



2016–2017 Central Italy seismic sequence: strong-motion data analysis and design earthquake selection for seismic microzonation purposes

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Abstract

This work describes the analysis of the strong-motion data from the Engineering Strong Motion database (ESM, <http://esm.mi.ingv.it>), aimed at: (1) extract a dataset of accelerometric waveforms recorded during the 2016–2017 Central Italy seismic sequence; (2) identify the recording stations to be used as reference sites for further seismological analysis; (3) select the records to be used as input for seismic microzonation of higher level at 137 municipalities. Firstly, a residual analysis is carried out on the extracted dataset to perform: (1) the quality check of the waveforms recorded by temporary networks installed soon after the occurrence of the first main shock (M 6.0, 24 August 2016); (2) the estimation of the site-to-site residual term for each recording station with the aim of recognising potential reference rock sites. Finally, the software REXELite, integrated within the ESM website, is adopted to select suites of spectrum-compatible accelerograms, that will be used as input for calculating site amplifications through 1D and 2D simulations at sites which suffered the greatest damage. The results of this work demonstrate the success of the synergy among Italian institutions. The setup of key infrastructures, such as emergency networks and data repositories, together with the knowledge developed during national projects, turned out to be successful in terms of timely intervention during the emergency phase and the planning of the post-emergency.

Keywords Seismic sequence · Seismic microzonation · Design spectra · Residual analysis

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1 Introduction

The 2016–2017 Central Italy seismic sequence struck one of the territories with the highest seismic hazard in Italy (Meletti et al. 2016; CPTI15, Rovida et al. 2016) and caused large damages and fatalities (Galli et al. 2017; Fiorentino et al. 2018), suffered by more than hundred municipalities included in a wide area involving four Italian regions (Lazio, Abruzzo, Umbria and Marche).

This territory has been experiencing a long history of damaging earthquakes (CPTI15, Rovida et al. 2016), that sometimes occurred within sequences, such as that of 1703, representing the historical maximum of the area. The Central Italy is characterized by a moderate to high seismic hazard according to the current Italian seismic hazard map (MPS04; Stucchi et al. 2011): Peak Ground Accelerations (PGAs) expected with a probability of exceedance of 10% in 50 years are in the range 0.225–0.275 g (Fig. 1a).

After the first emergency phases, in 2017, the Italian government has implemented regulatory measures in support of the population affected by the disaster (ord. 24, 12/05/2017, see <https://sisma2016.gov.it/2017/05/15/ordinanza-n-24-registrata-il-15052017-al-numero-1065/>, in Italian), including the most detailed level of Seismic Microzonation (so called third level, MS3, Dipartimento della Protezione Civile 2008) in the territory of 137 municipalities (Fig. 1b). The “Center for Seismic Microzonation and its applications” (*Centro di Microzonazione Sismica e sue applicazioni*, CMS; www.centromicrozonazione.sismica.it), on behalf of the Department of Civil Protection (DPC), was in charge of supporting and coordinating the scientific and technical activities of the microzonation by means the establishment of several thematic units. The Seismic Input Thematic Unit (UTIS), in particular, had the task to select: (1) the reference sites for the thematic unit in charge of the seismological analysis (Priolo et al. 2018, this issue), and (2) suites of seven accelerograms to be used as input for the site response modelling of the 137 municipalities.

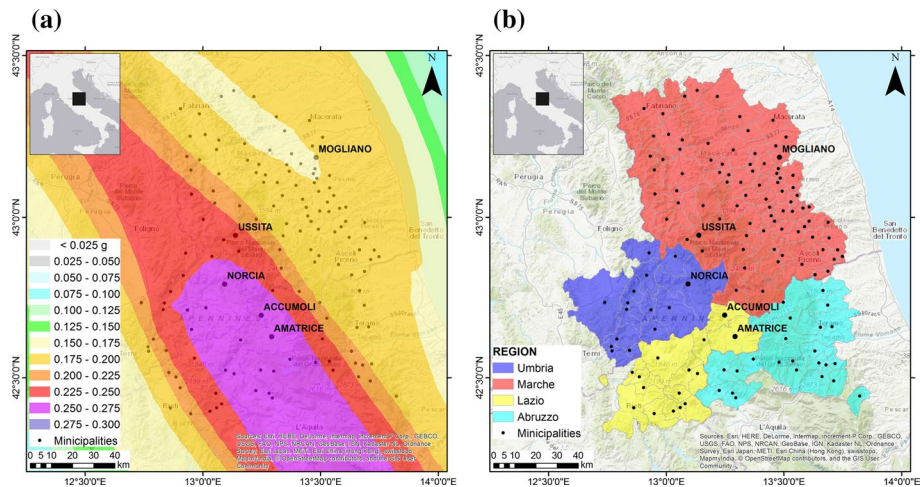


Fig. 1 **a** Zoom on the Italian seismic hazard map (PGA for return period of 475 years; Stucchi et al. 2011); **b** location of the 137 municipalities involved in the seismic microzonation studies of third level: the grey lines represent the borders of the municipality, the black points the centroids, the coloured area indicate the regions

Due to the need to provide useful products for the reconstruction phase, this work was carried out in few months. This result was possible thanks to the synergy among public institutions in the development and maintenance of key infrastructures, such as emergency networks and data repositories, allowing to reduce the timing of intervention during the emergency phase and the following actions of the post-emergency.

2 The 2016–2017 Central Italy strong-motion data collection

The Central Italy sequence is the first important test bench of the infrastructures set up by the long-standing collaboration between INGV (Istituto Nazionale di Geofisica e Vulcanologia) and DPC.

In the period from August 2016 to June 2018, an area of about 80 km long and 20 wide (Fig. 2), characterized by crustal extension, has been struck by 69 events with magnitude larger than 3.7 and three events exceeding magnitude 5.8 (stars in Fig. 2a). These events occurred in an area of the Central Apennines bounded to the South by the 2009 L’Aquila sequence and, to the North, by the 1997 Umbria-Marche sequence (Gruppo di Lavoro INGV 2017).

Nearly all earthquakes have been generated by normal fault segments, generally dipping south-westwards, with an angle of about 50 degrees (Pizzi et al. 2017). Table 1 lists the features of the six main events occurred in the period August 2016–January 2017.

