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ORIGINAL RESEARCH PAPER

The Italian strong motion network

Antonella Gorini · Mario Nicoletti · Paolo Marsan · Riccardo Bianconi · Rita De Nardis · Luisa Filippi · Sandro Marcucci · Franco Palma · Elisa Zambonelli

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Abstract The Italian Strong Motion Network is a permanent monitoring system run by the Italian national emergency management department (Dipartimento della Protezione Civile, DPC). The network is known as RAN (Rete Accelerometrica Nazionale). An extensive project for updating and improving the technology of RAN instruments as well as the number of recording points was performed in the last 10 years. A wide site selection survey was carried out from eastern Sicily along the Italian peninsula, covering high seismic risk areas. The recording station density and the choice of high-quality digital strong motion instruments ensure reliability of the RAN network in the long-term. At the end of 2008, the free field sites selection and instruments installation, planned in the project, were quite completed. In planning and drawing the new RAN, special attention has been devoted to the robustness of the transmission systems, and to the distribution of new stations in order to ensure plenty of data during a seismic emergency. We spent special care both in the estimation of the RAN site responses and in the diffusion of the strong motion data. In order to better identify damaged earthquake areas, improved ground motion parameters need to be set. Such parameters will also assist future progress for engineering seismic design techniques as well as disaster mitigation.

Keywords National strong motion network · Free field site selection · Strong motion instruments · Strong motion data centre

A. Gorini (✉) · M. Nicoletti · P. Marsan · R. Bianconi · R. De Nardis · L. Filippi · S. Marcucci · F. Palma · E. Zambonelli
Dipartimento Protezione Civile (DPC), Presidenza del Consiglio dei Ministri, Via Vitorchiano, 4, 00195 Rome, Italy
e-mail: antonella.gorini@protezionecivile.it

M. Nicoletti
e-mail: mario.nicoletti@protezionecivile.it

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1 Introduction

A strong motion network supplies information required for evaluating the ground motion parameters, the dynamic response of ground types layer, the amplification effects, the kinematic of source process and the improvement of the seismic codes. High density networks have been installed all over the world in high seismic countries (USA, Japan, Taiwan, China, Greece, Turkey) (Gulkan et al. 2007; Hutton et al. 2006; Kinoshita 1998; Shakal and Scrivner 2000; Skarlatoudis et al. 2004; Tsai and Lee 2005; Wu et al. 1997, 2000; Xiaojun et al. 2008) as well in low to moderate seismic countries, like Germany or French, that suffered damage and casualties (Hinzen and Fleischer 2007; Pequegnat et al. 2008)

Modern digital stations in combination with faster computing and sophisticated analysis software have produced new potentialities, with important implications for public safety in earthquakes.

The seismic rate and a high density population make the Italian peninsula an area of high seismic risk, which highlights the need for a modern and extensive accelerometric network.

A strong motion network was designed and installed, in the 1970s of the past century, by an Italian Joint Commission on seismic problems, involving ENEA (Ente Nazionale Energie Alternative) and ENEL (Ente Nazionale Energia Elettrica). This network was mainly designed for the seismic risk of nuclear power plants issue and was the first example of a strong motion monitoring system on a national scale.

In less than 20 years the permanent network, managed, at that time, only by ENEL, operated on the entire Italian territory and collected about a thousand records mostly relative to the Friuli, September 1976 (Mw = 5.9) and Irpinia, November 1980 (Mw = 6.9) seismic sequences (CPTI 2004). The recorded waveforms were widely disseminated and organized in collection as the European strong motion data CD-ROM (Ambraseys et al. 2000).

At the end of 1997, the ENEL strong motion network, including all instruments and strong motion data, was taken over by the Italian national seismic agency, Servizio Sismico Nazionale (SSN), now incorporated into the Seismic office of the Italian national emergency management department, Dipartimento della Protezione Civile (DPC). After this acquisition, an extensive program of implementation and technological updating began; hence, the project of the RAN (Rete Accelerometrica Nazionale) permanent network started.

Nowadays, in Italy, besides the national network, several seismic monitoring systems are operative, managed by local Public Institutions and research centres (Friuli-Venezia Giulia Accelerometric Network—RAF; Basilicata accelerometric network; Irpinia seismic network—ISNet; Italian National Seismic Network —Istituto Nazionale di Geofisica e Vulcanologia—INGV). DPC established formal agreements with them in order to data exchange and to collect, validate and organise all the Italian strong motion data in a public database, named ITACA ITalian ACcelerometric Archive (http://itaca.mi.ingv.it/ItacaNet). ITACA is updated inside a scientific project again in progress.

