THE EMILIA THRUST EARTHQUAKE OF 20 MAY 2012 (NORTHERN ITALY): STRONG MOTION AND GEOLOGICAL OBSERVATIONS

- Report 1 -

NATIONAL CIVIL PROTECTION DEPARTMENT (DPC): M. Dolce, M. Nicoletti, A. Ammirati, R. Bianconi, L. Filippi, A. Gorini, S. Marcucci, F. Palma, E. Zambonelli

GEOSIS-LAB UNICHIETI: G. Lavecchia, R. de Nardis, F. Brozzetti, P. Boncio, D. Cirillo, A. Romano

UNIVERSITY OF TRIESTE: G. Costa, A. Gallo, L. Tiberi, G. Zoppé, P. Suhadolc

REGIONE UMBRIA - REGIONAL CIVIL PROTECTION: F. Ponziani, A. Formica

INTRODUCTION

On 20 May 2012, at 02:03:53 (UTC), Northern Italy was struck by an earthquake of magnitude M_l 5.9 (lat 44.890 long 11.230). The mainshock was preceded by a M_l 4.1 event on 19 May and followed by four relevant aftershocks with $4.8 \leq M_l \leq 5.1$ within a few days: two events with M_l 5.1, one with M_l 4.9 and one with M_l 4.8. Eleven events with magnitude $4.0 \leq M_l \leq 4.5$, plus several other minor earthquakes, occurred in the same area from 20 to 23 May, as reported in Italian Instrumental and Parametric Data-Base (ISIDe) available at *http://iside.rm.ingv.it/iside/standard/index.jsp*. The seismic sequence covered a large area extending in the E-W direction for a length of nearly 40 km, between the localities of Mirandola and Ferrara, close to the buried front of Ferrara-Romagna northward-verging active thrust belt.

Seven stations of the Italian strong motion network (RAN), managed by the National Civil Protection Department (DPC), were operating within 50 km from the the mainshock epicentre (Figs. 1 and 2B). The RAN stations recorded the strong motions of the mainshock, as well as of the foreshock and of the aftershocks of magnitude $M_l \geq 4.0$. Soon after the mainshock, the DPC began to install further stations to increase the network coverage in the epicentral area involved by the aftershocks in sites of particular interest for Civil Protection purposes.

This report is aimed at:

1- providing the mainshock waveforms to engineers, geophysicists geologists and scientists in general, for professional, technical works and scientific purposes;

2- showing the spatial distribution and geological setting of the temporary accelerometric network, consisting of 13 stations installed within the epicentral area. Such temporary network represents an extension of the permanent Italian strong motion one and is aimed at supporting the emergency response by the civil protection authorities by improving the network coverage. Two of the new stations (Cento and Carpi) must be considered as permanent.

RAN AND TRIBUTARY NETWORKS

The RAN counts, to date, 464 stations and provides dense station coverage for all high seismic hazard areas of the Italian territory (Fig. 1). All the stations are equipped with three components digital instruments and make use of the GPRS data transmission. The data acquisition centre of the network is located in Rome, at the DPC (Gorini et al.,2010; Zambonelli et al., 2011).

The RAN includes both the stations of an historical network, located inside ENEL electric transformer cabins (192 stations), and the 272 stations installed in free field, mostly on land owned by municipalities close to urban areas.

The network development to the current configuration has been possible thanks to inter-institutional agreements with local and regional authorities, that cooperated to identify the sites for the new stations, and that ensure electrical power to the same stations.

Today, thanks to agreements among DPC, universities and research institutes, signals from 46 accelerometric stations of two local networks, namely Irpinia Seismic Network ISNet - 31 stations (Weber et al., 2006; http://isnet.na.infn.it/) and the Friuli Venezia Giulia Accelerometric Network RAF - 15 stations (Costa et al., 2010; http://rtweb.units.it/), flow into in the data acquisition system of the RAN at DPC (FIG. 1A).

