THE FERRARA ARC THRUST EARTHQUAKES OF MAY-JUNE 2012 (NORTHERN ITALY): STRONG-MOTION AND GEOLOGICAL OBSERVATIONS

-Report II-

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INTRODUCTION

On 29 May 2012, at 07:00:03 (UTC), Northern Italy was struck by an earthquake of magnitude M_l5.8 (lat 44.851 long 11.086), located nearly 12 km WSW-ward of the 20 May M_l5.9 event. The 29 May event was followed by three relevant aftershocks with $M_l \geq 5.0$: two events with M_l 5.3 and M_l 5.2 occurred on 29 May 2012 at 10:55:57 (UTC) and at 11:00:25 (UTC), respectively, and another one on 3 May 2012 at 19:20:43 (UTC). Ten events with magnitude $4.0 \leq M_l \leq 5.0$, plus several other minor earthquakes, were released few kilometers westward of the epicentral area of the 20 May event. The aftershocks distribution of the 29 May event covers an area extending in the E-W direction for a length of nearly 20 km, between the localities of Novi di Modena and San Felice sul Panaro, close to the buried front of the northward-verging active Ferrara thrust.

Twenty stations of the Italian strong motion network (RAN), inclusive of temporary stations (see Mirandola Earthquake Working Group - Report 1), owned and managed by the National Civil Protection Department (DPC), triggered within 50 km from the 29 May event epicentral area (Figs. 1A, 1B, 1D). Taking into account the spatial and temporal evolution of the local seismicity, DPC continued to install temporary stations deploying other 3 strong motion instruments.

This second report is aimed at:

1- providing the waveforms of the 29 May 2012 event to engineers, geophysicists geologists and scientists in general, for professional, technical works and scientific purposes;

2- showing the final configuration of the temporary accelerometric network, consisting of 17 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.

THE FERRARA ARC 2012 SEISMIC SEQUENCE

At to-day (8 June 2012), the Ferrara arc seismic sequence is characterized by about 1626 events occurred since 19 May 2012 with magnitude that ranges between ~1 and 5.9. Two relevant events of M_l 5.9 and 5.8 occurred on 20 and 29 May, respectively. Both were located close to the buried front of Ferrara northward-verging active thrust belt (Fig. 1A and Fig. 1B). These two earthquakes were followed by five $M_l \geq 5.0$ events with the amount of cumulative seismic energy released of ~ER= 1.E+14 Joule comparable to the one associated to the main event (06/04/2009 M_w 6.3) of the 2009 L'Aquila seismic sequence (ER=2.E+14). The aftershocks distribution covers an area of 800 km^2 extending in the E-W direction for a length of nearly 55 km, between the localities of Fabbrico and Ferrara (Fig. 1D). Specifically, the first relevant event (20 May) occurred in between the small cities of San Felice sul Panaro and Finale Emilia, involving the central part of the Ferrara arc. The second relevant event (29 May) is located west-southwestward with respect to the 20 May event, close to the San Felice sul Panaro locality and the related aftershocks cover the western-central part of the thrust front.

