



Site characterization report at the seismic station IT.NVG – Novi Ligure (AL)

Report di caratterizzazione di sito presso la stazione sismica IT.NVG – Novi Ligure (AL)

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INDEX

<i>Introduction</i>	3
A. Geological setting	4-12
1. Topographic and geological information	4
2. Geological map	6
3. Lithological map	7
4. Lithotechnical map	8
5. Survey map	9
6. Geological model	10
6.1 General description	10
6.2 Geological section	10
6.3 Subsoil model	11
B. Vs profile	13-23
1. Geophysical Investigations	13
2. Seismic Velocity Model	21
3. Conclusions	23
<i>Acknowledgements</i>	23
<i>References</i>	24
<i>Disclaimer and limits of use of information</i>	27



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 IT.NVG (Novi Ligure).

Location and coordinates are reported in Table 1.

Table 1

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IT.NVG	Novi Ligure (AL)	44.7585 *	8.7711 *	221 **
ADDRESS	Via U. Terracini, 1, 15067 Novi Ligure (AL), Italy			

* Coordinates from ITACA (Nov. 2021) ** Elevation from CTR 10k Regione Piemonte



A. Geological setting

A1. TOPOGRAPHIC AND GEOLOGICAL INFORMATION

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

Table 2

Topography	Description	Topography Class	Morphology Class
	Flat surfaces, isolated slopes and reliefs with slope $i \leq 15^\circ$	T1	Valley centre (VC)

Table 3

Geological map	Source	Scale
IT.NVG	Geological Map of Italy, sheet 70 (Alessandria)	1:100.000

In Table 4 Geological, Lithological 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 a preexisting cartography according to the nomenclature of corresponding cartography.

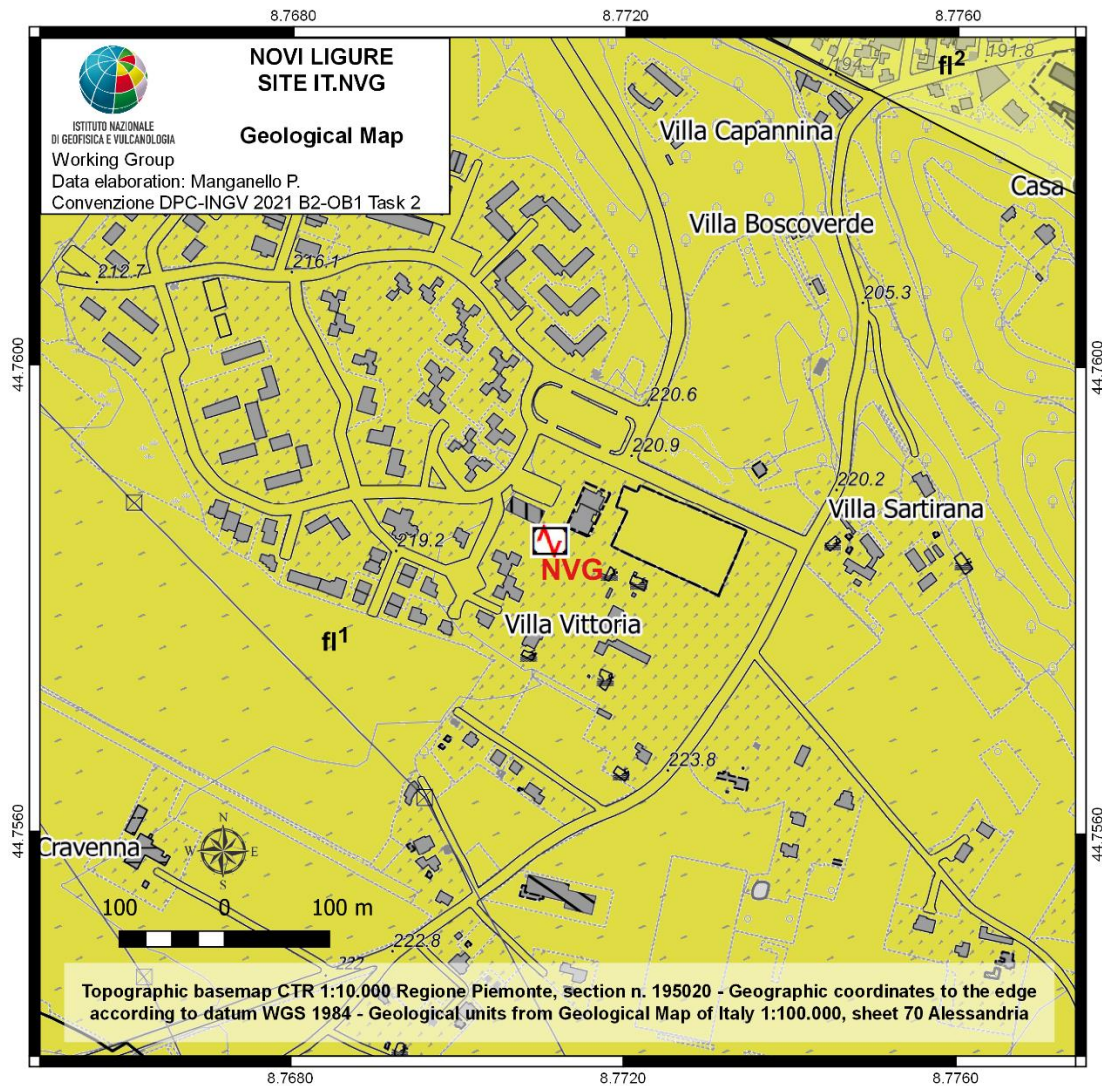
**Table 4**

GEOLOGICAL UNITS		LITHOLOGICAL UNITS		LITHOTECHNICAL UNITS	
Geological Map of Italy 1:100.000, sheet 70 (Alessandria) <i>original</i>		<i>Amanti et al. (2008) deduced</i>		<i>(MZS) deduced</i>	
code	description	code	description	code	description
fl ¹	Ancient Fluvial	B3	Gravelly-sandy sediments	GP tf	Gravel-sand mixture
fl ²	Middle Fluvial	B4	Mixed grain size sediments	GM tf	Gravel-sand-silt mixture




