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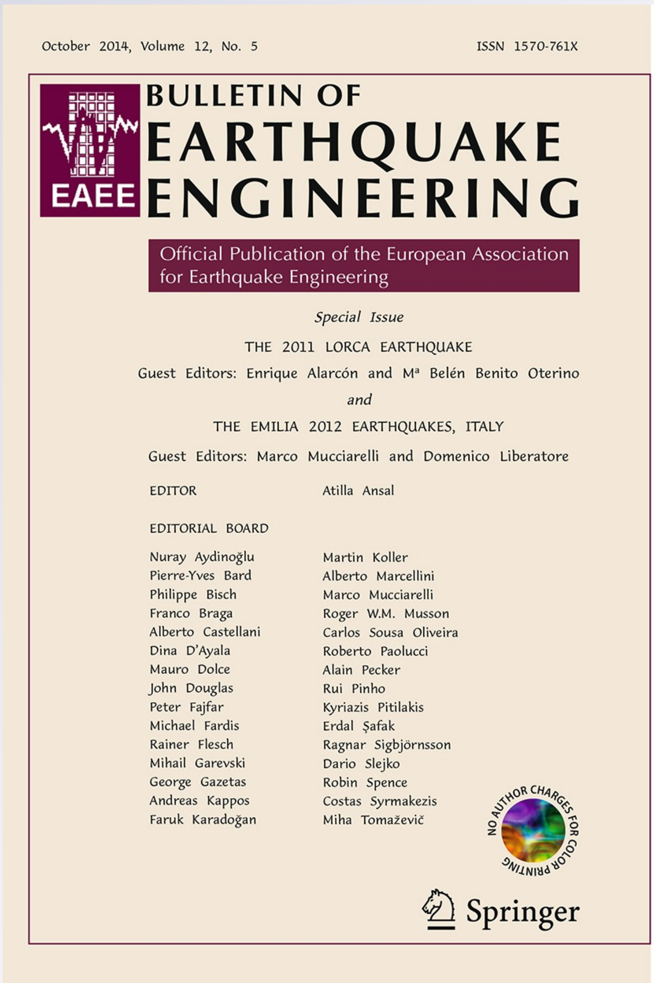

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ORIGINAL RESEARCH PAPER

National Civil Protection Organization and technical activities in the 2012 Emilia earthquakes (Italy)

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Abstract On May 2012, a severe seismic sequence occurred in the central part of the Po Plain (Northern Italy). It was characterized by two main shocks displaying local magnitudes 5.9 (on May 20th) and 5.8 (on May 29th), respectively; the maximum observed intensity was VII–VIII on the MCS scale. The emergency response was coordinated as usual by the Department of Civil Protection (DPC), within the general framework provided by the components and operational structures of the National Civil Protection Service. In addition to the search and rescue and to the population assistance activities, many technical activities were carried out to support the civil protection management of the recovery phase. Among these, mentioning is deserved by: the acquisition and dissemination of the accelerometric data from the National Accelerometric Network and the Seismic Observatory of the Structures, owned and operated by DPC; the evaluation of the liquefaction phenomena; the damage and building safety assessment; the regulations for the seismic safety assessment of industrial buildings, aimed at a rapid re-establishment of the productive activities; the actions undertaken following the evaluations by the Grandi Rischi Commission on the possible evolution of the seismic sequence. All these aspects will be examined under a civil protection perspective.

Keywords Earthquake · Civil Protection · Emergency Management · Damage · Italy

1 Introduction

On May 2012, the central part of the Po Plain, in Northern Italy, was struck by a severe earthquake sequence. The main shock occurred on May 20th at 4.03 a.m., and caused the death of 7 people. Its epicenter was located in the Emilia region, about 30 km to the West of Ferrara. Its local magnitude was Ml 5.9 (Mw 5.86; Scognamiglio et al. 2012).

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Few days later, on May 29th, a second main shock occurred about 20 km to the West of the first one, with local magnitude Ml 5.8 (Mw 5.66; Scognamiglio et al. 2012). This second main shock worsened the damage of the area and caused the death of another 19 people.

The overall sequence, formed by thousands of aftershocks, presented seven shocks characterized by Ml $\geq$ 5.0, the latest of which occurred on June 3rd, 2012. The sequence is still lasting at present, with few events per week (data source: 2005–2013 ISIDe; Mele et al. 2007). The aftershocks distribution covers an E-W striking area more than 50 km long. The hypocentral depths are mainly concentrated in the first 15 km of the crust (Marzorati et al. 2012).

The damage in the epicentral area was characterized by a maximum intensity VII–VIII on the MCS scale (Galli et al. 2012), and VIII on the EMS scale (INGV-QUEST; Tertulliani et al. 2012), both referred to the cumulative damage of the two main shocks. The maximum horizontal peak value of ground acceleration recorded by the National Accelerometric Network operated by the Department of Civil Protection (RAN-DPC) was about 300 cm/s ^{2}, at the sites of Mirandola and San Felice sul Panaro in the epicentral area, while on the vertical component a value as high as 900 cm/s ^{2} was recorded at the site of Mirandola.

The focal mechanisms of main shocks and largest aftershocks show reverse slip kinematics and circa E-W-striking nodal planes (Pondrelli et al. 2012). This is in good agreement with the tectonic setting of the area, where top-to-the north active thrust faults, forming the frontal part of the Northern Apennines orogenic wedge, are buried under the sedimentary cover of the Po Plain (Bigi et al. 1992; Burrato et al. 2003; Toscani et al. 2009). As such, the seismogenic faults are blind, and in fact no surface faulting was observed. Surface deformation was instead captured by satellite interferometric analyses, which highlighted a maximum coseismic uplift of about 12 cm (Salvi et al. 2012). The uplift is shaped as two elliptical areas corresponding to the activated seismogenic faults. Considerable coseismic effects accompanied this deformation, such as ground fractures and important liquefaction phenomena (Di Manna et al. 2012; Caputo et al. 2012).

From a historical point of view, the 2012 Emilia earthquake occurred in an area previously affected by other low-to-moderate seismic events (catalogue CPTI11; Rovida et al. 2011). Earthquakes with magnitude ~5.5 are known to have occurred near Ferrara (in 1346, 1561) and in the areas of Finale Emilia-Bondeno (1574, 1908, 1986), Mantua (1901) and Cento (1922). However, according to Castelli et al. (2012) this picture might be incomplete, as suggested by the recent discovery of a previously unknown earthquake that occurred in 1639, and whose maximum intensity was assessed as VII–VIII degree MCS in Finale Emilia (Camassi et al. 2011).

The best known historical earthquake occurred in the study area is the 1570 Ferrara earthquake (M 5.4). It was actually a long seismic sequence, which started on November 17th, 1570 with four shocks that caused severe structural damage and partial collapses in Ferrara and its surroundings (Guidoboni et al. 2007). The sequence went on discontinuously up to March 17th, 1574, when the last shock is reported to have caused damage in Finale Emilia.

Other historical earthquakes which deserve to be mentioned are the 1624 Argenta earthquake (M 5.4), which is characterized by an intensity VIII-IX MCS in Argenta (Guidoboni et al. 2007) and is currently under review (Caracciolo et al. 2012), as well as the 1796 (M 5.6) and 1909 (M 5.5) seismic events. Finally, in the Carpi-Reggio area, several moderate earthquakes occurred, among which the 1996 Correggio earthquake (M 5.4).

