Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions – Silvestri & Moraci (Eds)
© 2019 Associazione Geotecnica Italiana, Rome, Italy, ISBN 978-0-367-14328-2

Site amplifications in the epicentral area of the 2016, M 6, Amatrice earthquake (Italy)

F. Pacor, C. Felicetta, G. Di Giulio, G. Lanzano, L. Luzi, G. Milana, G. Cultrera, F. Cara & D. Famiani
Istituto Nazionale di Geofisica e Vulcanologia, Italy

S. Hailemikael
Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Rome, Itlay

I. Gaudiosi & M. Moscatelli
Istituto di Geologia Ambientale e Geoingegneri-CNRa, Montelibretti, Rome, Italy

D. Spallarossa
Università degli studi di Genova, Genova, Italy

R. De Franco
Istituto per la Dinamica dei Processi Ambientali-CNR, Milan, Italy

M.R. Gallipoli
Istituto di Metodologia per l'Analisi Ambientale-CNR, Matera, Italy

F. Pergalani
Politecnico di Milano, Milan, Italy

ABSTRACT: The first mainshock (Mw 6.0) of the 2016 Central Italy seismic sequence, severely struck the Amatrice village and the surrounding localities. After few days, some Italian Institutions, coordinated by the "Center for Seismic Microzonation and its applications", carried out several preparatory activities for seismic microzonation of the area. A temporary seismic network was installed that monitored about 50 sites in epicentral area. The network produced a huge amount of records in a wide range of magnitude up to Mw 6.5. For about half of the recording stations, detailed site characterization was undertaken, encompassing single-station noise measurements and S-wave velocity profiles. The geological and geophysical data together with the collected dataset of seismic signals were exploited to investigate the site response of selected stations. Significant amplifications are found in correspondence of several sites that experienced high level of damage (I_{mcs} >IX), mainly at short and intermediate periods.

1 INTRODUCTION

A wide region of Central Italy has experienced a long-lasting seismic sequence, started on August 24th 2016 with a Mw 6.0 earthquake occurred near Accumoli and Amatrice municipalities, followed by two other strong events (Mw 5.9 and Mw 6.5) located north-western of Amatrice, close to Ussita and Norcia hamlets, respectively (Figure 1).

The area is located in the Central Apennines mountain range, which is characterized by a rather complex geological and geomorphological setting due to its polyphasic tectonic evolution (Cosentino et al., 2010, and references therein). The first mainshock caused huge damages in the epicentral region, covering an area trending broadly N-S and extending 15 km in length and 5 km in width (Quest W.G., 2016). Some localities suffered total destruction (I_{mcs} X) such

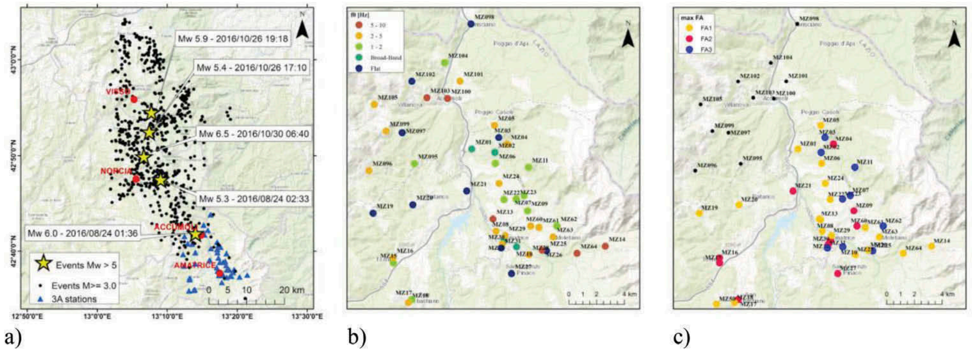


Figure 1. a): Map of the epicentral area, with the color scale proportional to the elevation. Events with M≥5 are shown as red stars; the seismic stations of the network 3A are shown as blue triangles. The analyzed events (M≥3) are indicated as black circles. b-c) Spatial distribution of the stations installed in the Amatrice municipality: b) the colors represent the fundamental frequencies (f0) evaluated from ambient noise analysis; c) the colors represent the maximum amplification factor (max FA, see Eq. 1) selected among the three values estimated in the frequency ranges: 2-10 Hz (FA1, in yellow), 1.25-2.5 Hz (FA2, in pink) and 0.9-1.45 Hz (FA3, in blue).

as the historical downtown Amatrice and several villages were severely damaged (I_{mcs} from VII to IX).

