Velocity profile report at the seismic station IV.NRCA-NORCIA

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Subject: **Final report illustrating measurements, analysis and results for station IV.NRCA**	

Convenzione DPC-INGV 2018, Allegato B2: Obiettivo 1 - TASK B: "Caratterizzazione siti accelerometrici" (Coord.: G.Cultrera, F.Pacor)

Cite as: Working group INGV "Agreement DPC-INGV 2018, Allegato B2, Obiettivo 1 - TASK B", (2018). Velocity profile report at the seismic station *IV.NRCA-NORCIA*. doi: 10.5281/zenodo.2358257

1. Introduction

In this report, we present the geophysical data and analysis obtained in the framework of the 2018 agreement between INGV and Civil Protection Department (DPC), called *Allegato B2: Obiettivo 1 - TASK B: Caratterizzazione siti accelerometrici (Responsabili: G. Cultrera, F. Pacor)* for the site characterization of the Italian accelerometric network.

Here the results for station IV.NRCA, belonging to the Italian National Seismic Network (RSN-INGV), are presented.

IV.NRCA (latitude 42.833549, longitude 13.114270; coordinates from http://esm.mi.ingv.it/) is situated in the locality of Pielarocca (Perugia, Italy).

Geophysical measurements consisted of 1D linear array of vertical geophones in active and passive configuration (MASW); in addition, two noise sparse measurements were performed nearby the NRCA station. The MASW analysis provides results in terms of dispersion curves, that are inverted to obtain shear-wave velocity (V_s) profiles for the studied area and suitable for assigning the soil class category.

2. Geophysical investigations

Figure 1 shows the location of IV.NRCA, the two sparse noise measurements (PIE01 and PIE02) and the line of seismic geophones (red line). Due to logistics, it was not possible to perform passive array measurements in a 2D configuration. The geophysical investigations were carried out on March 19, 2018.

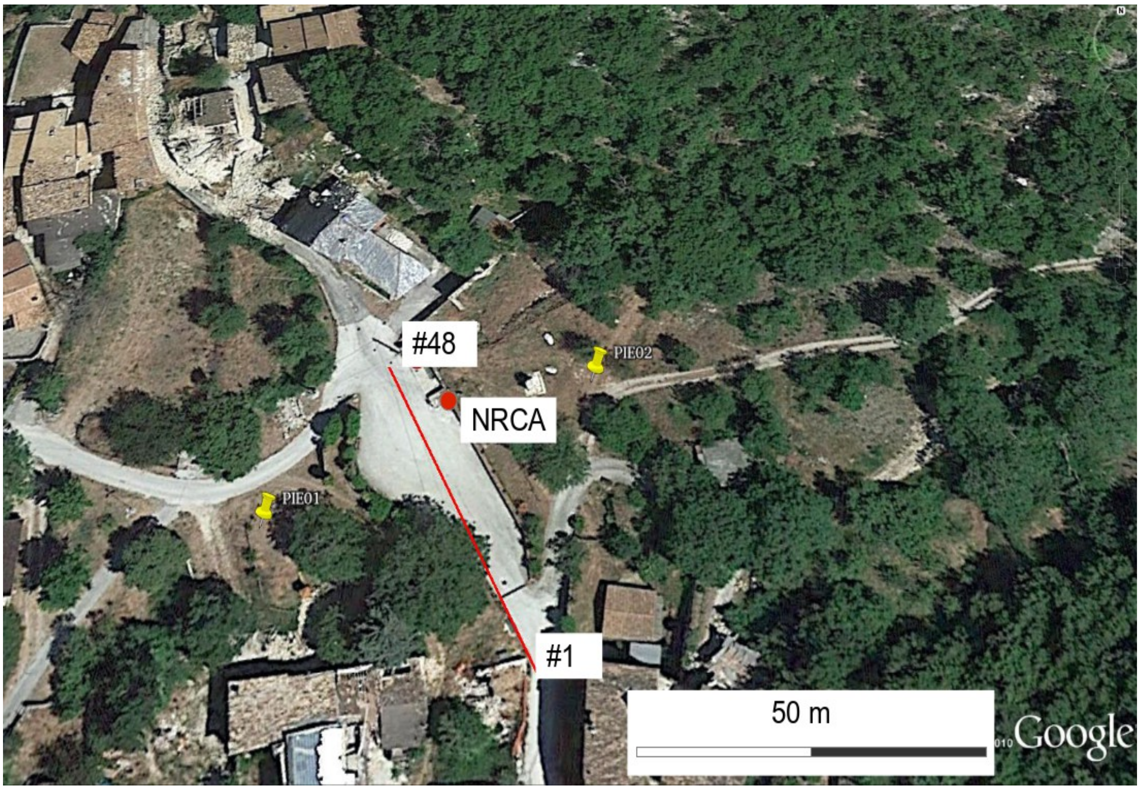

Figure 1: The positions of IV.NRCA and of the two noise measurements were indicated as red circle and yellow markers, respectively. The linear array of geophones (MASW survey) is shown as red line.

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2.1 NOISE MEASUREMENTS RESULTS

Noise measurements were performed using 2 seismic stations equipped with Reftek 130 digitizers and Lennartz 3d-5s velocimetric sensors. The duration of noise recordings was about 1 hour. A view of PIE01 is shown in Figure 2.

The HV noise spectral ratio of IV.NRCA is characterized by a prominent peak at about 7 Hz (Fig. 3). This high-frequency peak is confirmed by the HV results of the two nearby noise measurements (PIE01 and PIE02; Figure 4).

The analysis presented in this report was performed with the geopsy tool (www.geopsy.org).

Figure 2: PIE01 station.

