OPERATIVE GUIDE

DOWN – HOLE SEISMIC

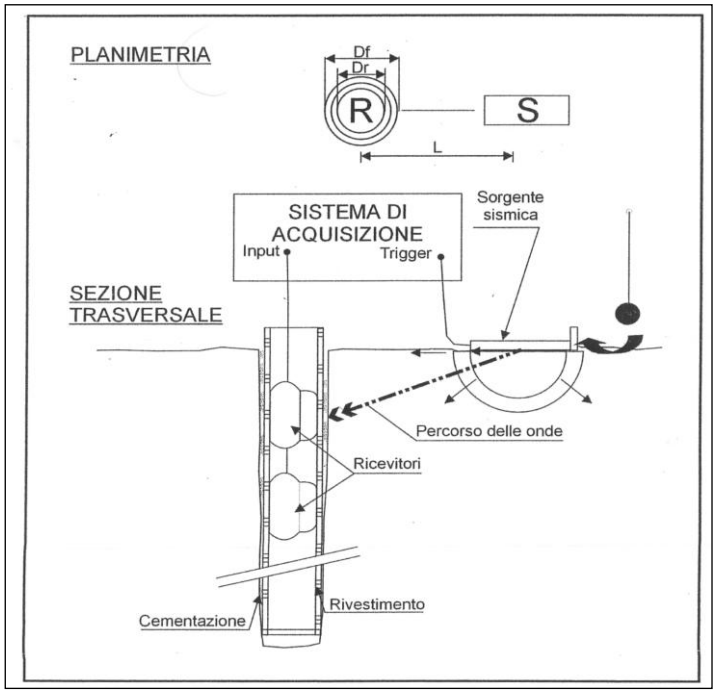
Down-hole seismic procedure

- **Generality**

Down-Hole method represents one of the best and most accurate techniques for determining physico-mechanical and dynamic properties of soils (Gasperini & Signanini, 1983).

Test aim is to produce an horizontal and vertical stress on ground surface, through a mechanical source, and to study P and S waves train that propagates within the ground at various depths in vertical direction with polarized vibrations in the propagation direction (waves P), and polarized on the horizontal plane with vibrations perpendicular to propagation direction (SH waves).

Through a receiver made up of a geophonic backbone oriented in the three spatial directions (z, x, y) placed into the hole at known depths, first arrival moment of P and SH waves train is compared to the moment (measured with the trigger) in which the stresses are induced to the source; therefore dividing for such values the distance between source and receivers, P and SH waves speed can be obtained. (**Fig. 1**).



Picture. 1: Execution scheme of down-hole test.

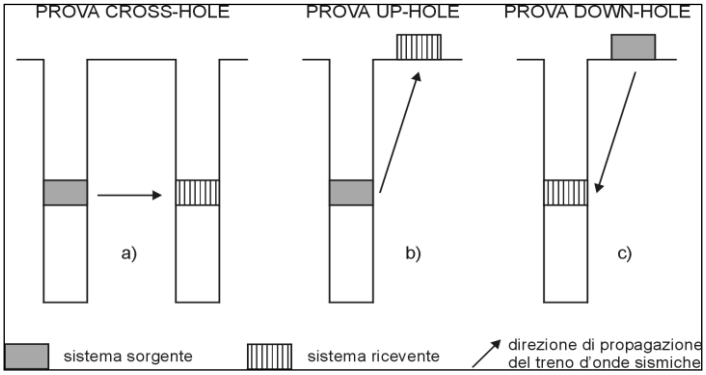
Down-hole test allows to detect horizons at lower speeds below an higher speed level, overcoming the refraction seismic limits known in the bibliography as "silent horizons".

For down-hole seismic surveys there are many different acquisition geometries, depending on how the energizing system and the receivers are arranged among themselves; each different geometry gives a different name to the test.

We have three kind of surveys: down - hole, cross - hole and up – hole (**Picture. 2**).

In down - hole survey, the elastic waves source is in surface, while receivers are in hole. In up – hole test, the opposite happens, that is source in hole and receivers in surface. The cross - hole survey needs positioning of the source and receivers

In two perforations at a distance of usually no more than ten meters.