Few days after the first mainshock, the Department of Civil Protection (DPC; www.protezionecivile.gov.it) commissioned the “Center for Seismic Microzonation and its applications” (CentroMS; www.centromicrozonazionesismica.it) to coordinate a series of geophysical, geological, and geotechnical surveys, with the final goal of performing detailed preparatory work for seismic microzonation (MS3, so called “level 3”, after, SM Working Group, 2008). Among these activities, the installation of two temporary seismic networks was also planned to monitor four municipalities, with the aim of providing accelerometric and velocimetric records useful for investigating the amplification effects in the most damaged hamlets: Amatrice and Accumoli, in the Lazio Region, and Arquata del Tronto and Montegallo, in the Marche Region (Laurenzano et al., 2017).

This work focuses on the site response assessment of the temporary seismic network installed at Amatrice and Accumoli municipalities, using Standard Spectral Ratio (SSR) and the Horizontal-to-Vertical Spectral Ratio (HVSR) and 1D modelling.

2 TEMPORARY NETWORK AND RECORDINGS

The 3A temporary network ((doi: 10.13127/SD/ku7Xm12Yy9; Cara et al. submitted), composed by 50 seismic stations, was installed for seismic microzonation purposes in the epicentral area (Figure 1) by different institutes, operating from about mid of September to end of November 2016. . In particular, one of the aim of this network was to provide seismic data useful to evaluate empirical amplifications functions and factors for comparing and validating numerical simulation results. Each station of the network 3A operated in continuous modality, and the majority of the sites was instrumented with both velocimeter and accelerometer. Recording stations were deployed in correspondence of the localities that suffered the most damages, also monitoring local geological-geomorphological conditions that could severely affect the ground-motion characteristics in the area. Moreover, some stations were installed on outcropping rock to be used as reference sites (Table 1).

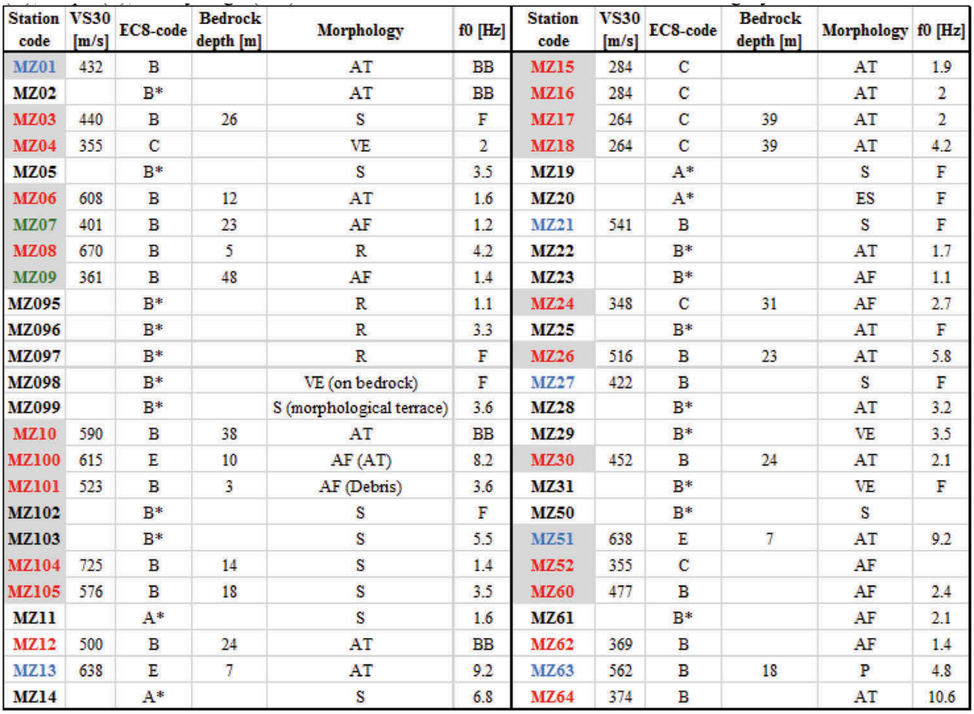
The number of earthquake recordings is huge, especially at short epicentral distance (< 50 km), including the two stronger events after the Mw 6.0 August 24 earthquake. The records relative to the main events are available in the Engineering and Italian Strong Motion databases (ESM, http://esm.mi.ingv.it, ITACA 3.0 http://itaca.mi.ingv.it) The complete and revised dataset (99 Gb archive of continuous waveforms in miniseed format) will be soon distributed in the EIDA archive (http://eida.rm.ingv.it).

