ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IV.TRTR– Tortoreto (TE)

Report di caratterizzazione di sito presso la stazione sismica IV.TRTR – Tortoreto (TE)

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Subject: **Final report illustrating the site characterization for seismic station IV.TRTR**	

Convenzione DPC-INGV 2019-21, All.B2- WP1, Task 2: "Caratterizzazione siti accelerometrici" (Coord.: G.Cultrera, F. Pacor)
Cite as: Working group INGV "Agreement DPC-INGV 2019-21, All.B2- WP1, Task 2", (2020). Site characterization report at the seismic station *IV.TRTR– Tortoreto Teramo http://hdl.handle.net/2122/14051*

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INTRODUCTION

In this report we present the geological setting and the geophysical measurements and results obtained in the framework of the 2019-2021 agreement between INGV and DPC, called *Allegato B2: Obiettivo 1 - TASK 2: Caratterizzazione siti accelerometrici (Responsabili: G. Cultrera, F. Pacor)* for the site characterization of station IV.TRTR (Tortoreto, Teramo).

Location and coordinates are reported in Table 1.

Table 1.

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IV.TRTR	Tortoreto (TR)	42.80810*	13.91380*	160*
ADDRESS	Località Tortoreto Alta, Stadio delle Fontanelle, Via dello Sport, 64018 Tortoreto Teramo TE, Italy			

* Coordinates from ITACA (Nov. 2020)

A. Geological setting

A1. TOPOGRAPHIC AND GEOLOGICAL INFORMATION

Topographic information related to the site is reported in Table 2. Table 3 summarizes all available geological maps from literature for geological analyses.

Table 2.

Topography	Description	Topography Class	Morphology Class	EC8 Class
	Flat surfaces, isolated slope and reliefs with slope i<=15°	T1	P*	B

*Reference table from ITACA (Nov. 2019)

Table 3.

Geological map	Source	Scale
IV.TRTR	Geological map of Italy sheets 133-134 (Ascoli Piceno-Giulianova)	1:100.000
IV.TRTR	Carta Geologica d'Abruzzo (Vezzani & Ghisetti, 1998).	1:100.000
IV.TRTR	Carta Geologica-Tecnica per la Microzonazione Sismica di Livello 1, Regione Abruzzo, comune di Tortoreto(TE) (January, 2014)	1:5.000

In Table 4 Geological and Lithotechnical Units (according to Seismic Microzonation classification; Technical Commission SM, 2015) are described and are concerned to maps of following chapters. The term “original” means the result comes from a preexisting cartography (Table 3); the term "deduced" means the result comes from an interpretation of preexisting cartography according to the nomenclature of corresponding cartography.

Table 4

GEOLOGICAL UNITS		**LITHOTECHNICAL UNITS**	
"Geological Map of Italy, scale 1:100:000" (Sheets 133-134; Ascoli Piceno-Giulianova) *original*		(MZS) *deduced*	
code	**description**	**code**	**description**
col	colluvial deposits	GMec	gravel, mixture of gravel, sand and silt
col	colluvial deposits	MLec	inorganic silt, fine grained silty or clayey sand, clayey silt with low plasticity
Q1c	conglomerates	GR	Cemented granular rocks.
Q1b	stratified yellow sands	GRS	Layered cemented granular rocks.

A2. GEOLOGICAL MAP

In Figure 1 Geological Map is reported in a 1kmx1Km square around the station.

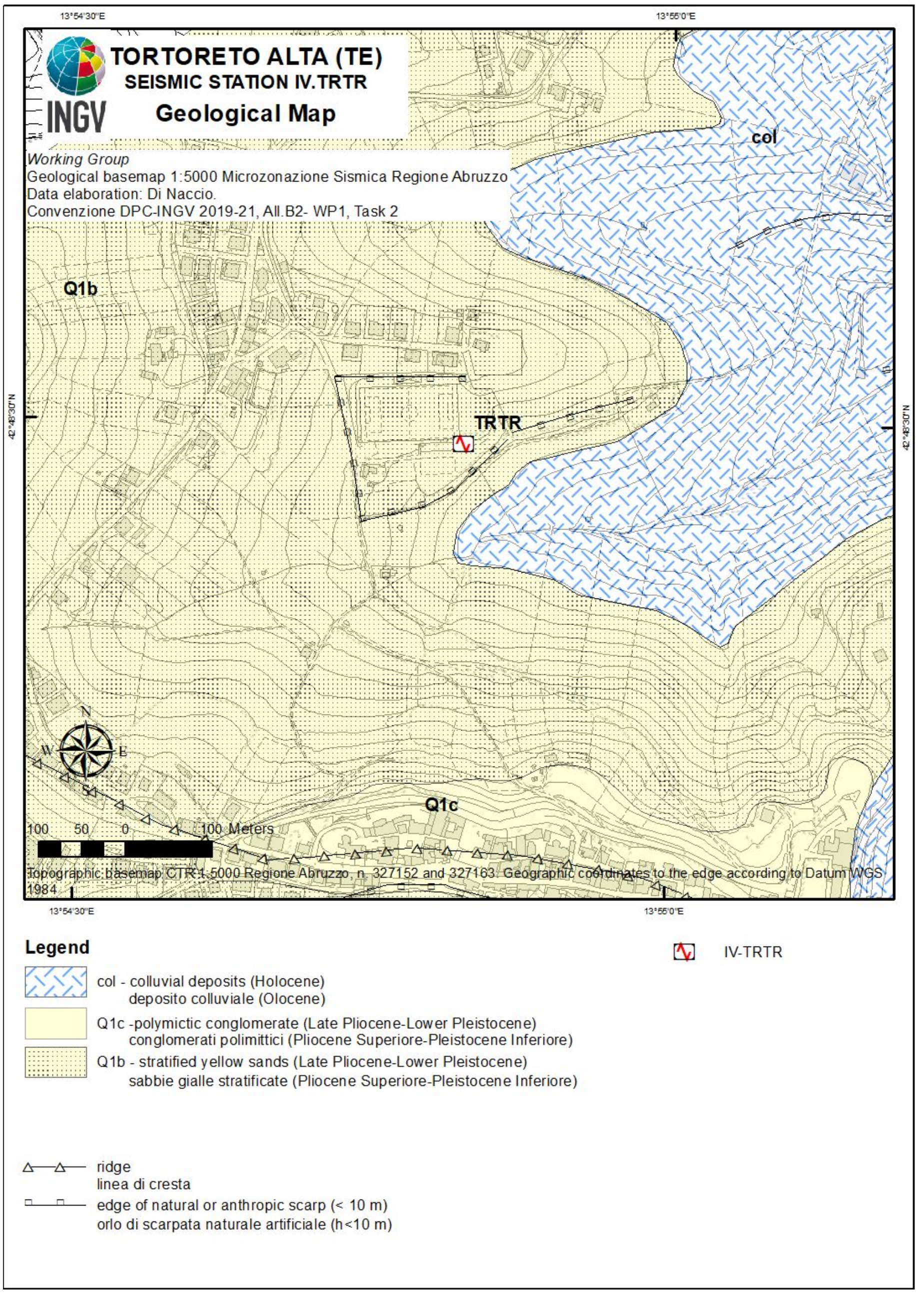


Figure 1. Geological map of seismic station IV.TRTR. Scale 1:5.000. Geological units come from the "Geological Map of Italy, scale 1:100:000 (Sheet 133-134; Ascoli Piceno-Giulianova)".

A3. LITHOTECHNICAL MAP

In Figure 2 Lithotechnical Map is reported in a 1kmx1Km square around the station.

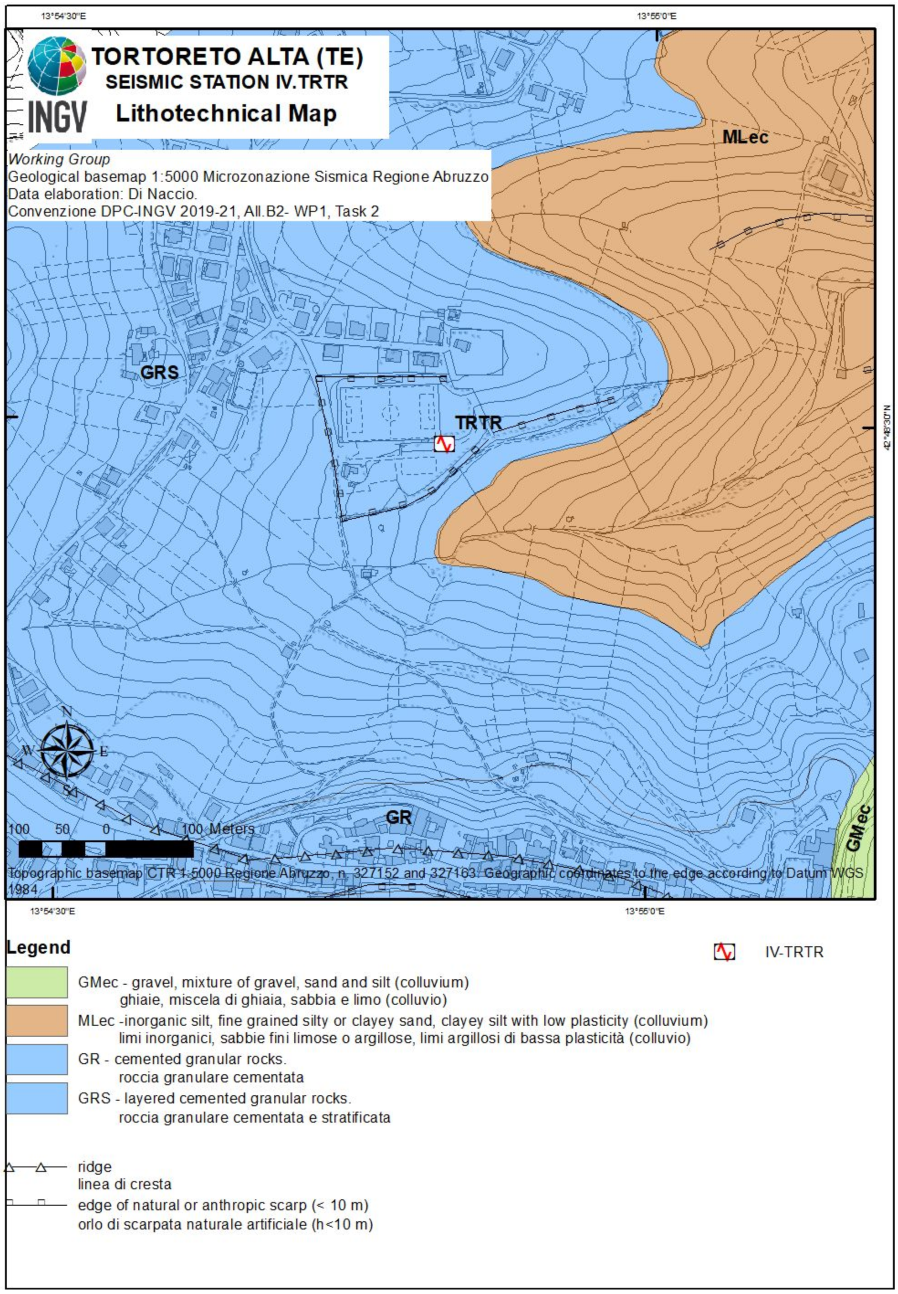


Figure 2: Lithotechnical map of the seismic station IV.TRTR. Scale 1:5.000. The lithotechnical units are deduced from the "Carta Geologica-Tecnica per la Microzonazione Sismica di Livello 1, Regione Abruzzo, comune di Tortoreto(TE), scale 1:5:000 (2014) and assigned according to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).