A2. GEOLOGICAL MAP

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



Legend

 Seismic station
Stazione sismica

CONTINENTAL FORMATIONS FORMAZIONI CONTINENTALI



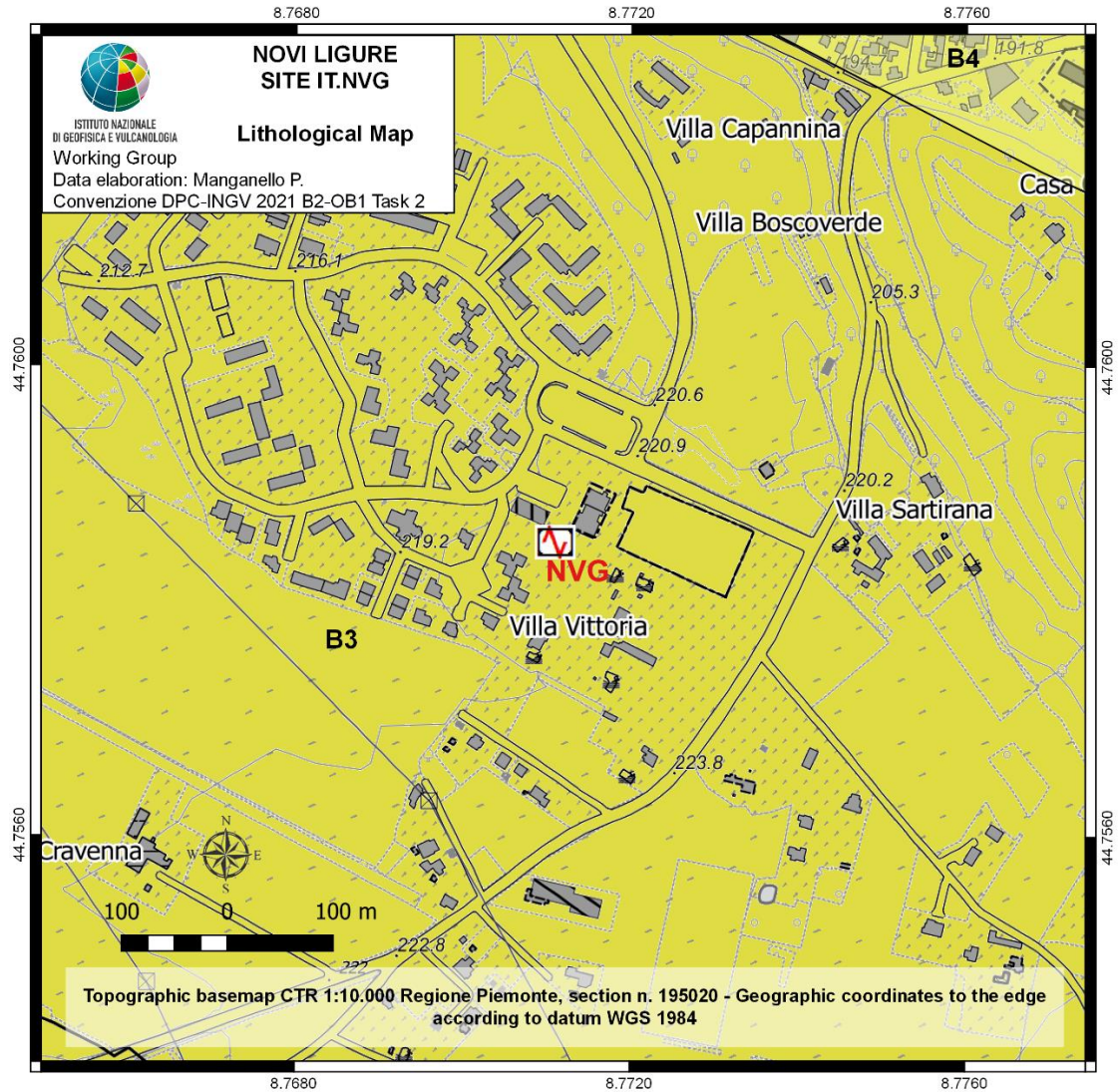
-  fl¹ - Ancient Fluvial (Middle Pleistocene)
fl¹ - Fluviale Antico (Pleistocene medio)
-  fl² - Middle Fluvial (Middle-Upper Pleistocene)
fl² - Fluviale Medio (Pleistocene medio-superiore)

Figure 1: Geological map of seismic station IT.NVG. Scale 1:5.000. Geological units come from Geological Map of Italy 1:100.000, sheet 70 Alessandria.




A3. LITHOLOGICAL MAP

In Figure 2 Lithological Map is reported in a 1 km × 1 km square around the station.



Legend

 Seismic station
Stazione sismica

Lithological units
Unità litologiche


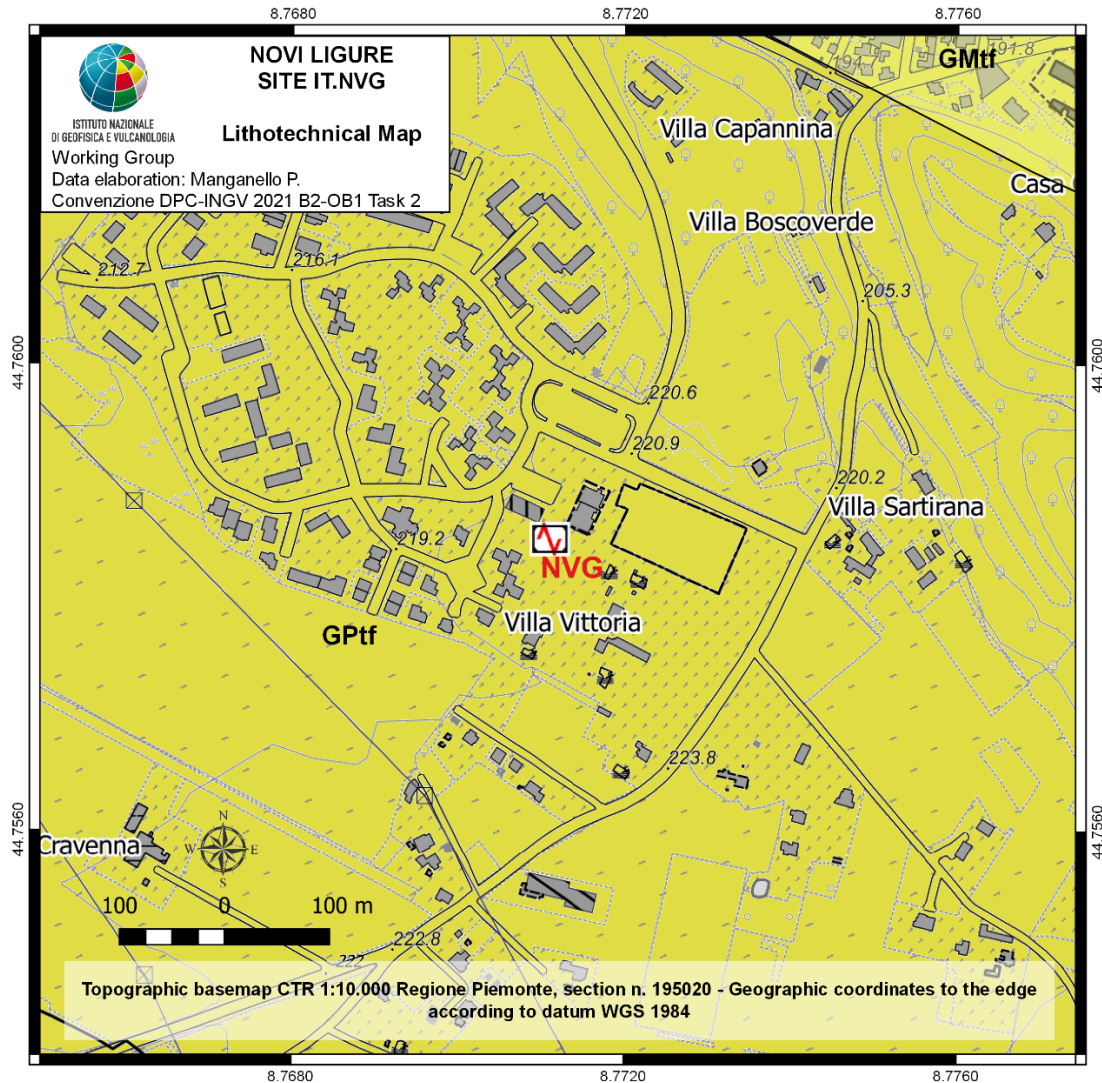
-  B3 - Gravelly-sandy sediments
B3 - Sedimenti ghiaioso-sabbiosi
-  B4 - Mixed grain size sediments
B4 - Sedimenti a granulometria mista

Figure 2: Lithological map of the seismic station IT.NVG. Scale 1:5.000. The codes of the lithological units are assigned according to the nomenclature of the Lithological map of Italy ISPRA 1:100.000 (Amanti *et al.*, 2008).