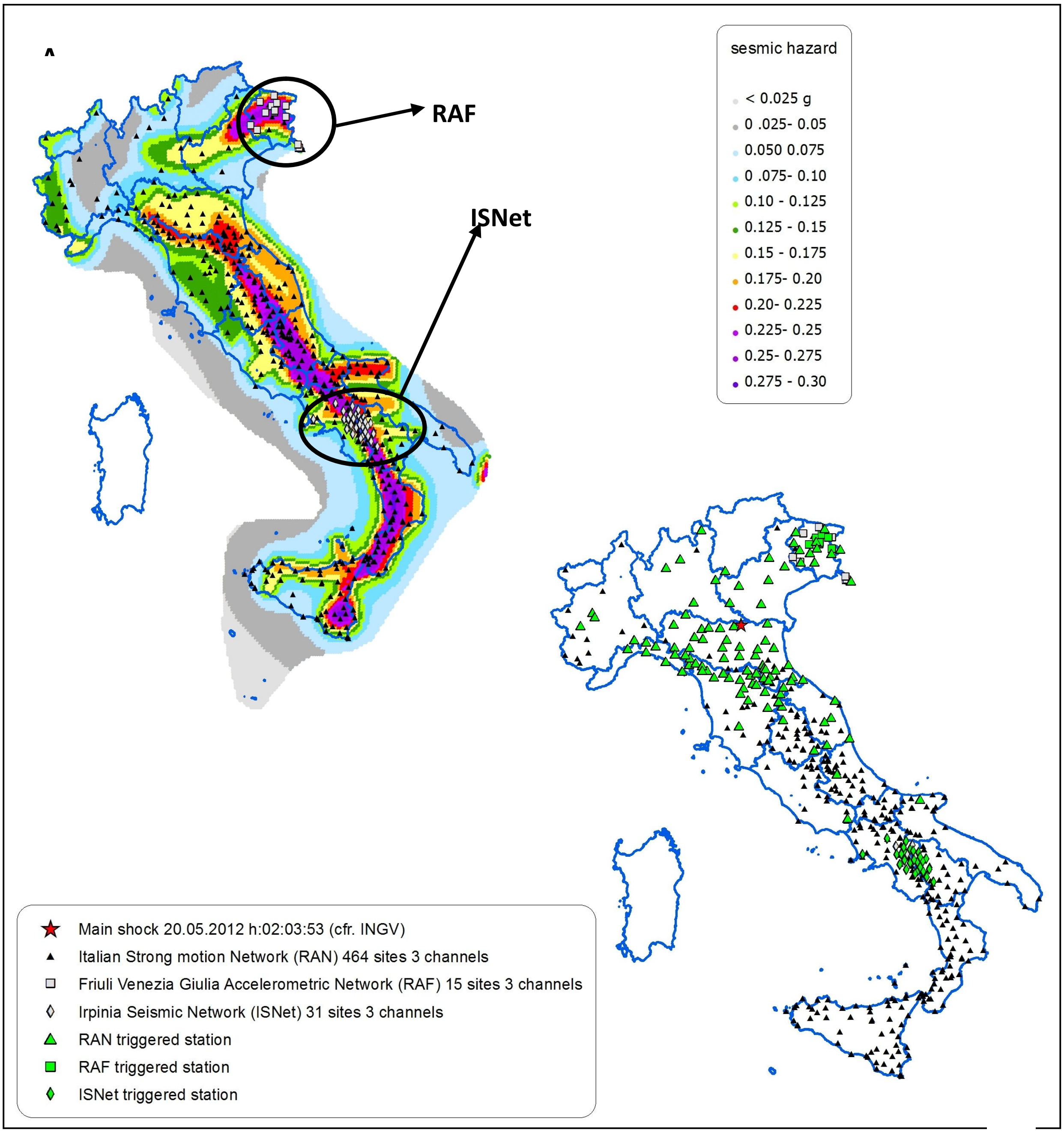

Figure 1: Configuration of the Italian strong motion network (RAN) and of the tributary networks. (A) The distribution c 464 digital strong motion stations of the Italian Civil Protection Department (black triangular symbols), the Irpinia Seismic /ork ISNet (Weber et al., 2006; http://isnet.na.infn.it/) (grey diamond symbols) and the Friuli Venezia Giulia Accelerometric /ork RAF (Costa et al., 2010; http://rtweb.units.it/) (square diamond symbols). The underlying base map is the Italian seism :ard map (Working Group MPS, 2004); different colors depict Peak Ground Acceleration (PGA in g) with a 10% c : of exceedance in 50 years (see legend at the top right corner).

(B) Distribution of the triggered stations during the Emilia earthquake mainshock (M_l 5.9) (Modena- Ferrara).

THE EMILIA 2012 SEISMIC SEQUENCE IN THE SEISMOTECTONIC FRAMEWORK OF THE NORTHERN APENNINES

The Padan-Adriatic thrust belt of northern Italy, active since Late Pliocene times, is articulated in a number of minor outward convex arcs (Lavecchia et al., 1994). From west to east they are known as: Emilia, Ferrara-Romagna and Coastal-Adriatic arcs (Fig. 2A). The associated thrust structures are affected by small-to-moderate crustal seismicity with maximum magnitude that never exceeded Mw 6.0 over the past 1000 yrs (CPTI11 Working Group, 2011; Fig. 2C). The available fault plane solutions in that area show prevalent reverse and reverse-oblique kinematics with P-axes arranged nearly perpendicular to the structural trend (Boncio and Bracone, 2009 and references therein). The state of active stress across the northern Apennines has been recently summarized by Montone et al. (2012). More specifically, the state of stress across the Mirandola anticline has been reconstructed by Carminati et al. (2010) and interpreted as typical of normal faulting at shallow depths, strike slip faulting at intermediate depths and thrust faulting close to the basal thrust.

