ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IT.MRN – Mirandola "Napoli" (MO)

Report di caratterizzazione di sito presso la stazione sismica IT.MRN – Mirandola "Napoli" (MO)

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

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INDEX

INTRODUCTION

This report summarizes the geological features and the results of geophysical measurements used for the seismic characterization of the IT.MRN station site (Mirandola "Napoli"). This activity has been developed in the framework of the 2019-2021 agreement between INGV and DPC, named Annex B2: Objective 1 - TASK 2: Characterization of accelerometer sites (Responsible: G. Cultrera, F. Pacor)

Location and coordinates are reported in Table 1.

Table 1.

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IT.MRN	MIRANDOLA (NAPOLI)	44.87823*	11.06174*	15*
ADDRESS	Via Napoli, 18 – 41037 – Mirandola (MO), Italy			

* Reference table from ITACA – D'Amico et al., 2020 (December 2021)

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	EC8 Class
	Flat top of isolated relief with slope i<=15°	T1*	P	C*

* According to nomenclature of ITACA – D'Amico et al., 2020 (December 2021)

Table 3.

Geological map	Source	Scale
IT.MRN	Geological map of Italy sheet *N.75* (Mirandola)	1:100.000
IT.MRN	Geological and technical map – Seismic Microzonation	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 a preexisting cartography according to the nomenclature of corresponding cartography.

Table 4.

GEOLOGICAL UNITS		LITHOTECHNICAL UNITS	
Geological map - Deduced. According to the nomenclature of geological map of Italy 1:50.000 (Sheet 202 – San Giovanni in Persiceto)		Lithotechnical Map - Deduced. According to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).	
code	**description**	**code**	**description**
AES8	Silt and silty clay of flood plain (Holocene)	OLpi	Organic silts or low-plasticity organic silty clays of flood plain
AES8	Silty sands, mixture of sands and silt of river channel (Holocene)	SMes	Silty sands, mixture of sands and silt of river channel

A2. GEOLOGICAL MAP

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

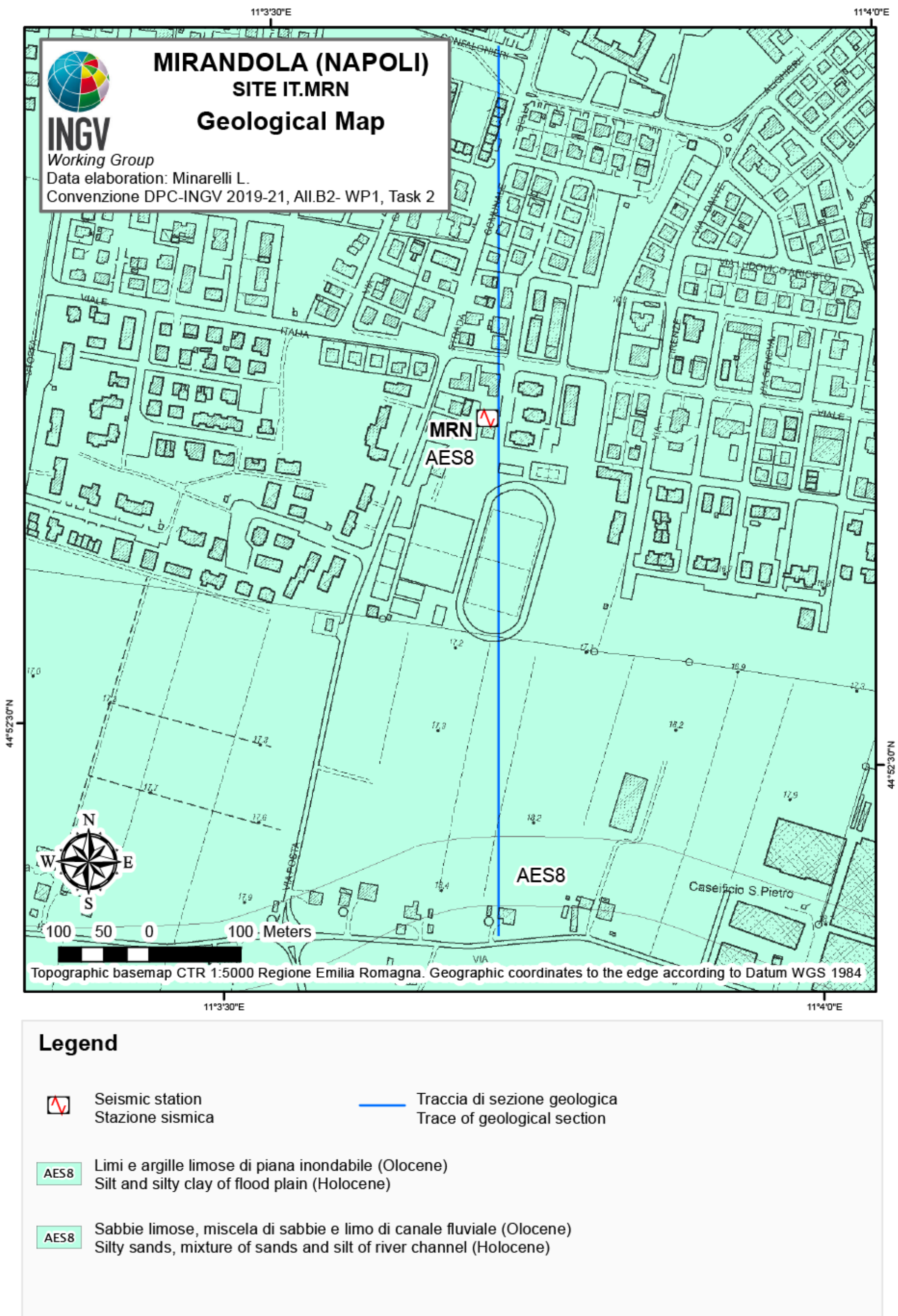

Figure 1. Geological map of seismic station site IT.MRN. Scale 1:5.000. Geological units are mapped according to the nomenclature of geological map of Italy 1:50.000

A3. LITHOTECHNICAL MAP

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

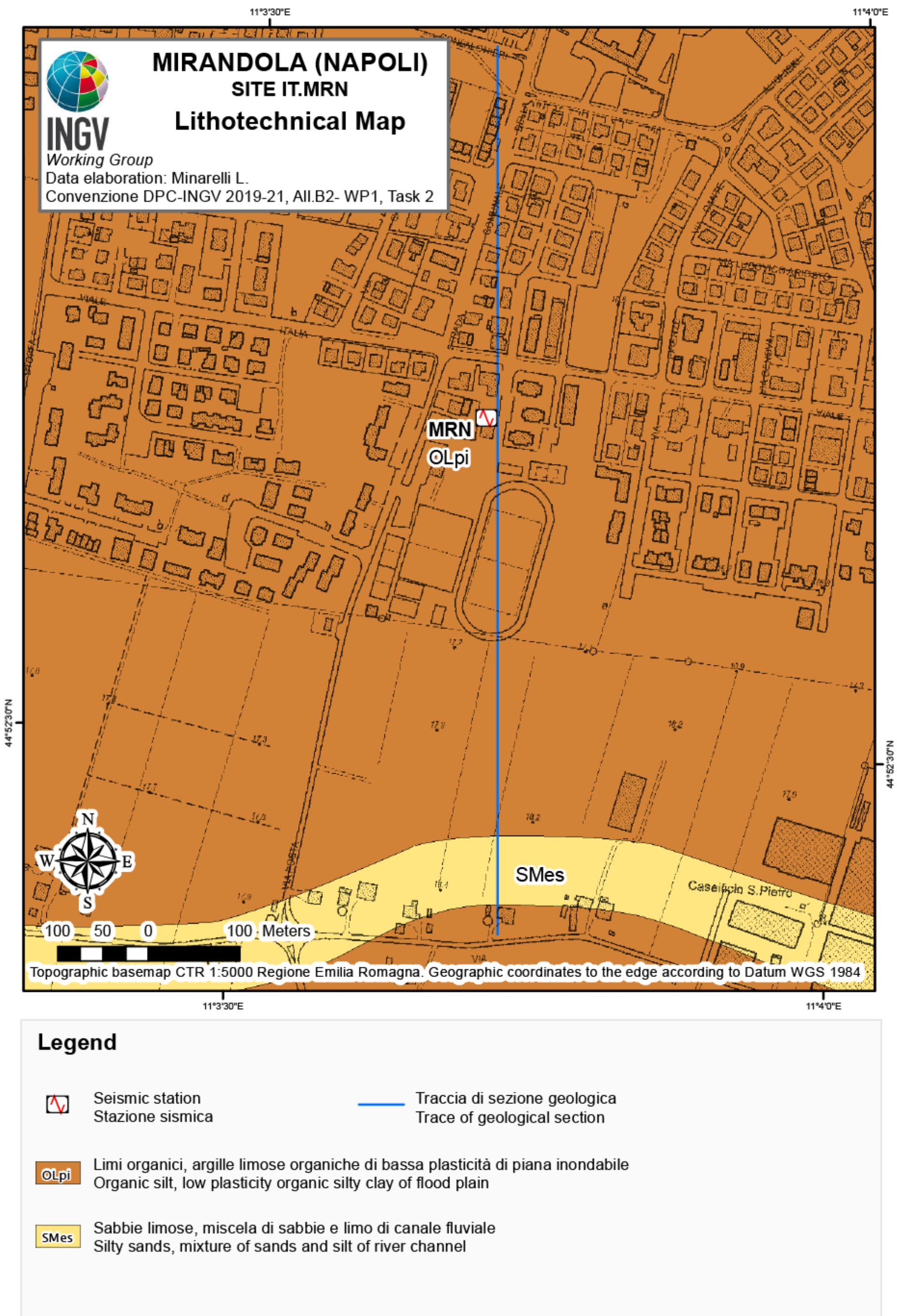

Figure 2. Lithotechnical map of the seismic station site IT.MRN. Scale 1:5.000. The lithotechnical units are attributed according to the nomenclature of Seismic Microzonation study (Technical Commission SM, 2015). The 2D geological section (trace in blue line) is shown in Fig. 6.

