Document	**Guidelines for *MASW, ReMi, ESAC* and *HVSR* acquisitions.pdf**
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WARNING

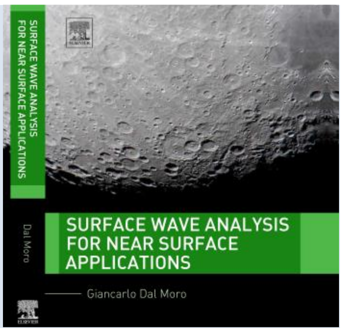
Buy and use horizontal geophones and jointly analyse Rayleigh (radial component) and Love waves!

Please, acquire the data strictly following provided guidelines and download and read the following old collection of case studies:

http://download.winmasw.com/documents/brochure_winMASW_EAGE.pdf

For more information about surface-wave acquisition and analysis:

Surface Wave Analysis for Near Surface Applications
Dal Moro G., 2014
***Elsevier,* ISBN 978-0-12-800770-9, 252 pp**
theory, field practice and advanced joint analysis



Basic guidelines for
MASW, ReMi, ESAC/SPAC and *HVSR* acquisitions

Foreword

The present document cannot be considered as exhaustive of the topic. What we need to know (both during field operations and in the data processing/analysis) can be fully understood only through a balanced synergy between a solid theoretical background and a long field practice.

Therefore, we recommend:

1. Robust theoretical background (books, articles and workshops)
2. Wide field practice in different soil conditions
3. Common sense

In general, we strongly suggest to do something only when we know exactly what we are doing.

Introduction

The acronym *MASW* stands for *Multi-channel Analysis of Surface Waves* and that clearly means that our aim is to analyze Surface Wave (SW) propagation in order to determine their dispersive properties (which will eventually allow us to reconstruct the vertical V_S profile).

The basic principle is that the lower the frequency (i.e. the longer the wavelength) the deeper the penetration (this is why we need 4.5Hz geophones). As, in most of the cases, deep layers are characterized by higher V_S velocities this will mirror in higher SW phase velocities for the low frequencies.

Please, notice that SW propagation depends mainly on V_S and thickness of the layers, being density and V_P almost irrelevant.

The so-to-speak standard *MASW* exploits Rayleigh-wave propagation (see Figures 1 and 2 to see how to generate and record Rayleigh waves) but **we strongly suggest to generate, record and jointly analyze Love waves as well**. This way, data interpretation (thus the final V_S profile) will be much more robust also avoiding possible errors in Rayleigh-wave spectra interpretation. In fact, Rayleigh-wave spectra can be very problematic to interpret (see e.g. Safani et al. 2005; Dal Moro and Ferigo 2011; Dal Moro 2012, 2014, 2019), while Love waves are much more simpler.

The joint acquisition and analysis of *MASW* (Rayleigh and Love) and *HVSR* is the suggested procedure (see next pages).