The sequence has been recorded by permanent and temporary networks, providing a valuable strong-motion dataset, that has been analyzed by various authors, in terms of ground motion amplitudes and variability, comparison with existing Ground Motion Prediction Equations (GMPEs), shaking scenarios, near source features and estimates of source parameters (Lanzano et al. 2016; Luzi et al. 2017; Bindi et al. 2018; D’Amico et al. 2018). The bulk of the strong-motion data have been provided by the two major permanent Italian networks (Fig. 2b): the Italian accelerometric network (code IT, Presidency of Council of Ministers—Civil

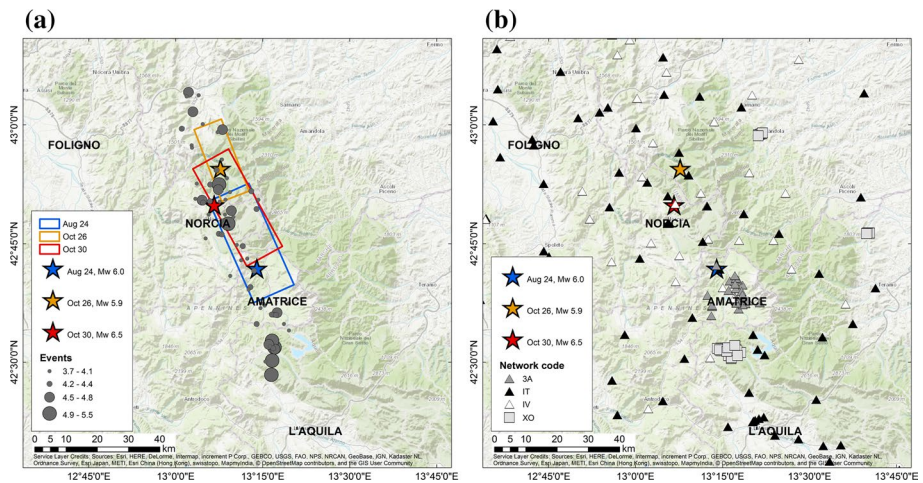


Fig. 2 Location of: **a** seismic events of the Central Italy sequence (stars indicate the three largest events and boxes represent the surface projection of the faults) and **b** recording stations (symbols and colours indicate the networks). Source and station data are taken from ESM

Table 1 Characteristics of the six main events of the Central Italy seismic sequence (*from Time Domain Moment Tensor, TDMT, <http://cnt.rm.ingv.it/tdmt>; †from Centro Nazionale Terremoti, CNT, cnt.rm.ingv.it). Length and width (in km) of causative faults are from literature: Tinti et al. (2016) for 2016/08/24 Mw 6.0; Chiaraluce et al. (2017) for 2016/10/26 Mw 5.9 and 2016/10/30 Mw 6.5

Date yyyy/mm/dd hh:mm:ss	Mw*	Depth [†] (km)	Latitude [‡] (°)	Longitude [‡] (°)	Strike* (°)	Dip* (°)	Rake* (°)	Length (km)	Width (km)
2016/08/24 01:36:32	6.0	7.93	42.70	13.25	156	50	-85	26	16
2016/10/26 17:10:36	5.4	8.1	42.87	13.12	161	38	-90		
2016/10/26 19:18:05	5.9	7.5	42.91	13.13	159	47	-93	18	10
2016/10/30 06:40:17	6.5	9.4	42.84	13.11	151	47	-95	26	14
2017/01/18 10:14:12	5.5	9.6	42.53	13.28	161	51	-86		
2017/01/18 10:25:26	5.4	9.4	42.50	13.28	140	35	-81		

Protection Department 1972; <http://ran.protezionecivile.it/IT/index.php>) operated by DPC, and the Italian seismic network (code IV; INGV Seismological Data Centre 2006; <http://cnt.rm.ingv.it/instruments/network/IV>) operated by INGV. Additional strong-motion data have been recorded by temporary stations deployed by INGV (Moretti et al. 2016) and DPC to improve the accuracy of the event location.

In addition, temporary networks have been installed to monitor the site effects. The network coded XO, has been deployed during the period August–September 2016 by the task-force EMERSITO (<http://cnt.rm.ingv.it/instruments/network/XO>, INGV 2017a; Cultrera et al. 2016) in four towns close to the epicentral area (Amandola, Civitella del Tronto, Montereale and Capitignano in Fig. 2b), with the aim of studying site effects caused by topographic irregularities and alluvial basins.

Under the coordination of the CMS, the network coded 3A, managed by several institutions (CNR, ENEA, INGV, Cara et al. 2019, submitted), and the network coded MZS, managed by OGS (Laurenzano et al. 2018), have been deployed in the epicentral area of the first shock (24 August 2016) with the aim of evaluating the site effects in the most damaged villages (Accumoli and Amatrice, and Arquata del Tronto and Montegallo, respectively). In particular, the network 3A, composed by more than 30 stations, operated from September to November 2016 (<http://cnt.rm.ingv.it/instruments/network/3A>, INGV et al. 2017b) recorded the Ussita and Norcia earthquakes (Table 1), providing several strong motion data in near source region.

About 10,000 three components accelerometric waveforms (from events with $M \geq 4$), have been globally recorded from 24 August 2016 to the end of June 2018, in the latitude range 41.50–44.00 and longitude range 11.00–14.00. About 15% of the dataset has been recorded by temporary stations: 600 records are relative to the 3A and 186 to the XO networks, respectively.

We analysed the accelerometric waveforms stored in the ESM (<http://esm.mi.ingv.it>; Luzi et al. 2016) and its Italian node (Italian Accelerometric Archive, ITACA, <http://itaca.mi.ingv.it>; Luzi et al. 2008; Pacor et al. 2011), set up since 2006 as a collaborative effort between INGV and DPC. The ESM database (last accessed on May 2019) collects strong-motion data relative to events with $M > 4$, from Europe and Middle East in quasi-real time and is specifically designed to provide high quality and uniformly processed waveforms. It also contains event and station metadata that are periodically revised. An overview of ESM database can be found in Luzi et al. (2016). The ITACA database (last accessed on May 2019) contains waveforms of earthquakes ($M > 3.5$) occurred in Italy in the period 1972–2018, recorded by national, regional and international networks operated by various providers. Differently from ESM, ITACA is released with annual frequency, maintaining the access to the previous versions.