A4. SURVEY MAP

Figure 3 shows the survey Map depicting the previous geotechnical and geophysical investigations used for the characterization of the area.

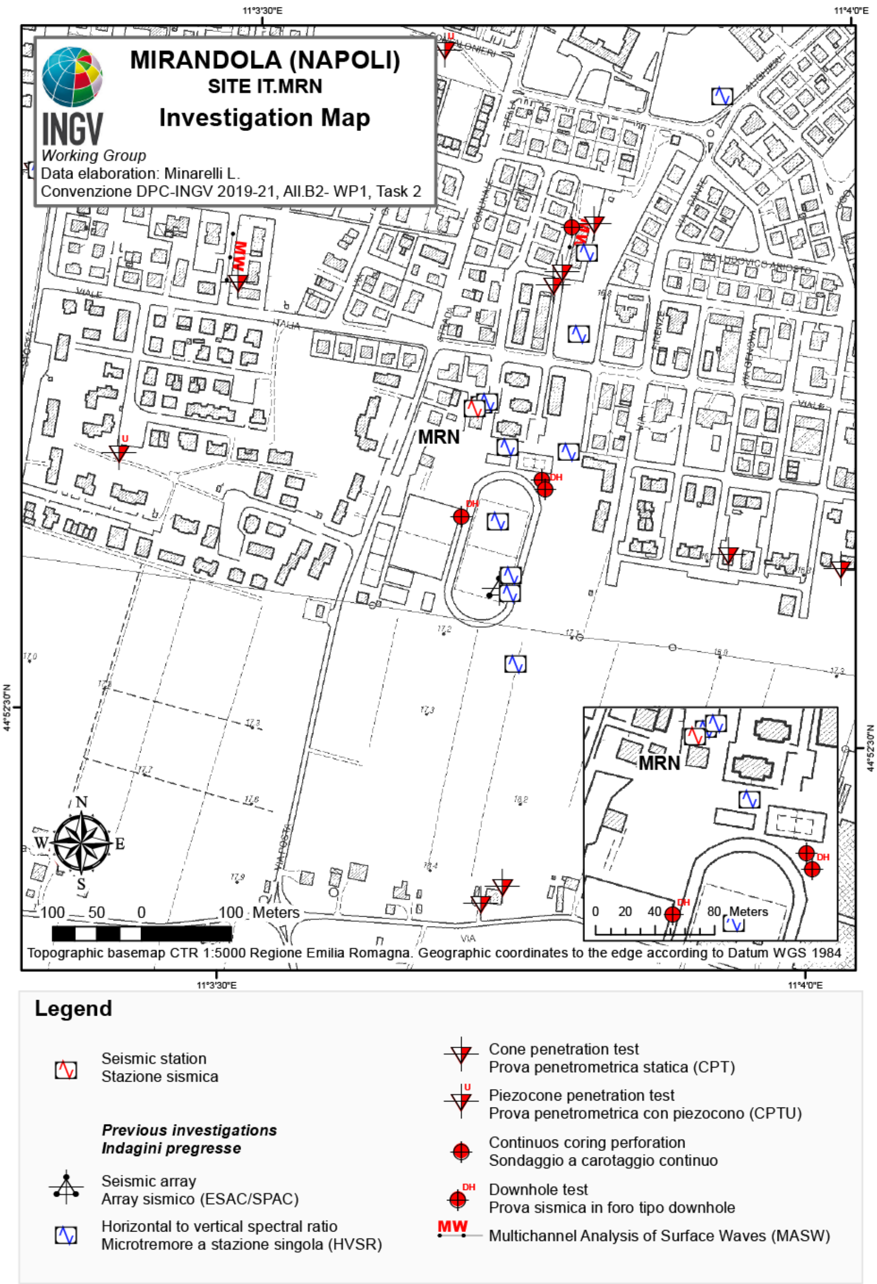

Figure 3. Map of the surveys in the surroundings of the station IT.MRN. Scala 1: 5.000. The box at the bottom right contains a zoom of the area with the detail of the cross-hole and down-hole geophysical investigations used for the seismic characterization of the site. (Martelli & Romani 2013, Paolucci et al. 2015, Garofalo et al. 2016). http://itaca.mi.ingv.it/ItacaNet_31/#/station/IT/MRN.

A5. GEOLOGICAL MODEL

5.1 General description

The seismic station is placed in the southern outskirts of the town of Mirandola, in the Modena Province, at about 15 meters above sea level. The site belongs to the lower part of the Po River alluvial plain, corresponding to the foredeep basin of the Northern Apennines chain. The area is located on a complex structural fold and fault belt, forming the buried front of the Apennines chain (Pieri & Groppi, 1981). The tectonic structures developed through late Neogene and Quaternary times and are covered by thick Quaternary sedimentary successions, which are also affected by the tectonic deformation and differential subsidence. These successions infill the foredeep basin, recording and shallowing evolution from marine to continental environments.

The compressive stress-field affecting these structures is responsible for the intense seismic activity of 2012, characterized by two main events (Mw = 6.1 and 5.9; e.g. Pondrelli et al., 2012), and by a long sequence of aftershock (e.g. Saraò & Peruzza, 2012; Scognamiglio et al., 2012). The seismic event of moment magnitude 5.9 (29.05.2012) is associated to the individual seismogenic source ITIS107 “Mirandola” (DISS Working Group, 2018), present a few kilometers to the south of the station site.

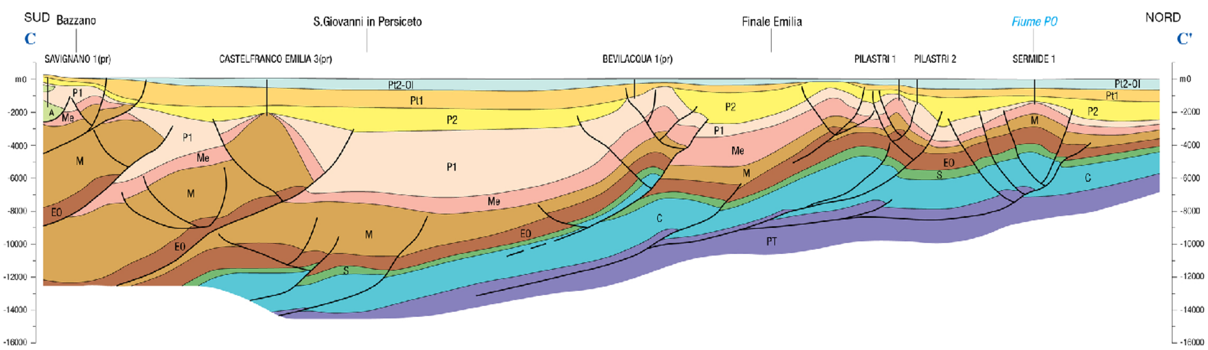

Figure 4. Structural profile (Martelli et al. 2017). The Cretaceous-Tertiary formations are detached from the Permo-Jurassic units. Several complex anticline structures are involved into active compressive deformation and are associated with ramp overthrusts, interspaced by synclines.

The local tectonic deformation superposed to the regional subsidence of the foredeep generated the lowest subsidence rates in correspondence of the buried anticlines and the highest values in the synclinal areas (Ghielmi et al. 2013; Vannoli et al. 2015, Stefani et al. 2018). The different subsidence rates determined great lateral variations in the depositional thickness, facies, and petrophysical properties (Figure 4). The profile (Figure 4) is elongated perpendicularly to the structural strike and passes about 15 km to the east of the seismic station, which is located over the same complex anticline structure visible in the profile beneath the "Bevilacqua 1" drill. In the profile area the anticline is however more depressed than under the Mirandola station site.

The combined effect of the Quaternary glacio-eustatic fluctuations and of the tectonic deformation pulses generated a series of regional discordance surfaces, which are used as key levels to subdivide the sedimentary successions into allostratigraphic units, such as Synthems and Subsynthems (Emilia-Romagna Region and ENI/AGIP, 1998).

5.2 Geological section

The seismic station site corresponds to the culmination of a ramp anticline related to the external thrust belt of the buried Apennines Chain (Pieri & Groppi 1981) (Figure 5). The complex anticline structure is detached from the metamorphic basement and Permo-Jurassic units and involves a Mesozoic carbonates slab, followed by Tertiary deep-water mudstones and by Neogene sandy turbidites (Fig.s 4 and 5). The Quaternary uplift of the structure induced sharp stratigraphic discordances. The Miocene and lower Pliocene are therefore cut off by an erosive surface, associated with an angular unconformity.