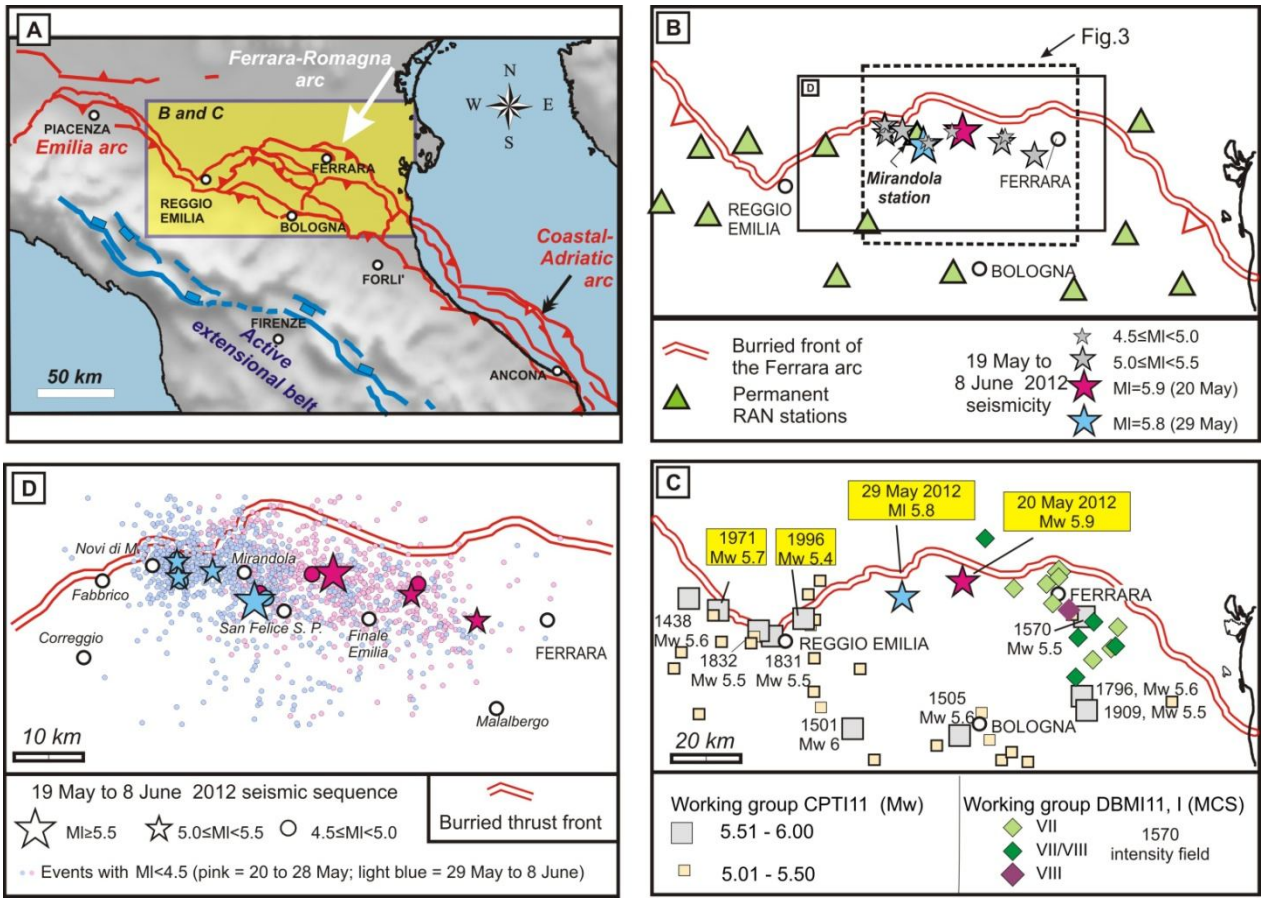

Figure 1: Seismotectonic framework of the Emilia 2012 earthquake. (A) Schematic map of the Padan-Adriatic Thrust Belt of northern Italy with boundary of the study area (yellow rectangle). (B) Major epicentres of the Emilia 2012 seismic sequence from 19 May to 8 June, with the RAN configuration in the epicentral area. (C) Major historical earthquakes within the study area and macroseismic field of the 1570 earthquake. (C) Seismicity distribution related to the 20 and 29 May main events represented with two different colour scale. Key: pink-scale = time interval 19-29 May 2012; light blue-scale = time interval 29 May (07:00:03 -UTC)- 8 June 2012.

FERRARA ARC 29 May EVENT: STRONG MOTION DATA

The main event (M_l 5.8) of the Ferrara arc seismic sequence (29 May 2012, 07:00 UTC) was recorded by 145 RAN, RAF and ISNet stations located at epicentral distance ranging from 2 km up to more than 800 km (Fig. 2).

The closest station was Mirandola (MRN), located at epicentral distance of 2 km (Fig. 1B). The MRN, classified as C site (EC8, Comité Européen de Normalisation 2004), recorded a maximum PGA of 900 cm/s^2 on the vertical component*.

The waveforms recorded by the stations triggered by the 29 May event, were extracted from the DPC archive. The extracted waveforms have a length which depends on the station – epicenter distance (i.e. two and a half minutes are used for the closest stations and a wider time windows for larger distance).

The waveforms for all the stations that recorded the event are made available in the present report. Specifically, there are three files, both in SAC and ASCII format, for each station referring to each recording channel. In the header of files the polarity of the signal is indicated.

(*) Specific controls were performed in order to check the status of measurement station. For this purpose DPC added a temporary instrument (see section temporary network) that confirmed the reliability of the MRN recordings.