A4. SURVEY MAP

Figure 3 shows the Survey Map reporting investigations and geophysical surveys conducted by INGV Working Group.

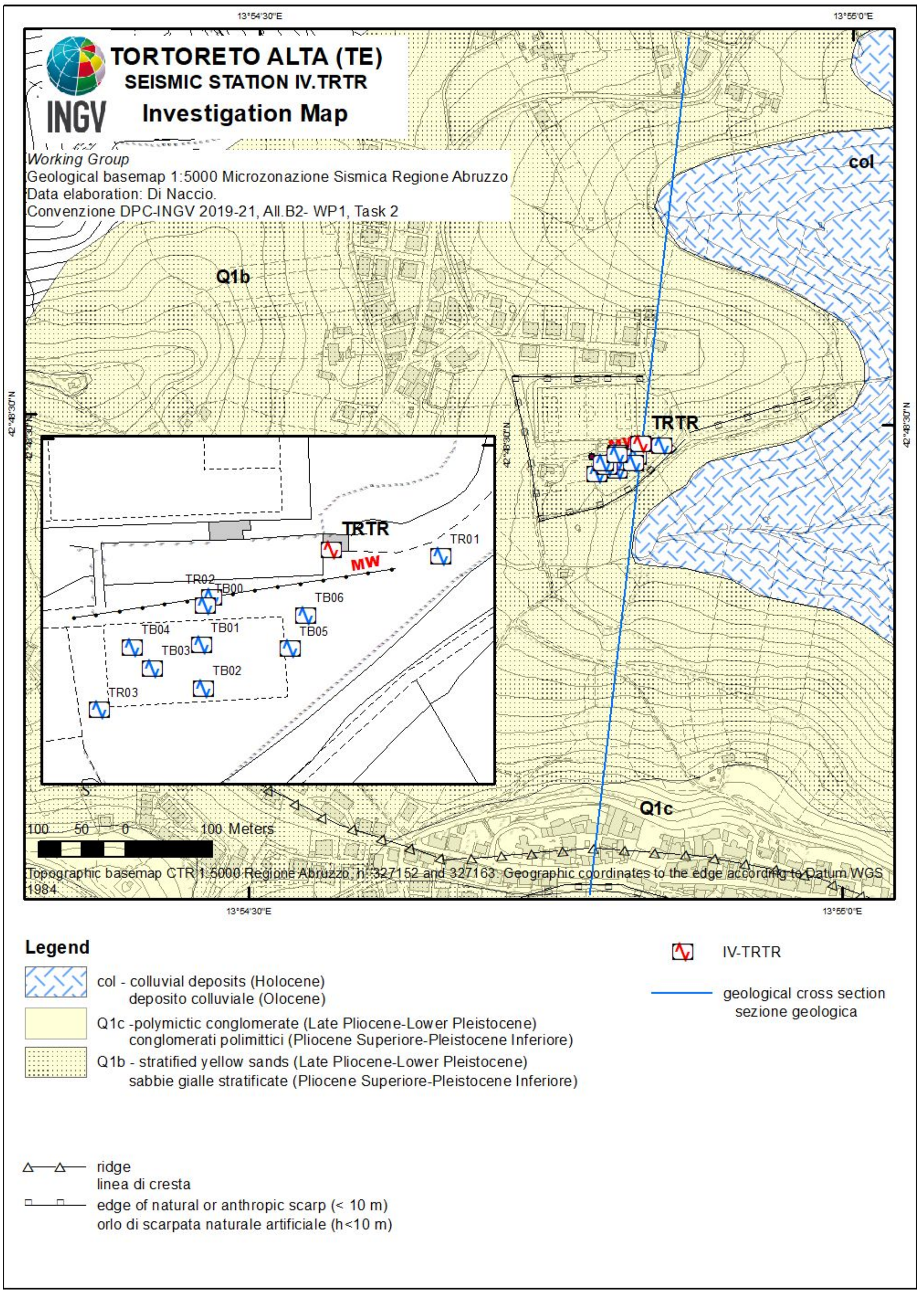


Figure 3: Map of the surveys in the surroundings of the station IV.TRTR. Scale 1:5.000. The box at the left contains a zoom of the area with the detail of the geophysical survey conducted by INGV Working Group for the seismic characterization of the site (see part B. "Vs profile" in this report).

A5. GEOLOGICAL MODEL

5.1 General description

The seismic station is installed in the Marche-Abruzzi sector of the Periadriatic basin developing at the front of the Apennine chain. The basin records the latest evolutionary stages of the compressional tectonic and regional uplift of the Apennine thrust and fold belt since Neogene-Quaternary time.

Meso-Cenozoic carbonate successions crop out in the Montagna dei Fiori-Montagnone ridge to the west and in the Gran Sasso, Morrone and the Maiella Mountains to the south.

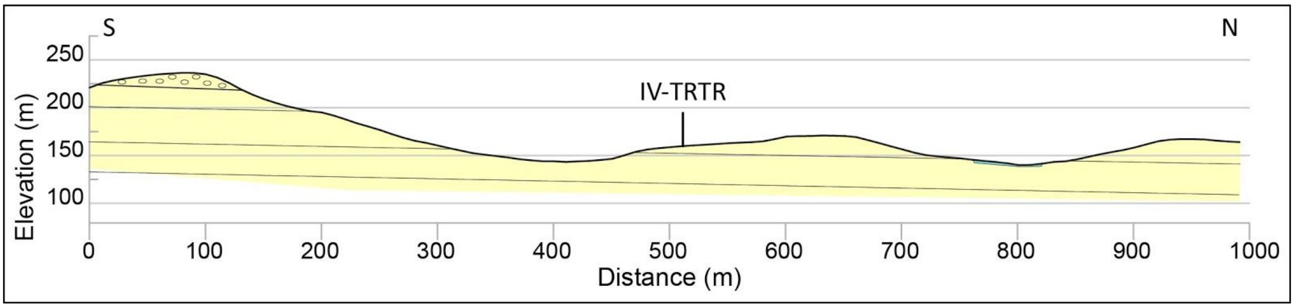
To the east of thrust fronts, foredeep siliciclastic sequences, progressively younger moving toward the Adriatic sea, crop out. They correspond to the Upper Messinian turbidites of the Laga basin, to the Lower Pliocene sandstones and clays of the Cellino basin, and to the Middle Pliocene-Pleistocene post-orogenic sequences deposited within the Periadriatic basin.

In the studied area the geological bedrock consists of a sequence of marine clayey-sandy-conglomeratic deposits (Upper Pliocene–Lower Pleistocene) in a gently NE-dipping monoclinal setting. Alluvial, slope, colluvial and landslide superficial deposits cover the bedrock.

The seismic station is at an altitude of ~ 160 m above sea level and it is located in a local plain. The bedrock is represented by the yellow sands (Q1b in Figure 1). Conglomerates (Q1c in Figure 1) overlay the Q1b unit and generally crops out at the top of hills (Figure 1). Downward, the sequence consists mostly of silt and clay strata not outcropping in the studied area and indicated as blue-grey clays (Q1a) in the Geological map of Italy (sheet 133). The bedrock is covered by colluvial deposits of ~ 3-20m-thick.

5.2 Geological Section

The geological cross section and the subsoil model (Figures 3 and 4) accompanying geological survey map provide an interpretation of the third dimension. It is based on the extrapolation of surface data with pre-existing geological and structural studies, geophysical investigations and the determined seismic velocities profiles (see part B of this report) as well as data from other subsurface sources.



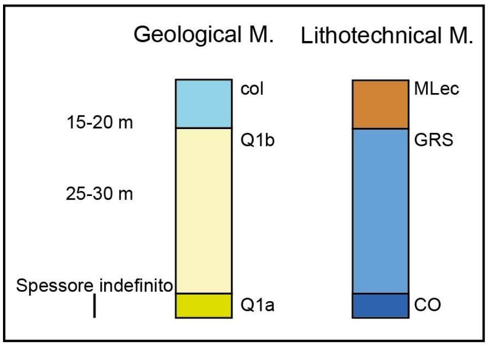


Figure 4. Top: Geological section across IV.TRTR seismic station (see Figure 3 for location); Bottom: subsoil model for the site. See Figure 1 and 2 for symbology.

5.3 Subsoil model

The lithotecnical units considered representative of the site around the IV-TRTR-seismic station (Figures 1-2 and Table 4) are the following:

GRS: layered granular rocks consisting of yellow sands. A thin layer of colluvium-eluvium (MLec) mainly consisting of fine grained deposits can cover the GRS deposit whereas its bottom can overlay cohesive clays (Q1a, in the Italian Geological Map) as recognized by geophysical modeling (part B of this report).

B. Vs profile

B1. PREFACE

In this section, the geophysical surveys carried out to characterize IV.TRTR station are presented. We performed a MASW experiment with an active source by using 72 vertical geophones installed in linear configuration. In combination with the MASW survey, we installed 10 seismic stations near IV.TRTR for ambient seismic noise recordings that were used for computation of the H/V curve (horizontal-to-vertical noise spectral ratio). Data records of IV.TRTR were also extracted and analyzed in terms of H/V noise ratio. Using surface-wave frequency-wavenumber analysis, we provide results in terms of resonant peaks of the H/V curves, and dispersion curves that were inverted to obtain shear-wave velocity (V_s) profiles for the studied area. The inverted models are suitable for determination of the average Vs velocity in the uppermost 30 m (V_{s30}) and assigning then the soil class category as prescribed by building codes (EC8, NC8 or NC18). The software of analysis was Geopsy (www.geopsy.org; Wathelet et al. 2020). The date of the geophysical survey was 15 September 2020. A preliminary survey to check the field logistic was conducted on 24th of June 2020, with two further noise measurements. Both days of the experiments were sunny and without wind. The first survey of 24th June 2020 helped us to decide the position of the extensive geophysical investigations carried out the 15th September 2020. The position of the cabinet hosting IV.TRTR is attached at the concrete bleacher of a football/rugby field (called "Stadio delle Fontanelle"; see Figs. 1 and 2). The difference in elevation between the housing of IV.TRTR and the football field is about 10 m, and the ground morphology indicates that the football field was subjected to an anthropic leveling especially in the eastern part. To investigate the homogeneity of the seismic response between the football field and its base (where IV.TRTR is ubicated), during the preliminary survey we performed two simultaneous noise measurements using 2 stations equipped with triaxial geophones (4.5 Hz natural frequency, Terrabot stations by Sara Electronics). These two stations (T106 and T105; Fig. 1) were installed at the level of the football field and at its base (i.e. same level of IV.TRTR), and the time-length of each noise recording was about 2 hours. The H/V noise spectral ratio at the uppermost T106 site shows a magnification in the frequency band 3-10 Hz which is absent at the bottom T105 site. Because the H/V spectral ratios using data records of IV.TRTR (see ???)

are in good agreement with the H/V ratios of T105, we decided to perform the extensive geophysical investigation of 15 September 2020 not in the football field, but along the driveway and on the concrete square at the base of the blatcher (i.e. at the same level of the IV.TRTR position; Fig.s 1 and 2).