The top of the lithified bedrock here reaches 110 m, a much shallower depth than in the surrounding areas. On both the sides of the anticline structure, Quaternary marine deposits rest on the major discordance surface, showing a great increase in thickness moving away from the anticline culmination, both southward and northward, exceeding also 300 m, in the depocenter areas. A younger angular discordance surface cut the top of the Quaternary marine successions, which are totally lacking on the anticline culmination, and thus beneath the seismic station.

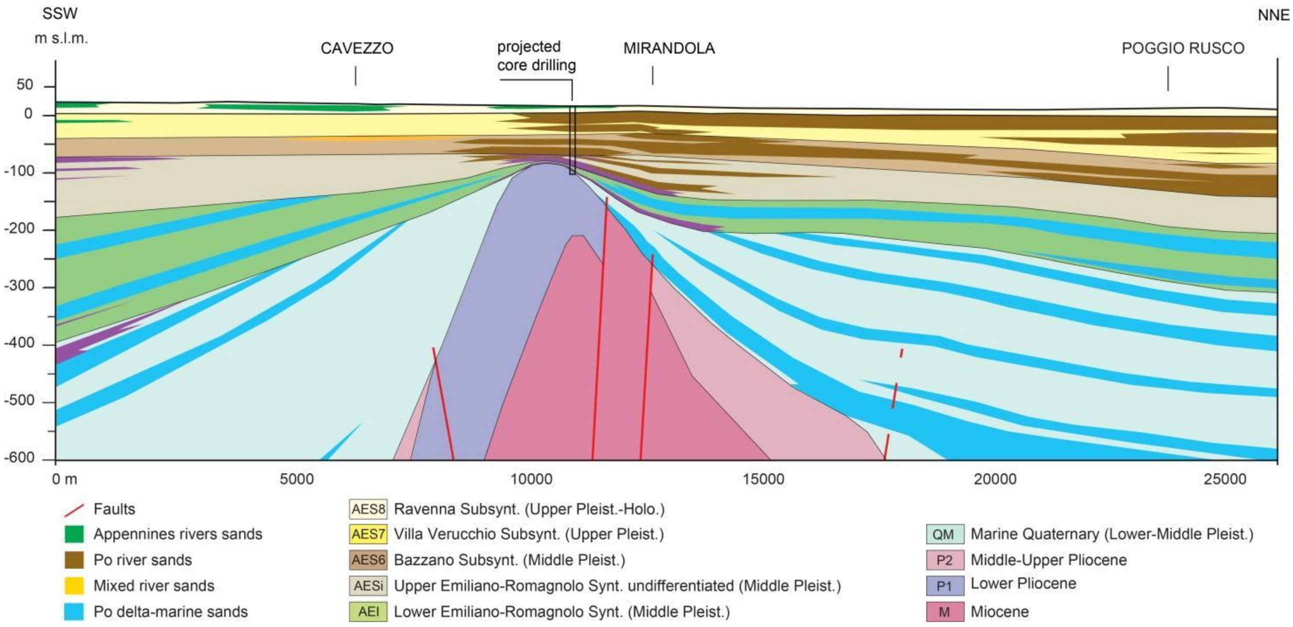

Figure 5. Schematic geological cross section, oriented SSW-NNE, showing the geometrical relationships between the Neogene sandy turbidites and the Quaternary sedimentary infilling of the foredeep basin of the Northern Apennines chain (modified from Martelli & Romani, 2013; Paolucci et al., 2015). The seismic station site is placed 1,300 m from the section and therefore it shows some difference in the depositional units thickness.

These units also record a massive increase in the stratigraphic thickness, moving away from the anticline culmination. On the anticline culmination and at the north of it, the Quaternary successions record an evolution from River Adige to River Po inputs, and, only in the uppermost few meters, a sedimentation fed by Apennines streams. To the south of Mirandola, both the Emiliano Romagnolo Inferiore (AEI) and Emiliano Romagnolo Superiore are much finer grained and were largely fed by rivers flowing from the Apennines.

5.3 Subsoil model

A detailed knowledge of the first 130 m of the site subsurface is available, thanks to a stratigraphic core drilled at less than 100 m from the seismic station, within the framework of the geological research performed by the Servizio Geologico, Sismico e dei Suoli della Regione Emilia-Romagna. Several seismic velocity logs were measured in the borehole (Martelli & Romani 2013, Garofalo et al. 2016). A synthetic description of the cored stratigraphy and the geological reference model for the seismic station (Figure 6) is hereafter provided. The first 9 m of subsurface belongs to the Subsintema di Ravenna (AES8), consisting of clay and silty clay, sedimented into an interfluvial area, influenced by rivers out-flowing the Apennines Chain (e.g. Secchia). Between 6 and 9 m, calcified paleosol levels are developed.

The following interval (approximately 9-25 m) belongs to the Subsintema di Villa Verucchio (AES7). The stratigraphic interval was deposited into fluvial systems, mainly during synglacial times, and it is dominated by the Po River input. Its upper portion (9-12 m) is formed by middle-fine sands and silty sands, the lower one (12-25 m) consists of middle-coarse sands, rich in mica and poor in wood remain. The base of the subsynthem is here poorly defined, since it is amalgamated with the underlying sands.

The Subsintema di Bazzano (AES6) follows (25-59 m). The upper interval (25-39 m) is dominated by coarse gravelly sands, with clasts derived from the Alps. The following interval (39-50 m) is formed by middle-coarse sand, with some pebbly sand layers, deposited into a synglacial alluvial plain. The lower portion (50-59 m) consists of clay, sitly clay, organic rich clay with peat, wood, and root remain, recording interglacial alluvial plain deposits.

The lower portion of the AES Synthem (59 - probably 100 m) consists of four units: an upper sand interval (59-67 m); an argillaceous unit (67-74 m), often rich in organic matter and vegetable remains; a lower middle-coarse sand interval, rich in quartz and mica (74-92 m), a unit (92-100 m), often reddish in color, consisting of silt and clay layers with pebbly sand intercalations, showing centimetric clasts of Permian riodacites. The described lower part of the AES Synthem can probably be subdivided into two subsyntems; the lower reddish interval is however still of uncertain stratigraphic attribution.

The stratigraphic framing and age of the following interval (100-113 m) is still not completely clear, but it likely belongs to the Lower Emiliano-Romagnolo Synthem (AEI) and not to the Marine Quaternary unit, which seems to be absent.

The interval is rich in gravelly sands, with coarse pebbles, interlayered with silt and clay beds and shows peculiar petrographical and sedimentological features. The composition of the clasts, of clear Souther Alpine origin, is quite varied, with Permian ignimbritic rhyodacite, Mesozoic carbonates, and rarer metamorphic and intrusive lithologies. An input by the Adige basin from the Garda area is likely. No lithification hardening is visible.

At 113 m, a major discordance surface, angular in nature, marks the eroded top of partially lithified, sharp based, graded sands and marine silts. The sediments probably belong to a lower Pliocene turbiditic formation.

