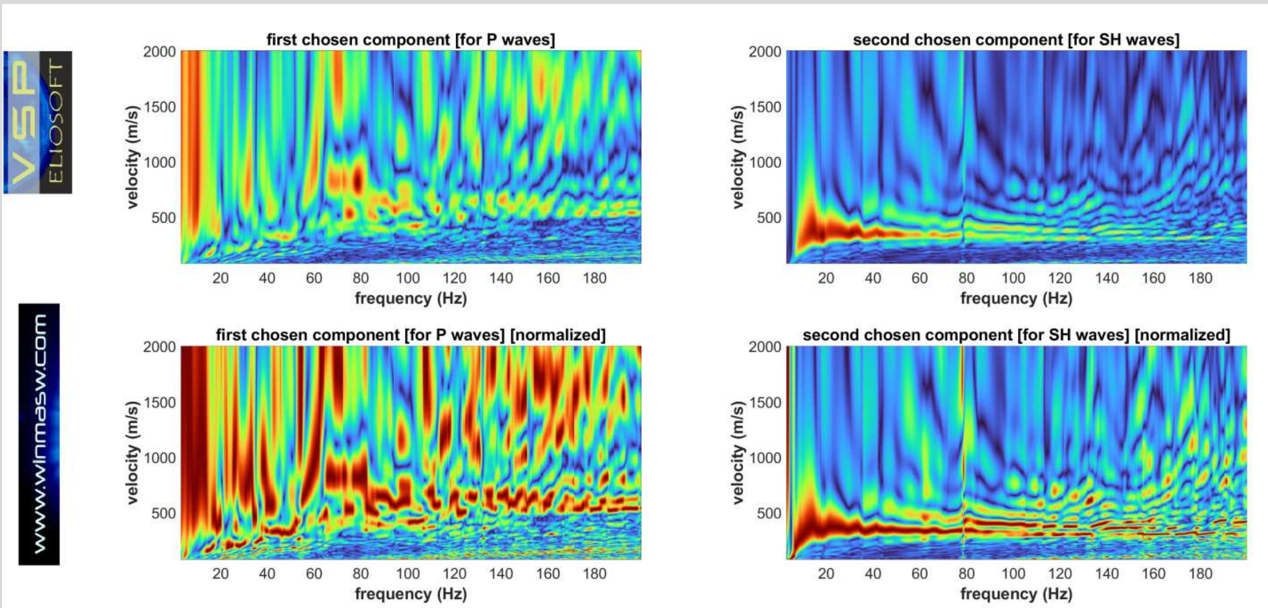
Let us suppose you uploaded the data (by means of the *Project file*) and chosen the two best components useful to identify the P and SH-wave arrivals.

Now you can follow different approaches: 1) the old-fashioned pick-and-invert approach (not recommended); 2) the forward model way (recommended). This section is about this second approach.

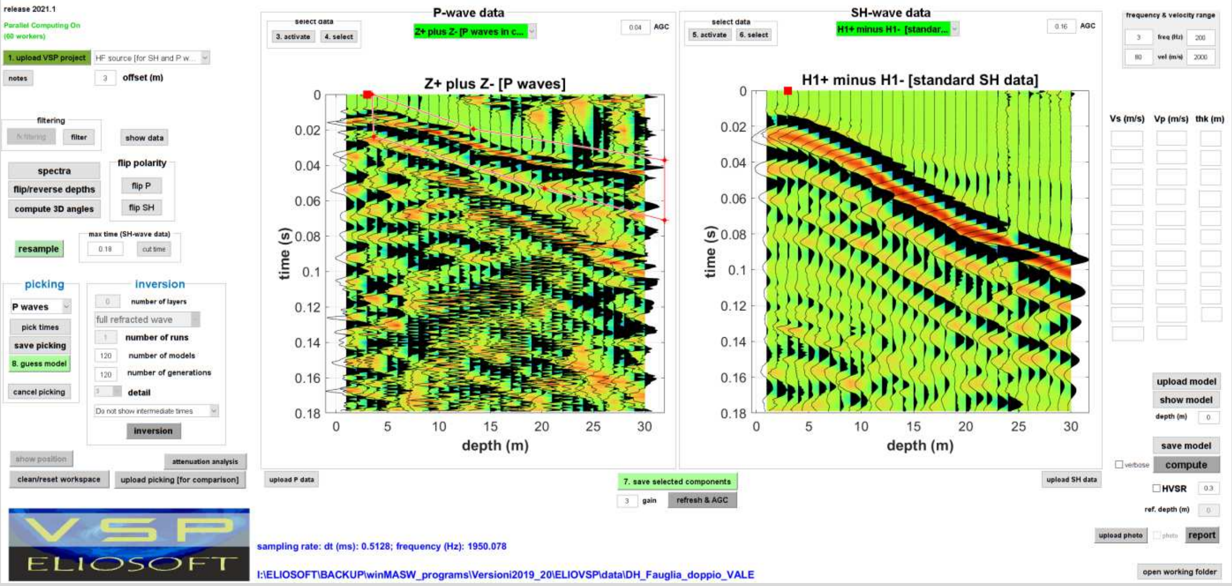
The guess model button

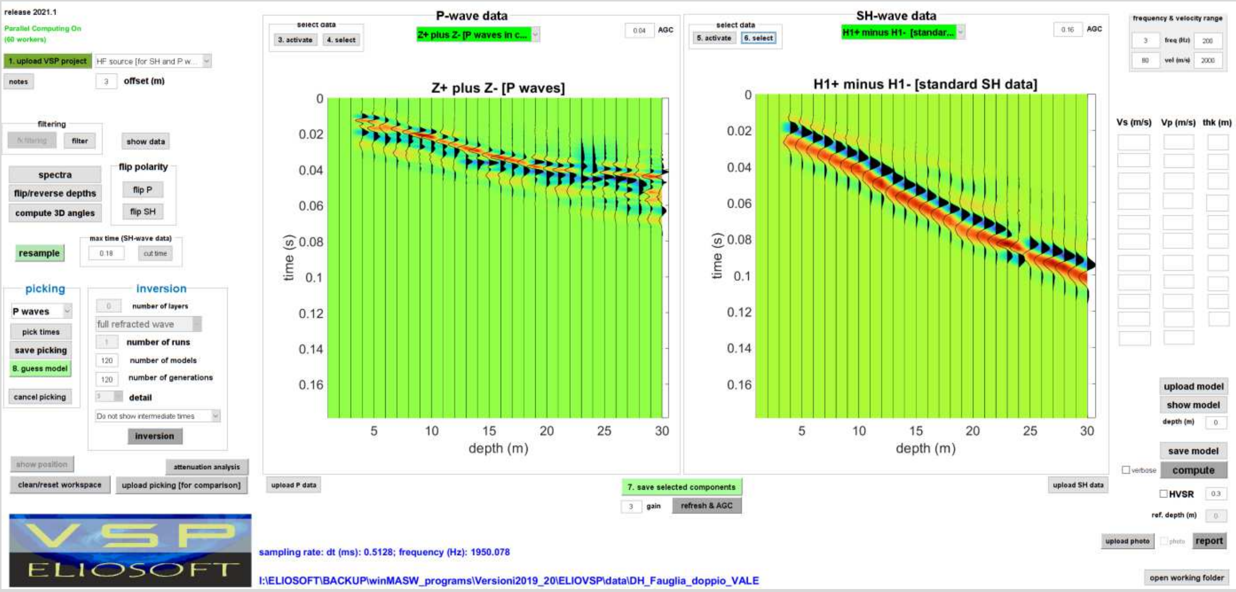
If you click the **guess model** button without having picked anything, the phase velocity spectra of the selected components are shown, providing an estimate of the respective velocities.

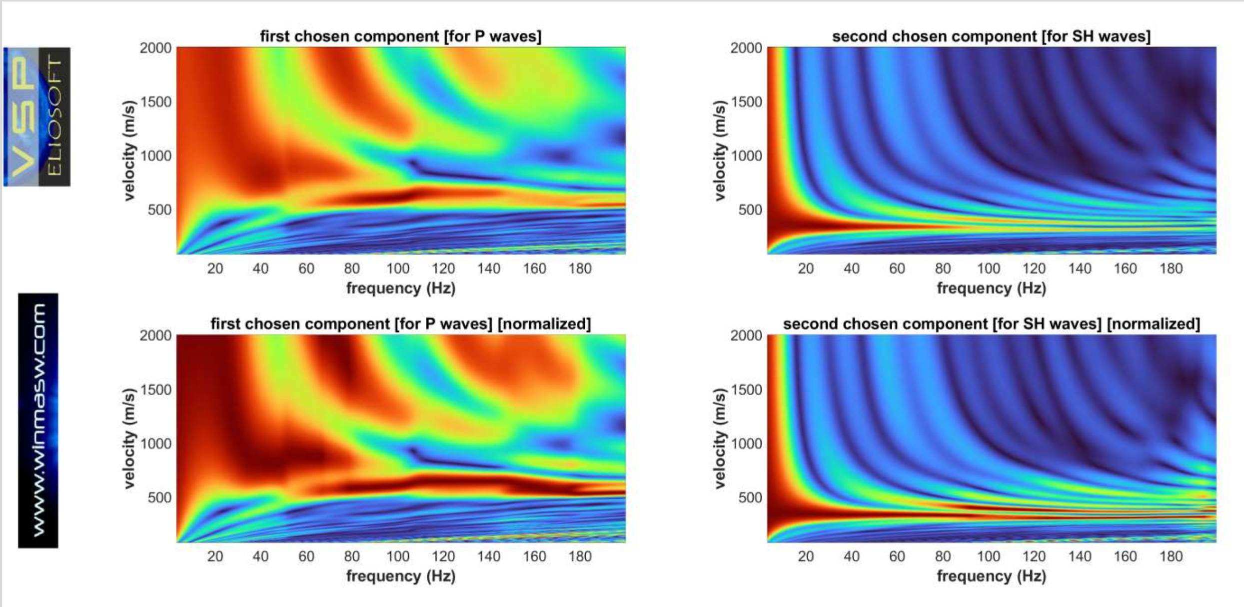




If you want to have a more accurate estimate of the velocities by means of the phase-velocity spectra, you need to select **just the first arrivals**. You can do that by removing the data not related to the first arrival. Do that with the selection/cleaning tools ("**activate**" and "**select**" buttons in the upper-left corner of the P and SH panels) [see next snapshots].







Important: this operation can provide useful information only if the offset used during the acquisition is sufficiently small (with respect to the depth of the borehole).

If you decide to pick for instance the P-wave arrivals, it is possible to obtain a first (*starting*) model concerning the P waves by clicking the "**guess model**" button (but having an initial “guess model” **is not necessary**).

Of course, when the picking of the arrivals of the SH waves has been done, it is possible (by clicking the same "**guess model**" button) to have a starting model about the SH waves.

Remember that, for P and SH waves, picking must be done at the same points (depth) [in other words, the models must have the same number of layers].

Through the ***forward modeling*** (i.e. when the user modifies personally the velocities and thicknesses – **this is the recommended approach**) it is possible to modify the model, also taking into account the HVSR. You will find that the "first model" obtained through the "guess model" procedure is generally reasonably good, thus making quite easy to optimize the model manually/personally through the *forward modeling* (i.e. by changing the velocities and thicknesses of the layers, following the elementary concept that if the computed arrival times are smaller than the experimental data it means that the velocities of our model are too high and you need to make your model “slower” decreasing the velocities – and vice versa). Please, see the following table to have a rough idea of typical V_S values.

Type of sediment/material	Typical V_S (shear-wave velocity) value (m/s)
peats	20-70
silt/clay	100-300 (over-consolidated clay can reach higher velocities)
sand	150-500
gravels	300-600
conglomerates	600-1000
weathered rock	500-800
solid rock	800-2000

Typical V_S values for the main classes of sediments (V_P values are much more variables because depend on saturation conditions – i.e. on the amount of water)

Modeling for *beginners*

1. Create a folder (which will be the *working folder*), put the recorded data in a *subfolder* and prepare/compile the *project file* about the **HF acquisitions (if you have recorded the data as recommended in the "Data acquisition: recommendations" section, P waves will be very clear [along the Z component] even while considering the HF shots [no need for VF acquisitions])**

2. Upload the *project file* (i.e. the data) [click the "*upload VSP project*" button and choose your previously-fixed .vsp project]

3. Choose the component where the first arrivals of the SH waves are most clear (**P waves are always analyzed considering the data along the Z vertical component**). Usually, if data where recorded according to our recommendations, the "**H2+ minus H2- [standard S-wave data]"** component is the one where SH waves are clearer

4. To emphasize the first arrivals click the "**refresh & AGC**" button. In this way, both the gain value and the AGC will be applied to the data (note that the AGC values for P and SH waves are different). Try to modify the gain and the AGC values so to obtain clear first arrivals

5. Once you understand the first arrivals of both P and SH waves (you can change the gain and AGC values and, in case, apply some filter), you can start *picking* the P waves (having activated the P waves in the *picking group*)

6. Save the picked arrival times (***save picking*** button)

7. Now activate the SH waves (pop-up window within the *picking group*) and repeat the same procedure you just did for P waves (*picking* and *saving*)

8. Now you can click the "**guess model**" button and on the far right of the panel the estimated values for P and S waves velocities will appear

9. Now - if you want - you can upload a previously-computed HVSR curve and proceed with a joint modeling starting from the P and SH model generated through the previous steps.

When you are satisfied with the agreement between data and model, you can click the "**report**" button and, in the *report subfolder* that will be automatically created, a series of figures and data (e.g. an Excel *xls* file with computed travel times) are saved.

The picking rules

1. The first and last traces **must be always** picked;
2. The number of layers is given by the number of points minus 1 (if - for instance - four points are picked, we are telling the software that we have a three-layer model);
3. **Do not pick each single trace**. You need to identify the "trends" (which identify the actual number of layers). So far the maximum number of picks is 12 (number of layers = number of picks – 1) [see previous point];
4. For P and SH waves, the **same points** (traces/depth) must be picked;
5. You must pick first the P waves (left panel) and then SH waves (right panel): at the end of the P-wave picking (left panel), a series of points will appear on the right panel (about SH waves) at the depths used for the P-wave picking. These points are useful to guide you while picking the SH waves (that must be done for the same depths/points).

Important notes

Remember that the picking is always subjective and, given the small distances considered in the ordinary surveys, very few milliseconds of difference can lead to significant variations in the obtained velocities. For this reason, we suggest and recommend the *forward modeling* (possibly together with the HVSR curve) and not the *picking-inversion approach* (described in the previous page).

Remember that a joint analysis (of any kind) is always a compromise: we cannot obtain a perfect solution with respect to each single *observable* and we should rather try to achieve an overall consistency/agreement [see for example the P + SH + HVSR joint analysis presented in the next sections of this manual as well as Dal Moro and Puzzilli 2017].

The recommended workflow: the *forward modelling*

As a matter of fact, **an initial "guess model"** (which can be used once the picking of both P and SH waves has been made) **is not necessary**. In fact data modeling can be easily performed on the basis of elementary reasoning: when the arrival times of *your model* are lower than the observed data it means that the velocities of your model are too high (and vice versa).

Here the simple **sequence of operations you need to get familiar with** (the first four steps are the same as seen before since they are meant to upload and pre-process the data):

1. Create a folder (which will be the *working folder*), put the recorded data in a *subfolder* and prepare/compile the *project file* about the **HF acquisitions (if you have recorded the data as recommended in the "Data acquisition: recommendations" section, P waves will be very clear [along the Z component] even while considering the HF/inclined shots [no need for VF acquisitions])**

2. Upload the *project file* (i.e. the data) [click the "*upload VSP project*" button and choose your previously-fixed .vsp project]

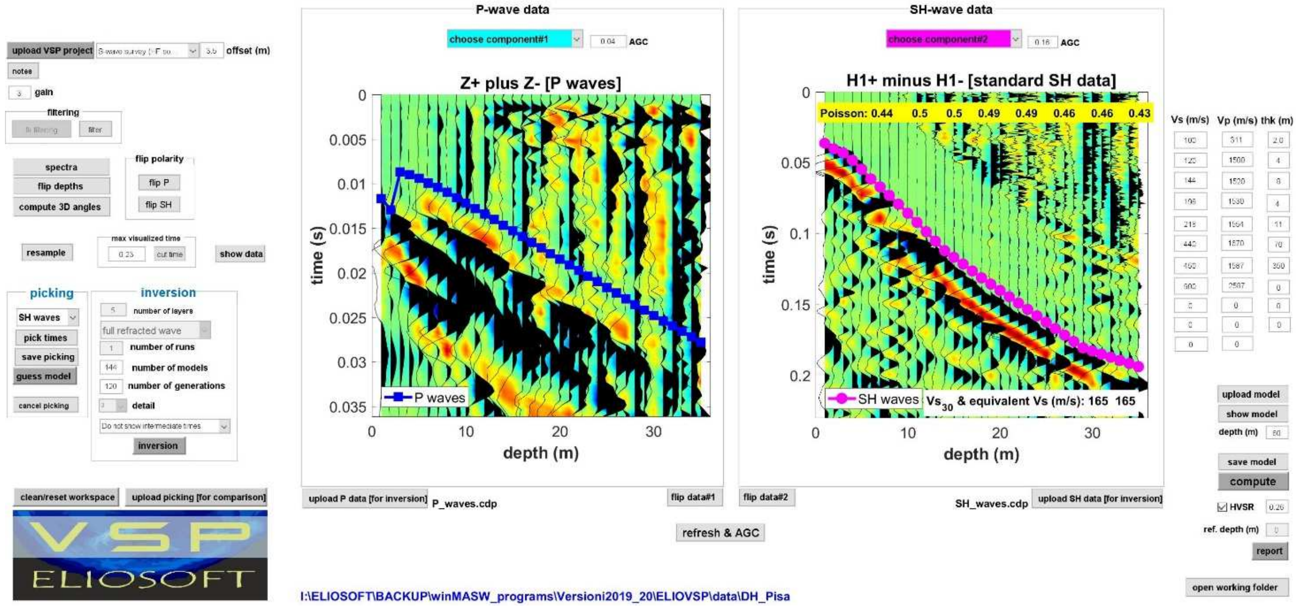
3. Choose the horizontal component where the first arrivals of the SH waves are most clear (P waves are always analyzed considering the Z component/geophone). Usually, if data where recorded according to our recommendations, the "**H2+ minus H2- [standard SH VSP]"** component is the one where SH waves are mostly clear

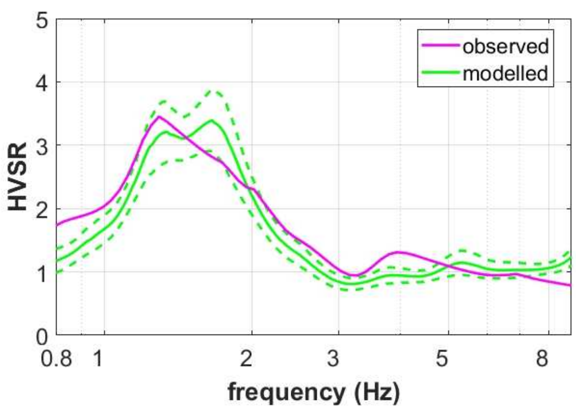
4. To emphasize the first arrivals click the "**refresh & AGC**" button. In this way, both the gain value and the AGC will be applied to the data (note that the AGC values for the P and SH waves are different). Try to modify the gain and the AGC values so to obtain clear first arrivals

5. Upload (this is optional but strongly recommended) a previously-computed HVSR curve [remember it is not recommended to record a single HVSR; compute two or more HVSRs at different points around the borehole and compute the average HVSR curve – you can do that with the software you use to process HVSR data, for instance *HoliSurface*® or *winMASW*®]

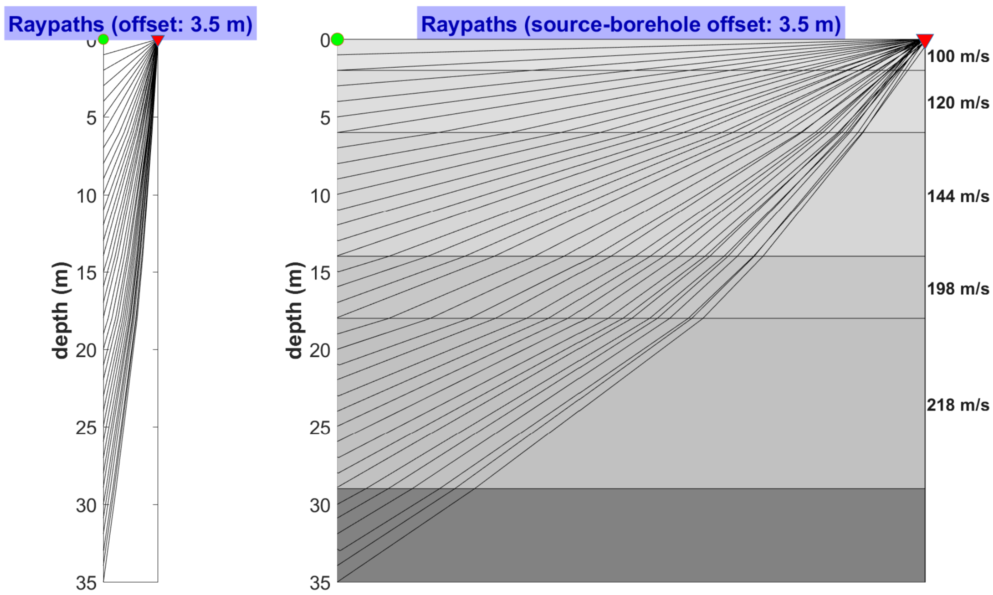
6. **Start the *forward modeling***. In order to do that, insert the V_S, V_P and thickness values you suppose/guess for the site and click the **"compute" button**. Then modify the velocities and the thickness of the layers (and click the "compute" button) so that the computed arrivals of the P and SH waves (and possibly the HVSR) are consistent with the field traces (see the examples shown in the next pages). The concept is extremely simple: if the computed arrival times are smaller than the ones of the field traces it means that the velocities of your model are too high and you need to decrease the velocities of the pertinent layer(s) (and vice versa). This might seems "complicated" but a few minutes of practice will allow you to get familiar with this approach.