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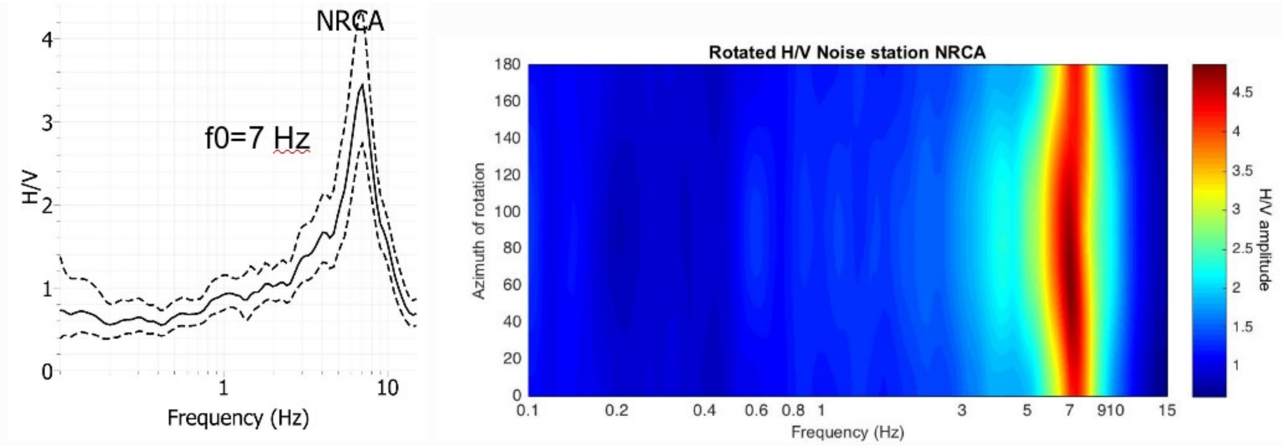

Figure 3: HV noise spectral ratio and rotated HV for IV.NRCA station (redrawn from http://crisp.rm.ingv.it; Site Characterization of the Italian national seismic network).

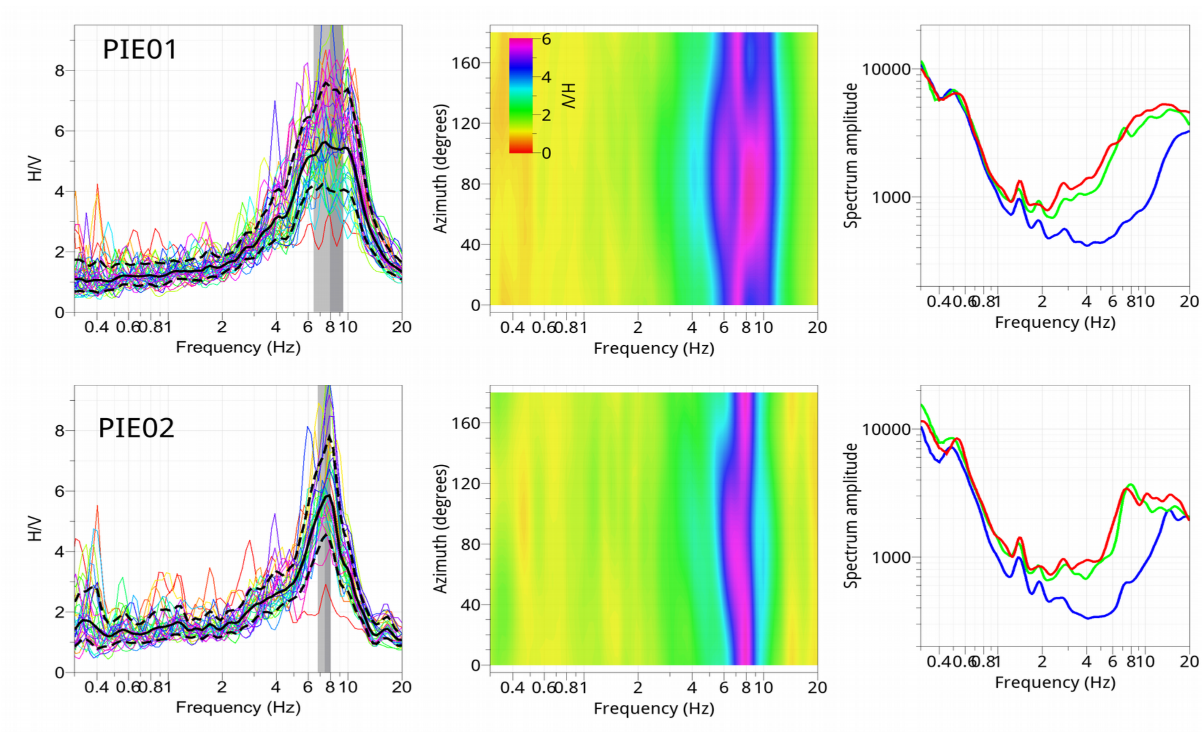

Figure 4: H/V curves of PIE01 and PIE02 stations are shown in the left panel. Rotated HV noise analysis is reported in the middle panel. Fourier Amplitude Spectra of the three components of the ground motion are shown in the right panel (vertical, NS and EW components are plotted in blue, green and red colors, respectively).

2.2 LINEAR ARRAY MEASUREMENTS RESULTS

Figure 5 shows pictures of the MASW measurement. We used 48 vertical geophones, recording active data using as source a sledge hammer situated at different offset. We recorded also passive data.

Figure 5: MASW measurement pictures

General data from MASW measurement as well as the main parameters used for the spectral (linear frequency-wavenumber) analysis are indicated hereafter.