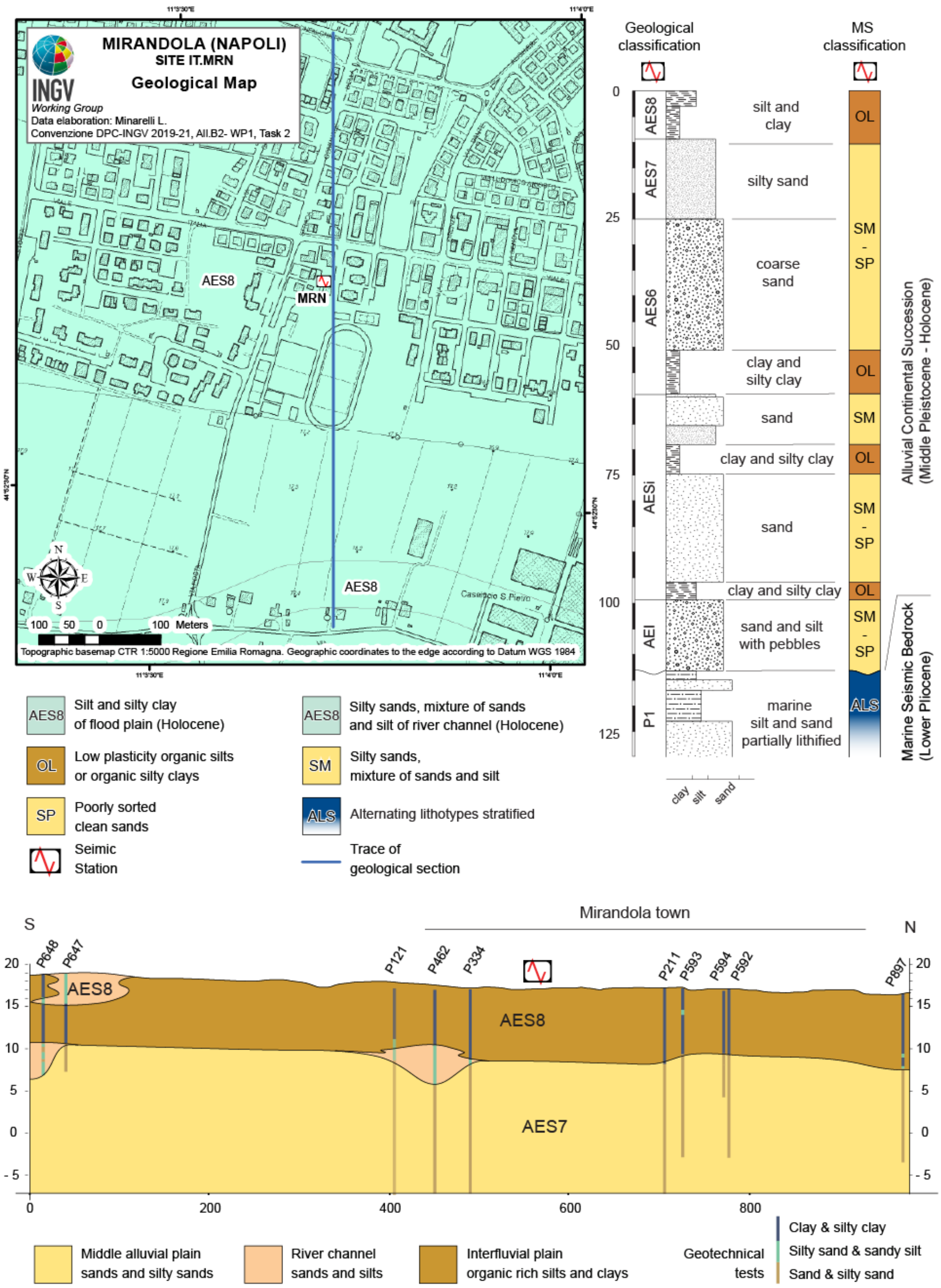

Figure 6. Bottom - Geological section crossing seismic station IT.MRN. Right - Subsoil model under the IT.MRN seismic station and classification according to the nomenclature of the geological map of Italy 1:50.000 and according to Seismic Microzonation (SM).

B. Vs profile

B1. GEOPHYSICAL INVESTIGATIONS

Mirandola was the target of extensive geophysical investigations by a past project, therefore specific ad-hoc surveys were not carried by our team. The seismic characterization of IT.MRN station from geophysic was based on the analysis described in the following papers:

- *Garofalo, F., Foti, S., Hollender, F., Bard, P.Y., Cornou, C., Cox, B.R., Ohrnberger, M., Sicilia, D., Asten, M., Di Giulio, G. and Forbriger, T., 2016a. InterPACIFIC project: Comparison of invasive and non-invasive methods for seismic site characterization. Part I: Intra-comparison of surface wave methods. Soil Dynamics and Earthquake Engineering, 82, pp.222-240.*

- *Garofalo, F., Foti, S., Hollender, F., Bard, P.Y., Cornou, C., Cox, B.R., Dechamp, A., Ohrnberger, M., Perron, V., Sicilia, D. and Teague, D., 2016b. InterPACIFIC project: Comparison of invasive and non-invasive methods for seismic site characterization. Part II: Inter-comparison between surface-wave and borehole methods. Soil Dynamics and Earthquake Engineering, 82, pp.241-254.*

- *Foti, S., Hollender, F., Garofalo, F., Albarello, D., Asten, M., Bard, P.Y., Comina, C., Cornou, C., Cox, B., Di Giulio, G. and Forbriger, T., 2018. Guidelines for the good practice of surface wave analysis: a product of the InterPACIFIC project. Bulletin of Earthquake Engineering, 16(6), pp.2367-2420.*

This part is intended as a short summary of the results obtained in the above publication. In detail, a blind test exercise was organized in the InterPACIFIC (Intercomparison of methods for site parameter and velocity profile characterization) project. The main aim of the

InterPACIFIC project was the evaluation of the reliability of in-hole and surface-wave methods for deriving the shear-wave velocity (Vs) at three different sites. Mirandola was one of these sites selected in the project activity (Fig.s 7 and 8). Several ambient vibration data of some hours were recorded by three-component velocimeters (Güralp broadband CMG-6TD) in 2D array configurations and were sent to invited groups of experts in the surface-wave analysis. The involved international groups (Table 5) provide the results in terms of dispersion curve (DC) and Vs profile, using their preferred method for the surface-wave analysis. The 2D array configurations were (Fig. 8): i) circular with diameters ranging from 5 to 405 m with 7 stations deployed on two main rings, ii) triangular with 5 nested triangles and sides of each triangle varying from 12.5 m to 300 m. Also a L-shape geometry dataset was collected in the finality of the project with two perpendicular lines crossing each other (Fig. 8). Active data along a linear array of geophones (MASW tests) were also acquired and distributed to the different teams (using Geode seismographs manufactured by Geometrics with spacing varying from 0.5 to 2 m according to site logistic).

The DCs of Rayleigh-wave fundamental mode derived from not-invasive methods by the InterPACIFIC teams are reported in Fig. 9, showing a good agreement from 0.8 to 20 Hz. The Vs models resulting from DCs inversion (Fig. 10) also are in good match up to a depth of 100 m, for larger depths the uncertainties increase due to the loss of resolution in depth of not-invasive techniques.

In terms of H/V noise spectral ratio, the entire area is characterized by a sharp peak at 0.7 Hz (Fig. 11) related to the "Alto di Mirandola" as documented by many papers in literature (Milana et al. 2014; Paolucci et al. 2015; Tarabusi and Caputo 2017; Laurenzano et al. 2017; Asten and Hayashi 2018; Mascandola et al. 2019 and 2021; Martelli 2021) and by seismic microzonation activities (Geotema, 2018).

Because one aim of the InterPACIFIC project was the comparison between non-invasive and invasive techniques, different borehole surveys (downhole, crosshole, suspension logging, seismic dilatometer test) were also conducted at Mirandola. Vs profiles obtained from non-invasive techniques are shown in Fig. 12 indicating still a good overall agreement up to a depth of 120 m. The ESM archive (Luzi et al. 2020), as well as ITACA database (D'Amico et al., 2020), reports for IT.MRN a consistent Vs profile from a CrossHole test (provided by Servizio Geologico, Sismico e dei Suoli Regione Emilia-Romagna; Martelli and Romani 2013, Paolucci et al. 2015) as illustrated in Fig. 13 and Table 7.

Figure 7. Plan view with the position of IT.MRN station (red symbol; Via Napoli, Mirandola). IT.MRN was inside the area investigated by the field experiment of the InterPACIFIC project, with the barycenter of InterPACIFIC measurements corresponding to the green area (indicated by a yellow mark) in the southern direction.

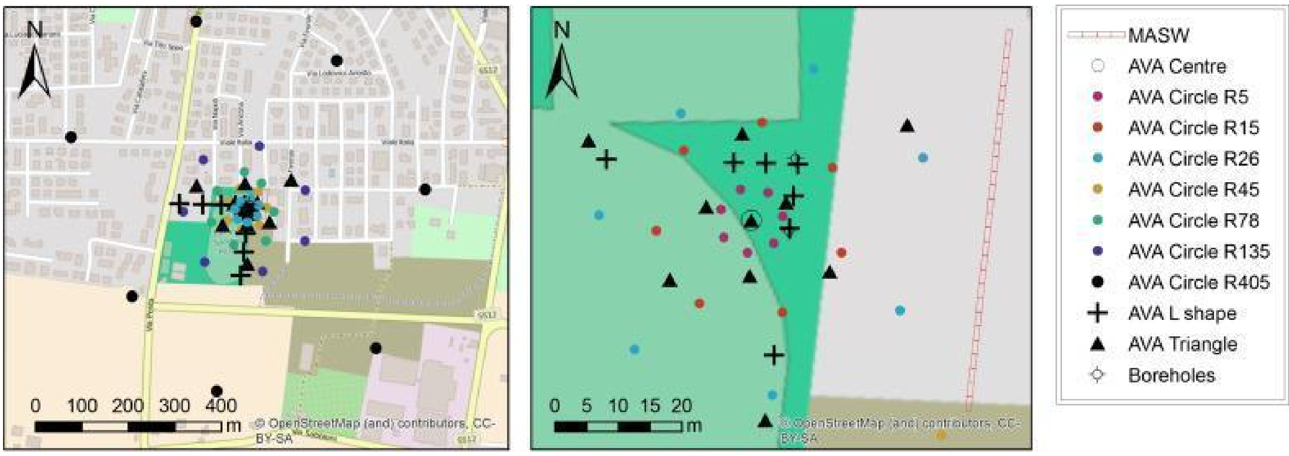

Figure 8. Mirandola. Plan view of the experiment performed by InterPACIFIC project (redrawn from Garofalo et al. 2016a). The legend refers to the position of different stations deployed in array configuration and of boreholes used for comparison between non-invasive and invasive methods.

Table 5. List of fourteen expert teams involved in the InterPACIFIC project (Garofalo et al. 2016 a).