In both databases, the archived waveforms are manually processed according to the procedure proposed by Paolucci et al. (2011) and implemented in the strong-motion processing service (<http://esm.mi.ingv.it/processing/>; Puglia et al. 2018), also developed in the framework of a collaboration between INGV and DPC.

The use of the robust infrastructures built in the last decade, allowed to reduce the time of data collection (e.g. 6 months), which, in general, is the most time consuming task.

3 Analysis of the strong-motion data of the Central Italy sequence

The residual analysis is a well-known technique that allows to breakdown the components of the ground-motion variability from the residuals between observed and predicted intensity measures (Al Atik et al. 2010). In this work we extend the analysis performed by Luzi et al. (2017) on the strong-motion data recorded in Central Italy in the period August–December 2016, to perform a quality-check of the records following August 2016 and estimate the site residual terms.

The dataset used for the residual calculation is composed by 6934 records of 69 events ($M \geq 3.7$) and 313 recording stations, in the time interval between 2016-08-24 and 2018-04-10. The magnitude-distance distribution of the records is shown in Fig. 3a. The amount of near source data is relevant (about 300 records in the Joyner and Boore distance $R_{JB} < 10$ km) as well as the records of temporary stations (white circles in Fig. 2a). The recording stations are classified according to Eurocode 8 classes (EC8; CEN 2003), based on the shear-wave velocity averaged over the topmost 30 m of the soil profile, $V_{S,30}$ (where EC8 class A ≥ 800 m/s, B = 360–800 m/s, C = 180–360 m/s, and D < 180 m/s). At the time of the experiment, the 2008 version of the Italian seismic code (NTC 2008) was in force, with the subsoil classification equivalent to the Eurocode 8, therefore this work will always refer to NTC08.

Most stations are classified on the base of geological information (Fig. 3b) whereas only 25% of them are characterized by shear-wave velocity profiles (from ESM). The majority of stations (about 50%) belong to the NTC08-B soil category (deposits of very dense sand, gravel, or very stiff clay), while the least populated categories are NTC08-D and NTC08-E.

Following Luzi et al. (2017), the ground motion prediction equation (GMPE) selected for the computation of residuals (logarithm difference between observed and predicted intensity measures) is the model by Bindi et al. (2011), named ITA10, calibrated for an Italian strong-motion data set up to 2009. ITA10 was derived from the records of earthquakes in the shallow crust (depth < 30 km) and it can be considered reliable in the magnitude range 4.0–6.9 and in the distance range 0–200 km (Joyner-Boore distance for event with $M > 5$ and epicentral distance otherwise).

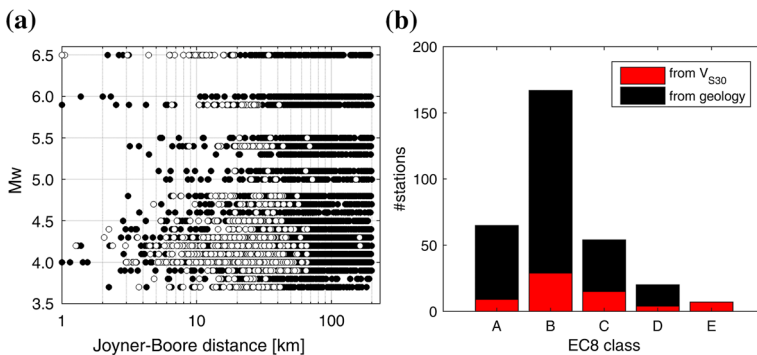


Fig. 3 **a** Magnitude-distance distribution of the records used for the residual analysis. White symbols are the data recorded by temporary stations; **b** Station distribution as soil categories according to NTC08; red bars are categories assigned from measured shear-wave velocity; black bars are categories inferred from surface geology

Figure 4 shows the comparison between observations and predictions for two events of the sequence (26 and 30 October 2016, Mw 5.9 and 6.5, respectively, Table 1) in terms of Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV), proxies of spectral acceleration amplitudes at short and intermediate periods. The two events are selected because they have been also recorded by the temporary network 3A. Figure 4 shows that observations and predictions are in good agreement, with the exception of near source ($R < 10$ km) and long distance ($R > 100$ km) records. This is somehow expected, as the GMPEs by Bindi et al. (2011) are derived from a data set that poorly constrains the anelastic attenuation term, with the result of an overestimation of the ground motion amplitudes at distances larger than 100 km (see also Luzi et al. 2017). The records of the network 3A are at short distances from the source (20–40 km) and exhibit larger amplitudes than the ITA10 median, although they are within one standard deviation of the reference model.

Figure 5 shows the results of the residual analysis for PGA and PGV, in terms of total residuals R_{es} , between-event residuals, δB_e (mean residual for single earthquakes), and within-event residuals, δW_{es} (event-corrected residuals). Detailed explanations of the residual components can be found in Al Atik et al. (2010). The overall patterns of the residuals do not evidence outliers in the distributions (e.g. residuals larger than 3 standard deviations), indicating the absence of low quality records in the dataset.

The records of the sequence exhibit, as observed in the single event plots of Fig. 4, a positive bias at short distances ($R < 10$ km) and negative bias at long distances ($R > 100$ km), specially in the case of PGA and, more generally, at short periods. The largest δB_e are obtained for small magnitude events (M 4–4.5), that can be attributed to the large variability of the earthquake stress drops found by Bindi et al. (2018).

