Seismic Surveillance of Active Volcanoes: The Osservatorio Vesuviano Seismic Network (OVSN - Southern Italy)

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INTRODUCTION

Since 1970 the Osservatorio Vesuviano (Vesuvius Observatory of Naples, Italy) has maintained local seismic networks to monitor the active volcanoes of the Neapolitan area (Vesuvio, Campi Flegrei, Ischia island) as well as the most active seismic zone of the Campania Region and Southern Apennines. During 2000-2001 the local seismic networks in the volcanic regions and the regional network were restructured and unified to form the Osservatorio Vesuviano Seismic Network (OVSN) with the purpose of improving the quality of the recorded data and the consistency of data processing.

The Campania Region has suffered many catastrophic volcanic events, including the A.D. 79 eruption of Vesuvio, and many damaging earthquakes such as the 1980 magnitude 6.8 Irpinia earthquake. Moreover, seismo-volcanic activity has been occurring at Campi Flegrei for tens of centuries with slow uplift or subsidence of the ground and shallow seismicity. Due to the wide class of signals that must be detected (tectonic, volcano-tectonic, low frequency events), the OVSN includes both short period and broadband seismometers. A primary goal of this network is to recognize and analyze any seismic event that could be a precursor of volcanic unrest.

The area surrounding the Vesuvio and Campi Flegrei volcanoes is among the most densely populated in Europe. Consequently, the volcanic hazard in both regions is among the highest in the world. The earthquake hazard in Campania Region is very high also. The main purpose of the OVSN is to provide the most reliable and useful possible monitoring of the seismic activity and to alert civil defense and other authorities of events that are potentially dangerous for people and the economy. Moreover, seismic data are analyzed together with other data such as ground deformation and chemical analysis of emitted gases, with the aim of providing useful eruption forecasts.

In this paper we discuss the network improvements to give a summary of the seismic monitoring system deployed over a very hazardous region.

SEISMO-TECTONIC AND VOLCANIC ACTIVITY

Seismic activity and volcanic eruptions characterize the dynamics of the Campania Region. Seismo-tectonic activity mainly affects the Southern Apennines Chain (Figure 1), whereas volcanic activity is concentrated along the western margin of the region and includes several active volcanoes (Vesuvio, Campi Flegrei, Ischia Island; figure 1).

Southern Apennines Chain

In the Campania region (Figure 1) seismicity is associated with faults with Apenninic (NW-SE) and anti-Apenninic (NE-SW) orientations. Several seismogenic areas have been recognized based on their seismic behavior over recent and historic times (Alessio *et al*., 1993). Swarm-type activity seems to characterize the north-western sector of the chain, whereas in the central and south-eastern sector larger mainshock (and subsequent aftershock sequences) generally occur. The strongest historical and recent earthquakes in the Southern Apennines region are listed in Table 1. Instrumental locations of earthquakes in this area show an epicentral distribution clustered along the chain direction (NW-SE) and hypocenters that rarely exceed 20-25 km below sea level (Figure 1; Vilardo *et al*., 2001).

Vesuvio

Vesuvio (Figure 1) is a strato volcano formed by an older caldera (Mt.Somma) and a younger cone (Vesuvio Great Cone). It is located in the Campanian Plain at the intersection of two main fault systems roughly trending NW-SE and NE-SW (Hyppolite *et al*., 1994; Bianco *et al*., 1997). Volcanic activity has been characterized by explosive and effusive eruptions. In the last 18 kyears eight strong plinian eruptions occurred (Arnò *et al*., 1987). The last of these was the Pompei eruption of A.D. 79. Several less explosive eruptions (Arnò *et al*., 1987) occurred between 79 and 1631 A.D.. After the 1631 eruption, several eruptive cycles took place frequently until the last eruption occurred on March 1944 (Scandone *et al*., 1993). At present Vesuvio is in a quiescent state characterized by low activity (few crateric fumaroles and moderate seismic activity) (Civetta et al., 1997).

Modern instrumental recording of local seismicity began in 1971 with electro-magnetic seismometers and a local acquisition system (OVO station; figure 1). The seismicity has been characterized by low to moderate activity, both in terms of event rate and energy release. Periods of increased activity occurred in 1978, 1989-1990, 1995-1996 and 1999. During 1999 the strongest local event of the last fifty years occurred (M_D = 3.6). Vesuvio seismicity is concentrated around the crater area with hypocentral depths that do not exceed 6 km b.s.l. (Bianco *et al*., 1999). A complex local stress field has been inferred based on structural and seismological data (fault plane solutions and shear wave splitting), with a strong correlation between seismicity and both the local and regional stress fields (Bianco *et al*., 1998).