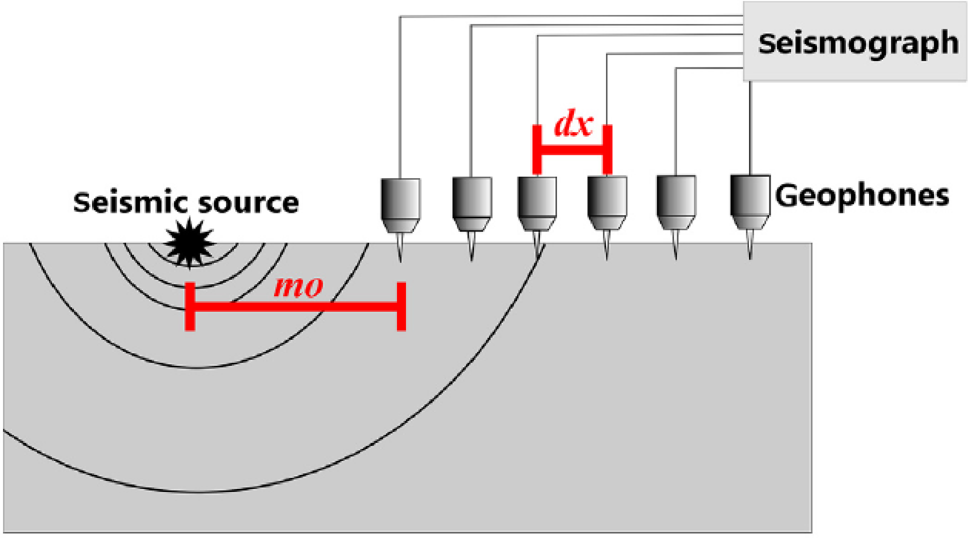


Figure 1. Seismic sources. In order to generate Rayleigh waves, it is necessary a vertical-impact source (e.g. the classical sledgehammer), while for generating Love waves (and/or SH-wave refractions) we need a shear source (see Figures 2 and 3).

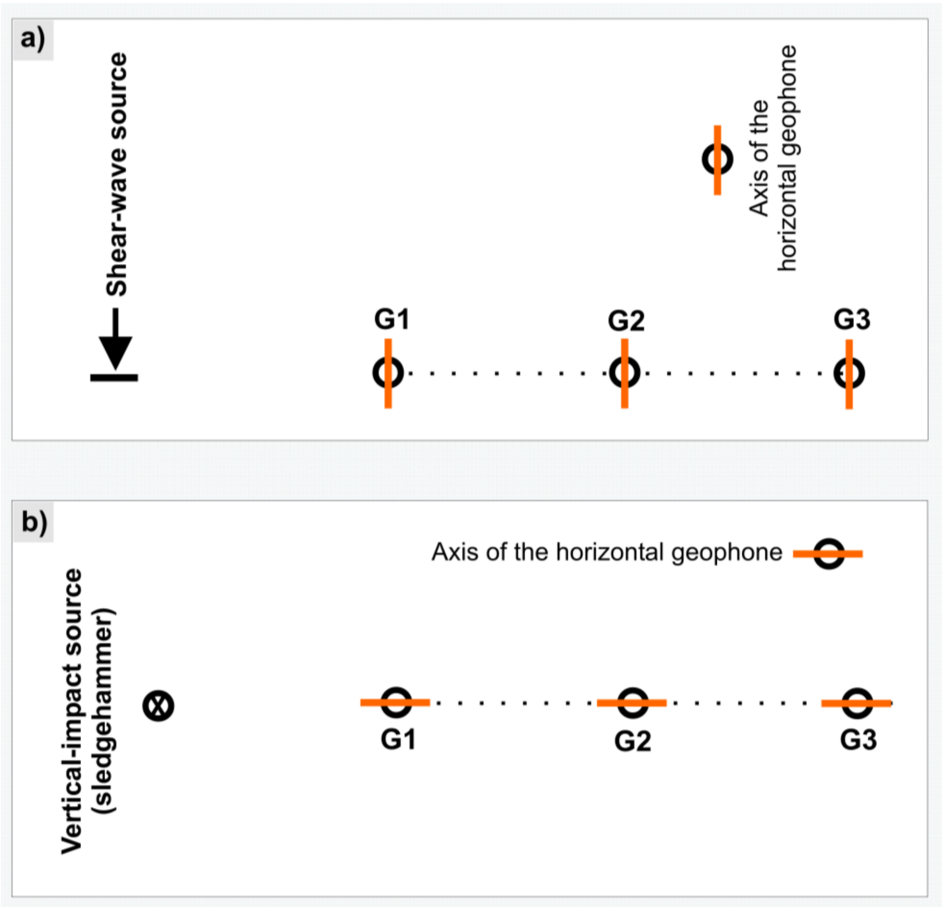


Figure 2. Data acquisition using only horizontal geophones: a) geophone array for SH-wave refraction and Love-wave analysis; b) geophone array for Rayleigh-wave analyses (radial component). Of course, Rayleigh waves can be detected using also vertical geophones but in case you are using horizontal geophones, you can record both Rayleigh (their radial component) and Love waves and, therefore, you can jointly analyze them and obtain a much more reliable V_S profile.