The Emilia seismic sequence of May 2012 reactivated the basal thrust in the central portion of the Ferrara-Romagna arc. Earthquake distributions and focal mechanisms indicate a WSW-dipping low-angle thrust fault source at depths between nearly 5 and 10 km. During the instrumental period, the westernmost side of the same arc was struck by the Reggio Emilia 1996 earthquake (Mw 5.4), which reactivated a NE-dipping back-thrust at middle crustal depths (Ciaccio and Chiarabba, 2002). The easternmost side was reactivated instead by the Faenza 2000 earthquake, which struck a middle crust segment of the SW-dipping basal thrust (Lavecchia and Boncio, 1993).

The geometric relationships at depths between the Emilia 2012 seismicity and the active geological structures are preliminarily interpreted in the section of Fig. 2D, drawn perpendicular to the thrust faults, across the epicentral area. The geometry depicted in the section is constrained by available seismic reflection profiles and related geological cross-section (Toscani et al., 2009 and references therein; Line ENI, App. East-1 at http://unmig.sviluppoeconomico.gov.it/deposito/videpi/sismicatitoli/Linea_App_Orient_01.pdf). The hypocentral locations are extracted from the ISIDe database. The 20 May 2012 (M_l 5.9) is located at depth of ~6.5 km; the aftershock distribution delineates a low-angle south-dipping source confined between 5 and 10 km depth, with a width of nearly 10 km. The largest aftershocks occurred on 20 May (one with M_l 5.1, one with M_l 4.9 and one with M_l 4.8), as well as the strongest foreshock (19 May, M_l 4.1), mostly fall along the section trace of the basal thrust, within the late Palaozic-early Triassic sedimentary sequence. The foreshock, main shock and aftershocks focal mechanisms show almost pure reverse solutions, with P-axes trending N10°E, sub-perpendicular to the direction of the thrust front.

Some of the surface geological effects following the 20 May 2012 earthquake were surveied during a fieldwork within an area nearly delimited by the towns of Mirandola, Crevalcore, S. Agostino and Bondeno, where most of the aftershock sequence occurred (Fig. 4). They are grouped in the following broad classes:

1) ground fractures not clearly associated to sand with: opening fissures, in some cases with offset (photos c and l in fig.5)

2) fractures, with or without offset, clearly associated to sand liquefaction (linear sand blows, sand volcanoes and sinkholes, breakdown of levees and of anthropic scarp edges) (photos a, b, d, g, h and I in Fig.5)

3) scattered liquefaction phenomena not directly related to fractures observable in the field (isolated or distributed sand vents, mud volcanoes, sinkholes, well overflow) (photos e and f in Fig.5).

4) post-earthquake damages at RAN sites (photos m and n in Fig.5).

The collection of field data is still ongoing in order to better detail the distribution of the earthquake surface effects and to verify their possible evolution through time. At the same time, their processing in a GIS database will allow to compare their pattern with the deep geometry of the active tectonic structures.