For investigating site effects on the 3A stations, we selected 615 events from the Italian Seismic Bulletin (http://cnt.rm.ingv.it/) in the magnitude range 3.0 - 6.5 (Figure 1a) within a radius of 55 km from Amatrice village.

3 GEOLOGICAL FRAMEWORK AND GEOPHYSICAL DATA

The Amatrice and Accumoli municipalities lie inside the Amatrice basin, filled by a thick succession of siliciclastic deposits Messinian in age (Laga formation), which represents the geologic bedrock of the area (Milli et al., 2013). This geologic formation is characterized by alternating of rigid arenaceous and more ductile pelitic units, that have different elastic properties. The Quaternary evolution of the area was characterized by continental sedimentation, which in turn, was controlled by the climate change and regional differential uplift (Cacciuni et al 1995). The continental units are mainly constituted by gravel and sand deposits in the valley floors, alluvial terraces, and fan, while thick debris covers are often found along the slopes, which are characterized by intense and widespread gravitational processes. Therefore, due to the complex origin and evolution of the area, there is a large variability in the geological and geomorphological conditions at the recording sites, as summarized in Table 1.

Table 1. Site parameters for stations of the network 3A: average shear-wave velocity in the upper 30 m ($V_{S,30}$), Eurocode 8 soil category (* if inferred from surface geology), seismic bedrock depth, morphological configuration and fundamental frequency (f0) estimated from HV spectral ratio from noise measurements. Station codes are colored according to the method for estimation of the Vs profile: blue for multichannel analysis of surface waves, red for down-hole measurement and green for passive 2D array measurements. Morphological configuration: alluvial terrace (AT); alluvial fan (AF); edge of scarp (ES); plain (P); ridge (R); slope (S); valley edge (VE). 1D subsoil model was built for the stations in grey.



Station code	VS30 [m/s]	EC8-code	Bedrock depth [m]	Morphology	f0 [Hz]	Station code	VS30 [m/s]	EC8-code	Bedrock depth [m]	Morphology	f0 [Hz]
MZ01	432	B		AT	BB	MZ15	284	C		AT	1.9
MZ02		B*		AT	BB	MZ16	284	C		AT	2
MZ03	440	B	26	S	F	MZ17	264	C	39	AT	2
MZ04	355	C		VE	2	MZ18	264	C	39	AT	4.2
MZ05		B*		S	3.5	MZ19		A*		S	F
MZ06	608	B	12	AT	1.6	MZ20		A*		ES	F
MZ07	401	B	23	AF	1.2	MZ21	541	B		S	F
MZ08	670	B	5	R	4.2	MZ22		B*		AT	1.7
MZ09	361	B	48	AF	1.4	MZ23		B*		AF	1.1
MZ095		B*		R	1.1	MZ24	348	C	31	AF	2.7
MZ096		B*		R	3.3	MZ25		B*		AT	F
MZ097		B*		R	F	MZ26	516	B	23	AT	5.8
MZ098		B*		VE (on bedrock)	F	MZ27	422	B		S	F
MZ099		B*		S (morphological terrace)	3.6	MZ28		B*		AT	3.2
MZ10	590	B	38	AT	BB	MZ29		B*		VE	3.5
MZ100	615	E	10	AF (AT)	8.2	MZ30	452	B	24	AT	2.1
MZ101	523	B	3	AF (Debris)	3.6	MZ31		B*		VE	F
MZ102		B*		S	F	MZ50		B*		S	
MZ103		B*		S	5.5	MZ51	638	E	7	AT	9.2
MZ104	725	B	14	S	1.4	MZ52	355	C		AF	
MZ105	576	B	18	S	3.5	MZ60	477	B		AF	2.4
MZ11		A*		S	1.6	MZ61		B*		AF	2.1
MZ12	500	B	24	AT	BB	MZ62	369	B		AF	1.4
MZ13	638	E	7	AT	9.2	MZ63	562	B	18	P	4.8
MZ14		A*		S	6.8	MZ64	374	B		AT	10.6

