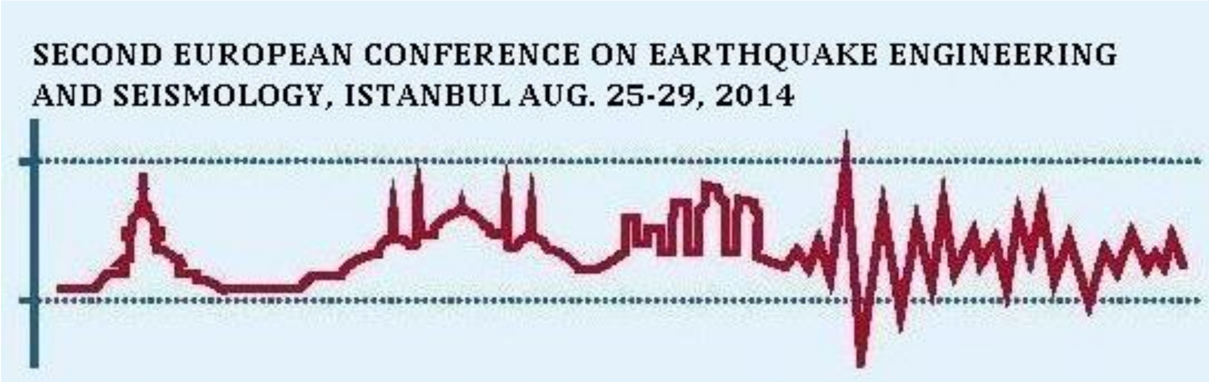

THE ITALIAN STRONG MOTION NETWORK (RAN), NEAR-REAL TIME DATA ACQUISITION AND DATA ANALYSIS: A USEFUL TOOL FOR SEISMIC RISK MITIGATION

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ABSTRACT

A network for monitoring the strong motion that can occur in a given area records data that provide an excellent opportunity to study how source, path, and site effects influence the ground motion, specifically that in the near-source area. Such data are essential for updating seismic hazard maps and consequently building codes and earthquake-resistant design.

Strong motion data of high quality are also of help in increasing the effective preparation against seismic disasters, and the response during seismic emergencies. The consequent increased ability of a community to quickly recover from the damages of an earthquake thus contributes to lower the seismic risk, usually measured in term of casualties and economic losses. The Italian network for monitoring the strong motions on the national territory, the Italian Strong Motion Network (RAN, Gorini et al., 2010) that counts at present more than 500 stations, is the result of a fruitful co-operation over the last 16 years between the Italian government, the regions and local authorities.

The priority of the Department of Civil Protection of Italy (DPC) in the past years was to focus mainly on the expansion of the network in terms of the number of measurement points and on the technological improvement of the instrumentation, as well as on the data transmission system.

A data acquisition centre was thus implemented where the Antelope software automatically collects, processes and archives the data of both the RAN and of the external strong motion networks that contribute to the RAN database. Recently, the DPC has dedicated specific resources to improve the response of the network, in particular, in case of emergency. The efficiency of the network on a daily basis is today not less than 95%. Within 24 hours after a strong earthquake temporary networks were installed in the epicentral area and connected to the data acquisition centre in Rome.

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A fast seismic data analysis is essential to provide rapid and useful information to Authorities that have to take decisions immediately after a strong earthquake occurrence. Modern accelerometers are the only instruments that can provide near-source high-quality data during a strong earthquake. Automatic and fast techniques for the automatic real-time strong motion data analysis have been developed at the University of Trieste (UniTS).

These techniques have been installed and customized in the data acquisition centre of the DPC to process the quasi real-time data of the RAN and to exploit information from RAN stations during seismic emergences for civil protection purposes.

INTRODUCTION

After a strong earthquake rapid, precise and clear information from the seismic network to the authorities, that have the responsibility to take decisions on the emergency management, is mandatory. This implies that it is necessary both to record and transmit high-quality seismic data in a very short (real- or quasi real-) time and to maintain an efficient and complete procedure of data analysis at the datacenter.

In case of a strong event occurrence the only seismological instrumentation that guarantees the complete recording of the signals, also in the near field, where the information is most important, is the accelerometer. Thus, the existence of strong-motion networks is essential in an area, like Italy, characterized by moderate-to-high seismicity.

High-quality data means reliable data with a high fidelity of ground motion recording that provide complete information also in case of a strong earthquake. At present, the quality of the 24-bit recording, the oversampling principle, and force-feedback type sensors assure excellent fidelity and reliability. The main problem in order to guarantee the recording of high-quality data is only the maintenance and calibration of the instrumentation, along with the system design, the seismic station sites selection, and the preparation and maintenance of data transmission.

Regular visits to the stations and a rapid intervention in case of a failure, together with the regular calibration of the instruments, guarantees the reliability and the completeness of the dataset.

A key problem today, mainly in the case of integrated networks, is the upgrading of the metadata in real time and its distribution. Only datasets with real-time updated metadata guarantee the reliability of the results of the subsequent strong motion data analysis.

An efficient, fast and reliable data transmission is also a key factor to guarantee, on one hand, the availability of data at the datacenter in quasi-real time, and on the other hand, the possibility to analyze a huge amount of data immediately after the event in order to obtain information as complete as possible to be transmitted to the Authorities.