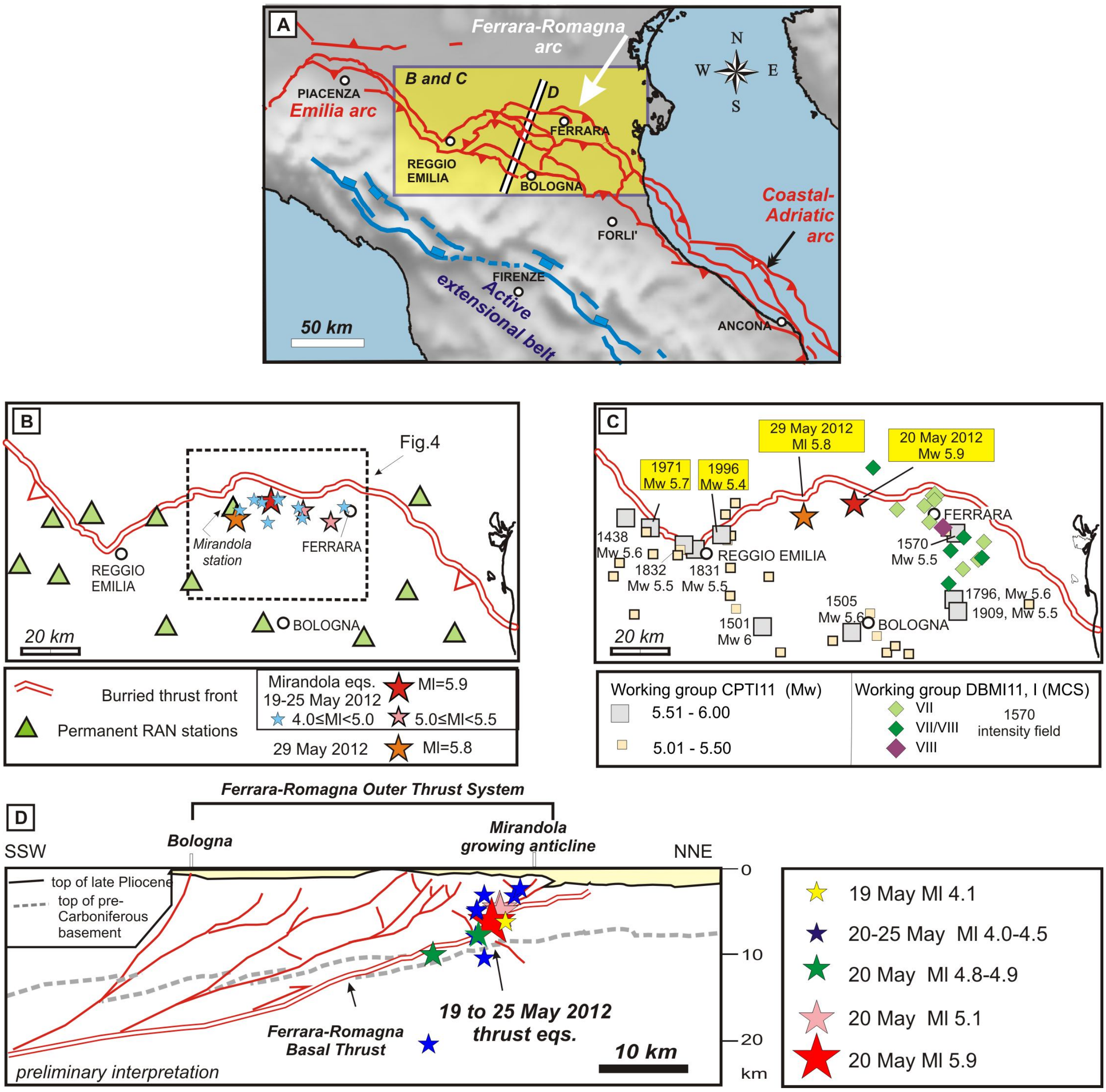

Figure 2: Seismotectonic framework of the Emilia 2012 earthquake. (A) Schematic map of the Padan-Adriatic Thrust Belt of northern Italy with boundary of the study area (yellow rectangle). (B) Major epicentres of the Emilia 2012 seismic sequence from 19 to 25 May, with the RAN configuration in the epicentral area. (C) Major historical earthquakes within the study area and macroseismic field of the 1570 earthquake. (D) Schematic structural sections across the Emilia 2012 hypocentral area redrawn from Toscani *et alii* (2009).

EMILIA 20 May MAINSHOCK: STRONG MOTION DATA

The main event (M_l 5.9) of the Emilia seismic sequence (20 May 2012, 02:03 UTC) was recorded by 139 RAN, RAF and ISNET stations located at epicentral distance ranging from 17 km up to more than 800 km (Fig. 1B).

The closest station was Mirandola (MRN) located at epicentral distance of 17 km (Fig. 2B). The MRN, classified as C site (EC8, Comité Européen de Normalisation 2004), recorded peaks of acceleration of about 300 cm/s^2. The station recorded continuously and the waveforms contains the mainshock and two of the more energetic aftershocks (M_l =4.8 at 02:06:30 UTC, M_l =5.1 at 02:07:31 UTC) according to the list of earthquakes provided from ISIDe database.

For stations that were triggered by the main event, the recorded waveforms have been extracted from the archive of the DPC. In particular, for the stations that have recorded continuously, was made an extraction of the waveform for a time interval not longer than six minutes.