7. Once you are satisfied with the agreement between field and synthetic data (P, SH and HVSR), click the **"report" button** (bottom-right corner of the software panel): a "report" folder will be created within the working folder and all the figures and data shown will the automatically saved in it.

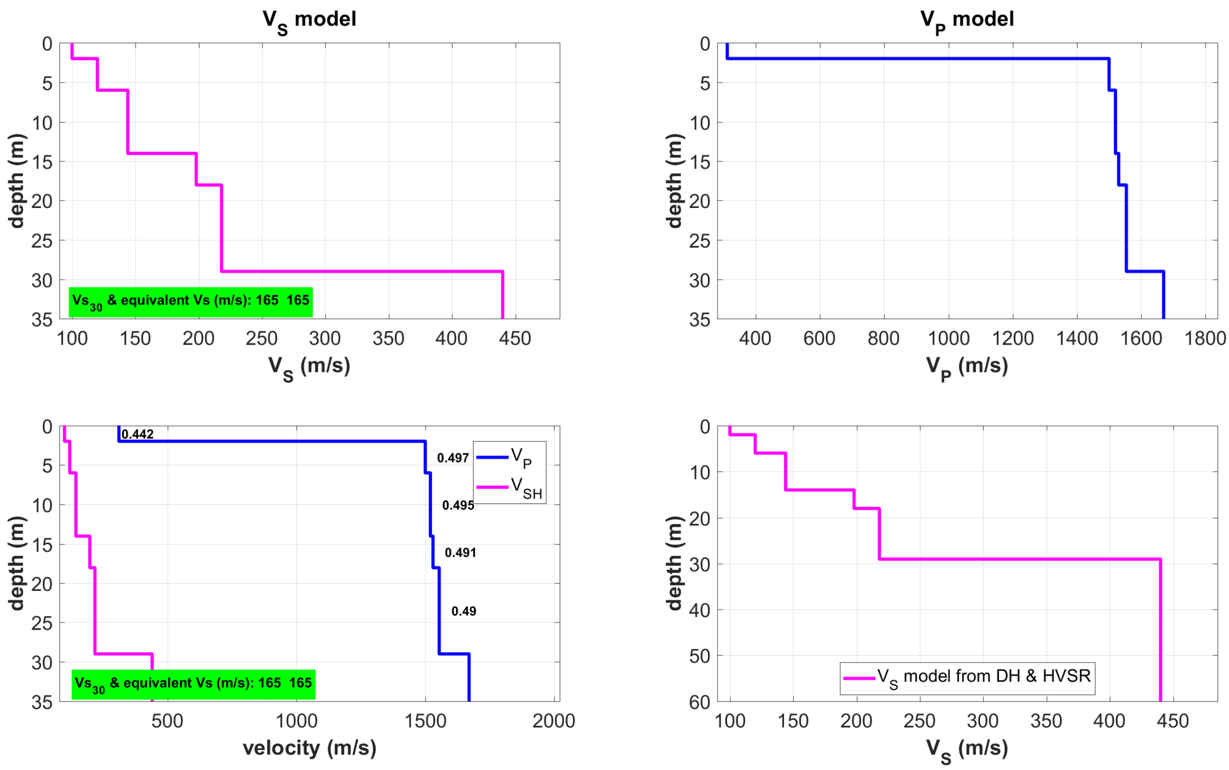

P-wave data
SH-wave data
Z+ plus Z- [P waves]
H1+ minus H1- [standard SH data]
Poisson: 0.44 0.5 0.5 0.49 0.49 0.46 0.46 0.43
time (s)
depth (m)
P waves
SH waves
Vs30 & equivalent Vs (m/s): 165 165
Vs (m/s) Vp (m/s) thk (m)
upload VSP project
offset (m)
notes
gain
filtering
spectra
flip depths
compute 3D angles
flip polarity
flip P
flip SH
resample
max visualized time
cut time
show data
picking
SH waves
pick times
save picking
guess model
cancel picking
inversion
number of layers
full refracted wave
number of runs
number of models
number of generations
detail
inversion
clean/reset workspace
upload picking [for comparison]
upload P data [for inversion]
P_waves.cdp
flip data#1
flip data#2
SH_waves.cdp
upload SH data [for inversion]
refresh & AGC
upload model
show model
save model
compute
HVSR
ref. depth (m)
report
open working folder
I:\ELIOSOFT\BACKUP\winMASW_programs\Versioni2019_20\ELIOVSP\data\DH_Pisa


observed
modelled
HVSR
frequency (Hz)

scale 1:1


Raypaths (offset: 3.5 m)
Raypaths (source-borehole offset: 3.5 m)
depth (m)
100 m/s
120 m/s
144 m/s
198 m/s
218 m/s

layer	Vs (m/s)	thickness (m)	depth (m)
1	100	2	2
2	120	4	6
3	144	8	14
4	198	4	18
5	218	11	29
6	440	70	99
7	450	350	449
8	900	0	0



depth (m)	P (ms)	SH (ms)
1	0.0117	0.0363
2	0.0129	0.0403
3	0.0087	0.0433
4	0.0090	0.0485
5	0.0094	0.0548
6	0.0099	0.0617
7	0.0104	0.0673
8	0.0110	0.0732
9	0.0116	0.0795
10	0.0122	0.0858
11	0.0128	0.0923
12	0.0134	0.0989
13	0.0140	0.1055
14	0.0147	0.1122
15	0.0153	0.1169
16	0.0159	0.1217
17	0.0166	0.1265
18	0.0172	0.1314
19	0.0178	0.1358
20	0.0185	0.1403
21	0.0191	0.1447
22	0.0197	0.1492
23	0.0204	0.1537
24	0.0210	0.1582
25	0.0216	0.1627
26	0.0223	0.1672
27	0.0229	0.1717
28	0.0236	0.1762
29	0.0242	0.1808
30	0.0248	0.1829
31	0.0254	0.1851
32	0.0260	0.1873
33	0.0266	0.1895
34	0.0272	0.1918
35	0.0278	0.1940

P_SH_TravelTimes_
milliseconds.xls

Picking and automatic inversion

The (saved) picked (P and SH) arrivals can be used (and/or re-uploaded later on) to perform the *automatic inversion* (which we do not recommend and which, as you will see from the goodness of the model obtained through the "guess model" and some *forward modeling*, it is usually unnecessary).

In order to *pick* and *save* the arrival times for P and SH waves see the "Work/modelling sequence for *beginners*" section and the “The picking rules” box.

Once the picking (of **both** the P and SH waves) has been done (remember to save both the arrivals), it is possible to perform the automatic inversion.

The sequence is therefore:

1) Select “P waves” in the pop-up window within the “picking group”

2) *Pick* the first arrivals for P waves [left panel]

3) Save them (“save picking” button)

4) Select “SH waves” in the pop-up window within the “picking group”

5) *Pick* the first arrivals for SH waves [right panel] [remember you must pick the same points used while picking the P waves]

4) Save them (“save picking” button)

5) Click the "guess model" button [this will define a starting model]

6) Click the “compute” button to verify how good is this *starting model* and modify it to improve it (this is pretty elementary – see “The workflow we recommend: the *forward modelling*” section)

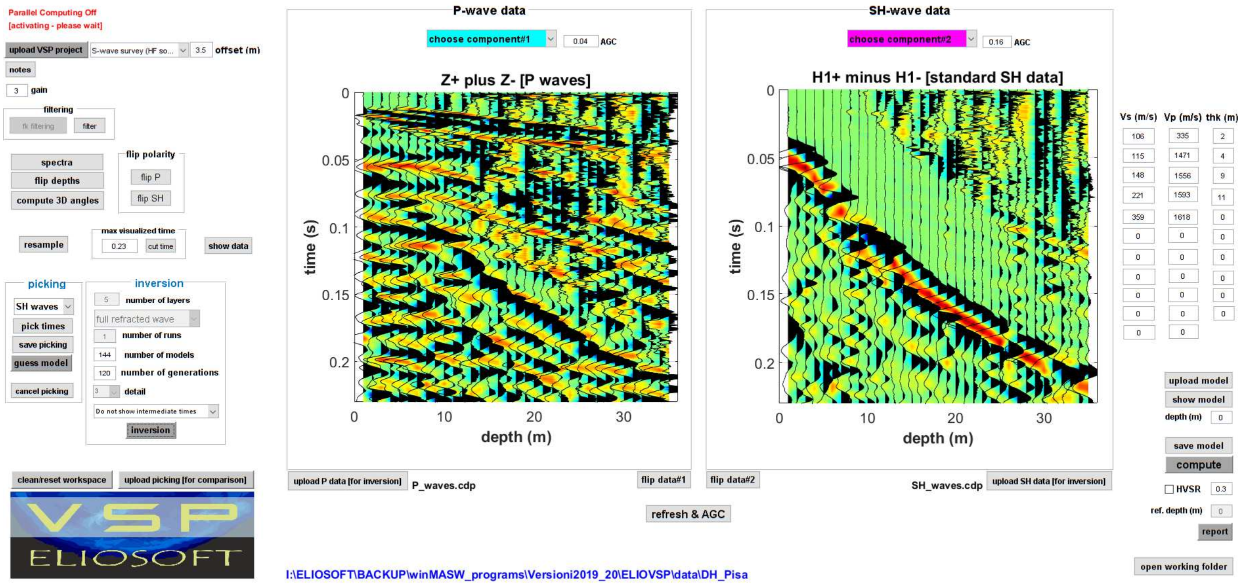
7) If, for some reason, this model still does not satisfy you (usually you can obtain a pretty good match already at this stage), you can launch the automatic inversion (**"inversion" button**) which will help you to optimize the model (V_{SH} and V_P)

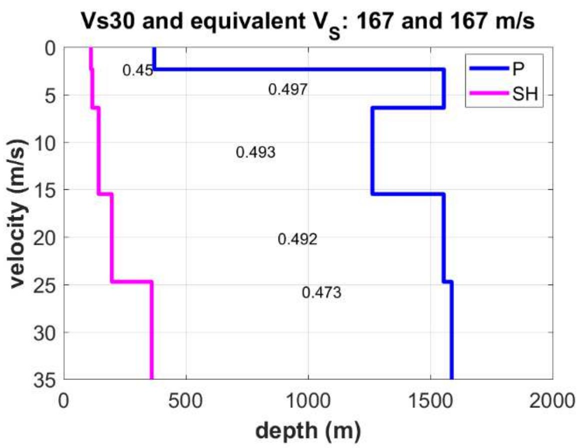
Above the "inversion" button there is a **pop-up menu** you can use to choose whether to view (**"Show intermediate times/solutions"**) or not (**"Do not show intermediate times/solutions"**) the arrival times computed for each generation/step of the optimization procedure (the visualization is a “nice option” that slightly slows down the computation times).
At the end of the joint inversion process (P + SH) in the **output folder** (**"\inversionRESULTS\"**) a series of files/figures and data (that summarize the overall process) will appear.

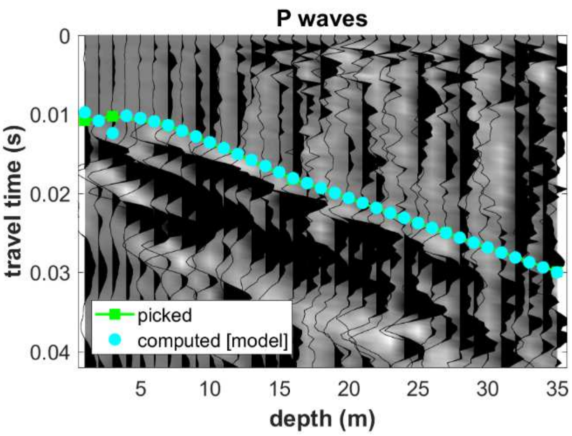
In the current release of ELIOVSP, the automatic inversion is "only" for the P and SH waves. On the other side, if we decide to perform a ***forward modeling*** (i.e. the procedure where the user modifies velocities and thicknesses of the model) we can also include the HVSR (which is a further reason why *forward modeling* is the approach to learn and use).

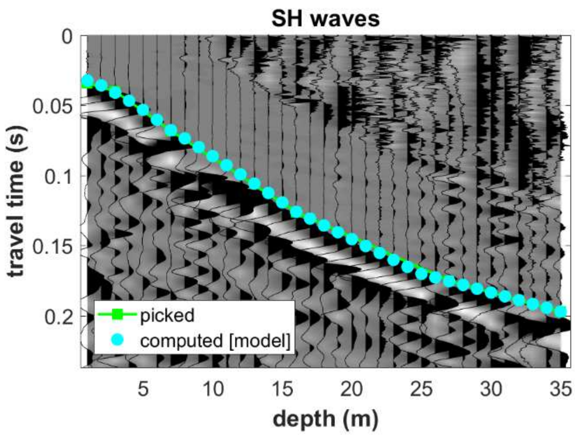
Always remember that while performing an automatic inversion you are not inverting the *data* but your data *interpretation* (your picking is your *interpretation* – which can be wrong or inaccurate).

This point applies to most of the inversion procedures (refraction studies, surface wave analysis etc. – see our Springer 2020 book) and is often poorly understood.









P_SH_TravelTimes_
milliseconds.xls

6. *Damping* evaluation

Available in the *next release*

General note: to perform this sort of analysis, it is **necessary** to record the data **strictly** following the recommendations reported in this manual and pay great attention to the fact that each shot should be accomplished with the same energy. To do this, the very first (and simplest) thing to do is to increase the *stack* as much as possible: in this way the inevitable differences between the single shots will be averaged.

7. Notes (miscellaneous)

Consider that, in general, due to possible complex *near source* effects, the first 2-4 m of your borehole are usually quite hard to solve (in the shallow layers, generated seismic waves are extremely complex and it is practically impossible to distinguish between different types of waves). Therefore, in the first few meters, do not give too much credit to the velocity values obtained from borehole data interpretation.

Possible cement leakage (the cement can filter inside porous sediments) is one of the main problems that can heavily affect the data quality and consequently the quality of the overall survey.

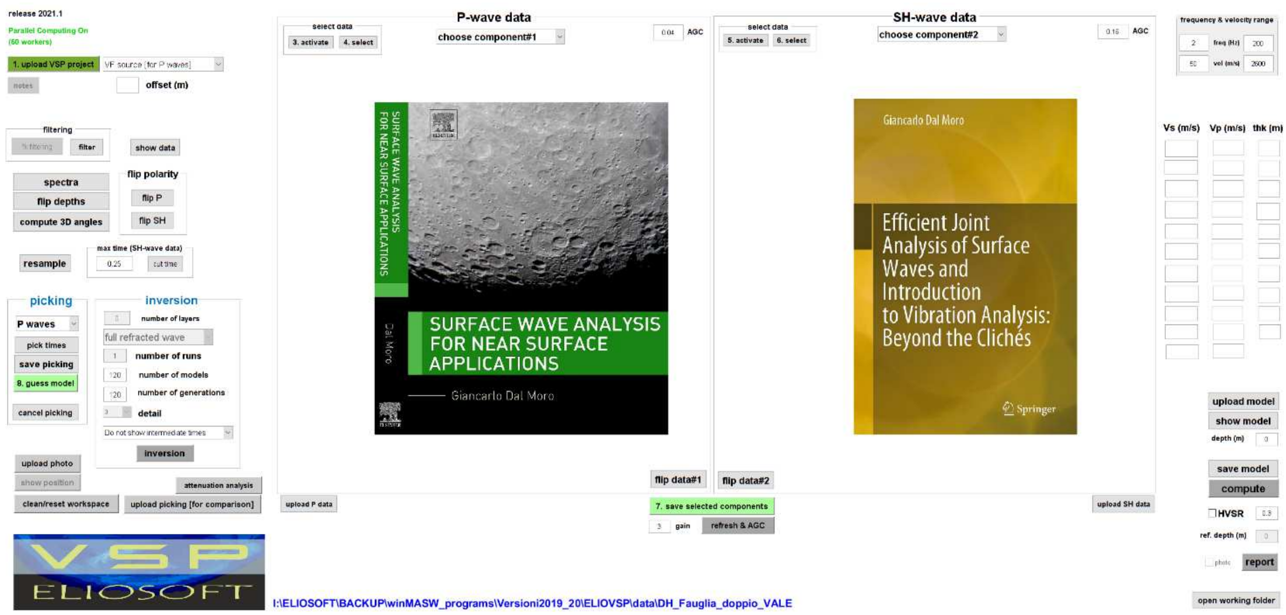
Remember and consider that, contrary to some popular preconceptions, borehole seismic **is not** *the truth*. The quality of the analyses (and therefore the velocity model) depends on the data quality, which is the result of a long series of bad or good decisions that are made while digging the borehole, during the data acquisition and during the data analysis.

8. Examples of data processing [recommended approach]

This section presents some examples of the processing sequence we recommended. Needless to say that, in order to achieve high-quality analyses, it is important to record the data according to the recommendations reported in the "Data acquisition" section.
The sequence of operations to be accomplished is facilitated by the fact that the related software buttons are marked with a progressive number that should help you to follow a logical sequence.