2 RAN background

The emergency management, the rapid simulation of earthquake damage scenarios and the risk reduction through the production of seismic risk maps and new building codes are fields in which the DPC is institutionally involved. For realising these targets, a strong motion network, densely distributed in the Italian seismic areas, was an important necessity that the acquisition of the ENEL analogue network satisfied.

Combined to the reorganisation of the permanent network, the SSN carried out some experiments in the strong motion field installing instruments both in array configuration (Aterno valley—L'Aquila city) and as temporary strong motion stations, deployed after the September 1997 (Mw 6.0) Umbria—Marche earthquake, the September 1998 (Mw 5.7) Pollino earthquake, and the October 2002 (Mw 5.8) Molise earthquake (CPTI 2004).

The Aterno valley strong motion array was installed, since 1994, with seven stations lined along a 2 km profile. The instruments were placed on sites with different geomorphological and geotechnical features for evaluating local seismic effects produced by regional or local earthquakes with high to medium seismic energy (Bongiovanni and Marsan 1995; Bongiovanni et al. 1995; De Luca et al. 2005).

The Umbria-Marche seismic sequence started in September 1997 and continued with hundreds of tremors, providing a good opportunity for testing the efficiency of the RAN network operative at that time.

In addition to the analogue stations of RAN that recorded the strongest earthquakes, a mobile digital network was installed, in order to increase the density of strong motion instruments in the epicentral area. Due to the high dynamic range of digital stations, and by lowering the trigger threshold, more than 700 waveforms were recorded. All data, produced by permanent and mobile strong motion networks, were made available in a CD-ROM (SSN 2001), and used as a base for following scientific studies (Zollo et al. 1999; Capuano et al. 2000; Marsan et al. 2000).

In September 1998, a moderate size seismic sequence (Mw 5.7) occurred in the Pollino, an area between Calabria and Basilicata regions. Besides the main shock, recorded by five analogue instruments (SMA-1 Kinemetrics), three additional, digital instruments (ETNA Kinemetrics), were deployed at Lauria, Lauria Galdo and Viggianello close to the epicentral area. These stations recorded 44 aftershocks of magnitude ranging from 2.9 to 3.7. The three-component waveforms were used both for estimating the site transfer function and as reference data for simulations of the main shock acceleration time history, using stochastic methodology (Beresnev and Atkinson 1997; Arrigo et al. 2006).

The RAN site survey started in 1999 from the east of Sicily where the first digital stations were installed (Alessandrini et al. 1999). In the meantime, a pilot network of 10 new digital instruments was carried out for testing the site selection, the station maintenance, the GPRS digital data transmission, and the collection of strong motion data.

In 2001, the SSN was incorporated by the DPC that took over the ongoing RAN network.

During the Molise 2002 seismic sequence, the RAN, in permanent and mobile configuration, produced 196 three components waveforms (DPC 2004). The analysis of the far field radiation, inferred from the Molise strong motion data, showed a strong anisotropy in the PGA distribution. Source dimensions and directivity effects were also evaluated, using a stochastic approach that could simulate ground motion in the most damaged areas where strong motion records were not available (Gorini et al. 2003, 2004).

After 10 years, at the end of 2008, the Italian strong motion network reached a size of 265 digital and 119 analogue permanent stations. The spatial distribution of the Italian strong motion network is shown in Fig. 1.

The RAN project, within at least 3 years, will be addressed to the substitution of the 119 analogue stations with digital instruments, the reactivation of 72, already removed, analogue stations which recorded historical earthquakes and the installation of 50 new digital stations. Thereby, the RAN station deployment of about 500 free field digital stations will be completed, with a 20–30 km mesh step, covering all the Italian areas with high seismic risk .