A4. LITHOTECHNICAL MAP

In Figure 3 Lithotechnical Map is reported in a $1\text{ km} \times 1\text{ km}$ square around the station.



Legend

 Seismic station
Stazione sismica

SEDIMENTARY COVER TERRENI DI COPERTURA



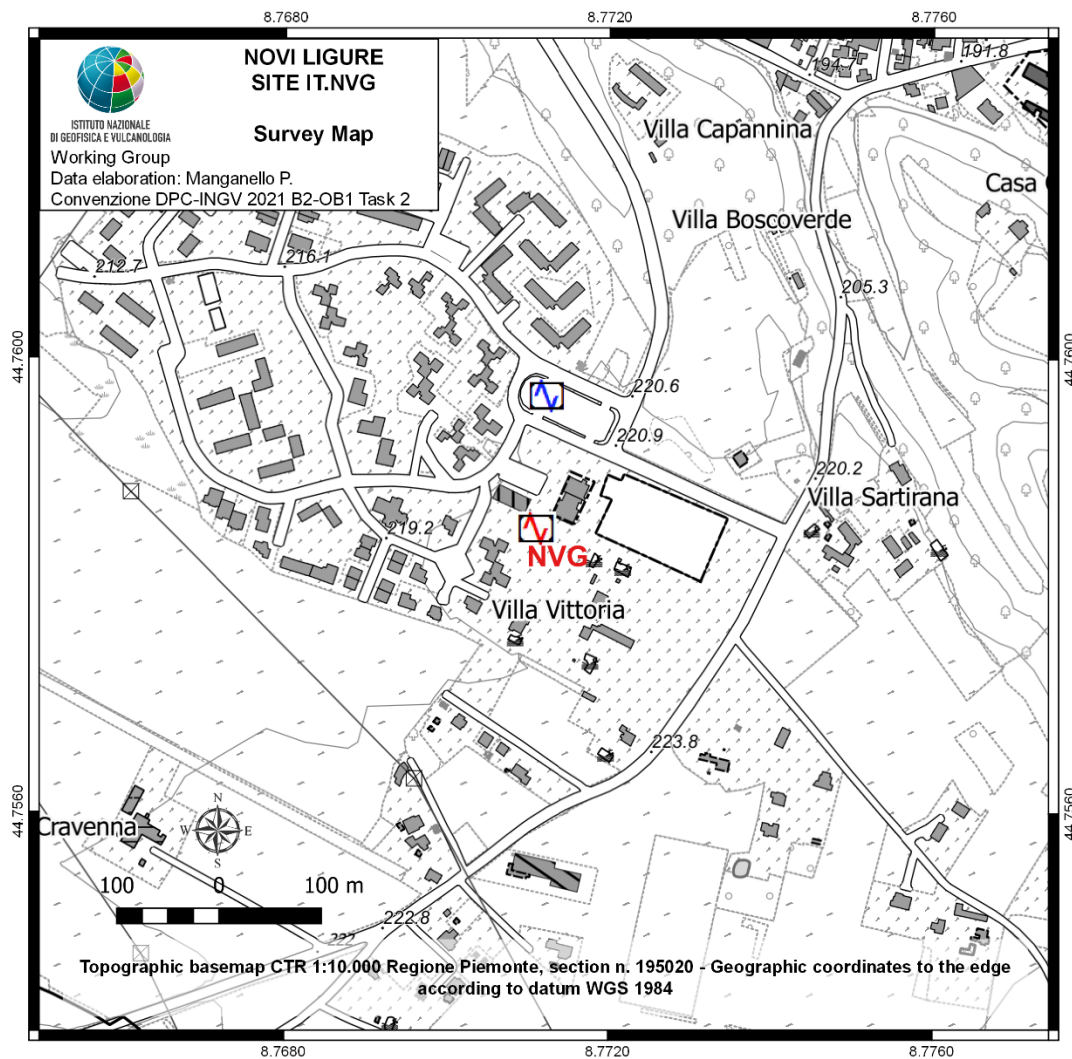
-  GPtf - Gravel-sand mixture (fluvial terrace)
GPtf - Miscela di ghiaia e sabbia (terrazzo fluviale)
-  GMtf - Gravel-sand-silt mixture (fluvial terrace)
GMtf - Miscela di ghiaia, sabbia e limo (terrazzo fluviale)

Figure 3: Lithotechnical map of the seismic station IT.NVG. Scale 1:5.000. The lithotechnical units are deduced according to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).



A5. SURVEY MAP

Figure 4 shows the Survey Map reporting both previous investigations and geophysical surveys conducted by INGV Working Group.



Legend



-  Seismic station
Stazione sismica
-  INGV 8-stations array
INGV array 8-stazioni

Figure 4: Map of the surveys in the surroundings of the station IT.NVG. Scale 1:5.000.



A6. GEOLOGICAL MODEL

6.1 General description

The seismic station IT.NVG is installed in the Novi Ligure municipality, which is located in the Alessandria Province (southern part of Piedmont Region).

The geological setting of the studied area is related with the evolution of the Tertiary Piedmont Basin, which is considered as a wedge-top basin located on top of the connection between the Western Alps and the Northern Apennines. The sedimentation of this sedimentary basin took place in the Upper Eocene-Miocene in relation to three main tectonic phases: the exhumation of the Ligurian sector of Western Alps, the opening of Liguro-Provençal basin and the formation of the Apennines thrust belt. The Tertiary Piedmont Basin is divided in four major paleogeographic domains: the Monregalese High, the Langhe basin, the Alto Monferrato High and the Borbera-Curone basin. The sedimentary succession of this basin is mainly characterized by clastic deposits, which are derived from the Pre-Cenozoic substratum of the Ligurian Alps in the western sector of the basin and from Ligurian units of the Northern Apennines in the eastern sector. Within the basin there are stratigraphic variations which depend on sea level variations. The Tertiary Piedmont Basin is not characterized by the presence of major tectonic structures, whereas small scale structural features are common (Gelati *et al.*, 1998; Maino *et al.*, 2013; Rossi and Craig, 2016).

The territory of Novi Ligure municipality is characterized by the presence of Pleistocene-Holocene alluvial deposits of the Scrivia torrent, both on the top of hilly reliefs and in the plain. These alluvial deposits consist mainly in sediments with coarse granulometry. The bottom of the alluvial deposits is quite shallow in the area of Novi Ligure municipality, whereas it becomes more deeper to the North in the Alessandria Basin.