Considering the earthquake effects, three kinds of buildings have suffered the most serious consequences: (i) monumental buildings (churches, towers and bell towers, castles, palaces;

Fig. 1 Collapsed clock tower; Finale Emilia (from http://www.protezionecivile.gov.it/)

Fig. 1); (ii) buildings for industrial use (especially prefabricated buildings); (iii) masonry rural buildings (farmhouses, storehouses).

On the contrary, buildings characterized by one or more floors and typically used as dwellings, schools, offices, have suffered limited damage with respect to the magnitude of the two main shocks. This behaviour is also reflected by the macroseismic intensity values, which are based on the observed damage and therefore resulted lower than expected for those magnitudes. It is worthwhile noticing that only recently (after the Prime Minister Ordinance n. 3274, of March 20th, 2003) the area hit by the 2012 Emilia earthquakes has been classified as seismic zone, precisely at the 3rd level out of the 4 levels foreseen by the national seismic classification. This implies that most of the buildings, even those quite recently built, were in principle designed and constructed without any antiseismic provision.

There is no doubt that the aforementioned selective difference observed for the damage, i.e. as function of the kind of considered buildings, is related to the specific spectra characterizing the shocks, which display significant amplifications for mean-to-high periods and large spectral displacements. These spectral characteristics affect in particular those kinds of buildings which were mostly damaged (Chioccarelli et al. 2012).

Soon after the May 20th earthquake, all the components and operational structures of the Italian National Civil Protection Service (SNPC) were activated to face up the emergency phase, which is aimed at rescuing people and providing a safe shelter to homeless. The management of the emergency phase was assigned to a governmental commissioner, that, until July 31st, 2012, was the Head of the Department of Civil Protection (DPC). In the same time, from June 8th, 2012, the Presidents of the involved Regions were also enforced as commissioners, with the full responsibility of the reconstruction phase, the assistance to the population and the economic recovery. Summing up, the emergency was in charge of the national level for the first two months, and then managed at the regional level.

In this paper the main problems dealt with and the solutions provided in the emergency phase are described from a Civil Protection perspective, mainly focusing on technical aspects.

2 Emergency management

Immediately after the May 20th earthquake, a first picture of the possible consequences was obtained from the epicentral coordinates and Richter magnitude that were made available

to DPC by the National Institute of Geophysics and Volcanology (INGV). Based on these parameters, a damage scenario immediately developed through the SIGE software (Bramerini and Lucantoni 2001) returned an estimate of the earthquake consequences in terms of number of people involved in collapsed buildings (between 400 and 6,000) and homeless (between 27,000 and 175,000), as well as of collapsed or unusable buildings (between 13,000 and 86,000). An expected VIII-IX degree MCS epicentral macroseismic intensity was estimated. Fortunately, it turned out to be more than one degree higher than the actual epicentral intensity (see Fig. 3A), probably due to the nature of the seismogenic fault and of the subsurface geological setting of the Po Plain. The overestimation of the epicentral intensity caused a considerable overestimation of the actual consequences of the earthquake. As a matter of fact, the SIGE results are calibrated on the basis of the Italian earthquakes typically occurring along the peninsula, especially in the Apennines mountain chain, which are produced by totally different fault rupture mechanisms.

The simulated possible effects were checked versus the reports directly coming from the epicentral area to the Operation Room of DPC, in the first hours after the event. Further checks were made on the basis of the data collected by the RAN-DPC strong-motion network and of the shake maps provided by INGV. These pieces of information allowed the earthquake effects assessed by the simulated damage scenario to be suitably and immediately recalibrated, in order to adjust the emergency intervention to the actual needs.

Less than one hour after the May 20th main shock, teams of DPC experts moved towards the epicentral area to carry out a first survey of the real damage distribution (Galli et al. 2012).

The entire Italian SNPC was immediately activated, its mandate being the safeguarding of human life and health, goods, national heritage, human settlements and environment from all natural or man-made disasters, under the coordination of DPC. In particular, the operational structures of the Ministry of Interior—i.e. National Fire Brigades, Police, Prefectures—and of the Ministry of Defence—i.e. Army, Navy, Air Force and Carabinieri—contribute to SNPC actions, together with the State Forest Corps and the Financial Police. Companies of road and railway transportation, electricity and telecommunication as well as Volunteers Associations are part of the system. Finally, an important strength of the system is represented by its link with the scientific community through the Centres of Competence, which enables timely translation of up-to-date scientific knowledge into operability and decision-making.

On May 20th, 2012, while the first assessment activities were under way, the following actions were undertaken at national level for the rescue and assistance to the population:

- h. 4.03: earthquake occurrence;
- h. 4.30: the Operational Committee, which involves all the components and operational structures of SNPC, was convened in Rome;
- h. 5.00: the first DPC teams left from Rome to the epicentral area for the emergency organization on site and the macroseismic survey;
- h. 6.00: the Operational Committee started its works in Rome; it continued to operate up to May 23rd.

On May 22nd, 2012, the Council of Ministers acknowledged the severity of the occurred earthquake and declared the "state of emergency" for a period of 60 days, referred to the provinces of Modena, Ferrara, Bologna and Mantova, under the coordination of the Head of DPC.

On May 29th, after the second main shock at 9 a.m., further actions were undertaken, both at national and local level, under the coordination of the Operational Committee, which was, again, convened in Rome at 10.30.

Table 1 Main operational structures of the Italian SNPC, and maximum number of personnel and equipment deployed

Main components of the SNPC	Operators	Means
Fire Brigades	1,247	643
Carabinieri	884	431
Army	367	74
Police	302	95
Volunteers	2,617	600
Total	5,417	1,843

A Direction of Command and Control (Di.Coma.C.) was established in Bologna, aimed at better coordinating the components and operational structures of the Italian SNPC involved in the rescue, assistance and provisional activities. It operated up to the end of July, i.e. to the end of the mandate of DPC for the emergency management.

Through the Di.Coma.C., different activities were coordinated, for instance:

- assisting the population in temporary accommodation areas and structures, like tent camps and hotels;
- assigning and monitoring the self-lodging financial support to families whose houses had been partially or totally destroyed, or evacuated;
- preparing, managing and closing the temporary accommodation areas and structures;
- assessing the damage and usability of buildings;
- managing the procedures for the requests of urgent provisional interventions;
- providing authorizations for the expenses needed for the various activities;
- facilitating link and cooperation among local and central coordination centres.

As mentioned before, the search and rescue operations and the assistance to the population started few hours after the May 20th main shock and continued more intensively after the May 29th second main shock. The final number of casualties was 26.

Table 1 shows the maximum number of operators and means deployed by the main operational components of the SNPC (fire-fighters, volunteers and others) during the emergency. The total number of operators was about 5,417, while 1,843 were the means. At the end of July 2012, there were more than 3,200 operators still active. The population assisted reached a maximum of 14,871 people in Emilia Romagna, 1583 in Lombardy and 64 in Veneto. 2,540 of them were hosted in hotels.

To fulfil the population needs, mobile modules for the population assistance from Friuli Venezia Giulia, Marche, Toscana, Umbria and Veneto Regions were deployed, as well as mobile modules provided by voluntary organisations.