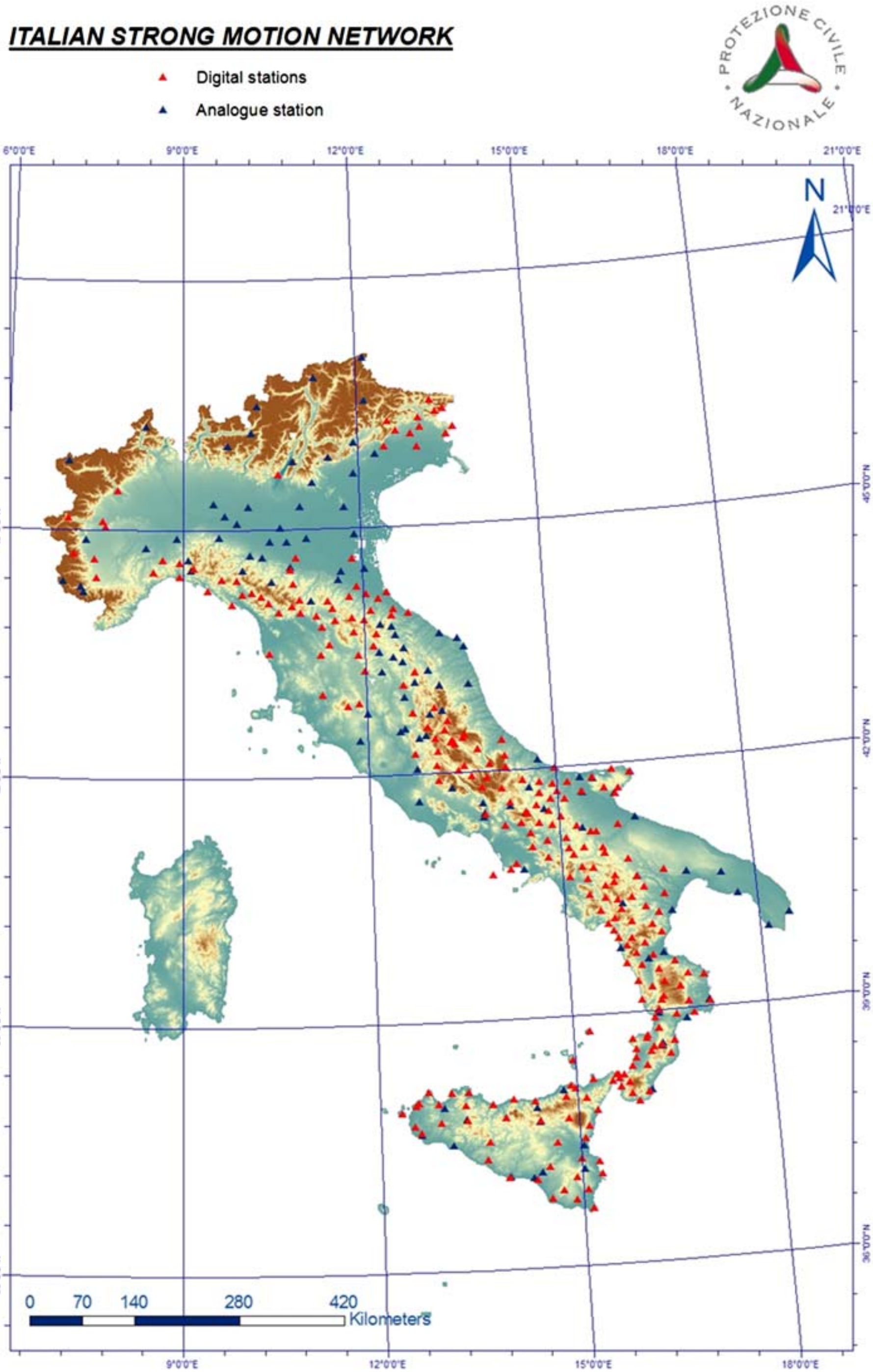

Fig. 1 The Italian Strong Motion network (RAN). *Red triangles* show the digital stations; *blue triangles* show the analogue stations

Fig. 2 An analogue installation inside an electrical transformation cabin

3 Goals of the RAN project

In order to achieve the final network configuration and the scheduled goals, the RAN project takes into account:

- Standard criteria for the free field site selection and for the recording housing construction;
- Installation of digital strong motion instruments;
- Good knowledge of the seismic response of the RAN recording sites;
- Good performance of the data transmission systems;
- New organization of the RAN data center;
- Widespread strong motion data diffusion.