Picture. 2: Different methods of acquisition for seismic surveys in hole.

Execution of drilling tests must be preceded by a preparatory phase in which the hole is made, if this is not already available, where to place the receivers or the source, and a preparation phase of the recording tools. During the drilling phase of the survey, it is necessary to work in such a way as to minimize the disturbance on the walls and surrounding areas around the hole. The drilling must be performed in rotation and it is advisable to support the walls with bentonite mud.

Subsequently the hole must be coated with a high vibration-resistant pipework such as PVC or ABS pipes with a thickness > 3 mm to be assembled by M / F threading or glued junctions.

Finally, the hole must be cemented at the annular space between the walls and the lining tube and closed with a packer to ensure the continuity of the ground-pipe contact.

Methodology consists in recording at various depths, through one or more geophones located into the hole, first arrivals of waves generated by a source placed on surface close to the hole, in order to get a distribution profile of body waves propagation speed across subsurface litotypes.

First of all, it is necessary to check lack of hole narrowings and that covering tube does not have fractures.

- **Recording modalities**

Necessary components for an accurate down-hole measurement are:

1. a mechanical source able to generate elastic waves full of energy and directional;
2. One or more tridimensional geophones with proper frequency response (4,5-14 Hz) and with diameter less or equal to 70 mm, directional and equipped with anchoring system of tube-hole at walls through a mechanical blocking device, pneumatical and / or electrical;
3. A seismograph with a number of channels equal or higher than number of used receivers, able to perform signal samples between 0,025 and 2 milliseconds and equipped with *high pass*, *bandpass* and *band reject* filters, of "*Automatic Gain Control*" and A/D convertors of sampling signal at 16 bit;
4. A transducer (*trigger*) located into the source necessary to identify starting instant of dynamic solicitation through swinging mass.

Source must be able to generate elastic waves of high frequency full of energy, with wave shapes repeatable and directional, that is with possibility to get mainly compression and / or shear polarized waves on horizontal planes (and eventually also vertical).

To generate P compression waves, classical methods such as the fall of a grave, hammer, seismic gun, oleopneumatical energizers etc…

To generate SH waves the source is generally made of a parallelepiped of wood or other material, with a shape that allows to hit laterally at both edges with a mass (pendulum or bat) in wedded way (180°).

It is important that parallelepiped is graved of a static additional weight and that it is located on a smooth surface mainly made of sandy thin material which can adhere to the ground both at striking moment than after, so that generated energy won't be partially lost.

Therefore it is extremely important to care a good *coupling* between ground and

energizing system, especially when SH waves are generated, to avoid loss of part of generated energy and avoid generation of shear waves only, without any important presence of P waves.

Coupling must be made through “contact” and not “piling”.

Receiver system, in its optimal version, is made of two (or more) receivers, each one made of a speed transducer oriented according to an orthonormal Cartesian triad components.

Transducers must have frequency and sensitivity characteristics so as to properly receive waves train generated by the source. Frequency response of transducers must not vary more than 5% on a range of frequencies between half and double of waves train main frequency which propagates into the mean.

In case of two receivers placed into the hole, they must be connected, according to their length, so as to fix their vertical distance (between 1 and 3 m) and related orientation (so that horizontal transducers are parallel and accorded at couples) and in order to check also absolute orientation of surface which shall remain the same for all measurements points. Particular attention must be paid to systems used to keep constant distances and to grant same geophones orientation; they shall not produce seismic interaction between two sensors.

Trigger is usually made of an electric circuit which is closed when input seismic solicitation is generated, allowing a condenser to discharge energy previously stored which is sent to a sensor connected to data recording system; in this way it is possible to detect and visualize exact instant when source is activated and dynamic solicitation starts.

Trigger system is very important because each bang represents a point in depth and a propagation velocity.

An optimal trigger-system (switch, starter geophone, etc.) at repeated solicitations shall not have differences in circuit closures higher than 0.5 milliseconds.