ID	Label	Participants	Country
1	MU	Michael Asten, Monash University	Australia
2	CE	Diego Mercerat, CEREMA	France
3	IST1	Cécile Cornou, ISTerre	France
4	UT	Brady Cox, University of Texas	USA
5	INGV	Giuseppe Di Giulio, INGV	Italy
6	BFO	Thomas Forbriger, Black Forest Observatory	Germany
7	Geom	Koichi Hayashi, Geometrics	USA
8	IST2	Bertrand Guillier, ISTerre	France
9	KU	Shinichi Matsushima, Kyoto University	Japan
10	TT	Hiroaki Yamanaka, Tokyo Institute of Technology	Japan
11	GV	Antony Martin, Geovision	USA
12	SED	Valerio Poggi, Stefano Maranò, Jan Burjanek, Clotaire Michel, SED-ETHZ	Switzerland
13	PU	Matthias Ohrnberger, Potsdam University	Germany
14	PT	S. Foti and F. Garofalo, Politecnico di Torino	Italy

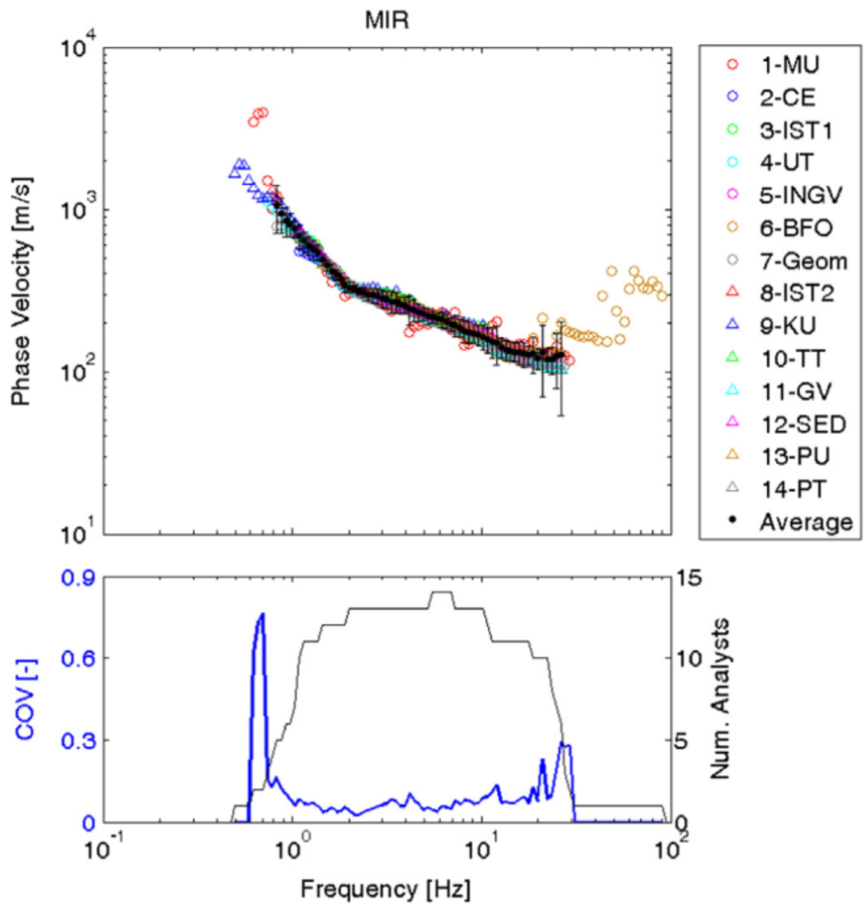

Figure 9. Mirandola site (redrawn from Garofalo et al. 2016a). Top) Dispersion curve (DC) of the fundamental Rayleigh-wave derived from the participants to the InterPACIFIC project. Bottom) Number of analysts and coefficient of variation (CoV defined as ratio between standard deviation and mean).

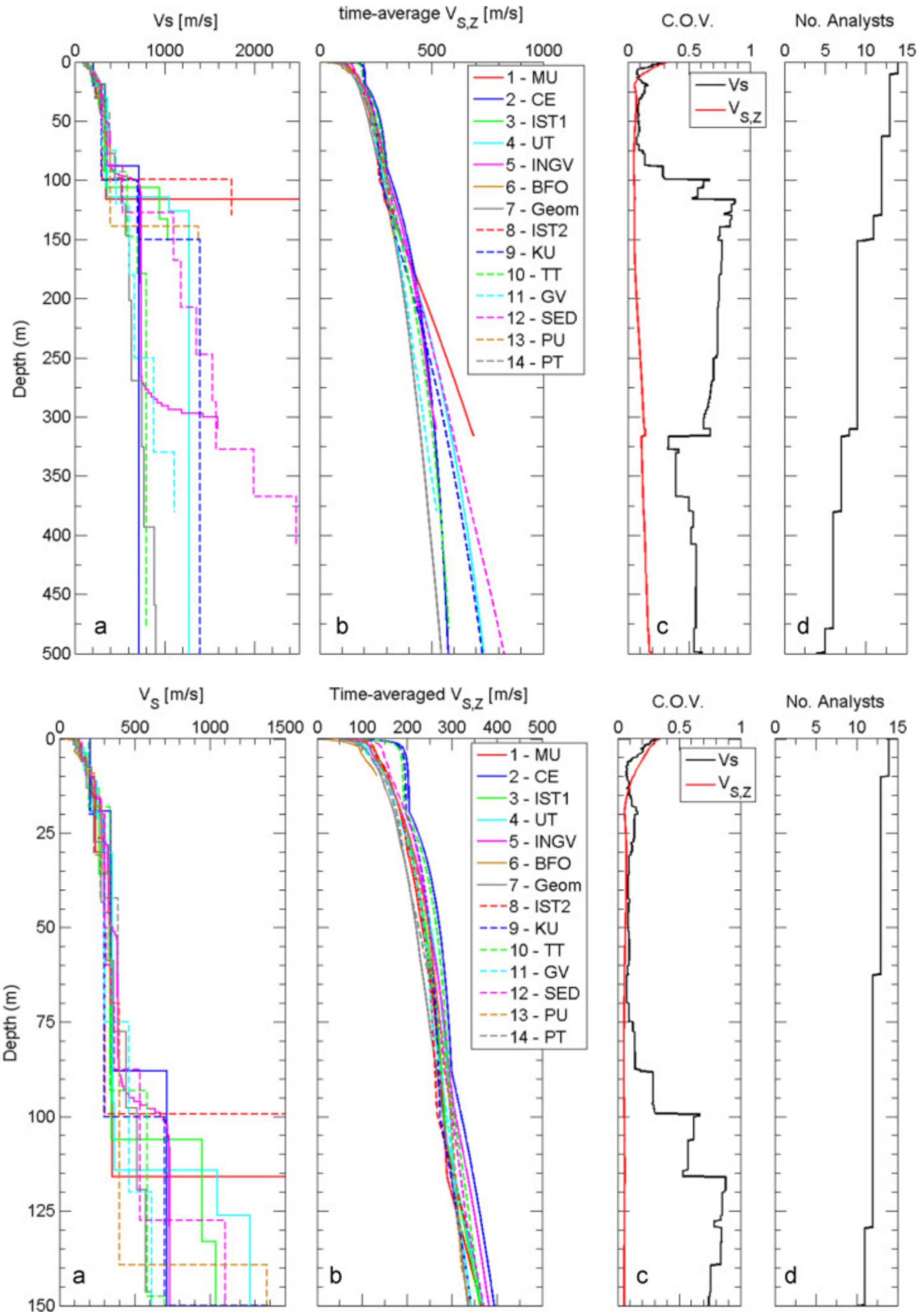

Figure 10. Mirandola (redrawn from Garofalo et al. 2016a). Top) (a) Shear-wave velocity (V_S) profiles, (b) time-averaged $V_{S,Z}$ profiles, (c) CoV(V_S) and CoV($V_{S,Z}$) values, and (d) number of profiles. Bottom) A zoomed view for the uppermost 150 m.