The availability today of a huge number of seismological data in quasi-real time at the datacenter give us the possibility to design software procedures to pre-process and analyze such data to be successively transmitted to the Authorities. All the ground motion parameters (PGA, PGV, PSA....) can be immediately obtained from high-quality preprocessed data. Seismologists and seismic engineers are working hard to try to associate these ground motion parameters to possible infrastructural damage and other effects of the event on the territory. A rapid and efficient procedure to compute these quantities will definitely help decision-makers.

Moreover, understanding strong motion data helps to increase the effective preparation and response to seismic emergencies, whereas the ability of a community to quickly recover from the damages of an earthquake contributes to lower the seismic risk usually measured in terms of casualties and economic losses.

The Italian network for monitoring strong movements on the national territory (RAN, Gorini et al., 2010) is the result of a fruitful co-operation over the last 16 years between the Italian government, the regions and local authorities. During this period, the DPC has given priority mainly to both the expansion of the network in terms of the number of measurement points and to technological improvements of the deployed instrumentation, as well as to the data transmission system.

At the DPC a data acquisition centre has been implemented (CAED) in which the Antelope software automatically collects, processes and archives the data of the RAN and of the external strong motion networks that contribute to the database of the RAN. Recently, the DPC has dedicated specific resources to improve the response of the network, in particular, in the case of an emergency.

In the framework of a collaboration between the UniTS and the DPC a fast seismic data analysis software have been developed by the Seismological Research and Monitoring group of UniTS (SeisRaM) for the automatic real-time strong motion data analysis. These techniques have been installed and customized at the data acquisition centre of the DPC to process the quasi real-time data of the RAN stations and to exploit the related information during seismic emergences for civil protection purposes.

THE ITALIAN STRONG MOTION NETWORK

RAN counts at present more than 500 digital stations and provides a dense station coverage for all high seismic hazard areas of the Italian territory (Fig. 1). The RAN comprises both the 198 stations of the network (Syscom isntruments), located inside ENEL electric transformer cabins, and the new 319 stations installed in free field (300 Kinemetrics instruments, 19 Edacs-Cesi intruments), mostly on land owned by municipalities close to urban areas.

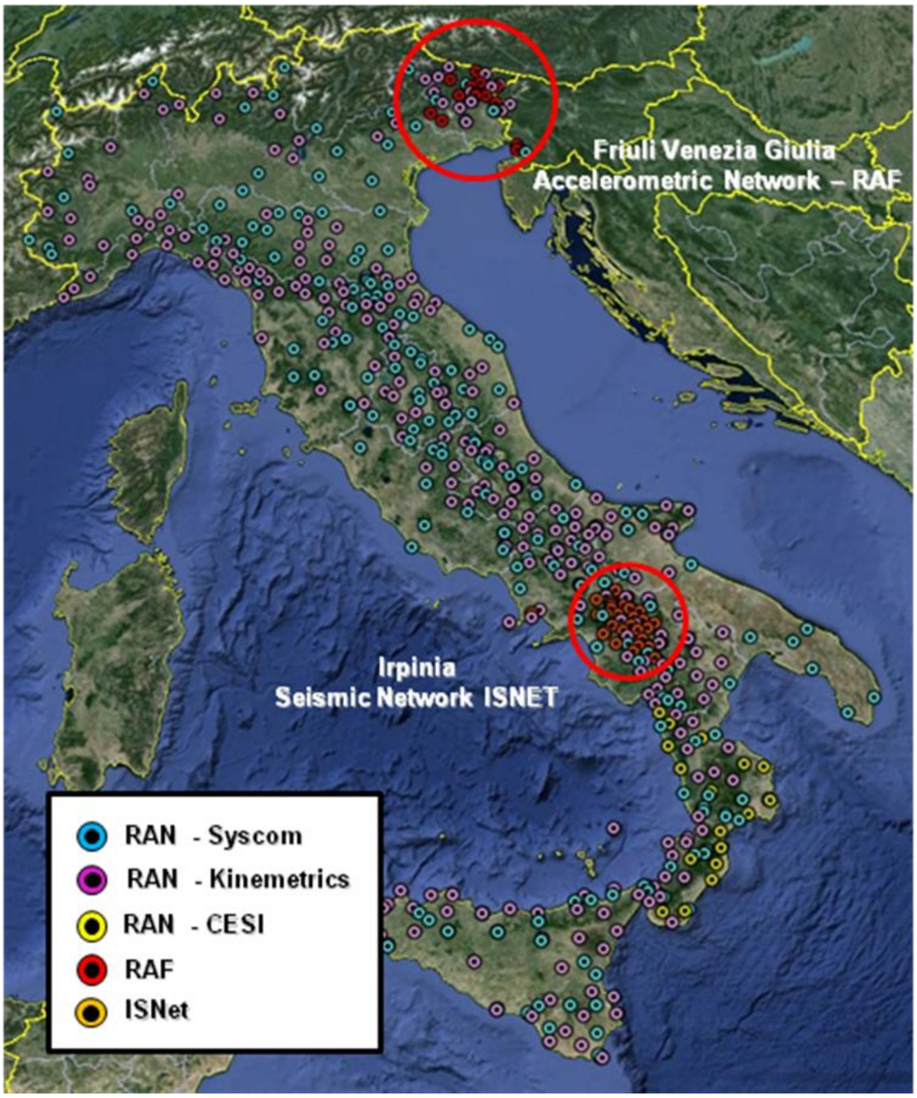

Figure 1. Distribution of the strong motion stations of the RAN and of the two tributary networks: the ISNet (Weber et al., 2006; http://isnet.na.infn.it/) and the RAF (Costa et al., 2010; http://rtweb.units.it/). The RAN Syscom stations are installed in the ENEL electric transformer cabins, equipped with Syscom instrumentation. The RAN Kinemetrics stations are installed mainly in free field and equipped with Kinemetrics instruments.

