ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IT.CSP – Castel San Pietro Terme (BO)

Report di caratterizzazione di sito presso la stazione sismica IT.CSP – Castel San Pietro Terme (BO)

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Subject: **Final report illustrating the site characterization for seismic station IT.CSP**	

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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 IT.CSP (Castel San Pietro Terme).

Location and coordinates are reported in Table 1.

Table 1

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IT.CSP	Castel San Pietro Terme	44.378487 *	11.580113 *	88 **
ADDRESS	SP21, 40024 Castel San Pietro Terme (BO), Italy			

* Coordinates from ITACA (Nov. 2020) ** Elevation from CTR 5k Regione Emilia-Romagna

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.

Topography	Description	Topography Class	Morphology Class	EC8 Class
	Flat surfaces, isolated slope and reliefs with slope i ≤ 15°	T1	VE	C

Table 2

*Reference table from ITACA (Nov. 2020)

Table 3

Geological map	Source	Scale
IT.CSP	Geological map of Italy sheets *088* (Imola)	1:100.000
IT.CSP	Geological map of Italy sheet *238* (Castel San Pietro Terme)	1:50.000
IT.CSP	Geological map from Emilia Romagna Region database	1:10.000
IT.CSP	Geological and technical maps – Seismic Microzonation level 3	1:5.000

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 (10k Regione Emilia Romagna) *original*		**LITHOLOGICAL UNITS** (Amanti et al., 2008) *deduced*		**LITHOTECHNICAL UNITS** (MZS) *original*	
code	**description**	**code**	**description**	**code**	**description**
AES8	Gravel, silt, sandy silt, sand	B4	Mixed clay sand gravel	GM	Mixture gravel sand silt

A2. GEOLOGICAL MAP

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

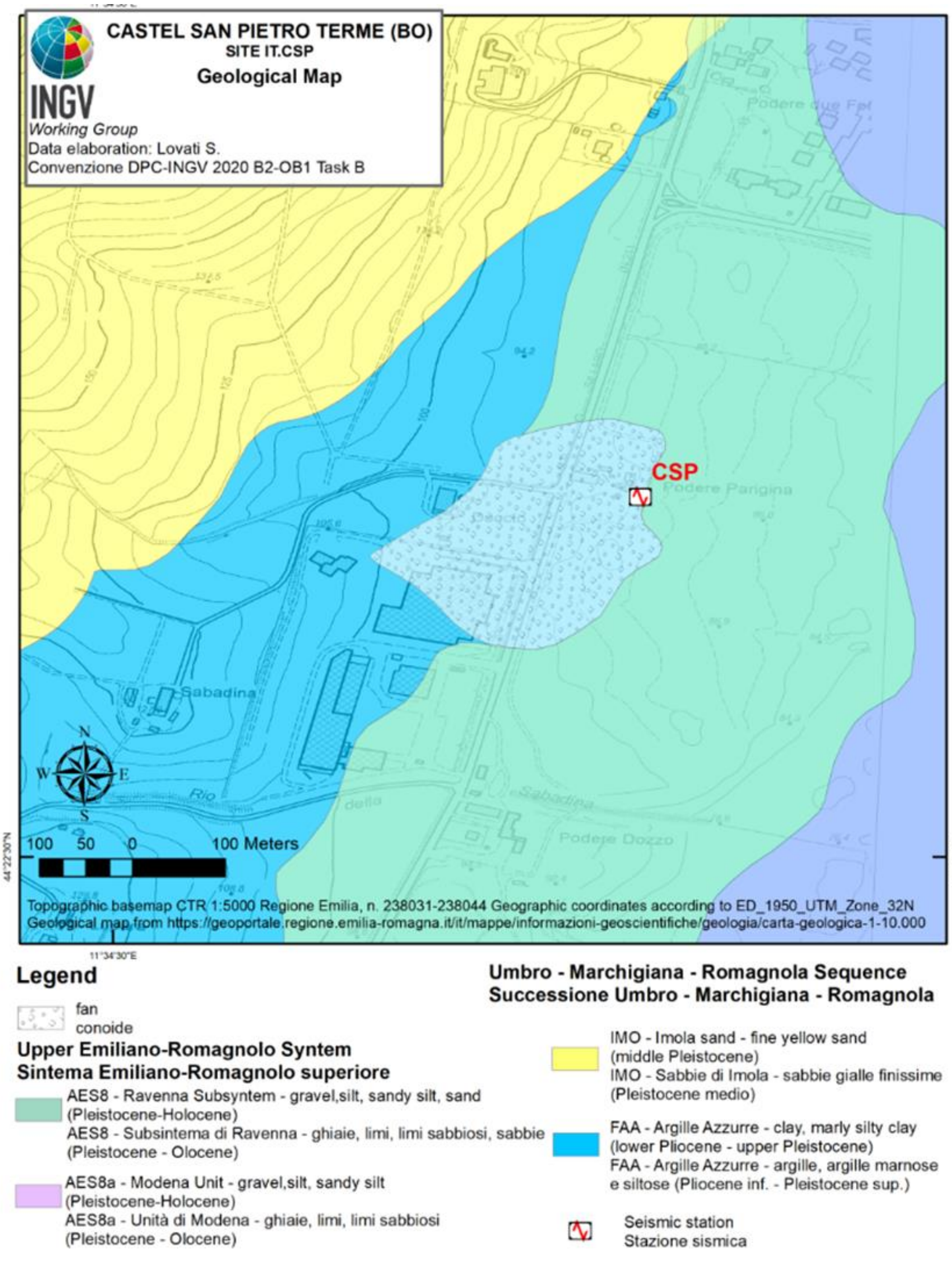

Figure 1: Geological map of seismic station IT.CSP. Scale 1:5.000. Geological units are established according to the nomenclature of geological map 1:10.000 of Emilia-Romagna Region.