At local level, several operational centres were activated, in order to guarantee the coordination of the emergency actions on site. In particular, Provincial Coordination Centres were opened in the Provinces of Modena, Ferrara, Bologna e Reggio Emilia, while Territorial Coordination Centres were opened in the Provinces of Rovigo and Mantova. Municipal Coordination Centres were activated in a large number of municipalities.

It was necessary to provide suitable shelters for the homeless, who were estimated since the beginning in the order of some thousands. Two solutions were conceived and set up: tents for people that did not want to go far away from their homes, hotels or autonomous housing arrangement, with a standard refund from the State, for the others. Many tent camps were immediately set up in the epicentral area since the first days (Fig. 2). The earthquakes occurrence during the spring season made it possible to keep the people in tents for several months, in order to prepare adequate temporary housing solutions, following an approach

Fig. 2 Tent camp; Finale Emilia (from http://www.protezionecivile.gov.it/)

similar to that adopted for the April 6th, 2009, Abruzzo earthquake. This was instead not possible after the 1997 Umbria-Marche earthquake, which occurred in late September. In that case, caravans and containers were used to recover homeless people during winter.

36 tent camps were set up in Emilia Romagna, for a total amount of 1.600 tents. Moreover, 220 hotels were identified, where some thousand people were hosted during the emergency. This number varied as a function of the changing needs through time. The use of tents was also favoured in case of farmers who asked to camp near their farms, encouraging them to try to maintain their activities. 20 tent camps were also set up in Lombardy, whereas in Veneto there was no need of tents, given the limited number of homeless.

3 Technical activities

3.1 Macroseismic intensity assessment

As said above, soon after being notified of the May 20th main shock, teams of experts moved from Rome to the epicentral area to carry out a first survey of the real damage distribution and make an on-site evaluation of the macroseismic intensities (Galli et al. 2012). Their work was preliminarily aimed at identifying the localities with the highest level of damage, in order to correctly address the first activities of rescue and assistance to the population.

The survey was carried out by utilising the Mercalli-Cancani-Sieberg Scale (MCS; Sieberg 1930), according to the procedure given by Molin (2003) for the specific civil protection objectives. This quick survey returned a maximum intensity VII MCS (Fig. 3A). To complete the final macroseismic survey, however, an overall reassessment was needed after the second main shock occurred on May 29th, which caused further damages and enlarged the affected area. At the end of the macroseismic survey, about 190 localities had been classified in terms of damage; the maximum intensity observed was VII–VIII MCS, due to the cumulative effects of the main shocks and of the strongest aftershocks (Fig. 3B). In general terms, the second main shock of May 29th, along with the main aftershocks that followed the earthquake of May 20th, determined a marked worsening of the effects in the western sector of the area, where increments of one and two degrees in the MCS intensity scale were observed, due to the heavy damage even to modern structures that occurred in Reggiolo (VI–VII MCS), Novi

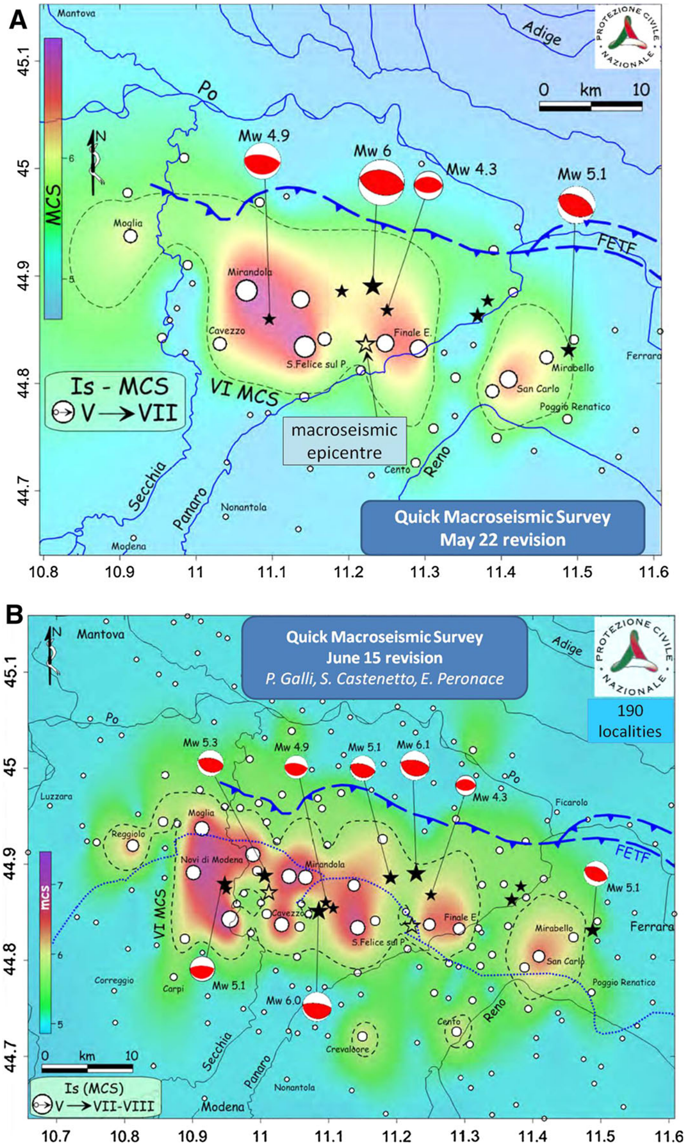

Fig. 3 Macroseismic fields (**a**) between the first and the second main shock and (**b**) after the second main shock (Galli et al. 2012). **A** Surveys up to May 22nd, **B** Surveys up to June 15th

di Modena (VII MCS), Concordia sulla Secchia (VII MCS) and, especially, at Rovereto, a village in the municipality of Novi di Modena (Fig. 3).

It is worthwhile noticing that in this case, differently from what had been done for previous earthquakes in Italy, the macroseismic survey was not used as a criterion for the identification of the earthquake-struck area (and municipalities) where special provisions of the emergency and reconstruction laws were applicable. Actually this is a critical issue of the post-event management that has not found a satisfactory solution until now and thus deserves specific

attention. In fact, to define the areas where tax break and other facilitations should be applied, the complex socio-economic interrelationships among different parts of the territory, which display a not homogeneous economic development and have been differently damaged by the earthquake, should be considered and evaluated with more objective criteria for the quantification of the indirect socio-economic consequences. In this framework, the damage to buildings, as summarised by the macroseismic intensity, appears to be a too rough indicator of the economical disease in a given municipality area.

3.2 Strong-motion monitoring

At the date of the Emilia earthquake, the RAN-DPC strong-motion network (Gorini et al. 2010) was formed by 468 permanent digital stations, whose data were teletransmitted to the DPC monitoring centre. This network is able to guarantee a dense cover of all zones of the national territory characterized by high seismic hazard, with an instrumental density proportional to the hazard level (Dolce 2011a). On May 20th, 25 permanent stations were already installed in Emilia Romagna, but only one of them was in the epicentral area, which was not classified as a high hazard area. Few seconds after the shock, ground motion parameters and complete waveforms were sent to the monitoring centre from the instruments located both in the epicentral area and far from it.

The first main shock was recorded up to 489 km distance, at the station of San Nicandro Garganico, in Southern Italy. The peak ground acceleration (PGA) in the epicentral area, at the Mirandola site (17 km from the epicentre), reached 300 cm/s^2 on the vertical component and 260 cm/s^2 on the horizontal component. Table 2 shows the parameters obtained from the waveforms recorded on May 20th from 5 stations located within 50 km from the epicentre.