The network development to its present configuration has been possible thanks to inter-institutional agreements with local and regional authorities. The latter helped DPC to identify the sites for the new stations, and are providing electrical power to them. It is important to keep the old stations active, because at several of these station sites some of the major historical events (Friuli 1980, Irpinia 1980) that occurred in Italy in the instrumental period, were recorded. The old analogical instrumentation has been obviously substituted with a digital one.

Two local networks, the Friuli Venezia Giulia Accelerometric Network (RAF, Costa et al., 2010), located in NE Italy, and the Irpinia Seismic Network (ISNet, Weber et al., 2007) in southern Italy, send their data to the RAN data acquisition system (Fig 1).

The free field station site typically consists of an isolated pillar anchored on rock, if present, or plunged into the sediments, in order to guarantee the best coupling possible with the ground. The instrumentation is protected with a plastic box (Fig 2).

Figure 2 The two typical installation used in the RAN. Free field stations on the left and ENEL electric transformer cabin on the right..

The quality of the recorded data is guaranteed by the instrumentation used. The RAN stations are equipped with three-component strong-motion, force-balance and broadband, sensors (Kinemetrics Episensor and FBA23, Syscom MS2007), and with 18 or 24 bits digital dataloggers with a high dynamic range (from 108 to 135 dB) (Kinemetrics Altus, Rock series and Reftek 130-01).

In order to avoid electrical problems a particular attention is given to the grounding. A discontinuity transformer is used to isolate the electrical circuit and dischargers are used to protect the instrument.

Two kind of configurations are used: a continuous data transmission in the case of the last generation acquisition systems equipped with Ethernet connection, and triggered data transmission for the older instruments equipped with serial connection. The data transmission from station to the CAED of Rome is obtained through the use of GPRS routers (continuous data) or GPRS modems (triggered data).

The data acquisition centre of the network is located in Rome, at the DPC (Gorini et al., 2010; Zambonelli et al., 2011), where the Antelope software automatically collects, processes and archives in a relation database, the data.

The performance of the network in the last years has been tested during the last strong and intermediate events occurred in Italy, Emilia (De Nardis et al., 2014; Dolce et al., 2012), Pollino (Dolce et al., 2012b)).

AUTOMATIC NEAR-REAL-TIME STRONG MOTION DATA ANALYSIS FOR CIVIL PROTECTION PURPOSES

A fast seismic data analysis is essential to provide useful information to the Authorities which have to take decisions immediately after a strong earthquake occurrence. During a strong earthquake, the modern accelerometers are the only instruments which can provide complete near-source high-quality data that are important both for scientific and for civil protection purposes.

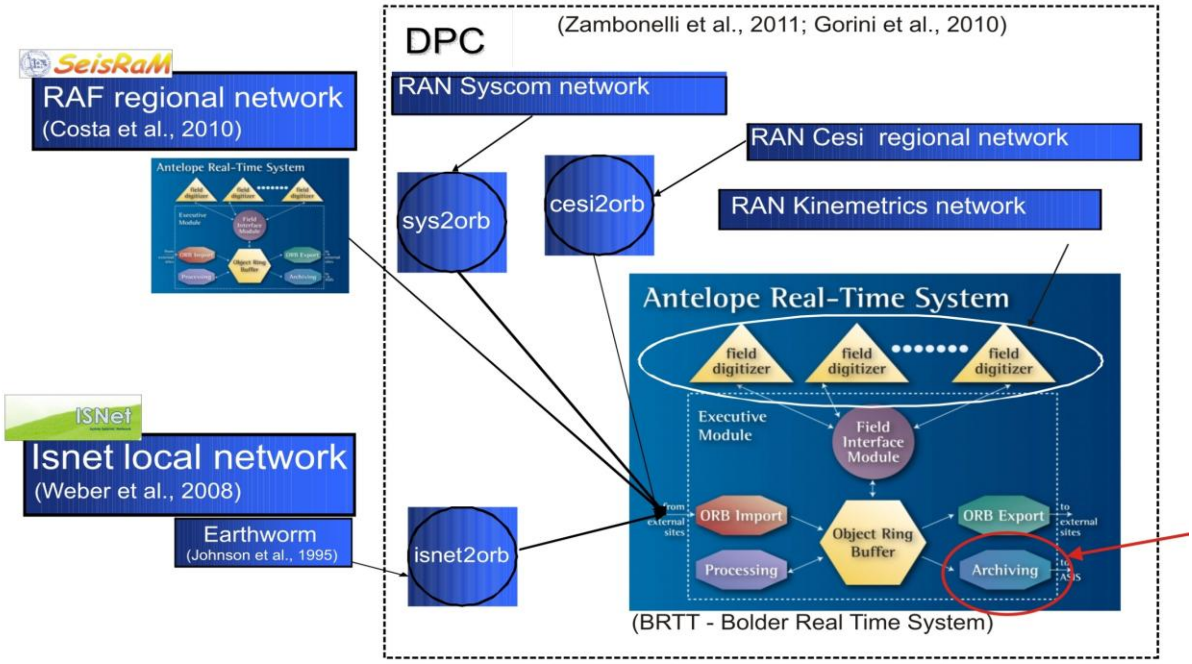

Figure 3 Flow chart of the acquisition system running at CAED.