6.2 Geological section

In the surroundings of IT.NVG seismic station there are not boreholes.

The WSW-ENE oriented geological section is reported and highlights the geological and structural setting of IT.NVG site. The trace with the location of the section is reported as a black line in the geological map (Fig. 5 upper left).

6.3 Subsoil model

The geological description reported from the surface to the bottom is described in the following part. A subsoil model is built up to a depth of 35 *m* on the basis of geological information (Fig. 5 bottom). The stratigraphic succession is characterized by the alluvial deposits of the Ancient Fluvial continental formation (Middle Pleistocene), represented by silty-clayey, sandy or gravelly deposits. At the bottom of the Ancient Fluvial formation there are weathered gravels (I²).

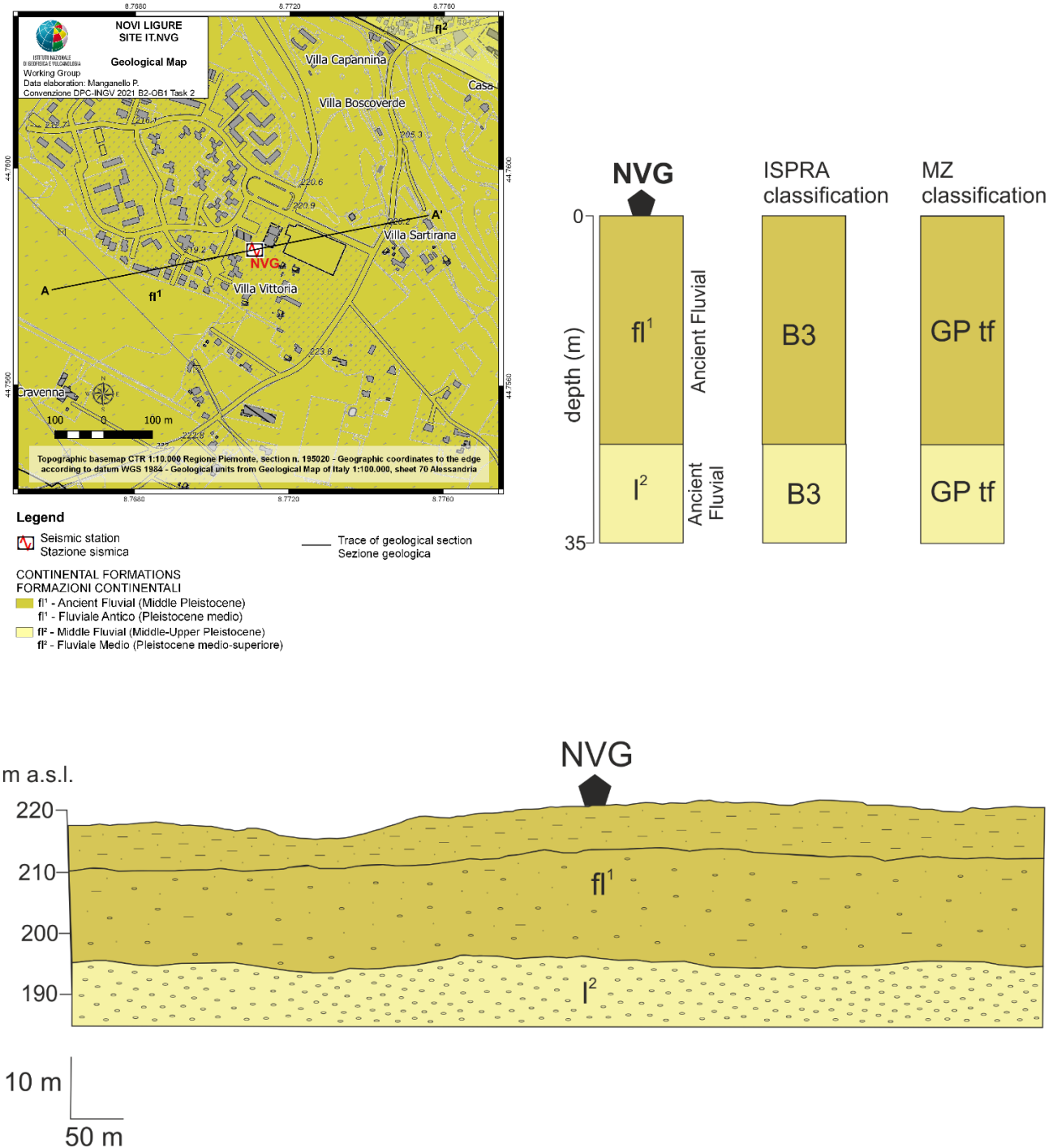


Figure 5: Upper left: Geological map of the study area where is installed IT.NVG seismic station. Upper right: Geological section. Bottom: Subsoil model for the site.



B. V_s profile

B1. GEOPHYSICAL INVESTIGATIONS

Geophysical measurements executed nearby the station NVG of the network IT (PCM-DPC, 1972) consist in ambient-vibration measurements in both single-station and 2D array configuration (Figure 6) that provide results in terms of resonance frequency of the soil deposits and in terms of dispersion curves of surface waves. These curves are inverted to obtain a shear-wave velocity (V_s) profile that, together with the geological study at section A, is suitable for assigning the soil class according to the current Italian seismic code (NTC18) and Eurocode (EC8). Figure 7 shows the location of the station IT.NVG (Latitude 44.7585, Longitude 8.7711 WGS84) installed at Novi Ligure (AL).

Seismic noise is acquired using 8 Reftek-130 24-bits recording systems equipped with short-period Lennartz LE-3D/5s sensors and GPS timing (Figure 7). The sampling rate is fixed to 200 Hz, while the gain is set as “high”. Ambient noise recordings have a minimum duration of 1 hour. The array geometry (Figure 8) is chosen in order to have a good coverage of both azimuths and inter-station distances, the latter between the minimum (less than 10 m) and the maximum (about 30 m). These ranges allow the analysis of a range of wavelengths that guarantee sufficient shallow resolution (Okada, 2003) in order to estimate the $V_{s,30}$ and the site-class according to current building codes (i.e. NTC18 and EC8).



Figure 6: Map of the geophysical measurements performed at the IT.NVG site. The yellow place-markers indicate the geometry used for 2D array in passive configuration. The red triangle indicates the IT.NVG accelerometric station (image from Google Earth <http://www.earth.google.com>).



Figure 7: Left: IT.NVG accelerometric station installed in Novi Ligure (AL). Upper right: single station ambient noise measurement. Bottom right: 2D passive ambient noise array installed close to the IT.NVG station.