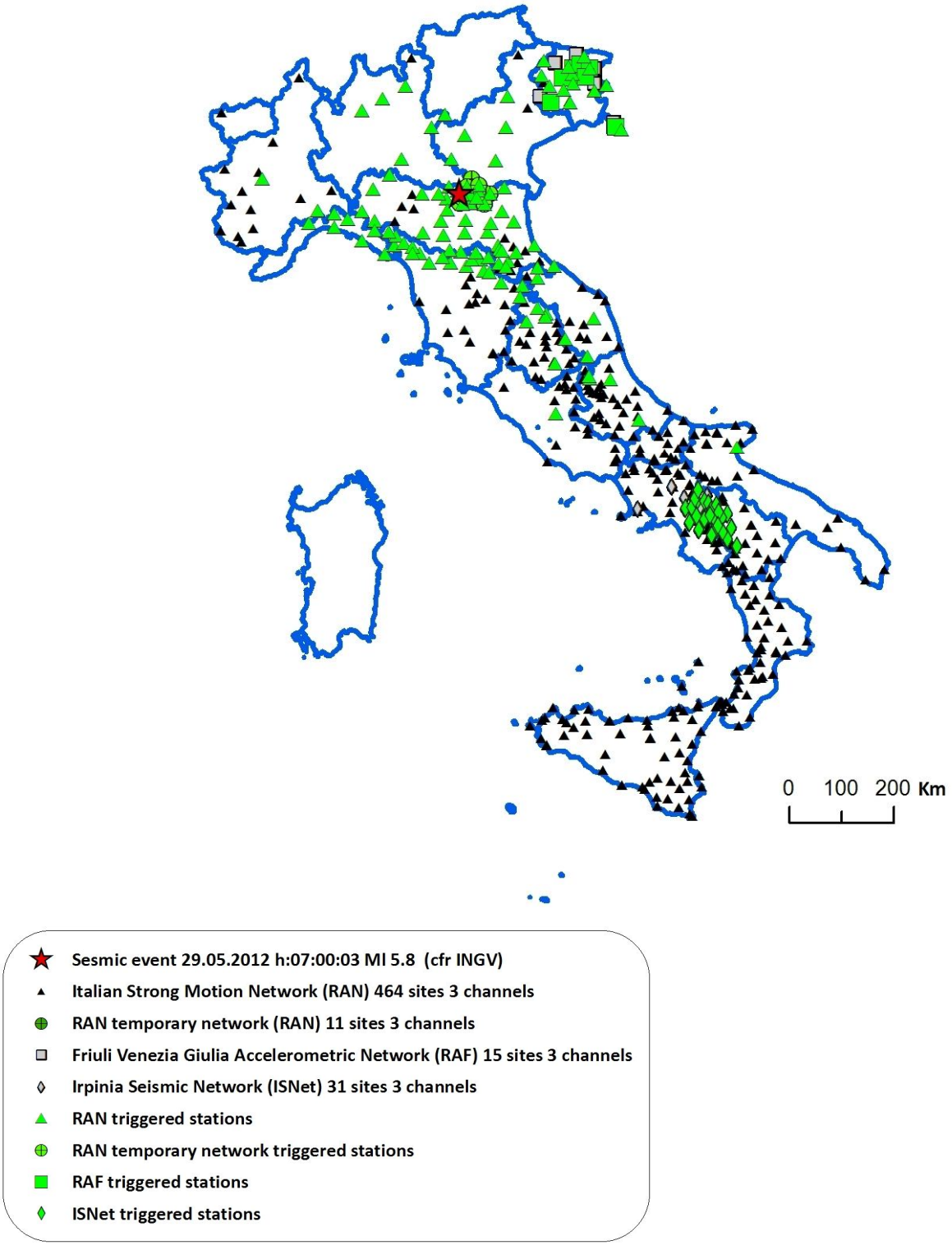

Figure 2 Distribution of the 145 triggered stations during the Ferrara arc earthquake (M_l 5.8). Digital strong motion stations of the Italian Civil Protection Department are represented by triangular symbols, Irpinia Seismic Network ISNet (Weber et al., 2006; http://isnet.na.infn.it/) by diamond symbols and the Friuli Venezia Giulia Accelerometric Network RAF (Costa et al., 2010; http://rtweb.units.it/), by square symbols.