Further, 15 temporary digital stations were subsequently installed nearby the epicentre, so that the May 29th second main shock was much better monitored. Table 3 shows the ground motion parameters recorded by the stations within 25 km from the epicentre. The PGA reached 900 cm/s^2 on the vertical component and 290 cm/s^2 on the horizontal component, again at Mirandola.

All the data recorded by the RAN-DPC, including complete waveforms and parameters, were published on the DPC institutional website (www.protezionecivile.it; Dolce et al. Report I, II, III, 2012a; 2012b; 2012c).

Like in the case of the 2009 Abruzzo earthquake, the records obtained for the Emilia earthquake increased considerably the Italian accelerometric data base, even with important near-field records that the additional 15 temporary stations allowed to get. Besides contributing to the management of the emergency phase, these data will surely improve the understanding of the local response and the peculiar damage determined by this earthquake sequence.

DPC owns and operates also another monitoring network, the Seismic Observatory of the Structures (OSS-DPC), a national permanent network which monitors the seismic response of more than 150 structures all over the Italian territory, including schools, hospitals, town halls, bridges, and a dam (Dolce 2011b). The OSS-DPC allows a remote estimation being made in few minutes of the damage suffered by the monitored structures after an earthquake and, by analogy, of the damage possibly suffered by similar structures in the same area. This provides pieces of information useful to improve the definition of the damage scenario and, therefore, to more accurately plan civil protection activities after an earthquake. With this aim, the most important parameter considered is the maximum interstorey drift.

In Emilia Romagna there were 9 public buildings monitored, mainly located in the western part of the Region and towards the Apennines. They were far from the area of the May 2012

Table 2 RAN-DPC strong-motion data (permanent stations) for the May 20th, 2012, earthquake, recorded by 5 stations within 50 km from the epicentre

Origin time: 20/05/2012 2.03.53 Lat. 44.890 Lon. 11.230 Ml 5.9 Agency: INGV

sta	chan	dist (km)	Td (s)	PGA (cm/s*s)	PGV (cm/s)	PGD (cm)	PSA03 (cm/s*s)	PSA10 (cm/s*s)	PSA30 (cm/s*s)	Housner (cm)	Arias (cm/s)	Location
MRN	HGZ	17	6	3.0e+02	5.9e+00	2.3e+00	1.9e+02	4.3e+01	1.3e+01	2.4e+01	4.5e+01	Mirandola
MRN	HGE	17	6	2.6e+02	3.0e+01	9.2e+00	8.3e+02	2.8e+02	4.9e+01	1.1e+02	6.4e+01	Mirandola
MRN	HGN	17	6	2.6e+02	4.7e+01	1.4e+01	7.3e+02	5.5e+02	7.6e+01	1.7e+02	7.8e+01	Mirandola
MDN	HGZ	40	23	2.9e+01	1.6e+00	1.2e+00	7.7e+01	2.8e+01	4.5e+00	7.4e+00	1.2e+00	Modena
MDN	HGN	40	32	3.3e+01	3.8e+00	3.4e+00	7.2e+01	5.4e+01	9.5e+00	1.7e+01	2.4e+00	Modena
MDN	HGE	40	30	3.6e+01	6.9e+00	4.6e+00	6.9e+01	6.3e+01	1.5e+01	2.0e+01	3.2e+00	Modena
NVL	HGN	41	16	5.1e+01	2.4e+00	1.4e+00	1.3e+02	2.9e+01	7.3e+00	1.0e+01	2.4e+00	Novellara
NVL	HGE	41	16	4.7e+01	2.8e+00	9.9e−01	9.5e+01	2.8e+01	7.6e+00	1.1e+01	2.5e+00	Novellara
NVL	HGZ	41	20	2.9e+01	1.0e+00	2.7e+00	2.6e+01	4.7e+00	2.7e+00	3.1e+00	8.4e−01	Novellara
ZPP	HGZ	42	49	2.0e+01	2.0e+00	2.2e+00	4.4e+01	1.7e+01	7.4e+00	6.8e+00	8.0e−01	Zola_Pedrosa_Piana
ZPP	HGE	42	61	1.6e+01	3.3e+00	5.6e+00	3.2e+01	4.0e+01	1.1e+01	1.2e+01	1.4e+00	Zola_Pedrosa_Piana
ZPP	HGN	42	46	2.3e+01	4.3e+00	4.4e+00	5.1e+01	6.0e+01	1.8e+01	2.1e+01	2.6e+00	Zola_Pedrosa_Piana
ISD	HGE	49	55	1.3e+01	2.1e+00	2.8e+00	3.6e+01	2.6e+01	1.1e+01	1.0e+01	8.4e−01	Isola_Della_Scala
ISD	HGZ	49	63	9.0e+00	1.2e+00	2.9e+00	1.8e+01	9.2e+00	6.6e+00	3.1e+00	1.9e−01	Isola_Della_Scala
ISD	HGN	49	53	1.6e+01	1.8e+00	1.0e+00	3.3e+01	2.8e+01	9.1e+00	1.0e+01	8.4e−01	Isola_Della_Scala

dist epicentral distance, *Td* duration (Trifunac and Brady 1975), *PGA, PGV, PGD* peak ground acceleration, velocity and displacement, *PSA03, PSA10, PSA30* spectral acceleration at 0.3, 1.0, 3.0 s *Housner* Housner spectral intensity, *Arias* arias intensity

Table 3 RAN-DPC strong-motion data (permanent and temporary stations, the latter identified with the suffix temp in the name of the locality) for the May 29th, 2012, earthquake, recorded by 9 stations (1 permanent and 8 temporary stations) within 25 km from the epicentre