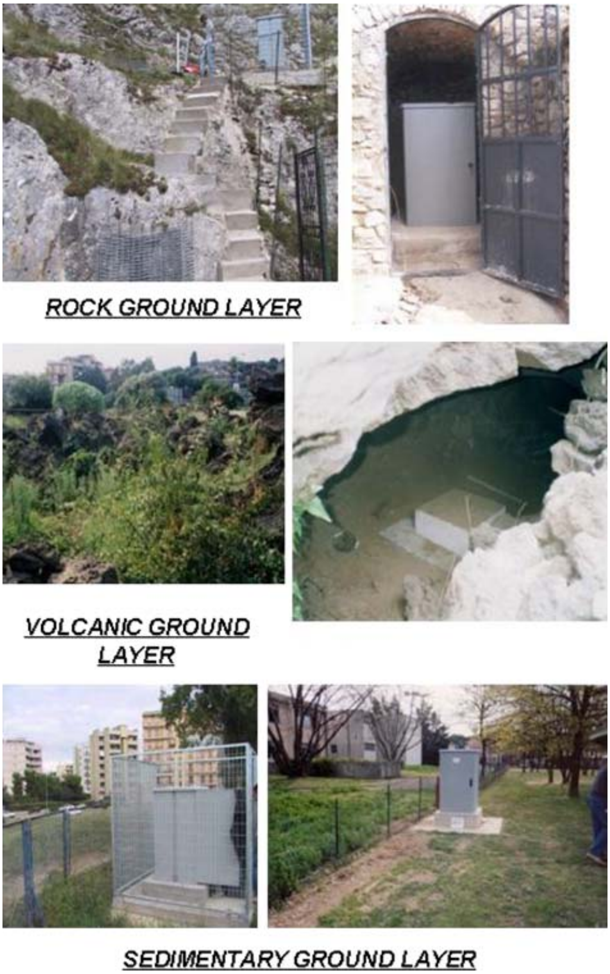

Fig. 3 Examples of RAN station geological ground layers

3.1 Standard criteria for the free field site selection and for the recording housing construction

The free field RAN sites are selected according to the minimum characteristics for TriNet reference strong motion stations (Heaton et al. 1996).

The old analogue stations were usually mounted inside—electrical transformer cabins (Fig. 2). New digital instruments are, usually, located in free field conditions, frequently in urban settings. Rocky or compact ground layers, with flat morphology, are preferred for the installations. Some examples of the RAN geological context are shown in Fig. 3.

The absence of important sources of noise and a sufficient distance from big buildings are taken into account for preventing, respectively, false triggering and dynamic interactions.

A wide survey allows to choose public protected areas, with easy access, in populous cities. The final choice of a suitable site is subjected to municipality agreement.

The technical specifications, for constructing the station housing, are listed in the Table 1.

Table 1 List of technical specifications for station housing

Reinforced concrete block, square in plan, for the sensor anchorage
R/c slab and cover for the block completion
Polystyrene panels for the block lateral isolation from the soil
R/c light floor slab around the block
Electrical equipment made in conformity with Italian regulations
Standard fibreglass box for the protection of all monitoring systems
External steel fence for the station security

The uninterrupted functionality of each strong motion instrument is assured also, in case of power fault, by an internal battery.

The construction planning of a standard station housing is displayed in Fig. 4.

In a few cases the external fence and the standard box were replaced by a masonry cabin, on municipality request. The installation phases of a typical RAN digital station are outlined in Fig. 5.

We organize a descriptive and synthetic monograph for each station. This form includes the station position with photos, road map, topographic map and geological map/sections with a simplified description of the lithology beneath the station (Fig. 6).

3.2 Seismic response of the RAN recording sites

The peak values of seismic ground motion can be strongly influenced by the local site conditions that can induce amplifications in different frequency ranges. The estimation of site amplification effects adds useful information to traditional magnitude and epicentral location data and to rapidly depict ground shaking and potential damage of an earthquake. Amplification effects are taken into account in rapid shake map production (Wald et al. 1999) and in building codes (Eurocode 8-EC8—European Norm for seismic design of buildings), using a soil-types classification, even if this approach is considered not realistic (Kawase 2003). The site effects on seismic records can be estimated by using geotechnical and/or geophysical methods.

Different levels of progress characterize the knowledge of local site conditions of the RAN network. The application of methodologies (down-hole, cross-hole, seismic refraction, seismic reflection, SASW measurements and noise array measurements), for estimating the site effects of the RAN stations, due to the high costs of such methods, is available only for the 10% of the sites. The results of all field investigations are published in the ITACA database and will be integrated with the other analysis, scheduled for other twenty RAN stations, in the framework of the DPC-INGV agreements.

The HVSR (Horizontal to Vertical Spectral Ratios) method, known as H/V method, is a low-cost and widely diffused geophysical investigation. Its applicability is strongly limited by geological and geometric complexities of subsoil (Gulkan et al. 2007), but allows to get information on site condition, considering that site amplification effects are usually characterized by frequency peaks.

The different geological conditions of the RAN stations need an extensive field investigation in order to model the seismic soil responses. In case of 1D condition and strong impedance contrast, the H/V method can provide an estimation of site transfer function.

The H/V method was evaluated, for 157 RAN stations, by means of J-SESAME specifications. J-SESAME is a current software solution for providing a graphical interface for H/V

Fig. 4 Construction planning of a standard RAN digital stations: **a** the anchorage reinforced concrete block is directly anchored to the foundation soil by means of oblique steel bars. The maximum depth of the excavation is 150 cm; **b** an rc slab and cover complete the block anchorage; **c** polystyrene panels and a light floor slab guarantee the block isolation; **d** a standard fibreglass box and an external steel fence install for the station security

spectral ratio technique in local site effect studies. The user guidelines can be downloaded from the website: www.geo.uib.no/seismo/software/jsesame/jsesame.html

A continuous record, for a time window of 12 h, was performed by means of Marslite LE-3d velocimetric data loggers, equipped with 5 s-sensor.

The results show an H/V ratio lower than 2 for the 40% of the analyzed sites. The other 60% stations show predominant frequency peaks, approximately, classified into 4 groups (Fig. 7). These results will be added inside the ITACA RAN station monographs.