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

At the DPC ftp site, the following auxiliary material given with this report, is available:

1. the strong motion dataset of the 29 May, 2012 event in SAC and ASCII 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 the Mirandola station (MRN) presents signal components at very high frequencies.
2. the list of stations that recorded the second main event, along the station code, the coordinates, the toponyms and the model of instrumentation. A "netcode" parameter identifies the integrated network the single station belongs to. IT code identifies the national accelerometric network RAN, RF refers to the RAF stations and IS refers to the ISNet stations;
3. a table summarizing a variety of strong motion parameters, calculated from the recorded waveforms for the stations from 2 to 232 km;
4. the response spectrum in acceleration (at 5% damping) between 0.05 and 3.5 seconds for the twenty stations sited within 50 km epicentral distance. The data related to the response spectra are in ASCII format and are expressed in cm/s^2.
5. the strong motion dataset of the 20 May mainshock in ASCII format, as requested by many users.

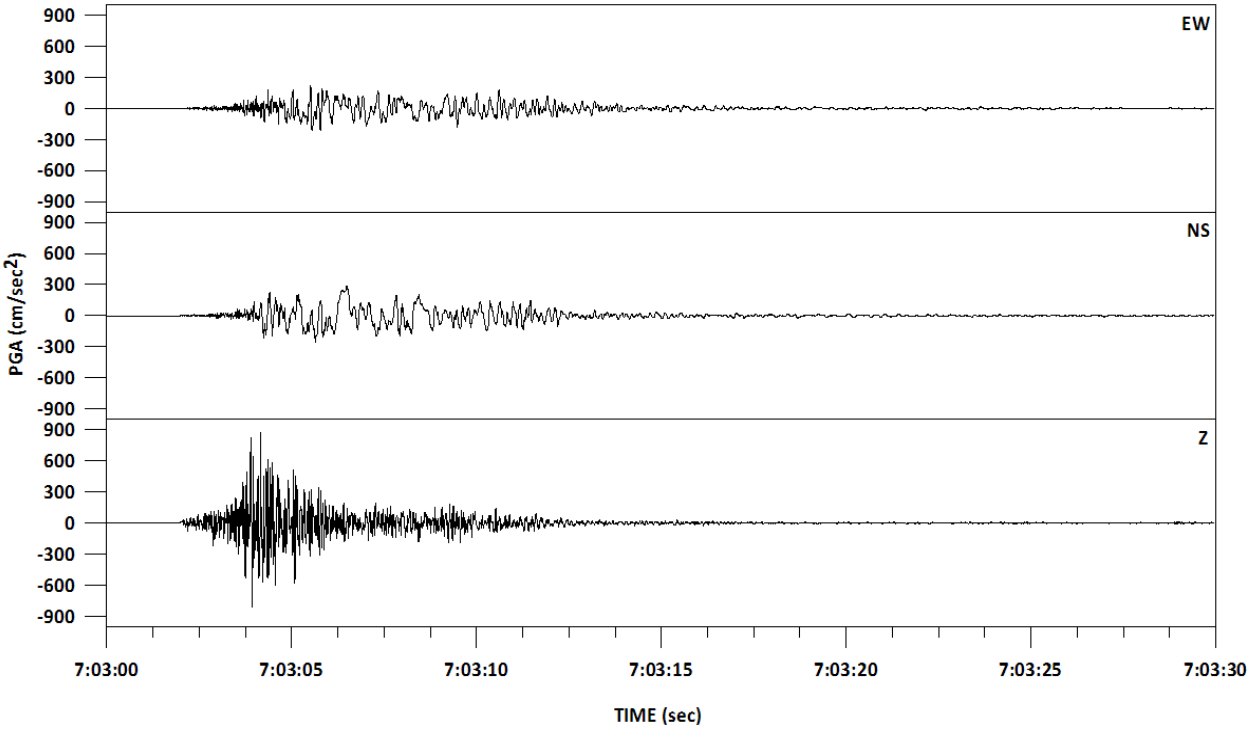

Figure 3: The recording at Mirandola-MRN station (E, N, Z channels) triggered by the 29 May 2012 07:03:00 (UTC time) event .