A3. LITHOLOGICAL MAP

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

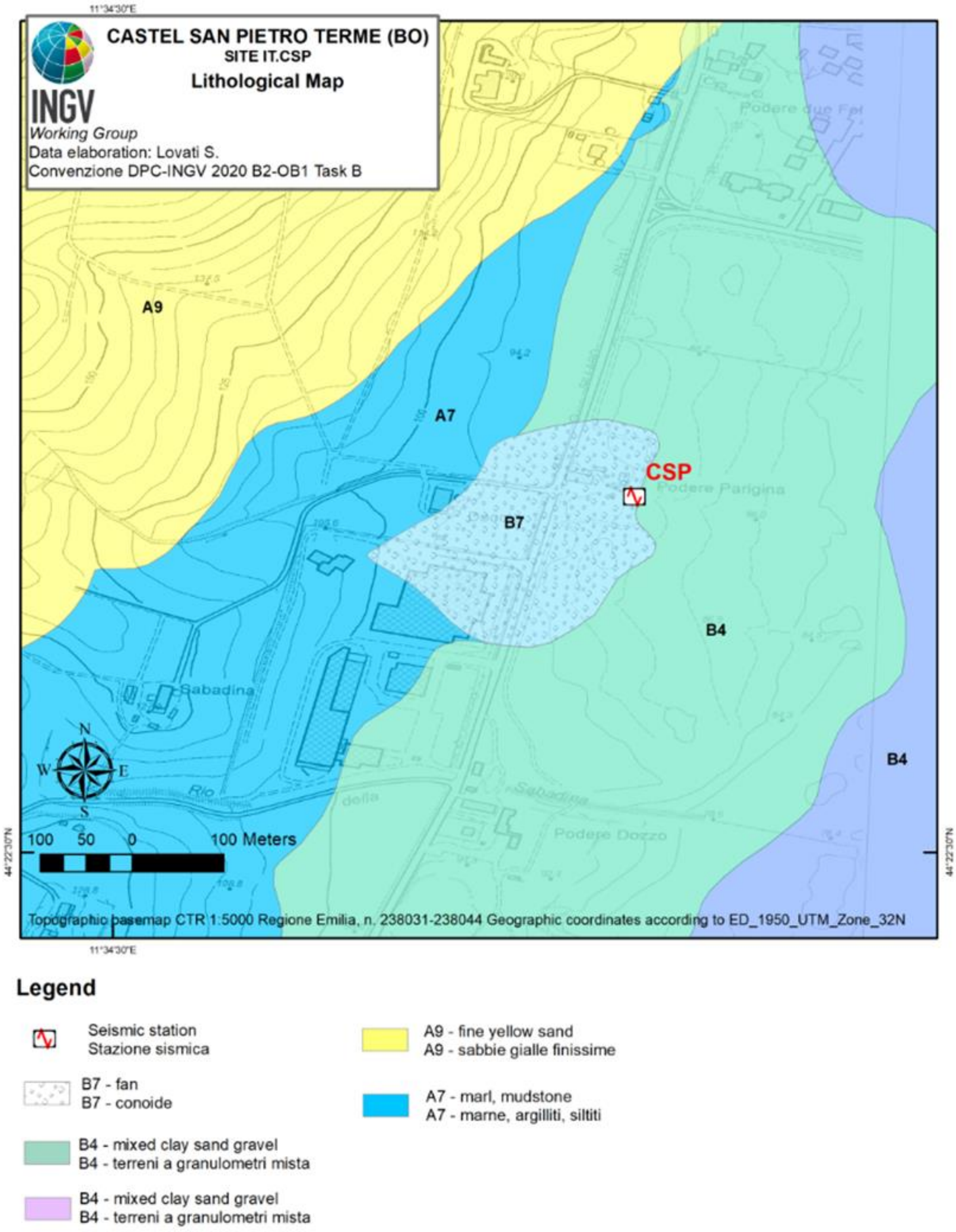

Figure 2: Lithological map of station IT.CSP. Scale 1:5.000. The codes of the lithological units are assigned according to the nomenclature of the Lithological map ISPRA 1: 100.000 (Amanti *et al.*, 2008).