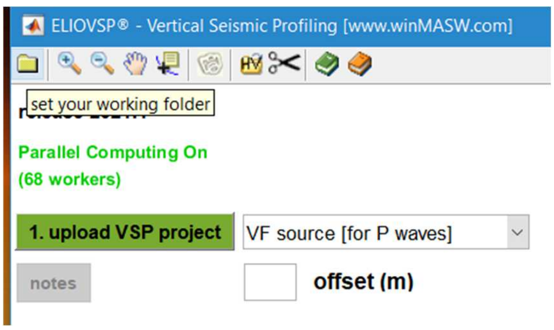
All the presented data are available on the ELIOVSP DVD (see “**Supplied data**” section).

The first processed dataset was kindly provided by **AB GEO snc** (Andrea Alessandrini & Francesco Bassano, Tolentino – Italy) and is available in the ELIOVSP DVD for your self-training (see “Supplied data” section).

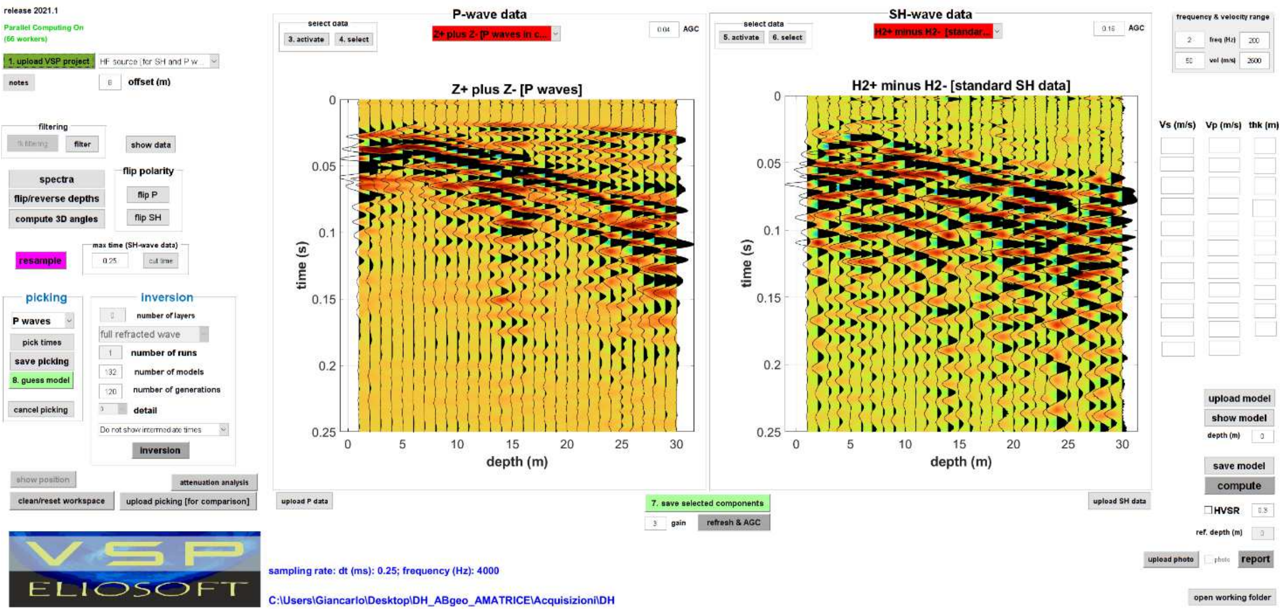


The main panel of the software as it appears before uploading the data

step#1. After setting the *working folder* [button on the top left corner of the toolbar – see below], you must upload the previously-compiled HF project file (see "**The Project file**" section) [button top left **1. upload VSP project**]

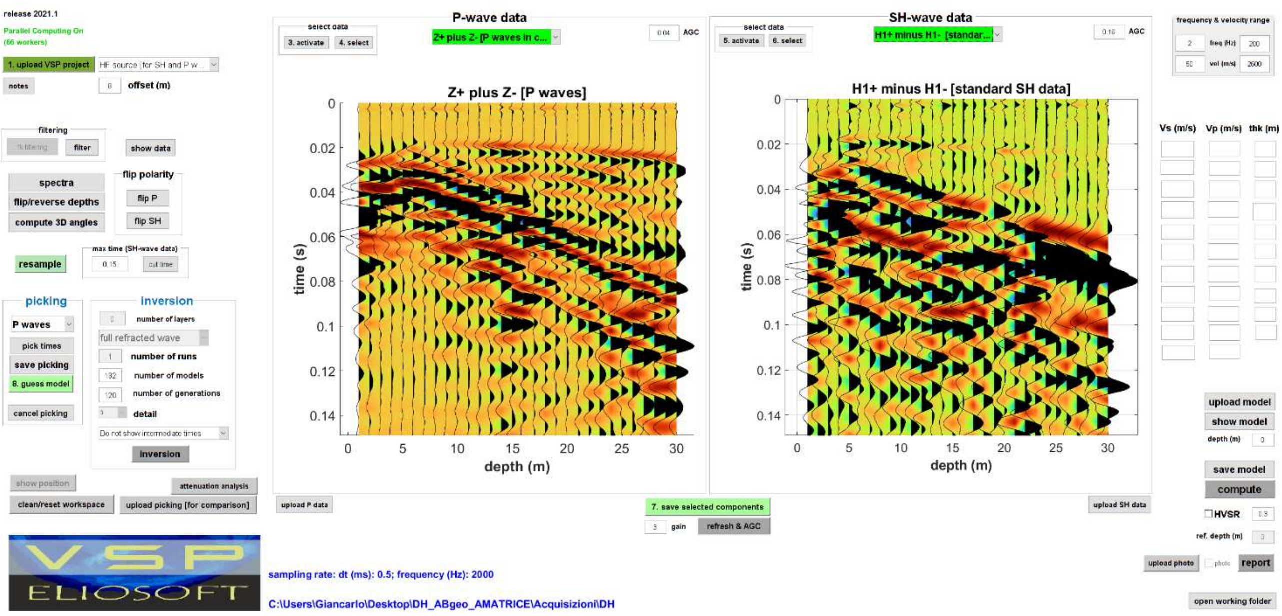


set up the *working folder* and *upload* the *Project file*

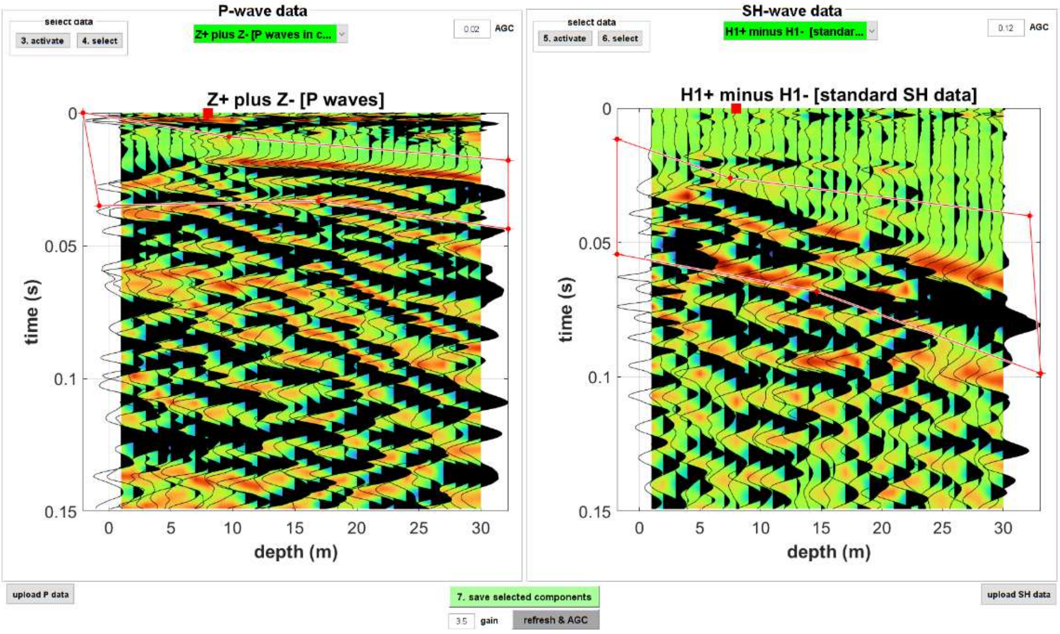


When you upload the data (in this case, as strongly recommended, from the HF acquisitions only), some *default* decisions are clearly applied: on the left panel are shown the Z-component traces (for the P-wave identification) while on the right panel are reported the traces obtained from the difference between the H2+ and the H2- traces (remember that H2 should represent the transversal T component and, consequently, “H2+ - H2-” means the difference between the *left* and the *right* HF shots, which is the very classical why to emphasize the shear waves).

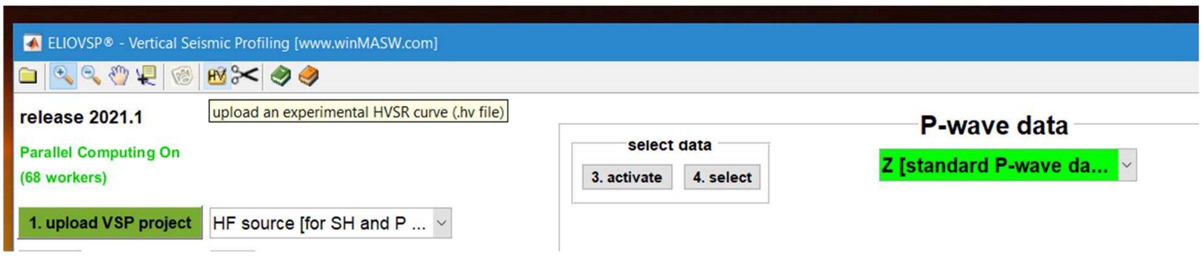
step#2. Choose/confirm the two components (pop-up menus in the top part of the two panels) and, in case, **re-sample the data**. Since the acquisition procedures may be different from those suggested in this manual, it is possible to choose (or confirm) the components that we want to consider in order to identify the first arrivals of the P and SH waves. After that, we can re-sample the data ("**resample**" button) so to get rid of useless data (always remember the [Nyquist-Shannon theorem](#)!).

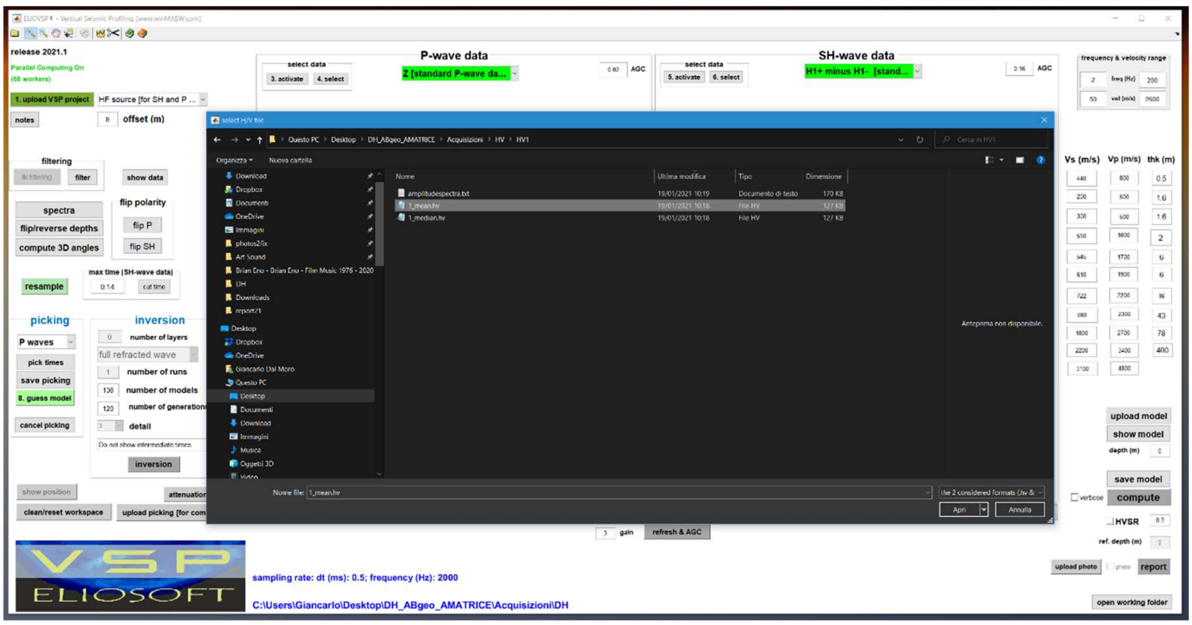


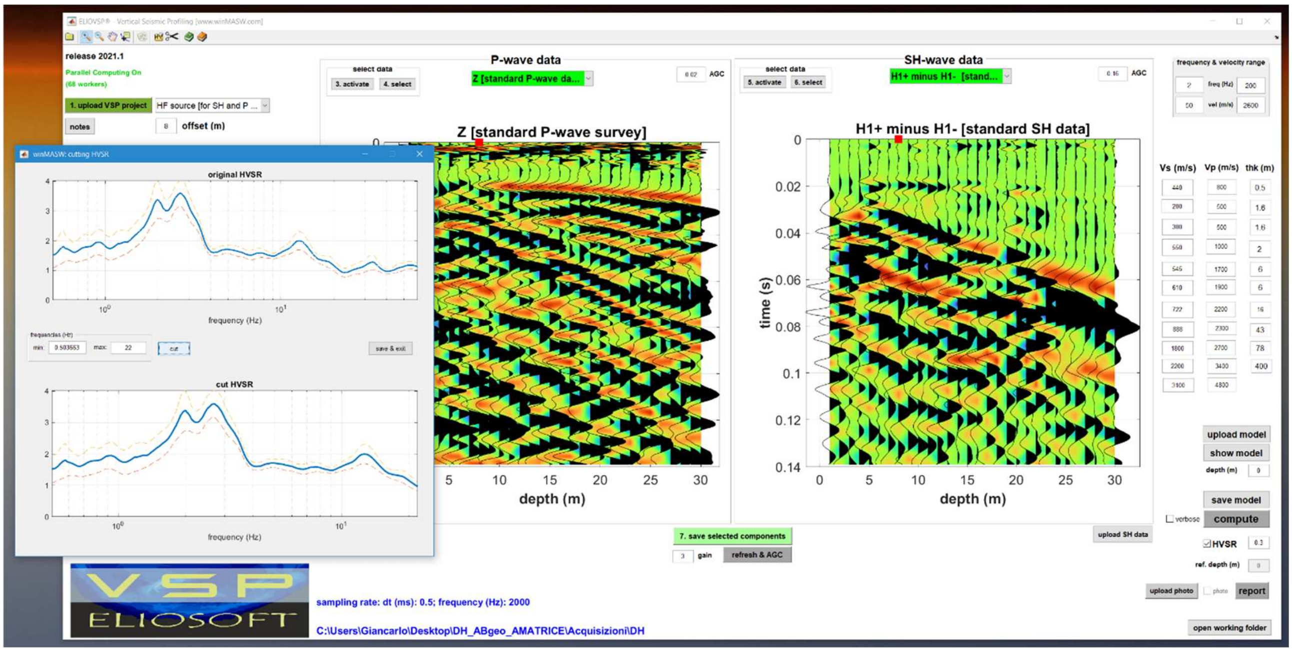
steps#3-6 [optional]. Trace cleaning so to isolate the P and SH-wave first arrivals ["activate" and "select" buttons in the upper left corner of each of the two panels]. First activate this tool and then modify the polygon so to keep inside only the first arrivals and, when you are satisfied, click “select” (data outside the polygon will be removed).



Now upload the HVSR curve – optional but recommended (both to better constrain the model and to extend the Vs model beyond the borehole depth). The HVSR curve needs to be previously computed (for instance with *HoliSurface*® or *winMASW*®). Use the **HV button on the toolbar** (see images here below).





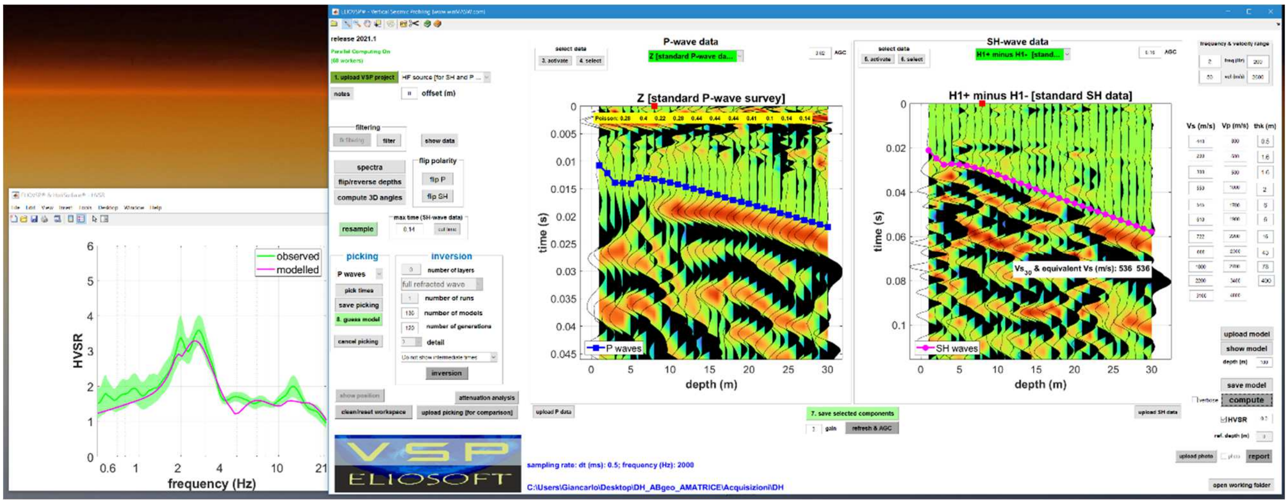


Uploading the HVSR curve

Now upload a survey photo – [optional but recommended]. Read carefully the "**Photo documentation of the survey site**" section.