Origin time: 29/05/2012 h:07:00:03 Lat. 44.851 Lon. 11.086 Ml 5.8 Agency: INGV

sta	chan	dist (km)	Td (s)	PGA (cm/s*s)	PGV (cm/s)	PGD (cm)	PSA03 (cm/s*s)	PSA10 (cm/s*s)	PSA30 (cm/s*s)	Housner (cm)	Arias (cm/s)	Location
MRN	HGZ	2	5	9.0e+02	2.8e+01	1.1e+01	3.7e+02	9.1e+01	3.0e+01	5.3e+01	3.0e+02	Mirandola
MRN	HGE	2	8	2.2e+02	2.9e+01	9.2e+00	5.0e+02	1.7e+02	8.1e+01	1.0e+02	7.2e+01	Mirandola
MRN	HGN	2	7	2.9e+02	5.7e+01	1.8e+01	7.0e+02	3.7e+02	1.5e+02	1.8e+02	1.2e+02	Mirandola
SAN0	HGN	4	7	2.2e+02	3.6e+01	1.2e+01	5.7e+02	2.0e+02	1.1e+02	1.2e+02	5.0e+01	San_Felice_sul_Panaro_temp
SAN0	HGZ	4	4	3.0e+02	9.0e+00	4.9e+00	3.0e+02	4.8e+01	2.1e+01	3.0e+01	4.1e+01	San_Felice_sul_Panaro_temp
SAN0	HGE	4	7	1.7e+02	2.1e+01	1.6e+01	3.6e+02	1.9e+02	8.1e+01	8.2e+01	2.9e+01	San_Felice_sul_Panaro_temp
RAV0	HGZ	15	9	6.3e+01	1.7e+00	1.2e+00	9.2e+01	1.6e+01	3.3e+00	6.7e+00	2.3e+00	Ravarino_temp
RAV0	HGE	15	15	5.8e+01	6.2e+00	1.4e+00	1.1e+02	7.2e+01	1.3e+01	2.1e+01	2.9e+00	Ravarino_temp
RAV0	HGN	15	13	8.2e+01	9.7e+00	6.0e+00	2.4e+02	1.5e+02	2.0e+01	3.4e+01	6.5e+00	Ravarino_temp
SMS0	HGZ	15	7	1.2e+02	3.1e+00	1.2e+00	1.0e+02	1.6e+01	8.2e+00	1.2e+01	1.3e+01	San_Martino_Spino_temp
SMS0	HGE	15	6	1.8e+02	1.3e+01	4.5e+00	6.0e+02	1.4e+02	2.8e+01	6.2e+01	4.3e+01	San_Martino_Spino_temp
SMS0	HGN	15	9	1.7e+02	1.4e+01	4.2e+00	3.5e+02	1.7e+02	3.7e+01	6.1e+01	3.0e+01	San_Martino_Spino_temp
FIN0	HGZ	16	6	2.1e+02	3.0e+00	9.8e−01	1.2e+02	2.1e+01	1.3e+01	1.5e+01	3.0e+01	Finale_Emilia_temp
FIN0	HGE	16	9	2.1e+02	1.8e+01	3.2e+00	3.7e+02	1.5e+02	2.9e+01	5.7e+01	2.8e+01	Finale_Emilia_temp
FIN0	HGN	16	9	2.3e+02	1.7e+01	2.9e+00	5.1e+02	1.0e+02	2.6e+01	5.3e+01	2.5e+01	Finale_Emilia_temp
MOG0	HGN	16	7	1.7e+02	2.1e+01	9.2e+00	4.4e+02	2.1e+02	3.1e+01	1.0e+02	3.7e+01	Moglia_temp
MOG0	HGZ	16	9	1.3e+02	5.1e+00	1.6e+00	2.5e+02	3.1e+01	1.9e+01	2.2e+01	1.5e+01	Moglia_temp
MOG0	HGE	16	7	2.4e+02	2.8e+01	1.7e+01	5.5e+02	2.3e+02	1.6e+01	9.4e+01	5.0e+01	Moglia_temp
CRP	HGZ	19	11	8.3e+01	2.3e+00	9.9e−01	7.8e+01	1.9e+01	1.2e+01	1.2e+01	7.0e+00	Carpi_temp
CRP	HGN	19	13	1.7e+02	6.8e+00	2.4e+00	2.0e+02	6.6e+01	1.5e+01	3.3e+01	1.9e+01	Carpi_temp
CRP	HGE	19	13	1.2e+02	9.2e+00	2.5e+00	1.9e+02	1.2e+02	1.6e+01	3.8e+01	1.5e+01	Carpi_temp

Table 3 continued

Origin time: 29/05/2012 h:07:00:03 Lat. 44.851 Lon. 11.086 Ml 5.8 Agency: INGV

sta	chan	dist (km)	Td (s)	PGA (cm/s*s)	PGV (cm/s)	PGD (cm)	PSA03 (cm/s*s)	PSA10 (cm/s*s)	PSA30 (cm/s*s)	Housner (cm)	Arias (cm/s)	Location
CNT	HGZ	21	9	6.4e+01	2.6e+00	8.5e−01	2.8e+02	1.7e+01	3.6e+00	9.5e+00	4.6e+00	Cento_temp
CNT	HGE	21	4	2.2e+02	1.7e+01	3.2e+00	7.9e+02	1.9e+02	2.5e+01	8.0e+01	4.2e+01	Cento_temp
CNT	HGN	21	6	2.9e+02	1.4e+01	3.6e+00	1.0e+03	1.2e+02	1.7e+01	5.6e+01	4.0e+01	Cento_temp
SAG0	HGE	25	18	7.9e+01	7.7e+00	2.0e+00	2.9e+02	5.1e+01	1.7e+01	2.8e+01	8.6e+00	Sant_Agostino_temp
SAG0	HGN	25	19	6.6e+01	6.3e+00	3.0e+00	1.8e+02	6.3e+01	1.7e+01	2.6e+01	5.5e+00	Sant_Agostino_temp
SAG0	HGZ	25	15	6.7e+01	2.2e+00	1.0e+00	7.6e+01	1.7e+01	1.4e+01	9.8e+00	3.1e+00	Sant_Agostino_temp

dist epicentral distance, *Td* duration, (Trifunac and Brady 1975), *PGA*, *PGV*, *PGD* peak ground acceleration, velocity and displacement, *PSA03*, *PSA10*, *PSA30* spectral acceleration at 0.3, 1.0, 3.0 s, *Housner* Housner spectral intensity, *Arias* Arias intensity

sequence for the same reasons stated above regarding the instrumental density of the RAN-DPC network. The nearest monitored structure was a nursery school at Lugo di Romagna, 76 km far from the epicentre, while a total of 12 monitoring systems were triggered up to 117 km distance from the epicentre. After the May 20th earthquake, two temporary systems were further installed to monitor the Ferrara Prefecture and the Modena Prefecture buildings. A total of 11 monitoring systems were triggered up to 149 km distance from the epicentre by the second main shock.

In both cases no damage could be associated to the very low drift and acceleration values recorded in the monitored buildings. As a matter of fact, the maximum drift value recorded during the first main shock in the aforementioned nursery school R/C building was 0.31 %, due to 0.0195 g PGA at the base of the building and a maximum storey acceleration equal to 0.0425 g.

Two lessons have been learned from this and the Abruzzo earthquake monitoring experiences (Zambonelli et al. 2011). The network density should be increased, in order to get both a more exhaustive picture of the ground motion feature in the epicentral area, and more reliable shake maps in the aftermath of the earthquake. If this is not economically feasible with high standard instruments, recent proposals for the use of inexpensive instruments or by exploiting croudsourcing techniques seem quite promising to improve the rapid response capability. On the other hand, the immediate deployment of temporary (high standard) instruments appear to be an important action to be implemented, in order to monitor the main aftershocks, sometimes occurring with magnitude of the same order as for the mainshock.

3.3 Evaluation and management of soil liquefaction

As briefly outlined in Sect. 1, the May 20th earthquake determined coseismic effects, among which ground fractures and important liquefaction phenomena (Di Manna et al. 2012; Caputo et al. 2012, Fig. 4), especially in the zone of Mirabello, San Carlo and Sant'Agostino, which is characterized by the presence of a paleo-riverbed of the Reno River.

Liquefaction mud came at surface through fractures up to ∼50 m long; fractures width ranged from few centimetres to some decimetres. In some cases, the formation of typical mud volcanoes was observed; in other cases, mud was ejected through large diameter water wells, or it uplifted pavements in urbanized areas.

Fig. 4 Example of liquefaction phenomena (from http://www.protezionecivile.gov.it/)

According to the descriptions reported by Papathanassiou et al. (2012), liquefaction phenomena started almost at the same time as the main shock. In the first seconds/minutes of the ejection process, clear water came to the surface first, only later mixed with sand. The maximum observed height was ∼2 m from the ground. The phenomenon duration ranged from few minutes to some hours, depending on the site. In some villages, in particular in the San Carlo village (municipality of Sant'Agostino), liquefactions made some buildings and roads temporarily unusable, and caused some interruptions in water, gas and electricity supply, due to the damage to the distribution networks.