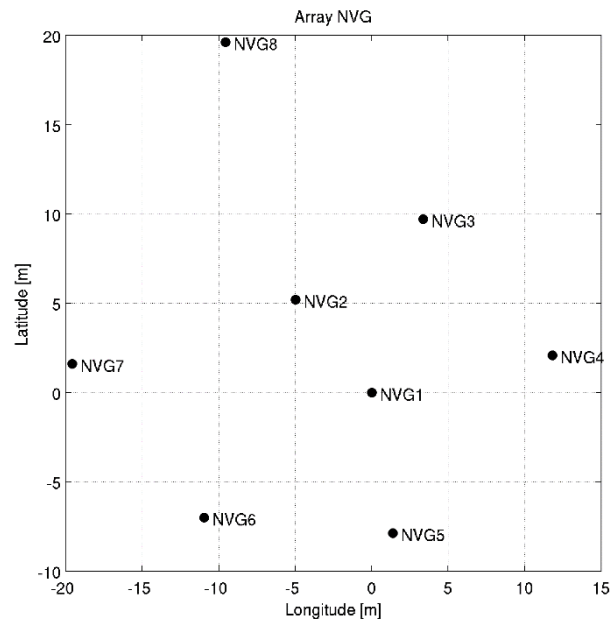


Figure 8: Array geometry.

The first step of the analysis consists in a visual inspection of the recordings at each station of the array. In particular, in order to identify malfunctioning and to select signal windows suitable for the surface wave analysis, the quality of the recording is evaluated analyzing the signal stationarity in the time domain, the relevant unfiltered Fourier spectra, and the H/V variation over time. Figures 9 and 10 provide graphical results about station NVG7.

It is common practice during surface wave investigation to verify the reliability of the one-dimensional site structure assumption (Aki, 1957; Okada, 2003). For this reason, we estimated the HVSR at each station of the array and the stability of HVSR among the array stations has been verified. Figure 11 depicts the HVSR assumed as representative for the array.

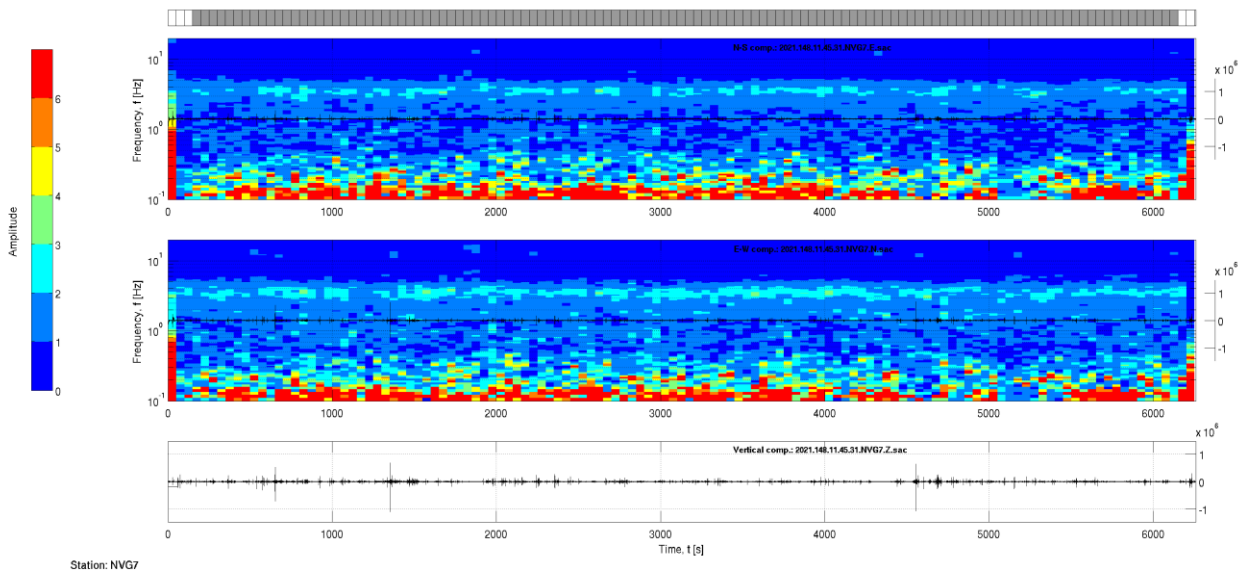


Figure 9: HVSr versus time (top and central panel for the NS and EW component, respectively) and corresponding time-histories.

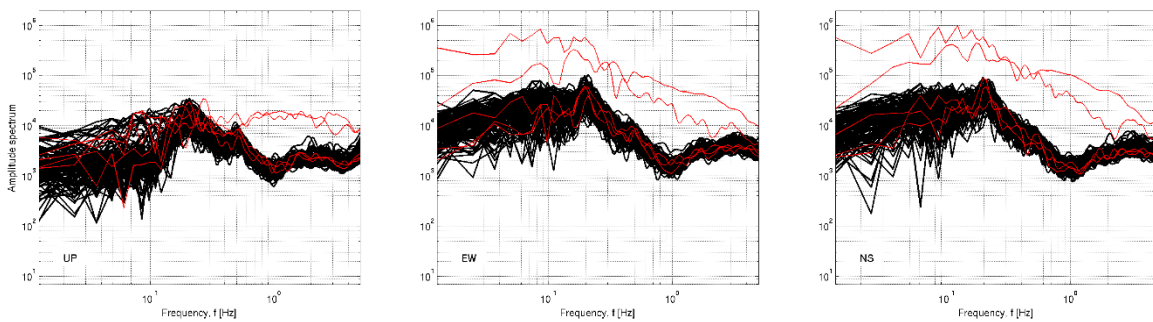


Figure 10: Fourier spectra for each noise window (left: Vertical, center: EW, right: NS). Red spectra are excluded from HVSr analysis.

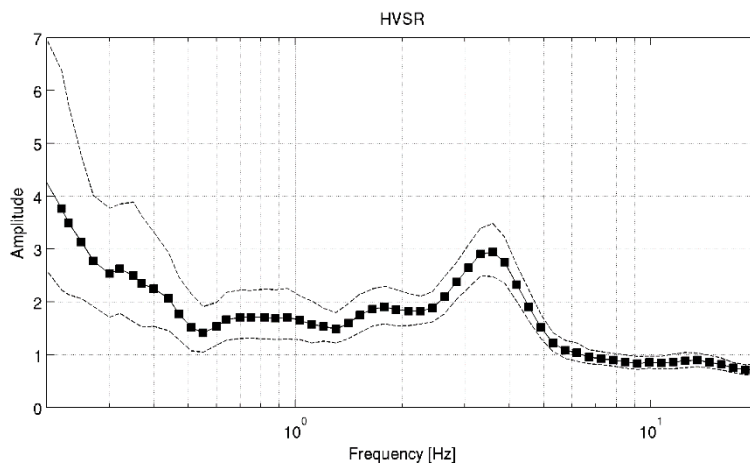


Figure 11: HVSr representative for the array. Dashed lines represent +/- one standard deviation.



The Rayleigh-wave dispersion curve is estimated by analyzing the vertical component of the recorded seismic noise. In particular, the Extended Spatial Auto-Correlation (ESAC; Ohori *et al.*, 2002; Okada, 2003) and the frequency-wavenumber (F-K; Lacoss *et al.*, 1969; Capon, 1969) methods are adopted. Further details about the combined use of ESAC and F-K approaches can be found in Parolai *et al.* (2006).

Both analyses use 22 synchronized signal windows of 60 s each, extracted from recordings within the UTC date-time interval 2021-05-28 12:05:00 – 2021-05-28 12:27, avoiding time periods affected by local disturbance.