The 1D subsurface seismic models of the recording sites were derived from detailed geological surveys and stratigraphic logs, geotechnical in-situ and laboratory tests and tens of geophysical surveys (resistivity, tomographies, single-station ambient vibration measurements, active and passive surface-wave tests, refraction surveys) performed during the preparatory activities carried out for seismic microzonation (EmerTer Project Working Group, 2018). Some of the drilled boreholes were also used to estimate the shear-wave velocity (Vs) profiles through down-hole (DH) in-situ tests. The majority of the profiles associated to the stations refer to DH performed within a radius of about 100 m from the site and, in first approximation, in similar subsurface conditions.. The maximum investigation depth varies from 20 to 50m, and in several cases, the geological bedrock was reached, showing high variability of Vs values, in the range 350-1500 m/s. The lower values are ascribable in the first 20 m depth and are likely due to the weathering processes. As a consequence, the shallower layers of the geologic bedrock cannot be assumed as the seismic bedrock (average shear-wave velocity of the top 30 m, VS30, > 800 m/s), according to the national and European building codes. For few sites, the Vs profiles were estimated by passive surface-wave surveys for depths greater than the maximum ones reached by core-drillings and down-holes, showing the presence of a significant seismic impedance contrast.

In Table 1 the inferred Vs30 values for the investigated stations are listed.

4 METHODS

Earthquake and seismic noise recordings were analyzed to provide several site parameters useful to characterize the seismic response of the investigated localities, such as the resonance frequency (f0), the amplification factors and the empirical amplification functions. Different spectral techniques were applied for estimating each parameter. The analyses were carried out in the frequency band 0.3 - 20 Hz.

4.1 *HV from noise and earthquake*

The Horizontal-to-Vertical Spectral ratios (HV) technique can be applied to ambient noise (HVSR) and seismic records (EHV) and it can be used both for determining the resonance frequency of the subsurface structure and for estimating the amplification function in those cases where a reference site is not available (Field and Jacob, 1993; Lachet and Bard, 1994), assuming that the vertical motion is not affected by site effects. The EHV ratios were evaluated using small events ($M < 4.5$), recorded by the network 3A, to minimize the source effects; they were automatically calculated by selecting fixed signal windows, with a length of 12s, starting from 0.1s before the arrival of the S-waves and smoothing the corresponding acceleration Fourier spectra following the method proposed by Konno & Ohmachi (1998) and using a coefficient of 30 for the bandwidth. For each station, the EHV ratio was then computed as the geometric mean of the individual ratios, calculated for each component and event. On the other hand, the ambient noise measurements were analyzed following the procedure proposed by Puglia et al. (2011) for estimating the fundamental frequencies f0 (Figure 1b); generally, the values of f0 obtained from EHV and HVSR are very similar, with minor differences when the amplitude of the peaks are small (amplitude around 2) or the curves are broad-band.