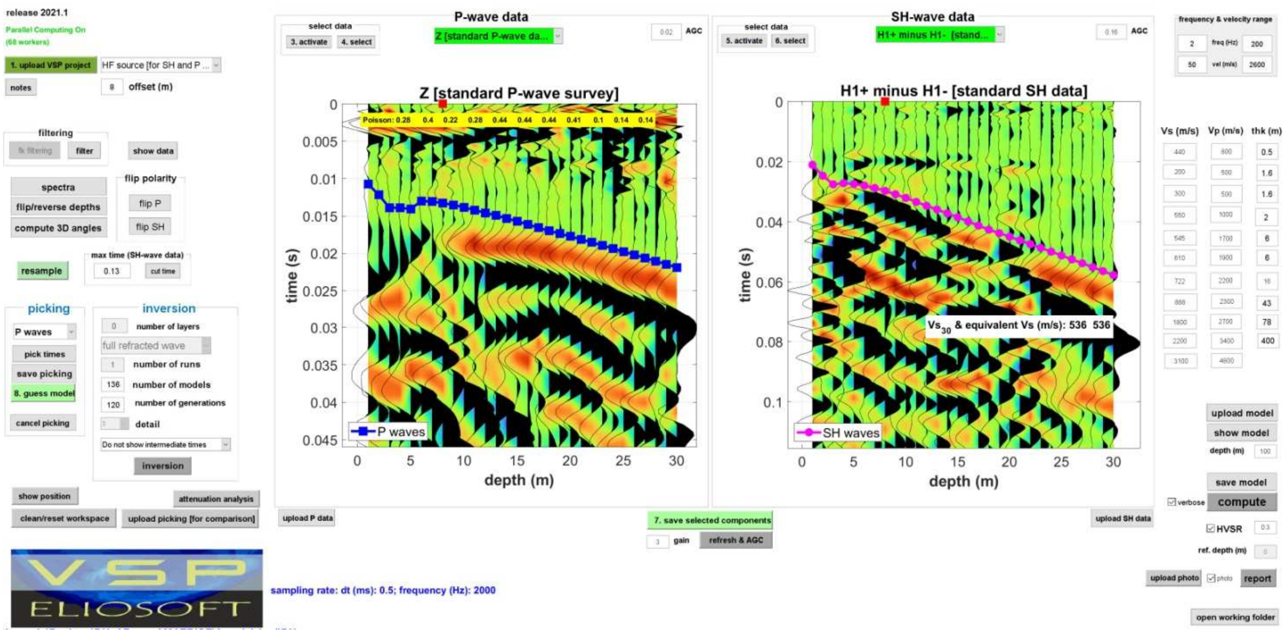
You can now start the forward modeling process

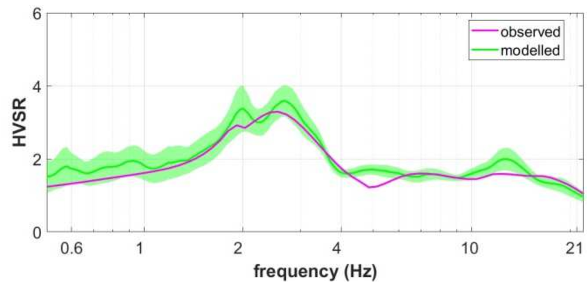
It is clearly necessary to enter and modify the V_S and V_P values (and thicknesses) on the right side of the software panel. If you want to (temporarily) skip the HVSR modeling (in case you had previously updated an HVSR curve), simply disable the check box at the bottom right corner.

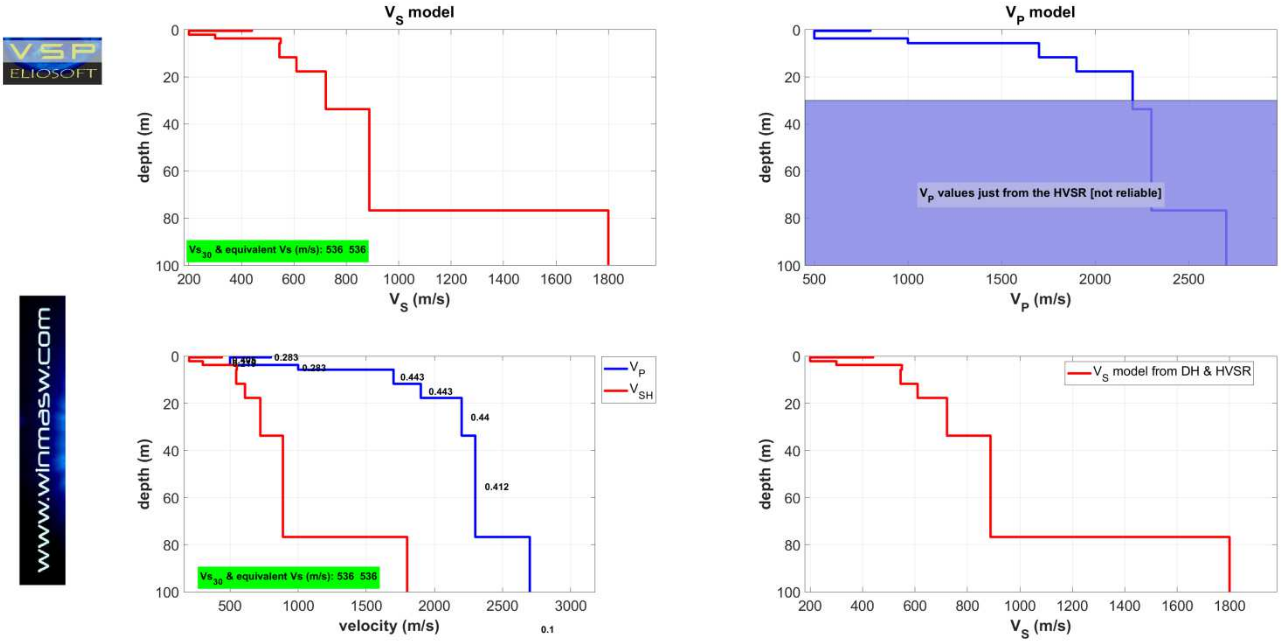


Example of joint modeling of the P and SH-wave arrival times together with the HVSR curve (the red square ■ along the seismic traces - at zero time - equals the *offset* and is useful to remember that, for the most superficial layers, data can be difficult to “understand”).

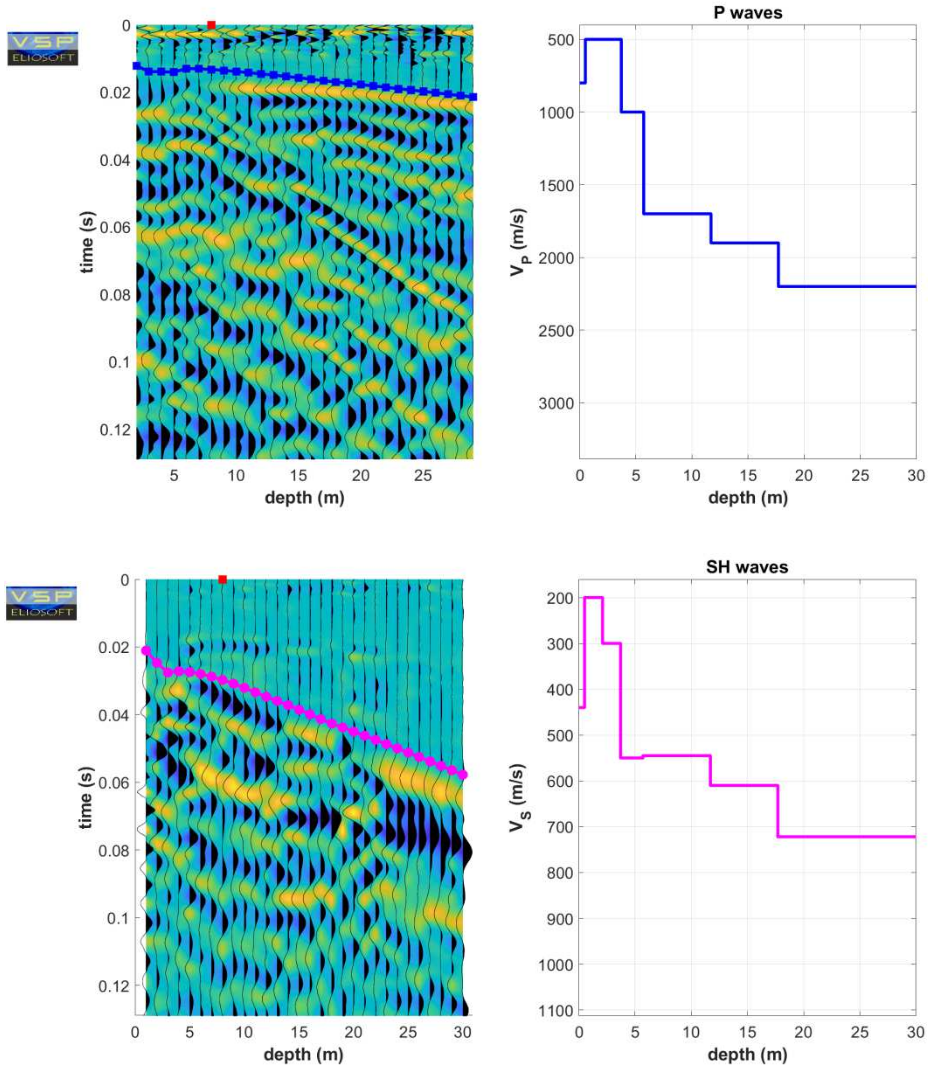
When you are satisfied with the agreement between the field data and your model, click the *report* button and obtain (automatically saved in the *report* subfolder that the software creates) all the figures and data shown here below (which summarize the analysis).

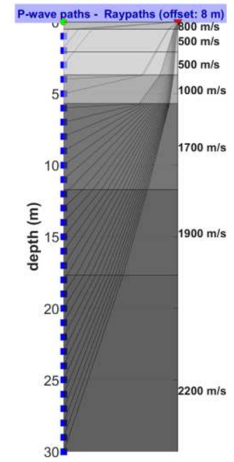


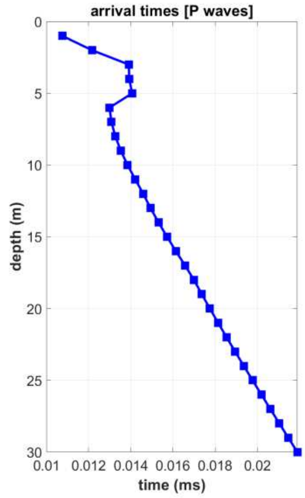


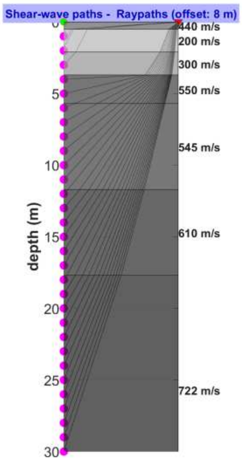


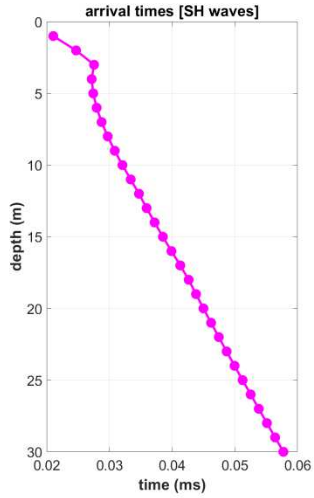
Please note that for the VP profile (top right plot) the values at depths greater than the borehole depth (in this case 30 m) are not reliable as they are from the HVSR only (which does not provide reliable information about the VP values but just about the shear-wave velocities).











depth (m)	P (ms)	SH (ms)
1	0.0108	0.0211
2	0.0122	0.0247
3	0.0139	0.0276
4	0.0139	0.0272
5	0.0141	0.0274
6	0.0130	0.0280
7	0.0131	0.0288
8	0.0133	0.0297
9	0.0135	0.0309
10	0.0138	0.0321
11	0.0142	0.0334
12	0.0146	0.0347
13	0.0149	0.0359
14	0.0153	0.0372
15	0.0157	0.0385
16	0.0161	0.0399
17	0.0166	0.0413
18	0.0170	0.0426
19	0.0174	0.0438
20	0.0177	0.0450
21	0.0181	0.0462
22	0.0185	0.0474
23	0.0189	0.0487
24	0.0194	0.0500
25	0.0198	0.0512
26	0.0202	0.0525
27	0.0206	0.0538
28	0.0210	0.0551
29	0.0215	0.0564
30	0.0219	0.0577

DH - Amatrice [quake area] - offset (m): 8

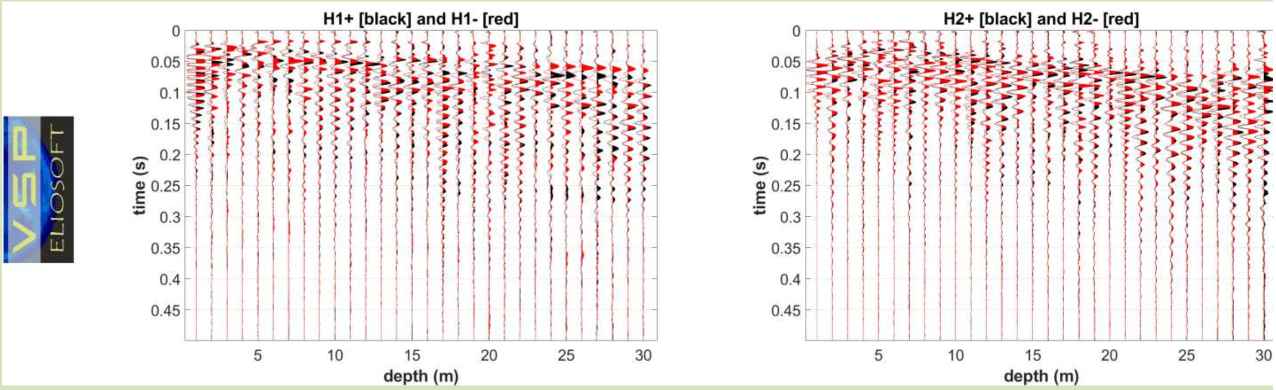
layer	Vs (m/s)	thickness (m)	depth (m)
1	440	0.5000	0.5000
2	200	1.6000	2.1000
3	300	1.6000	3.7000
4	550	2	5.7000
5	545	6	11.7000
6	610	6	17.7000
7	722	16	33.7000
8	888	43	76.7000
9	1800	78	154.70...
10	2200	400	554.70...
11	3100	0	0

Few notes about data and processing presented in the previous pages

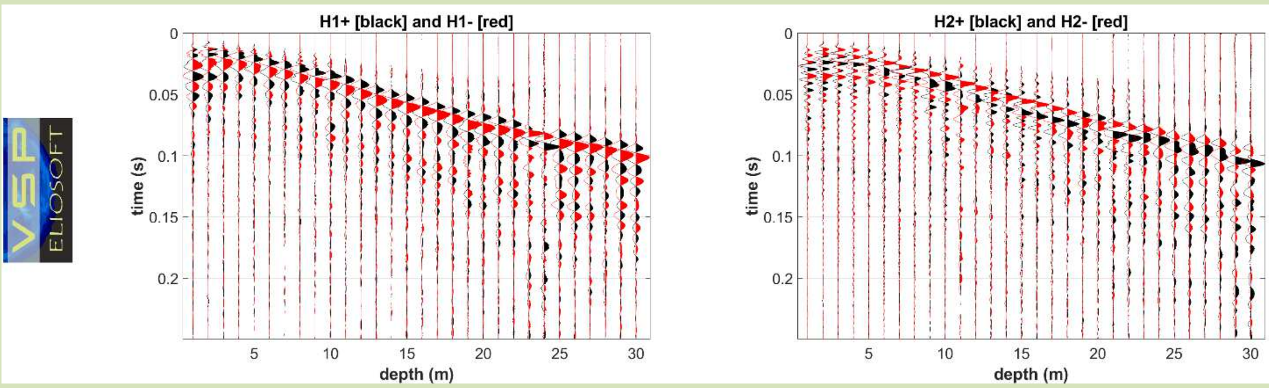
Due to logistical reasons, the *offset* (the distance between the source and the borehole) in this case was quite large (8 m – see the red ■ at the top of the traces). The optimal value is generally between 2 and 4 m (consider that the traces between the surface and a depth approximately equal to the *offset* can be difficult to understand, in that interval, many types of waves overlap).

When uploading an HF project, a double graph is also automatically provided with the comparison between the traces of the two acquisitions (the *right* and the *left* ones) for the two horizontal components.

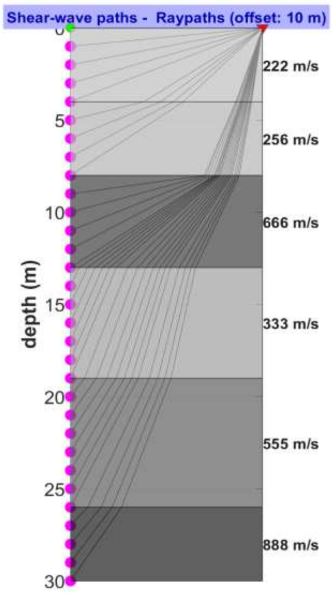
In the following figure are reported the data analysed in the previous pages and you can see how the polarity of the traces is not well characterized.

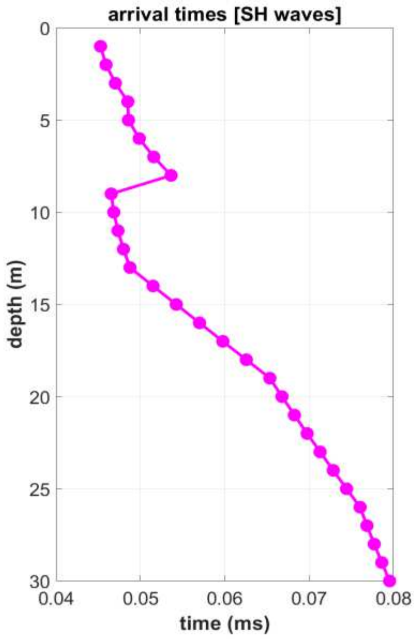


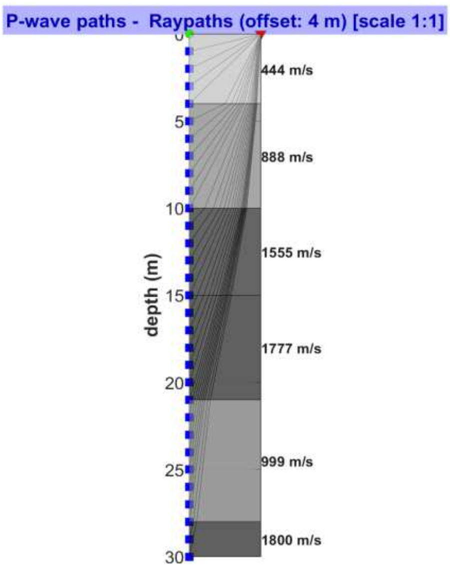
When the field operations are properly and accurately managed (and the medium is not too *scattering*), the comparison between the traces of the *right* and *left* shots for the two horizontal components (H1 and H2) are as clear as the data shown in the following figure: note that the amplitude is almost-perfectly the same but the polarity is (as expected) opposite.

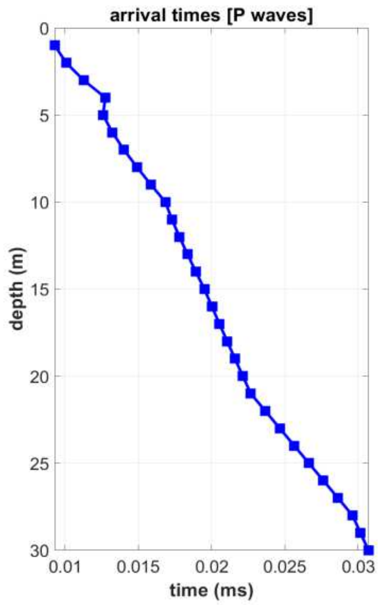


Finally, note that, because of the wave refraction, the trajectories of the seismic rays are not straight lines. First arrivals are therefore due to complex ray paths (ELIOVSP consider the full/correct ray paths).