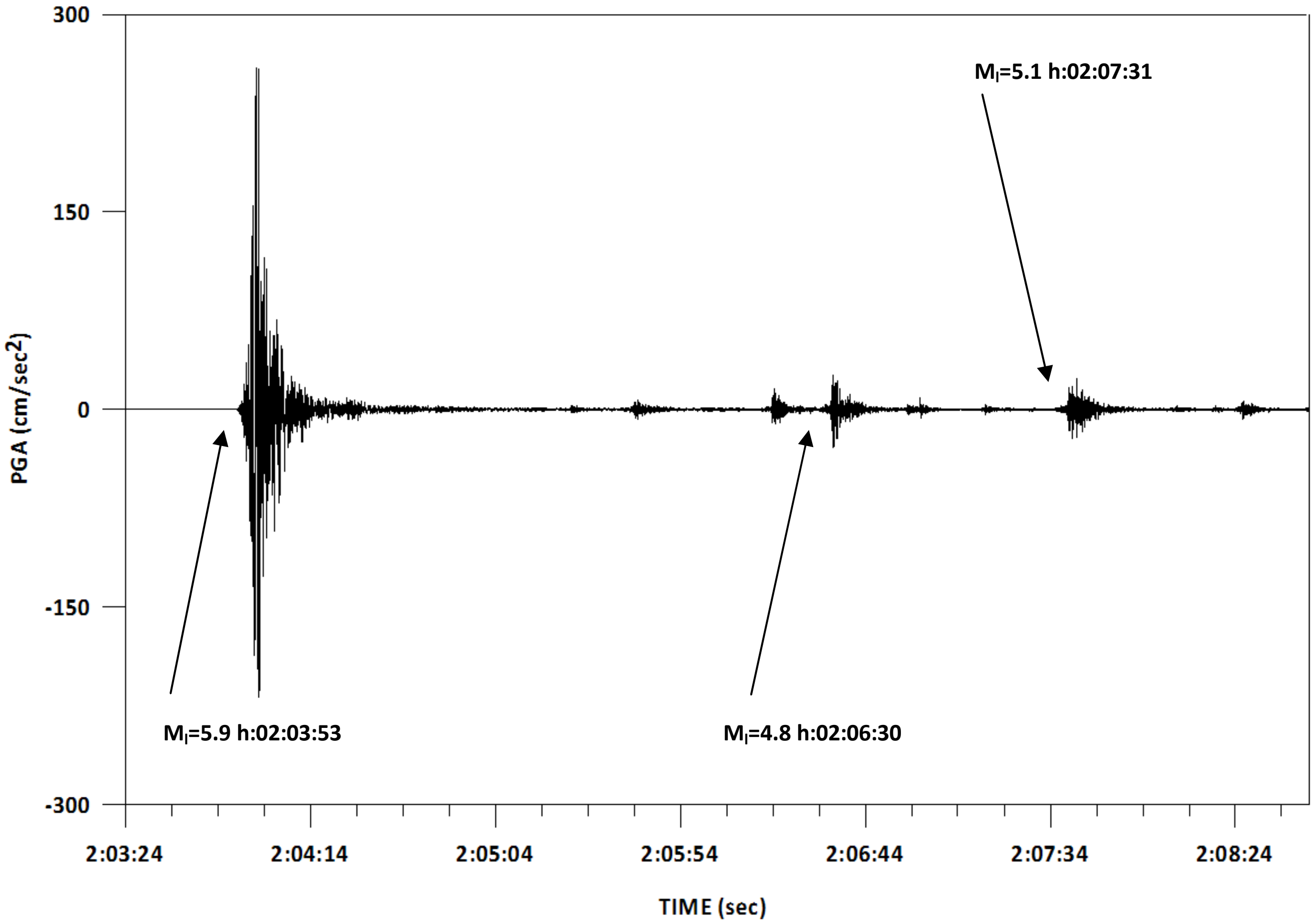

Figure 3: The ~ 6 minutes (02.03.24-02.08.24) of recording at Mirandola-MRN station (NS channel) triggered by the mainshock of the sequence. This record includes the mainshock and the some aftershocks as reported by the ISIDe database. Specifically, the arrows indicate the main event and the two main aftershock: M_l 4.8 and M_l 5.1.

The waveforms are available for all the stations that recorded the event. Specifically, there are three files, in SAC format, for each station referring to each recording channel.

In the header of files the polarity of the signal is indicated. The acceleration data are given in nm/sec^2, the standard unit for the acceleration waveforms in SAC format. Data provided are corrected: mean value of the signal was calculated and removed, as well as any trend. Moreover, only for calculating strong motion parameters and the response spectra, a butterwort filter with a typical frequency range between 0.2-50 Hz was applied.

At the DPC ftp site (ftp://ftp.protezionecivile.it), within the auxiliary material given with this report, are available:

1. the strong motion dataset of the maishock in SAC format. Please note that the data set is made available without making any selection on the quality of the signal. Moreover, the vertical component of the waveform of Mirandola station (MRN) presents signal components at very high frequencies. Currently these components are still being analyzed and therefore it is recommended to take this into account in the use of such registration.
2. the list of stations that recorded the main event, along the station code, the coordinates, the toponyms and the model of instrumentation. A "netcode" parameter identifies which integrated network the single station belongs to. IT code identifies the national accelerometric network RAN, RF refers to the stations of RAF network and IR to ISNet stations;
3. table summarizing a variety of strong motion parameters, calculated from the recorded waveforms for the stations from 17 to 221 km;
4. the response spectrum in acceleration (at 5% damping) between 0.05 and 3.5 seconds for the stations sited within 50 km (MRN, MDN, NVL, ZPP, ISD, CPC). The data related to the response spectra are in ASCII format and are expressed in cm/s^2.