4.2 *SSR*

The Standard Spectral Ratio technique (SSR; e.g., Borcherdt, 1970; Parolai et al., 2000) consists in comparing the horizontal Fourier spectra at nearby sites, using one as the reference. When we apply this method to estimate the site response, we assume that the contribution of the source and the propagation path is the same for the reference site (in general, a station installed on outcropping rock) and the other sites. Although the stations MZ11 and MZ14 were installed on the geological bedrock (sandstones and marls), these sites cannot be used as reference sites because preliminary analysis on HVSR curves showed small amplification at intermediate- and high- frequencies, probably due to the presence of weathered/fractured rock layer with Vs lower than 800 m/s. To overcome this problem, the INGV temporary station T1299 (Figure 1a,) Moretti et al., 2016) was selected as reference. This site is characterized by HVSR values lower than 2 in the entire frequency band and it is located in a relatively middle position with respect to the entire network 3A. To estimate the SSR functions, for each station and event we selected time-windows of 5s starting from 0.2s before the arrival of the S-waves of each horizontal ground-motion component. We then removed the mean, the linear trend and applied a 5% cosine taper to each end of the time-windows. Next, we computed the smoothed Fourier spectra and the corresponding spectral ratio relative to the reference site. The spectra were smoothed following the method proposed by Konno & Ohmachi (1998) using a coefficient of 40 for the bandwidth. Finally, the single horizontal SSR were combined using the geometric mean.

A similar approach was also applied to the acceleration response spectra (hereinafter SA), with the aim of computing the Amplification Factors (FAs). The SA were computed on 100 periods ranging from 0.01 to 10s, evenly spaced on a logarithmic scale, using a 15s length time window starting from 1s before the P-waves arrival. FA is defined according to the Italian Guidelines for Seismic Microzonation (SM Working Group, 2008), as the ratio between the integrated values of the response spectra, computed for site (RS_{site}) and reference (RS_{ref}):

$$FA_i = \frac{RS_{i,site}}{RS_{i,bed}} \qquad \text{where:} \qquad RS_i = \frac{1}{\Delta T}\int_{\Delta T} SA(T)_i dT \tag{1}$$

The FA_i evaluated for each event *i* were averaged using the geometric mean to obtain the amplification factor FA_{site} at the site. In agreement with the seismic microzonation studies, three period intervals were considered: ΔT1 [0.1-0.5s]; ΔT2 [0.4 - 0.8s]; ΔT3 [0.7 - 1.1s] and the amplification factors FA1, FA1, and FA3 were named accordingly.

4.3 *1 D modeling*

Data of the geophysical and geological surveys were used to assess a 1D subsoil model at 24 selected sites (Table 1, in grey) of the network 3A. For these sites, an accurate 1D layered model was built, exploiting the Vs profiles obtained mainly by DH tests and, only in few cases, by active surveys and passive surface-wave array experiments to constrain the Vs profile at depth larger than 50 m. Using these models as base, we computed theoretical transfer functions by a 1D convolution approach using the STRATA software (Kottke and Rathje 2009), which performs linear-elastic and equivalent-linear site response analyses. The software allows for stochastic variation of the site properties, including the values of Vs, layer thicknesses, depth to bedrock, and strain-dependent soil properties (i.e., shear modulus reduction, G/G0, and damping, D, curves).

As input motion at the bedrock level, we used 7 strong-motion data compliant with the 475 years return period spectrum of the Italian seismic code (Luzi et al., submitted). The input set includes records of the 2016 seismic sequence (4 records of the Mw 6.5 on October 30; 3 records of the Mw 5.9 event on October 26). The G/G0 and D curves were selected from literature data or from the laboratory surveys performed on few subsoil samples provided by borehole drilled in the epicentral area. (EmerTer Project Working Group, 2018).

For each investigated site, the transfer function (the ratio between the signals obtained at the surface and at the seismic bedrock in outcropping condition) was computed averaging 200 simulations, obtained varying the Vs values following the correlation models of Toro (1995) developed for NEHRP class B (Vs30 between 360 and 750 m/s), in a range ±20% with respect to the average Vs value. In this preliminary analysis we decided to use only one correlation model for all sites. The site class B was selected because the majority of the stations of the network 3A falls in this class and several C class sites present Vs30 values very close to the lower bound of site class B (MZ04=355 m/s, MZ24=348 m/s, MZ52=355 m/s, Table 1). When the seismic bedrock (i.e. Vs> 800m/s) was not found in the Vs profile by DH tests, the bedrock depth was also varied up to 200m using a uniform distribution and average Vs of 1250 m/s.