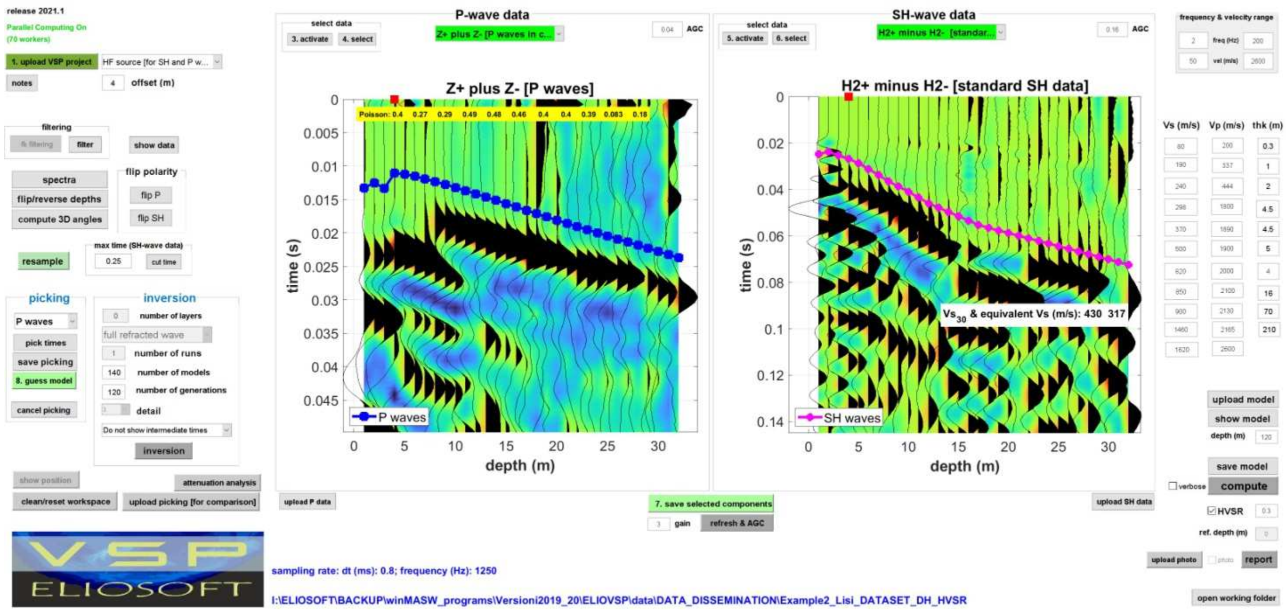


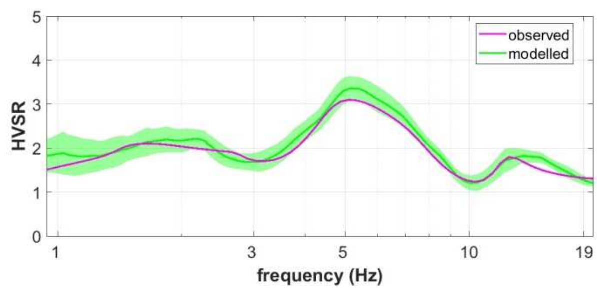


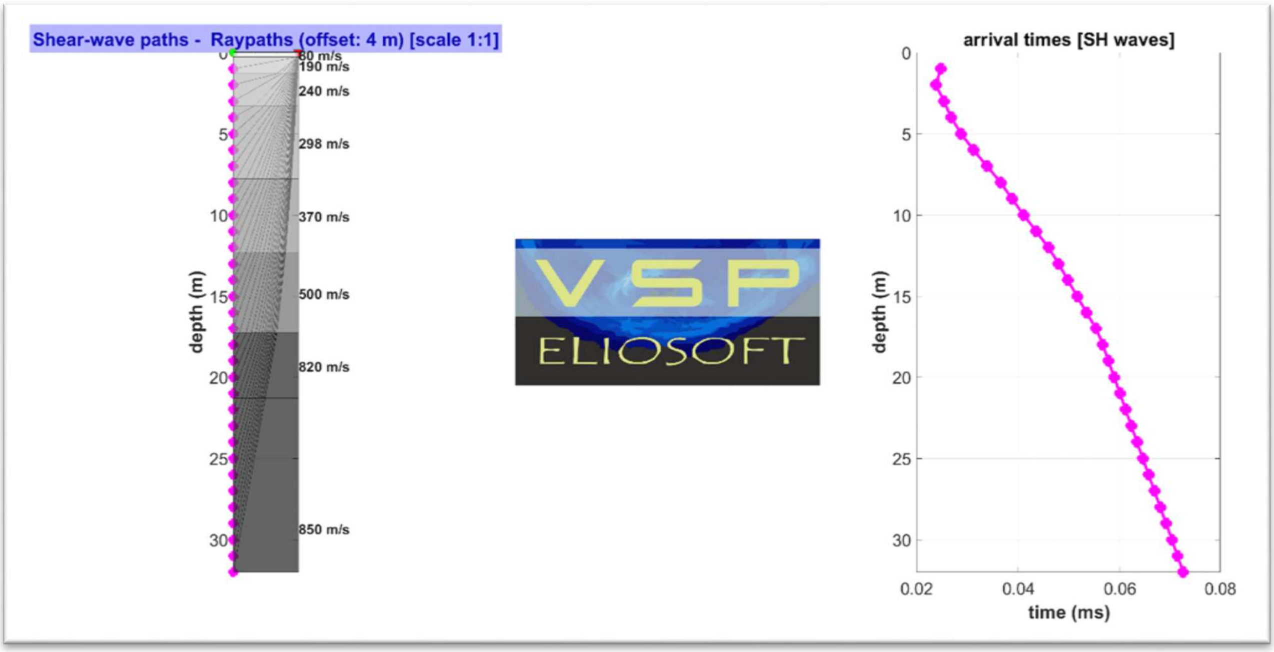
8.1 Example#2: P, SH and HVSR joint analysis

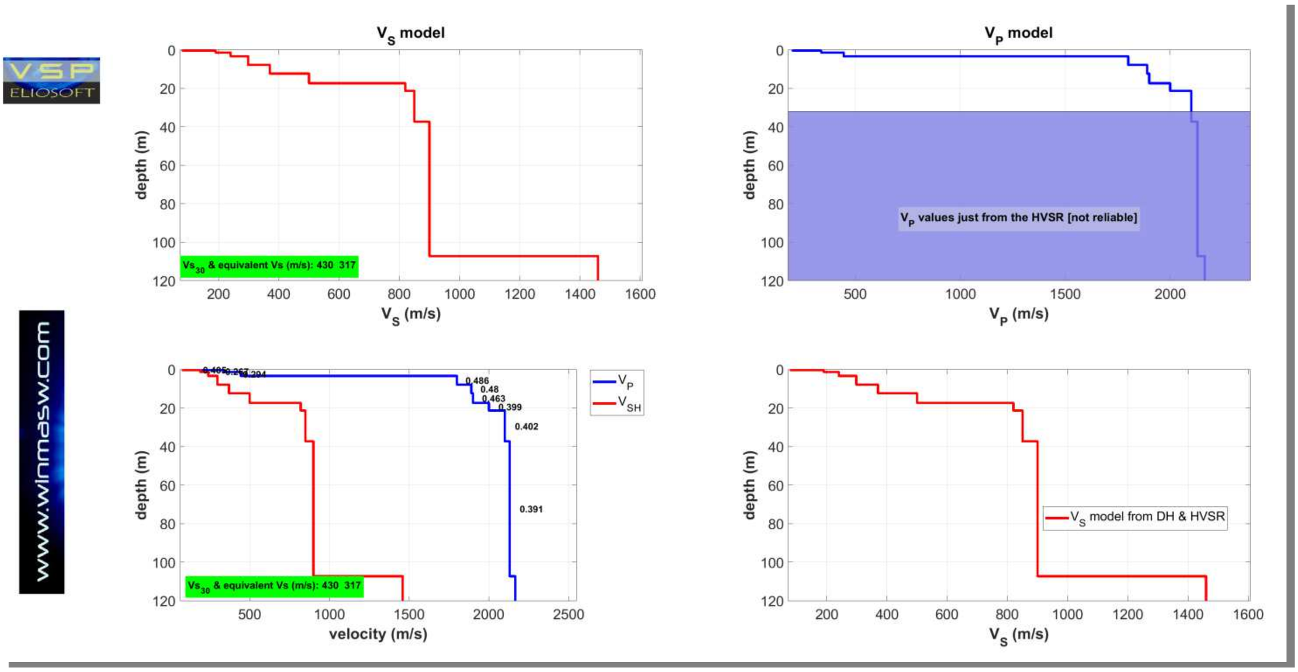
Here we analyze the data from a standard HF+ and HF- dataset (**remember that HF data are fine also for the identification of the P waves!**) with a standard beam [90°] (we recommend you to use a 70° source so to generate higher-quality P waves – see “Data acquisition” section).
Data were recorded by means of a borehole geophone with more than two horizontal components and you can choose the two best components by modifying the *project file* (by the way, as you can verify through a simple data comparison, having more than two horizontal geophones is actually pretty useless).

Data kindly provided by **Studio Geolisi** - Daniele Lisi (Arezzo – Italy).





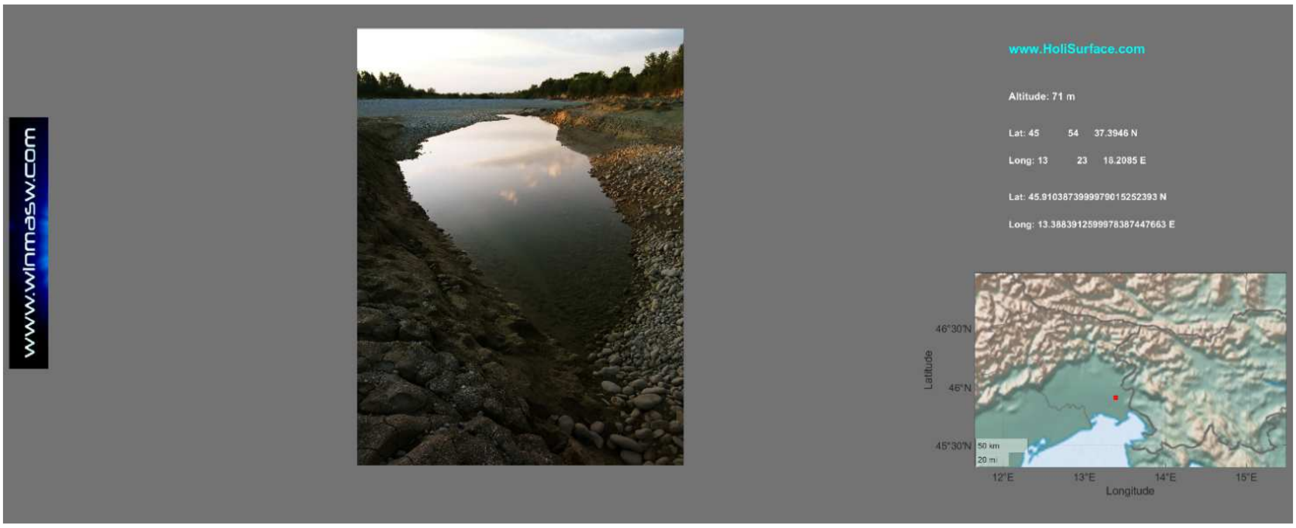


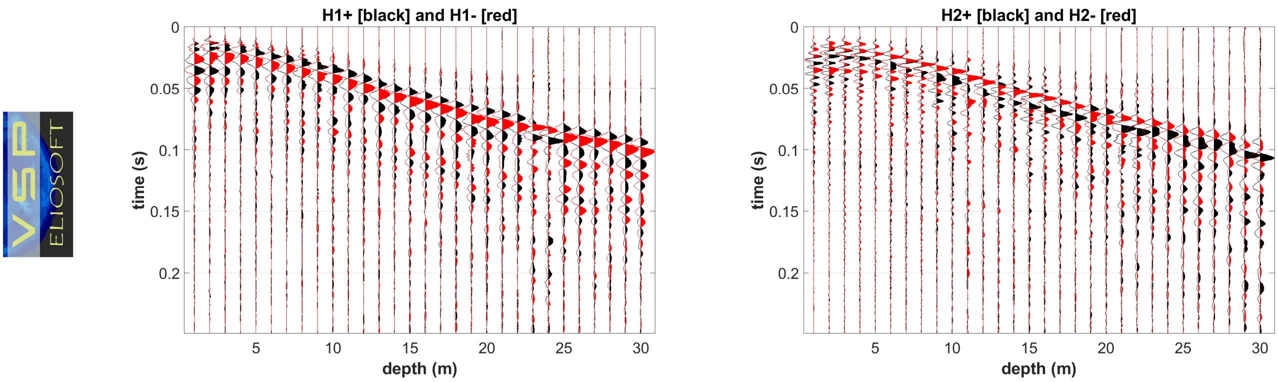


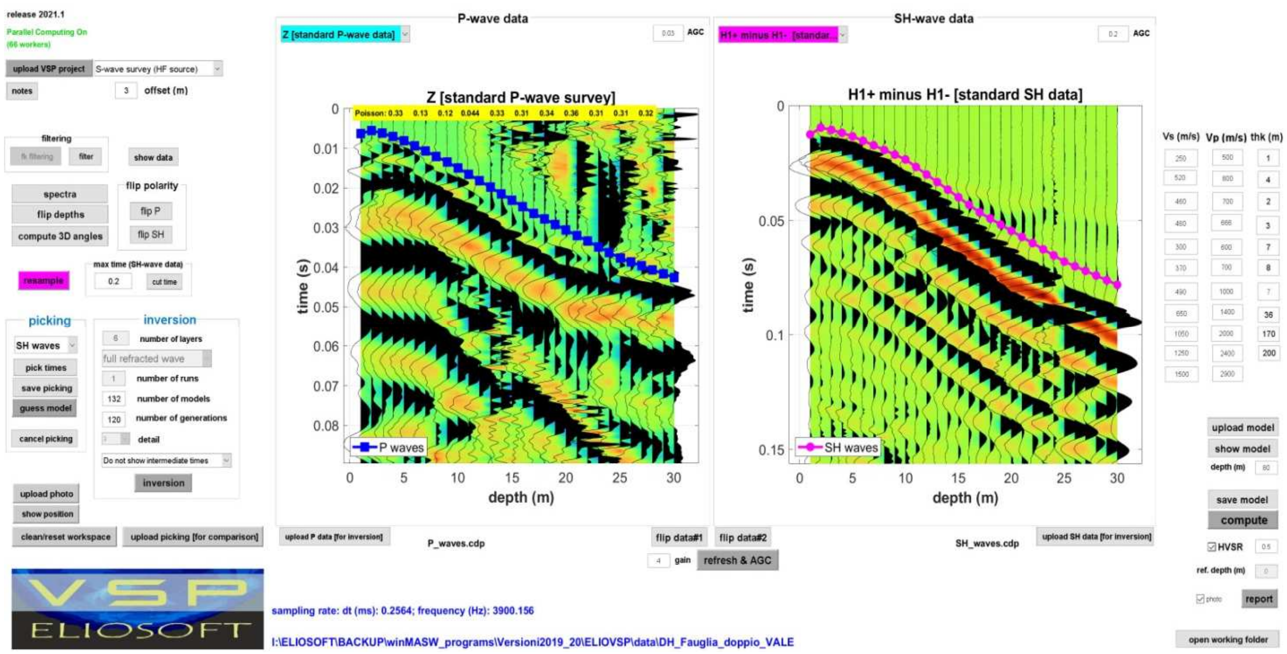
layer	Vs (m/s)	thickness (m)	depth (m)
1	80	0.3000	0.3000
2	190	1	1.3000
3	240	2	3.3000
4	298	4.5000	7.8000
5	370	4.5000	12.3000
6	500	5	17.3000
7	820	4	21.3000
8	850	16	37.3000
9	900	70	107.30...
10	1460	210	317.30...
11	1620	0	0

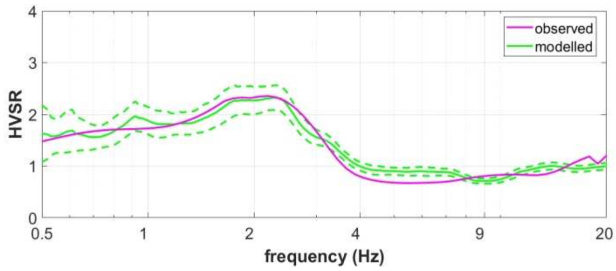
8.2 Example#3: P, SH and HVSR joint analysis

Example of simple joint modeling of the HF data collected with a **twin borehole geophone** (only 15 "positions" were therefore necessary). The first image (photo and positioning) is not the real one (for privacy reasons) but is obtained by simply uploading a photo taken with the *MapCam* app (see "**Photo documentation of the survey site**" section).
Data kindly provided by **P3 snc** (Alberto Benvenuti and Valentino Carnicelli, Pisa – Italy) [data are also available on the ELIOVSP DVD - see "**Supplied data**" section].



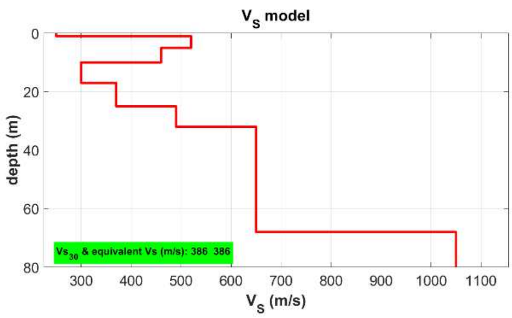


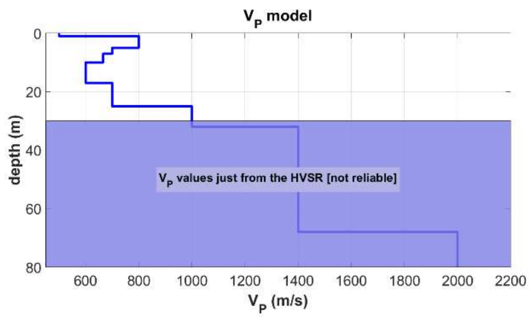




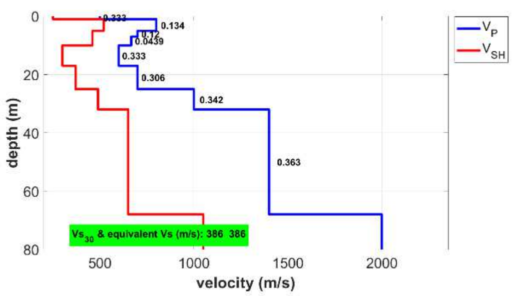
Fauglia (IT) - offset (m): 3

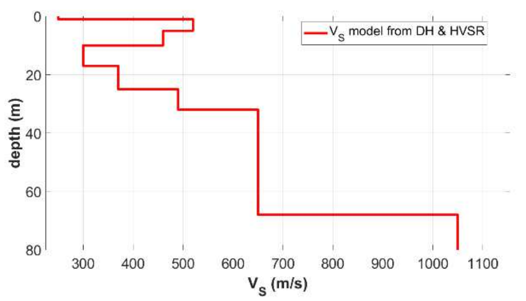
layer	Vs (m/s)	thickness (m)	depth (m)
1	250	1	1
2	520	4	5
3	460	2	7
4	460	3	10
5	300	7	17
6	370	8	25
7	490	7	32
8	650	36	68
9	1050	170	238
10	1250	200	438
11	1500	0	0





www.winmasw.com



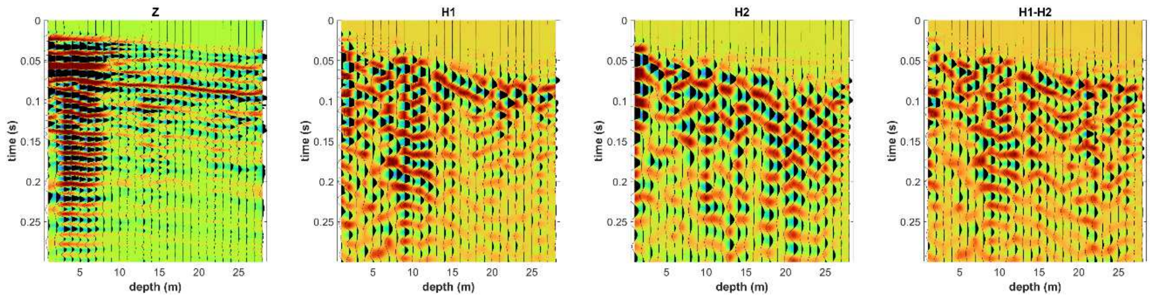


8.3 Example#4: using the “maximum H amplitude” component

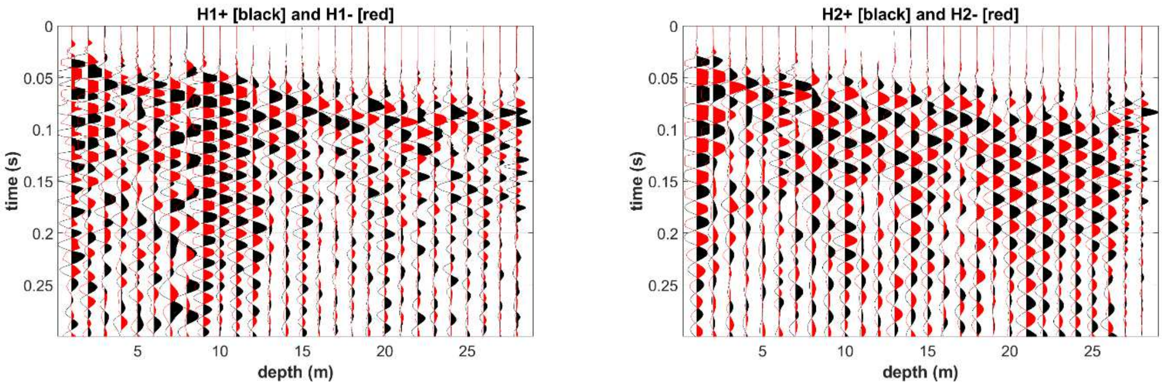
Here is an example where the HF+ and HF- data are rather complex (likely due to an highly-scattering medium). The consequence is that, in order to identify/follow the SH-wave arrivals, the best component to consider is the "**maximum H amplitude**" (a combination of the data recorded by the H1 and H2 geophones). As usual, the P-wave arrivals are clear also from the HF acquisitions (this is the reason why the VF acquisitions are a useless waste of time).
Remember that, in some cases, flipping the data polarity ("**flip P**" and "**flip SH**" buttons) can improve the visual identification of the first arrivals.
Data kindly provided by **ABGEO snc** (Andrea Alessandrini & Francesco Bassano, Tolentino – Italy).

