ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IV.CNCS – Concesio (BS)

Report di caratterizzazione di sito presso la stazione sismica IV.CNCS – Concesio (BS)

Working Group **Geology:** Paolo MANGANELLO, Sara LOVATI **Geophysics**: Rodolfo PUGLIA, Giulio BRUNELLI, Alessio LORENZETTI, Sara LOVATI, Paolo MANGANELLO, Marco MASSA	Date: December 2021
Subject: **Final report illustrating the site characterization for seismic station IV.CNCS**	

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" (2021). Site characterization report at the seismic station *IV.CNCS – Concesio (BS).* http://hdl.handle.net/2122/15017

INDEX

Introduction 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 12

B. V_S profile 13-22

- **1.** Geophysical Investigations 13
- **2.** Seismic Velocity Model 20
- **3.** Conclusions 20

Acknowledgements 22

References 23

Disclaimer and limits of use of information 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 IV.CNCS (Concesio).

Location and coordinates are reported in Table 1.

Table 1

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IV.CNCS	Concesio (BS)	45.6060 *	10.2154 *	212 **
ADDRESS	Via Alcide De Gasperi, 5, 25062 Concesio (BS), Italy			

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

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 ≤ 15°	T1	Valley centre (VC)

Table 3

Geological map	Source	Scale
IV.CNCS	Geological Map of Italy, CARG Project - sheet 99 (Iseo)	1:50.000

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 (Geological Map of Italy 1:50.000, sheet 99) *original*		**LITHOLOGICAL UNITS** (Amanti *et al.*, 2008) *deduced*		**LITHOTECHNICAL UNITS** (MZS) *deduced*	
code	**description**	**code**	**description**	**code**	**description**
VC	Mella River Supersynthem (fluvial deposits)	B3	Gravel	GP tf	Poorly graded gravels (river terrace)
POI	Po Synthem (alluvial deposits)	B3	Gravel	GP tf	Poorly graded gravels (river terrace)
SZ	Sarezzo Supersynthem (alluvial fan deposits)	B3	Gravel	GP ca	Poorly graded gravels (alluvial fan)
DB	Dosso Baione Supersynthem (slope and alluvial fan deposits)	B3	Gravel	GP ec	Poorly graded gravels (slope deposits)
FME	Medoloidi Limestones Formation	A1-A3	Limestone, marly limestone	SFALS	Alternance of lithotypes, layered fractured/weathered

A2. GEOLOGICAL MAP

In Figure 1 Geological Map is reported in a 1 $km \times 1$ km square around the station.

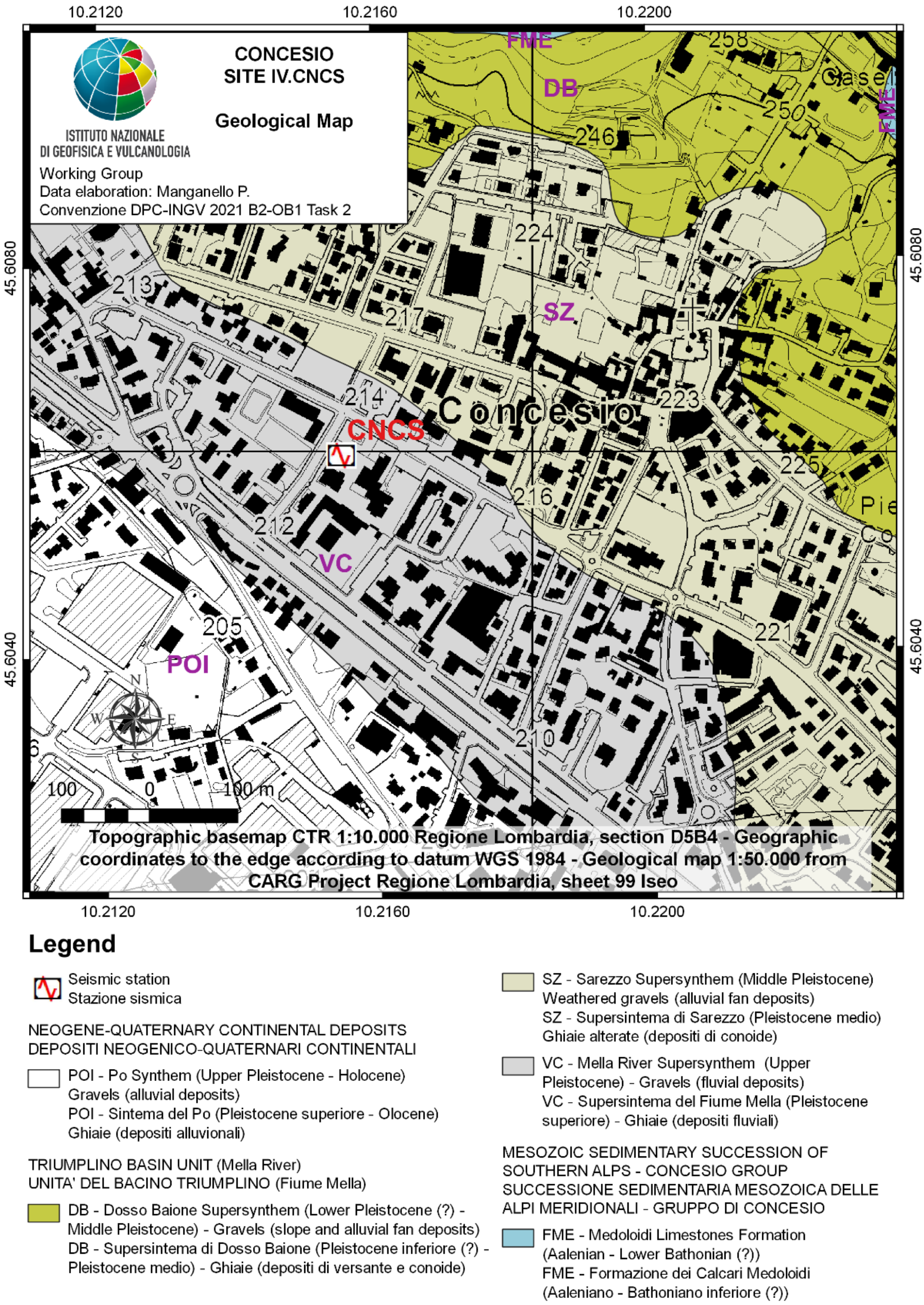

Figure 1: Geological map of seismic station IV.CNCS. Scale 1:5.000. Geological units come from the Geological Map of Italy 1:50.000, sheet 99 Iseo.