5 RESULTS

5.1 *Comparison with 1D modelling*

To evaluate the accuracy of the site characterization of the stations of the network 3A and the correctness of the 1D approximation in the evaluation of site response, we compared the empirical amplification functions (SSR and EHV) and with the theoretical 1D transfer functions. Considering that the empirical amplification functions come from a dataset of small-moderate magnitude events and that non-linear stress-strain and damping curves were not available at the time we performed this analysis, we compared only the numerical results obtained in the linear-elastic condition.

A systematic comparison between numerical and experimental results is still ongoing; as an illustrative example, the comparison for two sites, representative of widespread geological-geomorphological conditions in the area are shown: MZ10-San Cipriano (Amatrice municipality) and MZ105-San Giovanni (Accumoli municipality). MZ10 station was installed on the top of the Amatrice alluvial terrace, close to its SW gentle slope. The borehole log shows a 40m thick fining upward succession of alluvium (sands and gravels) with 40 m thickness overlying the bedrock. In this case, the geologic bedrock corresponds to the seismic bedrock because at depth of 38 m was found the Laga Formation with Vs of about 1200 m/s (Figure 2, top right panel). MZ105 was installed on a steep slope of the NE flank of the Sibillini Mts. In this sector, alternating sandstones and marls of the Laga Formation unit crops out and a large part of the slope is involved in gravitational processes. The Vs profile associated to MZ105 was retrieved by a DH test performed at a distance of about 100 m. The profile shows a sharp increase in Vs from about 250 m/s to 800 m/s at 5 m depth. The maximum Vs of more than 1400 m/s was reached at 22 m depth (Figure 3, bottom right panel). The two sites are both classified as EC8-soil category B (Table 1), having Vs30 equal to 590 m/s and 576 m/s), respectively, whereas they are located on different morphological conditions (Table 1). As expected, the seismic response between the two sites is different (Figure 2). MZ10 does not show significant amplification, and the agreement between experimental (black and blue curves, Figure 2 top left panel) and theoretical 1D transfer functions (red curve, Figure 2, top left panel) is fairly good. In contrast, MZ105 is characterized by larger amplitudes (Figure 2, bottom left panel): the experimental curves are peaked at 3Hz and 6Hz, with amplitude around 6, while the 1D transfer function only reproduces the high frequencies amplification (f >6Hz). The observed differences between the SSR and EHV curves may be related to the site response of the vertical components, that can amplify the ground motion, especially at frequencies > 8 Hz.

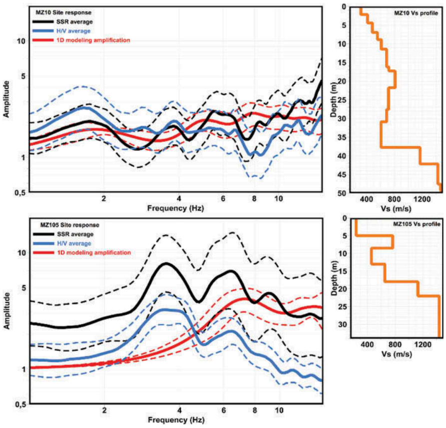


Figure 2. Comparison between experimental curves (EHV in blue, SSR in black) and 1D theoretical linear-elastic transfer functions (red curves). The top and bottom panels refer to sites MZ10 and MZ105, respectively. On the right, the Vs profiles derived from geophysical surveys are also shown.

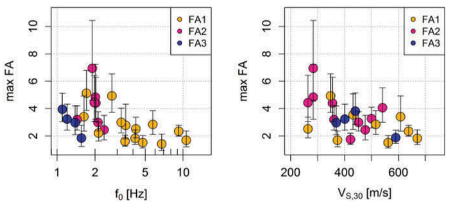


Figure 3. Maximum empirical amplification factors plotted in function of (left) the fundamental frequency f0 and (right) the average shear-wave velocity in the upper 30 m (VS,30). For each station, the maximum amplification factor (max FA) is selected among the three values estimated in the frequency ranges: 2-10 Hz (FA1, in yellow), 1.25-2.5 Hz (FA2, in pink) and 0.9-1.45 Hz (FA3, in blue).