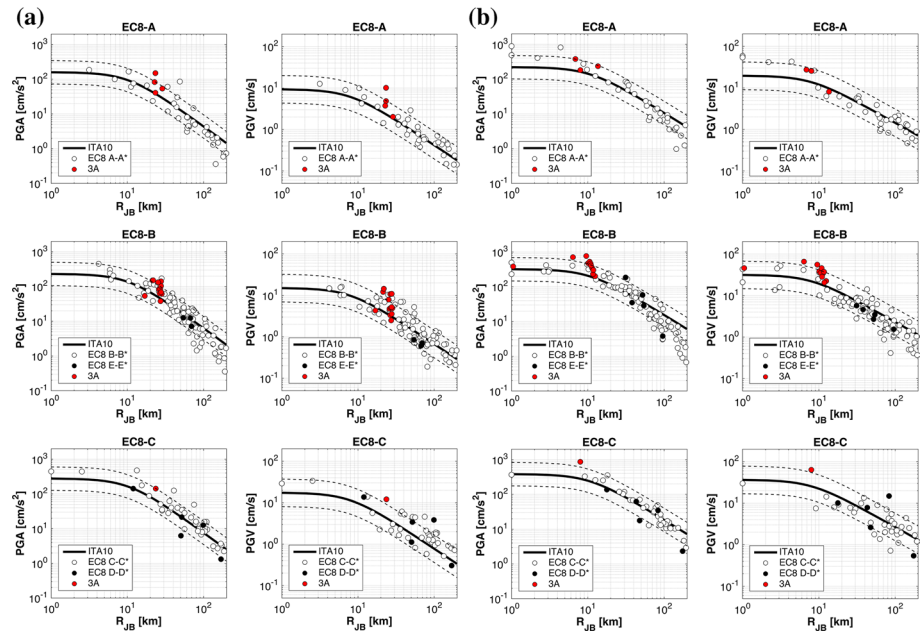


Fig. 4 Comparison between observations and ITA10 predictive equations (Bindi et al. 2011) for two events and different soil categories: **a** Mw 5.9, 26-10-2016 and **b** Mw 6.5, 30-10-2016. Temporary stations are plotted in red. Asterisks mean that the soil category has been inferred by geology

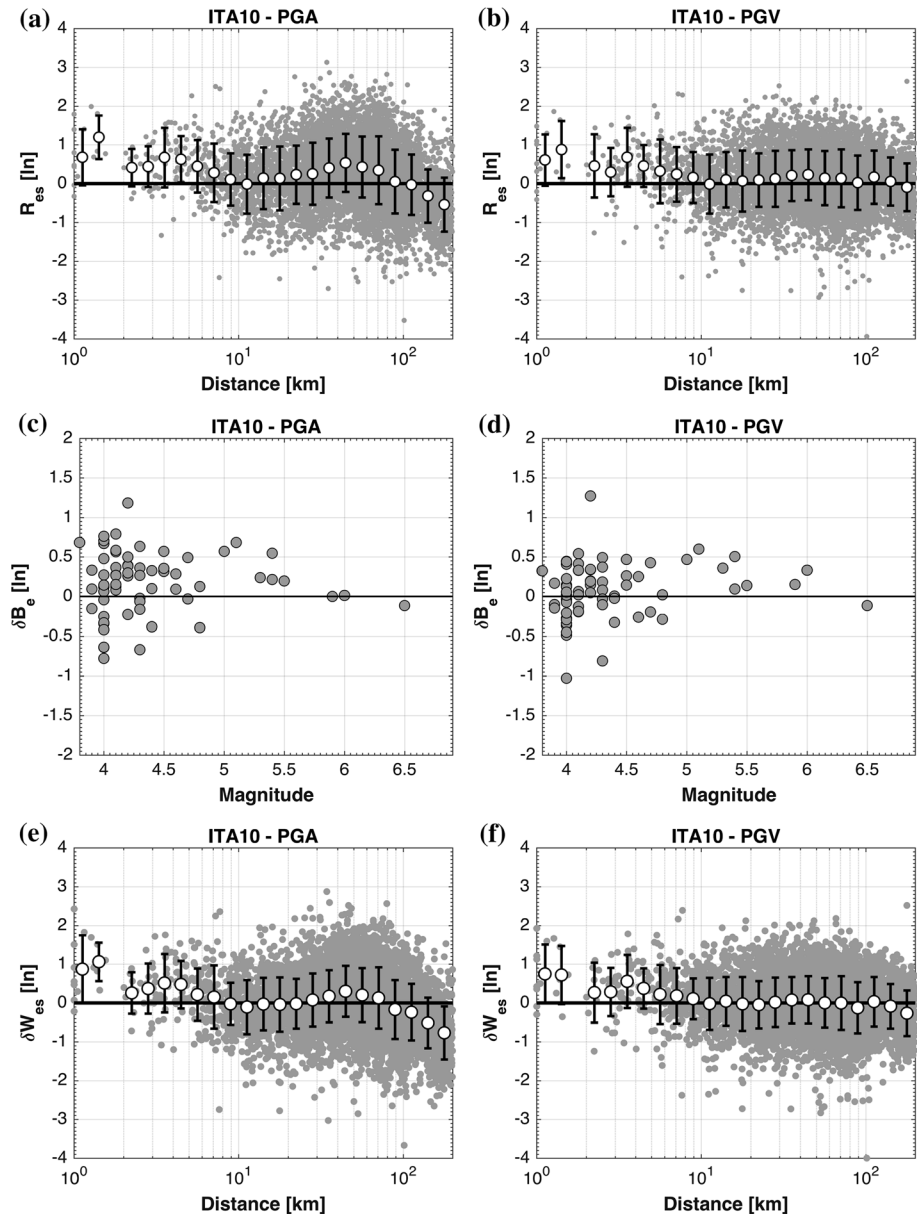


Fig. 5 Residual analysis of the data set in Fig. 2. **a, b** Total residuals (R_{es}); **c, d** between-event residuals (δB_e); **e, f** within-event residuals (δW_{es})

The site-to-site term $\delta S2S_s$ (the single station median error, after the event correction) is also calculated. $\delta S2S_s$ relative to stations belonging to the NTC08 A soil category (66 sites, Fig. 3b) can be used to identify reference sites for the seismological analysis and, in particular, for the estimation of the site amplification functions through the generalized inversion technique (GIT) and Standard Spectral Ratio (SSR) (Priolo et al. 2018, this issue).