A near-real-time automatic technique has been developed by the University of Trieste for a rapid a strong motion data analysis. This technique has been implemented in the Antelope real-time system implemented by the Boulder Real Time Technology of Boulder, running at the University of Trieste. Antelope is a commercial software which manages seismic data acquisition and signal processing. The acquired data and the results of the signal processing are stored, as metadata, in a relational database (Fig. 3).

The main goal of the procedure is to provide information on the ground motion parameters from high-quality previously pre-processed data. A key pre-process tool implemented in this procedure is the automatic filter, which guarantees to process the seismic data only in the frequency range where the SNR is large enough. The high-pass and low pass cut-off frequencies are automatically fixed in a pre-selected frequency range, normally 0.1 – 50 Hz. All the ground motion parameters are extracted after the data filtering. The filter used is a Butterworth band-pass filter.

After the pre-process and filtering the signals are derivated and/or integrated to obtain the acceleration, velocity and displacement. After this step the procedure follows two different directions, the seismic moment computation and the ground-motion parameters determination.

The seismic moment is computed from the S waves using the Andrews (1986) technique (Gallo et al., 2014). The S-wave train is identified using the S phase extracted from the database and the pre-selected time duration. The transverse component of motion is used to minimize conversion effects. The source spectrum is obtained by correcting the signals for geometrical spreading and intrinsic attenuation. Source spectra for both velocity and displacement are computed to obtain the seismic moment. Mw is estimated from the seismic moment using the Hanks and Kanamori (1979) relationship. The corner frequency, f_0, and the equivalent radius, r, are also computed. All the results, both for each station separately and for the network average values, are stored in the database in dedicated relational tables.

The implemented procedure is triggered each time when a new location is calculated by the Aspen (Kinemetrics Environmental Monitoring System) system and a new origin record is added to the database. The procedure takes the time series and all the necessary information (e.g., metadata, phases, site information, etc.) from the database tables and writes all the results in new dedicated database tables. A signal time windows is extracted starting from a pre-selected time before the P arrival and ending at a pre-selected time after the P arrival. The time windows before the P arrival must be selected to be long enough in order to calculate the noise spectrum used by the procedure to compute the SNR. In Fig.4 the flow chart of the procedure is shown. The data is pre-processed, the means and the trend are removed and the D2 filter is applied to the extracted signal. The complete instrumental correction is finally applied.