FERRARA ARC MAJOR AFTERSHOCKS (Ml≥4)

Besides the two more energetic events, the stations of the integrated networks (RAN, ISNET and RAF) recorded other aftershocks. In the table 1 is shown a list of all the event with $M_l \geq 4$ that occurred from 20 May to 8 June 2012. The number of stations activated for each event (Tab. 1) is still provisional and it is given below, together with hypocentral parameters and the values of magnitude provided by INGV
(ISIDe database 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
20/05/2012	2.06.30	44.886	11.189	7.7	4.8	11
20/05/2012	2.07.31	44.863	11.370	5.0	5.1	21
20/05/2012	2.11.46	44.840	11.367	7.8	4.3	9
20/05/2012	2.12.42	44.823	11.218	20.4	4.3	11
20/05/2012	2.21.53	44.892	11.155	5.0	4.1	10
20/05/2012	2.25.05	44.871	11.348	10.0	4	6
20/05/2012	2.35.37	44.876	11.548	10.0	4	5
20/05/2012	2.39.10	44.894	11.261	5.2	4	8
20/05/2012	3.02.50	44.860	11.095	10.0	4.9	27
20/05/2012	9.13.21	44.879	11.241	3.1	4.2	6
20/05/2012	13.18.21	44.831	11.490	4.7	5.1	27
20/05/2012	13.21.06	44.882	11.383	2.4	4.1	1
20/05/2012	17.37.14	44.876	11.382	3.2	4.5	14
21/05/2012	16.37.31	44.851	11.348	10.4	4.1	11
23/05/2012	21.41.18	44.868	11.251	4.8	4.3	21
25/05/2012	13.14.05	44.883	11.108	10.0	4	19
27/05/2012	18.18.45	44.882	11.158	4.7	4	18
28/05/2012	1.06.27	39.859	16.118	3.0	4.3	12
29/05/2012	8.25.51	44.901	10.943	3.2	4.5	20
29/05/2012	8.27.23	44.854	11.106	10.0	4.7	15
29/05/2012	8.40.58	44.892	10.962	5.3	4.2	17
29/05/2012	9.30.21	44.892	11.053	1.2	4.2	13
29/05/2012	10.55.57	44.888	11.008	6.8	5.3	70
29/05/2012	11.00.02	44.873	10.950	11.0	4.9	27
29/05/2012	11.00.25	44.879	10.947	5.4	5.2	37
29/05/2012	11.07.05	44.876	11.076	15.0	4	11
31/05/2012	14.58.21	44.880	10.867	5.8	4	21
31/05/2012	19.04.04	44.891	10.980	8.7	4.2	20
03/06/2012	19.20.43	44.899	10.943	9.2	5.1	49

TAB. 1. Number of available waveforms associated to the seismic events of $M_l \geq 4.0$ occurred up to June 8 2012 recorded by Italian strong motion network. The source of data for the hypocentral parameters and magnitude is provided by INGV ISIDe database.

TEMPORARY NETWORK

In case of seismic sequences, DPC deploys temporary strong motion stations in the field to increase the density of recording instruments in the epicentral area. In the present case DPC installed 17 digital stations from 20 May to 7 June. Two of these stations, Carpi and Cento, will be permanent and integrated to RAN (Fig. 4, Tab.2). Moreover, in order to verify the correct functioning of the MRN permanent station, soon after the 29 May event, DPC installed a temporary station (MRN0) equipped with a three-component strong motion instrument different from the one installed in the Mirandola station. Both permanent and temporary stations are equipped with GPRS modem and sent data to the data acquisition center in Rome. Data recorded are automatically integrated to the RAN database. Noise measurements have been performed at each station site.