General data

Date (mm/dd/yyyy) 19/04/2018
N. geophones: 48 vertical geophones (eigen-frequency 4.5)
Interdistance among geophones [m]: 1
Duration [sec]: 2 for the active survey, 240 for the passive survey
Sampling [msec]: 0.125 for the active survey, 4.00 for the passive survey
Shot source: sledge hummer of 5 kg
Shots' location for the active survey [m from the first geophone]: -5, -1, 23.5 (middle of layout), +48, +52
Number of shots for each location [#]: at least 3
Number of windows for the passive surveys [#]: 4

Spectral analysis

Minimum frequency [Hz]: 5
Maximum frequency [Hz]: 50 (active), 30 (passive)
Minimum velocity [m/sec]: 100
Maximum velocity [m/sec]: 1000 (active), 2000 (passive)

Main results from active measurements in terms of dispersion curves are displayed in the next for each single offset (Fig.s from 6 to 10).

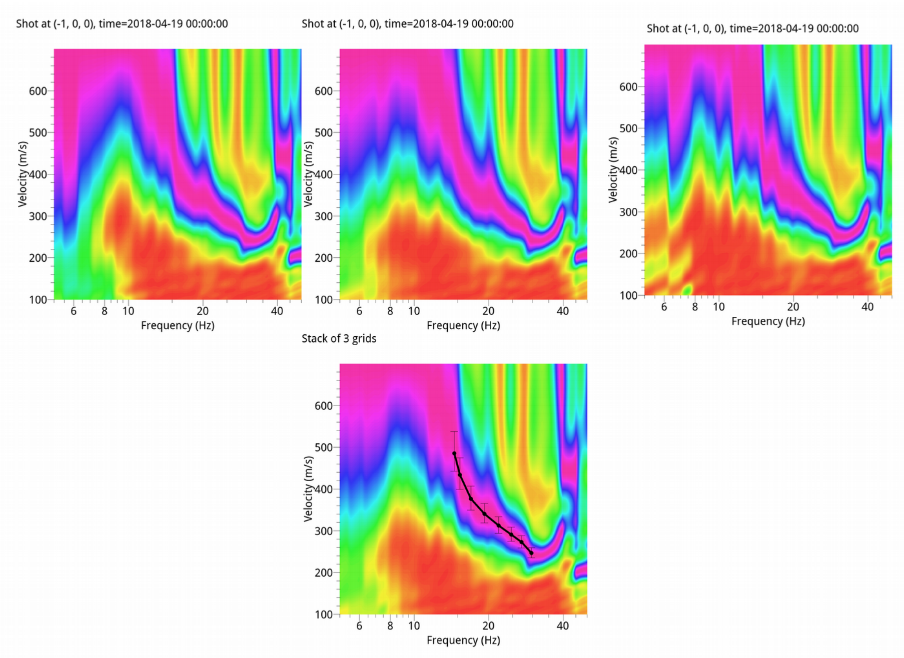

Figure 6: Velocity-frequency spectrum from MASW measurement using a shot offset of -1m (i.e. the distance from the first receiver). The spectrum of each single shot is shown on the top panel. The stacked spectrum is shown on the bottom panel. The picked dispersion curve is also indicated as black curve (vertical bars indicate the error associated to the picking).

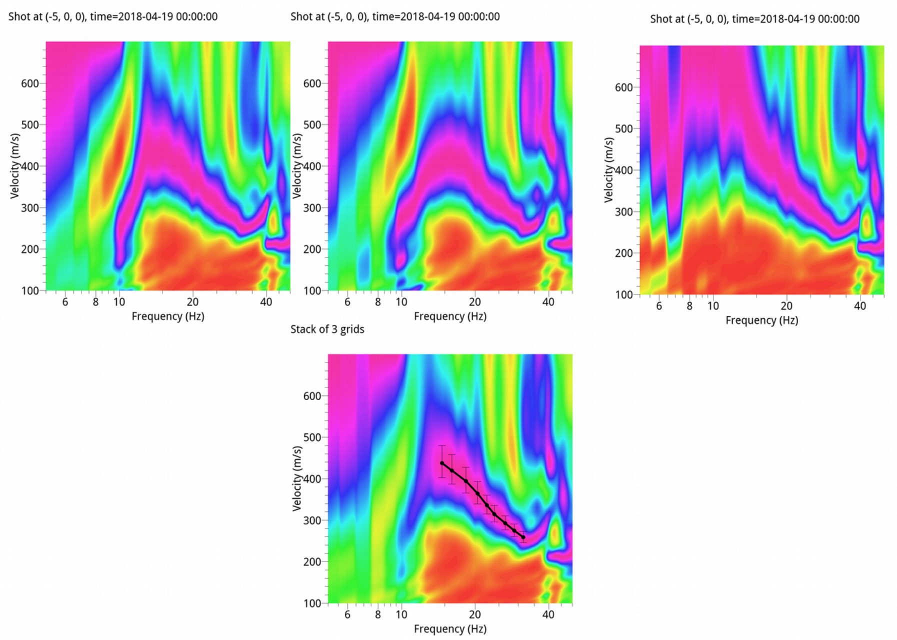

Figure 7: Velocity-frequency spectrum from MASW measurement using a shot offset of -5m (i.e. the distance from the first receiver). The stacked spectrum with the picked dispersion curve is shown on the bottom panel.