A3. LITHOLOGICAL MAP

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

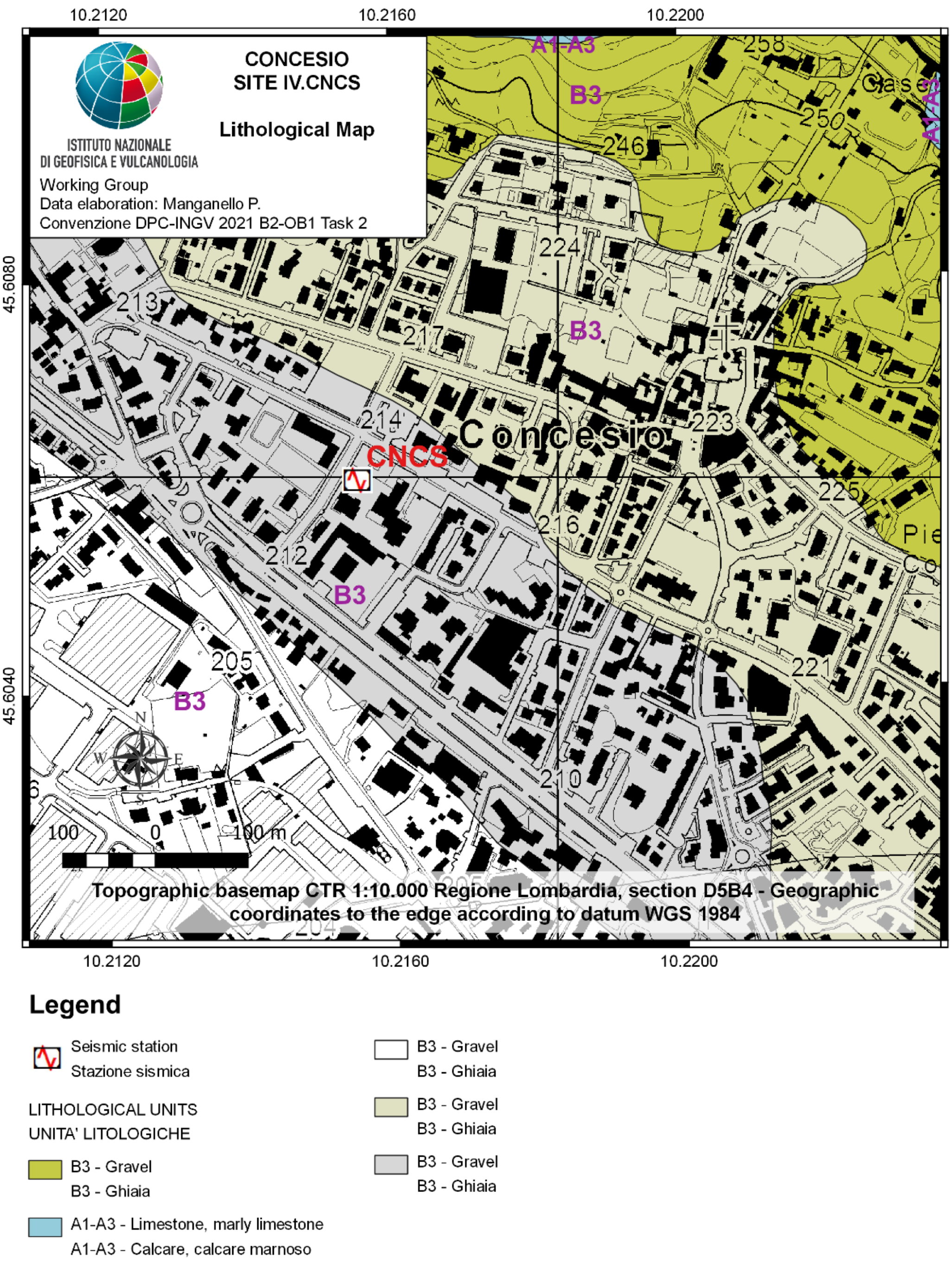

Figure 2: Lithological map of the seismic station IV.CNCS. Scale 1:5.000. The codes of the lithological units are assigned according to the nomenclature of the Lithological map of Italy ISPRA 1:100.000 (Amanti *et al.*, 2008).

A4. LITHOTECHNICAL MAP

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

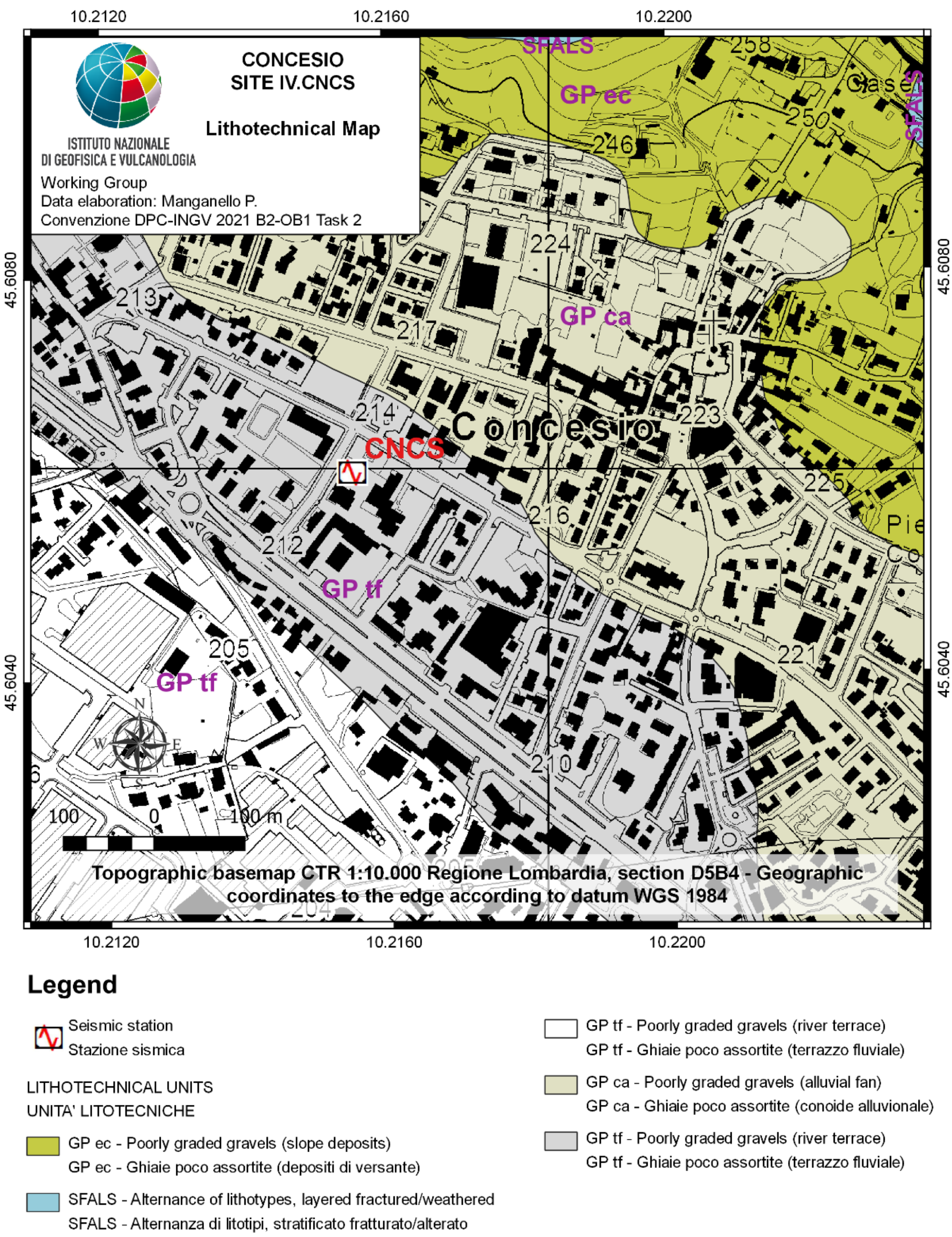

Figure 3: Lithotechnical map of the seismic station IV.CNCS. Scale 1:5.000. The lithotechnical units are deduced according to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).