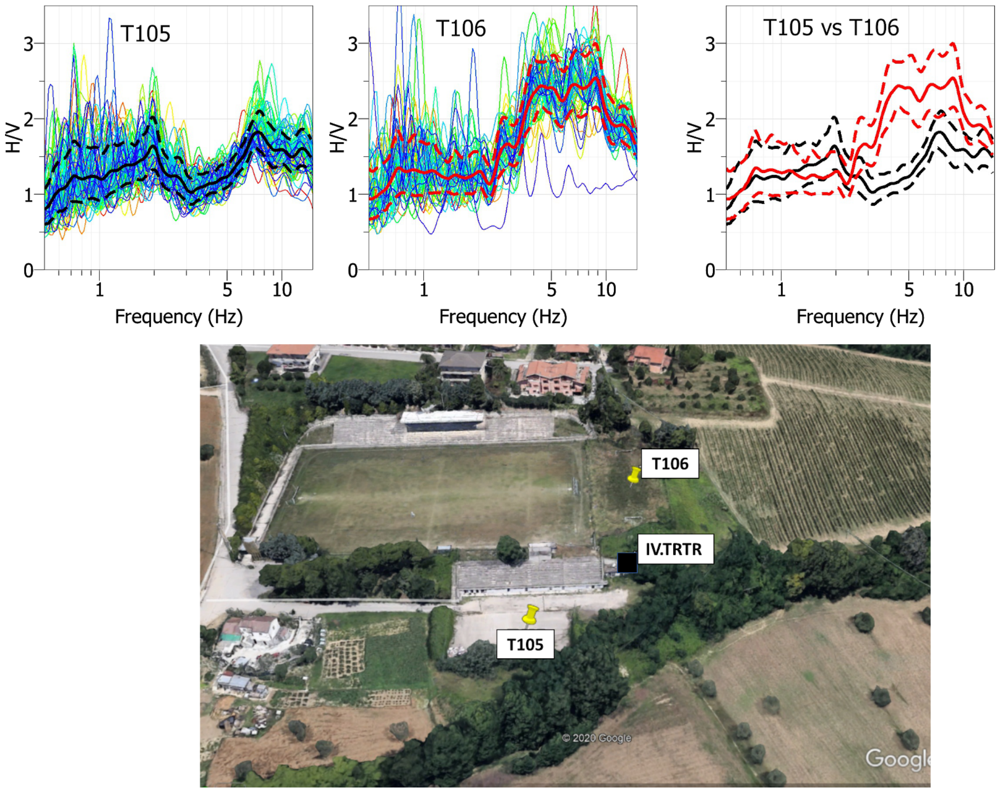


Figure 1. Preliminary geophysical survey (24th June 2020). The IV.TRTR station is indicated as black square in the google map. The yellow marks show the positions of the 2 temporary seismic stations deployed for seismic noise acquisition (T105 and T106, Terrabot equipment). On the top panel the H/V noise spectral ratios of T105 and T106 are compared.

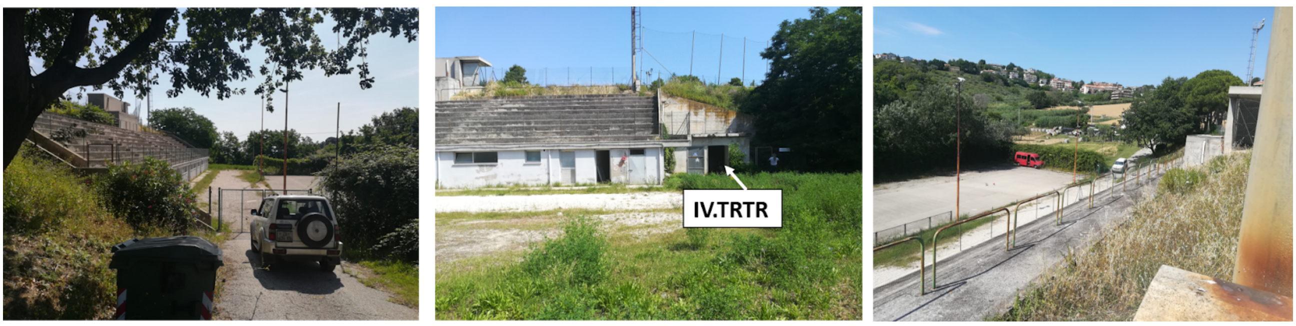


Figure 2. Pictures showing the driveway (left); the cabinet housing IV.TRTR and the bleacher of the stadium (middle); the driveway and the concrete square are seen from the level of the uppermost football field (right).

B2. GEOPHYSICAL INVESTIGATION

We now describe the extensive geophysical survey of 15th September 2002. The map of Figure 3 shows the position of: IV.TRTR station, the MASW line of geophones (yellow line), and the temporary seismic stations deployed in the target area (yellow and red markers of Fig. 3). The linear MASW array was composed of 72 vertical geophones equipped with vertical sensors (4.5 Hz natural frequency) equally spaced of 1 m for a total length of 71 m. Noise measurements were performed by 7 stations equipped with triaxial geophones (4.5 Hz natural frequency, Terrabot stations by Sara Electronics; the TB stations in Fig. 3 in red colour) and 3 stations composed of a Reftek130 digitizer with Lennartz-5s sensor (TR01, TR02 and TR03 stations in Fig. 3 in yellow color). The time-length of each noise measurement was about 3 hours.

TR02 and TB00 were collocated at the same position in proximity of the middle of the MASW line. Unfortunately the TR03 station was subjected to a malfunctioning of the vertical component and was not used in the analysis.

Figure 4 shows some details of the installation of the MASW line and seismic sensors. The vertical geophones were placed using ad hoc plastic bases and it was not possible to bury the sensors (with the exception of TR01). The position of the noise measurements and of geophones was taken by a GPS RTK Leica antenna, with a precision of the order of a few centimeters. All the geophysical measurements shown in Figures 3 and 4 were recorded the 15th September of 2020 (it was a sunny day, no wind).

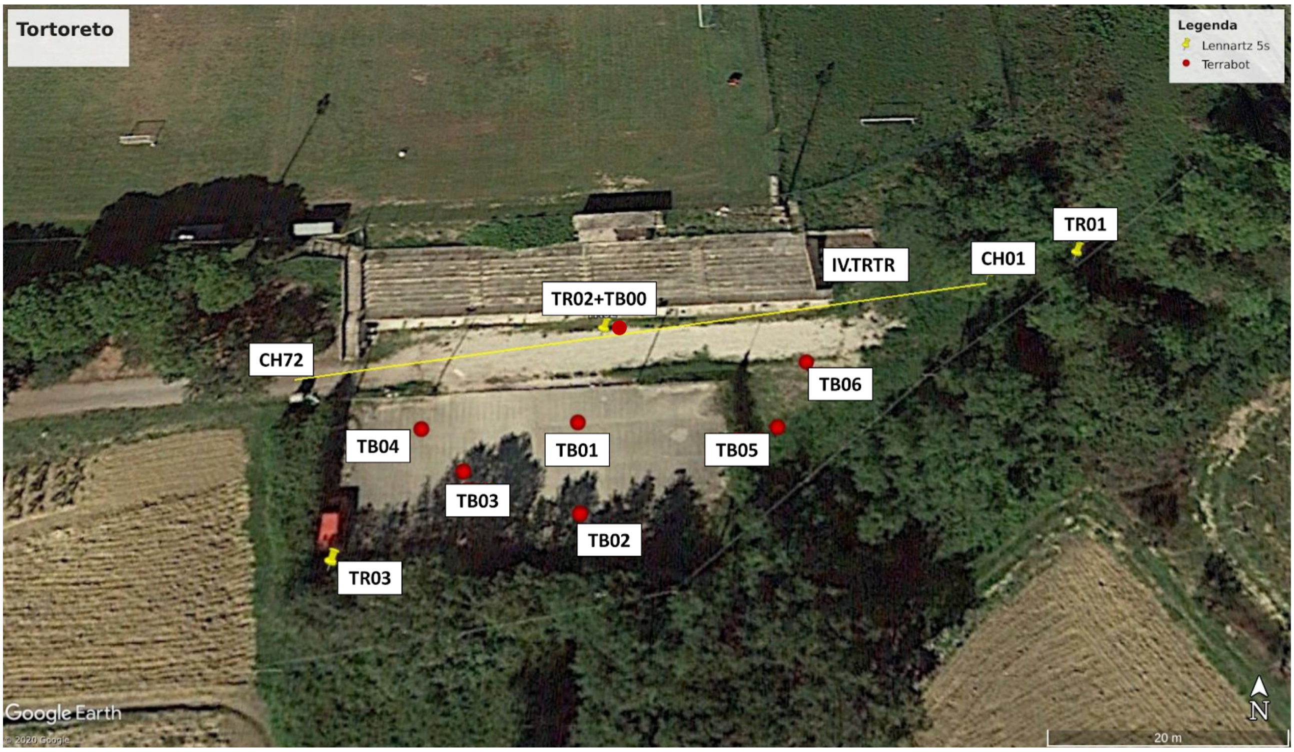


Figure 3. Google map of the geophysical surveys for the IV.TRTR station. The yellow line shows the linear MASW array of 72 vertical geophones (CH01 and CH72 indicate the first and last geophone of the line). The yellow and red marks show the positions of the 10 temporary seismic stations deployed for seismic noise acquisition (TB and red flag for Terrabot seismometer; TB and yellow flag for Lennartz 5s velocimeter). TR02 and TB00 were collocated to the same position.