An example of a complete seismic soil response is available for the AQV (L'Aquila—Centro Valle) RAN station. Starting from the Vs profile, obtained from a 51 m down-hole, an 1D ground response analysis (ProShake ver. 1.1) allows to compare, with a good agreement, the transfer function simulation result and the H/V microtremors (Fig. 8).

3.3 RAN strong motion instruments

The RAN instruments consist of analogue and digital stations with a distribution clearly shown in the Fig. 9. The old generation of analogue stations employs optical–mechanical

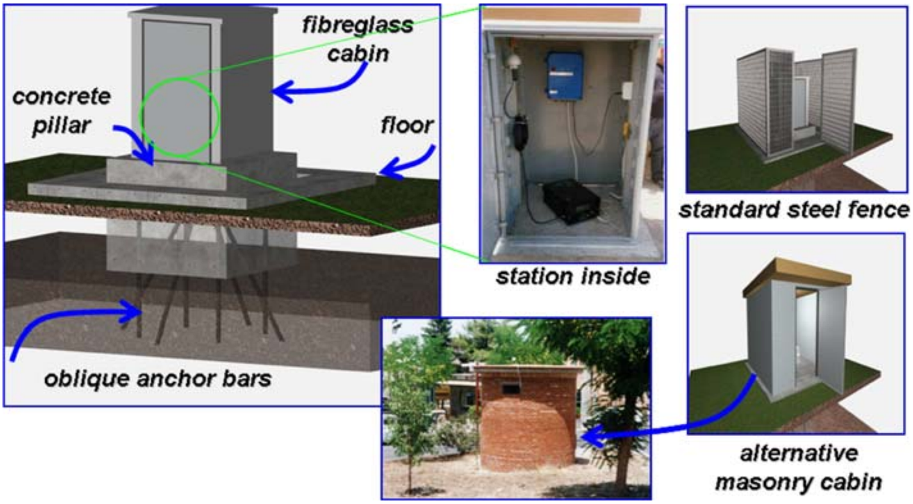

Fig. 5 Installation phases of a typical Ran digital station

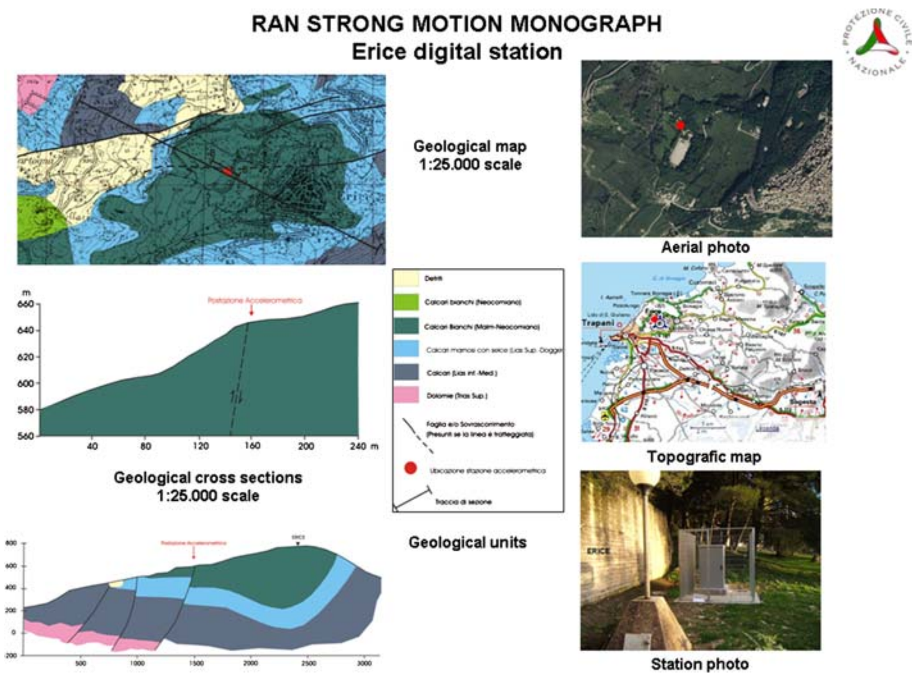

Fig. 6 Synthetic monograph of a Ran digital station

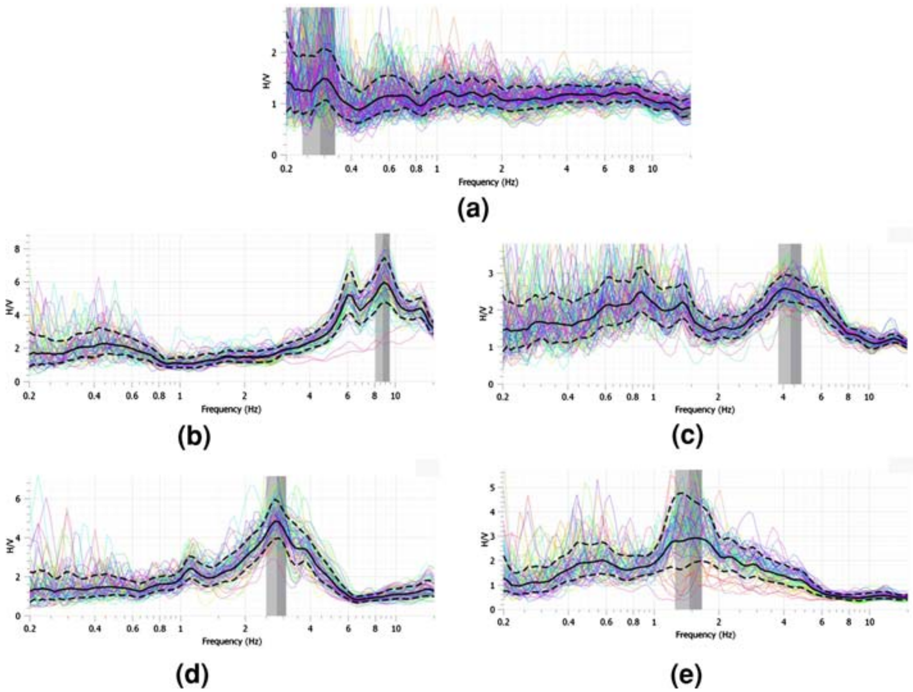

Fig. 7 H/V spectral ratios evaluated for several RAN stations. **a** An example of H/V spectral ratio lower than 2; **b–e** H/V spectral ratio classes. The predominant frequency peaks are indicate by highlight bands

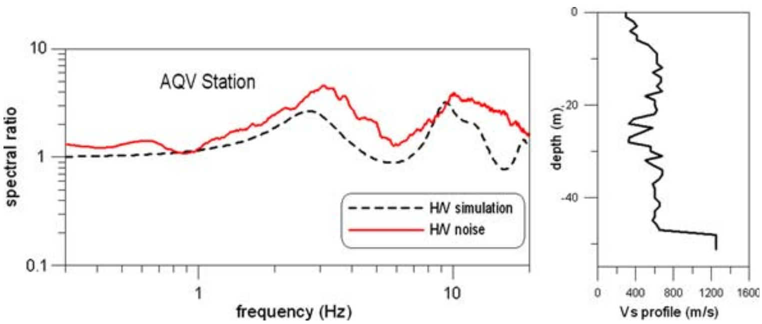