For SH recording, because it is necessary to know difference between trace related to right hammering and those related to left hammering of the parallelepiped, an instrument with “polarity inversion” tool is necessary.

Survey operating modalities shall be the following:

- placing and blocking energizers of compression and shear waves close to hole mouth (at

few mt distance, between 2 and 5 mt) oriented in orthogonal direction to a ray originating from hole axis;

- placing and blocking of receiver at hole bottom;

- normal wedded shear pulse generation with related recording of arrival times of shear waves to check recording parameters (*record time*).

Once decided exact recording parameters, acquisition can start in the following manner:

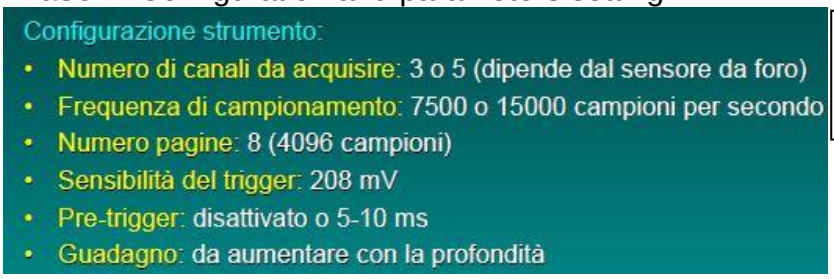
–energization of compression and shear waves and recording of related file;

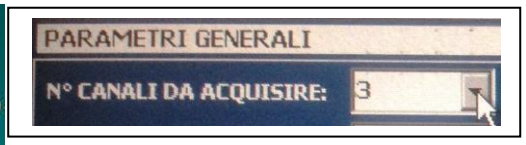
–place receiver 1 mt higher than hole bottom and repeat compression and shear energization as above;

–repeat same operations along investigation vertical line.

In detail:

Phase 1: Configuration and parameters setting





Phase 2: energize P compression wave and press iteration execution;

Phase 3: from iteration menu select no operation on first channel and replacement on 2 and 3 channels then move close to parallelepiped to perform hammer on one side;

Phase 4: from iteration menu select no operation on first channel and difference on channels 2 and 3, then proceed with hammering on the other side of the parallelepiped.

During this phase shear waves arrival must be clearly recognized through polarity inversion of recorded signal.

Phase 5: Saving of file in .seg2 format which will include both P and S waves.
Measurements will be related to range of considered depths; it is recommended to perform a measurement at each meter.

- **Elaboration**

Standard methodology of data elaboration consists of the following phases:

- picking of first arrivals;
- Measure of receiving times of first detected pulses (t);
- Compute of vertical times (t).

To determine arrival time of P and S waves to receivers, proceed with a visual analysis of recordings of vibrations detected by receiver transducers compared to trigger signal.

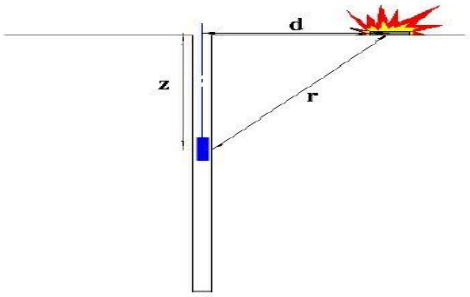
Operating with double energization system, vertical percussion for P waves and horizontal for SH waves, in recording energized vertically first arrival in P will be evaluated while in recordings energized horizontally, first arrival will be made of SH shear waves; with method of difference “right hammer – left hammer” any eventual compression waves generated during energization will tend to dissolve, contrary to SH waves which, through polarity inversion according to hammering direction, will tend to sum one another, increasing amplitude.

Picking phase of first arrivals allows to acknowledge cross arrival times (t).

Subsequent *processing* operation refers to cross times correction to vertical times, according to following equation:

$$t_{corr} = \frac{z}{r} t$$

where t_{corr} is vertical time, z is receiver depth, r is real distance between source and receiver, d is surface distance between source and hole centre and t is cross time recorded by the geophone, as visible in simplified scheme in Pic. 3.