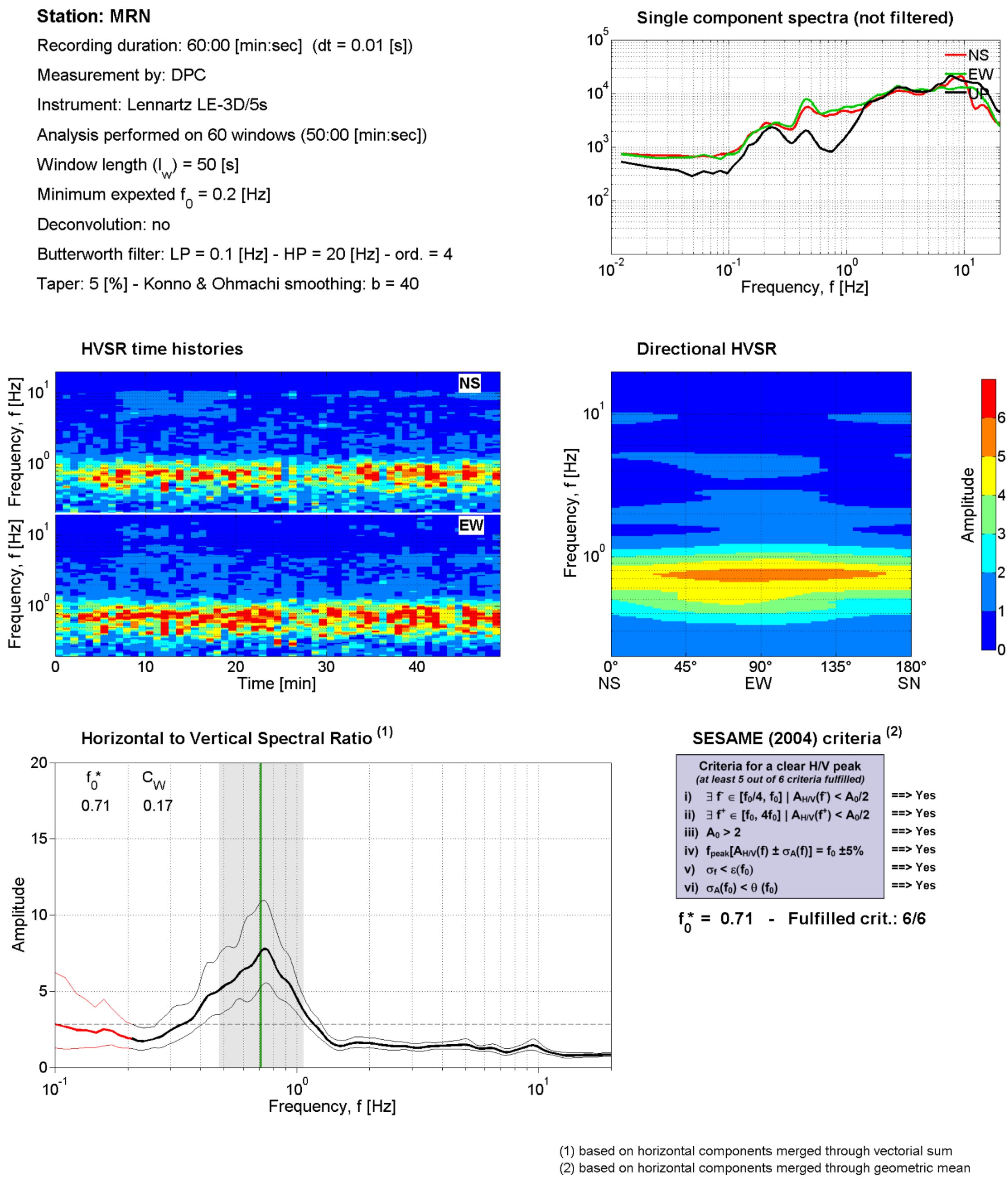

Figure 11. H/V noise spectral ratio analysis redrawn from ESM archive (https://esm-db.eu/; Luzi et al. 2020). A clear H/V peak is present at 0.71 Hz.

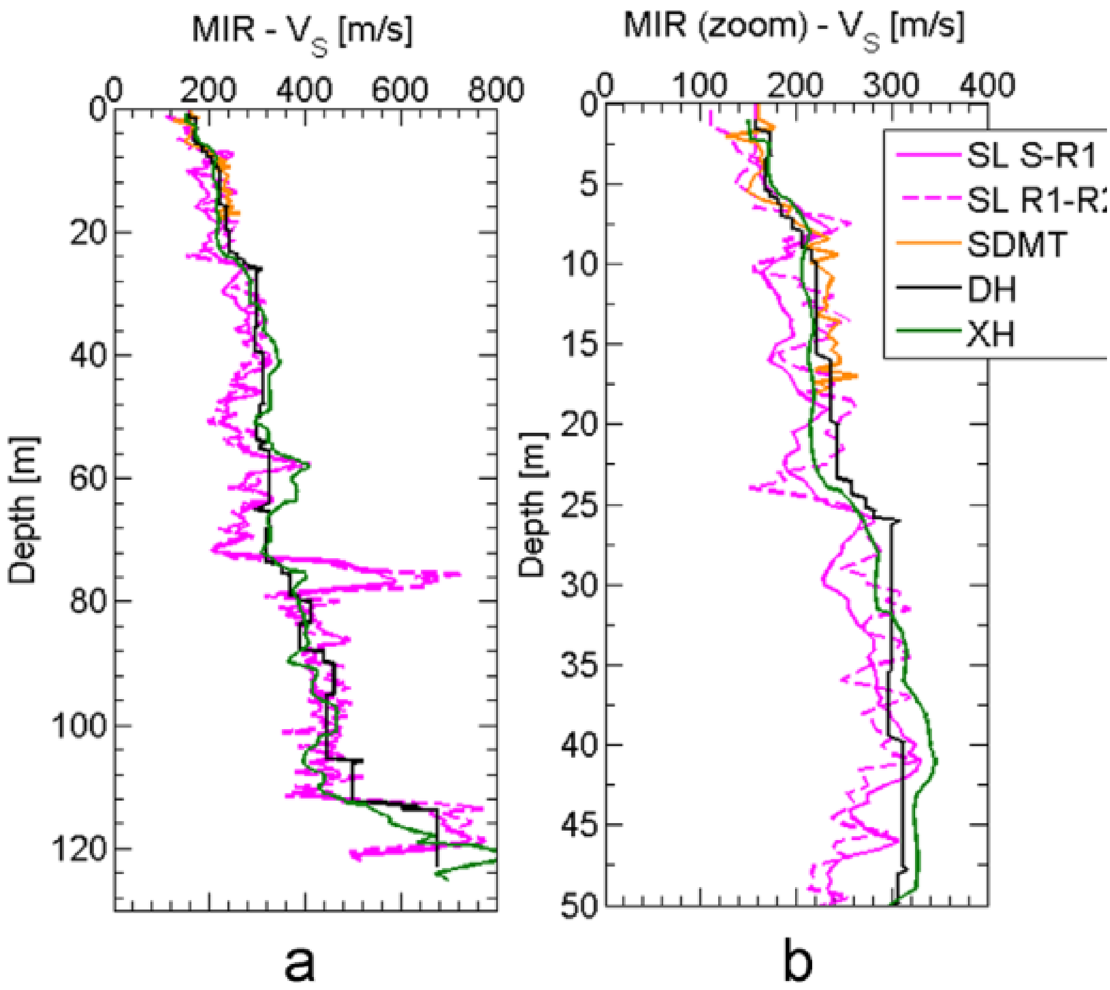

Figure 12. Mirandola. Results from invasive surveys by InterPACIFIC project (redrawn from Garofalo et al. 2016b). (a) Comparison of mean VS profiles from CrossHole (XH), DownHole (DH), P-S Suspension Logging (SL) and Seismic Dilatometer Test (SDMT). b) a zoomed view of the uppermost 50 m.

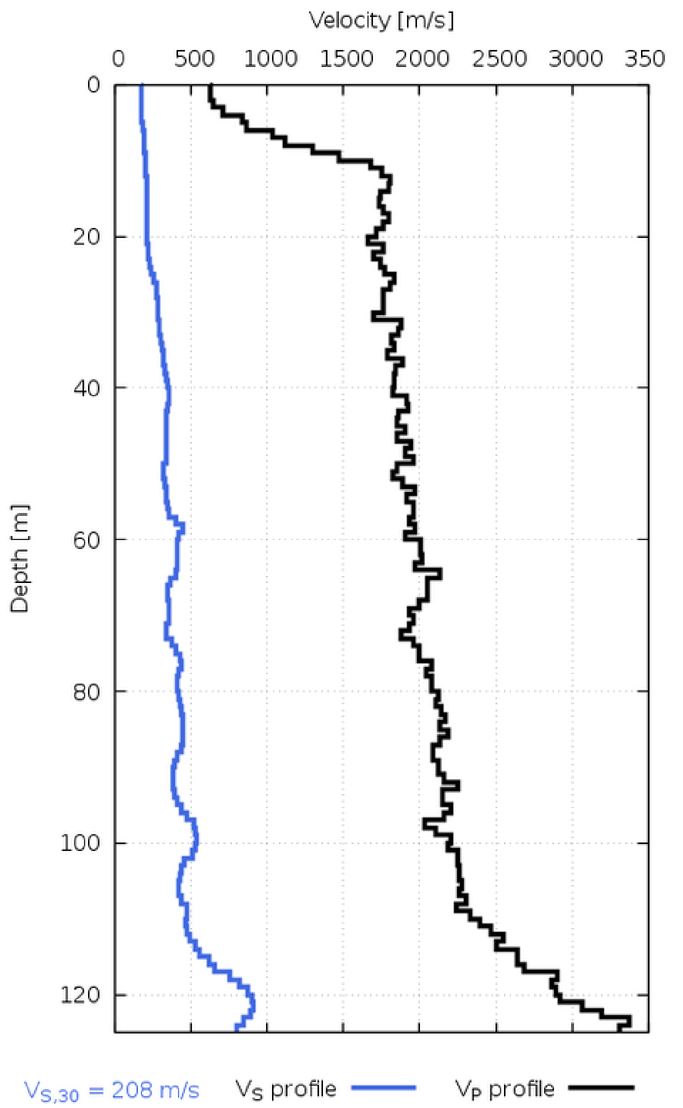

Figure 13. Velocity profiles from Cross-Hole test (CH; Martelli and Romani 2013) redrawn from ESM archive (https://esm-db.eu/). Numerical values are listed in Table 7.