A4. LITHOTECHNICAL MAP

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

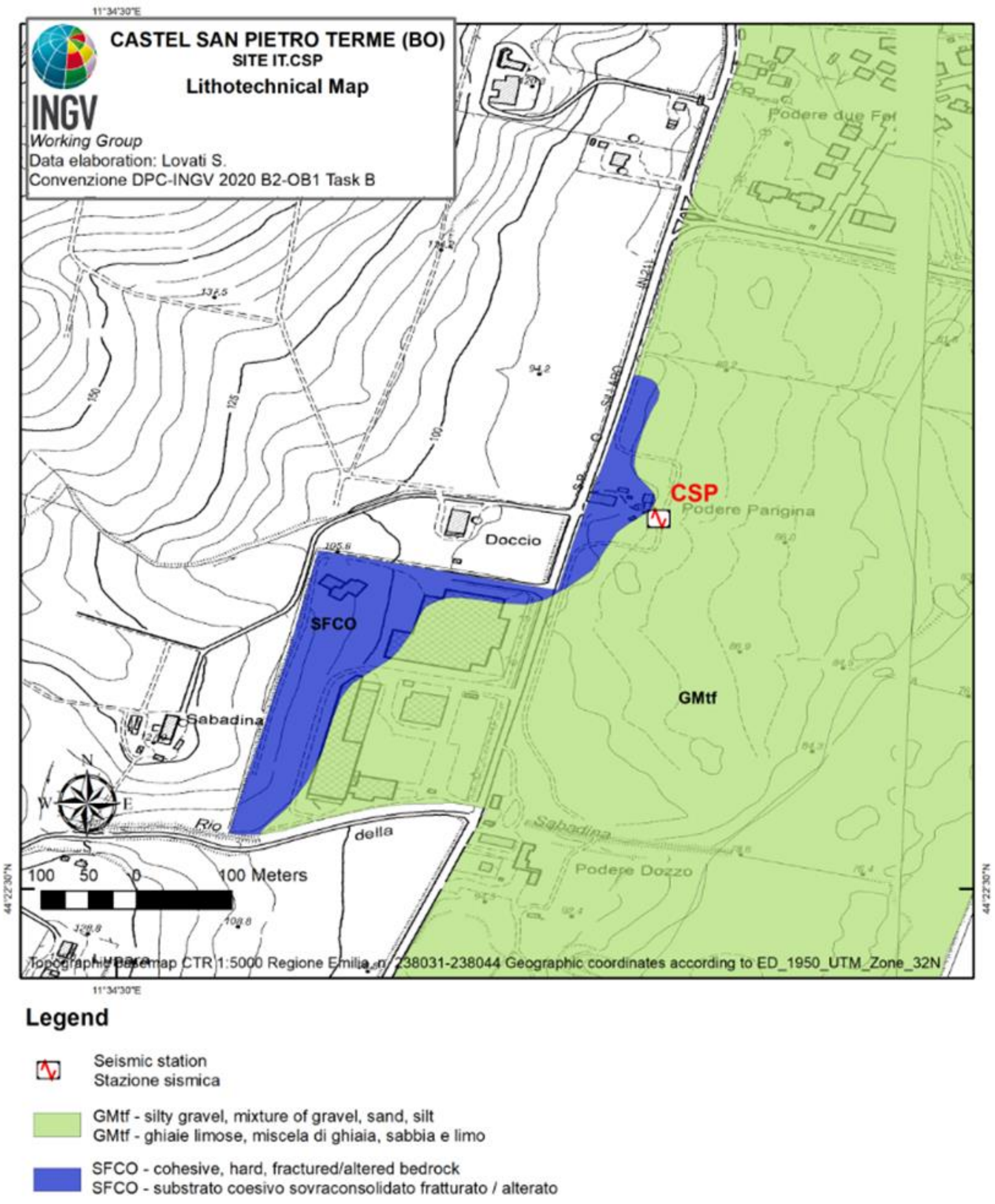

Figure 3: Lithotechnical map of the seismic station IT.CSP. Scale 1:5.000. The lithotechnical units are assigned according to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).