Pic. 3: Scheme of "shot – point" and receiver displacement in a Down – Hole survey.

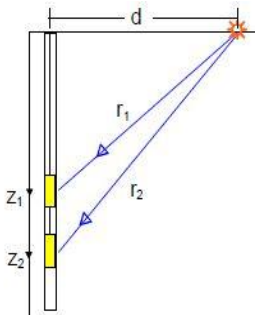
It must be underlined that not always traces recorded by receivers are clear and uniquely interpretable, both for the presence of refracted waves of important amplitudes that, preceding direct waves, can affect real arrival times indicating anomalies, both for difficulty in detecting waves first arrival especially in depth; exploiting number of available receivers, it is possible to refer to traces recorded by each of them by searching for characteristic points (picks or valleys) subsequent to first arrival, which can be found in both signals and estimating delay it is possible to get interval speed.

Once computed correct crossing times, times-depths diagram is generated.

Following step is to detect dromocrones, that is intervals characterized by a constant slope; those slopes are symptomatic of body waves propagation speed into different layers.

Described elaboration procedure is that of **Direct method**, as it is acquired through single receiver or 3 – 5 components receiver (S3-S5) which is lowered into the hole.

If test is performed with two receivers (S3-2), during elaboration **Interval method** is used, through which seismic wave transit time are measured between two consecutive receivers placed at different depths, allowing to improve measures quality (interval speed).



Pic. 4: Scheme of displacement with two receivers

Once obtained measures, it is possible to compute correct times with above mentioned formula and P and S waves interval speed with related graphic, through the following formula:

$$v = \frac{z_2 - z_1}{t_{2COR} - t_{1COR}}$$

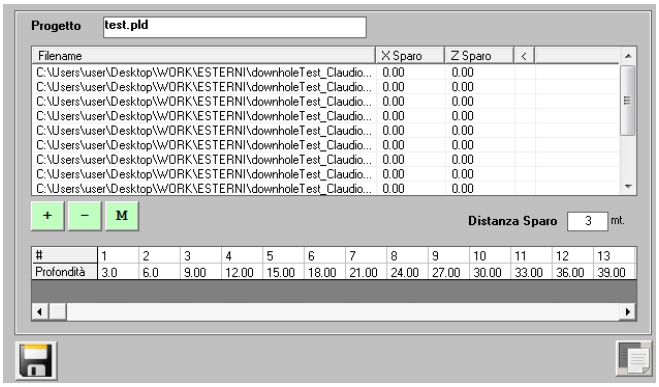
This method has some limits: does not consider above layers speed and it is not applicable in case of $t_{2cor} < t_{1cor}$.

Recording phase final result is a series of files in .sg2 format which will be included in dedicated *PSLab software* where they will be properly elaborated and interpreted.

Through guided procedure, *software* allows to get detailed report with graphics and tables starting from campaign data.

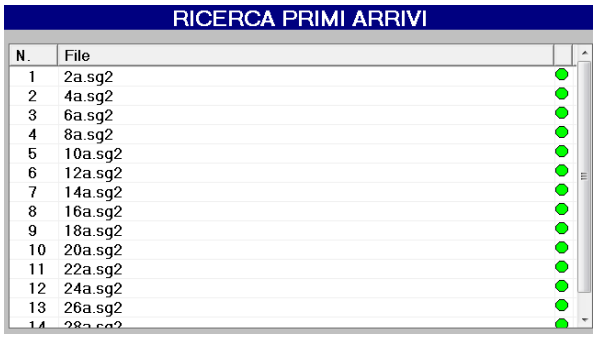
Once defined dromocrones and detected different seismic layers, Vs,30 parameter is computed, useful to determine soil category.