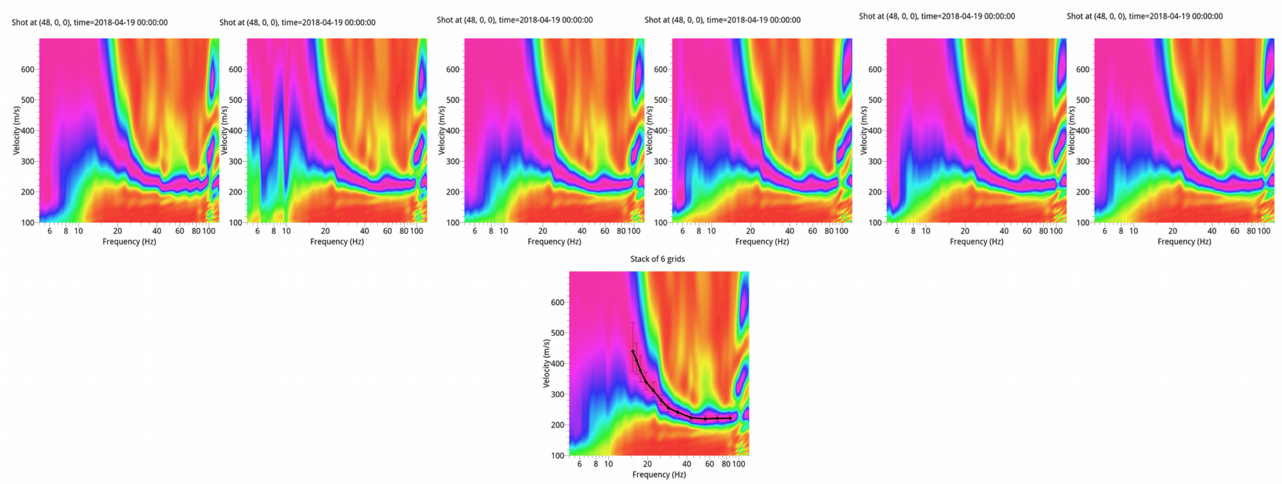

Figure 8: Velocity-frequency spectrum from MASW measurement using a shot offset of 48m (i.e. the distance from the first receiver). The stacked spectrum with the picked dispersion curve is shown on the bottom panel.

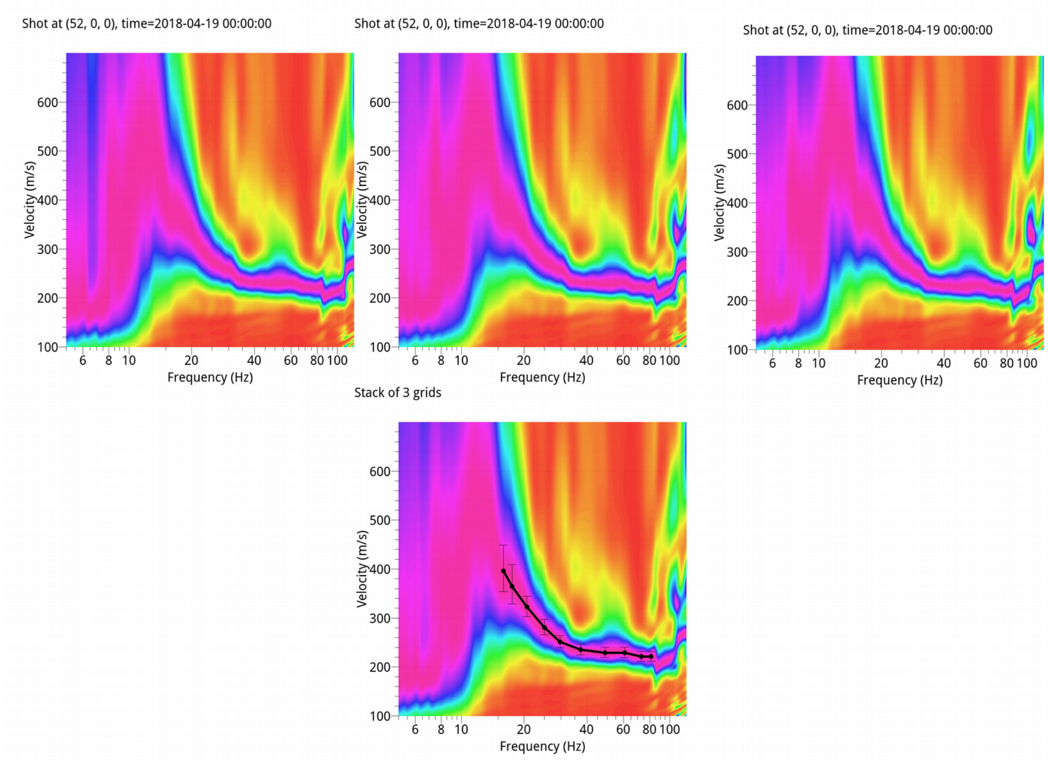

Figure 9: Velocity-frequency spectrum from MASW measurement using a shot offset of 52m (i.e. the distance from the first receiver). The stacked spectrum with the picked dispersion curve is shown on the bottom panel.