To carry out an in-depth evaluation of the liquefaction phenomena, especially aimed at restoring the buildings and roads usability and the effectiveness of the distribution networks, an ad hoc interdisciplinary working group for the evaluation of the effects of liquefaction was established, made of geologists, geotechnical and structural engineers from different institutions, universities and professional associations of geologists and engineers.

In an initial phase, after the two main shocks, all the buildings in the most affected area of San Carlo were evacuated, even in case they were not, or were only slightly, damaged. The first problem to be solved was then to evaluate the trend of the phenomenon in order to allow people to utilise their home in case of no or slight damage.

Summarizing, the procedure to be followed envisaged a first step, corresponding to the survey and classification of the damage to buildings (green: no damage; orange: minor damage, or needing further inspections; red: structural damage, making the building unusable). The second step consisted of a survey devoted to identify the geotechnical hazards possibly affecting the foundations of buildings assigned to the green damage class. The third step aimed at developing and implementing a program specifically addressed to monitor and survey the buildings and the ground water table, in order to define and characterize the phenomenon and provide information on the geotechnical hazard by interpreting the acquired data.

Results obtained in a time interval of about one month after the second main shock indicated that the transitory effects, due to the slow dissipation of the pore overpressure, were ended, and so was the post-seismic geotechnical risk. On the one hand, the post-earthquake usability of the buildings assigned to the green class, that had been temporarily evacuated, was confirmed, allowing people to come back home. On the other hand, there is still the possibility that liquefaction phenomena occur again, due to similar or stronger earthquakes. An in-depth reasoning is thus needed on which actions have to be undertaken to mitigate such a risk. The results of the working group activities are available on the institutional internet website of the Emilia Romagna Region (http://ambiente.regione.emilia-romagna.it/geologia/notizie/notizie-2012/istituito-un-gruppo-di-lavoro-della-regione-e-del-dpc-per-la-valutazione-degli-effetti-di-liquefazione).

If one looks at recent Italian earthquakes, liquefaction in Emilia determined a quite unprecedented situation. Although no catastrophic collapses were determined in this case, the need for a greater attention to these phenomena by the technical and the scientific communities has been emphasised. At this end, specific provisions for the seismic microzonation studies are being set up, to be incorporated in the next update of the Italian Guidelines (Working Group MS 2008).

3.4 Damage and usability assessment of ordinary buildings

As always happens after a severe earthquake, the damage and usability assessment of buildings is a main question to be faced in order to achieve an effective management of the emergency, post-emergency and reconstruction phases.

Fig. 5 Volunteers from the national Council of engineers, working at the damage and usability assessment (from http://www.protezionecivile.gov.it/)

As a matter of fact, this assessment allows:

1. the population to safely stay in or re-enter their homes;
2. the shelter and temporary housing needs to be properly scaled, both in the emergency (tent camps, hotels, self-lodging financial support) and in the post-emergency (temporary housing);
3. activities to be rapidly restarted;
4. cost analyses to be carried out, in order to define the funds needed for the reconstruction;
5. priority and funding criteria to be identified for the interventions on each building.

In Italy, the damage and usability assessment of ordinary buildings is executed using well grounded procedures, based on the experience acquired over 15 years of surveys carried out in Italy in the aftermaths of 1997 Umbria-Marche, 1998 Pollino, 2002 Molise-Puglia and 2009 Abruzzo earthquakes, and made official by a Decree issued by the Italian Prime Minister on May 5th, 2011, which enforces, at national level, the AeDES inspection form and the related manual (Baggio et al. 2000).

Also in the case of the 2012 Emilia earthquake, a huge effort was made to organize the damage and usability assessment survey. The assessment was actually performed by experts coming from different Regions and from the National Fire Brigades, by researchers of the DPC Centres of Competence (ReLUIS and EUCENTRE), and by engineers, architects and surveyors coordinated through the related national professional Councils (Fig. 5).

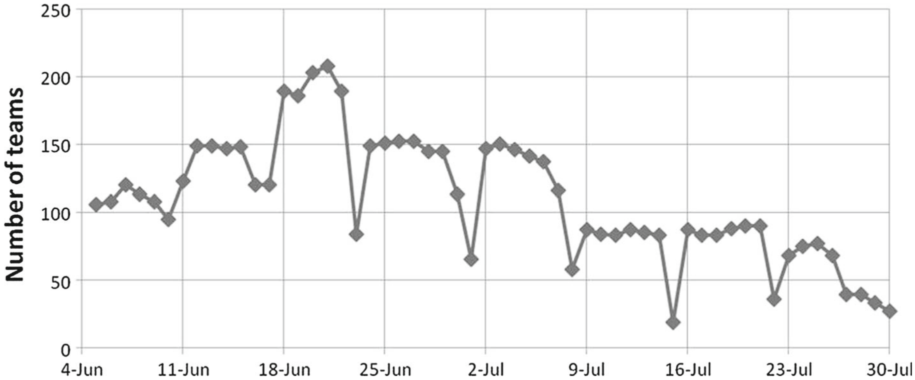

Fig. 6 Daily distribution of the teams working at the damage and usability assessment up to July 30th, 2012

A total of more than 40,000 inspections have been carried out, each of them corresponding to one AeDES inspection form. During the period of maximum activity, the damage and usability assessment involved about 180 teams per day (with a maximum of more than 200 teams; Fig. 6). The maximum number of inspections per day ranged between 1,000 and 1,200. About 3,000 experts were employed. On the one hand, the DPC team that coordinated this activity was under a high pressure by the local authorities, which asked for a fast response to the requests of the citizens, especially those living in slightly or not damaged buildings, notwithstanding the considerable number of inspections per day carried out. On the other hand, assessing the usability of a building implies awareness and responsibility, an issue that has to be managed and carefully considered even in the emergency rush.

According to the AeDES form, buildings are classified into the following usability categories:

A. Usable building. The building, albeit slightly damaged, can keep on housing the functions to which it was dedicated, keeping the human life reasonably protected in case of an aftershock as strong as the earthquake that motivated the inspection.
B. Building usable only after short term countermeasures. It is the case of a building with limited or no structural damage, but with severe non-structural damage. Once countermeasures are taken, however, the building can be re-used.
C. Partially usable building. It is the case of a building with limited or no structural damage, but with severe non-structural damage located in a part of the building. The possible partial or total collapse of the damaged part must not imply a risk for the usable part.
D. Building to be re-inspected. It is the case of unusual damage scenario, or of geological, geotechnical or other situations that require a specific, still visual, investigation.
E. Unusable building, as a consequence of at least one of the following conditions: high structural risk, high non-structural risk or high geotechnical risk.
F. Unusable building for external risk only, like in the case of landslides or adjacent near-collapsed constructions threatening the inspected building.