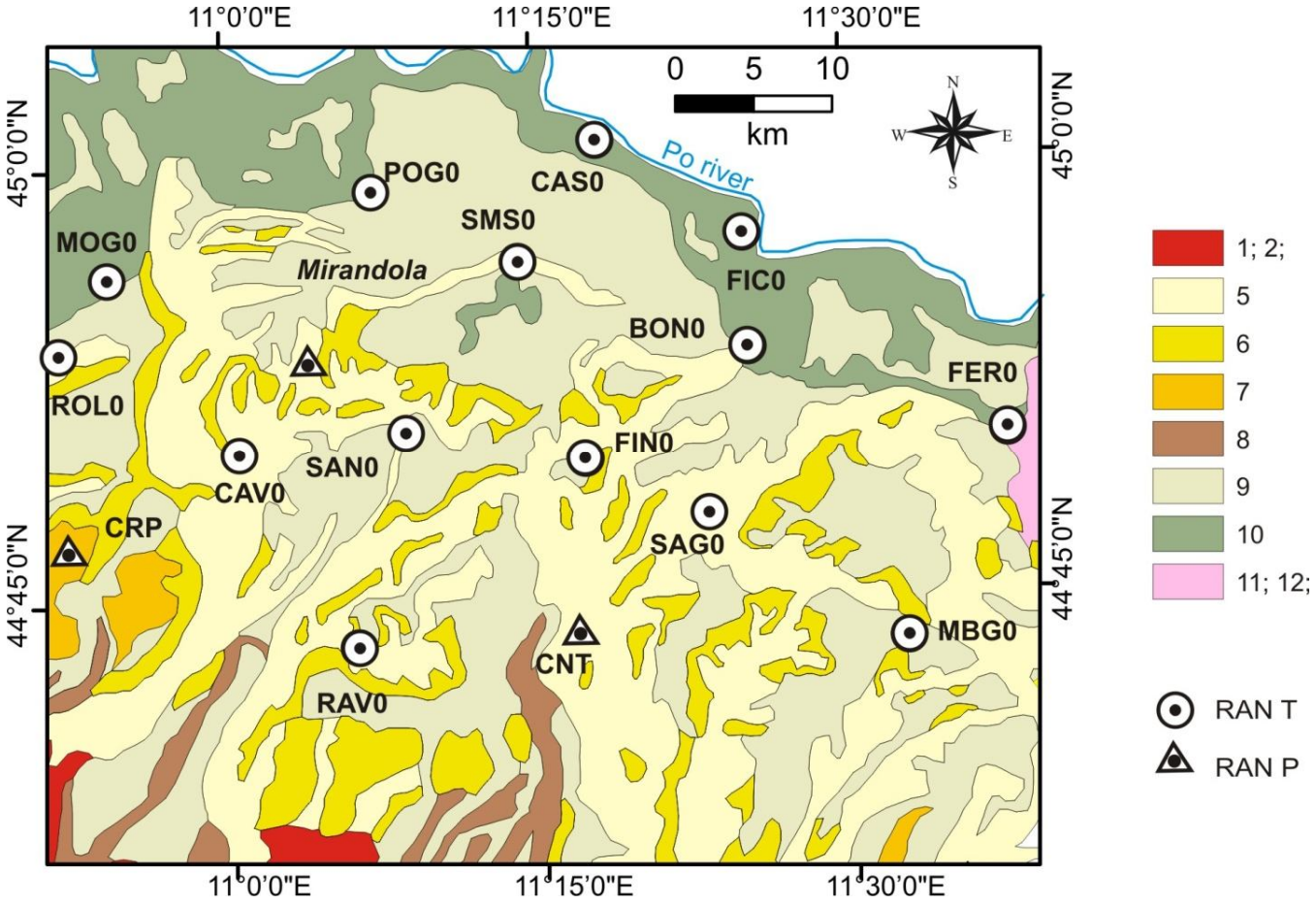

Figure 4: – Geological map and the temporary network distribution (from Carta Geologica di Pianura dell'Emilia Romagna, 1: 250.000). Key: 1-2) ALLUVIAL FAN AND TERRACED DEPOSITS- channellised gravels and sands alternating with thin-bedded sands and silts; 5-10) ALLUVIAL PLAIN DEPOSITS (5. thin-bedded medium to fine grained sands, silty sands, 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 T = temporary stations; RAN P = permanent RAN station.

Date of installation	Date of replacement	Municipality	Code	Lat (°)	Lon (°)	Elevation (m)	Type of installation
21/05/2012		Cento	CNT	44.7234	11.2867	68	new station
20/05/2012		Carpi	CRP	44.7834	10.8704	78	new station
21/05/2012		Bondeno	BON0	44.8854	11.4183	63	temporary
21/05/2012		Castelmassa	CAS0	45.0252	11.3114	62	temporary
20/05/2012		Ferrara	FER0	44.8408	11.6216	59	temporary
23/05/2012		Ficarolo	FIC0	44.9521	11.4337	59	temporary
20/05/2012		Finale Emila	FIN0	44.8297	11.2867	60	temporary
21/05/2012	30/05/2012	Malalbergo	MBG0	44.7189	11.5337	67	temporary
30/05/2012		Malalbergo	MAL0	44.7190	11.5340	63	temporary
21/05/2012		Moglia	MOG0	44.9318	10.9115	85	temporary
20/05/2012		Ravarino	RAV0	44.7238	11.1002	172	temporary
07/06/2012		Rolo	ROL0	44.8870	10.8560	68	temporary
21/05/2012		S. Felice sul Panaro	SAN0	44.8376	11.1427	87	temporary
20/05/2012		S. Agostino	SAG0	44.7911	11.3858	70	temporary
21/05/2012		S. Martino Spino	SMS0	44.9336	11.2352	61	temporary
30/05/2012		Cavezzo	CAV0	44.8344	11.0276	69	temporary
31/052012		Poggio Rusco	POG0	44.9779	11.1181	-	temporary
29/05/2012		Mirandola	MRN0	44.8782	11.0617	64	temporary

TAB. 2. List of the temporary stations in the epicentral area installed after 20 May, 2012.