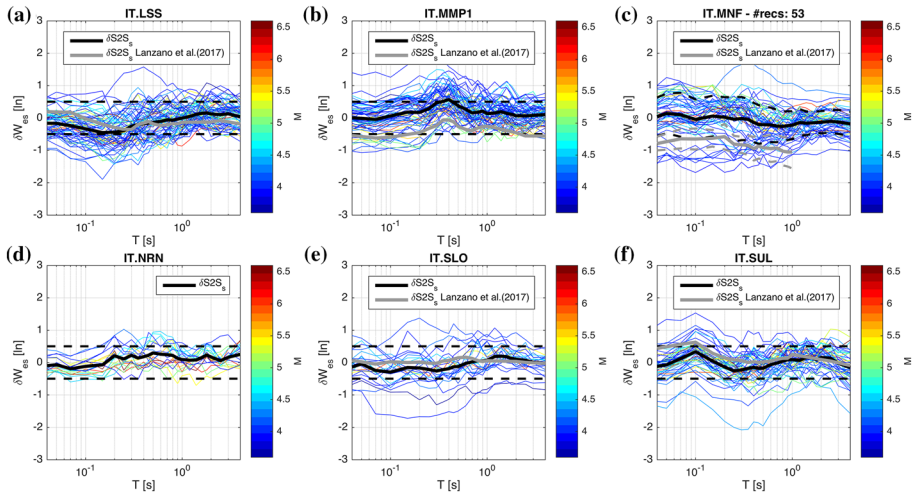


Fig. 6 a–f Event- and site-corrected residuals (δW_{es}) in function of period. The average of (δW_{es}) is the site-to-site term, $\delta S2S_s$; black thick curves represent the $\delta S2S_s$ obtained in this work, grey thick curves are the $\delta S2S_s$ by Lanzano et al. (2017), black dashed lines represent the selected range to recognize the reference site the colors of the δW_{es} curves indicates the event magnitude

Table 2 List of the candidate reference rock sites for the seismological analyses (#recs = number of records; A* indicates the site category inferred from surface geology)

Network code	Station code	#recs	Latitude (°)	Longitude (°)	Soil category	$V_{S,30}$ (m/s)
IT	LSS	61	42.56	12.97	A	1091
IT	MMP1	61	42.25	12.75	A	800
IT	MNF	53	43.06	13.18	A*	–
IT	NRN	19	42.52	12.52	A*	–
IT	SLO	22	42.90	12.95	A*	–
IT	SUL	46	42.09	13.93	A*	–

Given the short time available, we do not follow the approach proposed by Felicetta et al. (2018), based on several proxies to identify reference sites; in this study, the criterion assumed to identify a recording site as reference is that its site response was compatible with the response of the EC8-A class, estimated by the ITA10 ground motion model. For these reasons, we only verify that the residual site-term is flat and close to 0, i.e. the candidate reference sites for the seismological analysis (e.g. generalized inversion) must have a site-to-site term in the range $[-0.45, 0.45]$, in natural units, and a variability ($\phi_{W_{es}}$) lower than the within-event sigma of the ITA10 model $[0.28, 0.33]$. Using these criteria, six reference rock sites are obtained (Fig. 6) and reported in Table 2. The site-to-site terms obtained with the dataset of this study are also compared in Fig. 6 with those obtained by Lanzano et al. (2017) who used the same GMPEs (e.g. ITA10), and a set of records compiled before the Central Italy sequence (up to 2015). The similarity of the site terms confirms that $\delta S2S_s$ is quite stable and can be used as a proxy of the site-response of the stations. Small differences are found for IT.MMP and IT.MFN: after more recent in situ investigation, IT.MMP1 changed the EC8 soil

category moving from EC8-B to EC8-A and this is the reason of the observed $\delta S2S_s$ shift; concerning IT.MNF, the available data before 2016 are relative to very few analog records (< 10) and the estimation of $\delta S2S_s$ by Lanzano et al. (2017) was still rough. Two out of six selected stations (i.e. IT.LSS and IT.SLO) are finally used as reference sites in the seismological analyses by Priolo et al. (2018, this issue).

4 Selection of suites of accelerograms compatible with spectral shapes

The numerical simulations for the highest level of the seismic microzonation (third level) have to be carried out, using a suite of seven recorded accelerograms (Dipartimento della Protezione Civile 2008) that reproduce the seismic hazard at the examined site. The CMS adopted, as target spectra, the spectral shapes defined in the NTC08 (Ordinance n. 55, 2018 Extraordinary Commissioner for the reconstruction), selecting a 475 years return period, as the reference hazard level of the seismic microzonation is the urban development plan for residential estates (Fig. 1).

The selection of the accelerograms has been carried out using the software REXELite (Iervolino et al. 2011), a tool developed in 2010 in the framework of the agreement between INGV and DPC and available at the web site of the ITACA as well as the ESM database. In this study we opted for the ESM database in order to select the waveforms from the largest data set available. The elastic target response spectrum in REXELite is built according to NTC08 (cfr. equation 3.2.4), specifying the coordinate of the site, the subsoil and the topographic categories and the return period for the ground-motion.

For each municipality a preliminary selection of accelerograms is carried out specifying the following parameters: (1) magnitude and distance intervals; (2) event focal mechanism; (3) soil category of the recording site, according to NTC08. This preliminary recognition is aimed at obtaining only those waveforms that are potentially similar to the spectral shape of the seismic code. In particular, the magnitude-distance intervals are selected from the disaggregation of the MPS04, in terms of PGA (available at <http://esse1.mi.ingv.it>) and a normal focal mechanism is generally preferred, which is representative of the extensional tectonic regime of the area. As the accelerograms are the input for the 1D simulations required for the seismic microzonation, the subsoil category has been always set to A (regardless the $V_{S,30}$ is measured or inferred from surface geology).

The period range for the selection is 0.1–1.1 s, which is representative of the vibration period of the infrastructures target of the seismic microzonation. The records have not been scaled, in order to favour the final users, practicing geologists or engineers, and avoid manipulations. When we did not obtain any combinations of unscaled records, we decided to extend the search to strong-motion records of earthquakes occurred worldwide (e.g. Mw 6.5 New Zealand, November 13th 2016), thus allowing the use of records of events with strike-slip and reverse mechanisms too.

The combination of seven accelerograms is selected in a way that their average is in an interval between 10% (lower threshold) and 30% (upper threshold) of the reference spectrum, in the range of periods of interest. The selection and matching has been repeated individually for the 137 municipalities, investigated in the framework of seismic microzonation studies.