The survey site [image obtained through ELIOVSP and *MapCam*]

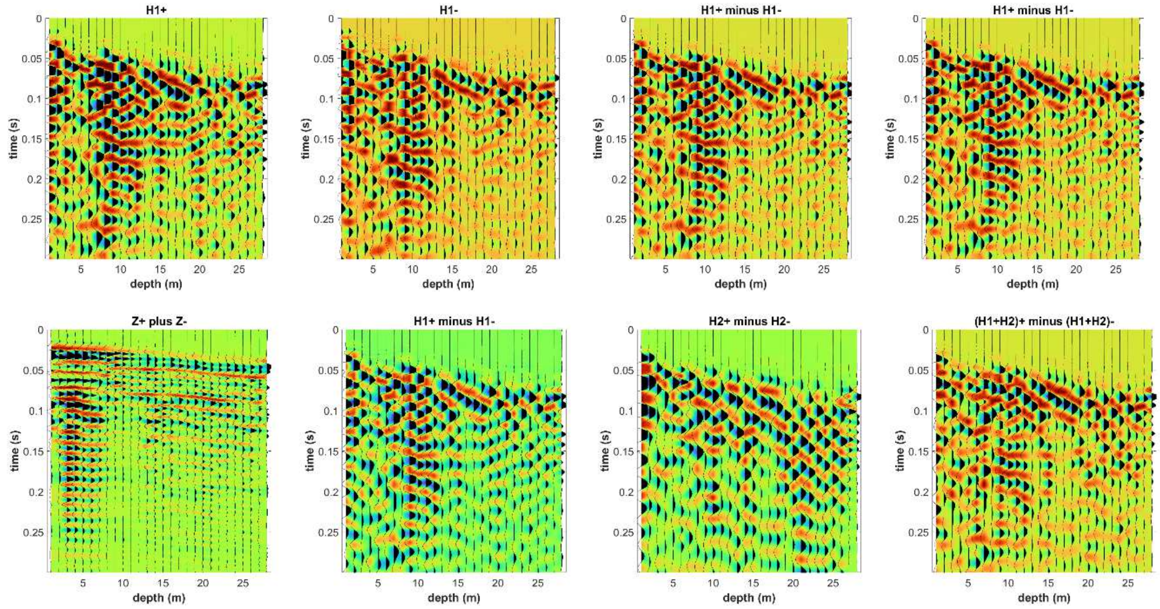
DATA FOR ALL THE COMPONENTS (DURING THE UPLOAD OF THE VF PROJECT FILE)



HF DATA (DURING THE UPLOAD OF THE HF PROJECT FILE)



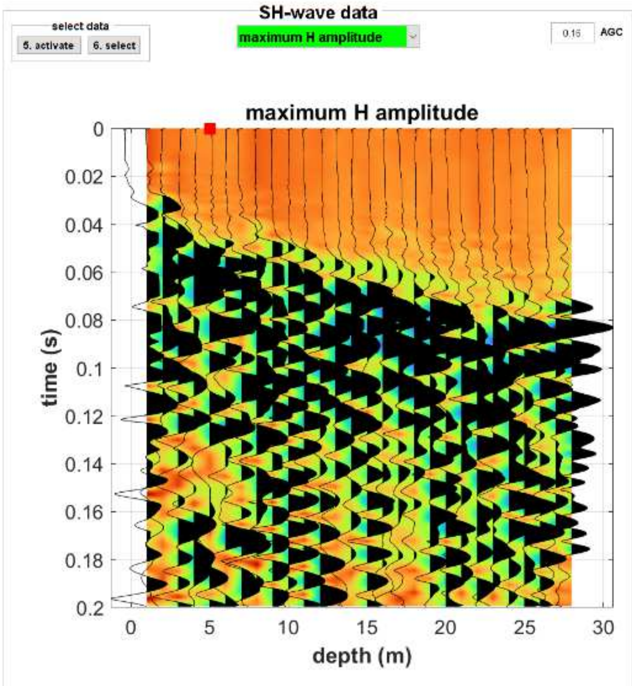
DATA FOR ALL THE COMPONENTS DURING THE HF PROJECT FILE UPLOAD



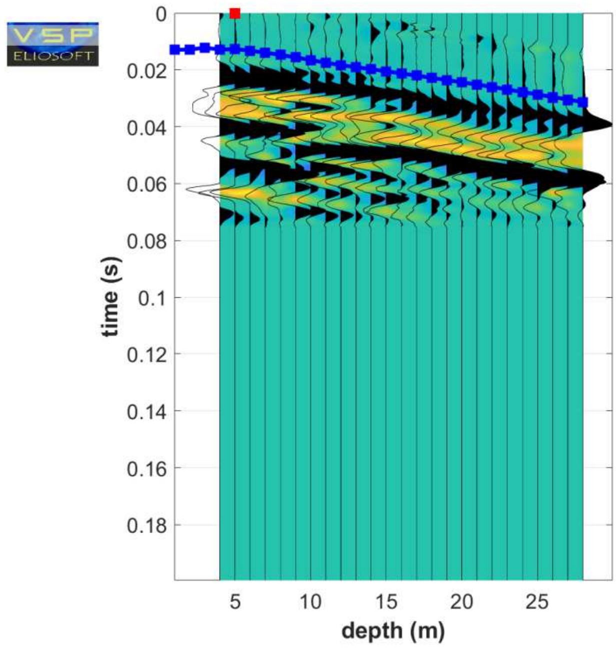
First, please note (once again) that the Z traces from the VF (Vertical Force) and HF (Horizontal Force) acquisitions are pretty much the same and this demonstrates once again that – in agreement with the theory – **it is not necessary to carry out VF acquisitions** with vertical shots to produce and identify the P-wave arrivals.

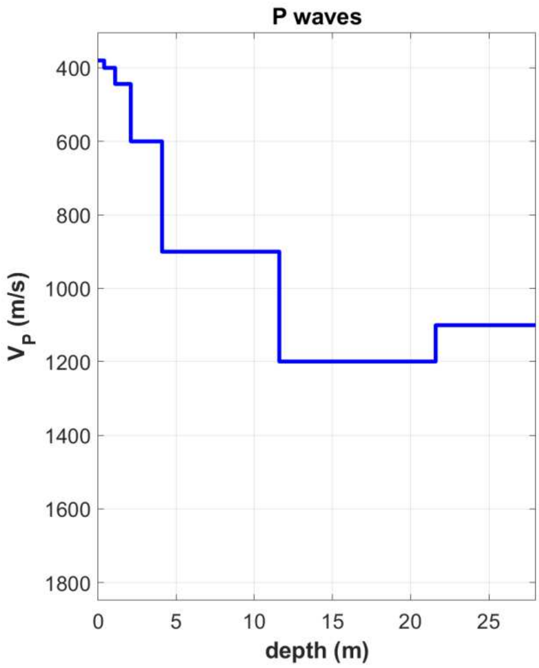
Comparing the H+ and H- traces (from the HF+ and HF- acquisitions) we can see that data are pretty complex. The reasons can be several and it is not possible to go into the details that would require extremely technical analyses and a detailed knowledge of the site (quite likely the medium is highly scattering).

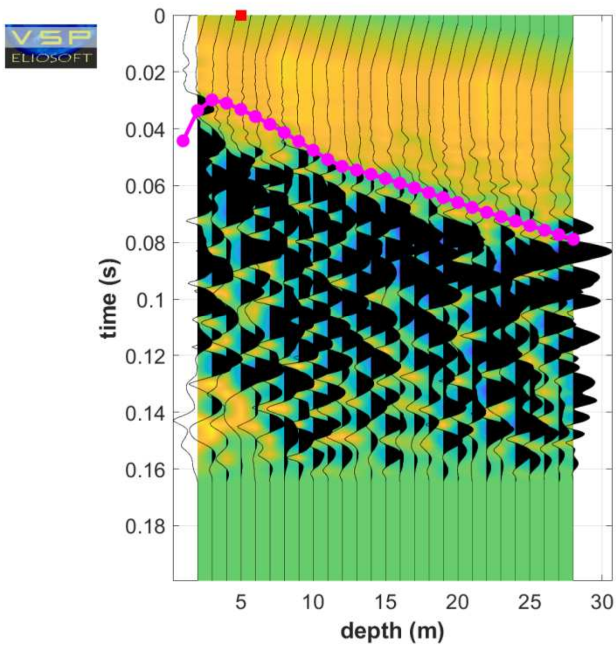
However, if we choose to visualize the maximum amplitude along the horizontal plane ("**maximum H amplitude**" in the pop-up window of the right panel) data appear quite consistent (see figure below) and it is therefore possible to proceed with the P+SH+HVSR joint modeling.

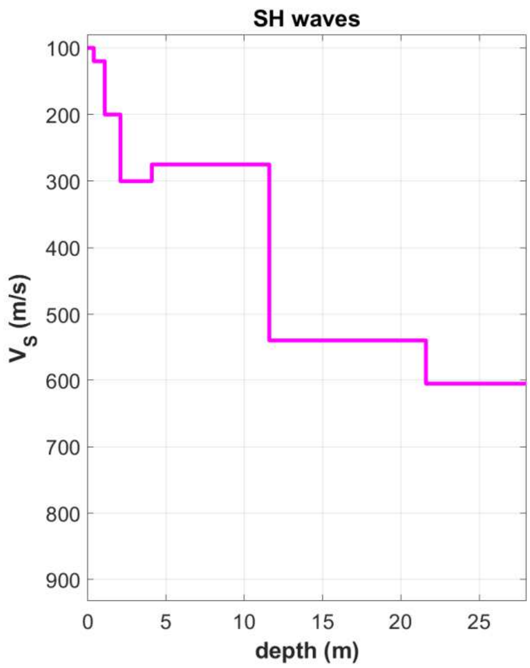


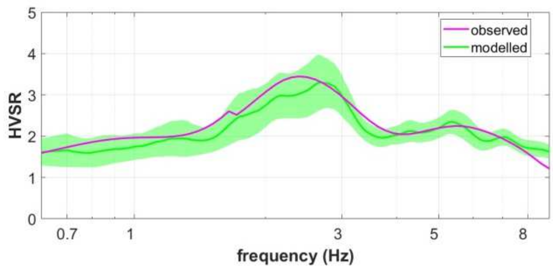
Below the result of the joint modeling. Please, remember and consider that **a joint analysis is always and necessarily a <u>compromise</u>** between the considered *observables* (see for instance also Dal Moro & Puzzilli, 2017).

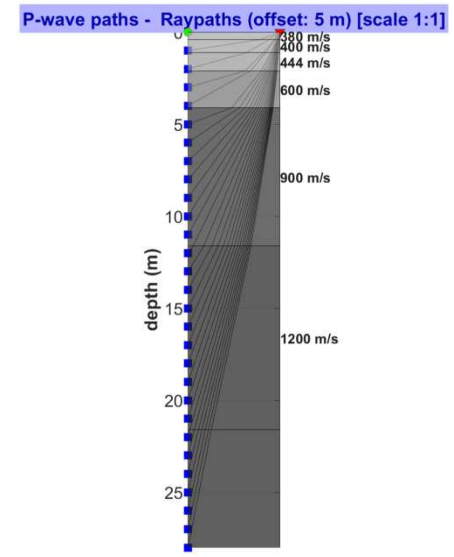


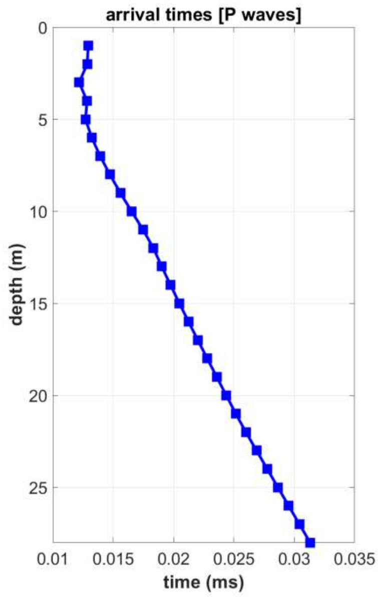


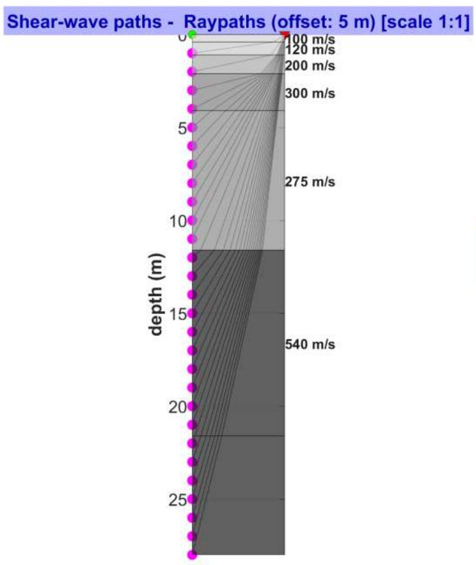


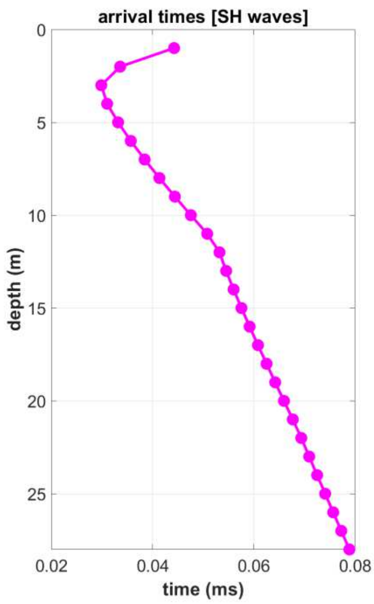


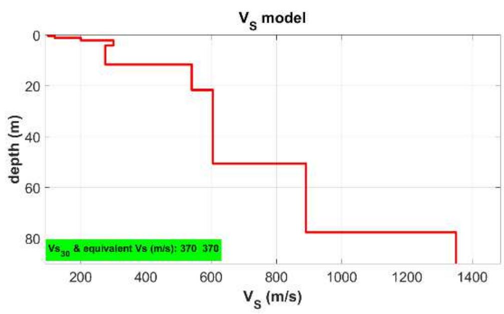


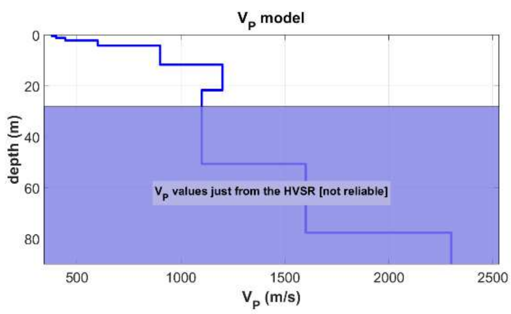

P-wave paths - Raypaths (offset: 5 m) [scale 1:1]
380 m/s
400 m/s
444 m/s
600 m/s
900 m/s
1200 m/s
depth (m)

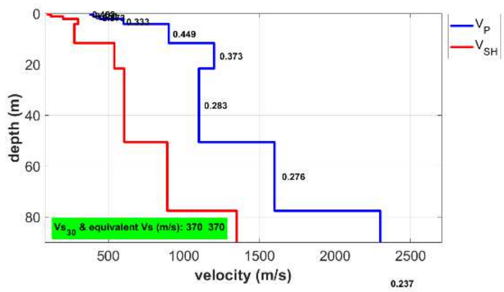

arrival times [P waves]
depth (m)
time (ms)

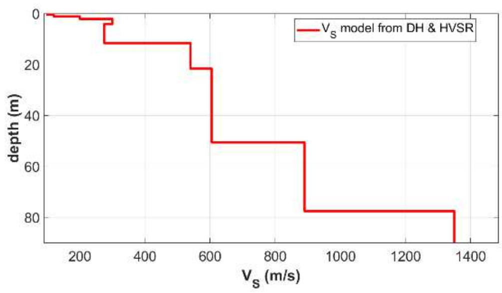

Shear-wave paths - Raypaths (offset: 5 m) [scale 1:1]
100 m/s
120 m/s
200 m/s
300 m/s
275 m/s
540 m/s
depth (m)


arrival times [SH waves]
depth (m)
time (ms)


V_S model
depth (m)
Vs30 & equivalent Vs (m/s): 370 370
VS (m/s)


VP model
depth (m)
VP values just from the HVSR [not reliable]
VP (m/s)


VP
VSH
0.449
0.373
0.283
0.276
0.237
depth (m)
Vs30 & equivalent Vs (m/s): 370 370
velocity (m/s)


VS model from DH & HVSR
depth (m)
VS (m/s)