Compared to Rayleigh waves (which can be extremely complex to understand), **Love waves** are much simpler and, therefore, represent an **extremely** useful tool for getting a more robust data interpretation and, consequently, a reliable vertical V_S profile (see the Elsevier book).

Dealing with Love waves is quite simple: the procedure to generate and record them is the same used for the acquisitions of the data used for SH-wave refraction studies.

Please, notice that just by rotating the horizontal geophones by 90° it is possible (just using horizontal geophones) acquiring datasets useful both for Rayleigh and Love analyses (see Figure 2).
In other words (and by using only a set of horizontal geophones):

1) Love waves: place the horizontal geophones with the axis perpendicular to the array (Figure 2a) and use a shear-wave source (see wooden been in Figure 3);

2) Rayleigh waves (radial component): rotate the horizontal geophones by 90° (so now the axis is parallel to the array - Figure 2b) and hit your plate vertically (vertical-impact sledgehammer)

Now we have two datasets (one about Rayleigh and one about Love waves) and your analysis will strongly benefit from it.

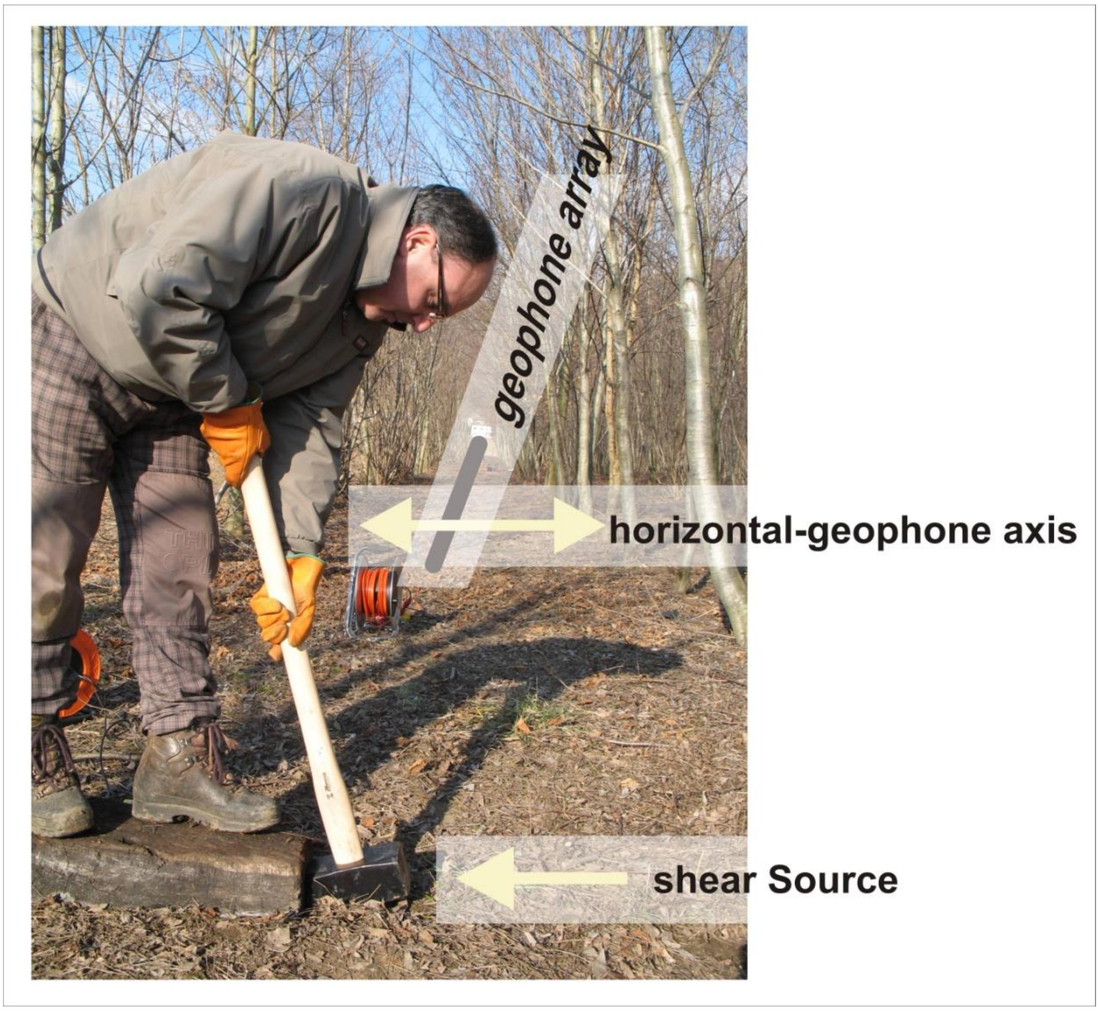


Figure 3. Data acquisition for SH-wave refraction travel time determination and Love-wave dispersion analysis (shear source and geophone-axis perpendicular to the array – see also Figure 2).

MASW **acquisition: Rayleigh and Love waves**

The geometry is very simple (see Figure 1). Remember that, in order to get good data in the low-frequency range (related to the deepest layers) it is important to have an array as long as possible. Geophone spacing is completely irrelevant: just take advantage of all the space available and spread the array accordingly.

For instance: if the available space is 75 meters and you have 12 geophones, then you can fix the geophone distance equal to 6 m and a minimum offset of 9 m.

Minimum offset **(mo): distance between source and first geophone**	5-20 m Suggestion: you could acquire a couple of datasets by moving the source so to have 2 dataset with two different minimum offsets. You will choose the best dataset while analyzing the data.