In Fig. 7, two examples of selection are shown. The first one illustrates the selection of one-component accelerograms for Norcia, Umbria region (lat: 42.78°–lon.: 13.08°), a site located in the epicentral area (Fig. 1b). For Norcia, the PGA with a 10% of probability

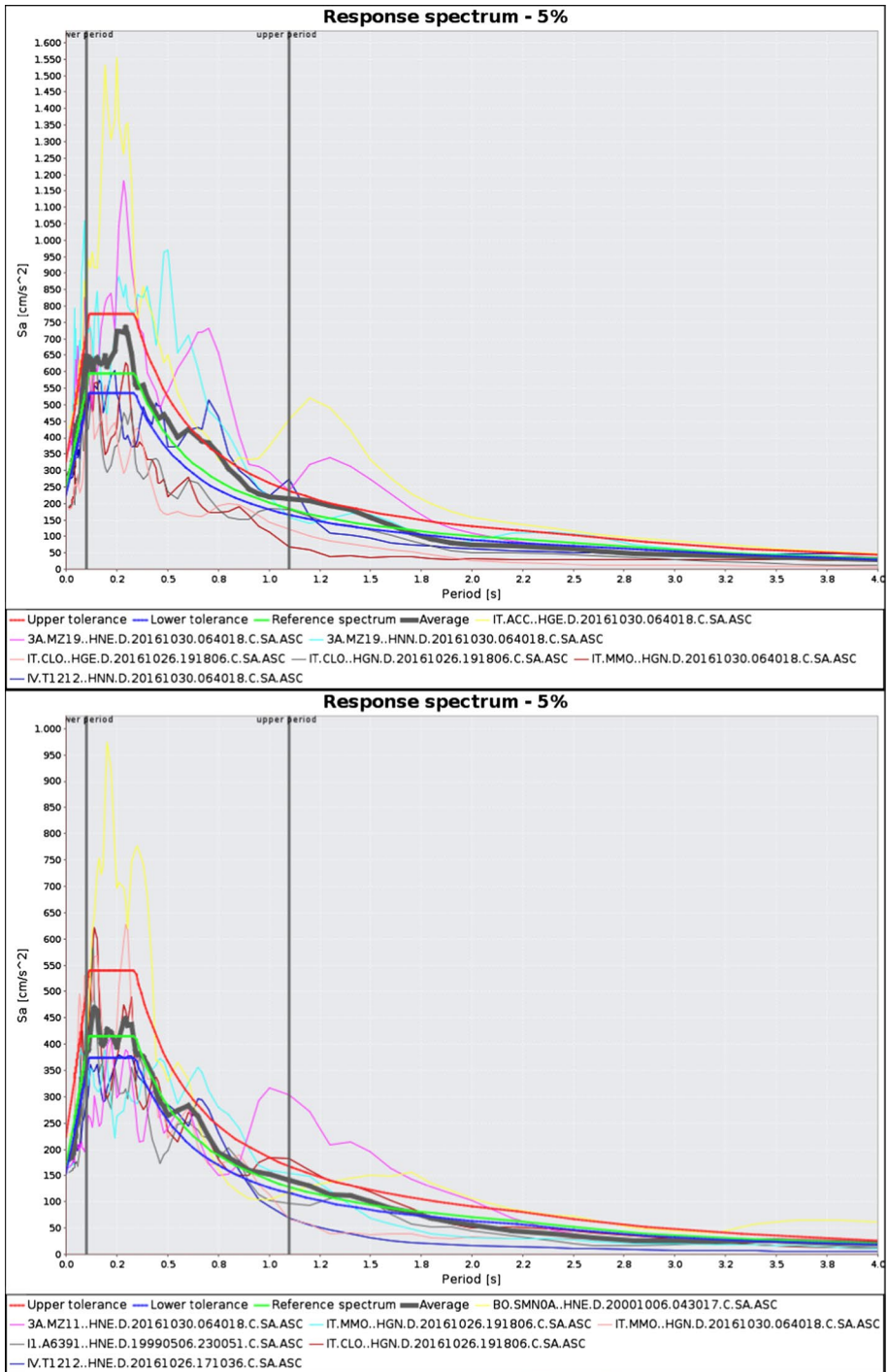


Fig. 7 Example of selection of the suite of accelerograms for the site response modelling (upper panel: Norcia, lower panel: Mogliano, in the Adriatic coast). Black thick line indicates the average spectra, thin red and green lines indicate the upper and lower tolerance, respectively

Table 3 List of 7 (one-component) accelerograms for the third level of seismic microzonation of the municipality of Norcia, Umbria region (lat.: 42.78°–lon.: 13.08°)

Network	Station	Event time	Comp	M_L/M_w	R_{JB}/R_{epi} (km)
3A	MZ19	30/10/2016 06:40	N	6.1/6.5	6.9/11.1
IT	MZ19	30/10/2016 06:40	E	6.1/6.5	6.9/11.1
IT	ACC	30/10/2016 06:40	E	6.1/6.5	2.3/18.6
IT	CLO	26/10/2016 17:10	N	5.9/5.9	3.1/10.1
IT	CLO	26/10/2016 17:10	E	5.9/5.9	3.1/10.1
IT	MMO	30/10/2016 06:40	N	6.1/6.5	9.8/19.2
IV	T1212	30/10/2016 06:40	N	6.1/6.5	8.8/10.5

Table 4 List of 7 (one-component) accelerograms for the third level of seismic microzonation of the municipality of Mogliano, Marche Region (lat.: 43.184°, lon.: 13.490°)

Network	Station	Event time	Comp	M_L/M_w	R_{JB}/R_{epi} (km)
3A	MZ11	30/10/2016 06:40	E	6.1/6.5	8/24.8
BO	SMN0A	06/10/2001 04:30	E	4.7/6.6	5.5/8.5
IT	CLO	26/10/2016 19:18	N	6.1/6.5	2.3/18.6
IT	MMO	26/10/2016 19:18	N	5.9/5.9	3.1/10.1
IT	MMO	30/10/2016 06:40	N	5.9/5.9	3.1/10.1
II	A6391	06/05/1999 23:00	E	6.1/6.2	-/27.0
IV	T1212	26/10/2016 17.10	E	5.4/5.4	-/15.2

of exceedance in 50 years is 0.275 g (Fig. 1a) and the corresponding mean values of the disaggregation, in terms of magnitude and distance, are $M=5.67$ and $R=7.5$ (Barani et al. 2009). The preliminary search of accelerograms is then performed around these values, considering magnitude M (both local M_L and moment M_w) and R within the ranges [5.2; 6.2] and [0 km; 30 km], respectively. Table 3 lists the selected accelerograms and their main features: all the selected waveforms are recorded both by temporary and permanent stations, during the main events occurred in October 2016.