The ESAC Rayleigh-wave dispersion curve is obtained by minimizing the root-mean-square (RMS) of the differences between experimental and theoretical Bessel functions (Figure 12). Values differing by more than two standard deviations from those estimated by the best fitting functions are automatically discarded (red circles in Figure 12) and the procedure is repeated iteratively. For this data set, data are also discarded whenever the inter-station distance is 2 times longer than the relevant wavelength. Figure 13 shows the Rayleigh-wave dispersion curve estimated using the ESAC approach.

The F-K analysis allows checking on the noise source distribution. One of the basic assumptions for the application of the ESAC method is indeed that the seismic noise wavefield is nearly isotropic. Figures 14 and 15 show results of the F-K analysis in terms of power density function for several frequencies using the Maximum Likelihood Method (MLM) and the Beam Forming (BF) respectively. Figure 16 shows the good agreement above 9 Hz between the Rayleigh wave dispersion curves estimated by both ESAC and F-K approaches. As expected, due to the array geometry, below this threshold the F-K analysis provides larger phase velocities.

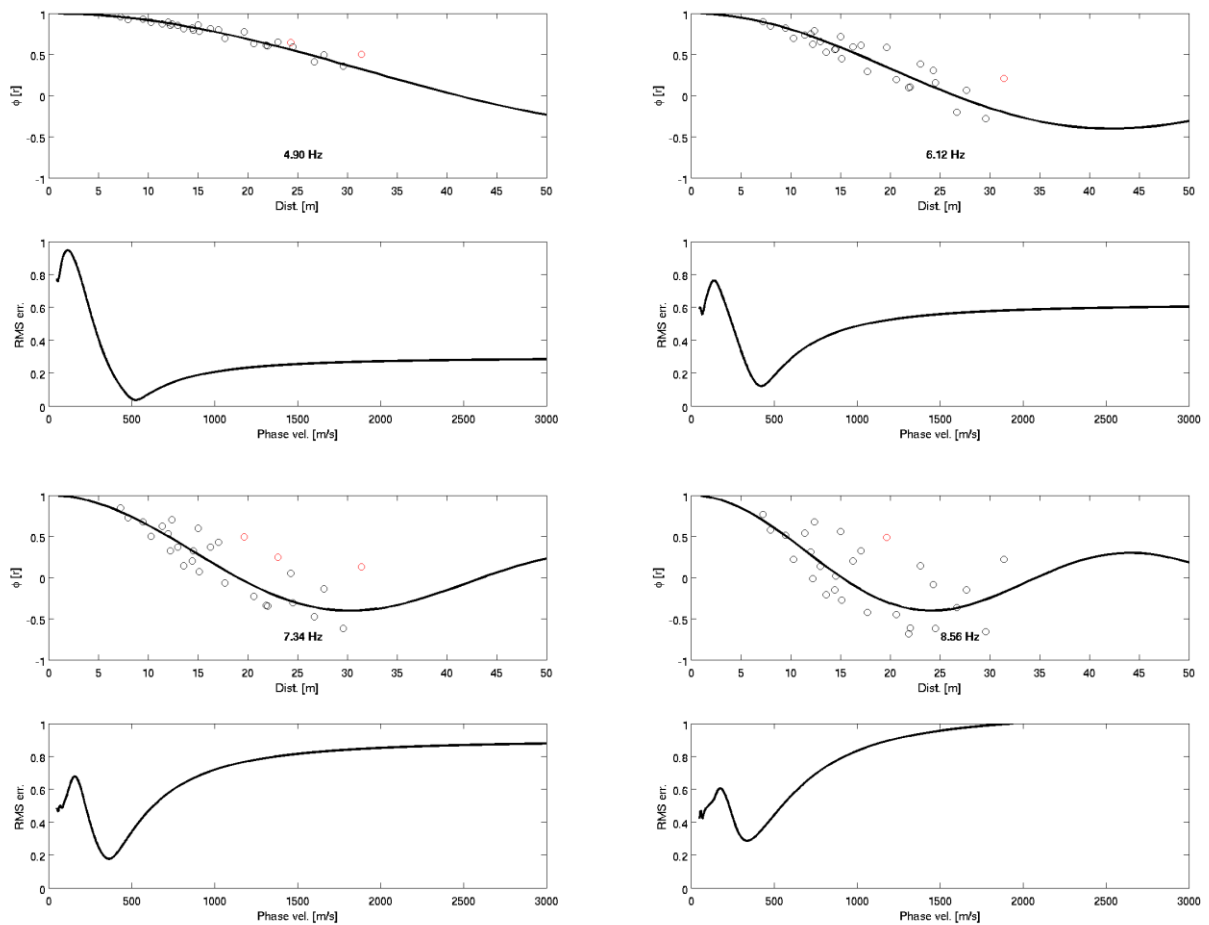


Figure 12: Experimental space-correlation function values versus distance (circles) for different frequencies. The red circles indicate values that are discarded. The black lines depict the estimated space-correlation function values for the phase velocity that furnishes the best fit to the data. The bottom panels show the relevant root-mean-square errors (RMS) versus phase velocity tested.

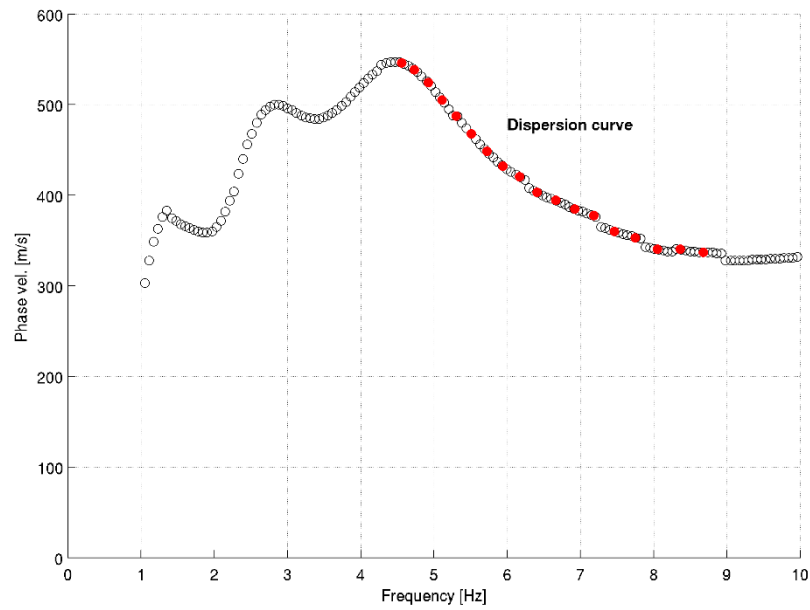


Figure 13: Rayleigh-wave dispersion curve from ESAC. Red-filled circles represent values potentially used for inversions.