A5. SURVEY MAP

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

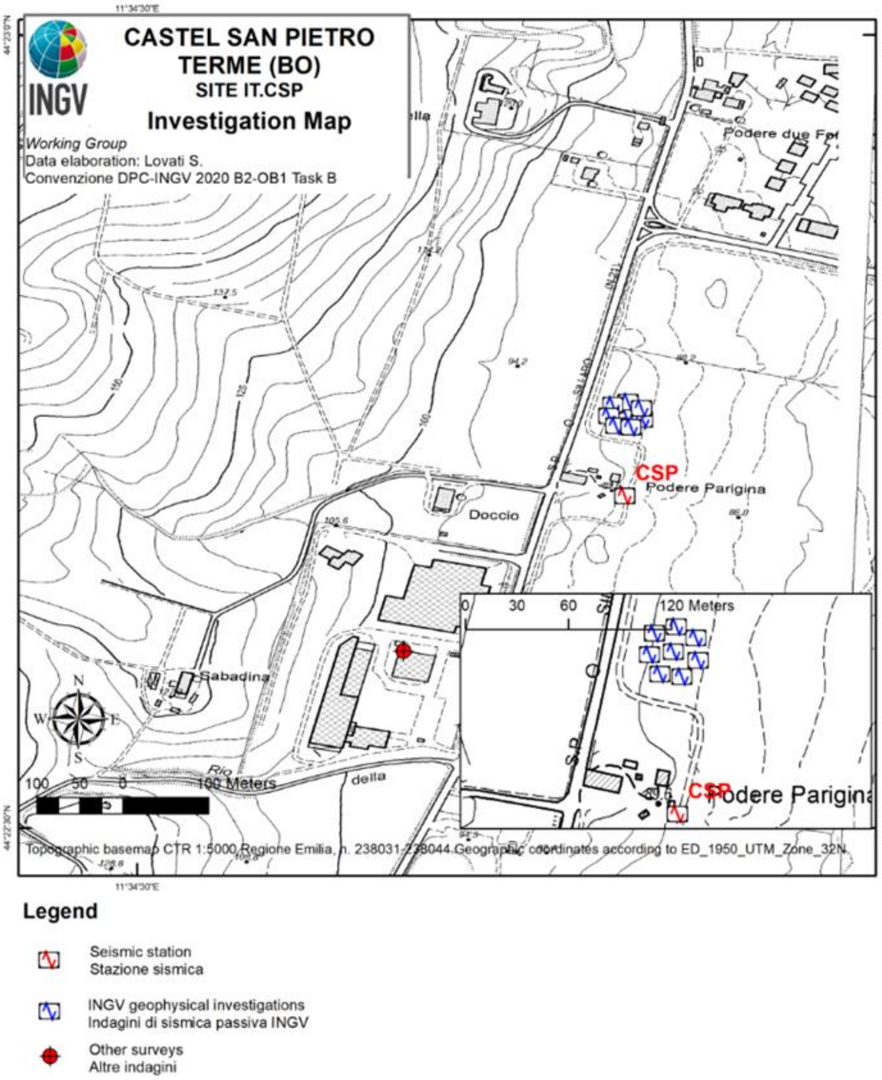

Figure 4: Map of the surveys in the surroundings of the station IT.CSP. Scale 1:5.000. The box at the bottom right contains a zoom of the area with the detail of the geophysical 8-stations array conducted by INGV Working Group for the seismic characterization of the site (Agreement DPC-INGV 2019-21, All. B2, WP1 - TASK 2, Velocity profile report IT.CSP).

A6. GEOLOGICAL MODEL

6.1 General description

The studied area is located in the east area of Castel San Pietro Terme Municipality, along the N-S street SP21, close to the Golf Club "Le Fonti".

Morphologically the territory is a plain landscape towards north, while, southern, to the border of the hills, where the substrate is clayey, the landscape is characterized by landslide and erosive processes that determinate landscape as *calanchi*, plain terraces above all along the main valleys.

In detail the study area is constituted of marine Plio-Pleistocenic sedimentary formations belonging to the Umbro-Marchigiana-Romagnola Sequence, Sabbie di Imola (fine yellow sands,/sandstone, middle Pleistocene) and Argille Azzurre (clay, marly silty clay, lower Pliocene-Pleistocene).

On the borders of hills and in the valleys these formations are covered in discordance by Pleistocenic-Holocenic continental fluvial deposits (AES8, Ravenna Subsynthem) constituted of a mixture of gravel, silt, sandy silt and locally sand. These deposits form morphological terraces along the rivers (Sillaro River).

From a structural point of view the territory around Castel San Pietro Terme Municipality is included in the system of the Northern Apennines, which is a mountain range formed by the superposition of "tectonic layers", structurally framed in the context of the accretionary prism model (Treves, 1984).

The genesis and evolution of the Apennine chain would have started at least from the Eocene, during the mesoalpine orogenic phase (AA.VV., 1992). In this period, the Ligurian succession were stacked on top of each other, to form a prism of accretion which, according to some authors, it should be considered a structural element of the alpine chain subsequently incorporated into the Apennine geological structure (Cerrina Ferroni *et al.*, 2004).

The frequent seismic activity that is found above all in the plain area, but also in the high Apennines, they are the direct and actual evidence that evolution of the chain has not yet ended. The main tectonic units that form the Northern Apennine accretionary prism (Treves,

1984) are Ligurian Units (Liguridi), Subligurian Units, Tuscan Units and Umbria-Romagna-Marche-Adriatic Units.

According to the model of the accretionary prism (Treves, 1984) the Ligurian Units overlap the Subligurian Units which are placed above the Tuscan Units and the Umbria-Romagna-Marche-Adriatic Units. This structural framework is further complicated by out of sequence tectonic overlaps and neotectonic extension faults.

The structural evolution of the Apennine chain continues as shown by the tectonic structures, that, with their seismic activity, had controlled the sedimentation in the Po plain basin, sometimes even displacing the more recent Plio-Pleistocenic marine sedimentary units (that outcrop in foothills) and the Pleistocenic-Holocenic continental deposits that form the subsoil of the plain).

6.2 Geological Section

Closing at IT.CSP station a schematic geological section A-A' crossing the IT.CSP RAN seismic station from NW to SE (Figure 5 bottom).

From NW to SE Imola Sand Formation (IMO, middle Pleistocene), and Argille Azzurre Formation (FAA, lower Pliocene-upper Pleistocene) well outcrops covered in discordance by Pleistocenic-Holocenic continental fluvial deposits (Ravenna Subsynthem) constituted of a mixture of gravel, silt, sandy silt and locally sand.

6.3 Subsoil model

A subsoil model is built up to a depth of 40 m in the area around the IT.CSP station on the basis of geological information from literature, public databases, stratigraphies of many surveys, dynamic and static penetrometric tests, single-station microtremor measurements and seismic MASW (Figure 5 right).

The comparison between all data obtained from different surveys and 8 stations array survey (INGV Working group, Figure 4), highlighted the presence of low thickened deposits constituted of a mixture of different lithologies (gravel, silt, sandy silt and sand) up to 10 m in depth. Beyond this depth there is a substrate lithotype (Argille Azzurre) that is hard cohesive, fractured, altered up to about 40 m in depth.