The second example concerns the selection for Mogliano, Marche Region (lat.: 43.184°, lon.: 13.490°), located close to the Adriatic coast (Fig. 1b). In this case, the Italian seismic hazard map provides a PGA equal to 0.175 g (Fig. 1a) while the disaggregation analysis indicates the magnitude-distance pair [5.2, 10.3] as the most contributing source to the hazard. The preliminary selections in the magnitude and distance intervals [4.7–5.7] and [5–45 km] do not provide any results, so the search intervals were enlarged extending the magnitude up to 6.1, including worldwide events with any focal mechanism.

Table 4 lists the selected accelerograms together their main features: besides the records of the Central Italy sequence, the set includes two records from strike events in Japan and Iran, respectively.

In total, a set of 39 records (Table 5) can be combined to build the 137 suites of 7 accelerograms (<https://annuminas.igag.cnr.it/share.cgi?ssid=0yprHoc>), used as input for the numerical modelling. The list of the combinations for each municipality and the files containing the records are available in the online resources ESM_1 and ESM_2, respectively. The statistics on the 39 waveforms, plotted in Fig. 8, show that the PGA varies in the interval 0.09–0.62 g, with mean equal to 0.24 g, while PGV is in an interval between 5 and 71 cm/s with mean equal to 19 cm/s.

Table 5 List of 39 records that form the 137 suites of 7 accelerograms to be used as input for further numerical modelling. (*P, permanent; T, temporary; ^sfocal mechanism; SS, strike-slip; NF, normal fault; TF, thrust fault; H, hypocentral depth; R_{epi}, epicentral distance)

Network code	Station code	NTC08 code	Inst Type*	Event ID	dd/mm/yy hh:mm	ML	Mw	H (km)	FM ^s	R _{epi} (km)	Channel code	PGA (g)	PGV (cm/s)
II	A6391	A*	P	IR-1999-0032	06/05/99 23:00	6.1	6.2	17.2	SS	22.6	HNE	0.159	11.0
II	A6391	A*	P	IR-1999-0032	06/05/99 23:00	6.1	6.2	17.2	SS	22.6	HNN	0.136	7.3
EU	106	A*	P	IS-2000-0048	17/06/00 15:40	5.3	6.5	10	SS	12.6	HN2	0.320	70.7
EU	106	A*	P	IS-2000-0048	17/06/00 15:40	5.3	6.5	10	SS	12.6	HN3	0.344	31.4
EU	108	A*	P	IS-2000-0048	17/06/00 15:40	5.3	6.5	10	SS	20.7	HN2	0.126	16.4
EU	108	A*	P	IS-2000-0048	17/06/00 15:40	5.3	6.5	10	SS	20.7	HN3	0.158	11.3
EU	107	A*	P	IS-2000-0053	21/06/00 00:51	5.5	6.5	10	SS	5.3	HN2	0.625	23.5
EU	112	A*	P	IS-2000-0053	21/06/00 00:51	5.5	6.5	10	SS	13.2	HN2	0.129	23.3
BO	SMN0A	A	P	JP-2000-0007	06/10/00 04:30	4.7	6.6	11	SS	31.7	HNE	0.231	21.0
EU	112	A*	P	IS-2008-0054	29/05/08 15:46	6.3	6.2	10	SS	2.3	HN3	0.334	34.3
EU	101	A*	P	IS-2008-0054	29/05/08 15:46	6.3	6.2	10	SS	1.8	HN2	0.505	43.3
NZ	LPCC	A*	P	EMSC- 20110416_0000019	16/04/11 05:49	4.3	5	10.6	TF	5.2	HNI	0.315	9.9
NZ	MRZ	A*	P	EMSC- 20140120_0000007	20/01/14 02:52	6.2	6.1	28	NF	19.9	HNE	0.170	6.7
3A	MZ21	A*	T	EMSC- 20161026_0000077	26/10/16 17:10	5.4	5.4	8.7	NF	27.9	HNE	0.196	8.5
3A	MZ21	A*	T	EMSC- 20161026_0000095	26/10/16 19:18	5.9	5.9	7.5	NF	30.7	HNE	0.183	11.2
IT	CLO	A*	T	EMSC- 20161026_0000077	26/10/16 17:10	5.4	5.4	8.7	NF	8.5	HGE	0.102	5.2
IT	CLO	A*	T	EMSC- 20161026_0000095	26/10/16 19:18	5.9	5.9	7.5	NF	10.8	HGE	0.183	12.3
IT	CLO	A*	T	EMSC- 20161026_0000077	26/10/16 17:10	5.4	5.4	8.7	NF	8.5	HGN	0.128	4.8
IT	CLO	A*	T	EMSC- 20161026_0000095	26/10/16 19:18	5.9	5.9	7.5	NF	10.8	HGN	0.193	12.8
IT	MMO	A*	T	EMSC- 20161026_0000095	26/10/16 19:18	5.9	5.9	7.5	NF	16.2	HGE	0.170	7.3

Table 5 (continued)

Network code	Station code	NTC08 code	Inst Type*	Event ID	dd/mm/yy hh:mm	ML	Mw	H (km)	FM ^s	R _{epi} (km)	Channel code	PGA (g)	PGV (cm/s)
IT	MMO	A*	T	EMSC-20161026_0000095	26/10/16 19:18	5.9	5.9	7.5	NF	16.2	HGN	0.168	13.5
IT	MNF	A*	P	EMSC-20161026_0000095	26/10/16 19:18	5.9	5.9	7.5	NF	17.4	HGE	0.121	8.3
IT	MNF	A*	P	EMSC-20161026_0000095	26/10/16 19:18	5.9	5.9	7.5	NF	17.4	HGN	0.085	9.7
IV	T1212	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	10.5	HNE	0.280	27.7
3A	MZ10	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	27.7	HNN	0.398	43.2
3A	MZ11	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	24.8	HNE	0.169	15.4
3A	MZ14	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	30.6	HNE	0.219	6.9
3A	MZ14	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	30.6	HNN	0.257	9.4
3A	MZ19	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	22.6	HNE	0.363	34.6
3A	MZ19	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	22.6	HNN	0.403	21.6
IT	ACC	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	18.6	HGE	0.434	44.1
IT	ACC	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	18.6	HGN	0.392	39.5
IT	MMO	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	19.2	HGE	0.189	8.9
IT	MMO	A*	T	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	19.2	HGN	0.189	11.4
IT	MNF	A*	P	EMSC-20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	26.0	HGE	0.133	6.4