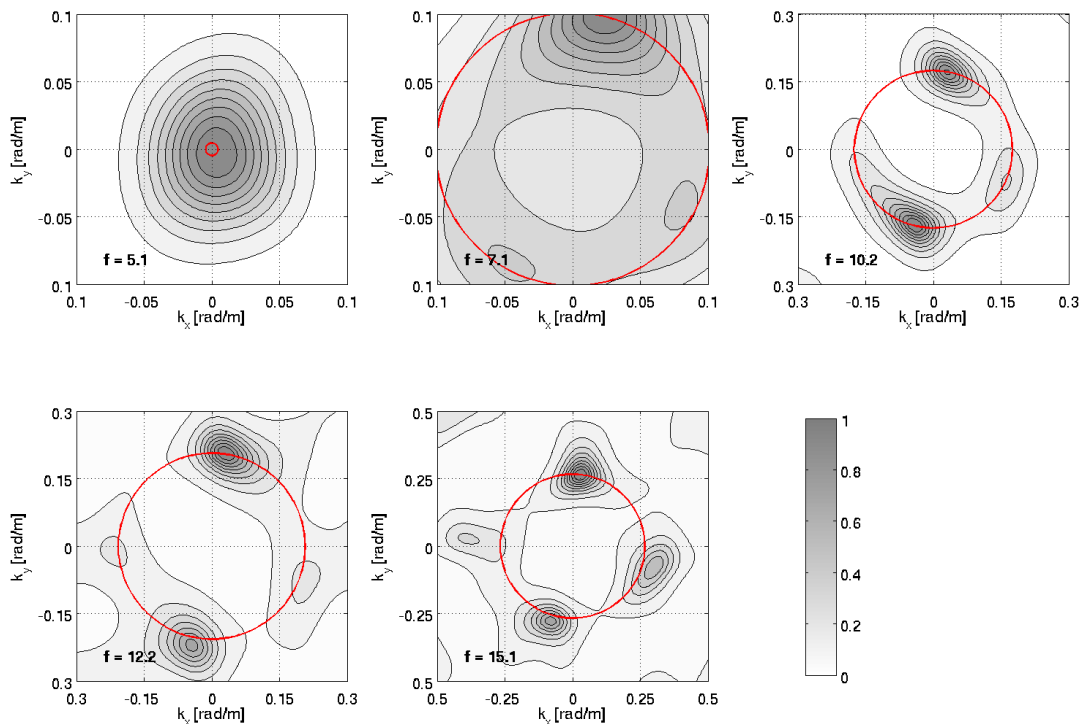


Figure 14: F-K power density function (Maximum-Likelihood Method) at selected frequencies.

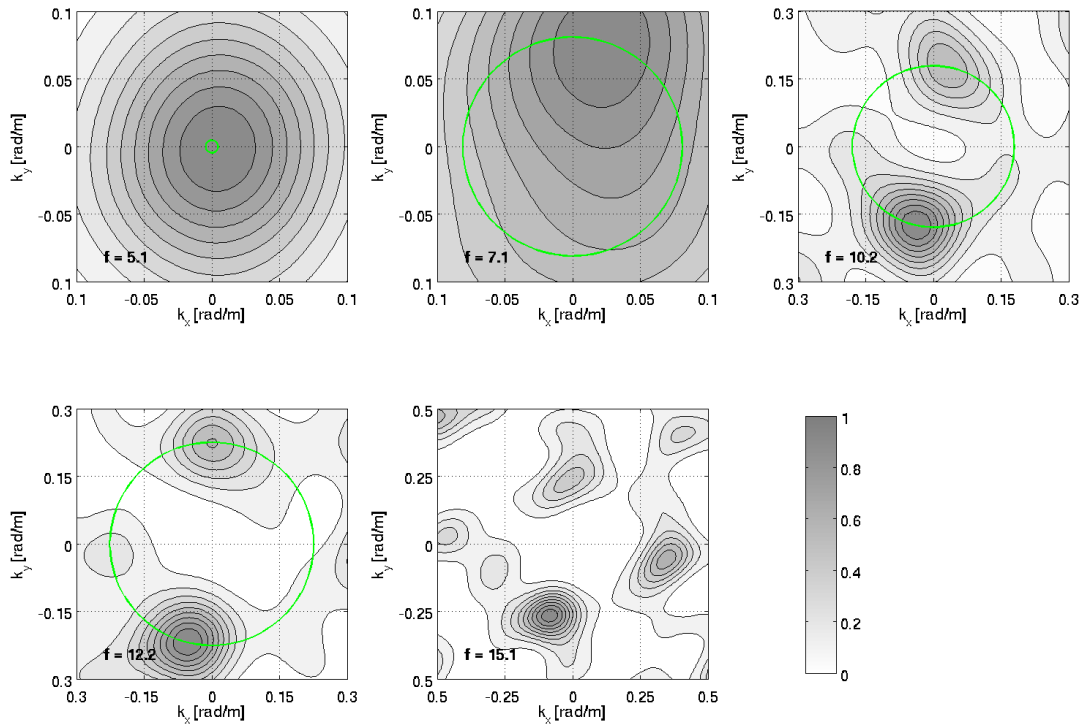


Figure 15: F-K power density function (Beam-Forming) at selected frequencies.

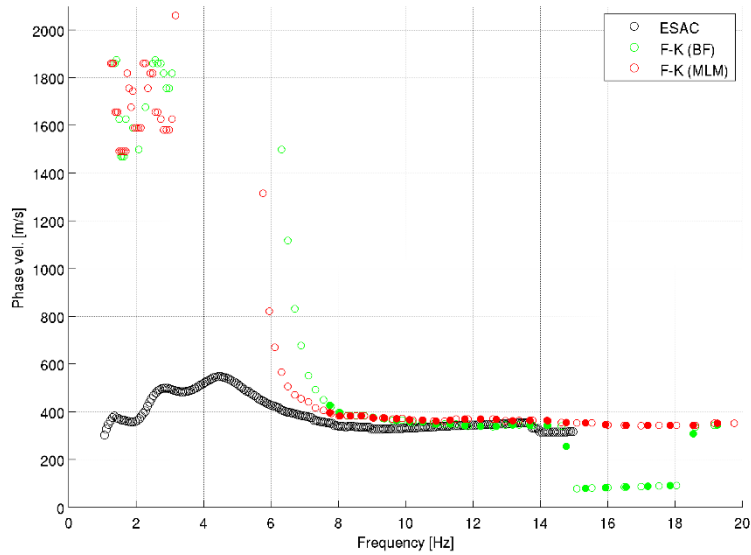


Figure 16: Comparison of experimental phase velocity estimated by the ESAC and the F-K (for both Beam-Forming and Maximum-Likelihood Method) methods. Filled circles represent values potentially used for inversions.



B2. SEISMIC VELOCITY MODEL

The non-linear inversions are performed using the software *joinv6* (Parolai *et al.*, 2005; Giustiniani *et al.*, 2020), which adopt a genetic algorithm (Yamanaka and Ishida, 1996). The forward modelling of Rayleigh wave phase velocities and HVSr curves is performed under the assumption of a vertically heterogeneous 1D Earth model using the modified Thomson-Haskell method proposed by Wang (1999) and following the suggestions of Arai and Tokimatsu (2004) and Tokimatsu *et al.* (1992). The modelling is not restricted to the fundamental mode, preserving the possibility that higher modes participate in simulating the observed dispersion and HVSr curves.