A5. SURVEY MAP

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

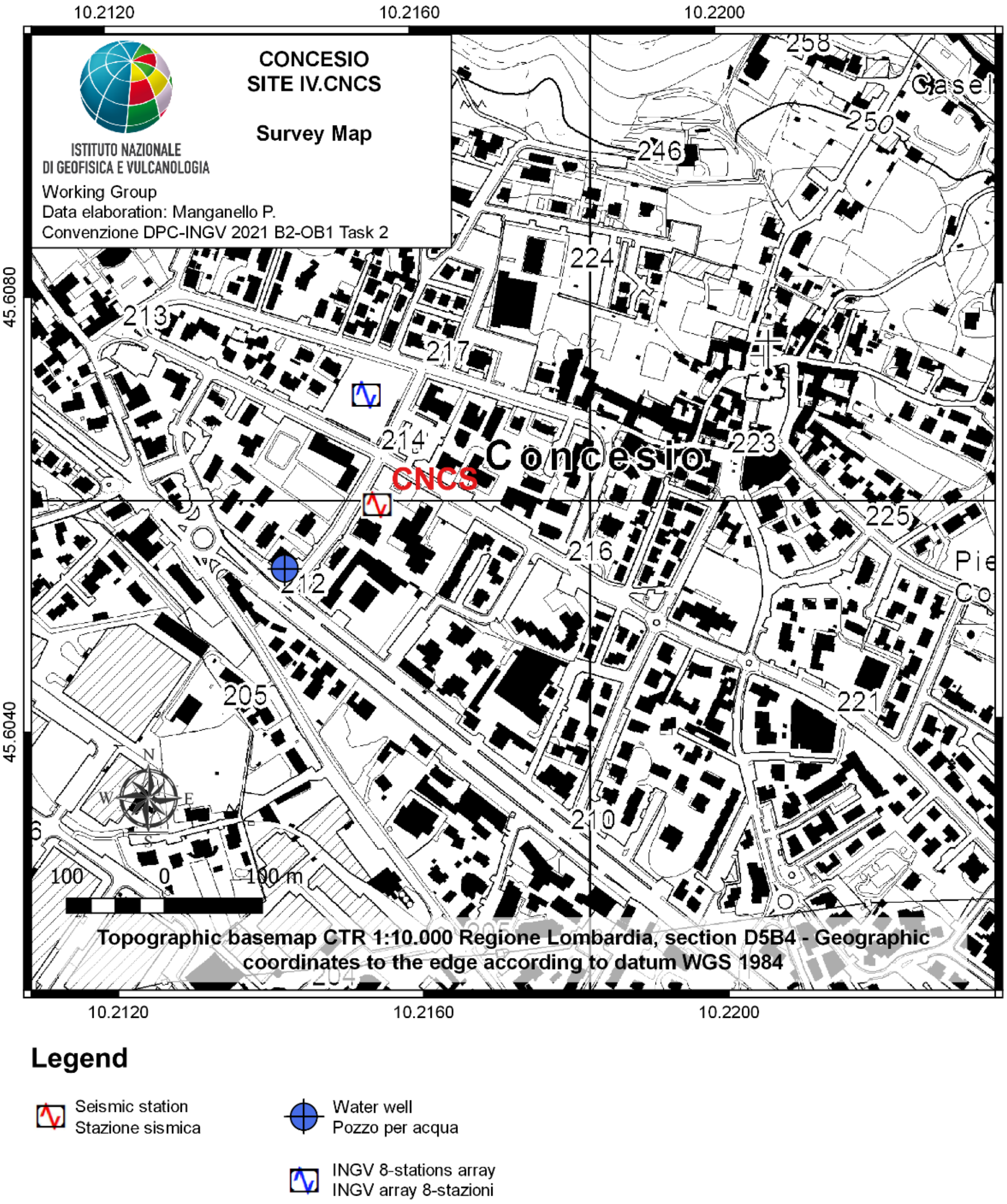

Figure 4: Map of the surveys in the surroundings of the station IV.CNCS. Scale 1:5.000.

A6. GEOLOGICAL MODEL

6.1 General description

The IV.CNCS seismic station is installed in the town centre of Concesio Municipality (Brescia Province), which is situated in the lower Trompia Valley and crossed by the Mella River.
From a geological point of view, the studied area is related to the evolution of the Lombardian Basin, which represents a structurally complex area of the Mesozoic South-Alpine rifted margin, between the Lake Maggiore fault and the Ballino - Garda fault. After the Liassic extension the Lombardian Basin consisted of several half-grabens delimited by normal faults. When the tectonic activity ended at the beginning of the Toarcian, turbiditic deposition was replaced by thick pelagic sedimentation across the entire Lombardian basin. The Cenozoic Alpine collisional history is primarily responsible for the structural setting of this area (Bersezio *et al.*, 1996; Bertotti *et al.*, 1993; Bertotti, 2001; Cassinis *et al.*, 2000).
In particular the area of interest is located in the Triumplino - Sebino Basin, which represents the eastern part of the Lombardian Basin. One of the most important considerations on the Quaternary evolution of the Triumplino - Sebino Basin is the lack of valley glaciers and the prevalence of gravity and fluvial processes.

6.2 Geological section

In the surroundings of IV.CNCS seismic station, stratigraphic data are represented by a water well (60 *m* depth).
The collected data allow to draw the SSW - NNE oriented geological section A - A', which highlights the geological and structural setting of the studied area. The trace with the location of the geological section is reported as a blue line in the geological map (Figure 5 upper left).