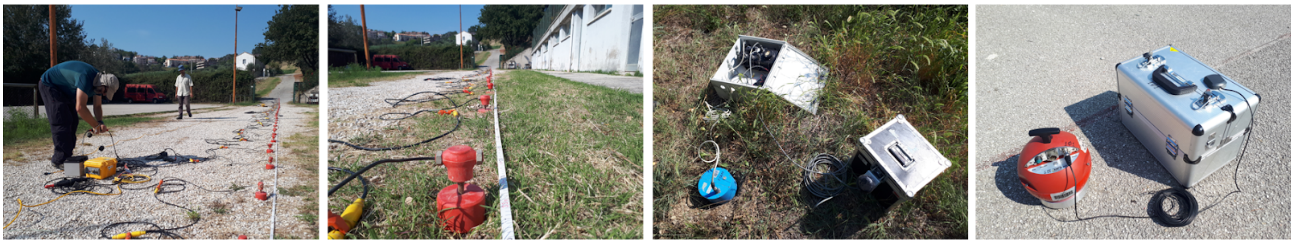


Figure 4. Deployment of MASW line and seismic stations. The last two pictures show the TR01 station (Lennartz 5s velocimeter with a Reftek130 digitizer) and the TB03 station (Terrabot).

2.1 H/V noise spectral ratio of temporary stations

Figure 5 shows the H/V curves obtained from the temporary seismic stations. Details of computations are reported in the summary reports. The results of Fig. 5 indicate a good agreement in terms of H/V shapes for all the stations, with a main peak in the H/V curves at very low frequencies, i.e. below 0.5 Hz. Of course the more reliable sites for such frequencies are the ones equipped with the Lennartz 5s (eigen-frequency of 0.2 Hz), even if the Terrabot stations provide in the studied environment similar H/V shapes in Figure 5. This low-frequency peak, at least at 0.2 Hz, is likely related to the presence of a very deep seismic contrast (order of 1 km) or to the Adriatic sea, which is about 2 km far in the easternmost direction. Other weak H/V peaks occur at 2 Hz and 6 Hz, with a moderate amplitude level which is below 2. TR01, the most eastern station, is the only site where the peak starting from about 6 Hz is most pronounced. The directional H/V curves are also shown in Figure 5, and the color scale is in some way biased by the high-amplitude peak at 0.2 Hz. For this reason, the same directional H/V curves are also presented in Figure 6 starting from a different lower frequency (0.5 Hz) and selecting an uniform logarithmic color scale. Figure 6 shows that the weak H/V peak as 2 Hz is almost isotropic, i.e. not depending by horizontal direction. Figure 7 shows the comparison of the H/V curves at all measurements points.

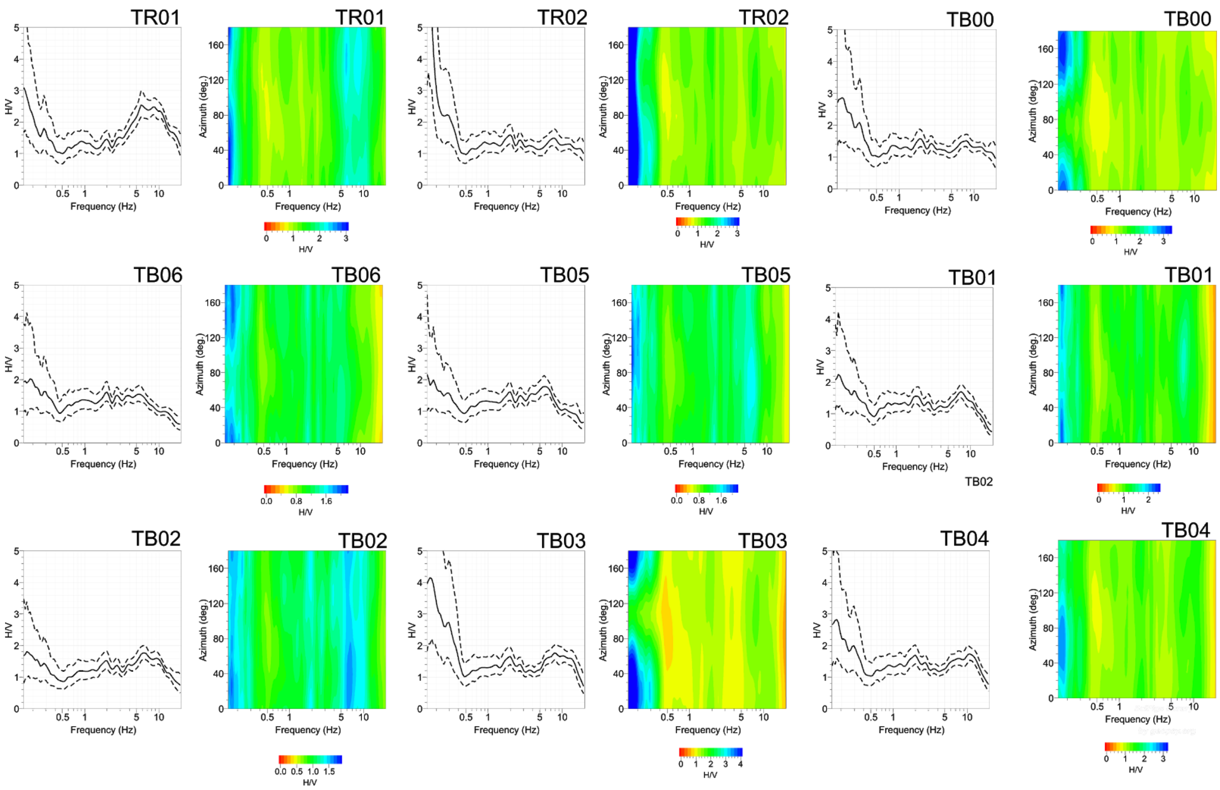


Figure 5. H/V noise spectral ratios. The seismic stations recorded ambient vibrations for about three hours (TR the Lennartz 5s velocimeters, TB indicates Terrabot instruments). TR03 was not considered in the analysis for a malfunctioning on the vertical component. TR02 and TB00 were colocated at the same position. The directional H/V curves use a linear colour scale, which is scaled for each site to a maximum value of H/V amplitude.

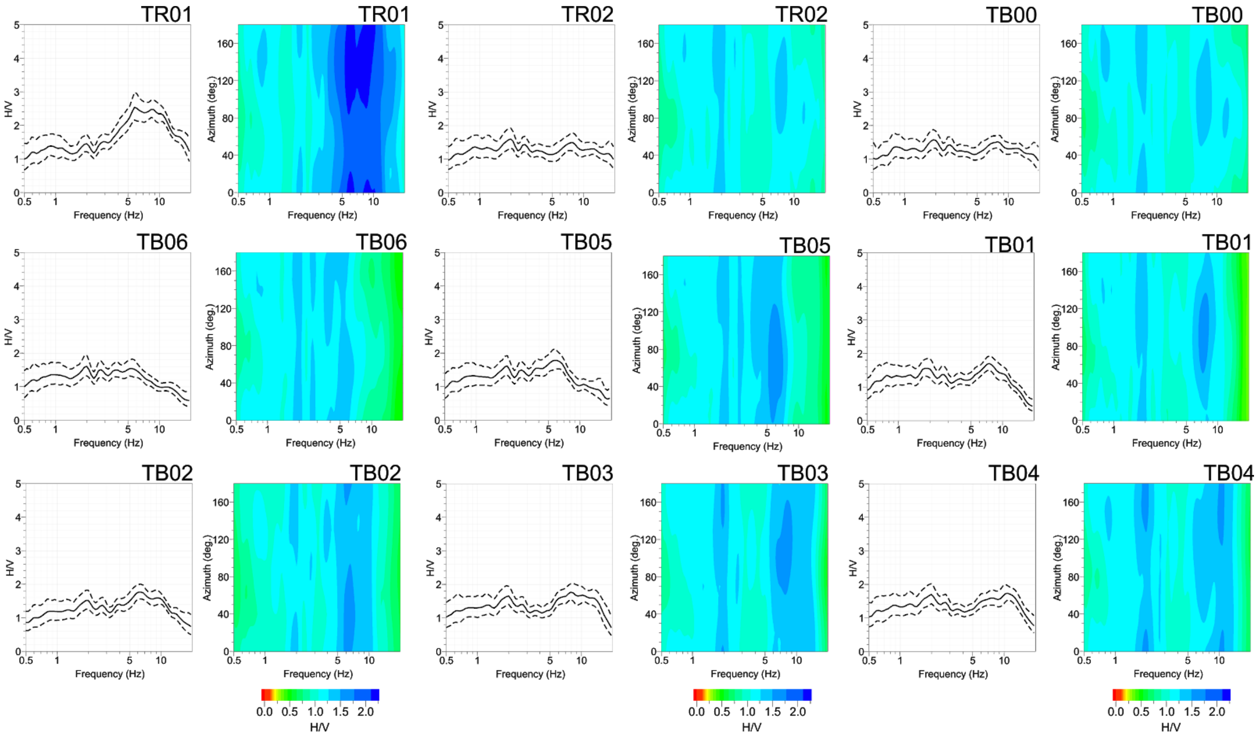


Figure 6. As Figure 5 but selecting the lower limit of the frequency axes at 0.5 Hz, and using a logarithmic color scale in the directional H/V curves (same colour scale for all the plots).

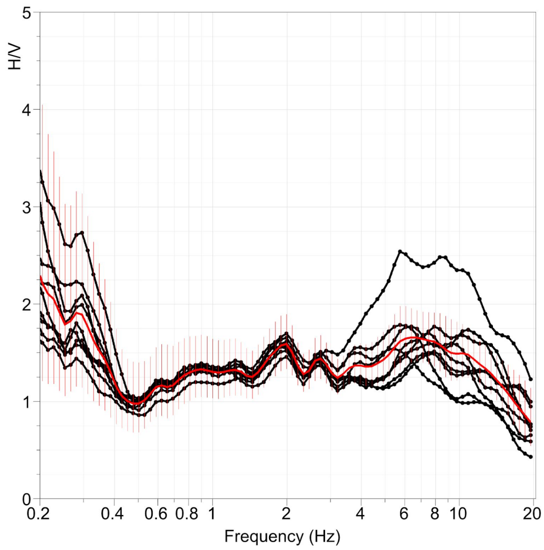


Figure 7. The mean H/V curves of all measurements are overlaid. Their average and standard deviation are shown by the red one.