geophone spacing (dx)	The point is the following: the length of the geophone array must be as long as possible. If the available space is for instance 75 meters and you have 24 geophones, then you can fix the geophone distance equal to 3m (with a minim offset distance equal to 5 m)
Geophones **(4.5 Hz)**	Rayleigh waves: vertical or horizontal (axis radial to the array) Love waves: horizontal perpendicular to the array (see Figures 2 and 3) **For active (MASW) data, we strongly recommend to buy just 12 horizontal 4.5Hz geophones to acquire both Love and Rayleigh (radial component) waves.** **For details, please see the Elsevier book "*Surface Wave Analysis for Near Surface Applications* ".**
Record time/length (s)	2 seconds are usually sufficient (it is essential that the full surface wave trend is entirely recorded even at the very last channel/trace)
Number of channels/geophones	12-24 Less channels are sometimes sufficient The crucial point is anyway the total length of the array, possibly not less than say 50 meters, much better 70-90meters (to reach the suggested length just act by modifying the geophone distance)
dt **(sampling rate)**	0.001s (1ms, 1 millisecond)
Important notes	No AGC (*Automatic Gain Control*) No filter Keep the same gain for all the channels. Be careful: avoid saturation (see later on)

Tab 1. Summary table for MASW acquisitions: main facts.

<u>Gain</u>

The amplification/gain should be the same for all the channels. This is not mandatory if you just need to deal with SW dispersion analyses (to estimate the V_S vertical profile). It is mandatory only to analyze seismic attenuation to estimate quality factors Q through Rayleigh-wave attenuation analysis for the very shallow part (say down to a depth of 10 meters).
Of course, in some case (if the site very noisy and the soil very attenuating) you might be forced to increase the amplification/gain of the distant offsets/channels (this is especially necessary when dealing with refraction studies where the amplitude of the first arrivals can be very small).

In case you want to analyze Surface Waves, <u>it is mandatory</u> to avoid trace saturation/clipping (see Figure 4). In case your traces are saturated, just decrease the gain until you obtain a dataset similar to the one shown in Figure 5.