B2. CONCLUSIONS

Based on the results of the InterPACIFIC project, invasive and non-invasive tests indicate IT.MRN station as a site of soil class C. The V_{S30} value using non-invasive or invasive methods is 218 and 209 m/s, respectively (Table 6); therefore IT.MRN is classified following EC8 prescriptions as soil class C consistently with the geological information of the area (see paragraph 5.3). The best Vp and Vs models (i.e. lowest misfit), resulting from the surface-wave inversion of the blind InterPACIFIC test, are proposed in Fig. 10 and show reliability up to a maximum depth of 120 m. The velocity models from invasive methods are shown in Fig. 12 and are consistent with the Cross-Hole test reported in the ESM and ITACA archive (Fig. 13 and Table 7). Because of the similarities between the Vs profiles from non-invasive and invasive methods, we consider the CH model of Fig. 13 as the preferred velocity model for IT.MRN.

Following the definition of $V_{S,eq}$ within NTC18 and because the layer at Vs > 800 m/s is reached at a depth above 30 m, the $V_{S,eq}$ is equivalent to V_{S30} and the soil class remains C (Table 6).

HV noise spectral ratios show in the area a clear peak at around 0.7 Hz.

Table 6. VS30 value from InterPACIFIC analysis by invasive and non-invasive invasive methods (redrawn from Garofalo et al. 2016b). Mean VS30 value, its standard deviation (std) and coefficient of variation (CoV).

Site	Method	$V_{S,30}$ mean [m/s]	$V_{S,30}$ std [m/s]	$V_{S,30}$ COV [–]
Mirandola	Invasive	209	12.1	0.058
	Non-invasive	218	16.3	0.075

Table 7. Best-fit model extracted from CH model in ESM (https://esm-db.eu/#/station/IT/MRN)

from (m)	to (m)	Vs (m/s)	Vp (m/s)
0	1	170	623
1	2	171	627

2	3	172	648
3	4	174	713
4	5	176	832
5	6	180	866
6	7	187	1038
7	8	190	1119
8	9	194	1295
9	10	198	1467
10	11	201	1681
11	12	203	1747
12	13	209	1803
13	14	213	1796
14	15	213	1743
15	16	212	1732
16	17	210	1759
17	18	211	1794
18	19	211	1764
19	20	212	1714
20	21	213	1659
21	22	214	1756
22	23	218	1699
23	24	223	1742
24	25	237	1769
25	26	258	1831

26	27	270	1805
27	28	274	1758
28	29	280	1761
29	30	282	1761
30	31	284	1694
31	32	287	1877
32	33	293	1857
33	34	300	1815
34	35	309	1832
35	36	314	1790
36	37	321	1891
37	38	331	1843
38	39	340	1831
39	40	346	1834
40	41	354	1819
41	42	356	1917
42	43	348	1923
43	44	337	1862
44	45	333	1852
45	46	333	1903
46	47	336	1846
47	48	338	1942
48	49	339	1908
49	50	335	1961

50	51	317	1853
51	52	316	1825
52	53	331	1891
53	54	338	1964
54	55	340	1917
55	56	343	1956
56	57	355	1962
57	58	402	1928
58	59	445	1967
59	60	416	1902
60	61	410	2006
61	62	408	2008
62	63	412	2014
63	64	410	1965
64	65	396	2135
65	66	367	2045
66	67	346	2045
67	68	345	2048
68	69	352	1997
69	70	358	1929
70	71	351	1960
71	72	337	1929
72	73	337	1879
73	74	368	1960

74	75	398	1995
75	76	428	2000
76	77	431	2076
77	78	415	2044
78	79	409	2081
79	80	411	2081
80	81	419	2126
81	82	428	2102
82	83	433	2144
83	84	443	2166
84	85	446	2129
85	86	442	2185
86	87	446	2129
87	88	438	2084
88	89	410	2084
89	90	390	2123
90	91	384	2126
91	92	380	2163
92	93	383	2251
93	94	394	2147
94	95	413	2147
95	96	439	2204
96	97	473	2163
97	98	515	2033

98	99	527	2102
99	100	533	2201
100	101	527	2182
101	102	506	2248
102	103	454	2251
103	104	439	2254
104	105	429	2257
105	106	419	2281
106	107	421	2260
107	108	436	2302
108	109	473	2240
109	110	476	2335
110	111	464	2391
111	112	471	2464
112	113	493	2547
113	114	528	2500
114	115	557	2643
115	116	618	2643
116	117	656	2684
117	118	750	2900
118	119	818	2864
119	120	875	2889
120	121	900	2919
121	122	905	3065

122	123	887	3192
123	124	844	3374
124	125	802	3310

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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)"

GENERAL INFORMATION

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Station description

Station name	Network code	Latitude [WGS84]	Longitude [WGS84]	Sensor depth [m]
MRN	IT	44.87823	11.06174	

Site characterization summary

Indicators				
fo +/ std [Hz]	Value	0.71	Quality index Qi1	1
	References	this report and ESM or ITACA archive		
	URL of report			
Velocity profiles [YES/NO]	Value	YES	Quality index Qi1	1
	References			
	URL of report			
Vs30 +/ std [m/s]	Value	208+/-12	Quality index Qi1	1
	References			
	URL of report			
Surface geology [short description]	Value	Silt and silty clay	Quality index QI1	1
	References	this report		
	URL of report			
Seismological bedrock depth +/ std [m]	Value	118	Quality index Qi1	0.67
	References			
	URL of report			
Site class EC8	Value	C	Quality index Qi1	1
	References			
	URL of report			
Engineering bedrock depth +/ std [m]	Value	118+/-5	Quality index Qi1	1
	References			
	URL of report			

Distance from the seismic station [m]		Final quality index (Final_QI)	Comments
min	min		
5	400	0.98	many geophysical surveys performed within InterPACIFIC project

RESONANCE FREQUENCY

fo +/ STD [Hz]	0.71
Quality index 1	1

Source	Earthquake	☐	Ambient noise	✔

Ambient noise

Method	H/V	✔	Ellipticity	☐	Other	☐
fo +/ std [Hz]	0.71					

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

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	Lennarts	0.2 Hz
Digitizer	**Type**	**Manufacturer**	**Sampling frequency [Hz]**
Measurement	**Number**	**Duration [min]**	
	1	60	

Analysis

Software	DPC analysis
Smoothing type (e.g. triangular, Konno Ohmachi, ...)	**Window length [s]**
Konno-Ohmachi	50

Fo uncertainty estimate from

Fo from individual windows	H/V curve width	Manual picking

Earthquake

Method	HVSR	☐	SSR	☐	GIT	☐	Other	☐
fo +/ std [Hz]	0.59						0.54 (S phase); 0.7 (coda)	

Recording period [DD/MM/YY] from	Recording period [DD/MM/YY] to	Number of earthquakes
		from 25 to 29

Epicentral distance [km] from	Epicentral distance [km] to	Magnitude range from	Magnitude range to
2	93	3	6.1

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]	209+/- 12
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	refer to InterPACIFIC papers			

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]				
DEM resolution		Slope range (degree)	from	
			to	
Reference relationship Slope Vs30				

DEM & Geology

Vs30 +/ STD [m/s]	
Reference relationship Slope Vs30 geology	

Vs profile

Quality index 1	1

refer to the geophysical part of the report

Source	Non invasive methods (active and/or passive seismics)				Invasive methods (measurement in borehole)	
	Active surface waves	✔	Refraction	☐	Cross-hole / Down-hole	✔
	Passive surface waves	✔	Refection	☐	Geotechnical methods (CPT, SPT, ...)	✔
	HV / ellipticity	✔			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
refer to InterPACIFIC papers			44.87715	11.06203

Active surface waves acquisition layout

Minimum receiver spacing (m)	from 1 to 2
Profile length (m)*	from 47 to 94
Geophones number	48
Number of profiles	2

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

Geophone cut-off frequency (Hz)	4.5 and 20
Geophone type (vertical / horizontal)	vertical/horizontal
Geophone manufacturer	
Source (hammer, vibrator, ...)	hammer
Digitizer type	Geode
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	see Table 4 of Garofalo 2016a paper
Minimum array aperture	
Maximum array aperture	
Number of arrays	
Minimum duration [min]	

Sensor cut-off frequency (Hz)	
Sensor type (vertical / horizontal)	
Sensor manufacturer	
Digitizer type	
Digitizer manufacturer	

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	✔	
Love DC	✔	
Ellipticity	✔	
H/V (DFA, EHVR)		
H/V (SH)		

Dispersion curves

	Rayleigh	*Love*
Min wavelength (m)	3	
Max. wavelength (m)	3000	
Min. phase vel. (m/s)	100	
Max. phase vel. (m/s)	2000	
Modes (R0, L0, ...)		

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	
Reference	see InterPACIFIC papers (Garofalo et al. 2016a and 216b; Foti et al. 2018).

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.	