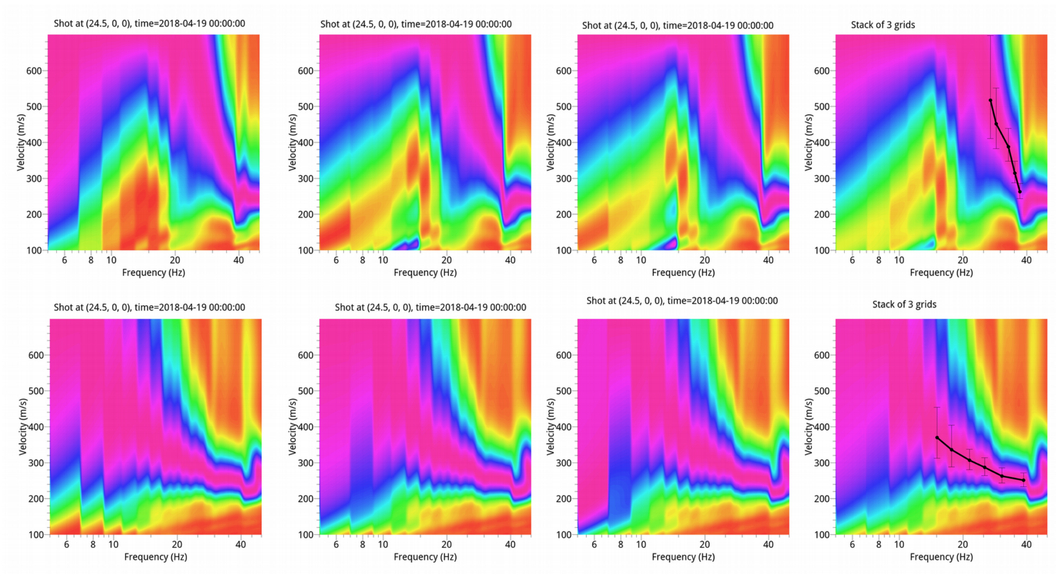

Figure 10: Velocity-frequency spectrum from MASW measurement using the shot offset of 24.5m (i.e. in the middle of the layout). The top and bottom panel shows the MASW spectra for the geophones from #1 to #24, and from #25 to # 48, respectively. The stacked spectrum with the picked dispersion curve is shown on the right.

The results of passive measurements is shown in Figure 11. As usually adopted in passive case, the lower envelope of the spectrum was picked .

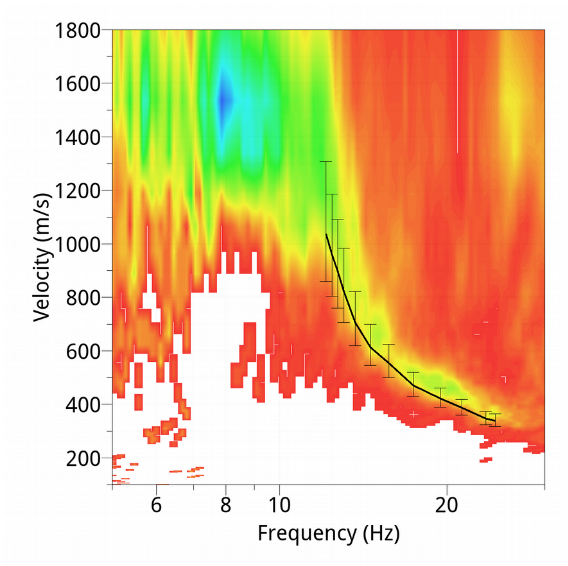

Figure 11: Stacked spectrum from passive measurements. The picked dispersion is also shown as black curve.

The comparison among the dispersion curves is shown in Fig. 12. A good consistency of the curves is observed; the outlier curve -showing larger values of velocities within 30-40 Hz- refers to the middle offset (group of geophones #1 to #24, see also Fig. 10). Passive data allow to extend the band of analysis towards lower frequencies (up to 12 Hz) with respect to active data. In the overlapping frequency band of analysis (15-25 Hz), the dispersion curves from passive and active data are fairly in agreement. As final dispersion curve, we select a mean average curve (red curve in Fig. 12) not taking into account the outliers (red curve in Fig. 12).

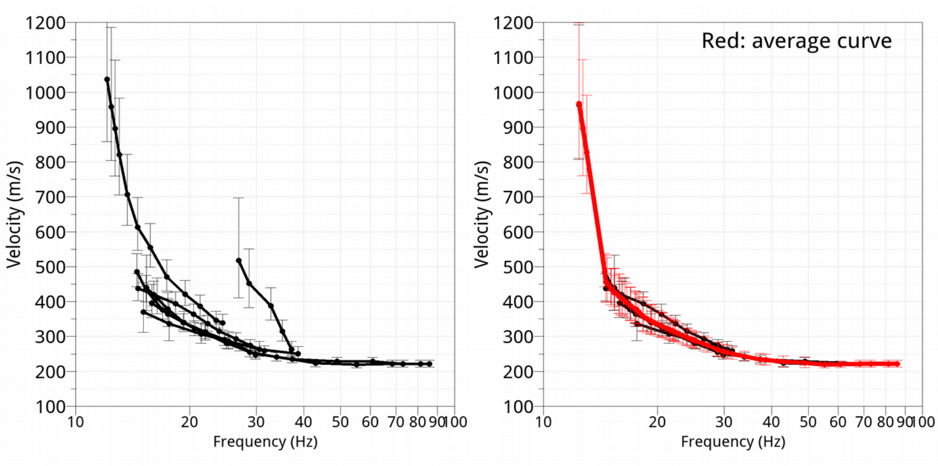

Figure 12: All the picked dispersion curves are shown on the left panel. The final average curve considered for the inversion is the red one in the right panel.

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3. Vs Model

To proceed with the inversion, we assume that the final dispersion curve (red one in Figure 12) derived from the linear array of vertical geophones was the fundamental mode of Rayleigh waves. Moreover, we insert the additional targets during the inversion process:

1) Ellipticity curve from the entire HV noise spectral ratio (from 2.3 to 20 Hz; see Figure 4);
2) Fundamental frequency (Fo=7.6 Hz).

Figure 13 shows the comparison between the experimental targets and the ones expected for the best models coming from the inversion process. Focusing on the Vs models of Figure 13, the models indicate a very uppermost first layer (thickness < 5 m) with Vs around 200-250 m/s, whereas the second layer show a Vs of about 600 m/s up to a depth of about 20 m. A bedrock layer (Vs > 1200 m/s) is obtained at a depth of about 20 m. The inversion shows also a further interface at a depth of 60 m, however very doubtful due to the absence of resolution of our dispersion curve (the maximum wavelength is about 80 m).