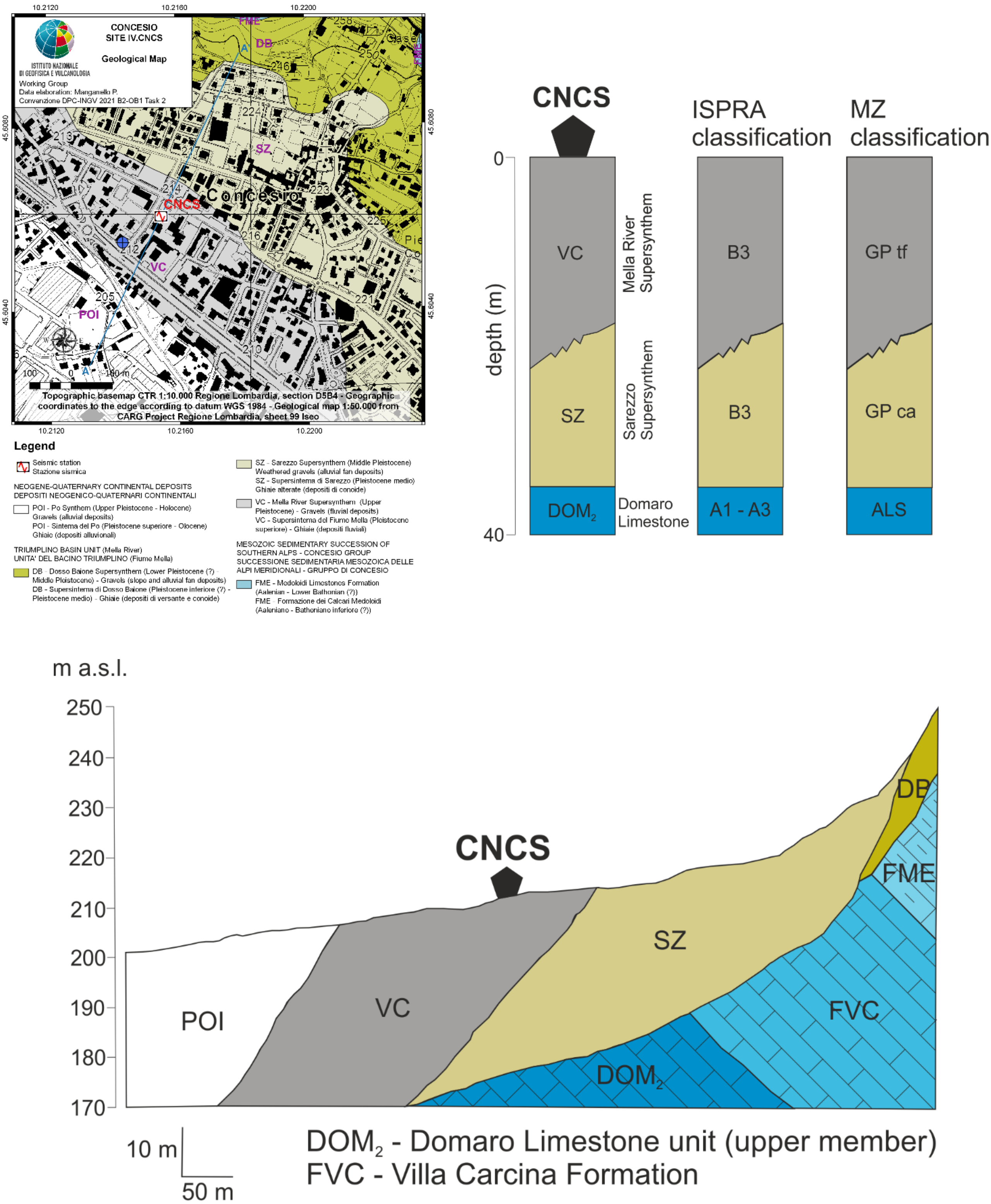

Figure 5: Upper left: Geological map of the study area where is installed IV.CNCS seismic station. Upper right: Geological section. Bottom: Subsoil model for the site.

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 40 *m* on the basis of geological information (Fig. 5 bottom).

The stratigraphic succession starts with gravels of the Mella River Supersynthem (Upper Pleistocene), which belongs to the Triumplino Basin Units. Below an erosional surface separates the Mella River Supersynthem from the Sarezzo Supersynthem (Middle Pleistocene - Triumplino Basin Units), which is characterized by weathered gravels (alluvial fan deposits). At a depth of about 35 *m* there is the upper member of Domaro Limestone unit (DOM_2), which belongs to the Medolo Group (Mesozoic sedimentary succession of Southern Alps).

B. V_S profile

B1. GEOPHYSICAL INVESTIGATIONS

Geophysical measurements executed nearby the station CNCS of the network IV (INGV, 2006) 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 curve of surface waves. This curve is 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 IV.CNCS (Latitude 45.6060, Longitude 10.2154 WGS84) installed in the basement of the municipality of Concesio (BS).

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).

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 CNS5.

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

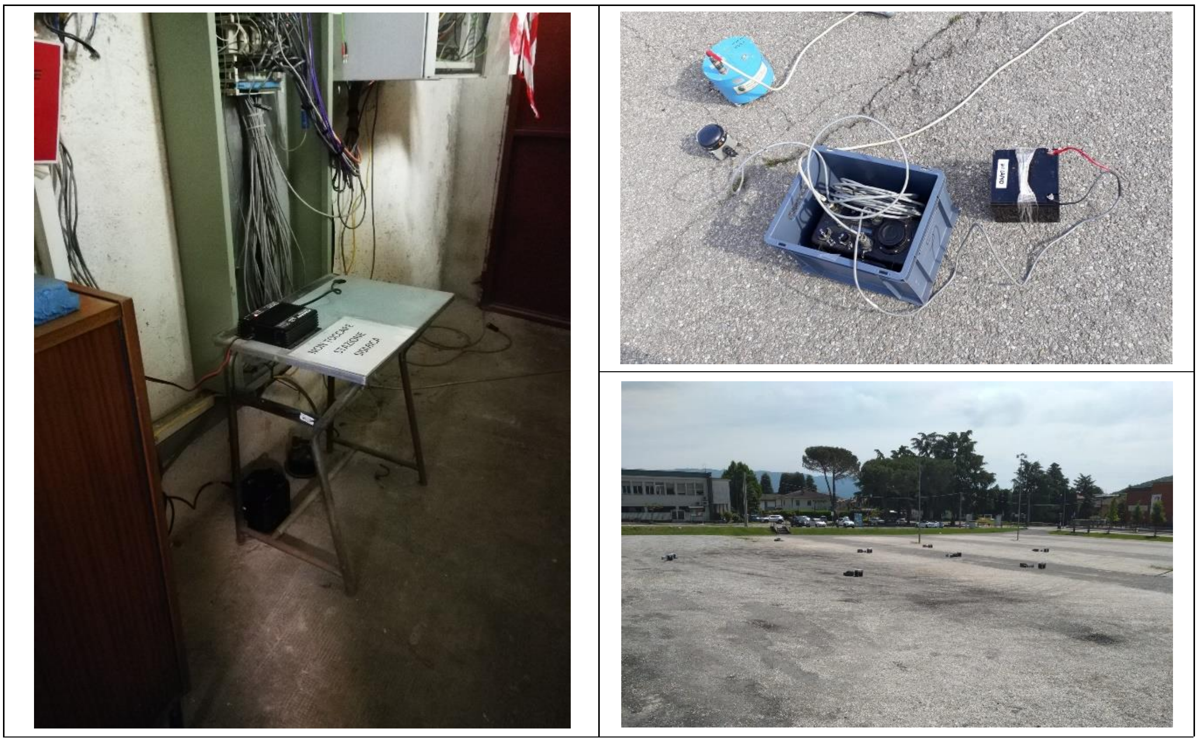

Figure 7: Left: IV.CNCS accelerometric station installed in the basement of the municipality of Concesio (BS). Upper right: single station ambient noise measurement. Bottom right: 2D passive ambient noise array installed close to the IV.CNCS station.