EMILIA EARTHQUAKE MAJOR AFTERSHOCKS (Ml≥4)

Besides the mainshock, the stations of the integrated networks (RAN, ISNET and RAF) recorded the strongest foreschock (19 May 2012, 23:13:27 UTC) and the 15 aftershocks with $M_l \geq 4$ that occurred from 20 to 23 May 2012.

The number of stations activated for each event (Tab. 1) is still provisional and it is however given below, together with parameters hypocentral and the values of magnitude provided by INGV (database ISIDe to http://iside.rm.ingv.it/iside/standard/index.jsp site).

Date dd/mm/yyyy	Time (UTC) hh.mm.ss	Lat (°)	Lon (°)	Depth (km)	Magnitude -Ml-	n. triggered stations
19/05/2012	23.13.27	44.898	11.258	6.20	4.1	6
20/05/2012	02.06.30	44.886	11.189	7.70	4.8	7
20/05/2012	02.07.31	44.863	11.370	5.00	5.1	18
20/05/2012	02.11.46	44.840	11.367	7.80	4.3	10
20/05/2012	02.12.42	44.823	11.218	20.40	4.3	11
20/05/2012	02.21.53	44.892	11.155	5.00	4.1	10
20/05/2012	02.25.05	44.871	11.348	10.00	4.0	7
20/05/2012	02.35.37	44.876	11.548	10.00	4.0	5
20/05/2012	02.39.10	44.894	11.261	5.20	4.0	8
20/05/2012	03.02.50	44.860	11.095	10.00	4.9	27
20/05/2012	09.13.21	44.879	11.241	3.10	4.2	8
20/05/2012	13.18.21	44.831	11.490	4.70	5.1	26
20/05/2012	13.21.06	44.882	11.383	2.40	4.1	1
20/05/2012	17.37.14	44.876	11.382	3.20	4.5	14
21/05/2012	16.37.31	44.851	11.348	10.40	4.1	11
23/05/2012	21.41.18	44.868	11.251	4.80	4.3	17

Tab. 1. Number of available waveforms associated to the seismic events of $M_l \geq 4.0$ occurred up to 23 May, 2012 recorded by Italian strong motion network. The source of data for the hypocentral parameters and magnitude is ISIDe database provided byINGV.

TEMPORARY NETWORK

In case of seismic sequences DPC can deploy temporary strong motion stations in the field to increase the density of recording instruments in the epicentral area. In the present case DPC installed 13 digital stations between the 20 and the 21 of May. Two of these stations, Carpi and Cento, will be permanent and integrated to RAN (Fig. 4, Tab.2). Both permanent and temporary stations are equipped with GPRS modem, and they sent data to the data acquisition center in Rome. Data recorded are automatically integrated to the RAN database.