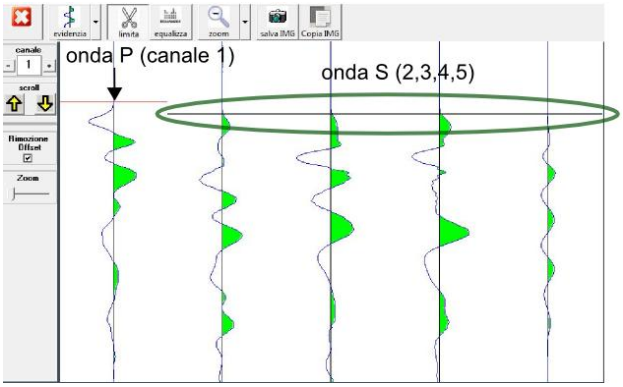
A job project can be created by saving a .pld file and importing traces geometry can be defined (distance between blast and depth).



Once uploaded all traces, first arrivals can be searched by opening each single trace and searching on different channels exact time of first arrival for P and S waves (picking).

It is possible to underline wave single phases (positive, negative), remove offset and perform zoom operations on amplitude and times in order to allow a better data interpretation.





Once completed picking on all traces uploaded in project, it is possible to visualize first arrivals table where correct time computing is included (vertical times) which allow in subsequent phase to evaluate speed in terms of Vp and Vs.

Compute is based on direct method previously described.

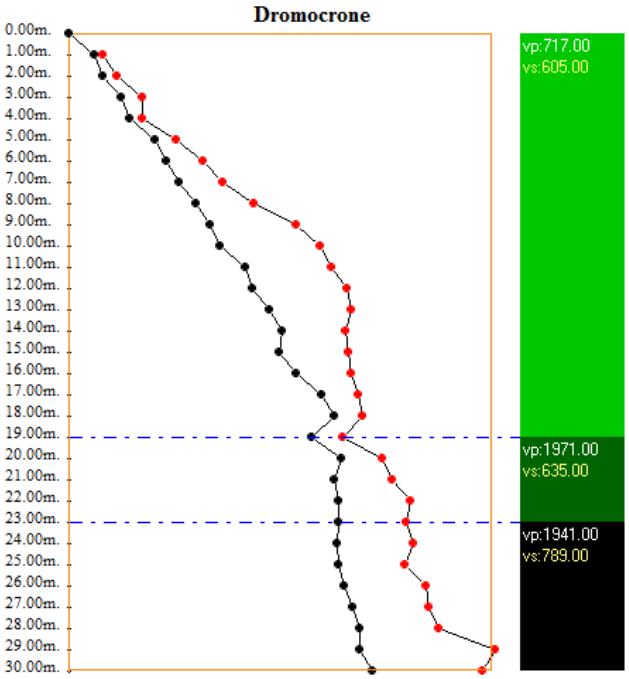
In software final phase dromocrones defined by picking will be detected;

From this record different seismic layers can be allocated and speed of each one will be automatically visualized.

Elastic-dynamic parameters will be computed by distributing density values to seismic layers intervals which have been adopted; therefore, it is fundamental to have stratigraphical and geotechnical data for a correct survey interpretation and a better estimation of the results.

TABELLA PRIMI ARRIVI

	Tp	Ts	Tp corr.	Ts corr.
18.0 mt.	27.27	30.20	26.90	29.79
19.0 mt.	25.00	28.20	24.69	27.85
20.0 mt.	28.00	32.20	27.69	31.84
21.0 mt.	27.20	33.20	26.93	32.87
22.0 mt.	27.67	35.00	27.42	34.68
23.0 mt.	27.60	34.60	27.37	34.31
24.0 mt.	27.40	35.20	27.19	34.93
25.0 mt.	27.53	34.33	27.33	34.09
26.0 mt.	28.20	36.47	28.01	36.23
27.0 mt.	29.00	36.80	28.82	36.57
28.0 mt.	29.67	37.80	29.50	37.58
29.0 mt.	29.67	43.53	29.51	43.30
30.0 mt.	31.00	42.20	30.85	41.99



In conclusion, down-hole surveys allow to characterize soil on site in terms of elastic-dynamic parameters and thickness of seismic layers.

Disadvantages consist of extremely punctual character of recorded data and poor reliability of the same when dealing with investigation depth lower than surface distance between seismic source and hole mouth.