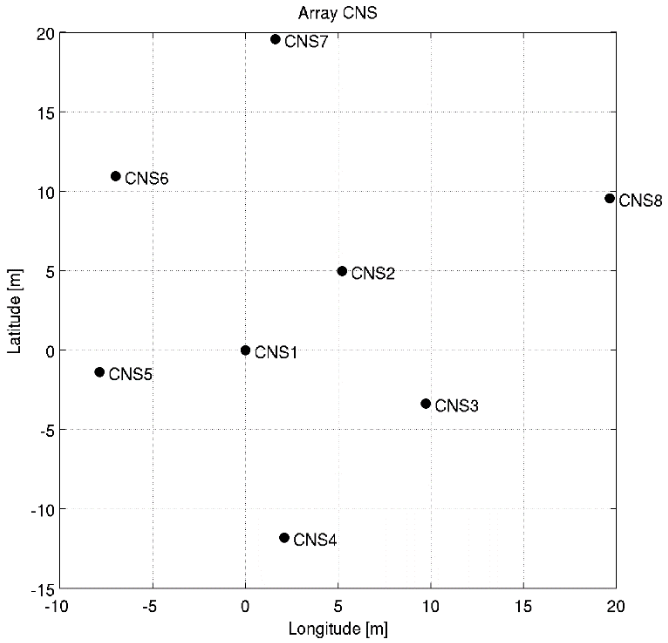

Figure 8: Array geometry.

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.

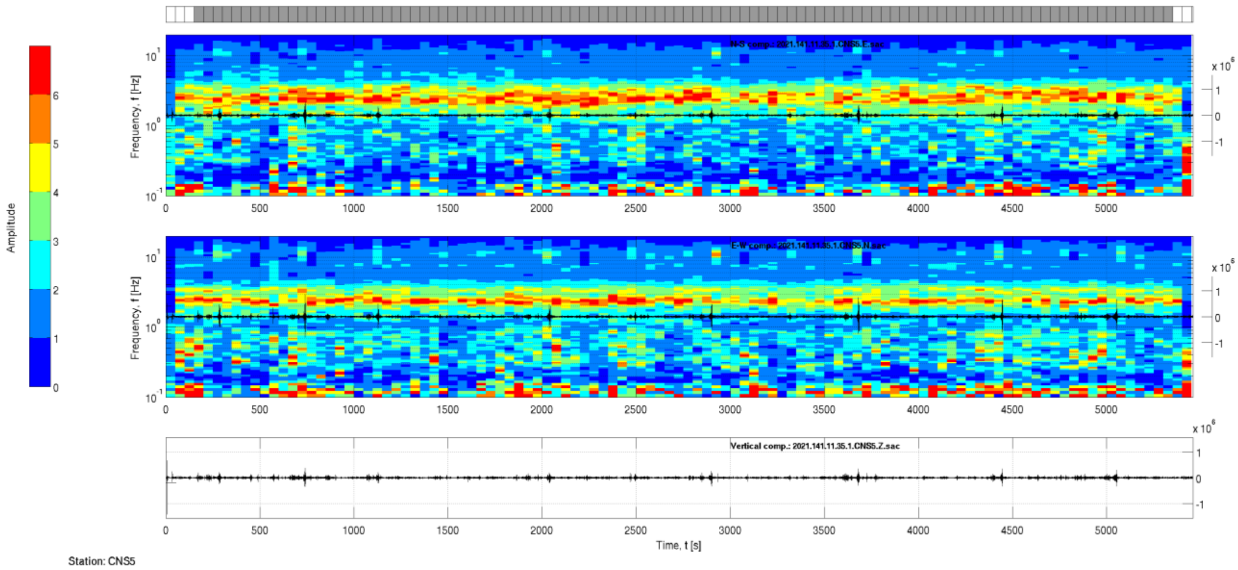

Figure 9: HVSR versus time (top and central panel for the NS and EW component, respectively) and corresponding time-histories.

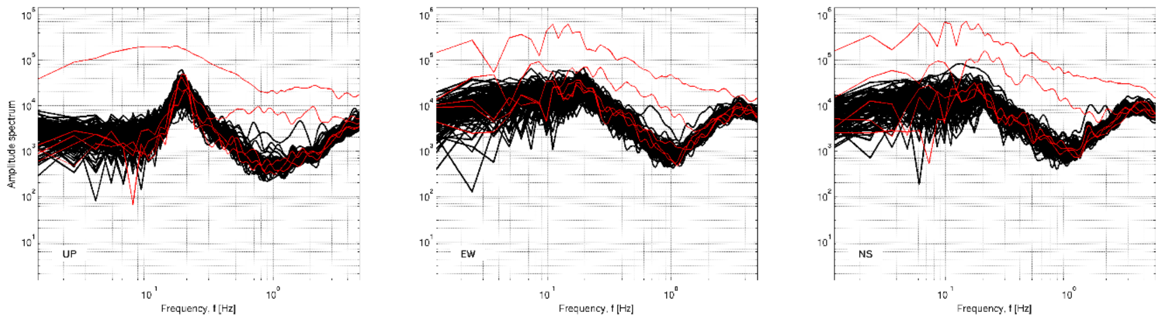

Figure 10: Fourier spectra for each noise window (left: Vertical, center: EW, right: NS); red spectra are excluded from HVSR analysis.

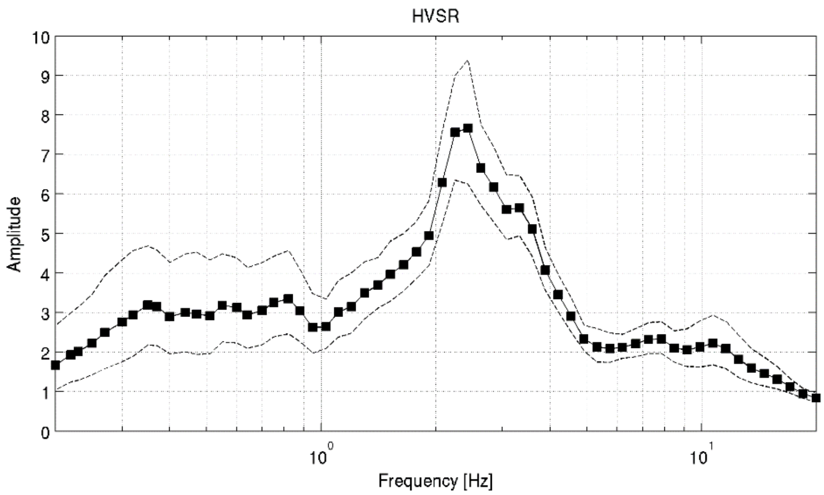

Figure 11: HVSR representative for the array. Dashed lines represent +/- one standard deviation.

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 60 synchronized signal windows, each 60 *s* long, extracted from recordings within the UTC date-time interval 2021-05-21 11:50:00 – 2021-05-21 12:50:00, 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 to check 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 between the Rayleigh wave dispersion curves estimated by both ESAC and F-K approaches, in particular above 6 *Hz* between “ESAC” and “F-K (MLM)”. As expected, due to the array geometry, below this threshold the F-K analysis provides larger phase velocities.