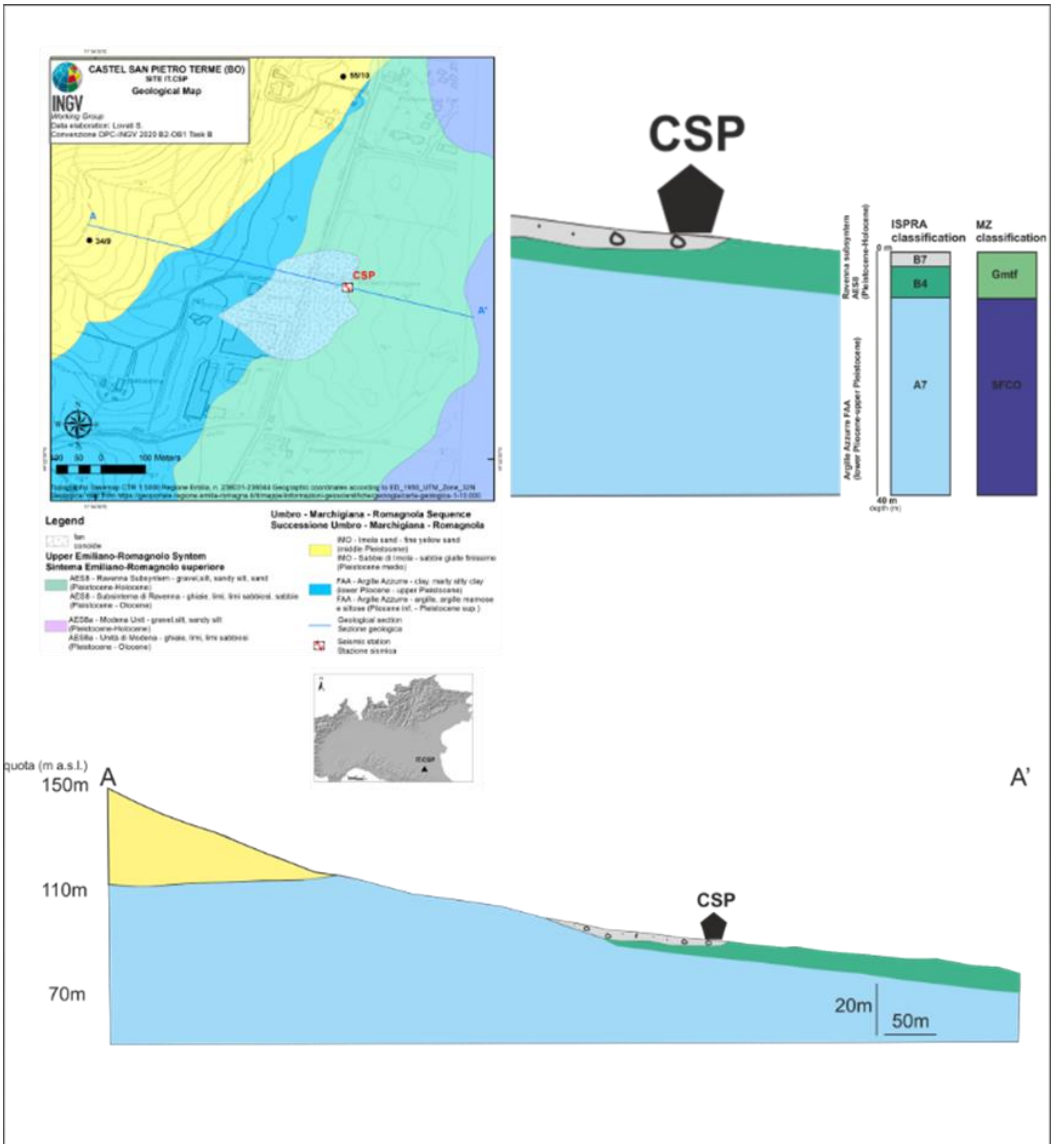

Figure 5: Bottom: Geological section A-A' crossing seismic station IT.CSP. Top right: Subsoil model under the IT.CSP seismic station and classification according to ISPRA: B7: fan, B4: mixture of clay, sand, gravel, A7: marl, mudstone; according to MZ: GM: mixture of gravel, sand, silt, SF: fractured/altered bedrock.

B. V_S profile

B1. GEOPHYSICAL INVESTIGATIONS

Geophysical measurements executed next to the station IT.CSP (Italian Accelerometric Network, RAN-DPC) consist in ambient-vibration measurements in both single-station and 2D array configuration 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 (Vs) profile that is suitable for assigning the soil class according to the current Italian seismic code (NTC 2018) and the current Eurocode (EC8).

Figure 6 shows the location of the station IT.CSP (Latitude 44.378487, Longitude 11.580113 WGS84) installed inside an ENEL transformation cabin. The seismic sensors were positioned in a circular geometry with a radius of 15 m, in order to have a homogeneous azimuthal coverage that allows a better performance of the array techniques.