2.2 H/V noise spectral ratio using data of IV.TRTR

To further investigate the H/V noise spectral ratios at IV.TRTR, we extracted continuous two-months data for four years recorded by this station (on channel HH which corresponds to a Nanometrics Trillium 40 s; data extracted from 1 january to 28 February for years 2016, 2017, 2018 and 2019). We performed the H/V computation averaging the H/V curve day by day. The results of Figure 8 confirm essentially the results of the temporary measurements of our geophysical survey, with the presence of a predominant peak in the low-frequency range below 0.2 Hz (average amplitude value around 2.2). Additional very weak peaks occur between 1 and 10 Hz, and in particular the peak at 1 Hz emerging from the H/V time-analysis is more defined with respect to the one shown in Fig. 7 by the temporary stations. The H/V signature of the several peaks in the range 1-10 Hz is very consistent over time, but due to their low-amplitude values are not considered as resonant frequencies in the next analysis.

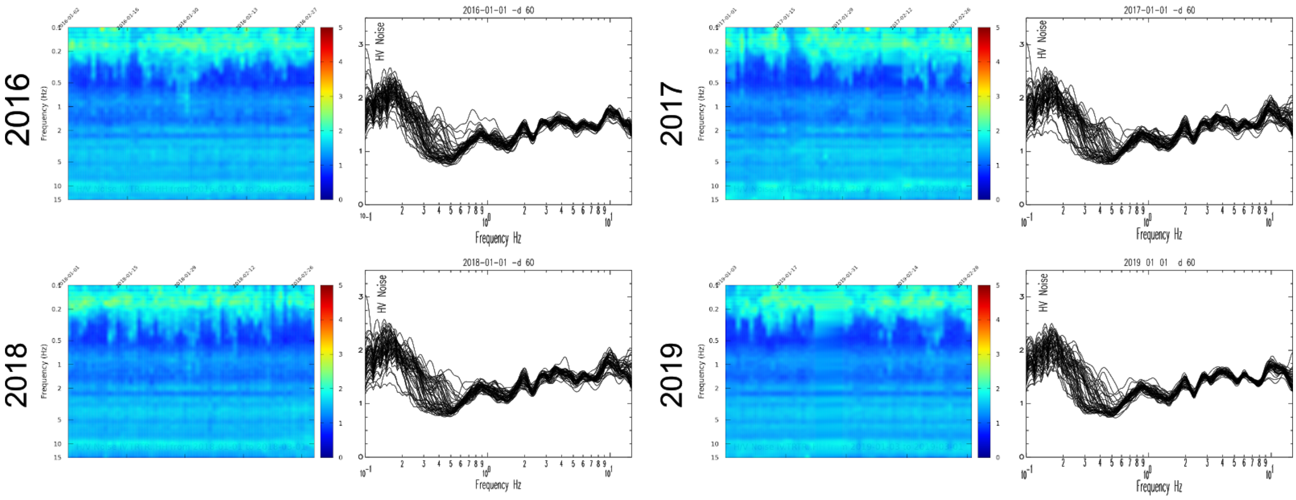


Figure 8. H/V spectral ratios using two months of continuous data extracted from IV.TRTR station starting from the 1st of January for the years 2016, 2017, 2018 and 2019. For each year, the continuous H/V curve is reported as contouring as a function of time on the left, with the color scale proportional to the amplitude of the H/V ratio. The daily average H/V curves are overlaid on the right panel.

2.3 Array analysis

The acquired data were processed using the *GEOPSY* software tools (www.geopsy.org) in order to extract the surface-wave dispersion properties of subsoil by applying frequency-wavenumber (FK) transform to the seismic signals. We analyzed using the FK technique the active data recorded by the linear array of geophones, and the passive data recorded by the seismic stations deployed in 2D configuration in Figure 3. Passive data recorded by the linear array of geophones were also processed by a cross-correlation technique.

2.3.1 Active data from the 1D array of geophones

The 72 vertical geophones were aligned in a straight line (yellow line in Fig. 3) and were equally spaced of 1 m. For the MASW analysis, we acquired the seismic signals produced by the impact of a 5 kg hammer on the ground. The shots were made along the line at distances (offset) of -5 m, -2, 35.5m, 73m and 76 m from the position of the first geophone (CH01 in Fig. 1 considered at 0m). In each shot point, the measurements were repeated three times in order to increase the signal-to-noise ratio. The seismic data were acquired using three multichannels systems (Geode manufactured by Geometrics) with a sampling rate of 0.125 ms for a duration of 2 s. Figure 4 illustrates the deployment of the MASW survey.

We also used the same linear array of 72 vertical geophones to acquire passive data, changing the sampling rate at 0.004 s (250 Hz) and recording several continuous records each of a time length of 4 minutes. The whole duration of passive data collected from the linear array of geophones was 1 hour and 40 minutes. Figure 9 shows the results obtained with the linear active survey (MASW). The analysis highlights a fairly consistent dispersion curve in the frequency range 6-50 Hz, with apparent phase-velocities between 150-350 m/s. Some small differences are observed between the shots at offset -5 and -2 m (from CH01) and the remaining shots, probably related to the presence of shallow soft colluvial deposits in the eastern sector of the MASW line (please refer to the geological map).

2.3.2 Passive data from the 1D array of geophones

The passive data recorded by geophones were analyzed in terms of cross-correlation (CC) using an ad hoc software (details in Vassallo et al. 2019). The cross-correlation functions are computed at the different geophones pair of the linear array, after one-bit normalization and spectral whitening (Bensen et al. 2007). To compute the dispersion curve of the seismic signals emerging from the cross-correlation functions, we applied a Constant Velocity Stack (CVS) analysis (Yilmaz, 1987). The cross-correlation functions were filtered in different frequency bands within 1-50 Hz, and for each band, the cross-correlation functions were shifted back in time according to the theoretical surface travel times computed for different constant velocities (from 50 m/s until 2000 m/s using a velocity step of 10 m/s). For each frequency band and applied velocity correction, the Phase-Weighted Stack (PWS, Schimmel and Paulssen, 1997) is computed, and the absolute maximum of PWS allows to estimate the presence of a horizontally aligned phase in the corrected seismic section.

Fig. 10 shows the computed cross-correlations functions (organized according to the distance between station pairs) and the results of the velocity analysis. The dispersion curve (black line) is identified on the basis of the maximum value of the stack function at each frequency.

2.3.3 Passive data from the 2D array of seismic stations

We used the passive data of the TB seismic stations in Figure 3 considered as a 2D array. We derived Rayleigh phase dispersion curves (Fig. 10) searching from the FK maxima in the wavenumber plane (kx, ky) using a three-components high-resolution beamforming (Wathelet et al. 2108). The results of the three-component analysis shows a Rayleigh-wave dispersion curve in the frequency range 3-5 Hz with apparent velocity between 250 and 500 m/s.

From the same analysis, it was not possible to estimate a Love-wave dispersion curve.

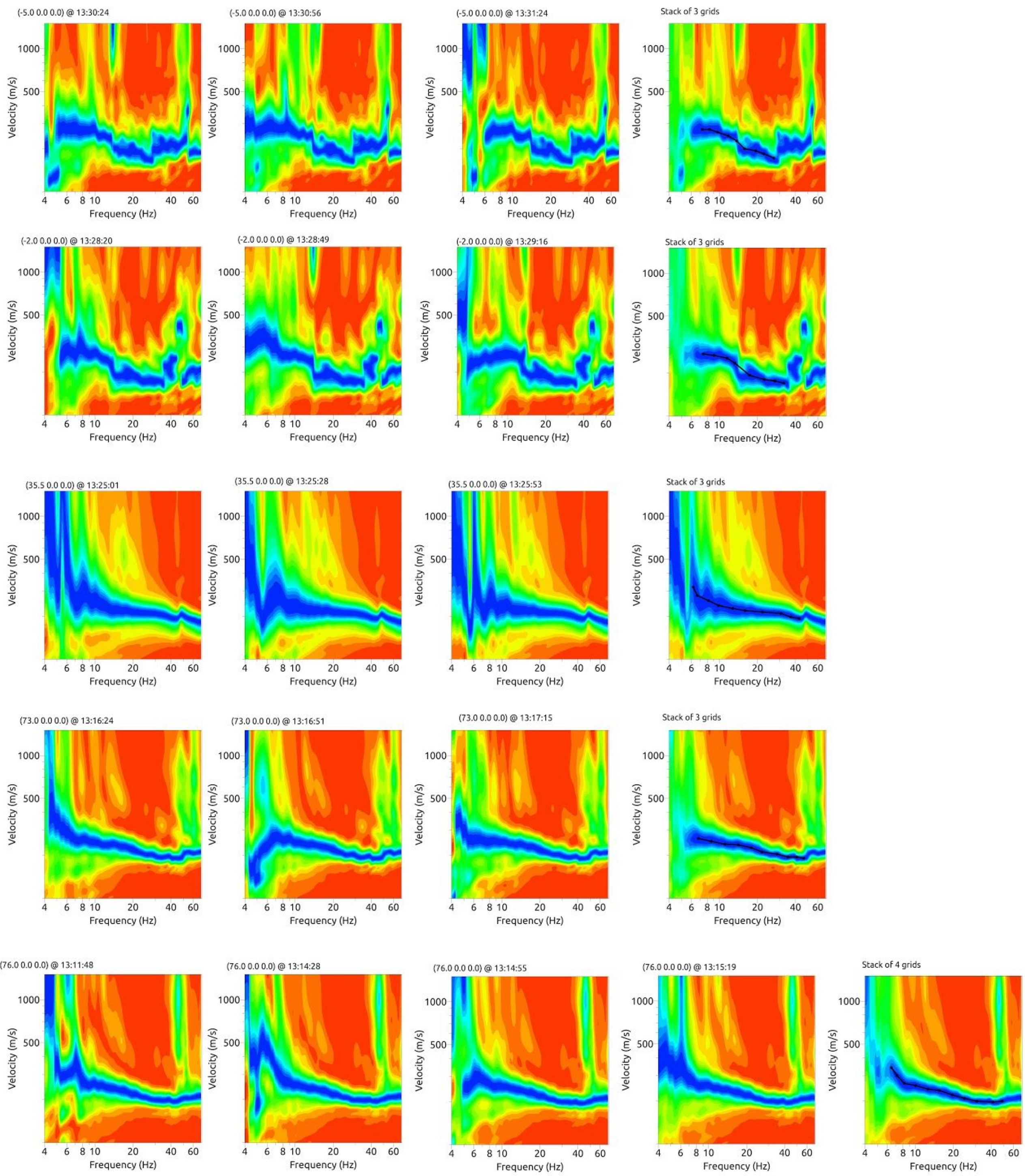


Figure 9. FK analysis on active data acquired by the MASW linear array of geophones. The results are shown for each shot; from top to down the offset is -5 m, -2 m, 35.5 m, 73m and 86m. Plots in the same horizontal panel refer to the same shot offset location. The plot of the last column shows the stack image obtained for the same offset; the black curve is the picked dispersion curve.