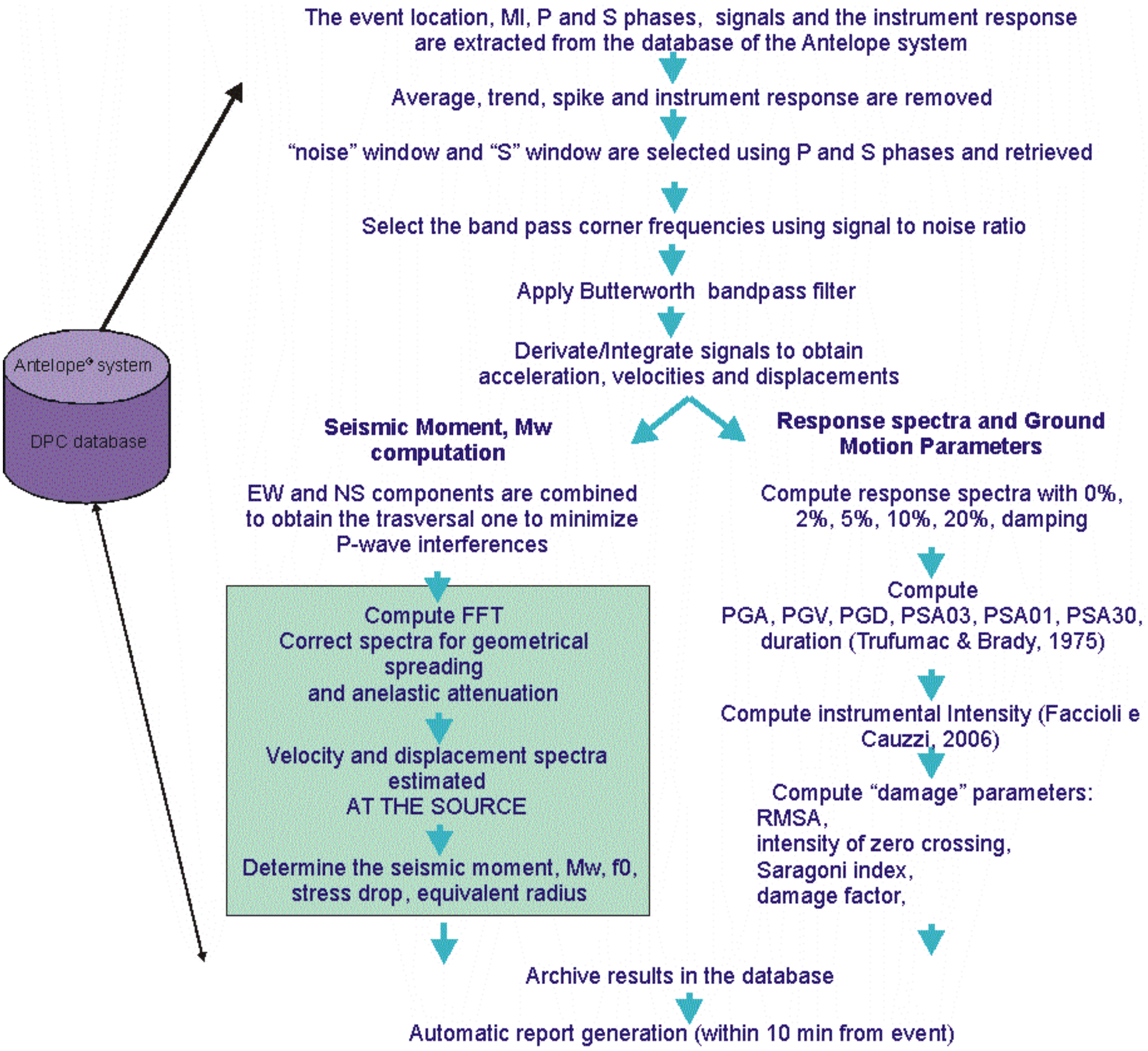

Figure 4. Flow chart of the automatic near real time data analysis running at University of Trieste and at CAED.

From the same signal window used for the seismic moment computation the ground motion parameters are determined. The peak ground acceleration (PGA), the peak ground velocity (PGV) and peak ground displacement are identified and stored in the database. The response spectra (SA) are computed for five different damping values (0%, 2%, 5%, 10%, 20%) and stored in the database, along with the determined peak spectral amplifications (PSA) at 0.3, 1.0 and 3.0 seconds. The Housner integral and the Arias integral are finally computed and stored in dedicated tables.

These values are used to produce, in an automatic way, also the ShakeMaps (Wald et al., 1999; Moratto et al., 2009).

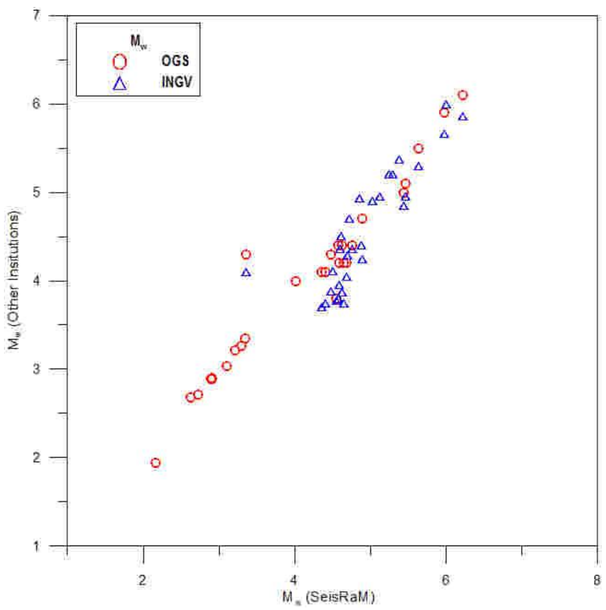

Figure 5 Comparison between the moment magnitude estimated by INGV (blue triangles) and OGS (red circles) and the moment magnitude estimated by technique describe in this work (Gallo et al., 2014).

After some discussions with the DPC seismic engineers, some others parameters have been added in order to have the maximum information possible, in near-real time, from the ground motion characteristics in order to help in our understanding of the possible effects of a strong earthquake on the territory. The parameters actually derived from the signals are the time duration (Trifunac and Brady, 1975), the root mean square acceleration (rmsa), the intensity of zero crossing, the Saragoni index and the damage factor.

The ground motion parameters strongly depend on the site condition and to have good information about the possible site effects it is essential to correctly interpret the data. Some tables have been added to the original Antelope system in order to give the possibility to store the geological and geophysical characteristics of the site (stratigraphy, morphology, Vs30, f_0, etc.). The related table contains the EC8 and NEHRP codes.

This procedure is now running already for several years at the Department of Mathematics and Geosciences of UniTS, using the data coming from the broadband and accelerometric stations of the “Central and East European Earthquake Research Network” (CE3RN), a transnational network managed by ARSO (SLO), ZAMG (AUS), UniTS (FVG) and OGS (FVG). A lot of data, strong motion parameters, seismic moment etc., are now available in the UniTS database, whose events span a large magnitude range. Both the procedure and the obtained results are very stable. The computed MW are in good agreement with the Mw computed by other Institutions using different techniques, starting from about Mw=2.5 (see Fig. 5).

The procedure has been installed and customized in 2012 at the data acquisition centre of the DPC (CAED) to process the quasi-real-time data recorded by the RAN stations and to exploit the related information during seismic emergencies for civil protection purposes. The procedure has been tested with success during the last strong and intermediate events occurred in Italy in the last years (e.g., Emilia (de Nardis et al., 2014; Dolce et al., 2012), Pollino (Dolce et al., 2012b).