The results of the survey are shown in Fig. 7 and, for their correct interpretation, they deserve to be briefly commented. The amount of usable buildings (category A) corresponds to the 37 % of the inspected buildings, and is significantly lower than the percentage obtained for the same category after the April 6th, 2009, Abruzzo earthquake (Dolce et al. 2009), which was of the order of 50 %. Moreover, in the Emilia case, the percentage of usable

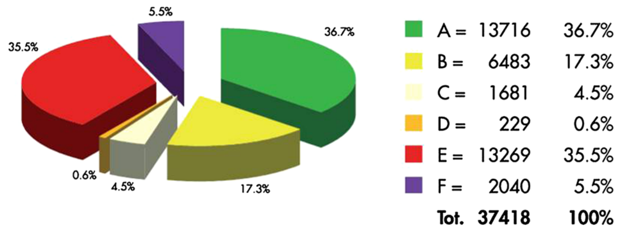

Fig. 7 Results of the damage and usability assessment, referred to August 3rd, 2012, and distributed according to the AeDES categories

buildings is quite the same as that relevant to unusable buildings in category E. For the Abruzzo earthquake, instead, the buildings assessed under category E were 25 %, in spite of the maximum observed macroseismic intensities being more than one degree higher than those assigned for the Emilia earthquakes.

The reasons for this apparent contradiction can be clearly understood if one considers how the damage and usability survey was organized in the two cases. For the 2009 Abruzzo earthquake, a complete survey was carried out for all the buildings located in the towns and villages characterized by an intensity I > VI MCS. In the 2012 Emilia earthquakes, instead, the assessment of a building was carried out only in case of specific request made by the owners or the tenants, and after a preliminary inspection aimed at providing a first quick survey aimed at identifying clearly usable buildings; in case of first positive assessment (i.e., no damage), the survey based on the AeDES form was no longer performed. Therefore, the AeDES inspections were carried out only on a selected sample of buildings having higher probabilities of being judged as not usable. This strategy was adopted in Emilia, as well as in other previous earthquakes, to speed up the survey, because of the high number of buildings in the epicentral area, a figure much higher than in Abruzzo, and, at the same time, of the low number of damaged buildings. The outcome of the usability assessment is urgently needed by the citizens and the authorities in charge of the emergency management, as it can be easily understood. Therefore, the most efficient way to complete the survey of damaged buildings as soon as possible must be pursued in any case.

Finally, some considerations are deserved on the use of the AeDES form and, more in general, on the related survey procedure. Generally speaking, once again the form turned out to be an effective tool to collect information on the state of the buildings and on the possible continuation of their use. Only some slight modifications are being introduced in the form and, especially, in the manual for its better use. They are essentially aimed at favouring the correct interpretation of the form by the surveyors and improving the uniformity of judgement. These aspects are crucial and need attention, since the compiled AeDES forms have become administrative documents, conditioning the right of citizens to benefit from the public assistance and from the reimbursement of the damage costs by the State. Given the experience of the Abruzzo 2009 and the Emilia 2012 earthquakes, the training of the experts and the organisation of the volunteers experts into well organised groups are now being further improved in Italy.

3.5 Damage and usability assessment of industrial buildings

The May 20th and, especially, the May 29th earthquakes shed light on the high seismic vulnerability of the buildings for industrial and productive use, most of them having prefabricated structures with large spans (Fig. 8). Such a vulnerability has to be ascribed to the late seismic

Fig. 8 Example of a strongly damaged warehouse at Moglia (from http://www.protezionecivile.gov.it/)

Fig. 9 Example of collapsed stands within a warehouse in the Moglia village (from http://www.protezionecivile.gov.it/)

classification (2003) of the epicentral area, as mentioned in the introduction. The bad seismic behaviour of these buildings was even worsened by the peculiarity of the response spectra of the May 20th and 29th shocks, exhibiting significant amplifications in the mean-to-high period range and large spectral displacements, due to the subsurface geological setting of the Po Plain.

In any case, it was evident that collapses and severe damage of these structures are to be fundamentally (although not totally) ascribed to:

– the lack of structural links between horizontal (beams, double tee roof decks, etc.) and vertical (columns) prefabricated structural elements;
– the use of very heavy prefabricated wall panels, inadequately anchored to the main structure, or so that unfavourable interactions were generated;
– the occurrence of notably heavy duty warehouse racks poorly or not at all braced, containing very heavy goods. The collapse of these stands caused an unexpected horizontal thrust on the main structure, favouring in turn its collapse (Fig. 9).

The specific analysis of the technical-scientific aspects, carried out in other papers of this journal issue, is out of the scope of the present paper. The attention is focused, instead, on the actions undertaken to solve problems from an operational point of view, through civil protection ordinances and related legislative measures.

After the May 29th earthquake, it was once more evident that the post-seismic damage and usability assessment of industrial buildings had to be conducted with a methodology different from that adopted for the typical multistorey ordinary buildings, that are characterized by masonry or R.C. continuous structures and limited window size. As a matter of fact, the use of the AeDES form is not appropriate for prefabricated one-storey large-span industrial buildings. Moreover, visual inspections from the ground level did not allow to ascertain the presence of structural links and their actual conditions. For this reason, an *ad hoc* ordinance was issued on June 2nd, 2012, stating that the owner of the production activity had to acquire the seismic usability certification, issued by a qualified expert after a safety check carried out in accordance with the current seismic code.

The choice to adopt this measure, as well as the identification of the municipalities where it had to be applied, were based on the following points:

1) the duration of the historical seismic sequence that started in the same area in 1570 was of about 4 years. This suggested that the seismic crisis which started on May 20th, 2012, was still ongoing in June 2012. Therefore, the occurrence of a M 5.5+ seismic event was possible in the following days/weeks/months, or even years, with an epicentre different from those of the May 20th and 29th main shocks. These possible future shocks would have been able, in principle, to locally cause stronger effects than those experienced for the mentioned main shocks;
2) the sequence was associated to a well defined geological structure, a buried arc-shaped thrust fault, elongated in West-East direction for a length of about 60 km. Up to that moment, the seismic sequence had been characterized by 7 earthquakes with magnitude ≥ 5, distributed all over the activated part of the thrust, besides many other seismic events with magnitude >3.5 and distributed all over the same area.

The area where M5.5+ earthquakes in the next future were more likely to occur was defined by considering all the epicentres of earthquakes with magnitudes higher than 3.5 occurred within the ongoing seismic sequence. They were supposed to be possible epicentres of future strong earthquakes, as they correspond to hypocenters located at depth on the same seismogenic fault system activated on May 2012. Then, an area defined by a radius of 10 km was centred on each of the above epicentres, assuming that this could be a reasonable schematization of the zone affected by near-fault effects in case of severe shock. The total area obtained by the coalescence of these circles was finally matched with the partially or totally overlapping municipal territories, as shown in the map of Fig. 10.

According to the issued provisions, if the results of the safety verification made according to the Italian standards (NTC08) returns a seismic capacity lower than the demand resulting from 60 % of the design seismic action, then the building must be retrofitted to achieve at least that seismic capacity level. The law also schedules a time period for the retrofit, which is shorter in case of lower seismic capacity of the building.

The safety verification was not compulsory for those buildings that were not damaged and lied in those parts of the territory where the seismic actions suffered during the sequence were greater than 70 % of the design seismic action specified by the current Italian code for the ultimate limit state. The values of the suffered seismic action come from the shake maps elaborated by the INGV for the earthquakes with magnitude M5+, and made publicly available on its institutional website.