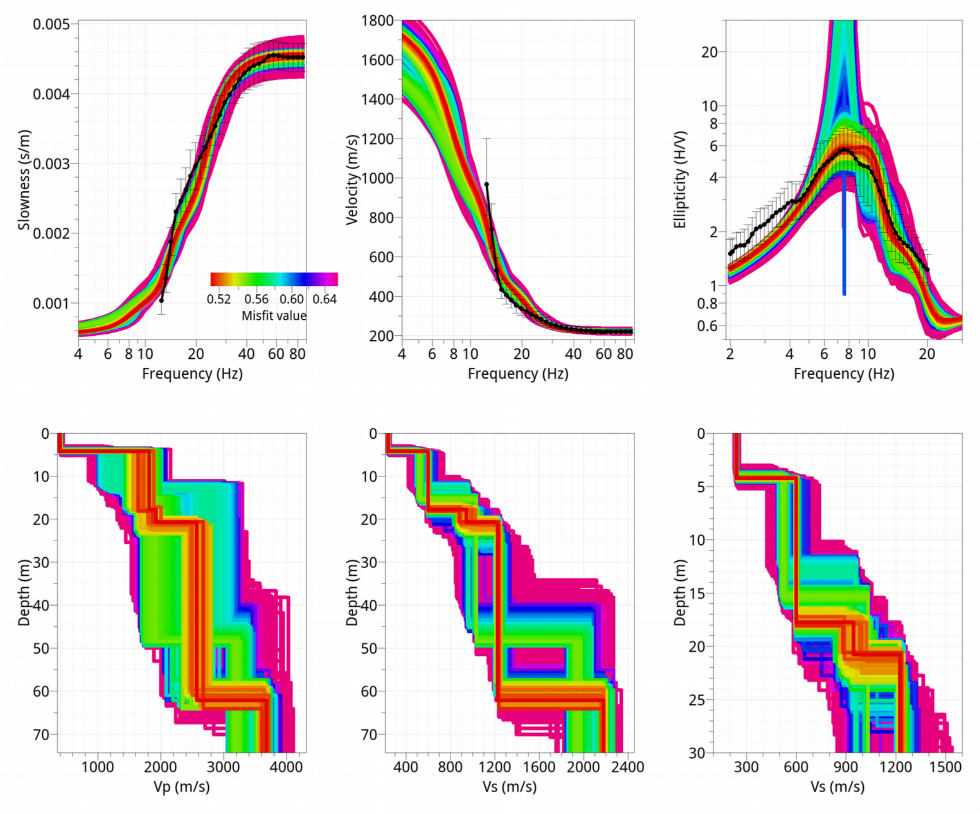

Figure 13: Inversion of the dispersion curves obtained with the 1D linear array, constrained with the H/V results. Dispersion and HV models are shown in the top panel. Velocity models (Vp, Vs and a zoomed Vs profiles) are shown in the bottom panel. Colour scale is proportional to the misfit between experimental (in black) and theoretical curves.

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The best fit model (i.e. lowest misfit) in terms of V_p and V_s are represented in Figure 14 and Tab 1.

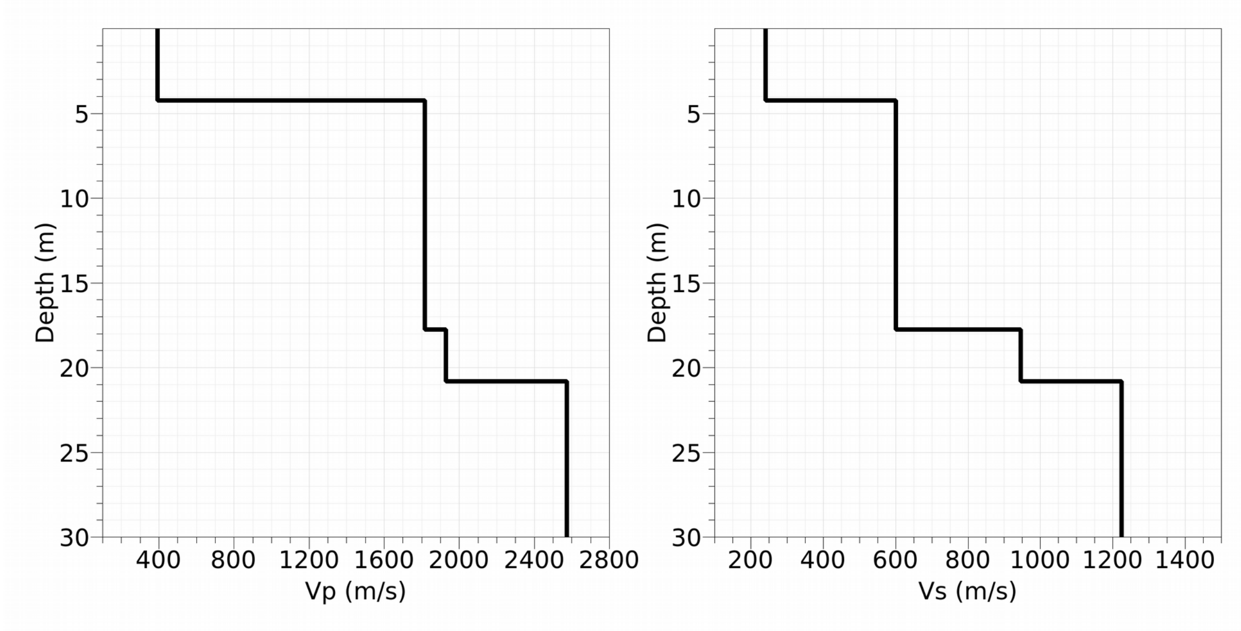

Figure 14: Best-fit models of Vp (left panel) and Vs (right panel) values.