8.4 A further small example: vertical-impact (VF) acquisitions are useless

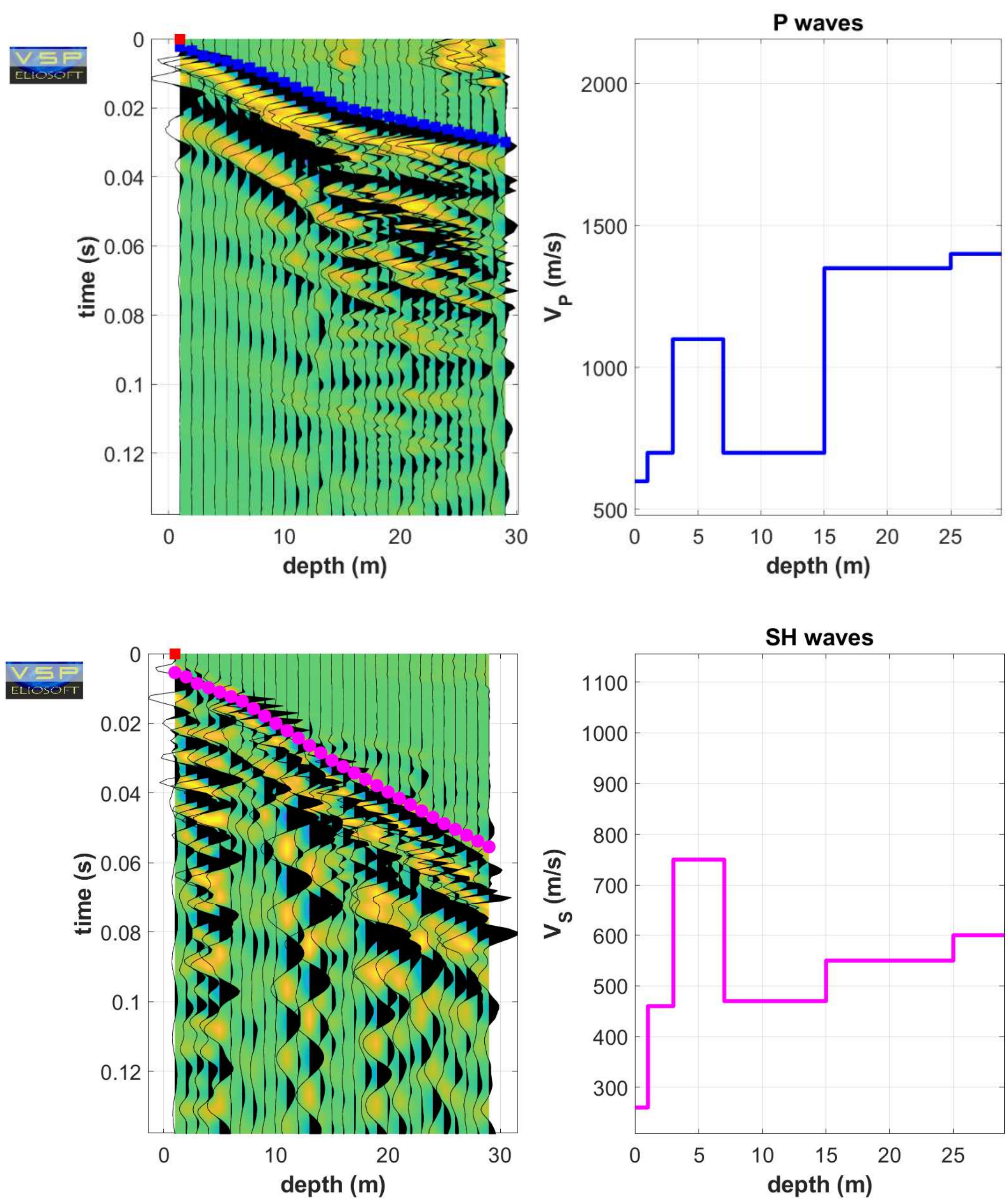
Here a further example to compare the data recorded considering a vertical (VF) hammering and horizontal/transverse (HF) hammering. If you compare the data recorded with the VF and HF hammering, you will easily see that the first P-wave arrivals are extremely clear also from HF acquisitions.

Unfortunately, this data acquisition was performed in the classical way (VF and HF sources) and no inclined source was used.

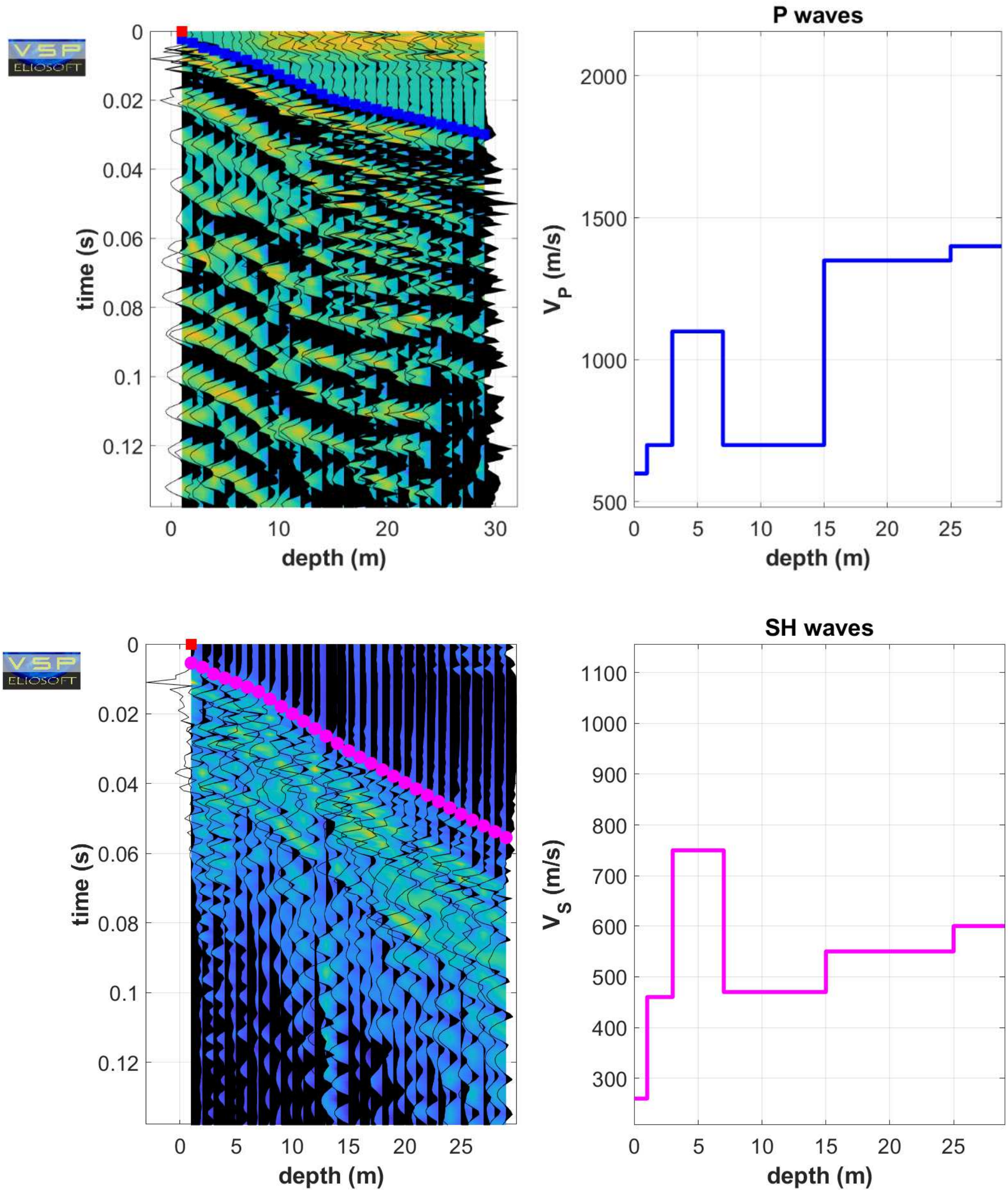
It is clear that in case an inclined source is used, everything (first arrivals of both P and SH waves) would be even clearer.

Moral: go to the “Data acquisition” chapeter to see how to record DH data in an efficient way (use just an inclined source).

Z & H data from a VF (Vertical Force, i.e. vertical-impact hammering) acquisition



Z & H data from a HF (Horizontal Force, i.e. horizontal-impact hammering) acquisition



Supplied data (for your self-training)

In order to help you learn how to use ELIOVSP, a series of datasets are provided (teogether with the compiled *Project files*) with the software (see the “DATA_DISSEMINATION” in the ELIOVSP DVD/USB stick).
Being simple ASCII files, the *project files* can/should be opened/modified with the ***Notepad*** software or any other similar software.

They are the same datasets presented in the previous section (so you already have the solutions).

Example#1: P+SH+HVSR analysis commented step by step

Example#2: P, SH and HVSR standard joint analysis

Example#3: P, SH and HVSR joint analysis [data from a twin borehole geophone]

Example#4: using the “maximum H amplitude” component

In addition, a further dataset (**Example #0**) is provided. We do not show the complete solution but it is the (pretty simple) dataset shown in the "Forward modeling" section of this manual.

Please, remember that if you record the data as recommended in the “Data acquisition” section, **the VF data (and therefore the related *project file*) are not necessary** to identify the P-wave arrivals.

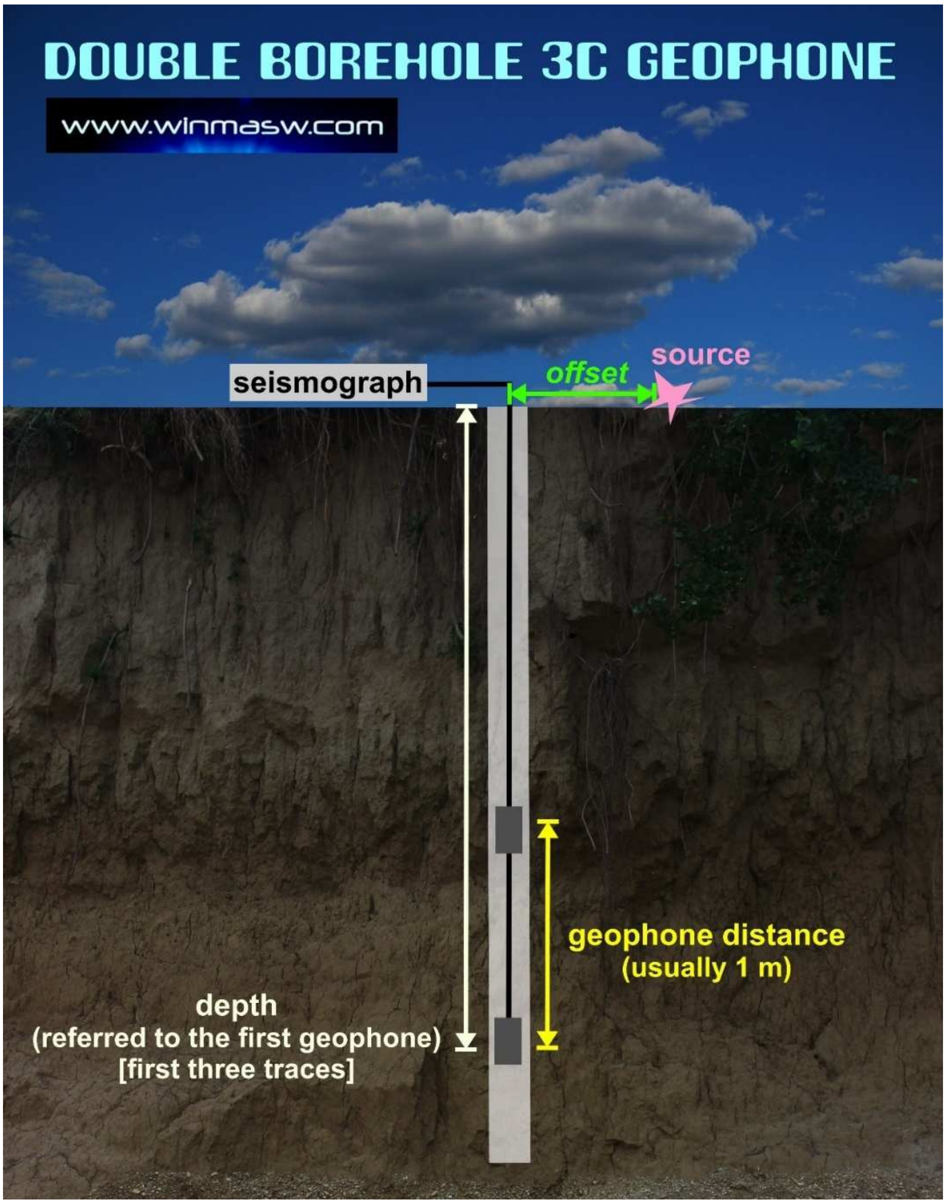
We recommend to record and work just with the HF+ and HF- data.

ATTENTION

You will notice that many of the provided training datasets are characterized by data length and sampling rate unnecessarily large.
Remember that body waves are very fast and that the "distances" in a common DH survey are usually quite limited (usually 30-40 m).
Always ask yourself what is the highest frequency you are interested in and consider the Nyquist-Shannon theorem. Recording 1 second of data with a sampling frequency of 10000 Hz [0.1 ms] for a 30-40 m DownHole is completely useless and needlessly overloads the computer memory. In these cases, re-sample immediately the data and use the "cut time" tool to get rid of all the useless data.

The twin borehole geophone we provide

Il geofono da pozzo che forniamo e raccomandiamo è del tipo **doppio**. Lungo il tubo che si cala nel pozzo sono cioè alloggiati 2 geofoni triassiali, distanti 1 metro l'uno dall'altro. Il vantaggio è che **in questo modo si vanno a dimezzare le operazioni di campagna** (ad ogni *shot* vengono acquisiti i dati riferiti a 2 profondità). Un bel vantaggio, vero?



Associato al sismografo da noi fornito, si avrà che **collegando il geofono al connettore 13-24 del sismografo ed attivando i canali 13-14-15-16-17-18**, la sequenza del file (da 6 tracce) che si va ad ottenere è Z H1 H2 del geofono profondo e Z H1 H2 del geofono più superficiale. **Questa è la soluzione che, per la sua semplicità e intuitività, raccomandiamo fortemente.**

La metratura riportata lungo il cavo si riferisce al geofono più profondo.

*C*onnettore *CANNON*–NK27 utilizzato di default per il doppio geofono da foro che forniamo.

Collegando invece il geofono al connettore 1-12 la sequenza sarà invertita a partire dal canale 12 fino al canale 7: i canali 12-11-10 saranno i canali Z H1 H2 del geofono profondo e 9-8-7 i canali Z H1 H2 del geofono più superficiale (soluzione sconsigliata).

Troubleshooting and Support

Any software can inevitably have some issues often due to the application of procedures different from those designed by the programmers.

Before contacting us, please carefully read this section of the manual

Please, report any other problems to winmasw@winmasw.com always indicating:

1) **the User ID (UID) and Serial Number (SN) of your USB dongle**
2) **your release (e.g., ELIOVSP release 2021)**
3) **the operating system of your computer (e.g. Windows 10 – 64 bit)**

Both the error and the situation in which the error occurs <u>**must**</u> be **clearly** described:

4) **Always include the <u>snapshot of the black (background) DOS window</u> at the time of the error**

Some important notes

1. Many problems are related to the operating system (remember that *winMASW*® and *HoliSurface*® and ELIOVSP only work on 64bit operating systems - <u>we strongly recommend windows-10 and advise against windows-7 [which badly manages certain system privileges]</u>).

2. Update often your operatying system ("windows update")

3. Some anti-virus software (currently with AVAST AVIRA and PANDA) may not be able to understand that the hardware protection system used for *winMASW*® and *HoliSurface*® is not a virus. The installer should be able to instruct the antivirus to ignore the contents of a certain installation folder. If you are not able to do so, we recommend a "smarter" anti-virus (e.g. AVG)

4. Pay attention to keep your PC in order with frequent cleaning and optimization operations possible with different software (for example Glary Utilities). A computer is a highly complex machine that must be taken care of (Desktops with dozens of files and folders are usually the first evidence of dangerous deficiencies in this sense).

Some problems originate from the (invasive) influence of some
Antivirus software

In those cases, before worrying try to disable your antivirus (or to add ELIOVSP to the software that the antivirus should trust and ignore).

Consider installing the AVG anti-virus (free and more discreet/reliable than many others).

In the following some possible problems that can be easily solved by the user

Error "**Undefined function or variable 'matlabrc'**"
(visible at program launch on the DOS window).

Solution:

1) activates the display of hidden folders and files (the procedure can be easily found on the internet);

2) manually delete the "temporary" folder of the *Matlab Runtime Compiler*.

Go to the folder *C:\Users [username]\AppData\Local\Temp[username]\mcrCache[version]*
and erase it.

3) re-install the file *MCRinstaller.exe* in the "*preELIOVSP*" folder of the *ELIOVSP* installation CD (i.e., simply run the executable *MCRinstaller.exe*).

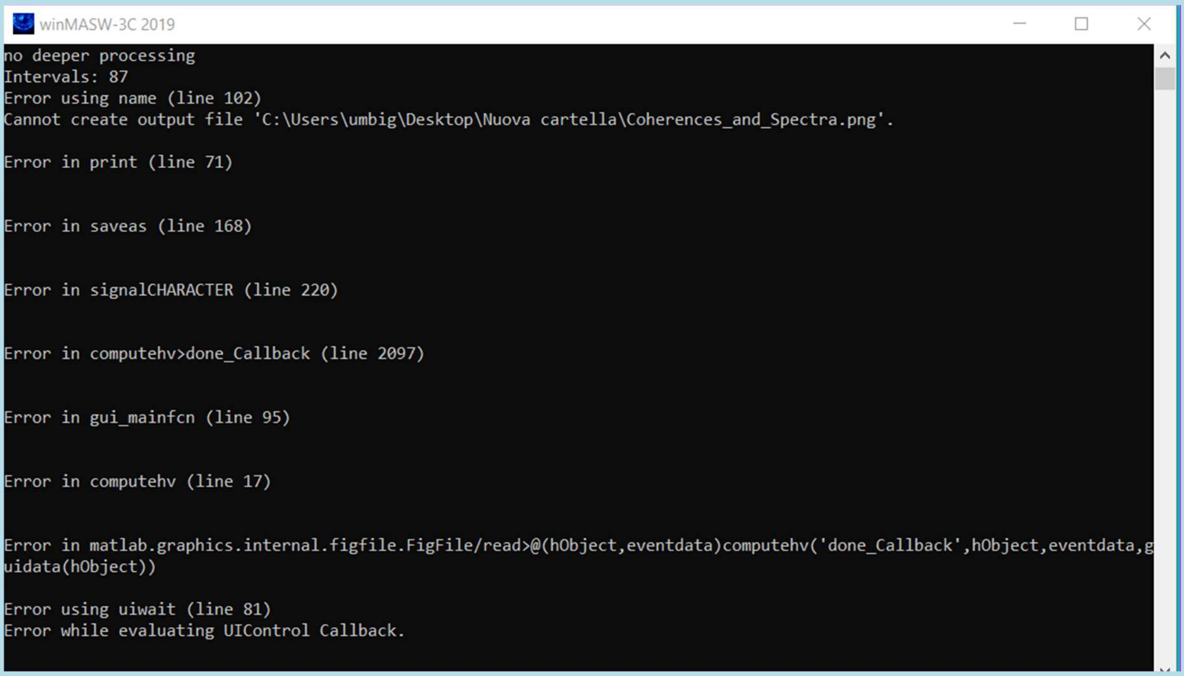
At this point everything should be fixed and you can try to run *ELIOVSP*.

Error "**Starting parallel pool (parpool) using the 'local' profile** ... Error using parpool (line 103) **Not enough input arguments**.

or

Error "**Cannot create output file**" (or similar)

(visible at program launch on the background DOS window).