The experimental dispersion curve used as input for inversions is the one estimated from the ESAC analysis in the frequency interval 4.5 - 9 Hz, in combination with the one from F-K (MLM) in the interval 9-16 Hz. The experimental HVSr is used between about 1 and 7 Hz. In the left panel of Figure 17 tested models are shown in different colors according to their cost value: the more reliable model (minimum cost) is in white, the models lying inside the 10% range of the minimum cost are in black and the other tested models are shown in grey. In the right-central and right-bottom panels of Figure 17 agreement between experimental and theoretical (grey and open circles, respectively) Rayleigh-wave dispersion curves and HVSr are shown. The agreement is good and, considering the wavelengths related to the dispersion curve frequency range, the V_s profile between about 5 - 60 m is well constrained. Table 5 reports the minimum-cost shear-wave velocity model.

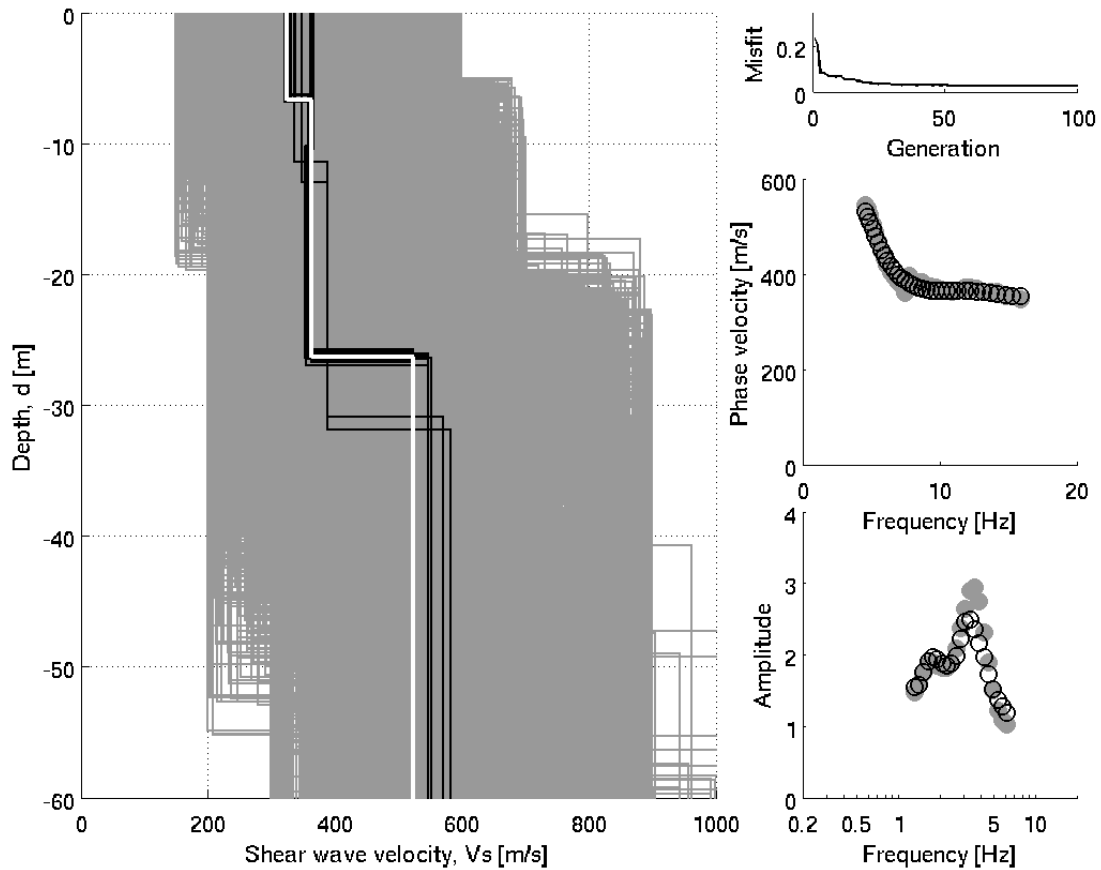


Figure 17: Shear-wave velocity models modeled during the inversion procedure (left panel): tested models (grey lines), the minimum cost model (white line) and models lying inside the minimum cost + 10% range (black lines); the generation values versus misfit (right-upper panel); the fitting of experimental data (grey circles) and empirical values relative to the minimum cost model (white circles) relevant to the dispersion curve (right-central panel) and to HVSr (right-bottom panel).

Table 5: Best-fit shear-wave velocity model

From [m]	To [m]	Thickness [m]	V_s [m/s]
0	6.7	6.7	325
6.7	26	19.3	363
26	-	-	524



B3. CONCLUSIONS

As evinced from results of geophysical investigations carried out by INGV Working Group, we can attribute to the alluvial deposits of Ancient Fluvial Formation V_s values between 325 and 363 m/s and to the gravels of l^2 V_s value of 524 m/s , compatible with EC8 class assigned at the site according to geological evidences.

According to the current Italian seismic code (NTC18), if the bedrock ($V_s > 800$ m/s) is more than 30 m in depth, the equivalent velocity ($V_{s,eq}$) is equal to the $V_{s,30}$. From Figure 17, the velocity of 800 m/s is reached for an unknown depth, well below the depth of 30 m .

Therefore, in this case, both $V_{s,eq}$ and $V_{s,30}$ are equal to 368 m/s . Of consequence, IT.NVG site is classified in the soil category B, for both the NTC18 and EC8 seismic codes (Table 6).

Table 6: $V_{s,eq}, V_{s,30}$ and soil classes

$V_{s,eq} = V_{s,30}$ [m/s]	Soil class (NTC18)	Soil class (EC8)
368	B	B

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INGV contributes, within the limits of its skills, to the evaluation of seismic and volcanic hazard in the Country, according to the mode agreed in the ten-year program between INGV and DPC February 2, 2012 (Prot. INGV 2052 of 27/2/2012), and to the activities planned as part of the National Civil Protection System. In particular, this document¹ has informative purposes concerning the observations and the data collected from the monitoring and observational networks managed by INGV. INGV provides scientific information using the best scientific knowledge available at the time of the drafting of the documents produced; however, due to the complexity of natural phenomena in question, nothing can be blamed to INGV about the possible incompleteness and uncertainty of the reported data.

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L'INGV concorre, nei limiti delle proprie competenze inerenti la valutazione della Pericolosità sismica e vulcanica nel territorio nazionale e secondo le modalità concordate dall'Accordo di programma decennale stipulato tra lo stesso INGV e il DPC in data 2 febbraio 2012 (Prot. INGV 2052 del 27/2/2012), alle attività previste nell'ambito del Sistema Nazionale di Protezione Civile. In particolare, questo documento¹ ha finalità informative circa le osservazioni e i dati acquisiti dalle Reti di monitoraggio e osservative gestite dall'INGV. L'INGV fornisce informazioni scientifiche utilizzando le migliori conoscenze scientifiche disponibili al momento della stesura dei documenti prodotti; tuttavia, in conseguenza della complessità dei fenomeni naturali in oggetto, nulla può essere imputato all'INGV circa l'eventuale incompletezza ed incertezza dei dati riportati.

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