From (m)	*To(m)*	*Thickness (m)*	*Vs (m/s)*	*Vp (m/s)*
0	4,20	4,2	240	393
4,2	17,70	13,5	600	1816
17,7	20,80	3,1	945	1928
20,8	?	?	1224	2573

Tab 1 Best-fit model.

Interestingly, a linear MASW analysis in close proximity to our experiment was performed by GEER association (http://www.geerassociation.org/administrator/components/com_geer_reports/geerfiles/GEER_2017_Report_Ver_2.pdf; doi 10.18118/G6HS39) following the 2016 seismic sequence occurred in Central Italy. GEER used 12 vertical geophones equally spaced of 4 m (Fig. 15). The comparison between the two independent experiments in terms of dispersion curves and final Vs models is shown in Fig. 16 and 17. Considering the differences in the equipment and experimental layout, the results seem in acceptable agreement, although the Vs30 value provided by GEER is lower than our value (490 m/s versus 590 m/s).

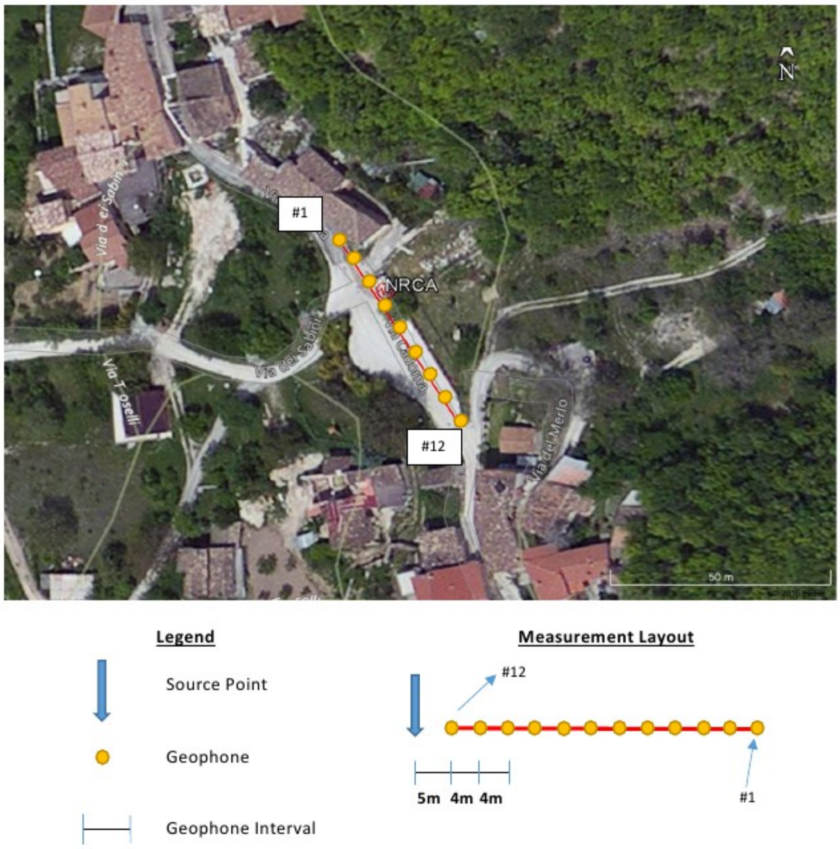

Figure 15: MASW experiment carried out by GEER in 2016 (see their report with doi 10.18118/G6HS39).

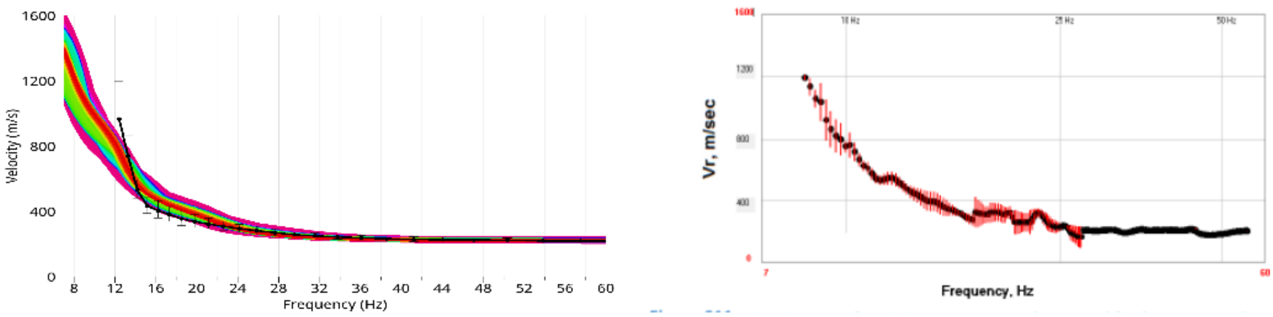

Figure 16: Dispersion curves from this (left) and GEER experiment (right).