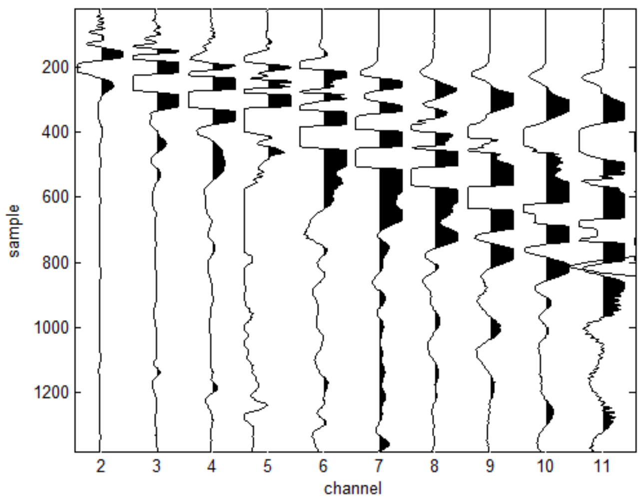


Figure 4. *Dataset* characterized by trace clipping (the amplitude is too high for the dynamic range of the seismograph: gain must be decreased).

Of course, in case just 1 or 2 traces (out of 24) are clipped there is no problem!

Figure 5 reports an example of correct gain: no trace is clipped and the signal-to-noise ratio is good even for the distant offsets.

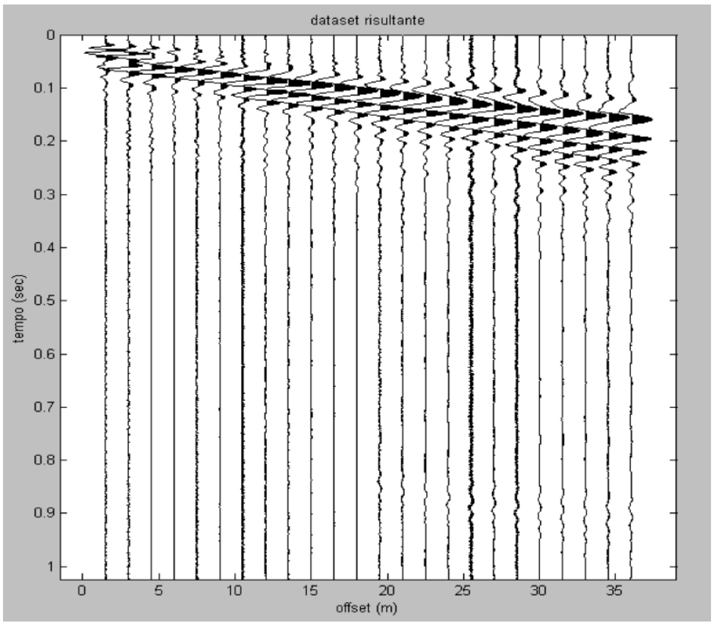


Figure 5. Dataset with a correct amplitude (gain values set to a correct value).

Combining 2 datasets (to double the number of channels)

In case you have a 12-channel seismograph and want to have a 24-channel acquisition (in general terms you can double the channels of your seismograph) you can perform a double acquisition on the field and eventually proceed in their combination through the software *winMASW*.

There are three possible procedures to do that (see Figure 6). The first method reported (Figure 6a) is definitely the best one in terms of field procedures and accuracy of the dataset.