Fig. 8 H/V spectral ratio estimates, respectively, for the AQV transfer function simulation and noise. On the *right side*, the AQV, Vs profile, applied for the 1D ground response analysis

accelerographs with film-recording. Almost all analogue data loggers are based on SMA1, Kinemetrics instruments. Only a few stations operate with RFT250 Teledyne instruments. The analogue instruments, due to their mechanical component design, have low dynamic range (<40 db) and response limitations at low frequencies. The data-loggers are equipped with a ±1 g full-scale range sensor and an internal clock that does provide a quick association between earthquakes and waveforms. The activation threshold set to 10^{-2} g on the vertical component involves to record waveforms frequently triggered only by the S-wave. This trig-

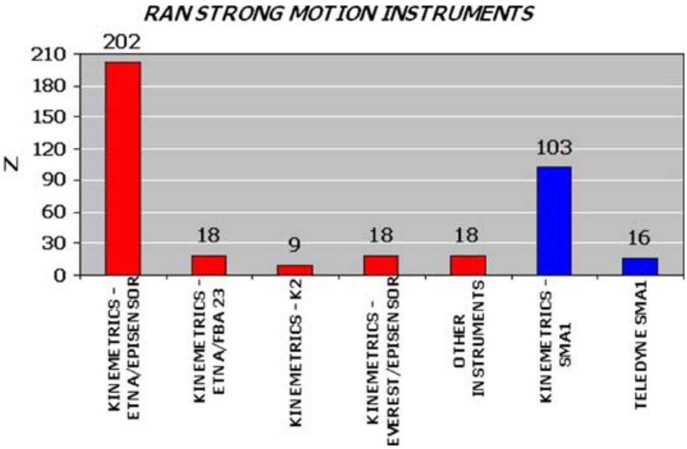

Fig. 9 Distribution of the RAN strong motion instruments

ger parameter, strongly influenced by the instrument low dynamic range, was selected on the old network for recording waveforms with a good signal to noise ratio.

The upgrade to the digital instruments has, considerably, improved both quality and quantity of the recorded strong motion data.