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

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

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 SL - SDMT
Borehole depth (m)	125	125	125			125 - 20
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	✔	see InterPACIFIC papers (Garofalo et al. 2016a and 2016b)

Authoritative velocity profile refer to Table7 of the report

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)
see this report					

Vs range		Vp range	
Vs min (m/s)	Vs max (m/s)	Vp min (m/s)	Vp max (m/s)

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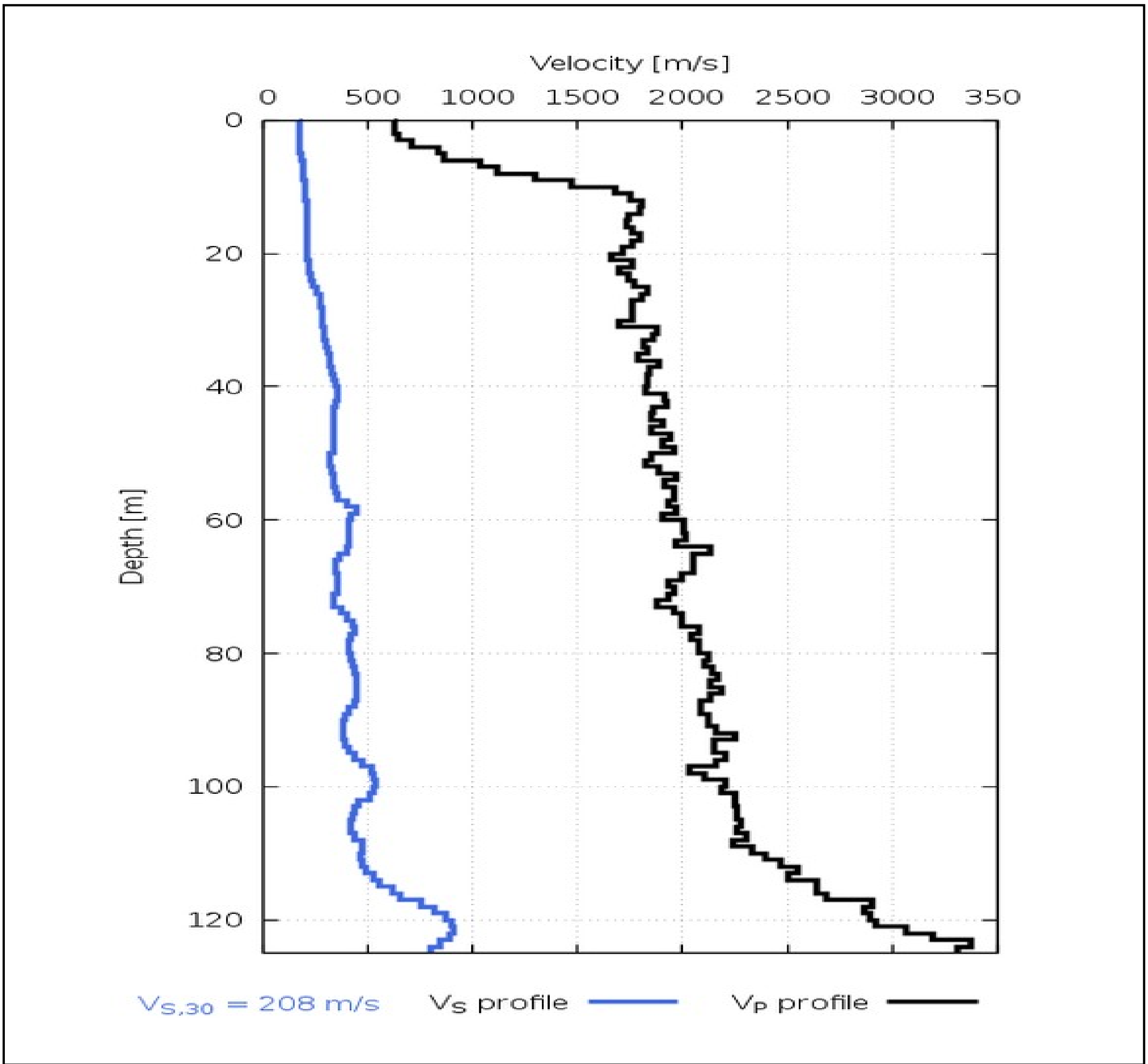
Figure with authoritative velocity profiles



Surface geology

Quality index 1	1

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

Geological map

Map reference	New geological map	
Map scale	1:5000	
Map sheet		
Predominent geologic/lithologic unit	Name :	AES8 - Ravenna Subsynthem
	Description :	Silt and silty clay of flood plain
	Age :	Holocene
	Thickness :	9 m
	Rock mass structure :	
Fault presence		
Weathering		
Cross section		

Field survey

Map reference		
Map scale	1:5000	
Predominent geologic/lithologic unit	Name :	see the report
	Description :	
	Age :	
	Thickness :	
	Rock mass structure :	
Fault presence		
Weathering		
Cross section		

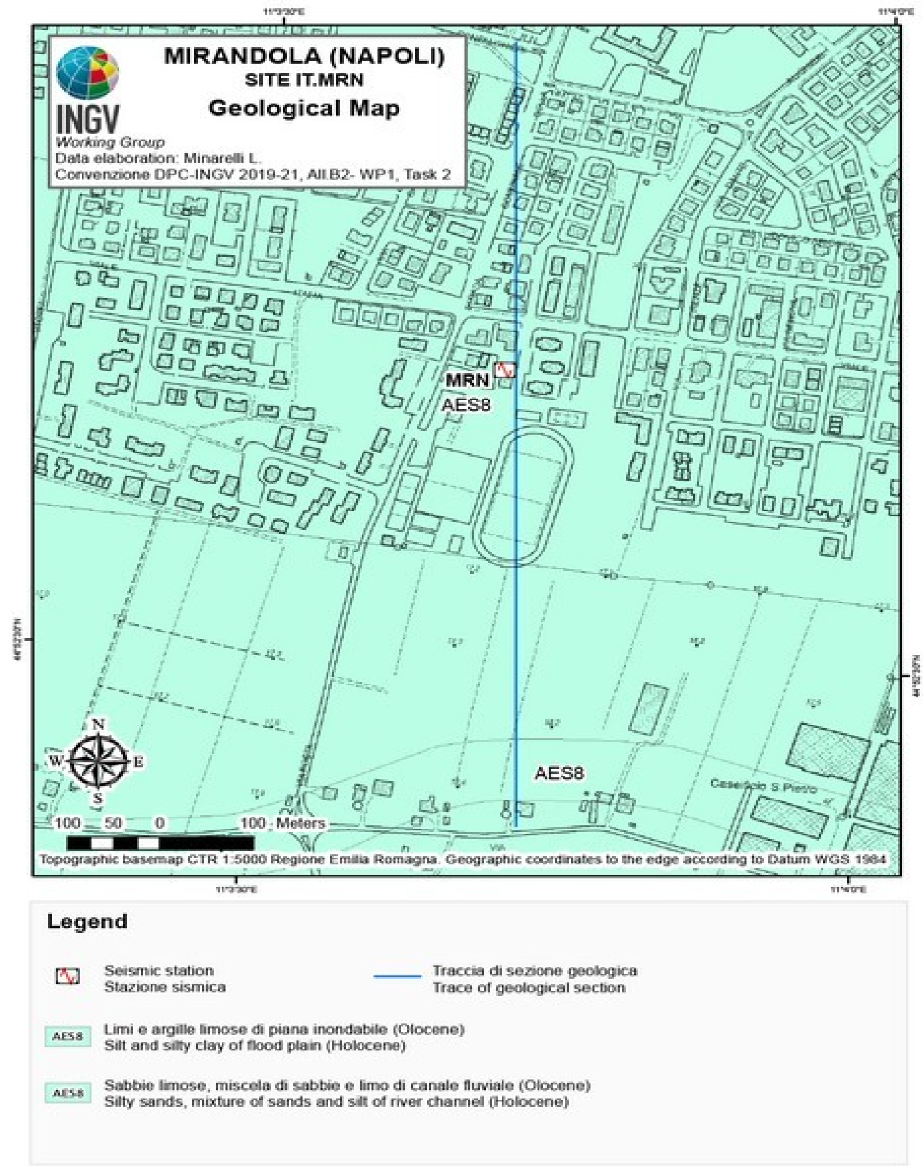
Stratigraphic log

log depth (m)	130

Top depth (m)	Bottom depth (m)	Stratigraphic description
0	9	Silt and silty 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, ...)	EC8, NTC08, NTC18

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

Reference relationship geology soil class	
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, VSEQ

Seismological bedrock depth

Depth +/ STD [m]	118
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)	118 +/- ?	118	
Bedrock Vs +/ STD(m)	818 +/- ?		
Bedrock Vp +/ STD(m)	2900 +/- ?		
Is Vs derived from Vp ?	Yes ☐ No ✔		

Resonance frequency

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

Geology

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

Stratigraphic log

Bedrock depth +/ STD(m)	113
Bedrock geological unit	Marine silt and sand partially lithified - Pliocene turbiditic formation
Reference	this report and Martelli&Romani 2013, Paolucci et al. 2015.

Other methods

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

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Engineering bedrock depth

Depth +/ STD [m]	118+/-5
Quality index 1	1

Reference Vs related to engineering bedrock in m/s	800	Reference building code for site classification (EC8 1, EC8 2, NEHRP, national code, ...)	EC8, NTC18

Source	Vs profile	✔	Geology		Stratigraphic log	✔

Vs profile

	Non invasive methods	Invasive seismic methods	Geotechnical methods
Bedrock depth +/ STD(m)	118	118	

Is Vs derived from Vp ?	Yes		No	✔

Geology

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

Stratigraphic log

Bedrock depth +/ STD(m)	113
Bedrock geological unit	Marine silt and sand partially lithified - Pliocene turbiditic formation
Reference	this report and Martelli&Romani 2013, Paolucci et al. 2015.