Clearly, such a trick is not possible for passive acquisitions

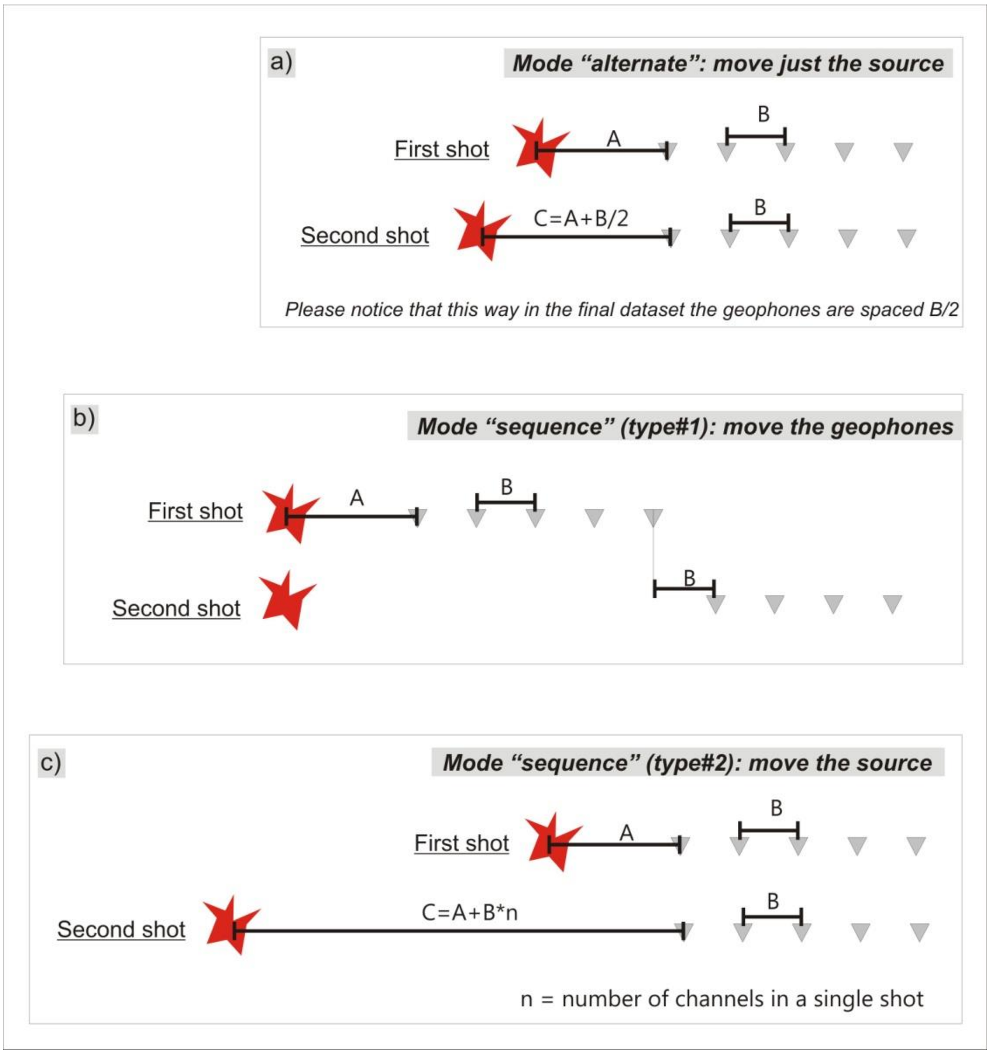


Figure 6. Three ways to combine 2 *datasets* (to obtain a final dataset with double number of channels).

A couple of notes on the process of *dataset* combination

1. Clearly, the combination of two or more datasets is useful for any kind of seismic study (reflection and refraction as well).
2. A *dataset* got from the combination of two datasets (to double the number of channels) is perfectly fine for most of the possible analyses (reflection, refraction, SW dispersion analysis) but not for attenuation (aimed at evaluating the quality factors Q) studies.

Acquiring data for *ReMi* analyses (for Rayleigh-wave analyses only)

Few important points:

1. the geophone array should be as long as possible (not less than say 69 m – i.e. 24 geophones spaced each 3 m or 12 geophones 6 m spaced).
2. vertical 4.5Hz geophones (*ReMi* acquisitions only allow for Rayleigh-wave analyses – for this kind of (passive) acquisitions horizontal geophones can be used by with some cautions).
3. Record time: 10-20 minutes
4. Sampling rate: 4 msec
5. In case there is a particular source of "noise" (such as a motorway or an industrial facility) orientate your geophone array perpendicular to it.

Acquiring data for *ESAC* analyses

Download the *winMAW* manual from our web site – www.winmasw.com

HVSR acquisitions

(necessary a calibrated 3-component geophone)

Just a couple of recommendations (search for the SESAME project guidelines for further information - http://sesame-fp5.obs.ujf-grenoble.fr/):

1. record time: 10-30 minutes (depending on the lowest frequency we are interested in)
2. sampling rate: 8 msec (125 Hz)
3. recommended (standard) format: first trace UD (vertical), second trace NS component, third trace EW component

Recommended equipment to start working seriously

In the Elsevier book *Surface Wave Analysis for Near Surface Applications* we explain why