Solution:

- *search* for the sub-folder "MathWorks" in the folder "users" (or "C:/users") and delete it. Attention, it is not a "C:/user/MathWorks" folder, it is a folder inside one of the "C:/user" folder, so search for "MathWorks".

- do the same for the *mcrCache* folder (always within the folder in C:/users). In some cases / systems, depending on your software release, the folder may also be called (for example) mcrCache9.2.
In some cases this folder is more easily identifiable with a search from C:/ (and not from the sub-folder C:/*users*). For example, you will find the folder "C:\Users\John\AppData\Local\Temp\John\mcrCache9.2", which must be deleted.
At this point everything should be fixed and you can try to launch ELIOVSP (*HoliSurface®* or *winMASW®*).

- if this does not work, re-install the *MCRinstaller.exe* file in the *"preELIOVSP"* folder on the *ELIOVSP* installation DVD (i.e., simply run the MCRinstaller.exe executable).

Remote sessions

In case it is necessary a solution from ELIOSOFT, a remote session via **AnyDesk** is necessary.

In that case:

1) download and install the **Anydesk** software (https://anydesk.com) and provide us with your ID (identification number of your PC)

2) send to winmasw@winmasw.com an appointment request for a remote session [it is important to be on time and carefully follow the provided instructions].

What is **AnyDesk**? You can have a look for instance here:
https://www.youtube.com/watch?v=g3W1nBbtqEE

OUR SOCIAL MEDIA:

https://www.facebook.com/HoliSurface/ [public page]

https://www.facebook.com/winMASW [per "friends"]

https://twitter.com/winmasw

https://www.youtube.com/user/winMASW/videos

https://www.researchgate.net/profile/Giancarlo_Dal_Moro

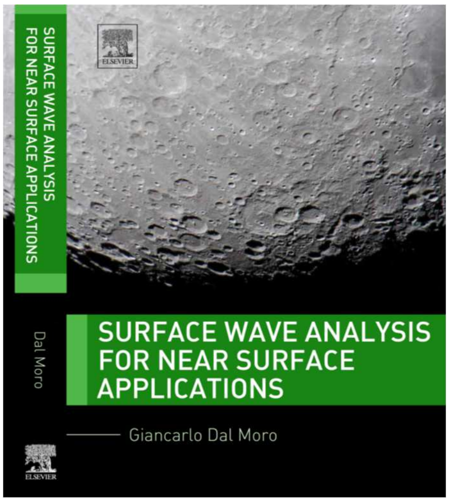
OUR FACEBOOK PAGE IS FREQUENTLY UPDATED WITH SMALL CASE STUDIES, NEWS AND TIPS

References

Surface Wave Analysis for Near Surface Applications

Dal Moro G., 2014, *Elsevier*, 252pp

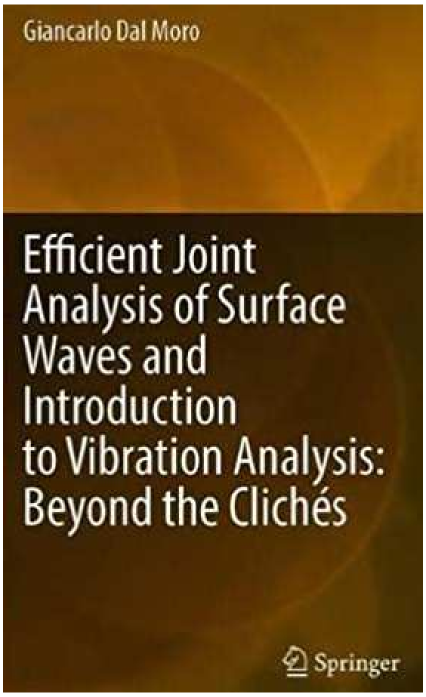
ISBN 978-0-12-800770-9

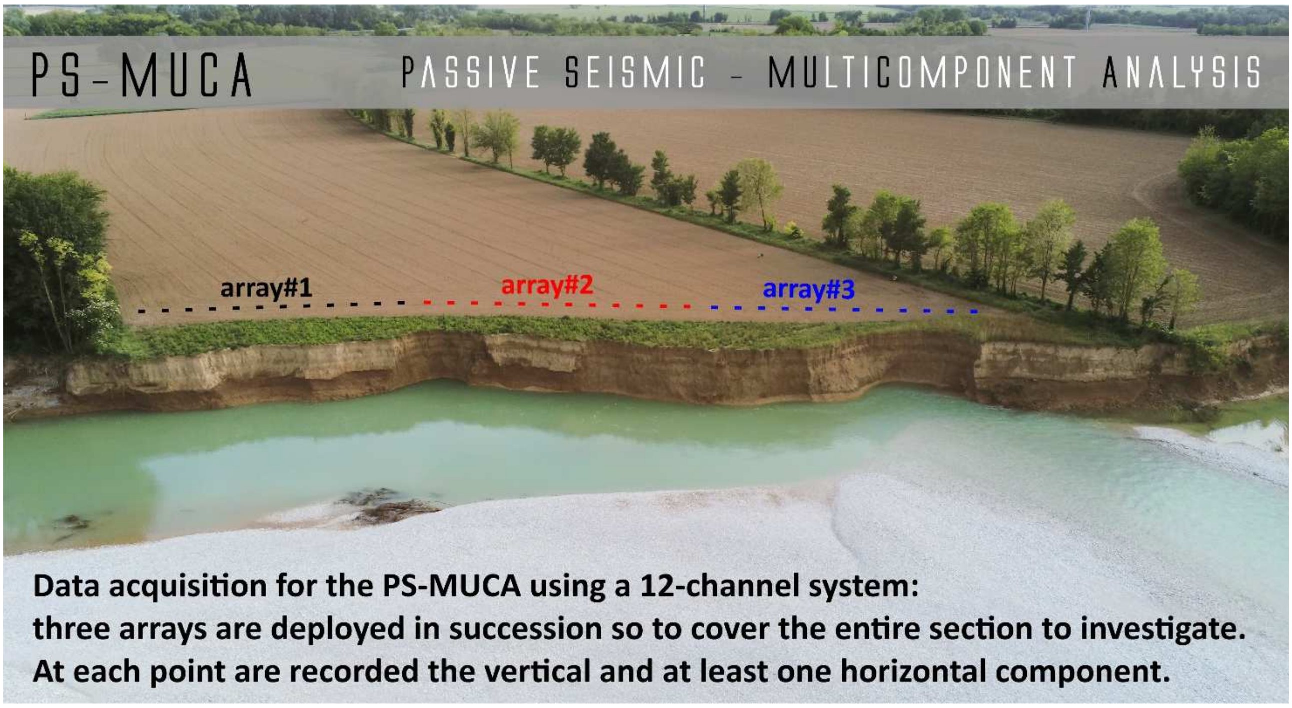


Dal Moro G., Puzzilli L.M., 2017. ***Single- and Multi-Component Inversion of Rayleigh Waves Acquired by a Single 3-Component Geophone: an Illustrative Case Study***, Acta Geodyn. Geomater., Vol. 14, No. 4 (188), 431–444, DOI: 10.13168/AGG.2017.0024 [**available on line**]

Galperin E.I., 1985. ***Vertical seismic profiling and its exploration potential***. Springer, 442 pp.

Efficient Joint Analysis of Surface Waves and Introduction to Vibration Analysis: Beyond the Clichés





ONE OF THE NEW TOOLS IN WINMASW® ACADEMY 2021

HS-QC [Quality Check] software: your field assistant

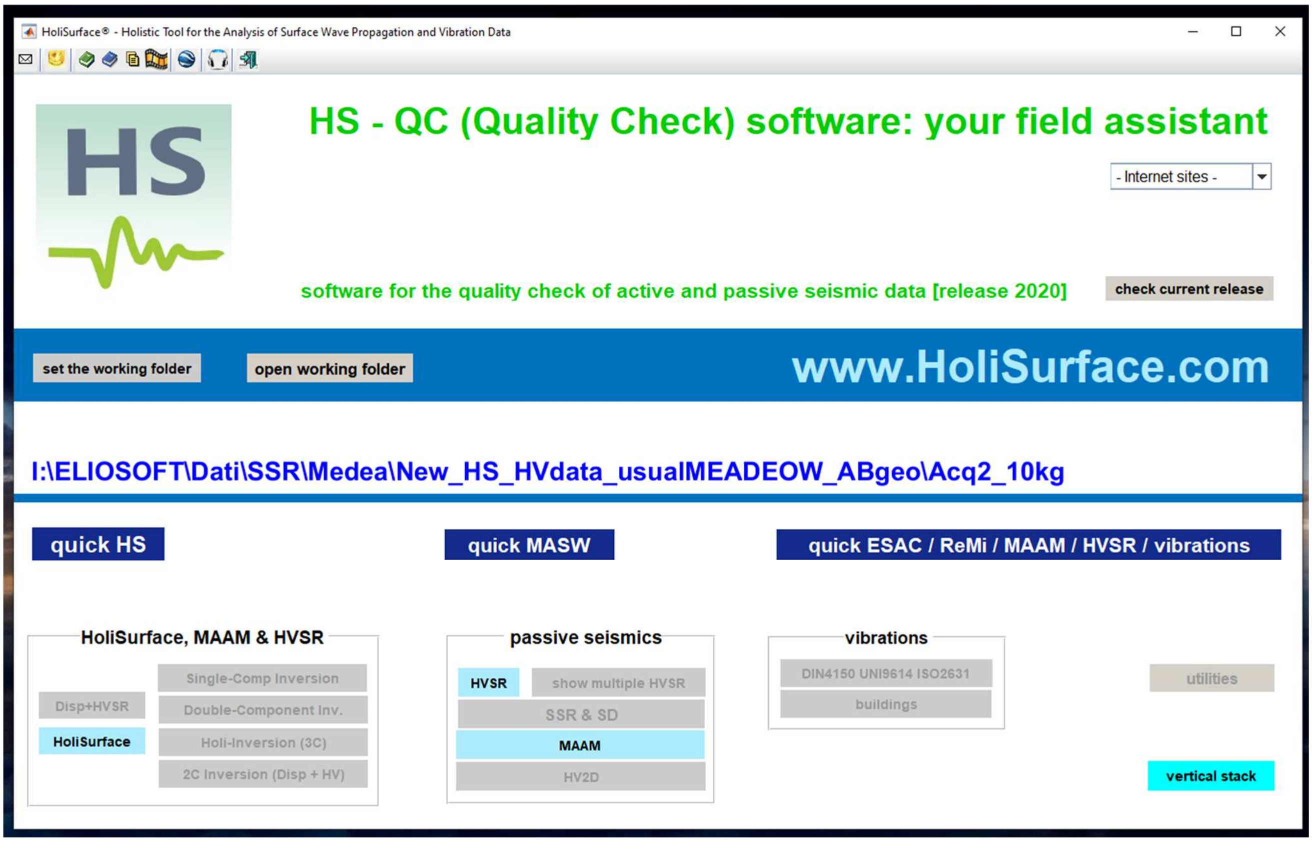
Almost all of the acquisition software of the different seismographs available on the market do not implement any tool for the assessment of the data quality. Once (active or passive) data are recorded, it is therefore impossible to evaluate the quality in clear and "quantitative" terms.
For this reason, in order to avoid the risk to bring home poor-quality data, a **QC** [**Quality Check**] version of our software has been implemented.
From the 2021 release, *HoliSurface*® and *winMASW*® Academy users also receive a USB dongle for the **HS-QC [HoliSurface - Quality Check] software.**
It is a software that allows you to **quickly check the quality of the data already on the field, during the data acquisition.**
The quality of the data can be assessed both with respect to active (MASW and HS) and passive (HVSR, ESAC/SPAC, ReMi, MAAM, vibration) data. The software is clearly available even for those who are not HS or winMASW ACD users, at a very-reasonable price.

From the main panel there are two series of possible analyses:

1) **quick analyses** [**dark blue buttons**]: they allow you a quick evaluation of your active and passive data;
2) **"full" analyses**: allow you to upload the data and perform more advanced analyzes (these are simplified versions of the analysis panels available in HS and/or winMASW®).

A tool for the stack of your data is also available (see button in the lower-right corner).

Some details about the use of the **HS-QC software** are reported in the *winMASW*® and *HoliSurface*® 2021 manuals.



Data Processing Service

Do you need to process data according to *DownHole, multi-component MASW, ReMi, ESAC/SPAC, MAAM, HVSR* or *HoliSurface®* methodologies but you do not have the software or the time to study the data processing?

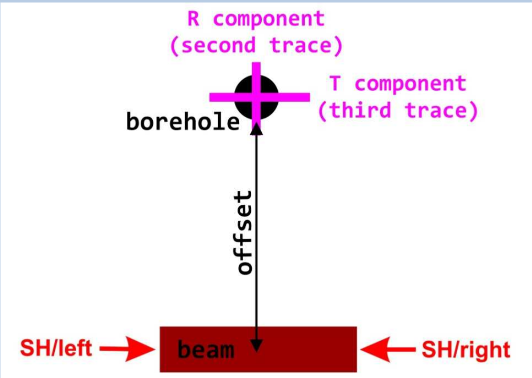
You can send us your data (recorded according to some simple rules we will forward you) and we will take care of the processing for the reconstruction of the V_S vertical profile (therefore also of the Vs30).

For DH (DownHole) data processing we need:

1) some information (at least in general) about the local stratigraphy

2) a couple of georeferenced photos of the borehole/site [see section "Photo documentation of the survey site"]

3) HF+ and HF- acquisitions (please use an inclined source – see "SH waves" subsection in the "2. Data Acquisition" chapter) within a single folder (possibly with the **compiled HF *project file*** – we can send you an example of .VSP file but it is a trivial ASCII file compiled as described in the "The Project File" section). It is important to clearly indicate the meaning of the traces of your data with respect to the Z, R, T scheme shown in the figure below: what is trace #1? what is trace #2? what is trace #3?



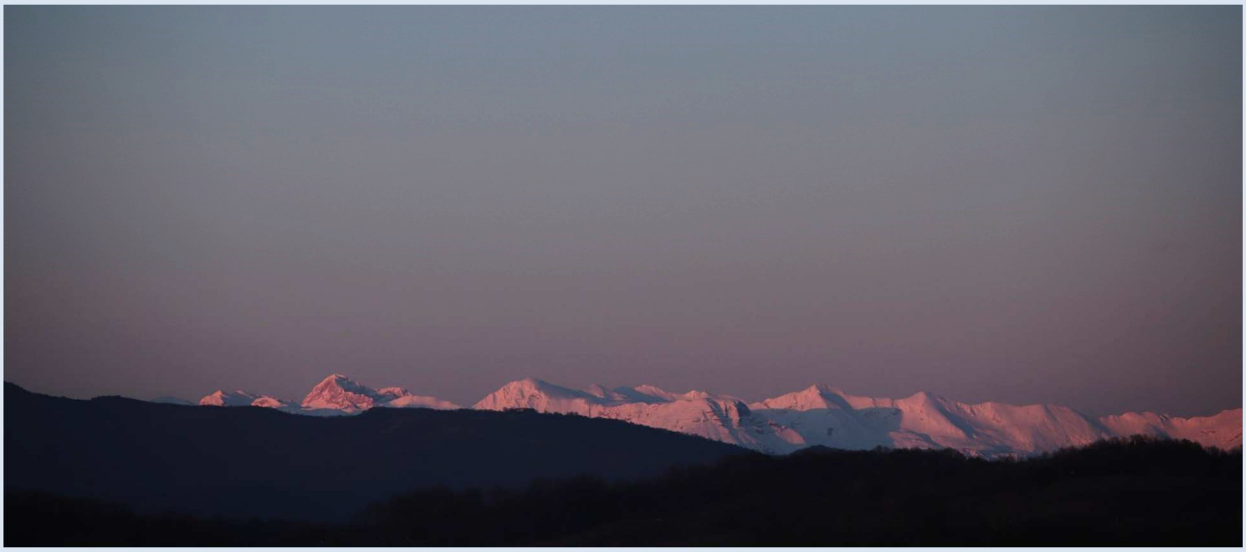
4) HVSR data: two datasets recorded according to the criteria illustrated in the data acquisition section, i.e. at two points around the borehole

5) Optional: VF acquisitions within a single folder (with the compiled VF project file)

Delivery times: approximately 2-4 days (to be discussed in advance).

ADAM-2D

Apparent Dispersion Analysis of Multi-component Data - 2D

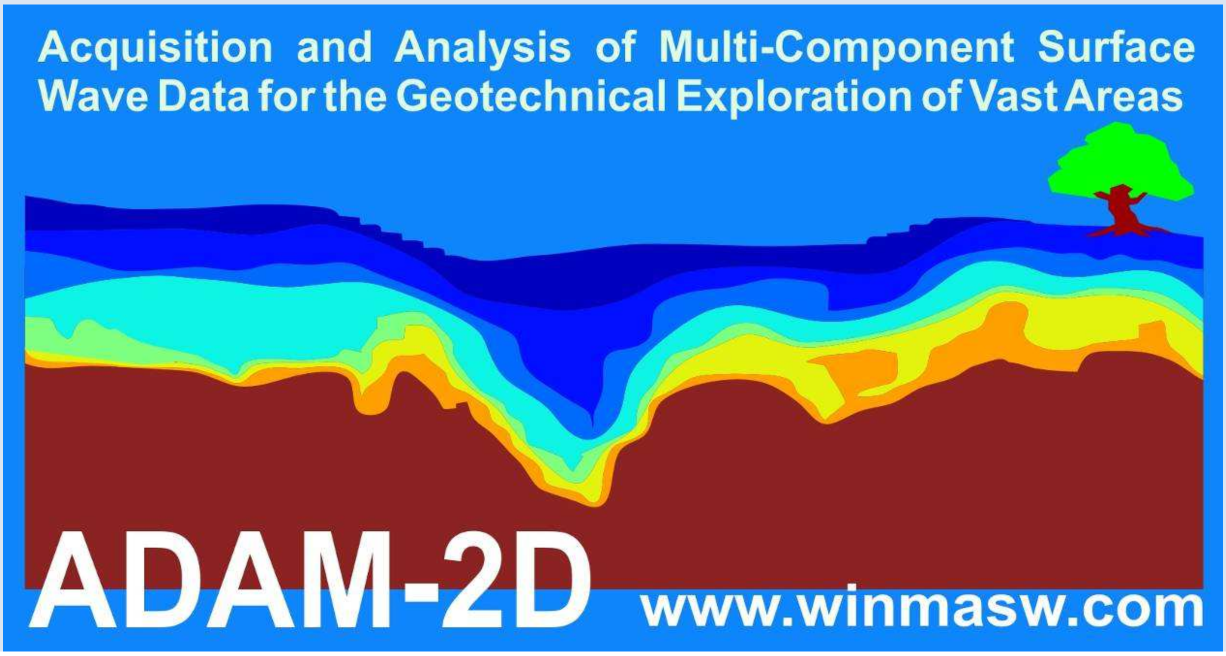


Acquisition and processing of multi-component data for the characterization of vast (2D and 3D) areas.

In partnership with some European partner companies and thanks to our procedures based on multi-component FVS (*Full Velocity Spectrum*) approach, we are able to **acquire and process multi-component data aimed at characterizing large areas (2D and 3D)** from the geotechnical point of view.

With ADAM2D, you get the most reliable maps of shear-wave velocity distribution in the subsurface, both in 2D and 3D.

Below the 2D V_S section obtained by the joint analysis of Rayleigh and Love waves via joint *Full Velocity Spectra* (FVS) inversion performed in the framework of an *Horizontal Directional Drilling* project.




www.winmasw.com