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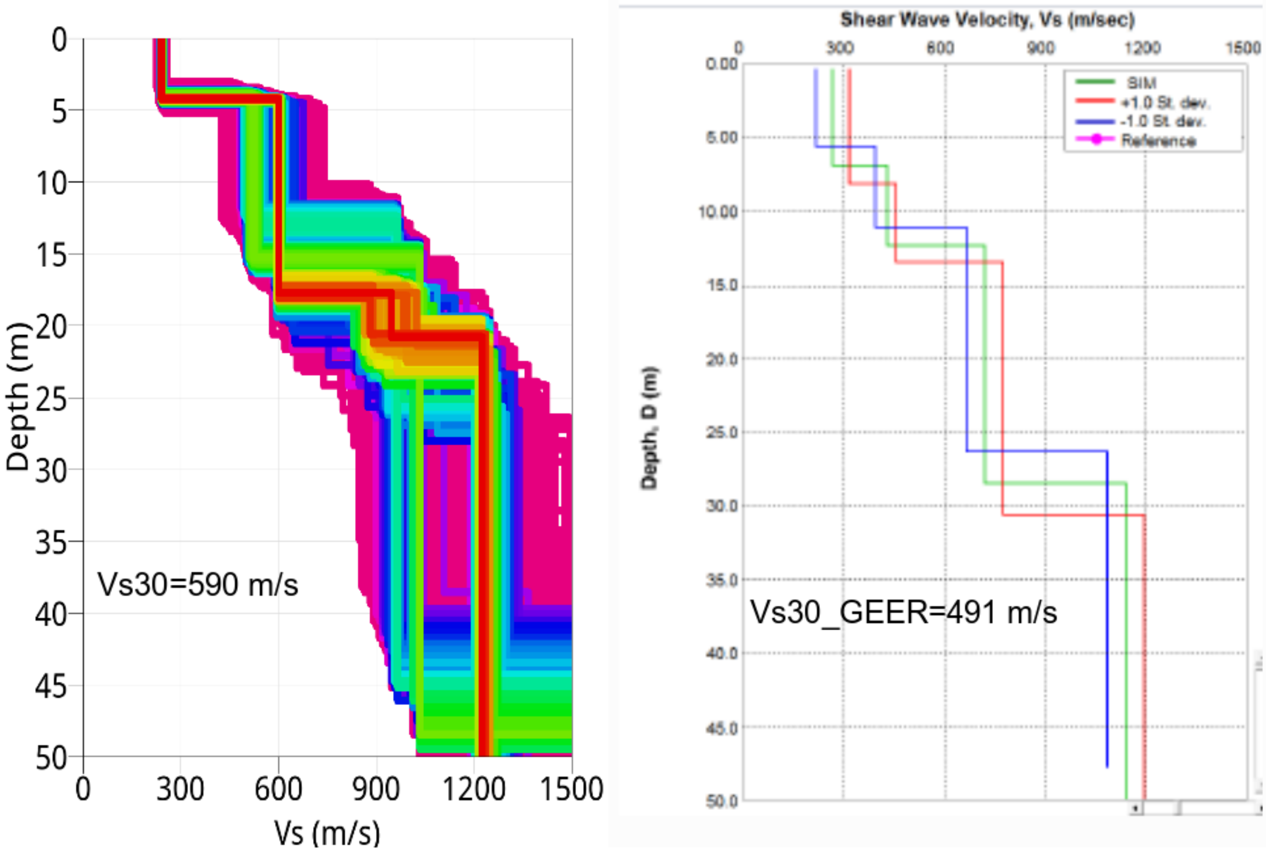

Figure 17: Vs profiles obtained from this (left) and GEER experiment (right). The values of Vs30 are also indicated in each panel.

4. Conclusions

The H/V analysis for site IV.NRCA shows a prominent resonant peak in the high frequency range (at about 7 Hz) suggesting a shallow and strong impedance contrast.

We can propose an interpretation of the velocity profile based on the general geological assessment of the area. The very uppermost 20 meters, with Vs values < 600 m/s (Fig. 14), could be linked to the presence of debris fan deposits (see also: Working group INGV "Agreement DPC-INGV 2018, Allegato B2, Obiettivo 1 - TASK B", 2018. Geological report at the seismic station IT.NRCA-NORCIA). These deposits lie over a stiffer layer, likely stratified massive bedrock, that below 20 m should represents the seismic bedrock of this site (Fig. 14).

The V_{s30} retrieved from the inversion of the dispersion curves is 590 m/s (Tab. 2); therefore IV.NRCA is classified as class B soil type in terms of NTC08 and EC8 seismic classification.

Because the bedrock interface is found at a depth less than 30 m, we compute also the Vs,eq following the NTC18 seismic classification. The Vs,eq retrieved from the best velocity model of Fig. 14 is 443 m/s (Tab. 3); therefore IV.NRCA still is classified in soil class B.

V_{s30} (m/s)	***Soil class***
590	B

Tab 2: Soil Class following NTC08

$V_{s,eq}$ (m/s)	***Soil class***
443	B

Tab 3: Soil Class following NTC18

We have to take into account that the inversion process of the data array can be improved by other independent information for this site; therefore the results can change adding this info, if available.

References

EC8: European Committee for Standardization (2004). Eurocode 8: design of structures for earthquake resistance. P1: General rules, seismic actions and rules for buildings. Draft 6, Doc CEN/TC250/SC8/N335.

GEER-050D Report (2017), Engineering Reconnaissance following the October 2016 Central Italy Earthquakes, version 2, Editors P. Zimmaro and J. P. Stewart, GEER Team Leaders J. P. Stewart and G. Lanzo, doi: 10.18118/G6HS39.

NTC08: Ministero delle Infrastrutture e dei Trasporti (2008). Nuove Norme Tecniche per le Costruzioni. DM 14 gennaio 2008, Gazzetta Ufficiale n. 29 del 4 febbraio 2008 - Suppl. Ordinario n. 30

NTC18: Ministero delle Infrastrutture e dei Trasporti (2018). Aggiornamento delle Norme Tecniche per le Costruzioni. Part 3.2.2: Categorie di sottosuolo e condizioni topografiche, Gazzetta Ufficiale n. 42 del 20 febbraio 2018 (in Italian).

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