Digital time histories, absolute timing GPS controlled, are recorded by high dynamic range data loggers (19–24 bits), mainly Etna Kinemetrics, equipped with three components sensors FBA23 or Episensor (internal or external). A ± 1 g full-scale range is suitable for recording the Italian seismicity. High sensitivity sensors allow to decrease the trigger threshold, set to 10^{-3} g on each component or using STA/LTA algorithm, tailored for particular sites according to the local noise conditions.

The magnitude—number of records bar charts, shown in Fig. 10, point out the rapid increase of recorded low magnitude earthquakes compared to the analogue ones. Clear and complete waveforms are retrieved by means of the pre and post-event memories fixed, respectively, to 30 and 40 s.

3.4 RAN data transmission systems

With the progress of modern digital accelerographs and digital communication systems, a telemeter network of instruments can allow a rapid reporting of the occurrence of a large earthquake.

Often analogue triggered waveforms are retrieved and processed after several days, due to their remote configuration. The transition to the dial-up interrogation mode of the digital stations, exploiting a fax-modem internal card or a standard modem, has changed drastically the data recovery.

The 265 RAN instruments are linked, via GSM mobile modems, in dial-in/out configuration to the data centre. The time retrieval of the strong motion waveforms ranges from few minutes to several hours after the earthquake, depending on the overload of the GSM cellular lines especially during a seismic sequence. The digital stations are also programmed for sending an SMS (short message service) containing synthetic parameters as the PGA (Peak Ground Acceleration) values and timing of the seismic event for a very rapid estimate of the ground motion.

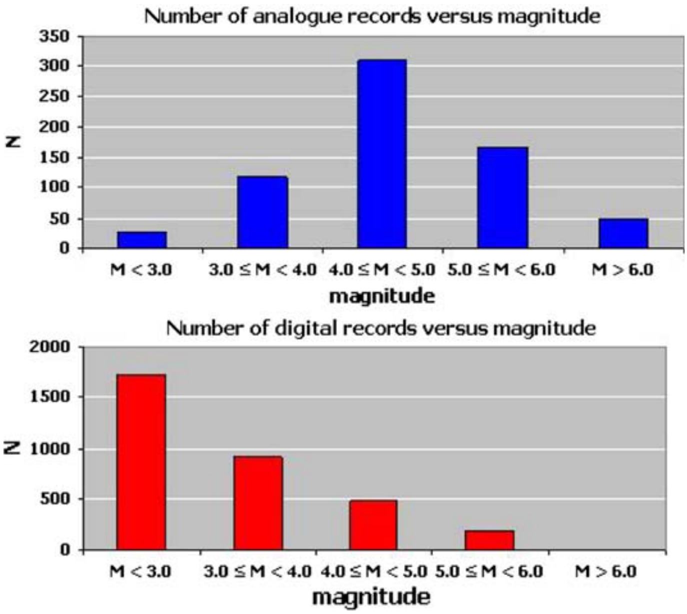

Fig. 10 Magnitude—number of records *bar* charts for the analogue and digital waveforms, recorded from 1972 to 2008

The GSM technology (Global System for Mobile communications) chosen to transmit the signals of the whole digital RAN network, has represented, until now, a good compromise despite of its slowness. The RAN data transmission, after good tests performed with GPRS (General Packed Radio Service) system, is going to migrate, definitively, towards this technology in order to retrieve faster, robust and reliable waveforms.

As reliability and overlap are fundamental parameters for the efficiency of data transmission, the probable collapse of the GSM or GPRS communication systems, following a seismic emergency, will be resolved by a redundant satellite transmission system. Therefore all the new digital instruments are going to supply with both transmission systems and the site recording are selected with a good quality GSM/GPRS signal and with a southward sky opening for the satellite transmission.

4 RAN data center

The RAN data center, placed in the DPC Rome office, controls the network efficiency and the strong motion data production.

The analogue network is checked after a Ml $\geq$ 5.0 seismic event and for periodic maintenance. The analogue recorded data are retrieved several days after a triggered earthquake and digitized, at a sampling rate of 200 Hz, by the film-recordings. The photo film, extracted from the instrument, is developed and digitalized by a scanning program. The offset and trend are removed from all signals.

The digital network is controlled, daily, by the software package "Antelope" provided by BRTT (Boulder Real Time Technologies). Antelope is a system of modules that implement acquisition, transport, buffering, processing, archiving and distribution of seismic information. Antelope consists of two major sub-systems: ARTS, the Antelope Real-Time System and ASIS, the Antelope Seismic Information System. The first sub-system, ARTS, brings raw data from the digital stations to the RAN data center and provides the state of health (SOH) for the RAN network by a comprehensive and interactive graphic user interface. Data are buffered and transported through a mechanism known as Object Ring Buffer (ORB) that can transfer and accommodate waveforms. The second sub-system, ASIS, processes and organizes the RAN strong motion data, into multiple tables, by means of a relational database structure.