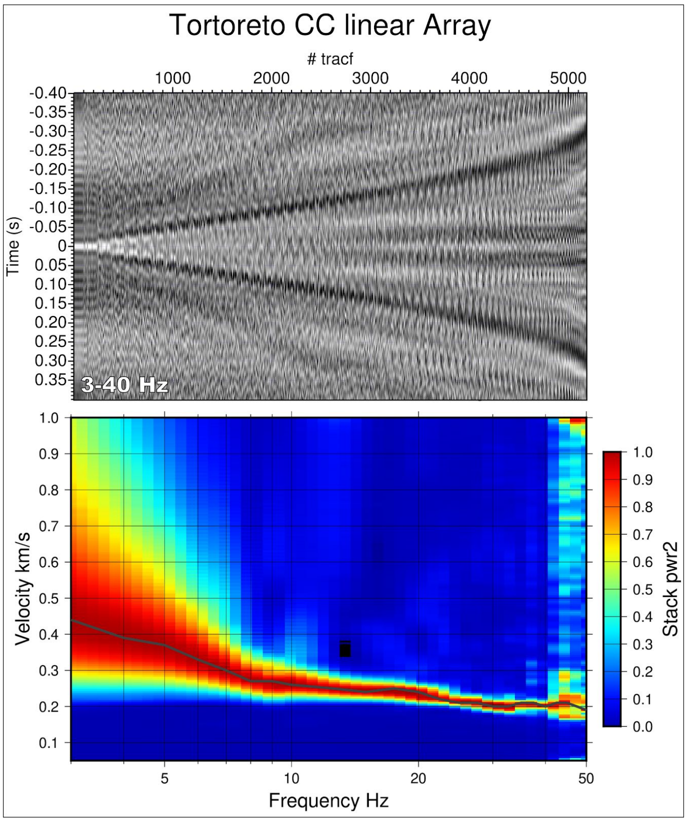


Figure 10. Cross-correlation (CC) analysis on passive data acquired by the 1D array of geophones. Top panel shows the CC signals estimated between 3-40 Hz. Bottom panel shows the resulting dispersion curve with the color scale proportion to the Phase-Weighted Stack (PWS); the black curve is the picked dispersion curve.

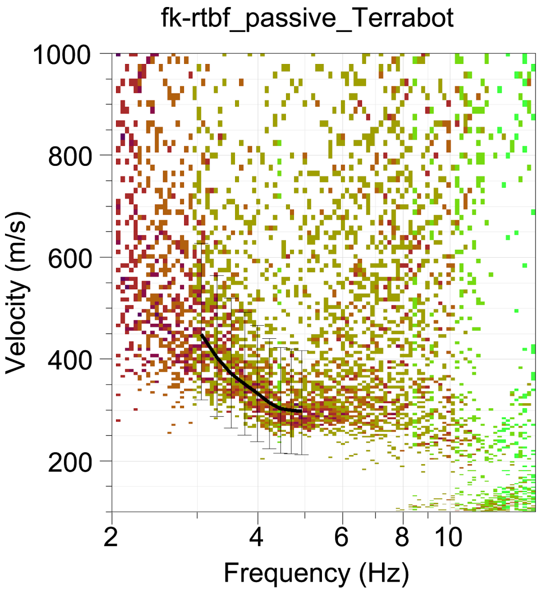


Figure 11. FK analysis on passive data acquired by the 2D array of Terrabot (see Fig. 3). The black curve is the picked dispersion curve.

2.3.4 Selection of the dispersion curve

For the selection of the final dispersion curve to be used in the inversion step, we combine all the experimental curves obtained in the previous analyses (summarized in Fig.s 9, 10, and 11) on active and passive data. The selected dispersions are reported in Fig. 12 showing a good agreement among the different techniques. An average dispersion was then computed (the black dashed curve) using the experimental curves (Fig. 12).

The final mean dispersion curve is in the frequency range 3-50 Hz, with apparent velocity values ranging from 450 m/s (at 3 Hz) up to 200 m/s (at 50 Hz). The maximum wavelength of our dispersion curve is 150 m , and as an experimental rule the depth of investigation is linked to ½ or ⅓ of the maximum wavelength (i.e. between 50-75 m of depth).

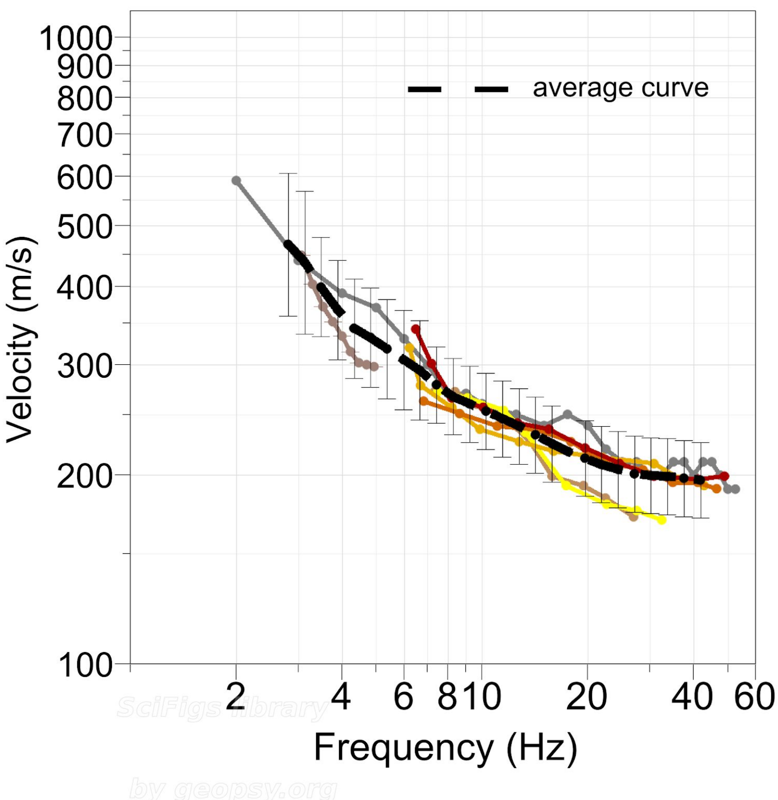


Figure 12. The final dispersion curve selected for the inversion step was computed as the average (black dashed curve) of the experimental curves (see Fig.s 9, 10 and 11). The experimental dispersions are the grey curve from 1D CC analysis on passive signals, the brown curve from 2D array analysis on passive data, the remaining curves (in red, magenta, orange and yellow color) are from active 1D analysis.

B3. 1D SEISMIC VELOCITY MODEL

The final dispersion curve used as target in the inversion procedure is the black one of Fig. 12. To proceed with the inversion step, the dispersion curve derived from the vertical component of motion has been associated with the fundamental mode of Rayleigh wave. Then, we inverted through the geospy tool the apparent surface-wave dispersion curve for recovering the shear-wave velocity (Vs) model. Because in the frequency band 1-10 Hz the HV curves were with very low amplitude peaks (see Fig.s 7 and 8), they were not considered during the inversion step. However we note that these H/V peaks are well persistent in time.

The resulting velocity models after the inversion of the dispersion curve are shown in Fig. 13. We tested several simple starting model-parameterization composed of a few layers (uniform or with linear increase of velocity) over halfspace. Our best results show (Fig. 13) an uppermost layer with thickness around 15-20 m characterized by a linear increase of shear-wave velocity (Vs) from 200 m/s to 320-280 m/s, a second uniform layer at Vs of 320-380 m/s up to 40-50 deep, and then the bottom layer with Vs of 500-650 m/s. The best Vp and Vs models (i.e. lowest misfit) resulting from the inversion are shown in Fig. 14 and Table 1.

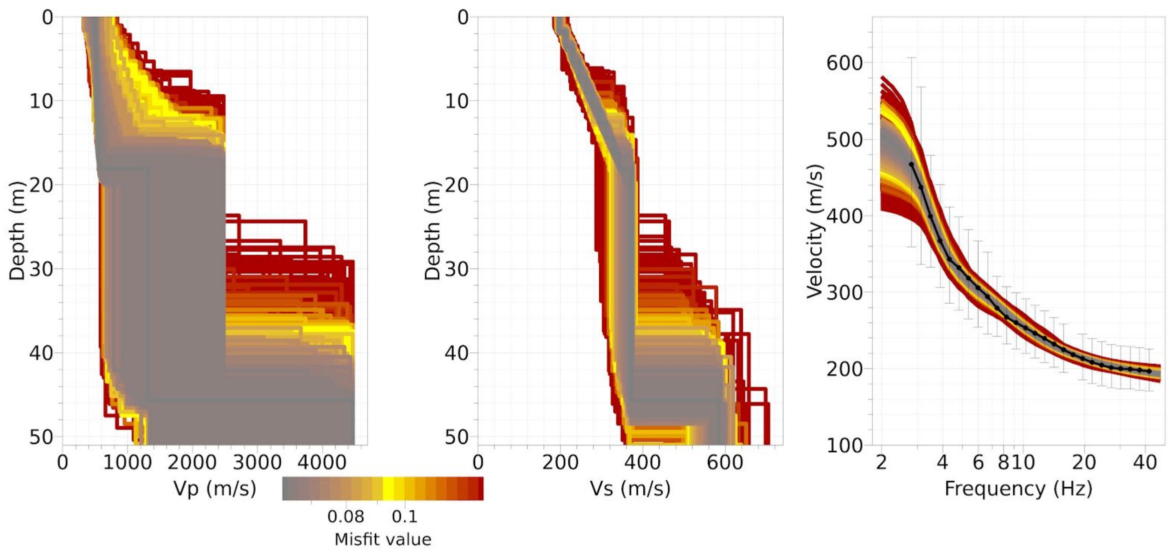


Figure 13. Resulting models after the inversion of the dispersion curves (the field dispersion is shown in black colour; the color scale is proportional to the misfit between experimental curve and theoretical models). The best Vp and Vs model (i.e. lowest misfit) are presented in Fig. 14.

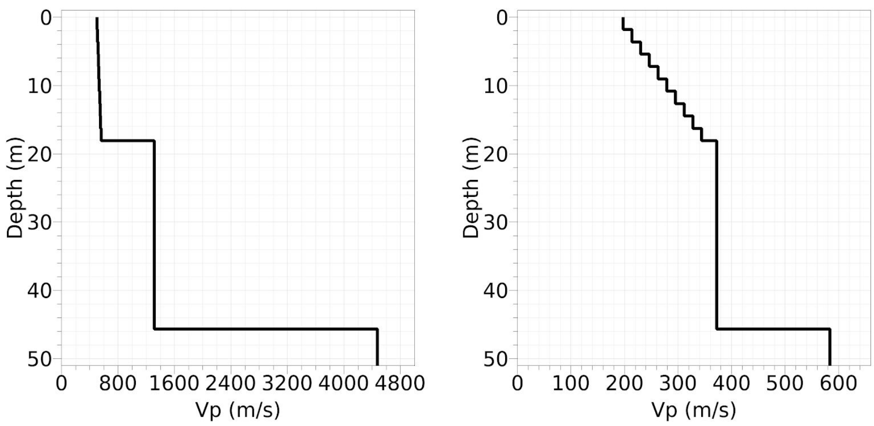


Figure 14. Best Vp and Vs models (extracted from the models of fig. 10) after the inversion of the apparent surface-wave Rayleigh dispersion curve.