Table 5 (continued)

Network code	Station code	NTC08 code	Inst Type*	Event ID	dd/mm/yy hh:mm	ML	Mw	H (km)	FM [§]	R _{spi} (km)	Channel code	PGA (g)	PGV (cm/s)
IV	T1212	A*	T	EMSC- 20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	10.5	HNE	0.280	27.7
IV	T1212	A*	T	EMSC- 20161030_0000029	30/10/16 06:40	6.1	6.5	9.2	NF	10.5	HNN	0.278	24.7
NZ	KIKS	A*	P	EMSC- 20161113_0000052	13/11/16 11:32	5.9	6.5	10	TF	11.7	HN2	0.103	14.8
NZ	MOLS	A*	P	EMSC- 20161113_0000057	13/11/16 11:52	5.7	6.1	14	SS	18.5	HN1	0.272	8.4

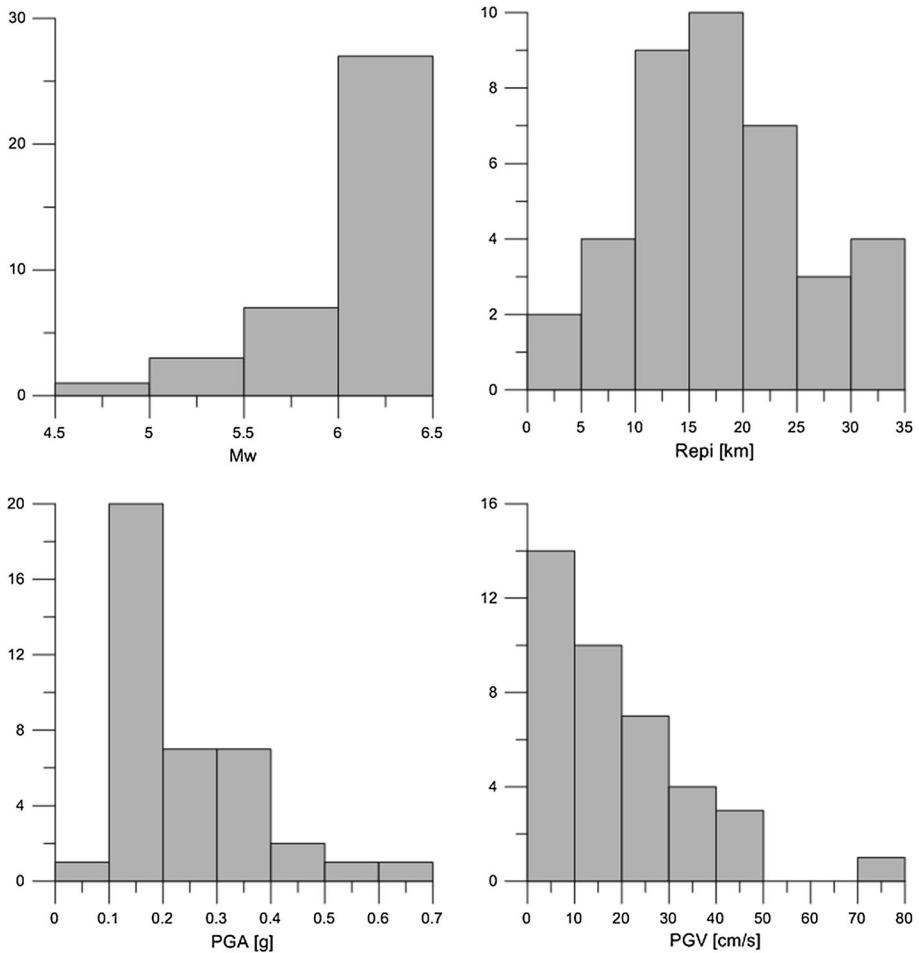


Fig. 8 Statistics of the 39 accelerograms compatible with the NTC08 response spectra of the 137 municipalities. Upper panel: distribution of earthquake magnitude and epicentral distance; lower panel: distribution of Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV)

5 Conclusions

This work has the goal of analyzing the ESM database in order to derive the seismological information necessary for the seismic microzonation of the 137 municipalities heavily damaged by the 2016–2017 Central Italy seismic sequence. In particular, the analysis aims at: (1) identifying the sites to be used as reference in the seismological analysis, based on generalized inversion technique (Priolo et al. 2018, this issue), and (2) select the seismic input needed for calculating site amplifications through 1D and 2D simulations.

The former task required the selection of the 2016–2017 Central Italy strong-motion dataset. The observed ground motion has been compared with the reference attenuation model for Italy by means of the residual analysis, carried out to perform the quality check of the waveforms recorded by temporary networks and estimating the site-to-site terms. The latter have been used to identify the reference rock sites for seismological analysis,

selecting those characterized by flat response and variability lower than the within-event standard deviation of the reference ground motion model.

The second task implied the selection of a suite of seven accelerograms compliant with the spectra of the Italian seismic code corresponding to 475 years return period. Since the area covered by the 137 municipalities is relatively small, the selection was limited to 39 waveforms. For the municipalities located in the epicentral area, the records of the Central Italy sequence and, in particular, the records of the temporary networks, make a significant contribution to the selection process. For the further sites, the suites of selected accelerograms should be enlarged, including records from other regions and focal mechanism different from normal faulting.

The results of this work can be used as a pilot case to illustrate how the synergy among public institutions is successful, as well in the emergency phase, as in the long-term planning. One of the aims of this work is to show the capability of existing infrastructures in Italy (repository of seismic records, monitoring networks, processing and analysis tool integrated within the databases) to provide useful products for Microzonation studies in a short time. The maintenance of seismological infrastructures becomes of key importance not only in the prevention of risks, but also in the management of emergencies.

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