12 horizontal geophones (for Rayleigh + Love waves + SH-refraction)
+
one 3-component geophone (for HVSR and much more)
+
Software *winMASW*-3C (joint analysis of Rayleigh+Love+HVSR)

Notes

If you send us your data for *MASW/ReMi/ESAC* (and *HVSR*) analyses, please remember to provide us the necessary information about the data: geophone distance and minimum offset.
It is also extremely important to use the file naming described in the **Elsevier book** (see paragraph 2.2).
If you acquired your data for passive analyses (ESAC/SPAC/ReMi/HVSR/MAAM), please indicate the orientation of the array with respect to main noise sources such as streets, industrial facilities etc.
It is also necessary to give us information about the local stratigraphy.

Please also provide us a photo of the site and geophone array.

Remember: in general terms, if you want to have a reliable V_S profile we recommend the acquisition and analysis of three observables:

Rayleigh waves

Love waves

HVSR

Some References

On the efficient acquisition and holistic analysis of Rayleigh waves: Technical aspects and two comparative case studies, Dal Moro G., Al-Arifi N., Moustafa S.R., 2019, Soil Dynamics and Earthquake Engineering 125 (2019) 105742, https://doi.org/10.1016/j.soildyn.2019.105742

Surface wave analysis: improving the accuracy of the shear-wave velocity profile through the efficient joint acquisition and Full Velocity Spectrum (FVS) analysis of Rayleigh and Love waves, Dal Moro G., 2019, Exploration Geophysics, DOI: 10.1080/08123985.2019.1606202

Effective Active and Passive Seismics for the Characterization of Urban and Remote Areas: Four Channels for Seven Objective Functions, Dal Moro G., Pure and Applied Geophysics, 2018, https://doi.org/10.1007/s00024-018-2043-2. Available for online reading at the following link: https://rdcu.be/bbT04

Improved Holistic Analysis of Rayleigh Waves for Single- and Multi-Offset Data: Joint Inversion of Rayleigh-wave Particle Motion and Vertical- and Radial-Component Velocity Spectra, Dal Moro G., Al-Arifi N., Moustafa S.R., 2017. Pure and Applied Geophysics, open access, click this link

Analysis of Rayleigh-Wave Particle Motion from Active Seismics. Dal Moro G., Al-Arifi N., Moustafa S.R., 2017, Bulletin of the Seismological Society of America, 107, 51-62

Shear-wave velocity profiling according to three alternative approaches: a comparative case study. Dal Moro G., Moustafa S.R., Keller L., Al-Arifi N., Moustafa S.R., 2016, Journal of Applied Geophysics, 134, 112–124

Four Geophones for seven possible objective functions: active and passive seismics for tricky areas. Dal Moro G., Invited presentation and Extended Abstract for the *Urban Geophysics* workshop of the 22nd *EAGE Near Surface Geoscience* conference (4-8 September 2016 - Barcelona, Spain)

Assessing ground compaction via time lapse surface-wave analysis. Dal Moro G., Al-Arifi, Moustafa S.R., Acta Geodyn. Geomater, 13, No 3 (183), 249-256, 2016. DOI: 10.13168/AGG.2016.0006

A Comprehensive Seismic Characterization via Multi-Component Analysis of Active and Passive Data. Dal Moro G., Keller L., Poggi V., 2015, *First Break*, 33, 45-53

Multi-component Joint Analysis of Surface Waves. Dal Moro G., Moura R.M., Moustafa S.R., 2015, *J. Appl. Geophysics,* 119, 128-138

Joint analysis of Rayleigh-Wave Dispersion and HVSR of Lunar Seismic Data from the Apollo 14 and 16 sites. Dal Moro G., 2015, *ICARUS,* 254, 338-349

Unconventional Optimized Surface Wave Acquisition and Analysis: Comparative Tests in a Perilagoon Area. Dal Moro G., Ponta R., Mauro R., 2015, *J. Appl. Geophysics*, 114, 158-167

Surface Wave Analysis for Near Surface Applications. Dal Moro G., 2014, *Elsevier,* ISBN 978-0-12-800770-9, 252pp (theory, field practice and advanced joint analysis)