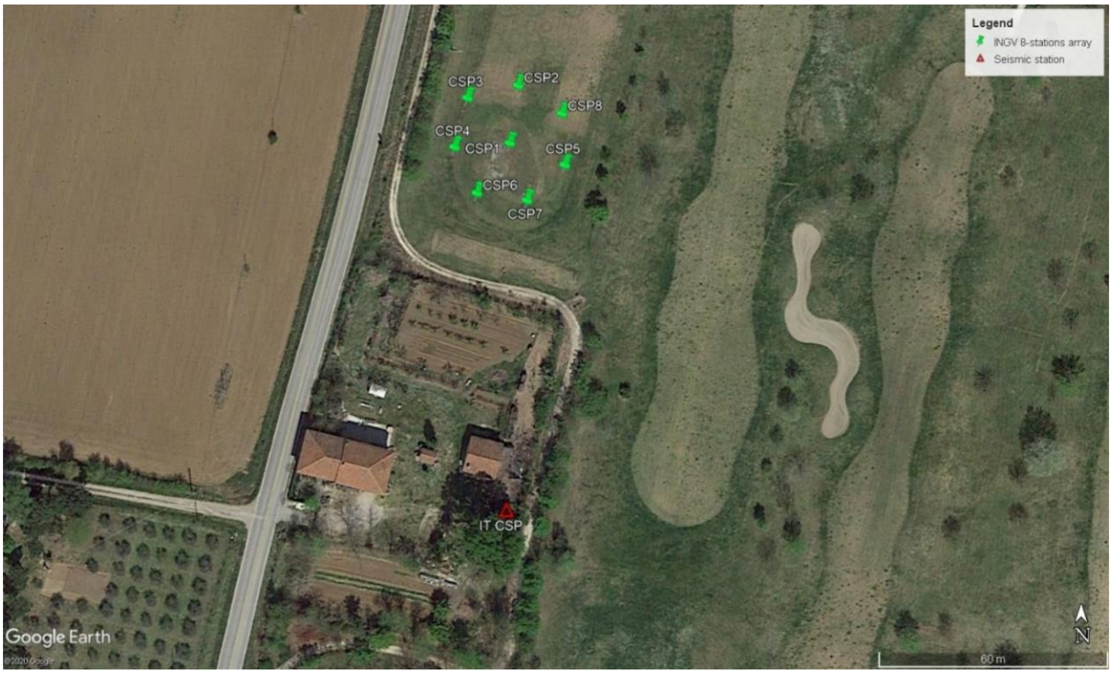

Figure 6: Map of the geophysical measurements performed at the IT.CSP site. The green placemarkers in circular geometry are the 8 stations of the 2D array in passive configuration. The red triangle indicates the IT.CSP accelerometric station (image from Google Earth http://www.earth.google.com).

Figure 7: Left: IT.CSP accelerometric station installed on a concrete insulated pillar inside an ENEL transformation cabin (Castel San Pietro Terme, BO). Upper right: single station ambient noise measurement performed at IT.CSP station. Bottom right: 2D passive ambient noise array installed close to the CSP station.

Both for single and 2D array passive measurements, the ambient noise vibrations have been acquired with Lennartz-5s velocimetric sensor coupled to the Reftek-130 (24 bits) digitizer. For 2D passive array the measurement has duration of about two hours. The sampling rate was set to 200 sps.

To assess the resonant frequency at IT.CSP station, the horizontal-to-vertical spectral ratio (H/V) has been calculated, using the *Geopsy* software (http://www.geopsy.org). The H/V analyses show a first peak (f_0) around 12 Hz and a second peak around 30 Hz, with amplitude in any case lower than 3. The directional H/V show for the f_0 a very slight polarization effect in the range 120°-160° N. The results are summarized in Figure 8.