Table 1. Example of the ground motion parameters table contained in the near real-time report.

Event: NORTHERN - Origin time: 2012/05/29 07:00:03 Lat:44.851 Lon:11.086 Ml = 5.8 Agency: INGV
Seismic moment: 1.130e+18 Nm - Mw = 5.8 Agency: UniTS

sta	chan	distа km	filter Hz	PGA cm/s*s	EPA cm/s*s	PGV cm/s	PGD cm	PSA03 cm/s*s	PSA10 cm/s*s	PSA30 cm/s*s	EC8	location
MRN	HGN	4	0.1-50.0	296.92	267.39	50.05	16.75	711.99	344.55	156.01	C	Mirandola
MRN	HGE	4	0.1-50.0	251.19	214.60	24.34	8.70	508.27	174.41	72.37	C	Mirandola
MRN	HGZ	4	0.1-50.0	895.78	239.98	21.64	5.86	381.48	87.98	25.17	C	Mirandola
SAN0	HGN	4	0.1-50.0	238.52	201.70	31.15	10.91	531.08	198.90	122.31	na	San_Felice_sul_Panaro
SAN0	HGE	4	0.1-50.0	152.70	148.42	23.65	6.08	388.62	208.71	81.58	na	San_Felice_sul_Panaro
SAN0	HGZ	4	0.1-50.0	327.18	134.34	9.01	3.55	295.06	42.03	20.32	na	San_Felice_sul_Panaro
SMS0	HGN	15	0.1-50.0	187.27	141.93	13.04	4.48	337.50	168.40	36.21	na	San_Martino_Spino
SMS0	HGE	15	0.1-50.0	177.15	238.06	15.51	4.11	606.28	137.93	28.43	na	San_Martino_Spino
SMS0	HGZ	15	0.1-50.0	122.37	52.29	3.08	0.97	106.20	17.54	7.95	na	San_Martino_Spino
RAV0	HGN	16	0.1-50.0	94.78	73.04	9.59	3.78	248.98	138.27	20.17	na	Ravarino
RAV0	HGE	16	0.1-50.0	57.84	42.25	5.55	1.32	105.47	74.58	8.96	na	Ravarino
RAV0	HGZ	16	0.1-50.0	64.19	27.69	1.65	1.35	92.57	14.67	3.25	na	Ravarino
FIN0	HGN	16	0.1-50.0	247.46	195.48	15.89	3.00	505.14	98.74	24.30	na	Finale_Emilia
FIN0	HGE	16	0.1-50.0	212.39	178.21	14.65	3.01	366.78	147.65	28.94	na	Finale_Emilia
FIN0	HGZ	16	0.1-50.0	208.85	54.58	3.17	0.87	119.62	21.46	13.31	na	Finale_Emilia
MOG0	HGN	16	0.1-50.0	161.37	175.17	20.21	5.77	461.52	205.73	31.90	na	Moglia
MOG0	HGE	16	0.1-50.0	252.91	227.59	25.65	2.92	578.92	225.31	17.26	na	Moglia
MOG0	HGZ	16	0.1-50.0	125.22	89.73	4.27	1.43	248.39	30.82	20.34	na	Moglia
CRP	HGN	19	0.1-50.0	172.60	109.54	7.27	1.96	193.82	66.86	15.93	na	Carpi
CRP	HGE	19	0.1-50.0	128.17	86.17	8.94	2.11	192.11	118.31	13.93	na	Carpi
CRP	HGZ	19	0.1-50.0	85.82	42.72	2.26	0.77	76.24	18.80	12.71	na	Carpi
CNT	HGN	21	0.1-50.0	301.71	245.93	14.63	2.55	1011.94	124.43	16.38	na	Cento
CNT	HGE	21	0.1-50.0	215.22	259.72	17.15	3.38	781.99	193.41	22.10	na	Cento
CNT	HGZ	21	0.1-50.0	67.00	55.26	2.68	0.50	280.57	15.83	3.88	na	Cento
SAG0	HGN	25	0.1-50.0	66.74	62.56	6.09	2.15	177.81	61.10	17.02	na	Sant_Agostino
SAG0	HGE	25	0.1-50.0	84.09	86.95	7.10	1.45	291.56	54.96	17.54	na	Sant_Agostino
SAG0	HGZ	25	0.1-50.0	67.09	35.01	1.94	0.56	75.62	17.14	13.06	na	Sant_Agostino
CAS0	HGN	26	0.1-50.0	42.08	40.79	7.50	3.50	113.65	64.96	26.12	na	Castelmassa
CAS0	HGE	26	0.1-50.0	71.49	69.43	6.16	2.74	172.57	43.31	16.80	na	Castelmassa

dista = epicentral distance
filter = automatic band pass butterworth filter
EC8 = site classification (Eurocode from ITACA)
PGA,PGV,PGD = peak ground acceleration, velocity and displacement
EPA = effective ground acceleration (Kramer, 1996)
PSA03,PSA10,PSA30 = spectral acceleration (0.3, 1.0, 3.0 sec)

AUTOMATIC NEAR-REAL-TIME REPORT TO AUTHORITIES FOR CIVIL DEFENSE PURPOSES

In order to give fast, complete and clear information on the characteristics of the ground motion during a strong earthquake and on its correlation with possible damage scenarios, an automatic procedure has been implemented to produce a report. This report is sent, by e-mail, few minutes after the event, to the decision maker in charge during the emergency management.