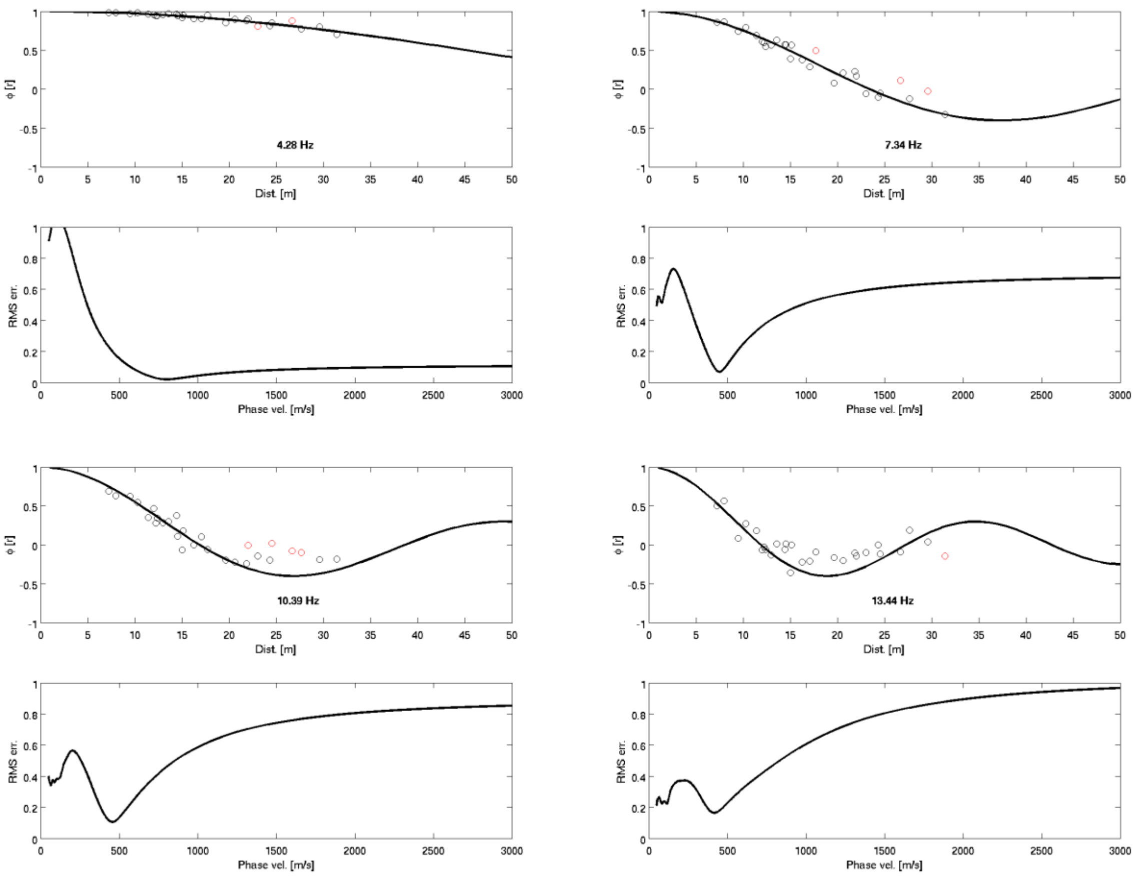

Figure 12: Experimental space-correlation function values versus distance (circles) for different frequencies. The red circles indicate values that are discarded. The black lines depict the estimated space-correlation function values for the phase velocity that furnishes the best fit to the data. The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

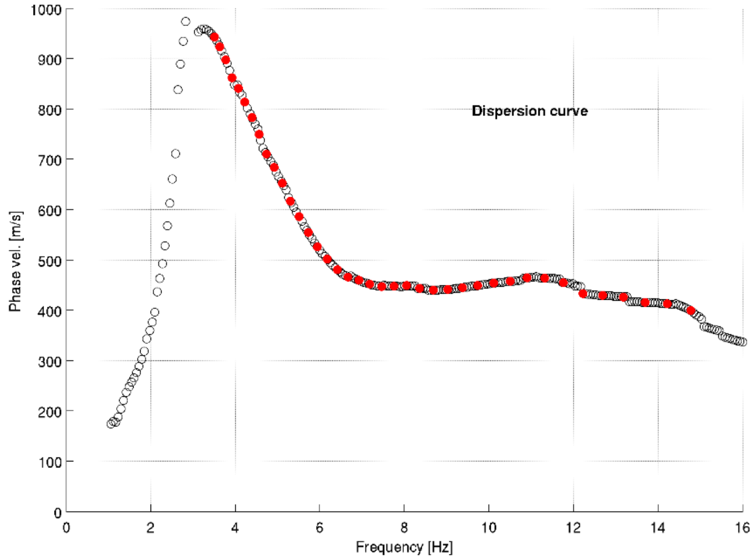

Figure 13: Rayleigh-wave dispersion curve from ESAC; red-filled circles represent values potentially used for inversions.

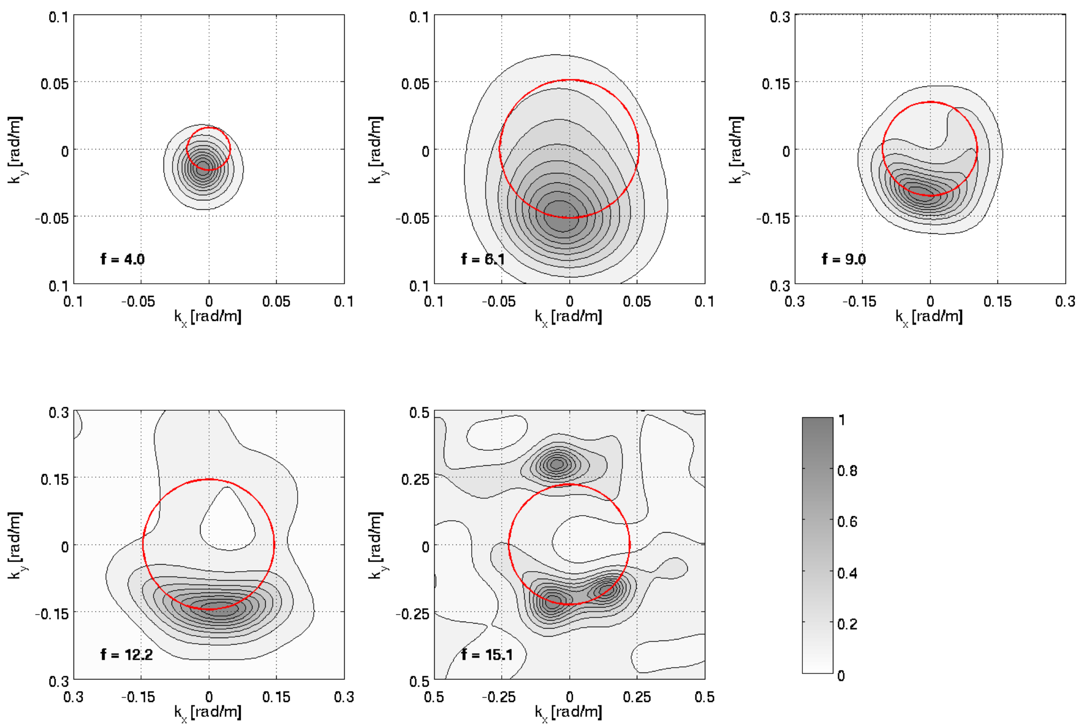

Figure 14: F-K power density function (Maximum-Likelihood Method) at selected frequencies.