The archived waveforms are sent to users on request but a fundamental and upcoming DPC objective will be the automatic data export to external users, exploiting the ORB feature.

For estimating the PGA (Peak Ground Acceleration), the PGV (Peak Ground Velocity), the Arias and Housner Intensities, the Effective duration, computed between 5 and 95% of the seismic energy, the acceleration time histories are converted from EVT format in separate seismic traces, relative to the three ground motion components. The signals are then filtered with a Butterworth pass band filter (0.2–35 Hz) and integrated, after removing the mean. The chosen broad band reduces the noise influence on the seismic signal. The strong motion parameters, computed according to their classical definitions (Arias 1970; Housner 1952; Husid 1969) are reported, along with the response spectra, widely used in earthquake engineering, in a synthetic report.

From 1972 to December 2008, 4,005 strong motion waveforms, 3,309 digital and 696 analogue, were recorded and stored in the RAN archive.

The high sensitivity of the RAN network is confirmed by the distribution of PGA and magnitude values versus epicentral distances, as shown in Fig. 11. Within an epicentral distance of 100 km, almost the 75% of the recorded data are included in a range from 1.0 to 5.0 Ml (local magnitude) and have PGA lower than 0.300 g.

The maximum stored PGA value, until the end of 2008, has a value of 0.77 g and it was recorded at the Colfiorito (Casermette) station, for a Ml 4.5, 1997 Umbria-Marche seismic sequence.

5 RAN strong motion data diffusion

The publication on CD-ROM of the Umbria-Marche (1997) and Molise (2002) strong motion data, and the expanding use of strong motion data made evident the need of a wide diffusion of the RAN recorded waveforms. Many applications in seismology and earthquake engineering make use of strong motion data, as the evaluation of empirical attenuation relationships or the seismic risk assessment.

The RAN data, collected in monthly PGA bulletins, a synthetic report of the network progress and a schematic description of the stations, triggered by Italian earthquakes with Ml $\geq$ 4.0, are published in the Seismic Risk section on the DPC website (www.protezionecivile.it)

Moreover the ITACA internet platform enables the users, with a large range of tools, to interactively search and retrieve the Italian strong motion waveforms linked to the correspondent seismic events together with a detailed monograph description of the recording stations (Luzi et al. 2008).

6 Concluding remarks

The Italian national seismic service, now incorporated into the Italian national emergency management department, took over the analogue strong motion network from the ENEL.

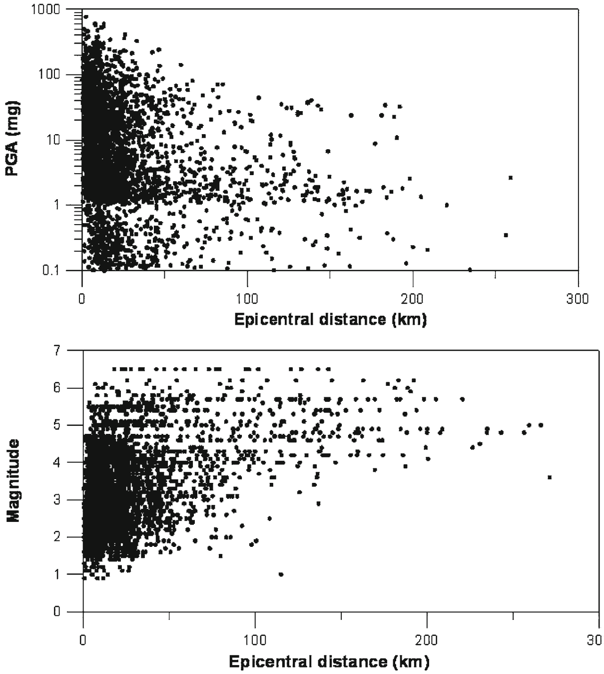

Fig. 11 PGA (*upper part*) and magnitude (*lower part*) versus epicentral distance graphs for the RAN strong motion records

This acquisition was the first step made by SSN, and continued by DPC, in order to fulfil its institutional task of strong motion monitoring at a national scale.

The RAN (Rete Accelerometrica Nazionale) project was set up for updating the technology of strong motion instruments and improving the network size. New selected recording sites, new digital instruments, implementation of data transmission systems accomplish the realization of a national network with a size of 265 digital and 119 analogue permanent strong motion stations, installed in the Italian areas exposed to high seismic risk.

By the end of 2011, the RAN network will be completed with the deployment of about 500 free field digital stations. Further developments of the RAN network will be concern the reliability of data retrieval and the improvement of strong motion data exchange capability.

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