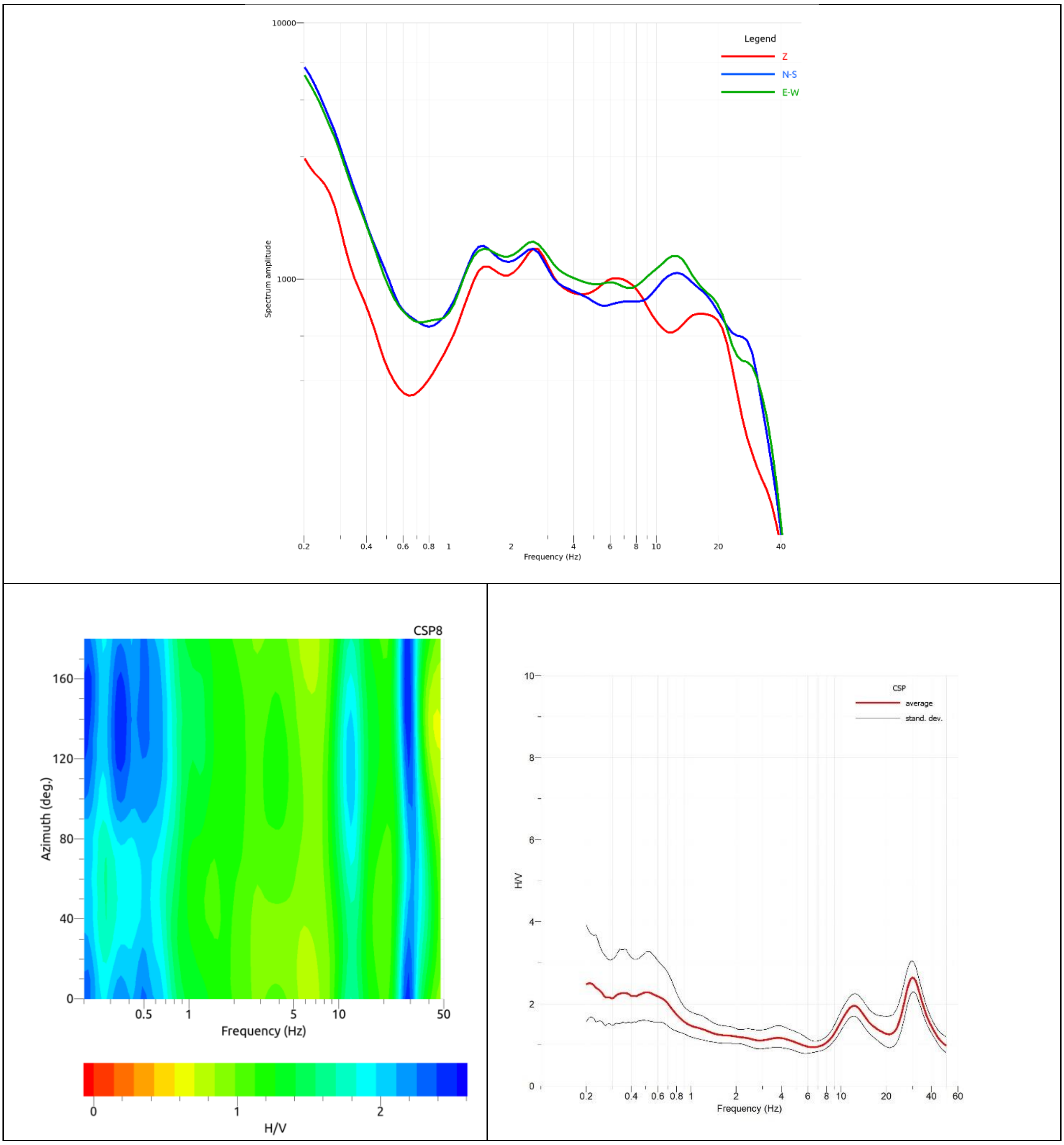

Figure 8: H/V results at IT.CSP station. Top: Fourier spectra of the three components. Bottom left: directional H/V. Bottom right: H/V curve (with mean and standard deviation in red and grey respectively).

Data from the 2D array have been analyzed with the GEOPSY code (http://www.geopsy.org) in terms of high-resolution FK analysis. The FK dispersion curve obtained from the vertical components is shown in Figure 9 (top panel). We interpret and assume that the dispersion curve is relative to the fundamental mode of the Rayleigh dispersive waves. The aliasing conditions (black lines) constrain the validity range of the picked dispersion curves in the frequency range 10-20 Hz.

In this case also the modified spatial autocorrelation technique (MSPAC) has also been applied to the passive data to obtain the autocorrelation curves. Figure 9 (bottom panel) shows the relative dispersion curve with the confidence interval (black lines) in the range 8-20 Hz.

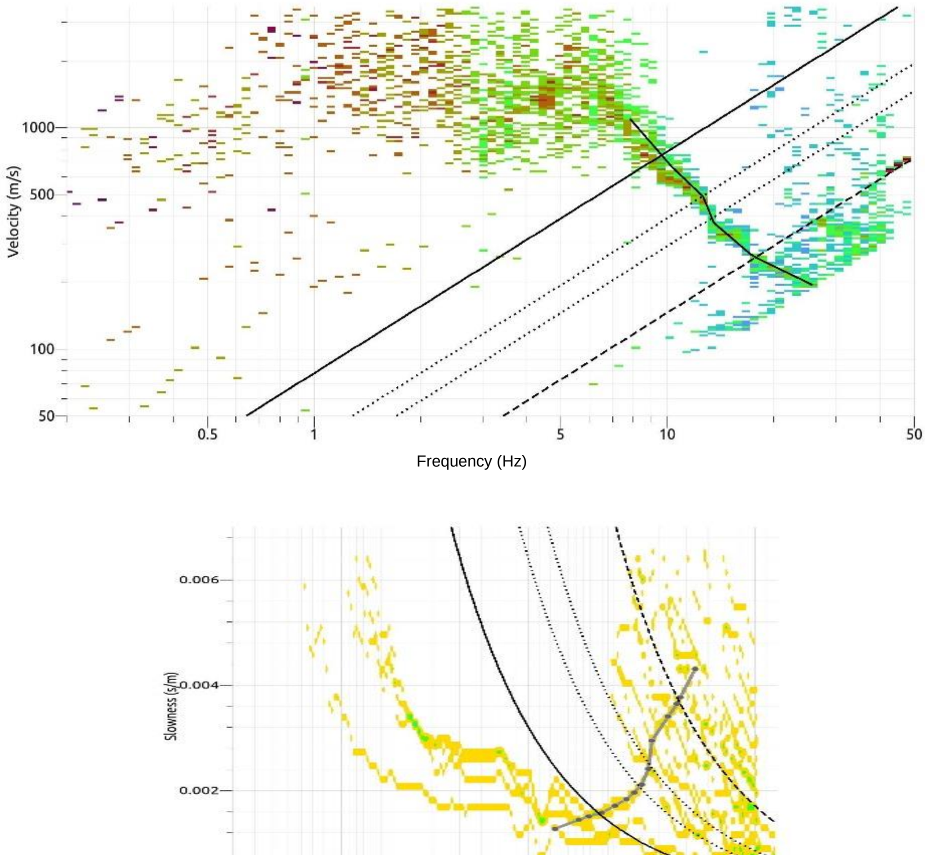

Figure 9: Top: FK analysis and picked dispersion curve for the 2D ambient noise passive array. Bottom: MSPAC analysis and picked dispersion curve.