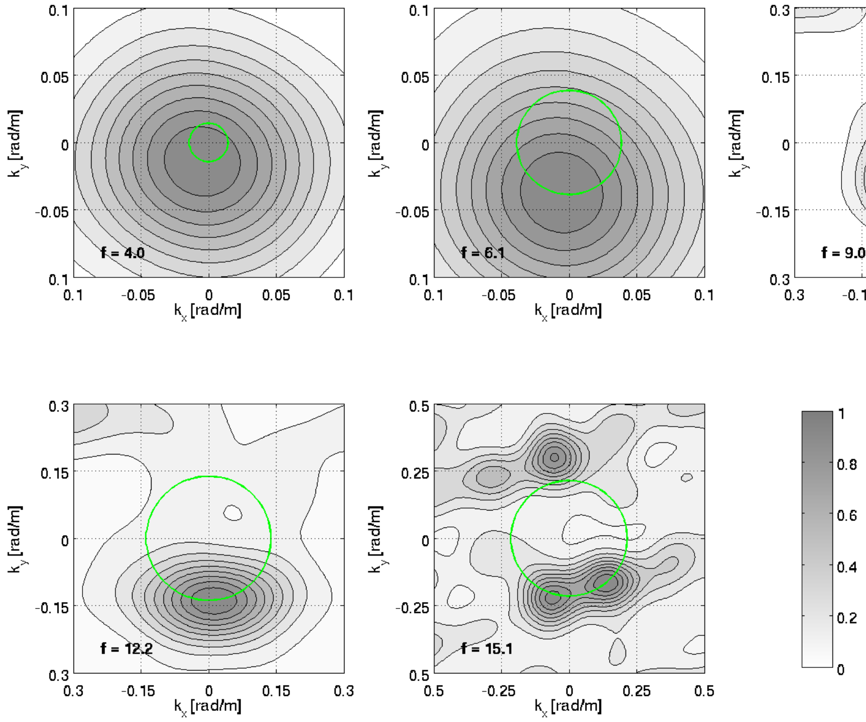

Figure 15: F-K power density function (Beam-Forming) at selected frequencies.

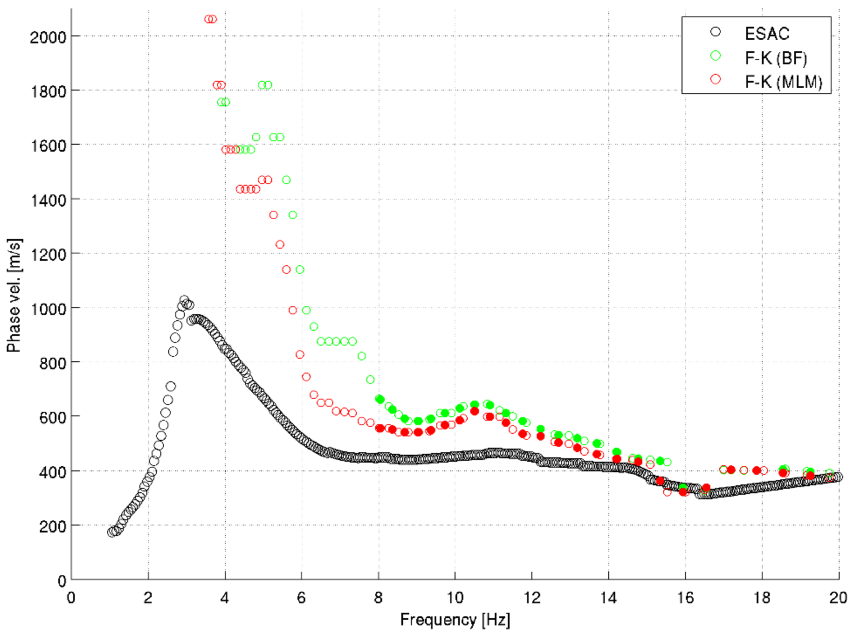

Figure 16: Comparison of experimental phase velocity estimated by the ESAC and the F-K (for both Beam-Forming and Maximum-Likelihood Method) methods; filled circles represent values potentially used for inversions.

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 3.5-15 *Hz*. The experimental HVSR is used between about 1 and 6 *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 5-75 *m* is very well constrained. Table 5 reports the minimum-cost shear-wave velocity model.

B3. CONCLUSIONS

As evinced from results of geophysical investigations carried out by INGV Working Group, we can attribute to the units of Triumplino Basin (Mella River Supersynthem and Sarezzo Supersynthem) V_S values between 305 and 425 m/s, compatible with EC8 class assigned at the site according to geological evidences. The V_S value of 789 m/s can be attributed to the upper member of Domaro Limestone unit (Medolo Group).

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 386 *m/s*. Of consequence, IV.CNCS site is classified in the soil category B, for both the NTC18 and EC8 seismic codes (Table 6).