Table 1. Best-fit model

From (m)	To (m)	Thickness (m)	Vs (m/s)	Vp (m/s)
0	1,81	1,81	197	503
1,81	3,62	1,81	213	509
3,62	5,43	1,81	230	516
5,43	7,24	1,81	246	522
7,24	9,05	1,81	262	529
9,05	10,86	1,81	279	535
10,86	12,67	1,81	295	542
12,67	14,48	1,81	311	548
14,48	16,29	1,81	327	555
16,29	18,1	1,81	344	561
18,1	45,66	27.56	372	1313
45,66	50	4.34	584	4473

B4. CONCLUSION

Surface-wave analysis at IV.TRTR station indicates a site of soil class C (Table 2). The best Vp and Vs models (i.e. lowest misfit) resulting from the inversion are proposed in Fig.s 13 and 14 and Table 1. HV noise spectral ratios of the temporary stations are characterized by a predominant peak at very low frequency (0.1-0.2 Hz) which could be tentatively related to a very deep (order of 1 km) seismic contrast or to the presence of the near Adriatic sea. Several peaks of very weak amplitude are also emerging in the frequency band 1-10 Hz. All the H/V peaks in the low- and high-frequency range are confirmed by the analysis of continuous two months data records extracted at the station IV.TRTR for different years (Fig. 8). Because of the low amplitude level of the H/V peaks within 1-10 Hz, we prefer to not indicate a resonance frequency in this report. The data analysis of the linear array of geophones and 2D array of stations gives a final dispersion curve from 3 to 50 Hz (Fig. 12), characterized by relatively low values of apparent phase-velocity.

The inversion procedure provides the Vs models of Fig.s 13 and 14 where the bottom layer is found at a depth of 46 m (Table 1). According to the geological model, the uppermost layer with thickness of about 20 m and Vs increasing with depth is interpreted as a colluvial layer, overlaying a deposit of stratified yellow sands (Q1b). Downward, the bottom layer at depth around 50 m is interpreted as the blue-grey clays deposit (Q1a)

The V_{S30} retrieved from the best inverted model is 297 m/s (Table 2), therefore IV.TRTR is classified following EC8 or NTC08 as soil class C also taking into account the geological observation described in the first part of the report.

Table 2. f0 value, and soil class following NTC08 and NTC18.

f_0 (Hz)	Note
	Not clearly identified; the main H/V peak is at very low frequency (0.1-0.2 Hz). The H/V peaks between 1-10 Hz are very weak although very persistent with time

V_{S30} (NTC08 or EC8)	Soil Class
297 m/s	C

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[1]This document is level 3 as defined in the "Principi della politica dei dati dell'INGV (D.P. n. 200 del 26.04.2016)"

RESONANCE FREQUENCY

fo +/- STD [Hz]	unclear
Quality index 1	0.67

Source	Earthquake	☐	Ambient noise	✔

Ambient noise

Method	H/V ✔	Ellipticity ☐	Other ☐
fo +/- std [Hz]			

Experiment date [DD/MM/YY]	Distance from station [m]	Lat. [WGS84]	Lat. [WGS84]
15/09/2020	10	42.807988	13.913469

Environment

Weather conditions	Sunny	Windy	Rain
	✔		
Soil-sensor coupling	Earth	Asphalt	Artificial
	✔	✔	
Urbanization	None	Dense	Scattered
			✔

Equipment

Sensor	Type [acc/vel]	manufacturer	cut-off frequency [Hz]
	vel	Lennartz (+S	0.2 (4.5)
Digitizer	Type	Manufacturer	Sampling frequency [Hz]
	Reftek130(+	Reftek+ (Sar	250
Measurement	Number	Duration [min]	
	7 (plus con	180 (two mo	

Analysis

Software	geopsy (www.geopsy.org
Smoothing type (e.g. triangular, Konno-Ohmachi, ...)	Window length [s]
konno-ohmachi	60

Fo uncertainty estimate from

Fo from individual windows	H/V curve width	Manual picking
?	?	

Earthquake

Method	HVSR ☐	SSR ☐	GIT ☐	Other ☐
fo +/- std [Hz]				

Recording period [DD/MM/YY] from	Recording period [DD/MM/YY] to	Number of earthquakes	Epicentral distance [km] from	Epicentral distance [km] to	Magnitude range from	Magnitude range to

HVSR

Seismic phase	P	S	Coda	S + coda	All

window duration [s]	Min	Max

SSR

Seismic phase	P	S	Coda	S + coda	All

window duration [s]	Min	Max

Reference station	Lat. (WGS84)	Lon. (WGS84)

GIT

Parameters	Free (to be inverted)	Imposed
Reference paper		

Reference station	Lat. (WGS84)	Lon (WGS84)

Vs30

Vs30 +/- STD [m/s]	297
Quality index 1	1

Source	Geophysical measurements	✔	Geotechnical measurements		Digital Elevation Model (DEM)		Geology	✔	DEM & Geology	

Geophysical measurements

Method	Surface waves methods (active, passive methods)		Borehole methods (DH, CH, PS-Logging)	
Vs30 +/- STD [m/s]	From Vs(z)	✔	From Down-Hole	
	From Vr40		From Cross-Hole	
	From Vsz-Vs30 correlation		From PS Logging	
Reference relationship Vsz - Vs30				

Geotechnical measurements

Method	N-SPT		CPT		Shear strength		OTHER	
Vs30 +/- STD [m/s]								

Experiment date [DD/MM/YY]	Distance from station [m]	Lat. [WGS84]	Lon. [WGS84]

Reference relationship Vs30-geotechnical parameter	N-SPT	
	CPT	
	Shear strength	
	Other	

Geology

Method	Geological map		Stratigraphic log	
Vs30 +/- STD [m/s]				
Geological map scale				
Geological unit name				

Stratigraphic log	Experiment date [DD/MM/YY]	Lat. [WGS84]	Lon. [WGS84]
Reference relationship Vs30-geology			
Reference relationship Vs30-Stratigraphic log			

Digital Elevation Model

Vs30 +/- STD [m/s]	? (soil class B)			
DEM resolution	10	Slope range	from	flat
			to	15
Reference relationship Slope - Vs30	ESM-ITACA working group Wald DJ, Allen TI (			

DEM & GEOLOGY

Vs30 +/- STD [m/s]	? (soil class B)
Reference relationship Slope - Vs30 - geology	S4 project (DPC-INGV, 2007-2009) - Di Ca

Vs profile

Quality index 1	1

Source

Non-invasive methods (active and/or passive seismics)			
Active surface waves	✔	Refraction	
Passive surface waves	✔	Refection	
HV / ellipticity			

Invasive methods (measurement in borehole)	
Cross-hole / Down-hole	
Geotechnical methods (CPT, SPT, ...)	
PS-Logging	

Non-invasive : surface waves methods

Experiment date [DD/MM/YY]	Distance from station [m] Min	Distance from station [m] Max	Lat. [WGS84] center location	Lon. [WGS84] center location
15/09/2020	13 (geoph	58 (geoph	42.807988	13.913469

Active surface waves acquisition layout

Minimum receiver spacing (m)	1
Profile length (m)*	71
Geophones number	72
Number of profiles	1

** Provide the length for the various profiles (e.g. 46 m, 94 m)*

Geophone cut-off frequency (Hz)	4.5 Hz
Geophone type (vertical / horizontal)	vertical
Geophone manufacturer	Geospace GS11I
Source (hammer, vibrator, ...)	hammer
Digitizer type	3 Geodes
Digitizer manufacturer	Geometrics

Weather conditions	Sunny	Windy	Rain	Soil-sensor coupling	Earth	Asphalt	Artificial	Urbanization	None	Dense	Scattered
	✔						✔				✔

Passive surface waves acquisition layout

Number of sensors	7 (72 for masw
Minimum array aperture	5 (1m for masw
Maximum array aperture	40 (71)
Number of arrays	1 (1)
Minimum duration [min]	80 (90)

Sensor cut-off frequency (Hz)	4.5 Hz
Sensor type (vertical / horizontal)	vertical
Sensor manufacturer	Terrabot Sara E
Digitizer type	Terrabot Sara E
Digitizer manufacturer	Sara Electronics

Weather conditions	Sunny	Windy	Rain	Soil-sensor coupling	Earth	Asphalt	Artificial	Urbanization	None	Dense	Scattered

Type of dispersion and/or H/V estimates

		Reference paper (Name, Journal, DOI)
Rayleigh DC	✔	FK on active and passive data (geops
Love DC		
Ellipticity		
H/V (DFA, EHVR)		
H/V (SH)		

Dispersion curves

	Rayleigh	*Love*
Min wavelength (m)	4	
Max. wavelength (m)	150	
Min. phase vel. (m/s)	200	
Max. phase vel. (m/s)	450	
Modes (R0, L0, ...)	R0	

H/V or Ellipticity curves

Min. frequency (Hz)	Max. frequency (Hz)

Inversion

Rayleigh waves	✔	Love waves		Ellipticity curves		H/V (DFA, EHVR)		H/V (SH)		resonance frequency	

A priori information used in inversion	seismic refraction		stratigraphic log		geotechnical information		water table depth	

Inversion algorithm/code	dinver
Reference	Wathelet M (2008) An improved neighborhood algorithm: para

Non-invasive : body waves methods

Experiment date [DD/MM/YY]	Distance from station [m]		Lat. [WGS84] center location	Lon. [WGS84] center location
	Min	Max		

Acquisition layout

Receiver spacing (m)	
Profile length (m)*	
Geophones number	
Number of profiles	
Shot spacing (m) - reflection meas.	