5.2 *Fundamental frequencies and amplification factors*

The spatial distribution of f0 (Figure 1b, left panel) is largely variable, with a dominance of sites with resonances at intermediate and high frequencies (>2Hz) or broad-band behaviors. Only few sites are free from any resonance (HVSR flat), and are located on the geological bedrock at the Eastern slope of the Sibillini Mts to the W (MZ19, MZ20, MZ097, MZ102) and at the foothill of the Laga Mts to the E (MZ03) over the geologic bedrock (Flysch Fm). Low values of f0 are found only at the stations located over unconsolidated sediments, at the foothill of the Laga Mts.

The empirical amplification factors FA reproduce the spatial distribution of f0 (Figure 1b, right panel), with the majority of the sites having the maximum amplification in the frequency range 2-10Hz. This result indicates that, in the investigated area, there is a good correlation between maximum amplification factors (maxFA) and fundamental frequencies, as shown in Figure 3 (left). Conversely, the correlation between Vs30 and maxFA is poor (Figure 3 right), suggesting that this parameter is not enough efficient to represent the site amplification. However, it is worth noting that, in some cases, although DH measurements were performed very close to the stations, they may not be representative of the real profile under the site, due to the complexity of the geological and geomorphological setting.

6 DISCUSSION AND CONCLUSION

This study produced the first results useful to characterize the site response of stations of network 3A and, more in general, to investigate the amplification effects occurred during the Amatrice earthquake in the epicentral area.

First of all, these results were used to compile crucial information of the station-form delivered to CMS, in the format proposed by Priolo et al. (submitted) for seismic microzonation purposes. In particular, the H/V curves, the fundamental frequencies, the EC8 soil category, the VS30 values and the empirical amplification factors were included. Furthermore, the main geological and geophysical information (geological map, shear-wave velocity profiles, morphological description) collected during this study to build the 1D geological models, as well as the results of the seismological analysis, were stored for the compilation of the station reports of the Italian and Engineering strong motion databases (http://itaca.mi.ingv.it and http://esm.mi.ingv.it).

The preliminary results on the comparison between empirical amplification functions and 1D theoretical site amplifications show a poor agreement, also in the linear-elastic condition. Considering the SSR function as the benchmark for site response estimation, the almost systematic bias in the numerical simulations may be explained by three main factors: i) a large part of the investigated sites is located in geological-geomorphological conditions which violate the 1D assumption (as shown in Table 1, several morphology classes are steep slopes, valley floors and terrace edges) and 2D and 3D seismic-wave propagation should be considered for evaluating realistically the site response; ii) in some cases, the Vs profiles inferred from DH tests may not be representative of the soil profile under the station, due to the high variability of the geological and geomorphological conditions of the investigated area; iii) even in those cases where the 1D wave propagation assumption may be considered fulfilled, the investigation depth of DH tests is, in general, within the first 30 m. Only in few cases the investigation depth reaches 50 m. When the seismological analysis estimate low values of f0 (< 2 Hz), corresponding to wavelength longer than 100m, the investigation depth may be not sufficient to reach the main seismic impedance contrast, responsible for low-frequency peaks observed in the amplification functions. Further efforts will be spent to carry out a systematic comparison between experimental and numerical site response estimates, in order to evaluate the goodness of the characterization obtained from all the microzonation studies and include the 2D and 3D effects in the amplification functions.

REFERENCES

Borcherdt, R.D., 1970, Effects of local geology on ground motion near San Francisco Bay, Bull Seism Soc Am 60, 29–61.

Cacciuni, A., Centamore, E., Di Stefano, R., and Dramis, F., (1995). Evoluzione morfotettonica della Conca di Amatrice, Studi Geologici Camerti, S.V.: 2, 95-100, in Italian.