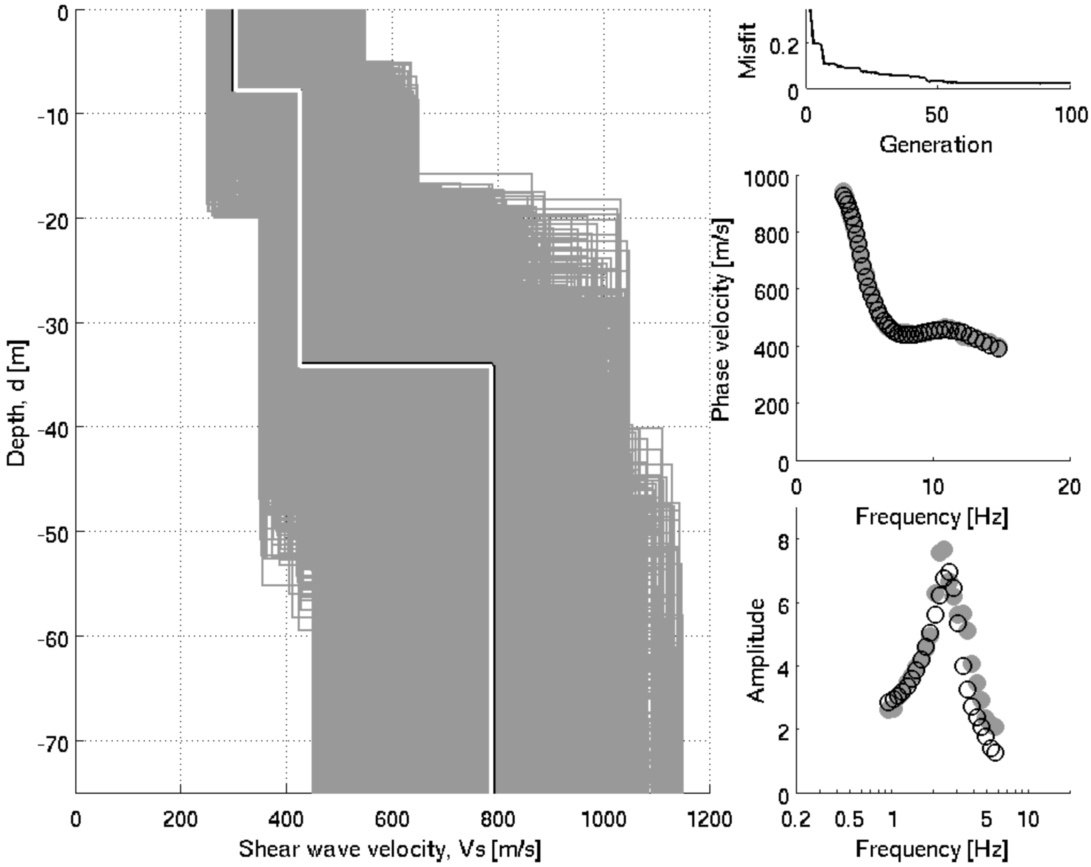

Figure 17: Shear-wave velocity models modeled during the inversion procedure (left panel): tested models (grey lines), the minimum cost model (white line) and models lying inside the minimum cost + 10% range (black lines); the generation values versus misfit (right-upper panel); the fitting of experimental 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	7.8	7.8	305
7.8	34	26.2	425
34	-	-	789

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)
386	B	B

ACKNOWLEDGEMENTS

Authors wish to thank Stefano Parolai, Paolo Bernardi and Ilaria Dreossi (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS), for providing us the software “joinv6”, which has been adopted as inversion procedure to estimate the shear-wave velocity model, and for the precious guide in its usage.

REFERENCES

Aki K. (1957). "Space and time spectra of stationary stochastic waves, with special reference to microtremors", Bulletin of the Earthquake Research Institute, 35, pp. 415–456.

Amanti M., Battaglini L., Campo V., Cipolloni C., Congi M. P., Conte G., Delogu D., Ventura R., Zonetti C. (2008). "The Lithological map of Italy at 1:100.000 scale: An example of re-use of an existing paper geological map", 33rd International Geological Conference, IEI02310L – 6-14th August, Oslo (Norway).

Arai H. and Tokimatsu K. (2004). "S-wave velocity profiling by inversion of microtremor H/V spectrum", Bulletin of the Seismological Society of America, 94, pp. 53–63.

Bersezio R., Felletti F., Lozar F., Ruggeri M. (1996). "The Concesio Formation of the Lombardian Rifted Basin (Southern Alps, Italy). Stratigraphy of a Jurassic Calcareous Turbidite Unit", Rivista Italiana di Paleontologia e Stratigrafia, Vol. 102, No. 1, pp. 49-64.

Bertotti G., Picotti V., Bernoulli D., Castellarin A. (1993). "From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the Early Cretaceous", Sedimentary Geology, Elsevier Science Publishers B.V., 86 (1-2), pp. 53-76.

Bertotti G. (2001). "Subsidence, deformation, thermal and mechanical evolution of the Mesozoic South Alpine rifted margin: an analogue for Atlantic-type margins", in "Non-Volcanic Rifting of Continental Margins: A Comparison of Evidence from Land and Sea", Geological Society, London, Special Publications, 187, pp. 125-141.

Capon J. (1969). "High-resolution frequency-wavenumber spectrum analysis", Proceedings of the IEEE, 57, pp. 1408–1418.

Cassinis G., Calabrò R., Perotti C. R., Schirolli P. (2000). "Tettonica e Sedimentazione: cenni introduttivi ed esempi nelle Successioni Paleozoiche e Mesozoiche Bresciane", Le Scienze della Terra: una chiave di lettura del mondo in cui viviamo, Ist. Lombardo, Incontro di Studio n. 18, pp. 61-90.

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.

Foti S., Parolai S., Albarello D., *et al.* (2009). Deliverable 6: Application of surface wave methods for seismic site characterization. DPC-INGV S4 Project 2007-2009 (http://esse4.mi.ingv.it) – last accessed in June 2021 at http://esse4.mi.ingv.it/files/images/stories/deliverable_d6.pdf

Foti S., Parolai S., Albarello D., *et al.* (2010). Deliverable 7: Application of surface wave methods for seismic site characterization of ITACA stations. DPC-INGV S4 Project 2007-2009 (http://esse4.mi.ingv.it) – last accessed in June 2021 at http://esse4.mi.ingv.it/files/images/stories/deliverable_d7.pdf

Giustiniani M., Tinivella U., Parolai S., Donda F., Brancolini G., Volpi V. (2020). "Integrated Geophysical Analyses of Shallow-Water Seismic Imaging With Scholte Wave Inversion: The Northern Adriatic Sea Case Study", Frontiers in Earth Science, vol. 8, 587898 https://www.frontiersin.org/article/10.3389/feart.2020.587898 doi:10.3389/feart.2020.587898

INGV Seismological Data Centre (2006). Rete Sismica Nazionale (RSN). Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy. https://doi.org/10.13127/SD/X0FXNH7QFY

ISPRA – Geological Survey of Italy – Geological Map of Italy 1:50.000 (CARG Project). Sheet 99 (Iseo) - https://www.isprambiente.gov.it/Media/carg/99_ISEO/Foglio.html.

Lacoss R.T., Kelly E.J. and Toksöz M.N. (1969). "Estimation of seismic noise structure using arrays", Geophysics, 34, pp. 21–38.

NTC 2018: 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).

Ohori M., Nobata A. and Wakamatsu K. (2002). "A comparison of ESAC and FK methods of estimating phase velocity using arbitrarily shaped microtremor analysis", Bulletin of the Seismological Society of America, 92, pp. 2323–2332.

Okada H. (2003). "The Microtremor Survey Method", SEG.

Parolai S., Picozzi M., Richwalski S.M. and Milkereit C. (2005). "Joint inversion of phase velocity dispersion and H/V ratio curves from seismic noise recordings using a genetic algorithm, considering higher modes", Geophysical Research Letters, 32, L01303. doi:10.1029/2004GL021115

Parolai S., Richwalski S.M., Milkereit C. and Fäh D. (2006). "S-wave velocity profile for earthquake engineering purposes for the Cologne area (Germany)", Bulletin of the Earthquake Research Institute, 4, pp. 65–94. doi:10.1007/s10518-005-5758-2

Regione Lombardia - Geoportale - https://www.geoportale.regione.lombardia.it.

Technical Commission SM, 2015 – Microzonazione sismica. Standard di rappresentazione e archiviazione informatica, Versione 4.0b (Commissione tecnica inter-istituzionale per la MS nominata con DPCM 21 aprile 2011).

Tokimatsu K., Tamura S. and Kojima H. (1992). "Effects of multiple modes on Rayleigh wave dispersion characteristics", Journal of Geotechnical Engineering, 118, pp. 1529–1543.

Wang R. (1999). "A simple orthonormalization method for stable and efficient computation of Green's functions", Bulletin of the Seismological Society of America, 89, pp. 733–741.

Yamanaka H. and Ishida H. (1996). "Application of generic algorithms to an inversion of surface-wave dispersion data", Bulletin of the Seismological Society of America, 86, pp. 436–444.

[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)"