The hypocenter, the ML, the seismic moment and the MW are taken from the database and merged with the tables containing the strong motion parameters (see previous chapter) and the site code EC8. See an example of such tables in Table 1.

In the report the SA, computed for a damping of 5%, are also inserted. The SA are compared with the predicted SA for a return period of 475 years given by the Italian Technical norms for buildings (NTC08). The information necessary to compute the NTC08, for each site, is also contained in the database. The predicted response spectra are corrected considering the site classification as derived from the dedicated database tables. The site classification for the RAN sites are mainly taken from the ITACA 2.0 (http://itaca.mi.ing.it) database.

On the same graph the recorded smoothed spectral acceleration (Sm), constructed following the criteria suggested by ISIDE Working Group MS (2008), is also reported. The example relative to the May 29 main shock of the Emilia 2012 sequence is reported in Fig. 6.

The Intensity is a parameter globally used, also by the media, to describe the effects of a seismic event and it is well understood by the population. The relationship proposed by Faccioli and Cauzzi (2006) is adopted by our procedure to compute the Instrumental intensity, starting from the PGA, PGV and effective peak acceleration (EPA) recorded on the horizontal components. Some thematic tables are also contained in the report.

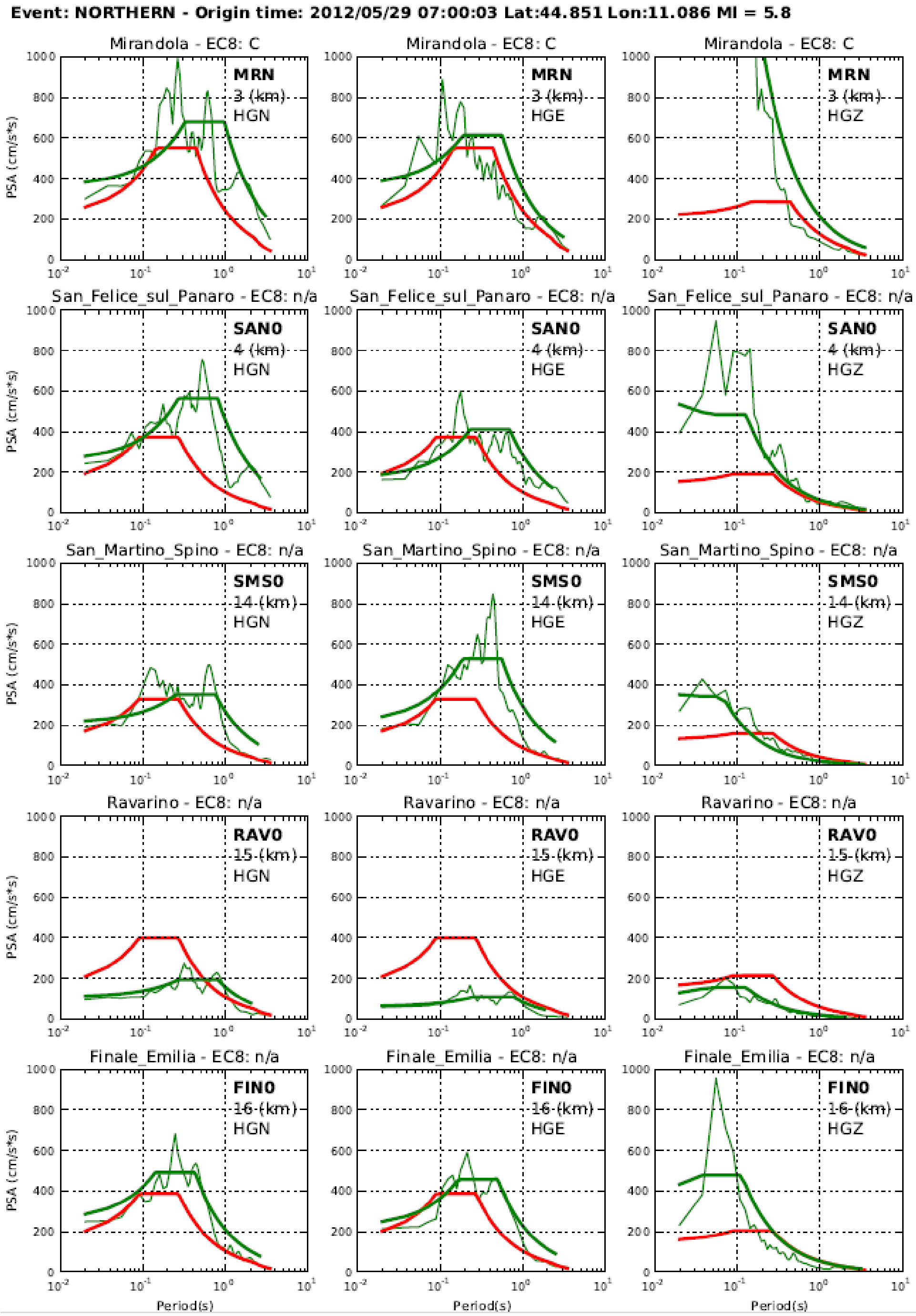

Figure 6. An example of the report page with the comparison of the spectral acceleration (SA) (5% damping ratio) (thin green line), with the predicted SA for a return period of 475 years as in the Italian Technical norms for buildings (NTC08) (red line). The predicted response spectra were corrected considering the site classification as in Online Resource 2. The thick green line represents the recorded smoothed spectral acceleration following the criteria suggested by Working Group MS (2008).