Cara F. et al. (submitted). Temporary dense seismic network during the 2016 Central Italy seismic emergency for microzonation studies

Cosentino, D., Cipollari, P., Marsili, P., Scrocca, D. (2010). Geology of the central Apennines: a regional review. In: Beltrando,M., Peccerillo, A., Mattei,M., Conticelli, S., Doglioni, C. (Eds.), The geology of Italy: tectonics and life along plate margins. Journal of the Virtual Explorer Vol. 36 (paper 12)

EmerTer Project Working Group (2018): Report relativo all'Accordo ai sensi dell'art. 15 Legge 7 agosto 1990 n. 241, e dell'art.6 della Legge 24 febbraio 1992, n. 225 tra il DPCe IGAG-CNR(Prot. CNR IGAG n. 1484 del 17/ 05/2017),Prot. CNR IGAG n. 359 del 30/ 01/2018(in Italian).

Field, E.H. and Jacob, K.H. (1993). The Theoretical Response of Sedimentary Layers to Ambient Seismic Noise, Geophys. Res. Let., 20, 2925–2928.

Konno, K. and Ohmachi, T. (1998). Ground-Motion Characteristics Estimated from Spectral Ratio between Horizontal and Vertical Components of Microtremor, Bull. Seism. Soc. Am., 88:1, 228–241.

Kottke, A. R., & Rathje, E. M. (2009). Technical manual for Strata. PEER Report 2008/10 Pacific Earthquake Engineering Research Center College of Engineering University of California, Berkeley.

Lachet, C. and Bard, P.Y. (1994). Numerical and Theoretical Investigations on the Possibilities and Limitations of Nakamura's Technique, J. Phys. Earth, 42, 377–397.

Laurenzano G, Barnaba C, Romano MA, Priolo E, Bertoni M, Bragato P L, Comelli P, Dreossi I, Garbin M (2018) The Central Italy 2016–2017 seismic sequence: site response analysis based on seismological data in the Arquata del Tronto–Montegallo municipalities. Bull Earthquake Eng. https://doi.org/10.1007/s10518-018-0355-3

Luzi L., Pacor F., Lanzano G., Felicetta C., Puglia R., D'Amico M. (submitted). 2016-2017 Central Italy seismic sequence: strong-motion data, seismic hazard and design earthquakes for the seismic microzonation.

Milli, S., Cannata, D., Marini, M., Moscatelli, M. (2013). Facies and geometries of Lower Messinian Laga Basin turbidite deposits (central Apennines, Italy). Excursion Guidebook, XI GeoSed Post-Congress Field Trip. Journal of Mediterranean Earth Sciences Vol. 5, pp. 179–225.

Moretti M et al 2016. The Amatrice seismic sequence: preliminary data and results, Annals of Geophysics 59(5), https://doi.org/10.4401/ag-7212

Parolai, S., Bindi D., and Augliera P. (2000). Application of the generalized inversion technique (GIT) to a microzonation study: Numerical simulations and comparison with different site-estimation techniques, Bull. Seismol. Soc. Am. 90, 286–297

Puglia, R., Albarello, D., Gorini, A. Luzi L., Marcucci S., Pacor F. (2011). Extensive characterization of Italian accelerometric stations from single-station ambient-vibration measurements. Bull Earthquake Eng 9: 1821. https://doi.org/10.1007/s10518-011-9305-z

Quest W.G.: Azzaro R. et al. (2016). The 24 August 2016 Amatrice earthquake: macroseismic survey in the damage area and EMS intensity assessment. ANNALS OF GEOPHYSICS, 59, FAST TRACK 5, 2016; DOI: 10.4401/ag-7203

Working Group SM (2008). Indirizzi e criteri per la micronozazione sismica. Conferenza delle Regioni e delle Provincie autonome - Dipartimento della protezione Civile, Roma. In Italian

Toro, G.R., (1995). Probabilistic models of site velocity profiles for generic and site-specific ground-motion amplification studies, Technical Report 779574, Brookhaven National Laboratory, Upton, NY.