29 May coseimic effects - Uccivello locality (2,5 km SW of Cavezzo)

29 May coseismic effect -
Tramaschio locality (7,5 km N of Mirandola)

20 May coseismic effect-
San Felice sul Panaro locality

20 May coseismic fracture
etween Sant'Agostino and San Carlo locality

20 May coseismic fracture
San Carlo locality

Figure 5. Examples of surface geological effects following the 20 and 29 May 2012 earthquakes.

NOISE MEASUREMENTS

Further efforts were made in order to characterize the temporary station sites. On all the station sites in epicentral area (Fig.4) noise measurements were completed (see Tab. 2). 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. Moreover, for comparison purpose, other measurements were carried out on several sites not comprising strong motions instruments. An example of H/V spectral ratio applied to ambient noise is shown in Fig. 6.

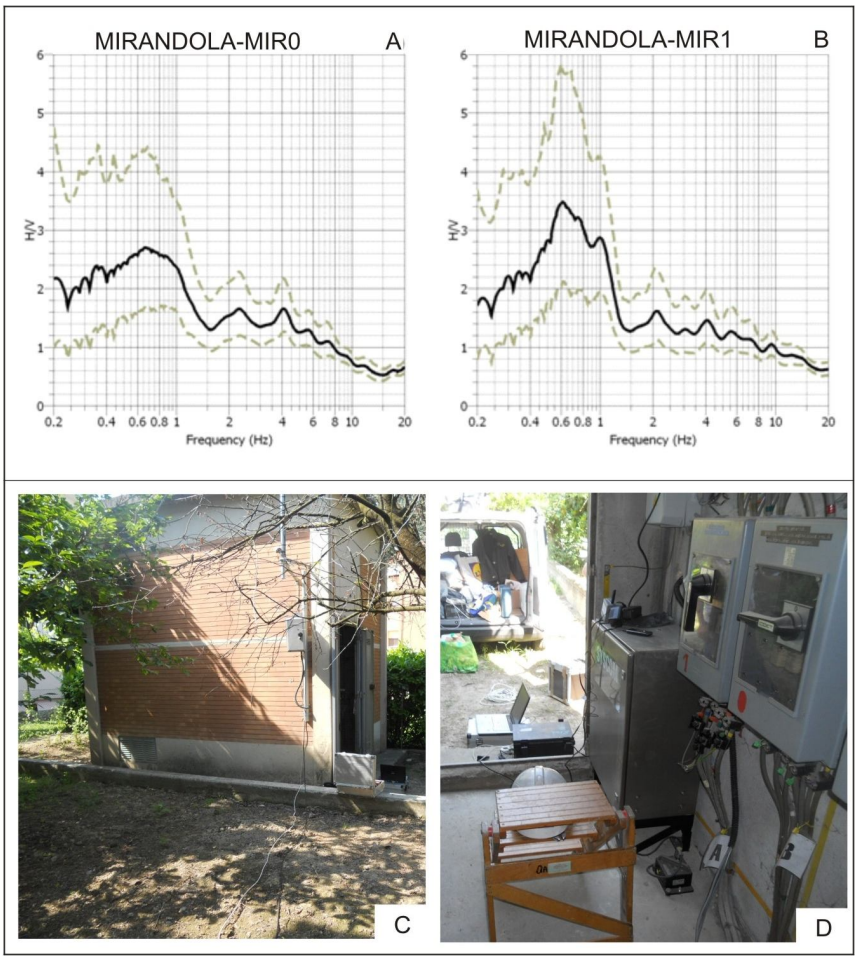

Figure 6: H/V spectral ratio applied to ambient noise (A and B). The outside and the inside (C and D) of the Enel electrical transfer cabin, in which the MRN strong motion station is installed. The MIR0 noise measurements (A) were performed out of the Enel cabin while the MIR1 measurements (B) were carried out close to the RAN permanent instrument that is visible in photo D on the right near the door.

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 2 - (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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