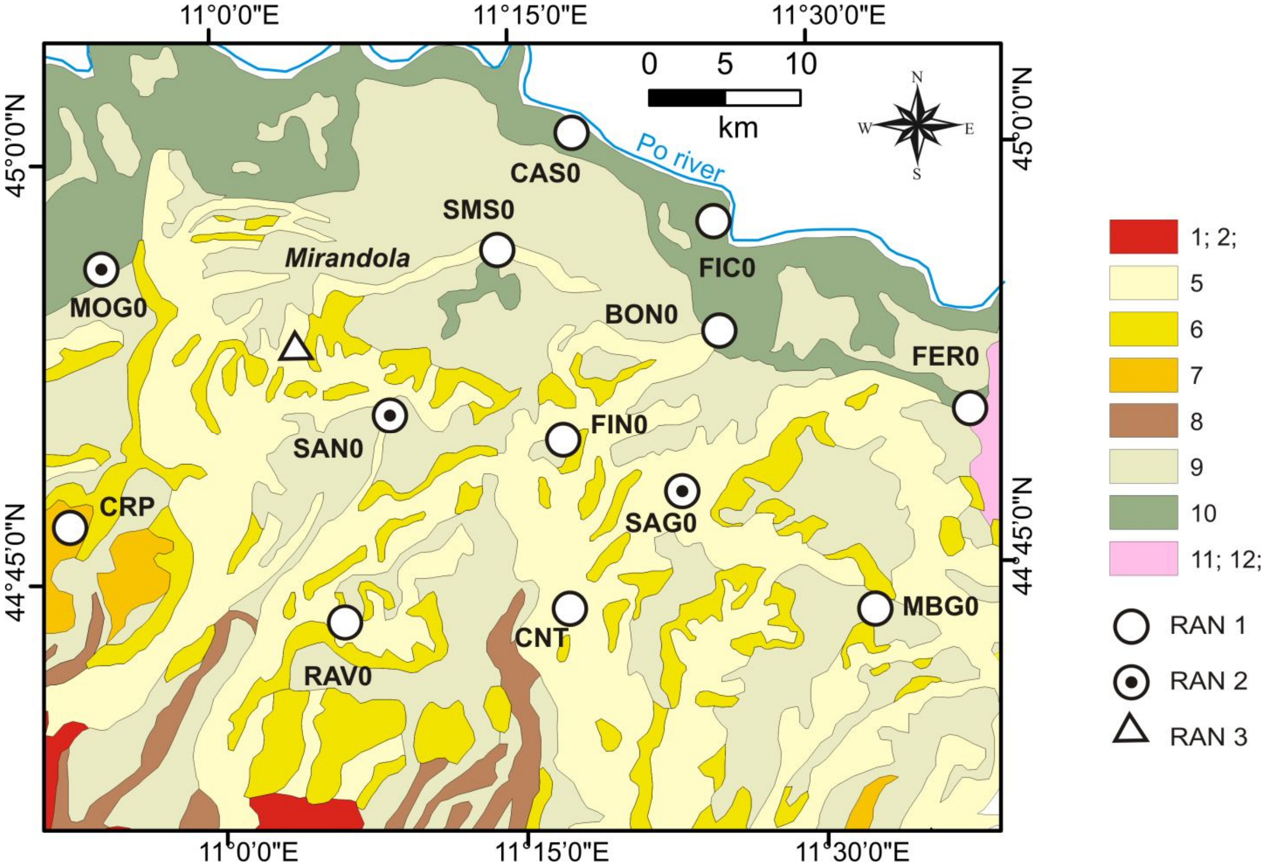

Figure 4: – Geological map and the temporary network distribution (from Carta Geologica di Pianura dell'Emilia Romagna, 1: 250.000). Key: 1-2) ALLUVIAL FAN AND TERRACED DEPOSITS- channellised gravels and sands alternating with thin-bedded sands and silts; 5-10) ALLUVIAL PLAIN DEPOSITS (5. thin-bedded medium to fine grained sands, silty sand, and minor clayey silts, 6. thin bedded fine and very fine sands with small amounts of silty-clays, 7. medium and fine-grained sands, silts and silty clays alternating to some decimeters-thick ribbons of medium and coarse sands, 8. thin to medium thick-bedded sandy silts, fine and very fine sands, 9. silty clays and laminated clays with minor coarse sands in lenses and ribbon-shape bodies, 10. medium and coarse sands with minor sandy gravels and silt lenses; 11-12) DELTAIC AND LITTORAL DEPOSITS (medium to fine sands laterally passing to fine and very fine sands and silts and to ribbon shaped bodies of medium-coarse sands; silt intervals locally bear centimeter-thick, partially decomposed organic layers. N.B. Soils of various degree of evolution close upward all the aforesaid units (2-9). RAN 1 = temporary stations; RAN 2 = temporary stations, whose noise is shown in FIG. 6; RAN 3 = Mirandola permanent RAN station.

Mirabello locality (6 km NE of Sant'Agostino)

Mirabello locality (6 km NE of Sant'Agostino)

Mirabello locality (6 km NE of Sant'Agostino)

Mirabello football field (6 km NE of Sant'Agostino)

San Carlo locality (close to Sant'Agostino)

San Carlo locality (close to Sant'Agostino)

San Carlo locality (close to Sant'Agostino)

Cimitery in between San Carlo and Sant'Agostiono

Finale Emilia Cimitery

Buonacompra locality (In between Finale Emilia and Sant'Agostino)

Figure 5: – Coseismic effects and post-earthquake view of some damaged sites within the area of the temporary RAN.

Date of installation	Municipality	Code	Lat (°)	Lon (°)	Elevation (m)	Type of installation
21/05/2012	Bondeno*	BON0	44.8854	11.4183	63	temporary station
21/05/2012	Castelmassa	CAS0	45.0252	11.3114	62	temporary station
21/05/2012	Cento	CNT	44.7234	11.2867	68	new station
20/05/2012	Carpi	CRP	44.7834	10.8704	78	new station
20/05/2012	Ferrara*	FER0	44.8408	11.6216	59	temporary station
23/05/2012	Ficarolo	FIC0	44.9521	11.4337	59	temporary station
20/05/2012	Finale Emila*	FIN0	44.8297	11.2867	60	temporary station
21/05/2012	Malalbergo*	MBG0	44.7189	11.5337	67	temporary station
21/05/2012	Moglia*	MOG0	44.9318	10.9115	85	temporary station
20/05/2012	Ravarino	RAV0	44.7238	11.1002	172	temporary station
21/05/2012	San Felice sul Panaro*	SAN0	44.8376	11.1427	87	temporary station
20/05/2012	Sant'Agostino*	SAG0	44.7911	11.1427	70	temporary station
21/05/2012	San Martino Spino*	SMS0	44.9336	11.2352	61	temporary station

Tab. 2. List of the temporary stations in the epicentral area installed after 20 May, 2012. Stars refer to the temporary stations where the noise measurements were performed.