To obtain the shear wave velocity profile for the area the FK and MSPAC dispersion curves have been inverted together the right flank of the H/V (first peak) curve shown in figure 8 (right bottom panel).

2. SEISMIC VELOCITY MODEL

The final result of the inversion is shown in Figure 10 where we can observe two discontinuities at about 3 and 8 m as the subsoil model highlights. We obtained a fairly good fit between experimental and theoretical curves using a model parameterization composed of two main layers over half space. The velocity is reported in table 5.

The first discontinuity is probably due to a transition from mainly clayly deposits to mainly sandy ones. The second discontinuity is due to a low-thickened layer (about 9 m) of deposits, consisting in a mixture of different lithologies passing to the hard cohesive substrate lithotype (Argille Azzurre).

The best -fit model of V_s is represented in Figure 11 and Table 5.

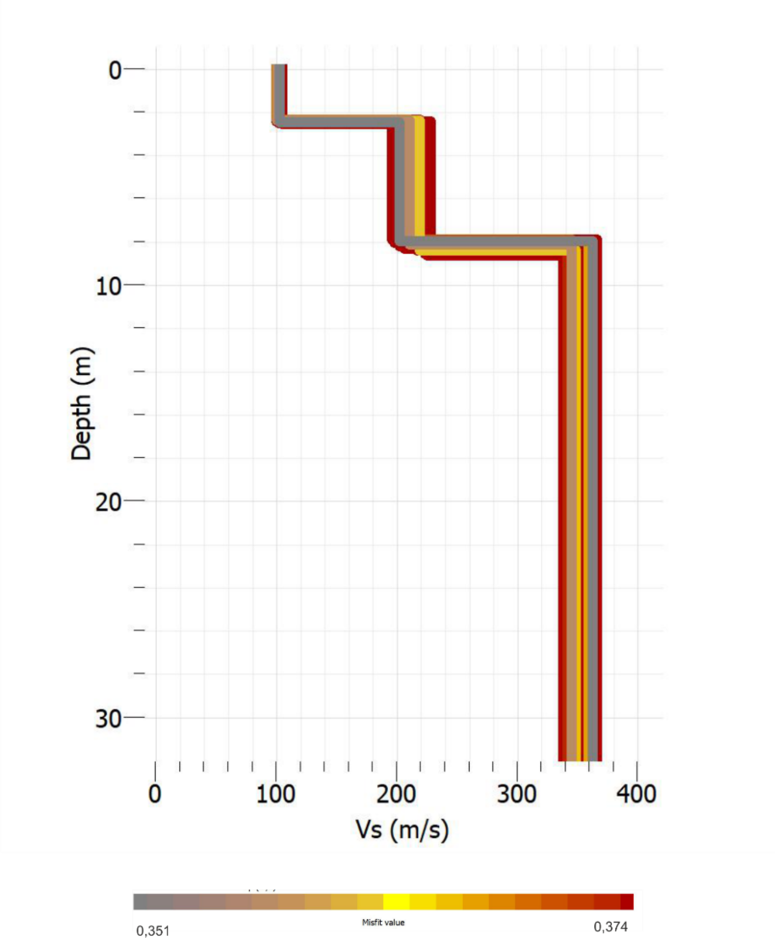

Figure 10: V_S profile obtained through the joint inversion of the FK and MSPAC dispersion curves (Figure 9) together with the right flank of H/V curve.

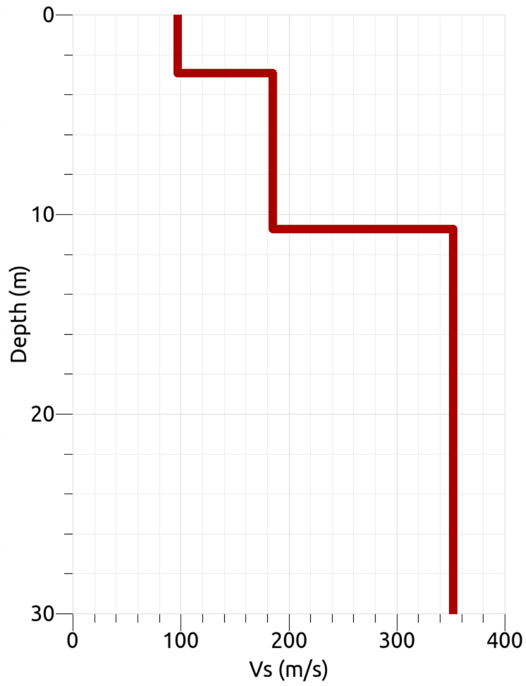

Figure 11: Best-fit model of V_s values

From	*To*	*Thickness (m)*	*V_s (m/s)*
0	2.90	2.90	98
2.90	10.80	7.90	185
10.80	30.00	19.20	352

Table 5: Best-fit model

B3. CONCLUSIONS

According to the current Italian seismic code (NTC 2018), 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 11, the velocity of 800m/s is reached for an unknown depth, well above the depth of 30 m. Therefore in this case both $V_{s,eq}$ and $V_{S,30}$ are equal to 236 m/s. Of consequence, IT.CSP site is classified in the soil category C, for both the NTC18 and EC8 seismic codes (Table 6).

***$V_{s,eq}$ = V_{s30}* [m/s]**	***Soil class (NTC 2018)***	***Soil class (EC8)***
236	C	C

Table 6: Soil Class

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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)"