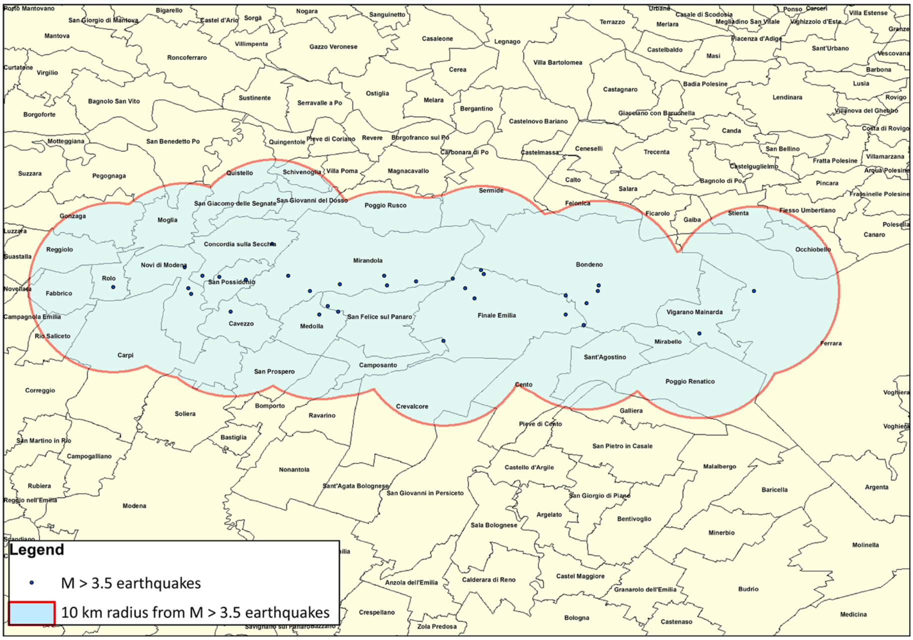

Fig. 10 Map of the 52 municipalities within a 10 km radius from the epicentres with M>3.5

Immediate safety measures had also to be taken, as established in the Decree-Law n. 74 (June 6th, 2012): structural connections had to be mandatorily realized if they were lacking or inadequate, both between vertical and horizontal elements (pillars and beams), and between wall panels and structure. These structural interventions have been regarded as "local interventions", as foreseen by the Italian building code (NTC08, issued through Ministerial Decree on January 14th, 2008). Their design required only the local strength to be verified, and not the overall safety of the structure. Moreover, adequate bracing for the warehouse racks were part of the mandatory provisions, as well as interventions in case of other evident structural needs.

To help designers, "Guidelines" for the local and global interventions on single storey industrial buildings designed without any seismic criteria (Gruppo di Lavoro Agibilità Sismica dei Capannoni Industriali 2012) were drafted. The first version was released on June 19th, 2012.

The problem of the high damageability of industrial prefabricated buildings was a unique feature of the Emilia earthquake with respect to previous earthquakes recently occurred in Italy. This was due to three main reasons: (i) the epicentral area is one of the most important and productive industrial districts in Italy (producing about 2 % of the GDP), resulting in a high exposure; (ii) the seismic classification was adopted late in the area, resulting in a high vulnerability of prefabricated buildings; (iii) the spectral features of the ground motion exhibited a specific shape, resulting in an increased hazard for buildings with high vibration periods, like industrial buildings. The catastrophic consequences, not only for the human losses but also for the considerable economic losses experienced in the event of the Emilia earthquake, highlighted this problem not only as a technical one. The attention of the owners of these buildings is now higher, so that they are taking spontaneously some prevention countermeasures even outside the epicentral area of the 2012 earthquake.

4 Possible evolution of the seismic sequence

After the May 29th main shock, the "Commissione Grandi Rischi" (national commission for the prevision and prevention of the major risks—CGR) sent a brief report to the Head of the Department of Civil Protection, where key findings and recommendations were reported on the possible evolution of the ongoing seismic sequence in Emilia.

In this report, the Commission underlined that no reliable methods are available at present to make short term earthquake predictions, and that the best strategy for an effective seismic prevention still relies on actions specifically focused on the vulnerability reduction of the building stock. The Commission, however, on the basis of both the structural and seismo-tectonic setting of the first kilometres of crust and of the seismic crisis started on May 20th, 2012, made some considerations on the possible evolution of the sequence. More precisely, "The Commission provided the following interpretations of the ongoing seismic phenomena:

- in the western and central segments of the tectonic structure, which have already recorded the major seismic events—between Finale Emilia and Mirandola—the number and magnitude of the aftershocks are reducing;
- in case of a new increase of the seismic activity in the area already affected by the ongoing sequence, there is a significant probability that the segment between Finale Emilia and Ferrara will be activated by seismic events comparable to the major earthquakes recorded during the sequence;
- besides, it cannot be ruled out that the seismic activity will further extend in the surroundings of the already activated area, although this is less probable".

Considering the hypothesis on the possibility of a fault segment activation between Finale Emilia and Ferrara, and the consequent possible occurrence of severe seismic events, a number of actions aimed at reducing the risk were undertaken by the national civil protection system under the coordination of DPC. These actions were aimed at enhancing the seismic prevention, powering the national system for the emergency response, verifying the local systems of emergency management and informing the population.

A damage scenario was modelled for a hypothetical M 6.0 earthquake in order to calibrate the upgrade of the seismic prevention countermeasures in the area potentially affected. In particular, a quick survey of the vulnerability of 3,416 buildings of the old town centre of Ferrara was carried out in about one month (Dolce and Speranza 2013). The relevant data were made immediately available to the Ferrara municipality and used to update the municipal emergency plan. This activity was completed very rapidly, with the collaboration of engineers and surveyors who worked as volunteers in coordination with their professional national Councils.

The Provincial Coordination Centres were urged to verify if the municipal emergency plans were update and, in collaboration with the Mayors, to carry out a quick check of the vulnerability of those buildings and infrastructures that have to guarantee, even during an emergency, the functionality of the essential services.

The National Fire Brigades and the Army were urged to prepare a quick emergency plan to rapidly bring rescue in case of a further emergency, programming to increase the availability of their personnel in the area.

Moreover, to provide a specific and correct information to the population:

- the CGR report was published on the DPC website, and frequently asked questions (FAQ) on that topic were answered;
- the section of the DPC website devoted to explain what to do in case of an earthquake was further developed;

– the DPC Contact Center was powered;
– a series of conferences titled: "Terremoti, parliamone insieme" (Earthquakes, let's talk about) for the population living in municipalities of the area affected by the earthquake sequence were organised by DPC and Emilia Romagna Region in cooperation with INGV, ReLUIS, the Regional Health Service and the organizations of civil protection volunteers.

5 Conclusion

The seismic sequence that, since May 20th, 2012, hit the central part of the Po Plain represented a new challenge for the response capability of the entire Italian civil protection system. The damage of an important industrial district in an economically complex period for the Country and the need to coordinate activities among many Regions have specifically characterized the experience of the emergency management of the Emilia earthquakes.

In this paper the main civil protection activities during the first emergency phase have been briefly described, paying particular attention to the technical aspects. It has to be remarked that the contribution provided by the scientific community and the national professional Councils was very relevant, both in quantitative terms and for the high technical content. This integration is the result of a long tradition of coordination and interaction strongly supported by DPC (Dolce 2008), which allows civil protection to deal with important and complex emergency situations in a more effective manner.

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