NOISE MEASUREMENTS

Further efforts were made in order to characterize the temporary station sites. On eight of the eleven temporary stations sites (Bondeno, Ferrara, Finale Emilia, Malalbergo, Moglia, San Felice sul Panaro, Sant'Agostino, San Martino Spino), noise measurements were carried out (see Tab. 2). In the very next future the noise measurements at the temporary stations, as well at the two new permanent network installation sites will be completed. Data will be available on this web site. The noise measurements were performed close to the accelerometric station site, using 20-24 bit digital datalogger equipped with 5sec F0 velocimeters and a recording length of more than 60 minutes at each site. Very preliminary results, show a common pattern of the H/V ratio, with fundamental frequency in the 0.6 – 0.9 Hz range, related to the presence of thick alluvial deposits. An example is given in Fig.6.

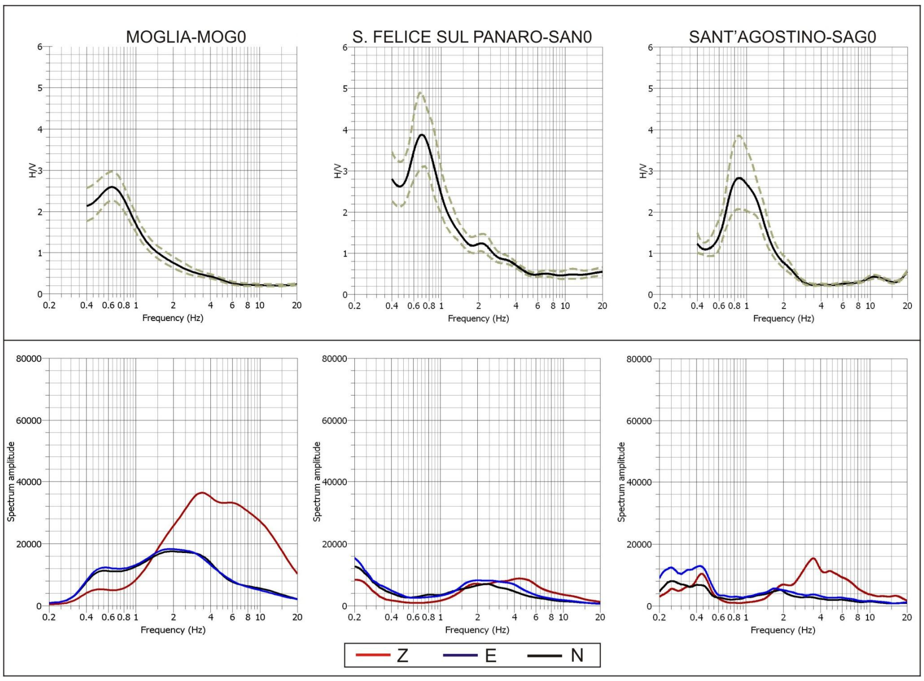

Figure 6: - Noise measurements at three temporary station sites.

FUTURE WORKS

The data acquired from the station of Mirandola (MRN), on the occasion of the 20 May main event, require a further revision, in particular for the vertical component of the waveform. The MRN station is located inside ENEL electric transformer substation and currently the site visit, at the station, is in progress. As soon as it is possible, the noise measurements, at the temporary stations and at permanent ones of RAN which recorded the sequence, will be completed. Meanwhile, a review of recorded data for events of magnitude greater than or equal to 4 was launched, to make them available as soon as possible to the technical- scientific community.

At to-day (29 May 2012), the Emilia sequence is still active. This morning, at UTC 7:00:03, another strong thrust earthquake (M_l 5.8, depth ~10.2 km), plus other two with M_l 5.3 and 5.2 and five others with M_l between 4.1 and 4.7, was released few kilometres SW-ward of the epicentral area of the May 20 sequence. As soon as we will have strong motion data revised on this event we will update the present report.

ELECTRONIC SUPPLEMENTARY MATERIAL

This report contains supplementary material which is available on line at the DPC ftp site (ftp://ftp.protezionecivile.it) and which will be published in a forecoming paper. It can be used upon quotation of the present report. The correct citation is :
Mirandola Earthquake Working Group (DPC, UniChieti, Uni Trieste, Regione Umbria) - Report 1 - (http://www.protezionecivile.gov.it/jcms/it/ran.wp)

TO DOWLOAD DATA, PLEASE REQUEST LOGIN AND PASSWORD TO THE FOLLOWING EMAIL ADDRESS: RANUSR@PROTEZIONECIVILE.IT

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