** Provide the length for the various profiles (e.g. 46 m, 94 m)*

Geophone cut-off frequency (Hz)	
Geophone type (vertical / horizontal)	
Geophone manufacturer	
Source (hammer, vibrator, ...)	
Digitizer type	
Digitizer manufacturer	

Weather conditions	Sunny	Windy	Rain	Soil-sensor coupling	Earth	Asphalt	Artificial	Urbanization	None	Dense	Scattered

Processing methods

		Reference paper (Name, Journal, DOI)
classical refraction		
refraction tomography		
classical reflection		
advanced method		

Invasive methods

	Down-Hole	Cross-Hole	PS-Logging	SPT	CPT	OTHER
Borehole depth (m)						
Geophone type						
Source type						
Distance between wells						
Depth resolution (m)						
Latitude (WGS84)						
Longitude (WGS84)						
Distance from station (m)						
P-wave velocity						
S-wave velocity						

Processing methods

		Reference paper (Name, Journal, DOI) or ASTM norm
Down-Hole		
Cross-Hole		
PS-Logging		
SPT		
CPT		
OTHER		

Authoritative velocity profile

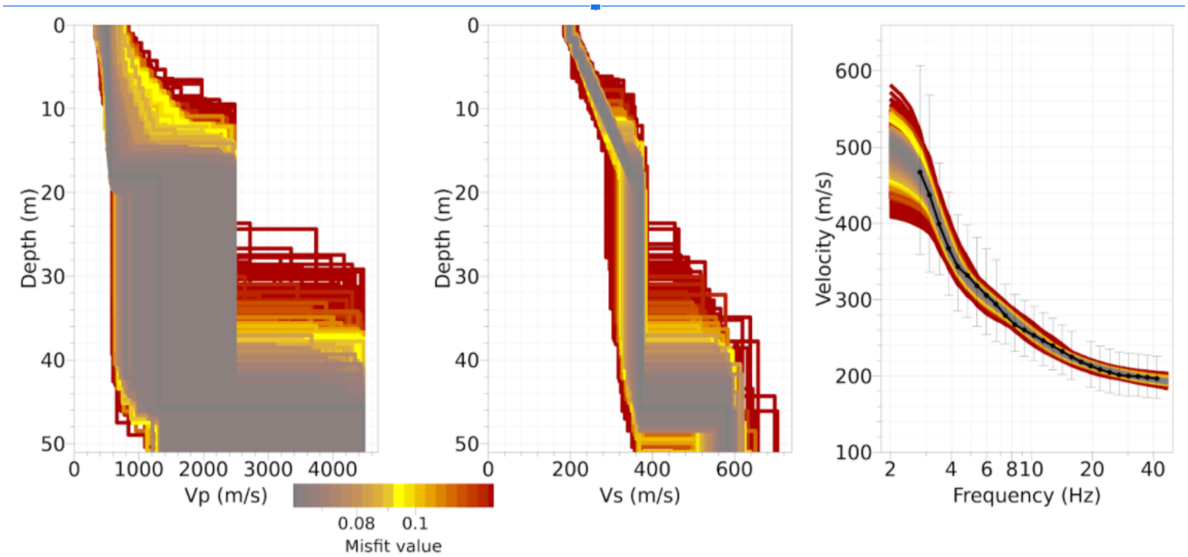
Note: You do not have to fill in all the columns. You can provide either single values for Vp or Vs (e.g. profiles derived from borehole measurements) or either a range for Vp and Vs (e.g. profiles derived from stochastic surface waves inversion)

Is Vs derived from Vp ?	Yes	☐	No	☑

Top depth (m)	Bottom depth (m)	Vp (m/s)	STD Vp (m/s)	Vs (m/s)	STD Vs (m/s)
0	1.81	503		197	
1.81	3.62	509		213	
3.62	5.43	516		230	
5.43	7.24	522		246	
7.24	9.05	529		262	
9.05	10.86	535		279	
10.86	12.67	542		295	
12.67	14.48	548		311	
14.48	16.29	555		327	
16.29	18.1	561		344	
18.1	45.66	1313		372	
45.66	50	4473		584	

Vs range		Vp range	
Vs min (m/s)	Vs max (m/s)	Vp min (m/s)	Vp max (m/s)
180	220	350	900
200	240	360	1000
210	250	390	1300
220	300	400	1400
230	330	450	1500
240	340	470	2000
260	360	470	2300
280	370	500	2400
290	380	520	2500
290	390	530	2500
300	400	800	2500
450	700	1000	5000

Figure with authoritative velocity profiles



Surface geology

Quality index 1	1

Source	Cartography (geological, lithological, ...)	✔	Field survey		Stratigraphic log	

Geological map

Map reference		Carta Geologica-Tecnica per la Microzonazione Sis
Map scale		1:5000
Map sheet		
Predominent geologic/lithologic unit	Name :	Q1b-GRS
	Description :	stratified yellow sands-layered cemented
	Age :	Late Pliocene-Lower Pleistocene
	Thickness :	
	Rock mass structure :	
Fault presence		
Weathering		
Cross-section		

Field survey

Map reference		2. Obiettivo 1 - TASK B;" (2018). Geological report
Map scale		1:5000
Predominent geologic/lithologic unit	Name :	Q1b
	Description :	stratified yellow sands
	Age :	Late Pliocene-Lower Pleistocene
	Thickness :	25-30 m
	Rock mass structure :	
Fault presence		
Weathering		
Cross-section		✔

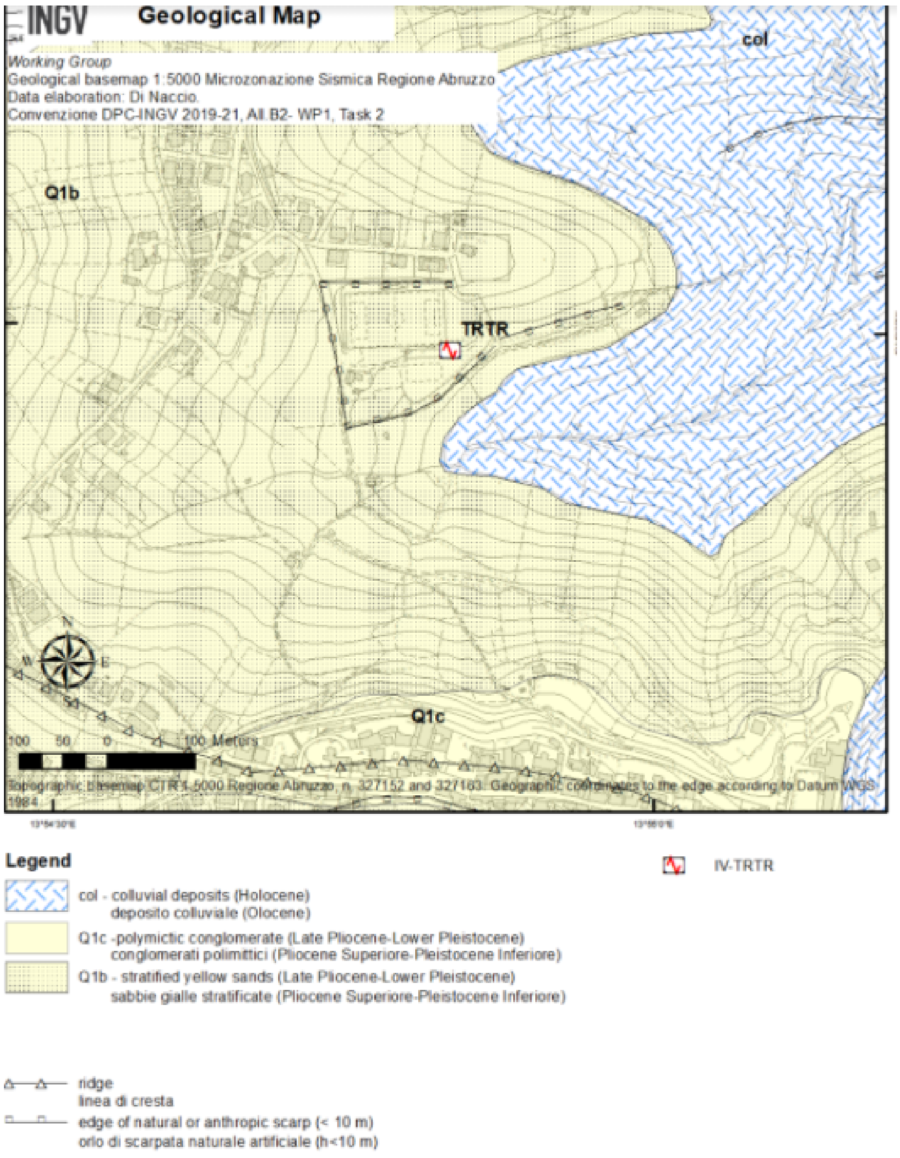
Stratigraphic log

log depth (m)	

Top depth (m)	Bottom depth (m)	Stratigraphic description
0	20	colluvial deposits
20	50	sand-sandstone
50	-	silt and clay

Surface geology

Map



Site class

Site class	C
Quality index 1	1

Reference building code for site classification (EC8-1, EC8-2, NEHRP, national code, ...)	

Source	Geophysical measurements	✔	Geotechnical measurements		Digital Elevation Model (DEM)		Geology		DEM & Geology	

Reference relationship geology - soil class	NTC18: Ministero delle Infrastrutture e dei Trasporti (2018). Agg
Reference relationship slope from DEM - soil class	
Reference relationship slope from DEM - geology - soil class	

Parameters for deriving soil class as prescribed in building code	Vs30 and bedrock depth

Seismological bedrock depth

Depth +/- STD [m]	46
Quality index 1	0.67

Source						
	Vs profiles	✔	Geology	☐	Other (gravity, seismic refraction, TDEM, ...)	☐
	Resonance frequency	☐	Stratigraphic log	☐		

Vs profile

	Non-invasive methods	Invasive seismic methods	Geotechnical methods
Bedrock depth +/- STD(m)	46 +/- 20		
Bedrock Vs +/- STD(m)	584 +/-120		
Bedrock Vp +/- STD(m)	4473 (large un		
Is Vs derived from Vp ?	Yes ☐	No ✔	

Resonance frequency

Bedrock depth +/- STD(m)	
Reference relationship Fo - bedrock depth	

Geology

Bedrock depth +/- STD(m)	50 m
Bedrock geological unit	Q1a: blue-grey clays
Reference	2, Obiettivo 1 - TASK B;" (2018). Geological

Stratigraphic log

Bedrock depth +/- STD(m)	
Bedrock geological unit	
Reference	

Other methods

	Bedrock depth +/- STD(m)	Reference
Gravity		
Seismic refraction		
Seismic reflection		
TDEM		

Engineering bedrock depth

Depth +/- STD [m]	undefined
Quality index 1	

Reference Vs related to engineering bedrock in m/s		Reference building code for site classification (EC8-1, EC8-2, NEHRP, national code, ...)	NTC18 (Itali

Source	Vs profile	✔	Geology		Stratigraphic log	

Vs profile

	Non-invasive methods	Invasive seismic methods	Geotechnical methods
Bedrock depth +/- STD(m)			

Is Vs derived from Vp ?	Yes		No	✔

Geology

Bedrock depth +/- STD(m)	
Bedrock geological unit	
Reference	

Stratigraphic log

Bedrock depth +/- STD(m)	
Bedrock geological unit	
Reference	