In order, to have an immediate idea of the ground motion parameter characteristics, the relative values are plotted in maps covering the epicentral area. Examples of such maps relative to EPA and Instrumental intensity are shown in Fig. 7.

The report is actually routinely used by DPC and its reliability has been tested during the last strong and intermediate events happened recently in Italy.

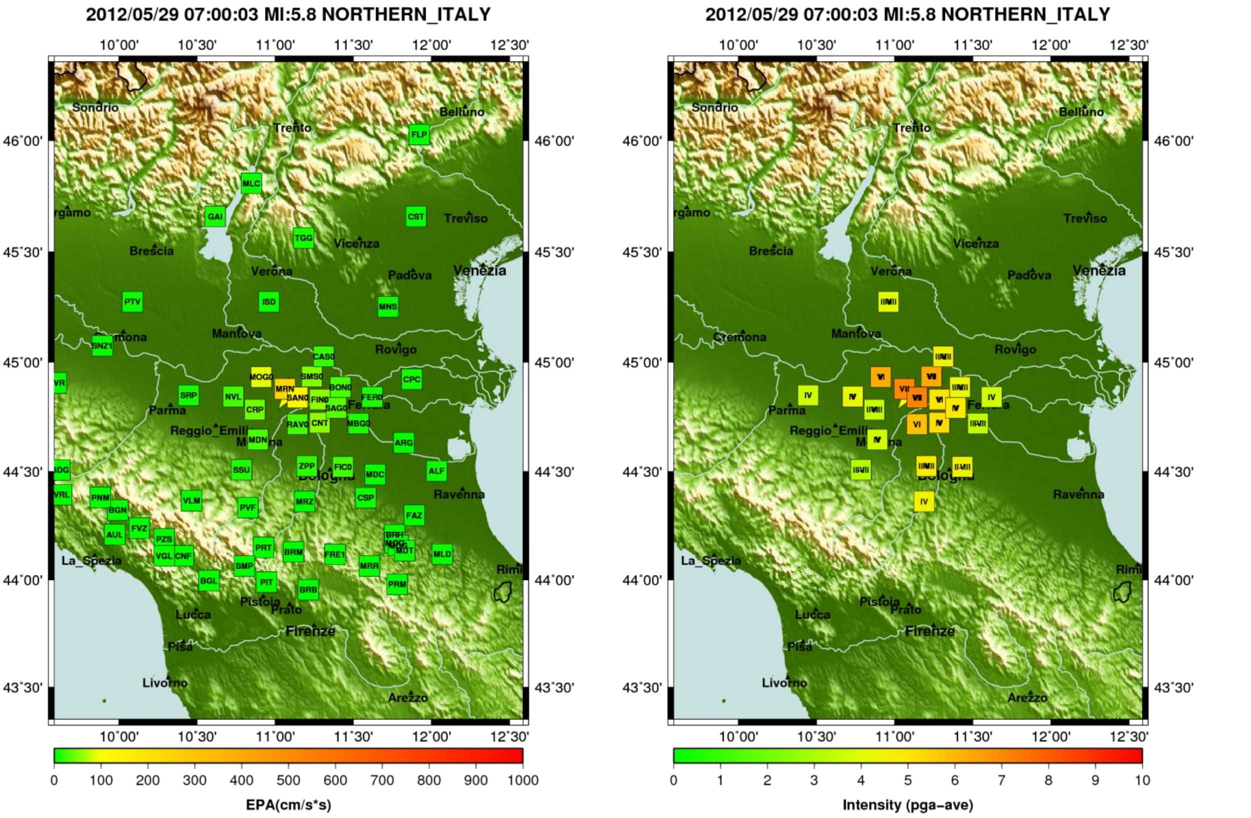

Figure 7. Two example of maps present in the report. On the left the effective peak acceleration, on the right, the instrumental Intensity.

CONCLUSIONS

In the last years, the DPC has dedicated specific resources to improve the response of the RAN, in particular, in case of an emergency. In the framework of bilateral agreements two regional accelerometric networks have been integrated into the RAN, the RAF and the Isnet.

The RAN, which covers with a high density all the seismic territory of Italy, represents a very efficient strong motion seismological network installed and maintained for civil defence purposes. The efficiency is guarantee by the characteristic of the installation, by the high quality of the deployed instrumentation used and by a constant and professional management of the installation. The data acquisition and the signal preprocessing is guarantees by the commercial software Antelope. The efficiency of the network on a daily basis is never less than 95%. The Emilia event has been recorded by 100% of the stations within 50 km from the source.

The procedure implemented by University of Trieste and installed at the CAED of the DPC for the creation of an automatic near-real time-report, provides immediately after a strong earthquake occurrence useful information to decision making Authorities.

The procedure has been tested during the last strong events occurred in Italy. Few minutes after these events a report, containing information on event origin, local and moment magnitude, on the ground motion parameters an relative maps, has been sent to the Italian civil defence.

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