Campi Flegrei

Campi Flegrei (Figure 1) is a complex volcanic area formed by a 8 km wide caldera inside of which tens of explosive monogenic volcanoes has occurred in the last 35 kyears. (Orsi *et al*., 1999). The last eruption occurred in 1538. At present volcanic activity is limited to diffuse fumarolic emissions particularly from the Solfatara volcano, located in the central part of the caldera. The caldera is resurgent and characterized by the phenomenon called *bradyseism* (from ancient Greek bradi = slow and seism = movement, i.e. slow earth crust movement; Issel, 1883), a slow subsidence or uplift of the ground (for example: subsidence rate between 1905 and 1968 = 13 mm/year, uplift rate of 1.4 mm/day during 1982-1984; Orsi *et al*., 1999) centered in the inner part around the town of Pozzuoli. The ground deformations are accompanied by low energy shallow seismicity (Dvorak and Gasparini, 1991). During the last bradyseismic episodes in 1969-1972 and 1982-1984, a maximum uplift of about 350 cm was observed and more than 16000 local earthquakes were recorded. Seismicity was characterized by swarm-type activity; the largest event (M_D=4.2) occurred on 8 December 1984 (Del Pezzo *et al*., 1987). Despite the small size of the earthquakes (more than 90% were $M_D \leq 2.0$) many events were felt and caused damage to several buildings of Pozzuoli because of the shallow hypocenters ($0 \leq Z \leq$ 3-4 km) (Barberi *et al*., 1984).

The most recent activity began in March 2000. A ground uplift up to 4 cm was accompanied by two swarms of about 50 low energy ($M_D \leq 2.2$) earthquakes occurred on 2-7 July and 22 August 2000. Detailed analysis of the July swarm indicates an involvement of fluids in the source process, whereas the August earthquakes display typical brittle shear failure characteristics (Saccorotti *et al*., 2001). The ground uplift stopped in early August and no further earthquakes have been recorded.

Ischia Island

Ischia Island (Figure 1) is the top of a volcanic structure located in the western part of the Gulf of Naples. The structural framework is characterized by tectonic and volcano-tectonic fault systems (Vezzoli, 1988). Historical volcanic activity is characterized by both effusive and explosive eruptions, with the formation of lava flow and lava domes. The last eruption occurred in 1302 (the Arso eruption; Vezzoli, 1988). Seismic activity is concentrated in the northern part of the island around the town of Casamicciola and is characterized by a very shallow hypocentral distribution with typical depths between 1-3 km. Because of their shallow depths the earthquakes have caused landslides and many damages to buildings. Several events with maximum intensity I ≥ VII MCS have occurred in the last few centuries (i.e. 1762, 1796, 1828, 1841, 1863, 1881 and 1883; Cubellis and Luongo, 1998). The strongest earthquake (I = X MCS) occurred on 28 July 1883 and destroyed Casamicciola, causing about 2500 fatalities. No seismic stations were located at Ischia Island at that time so the magnitude and hypocenter of 1883 earthquake have been inferred from macroseismic data. This analysis gives a magnitude between 4.6 and 5.2 and a depth of 1-2 km (Cubellis and Luongo, 1998). At present only sporadic instrumental seismicity is recorded and volcanic activity is limited to fumarolic emissions and hot springs.

PREVIOUS STATUS OF THE NETWORK

Until early 2000 the Osservatorio Vesuviano Seismic Monitoring System was limited to short period stations (both vertical and three component stations) with real-time transmission by a combination of UHF telemetry and dedicated phone lines.

Though the acquisition center was common, each monitored area was covered by an independent network with different instruments and installation type. This poor level of organization resulted in uneven quality of recorded data. The networks configuration until early 2000 is briefly described in the following sections.

Campania Region Network

This network comprised 7 stations (4 three-component and 3 vertical) with data transmission by UHF telemetry and dedicated phone lines. Sensor position was not optimal. Seismometers were installed on bedrock but some of them were exposed to the wind.

Vesuvio Network

Comprising 10 stations (1 three-component and 9 vertical), this was the first network to not be equipped with commercial modulators (Capello, 1996). In the 1990s it was subjected to a first upgrade and standardization regarding instrumentation and site condition. Data were transmitted via UHF telemetry.

Campi Flegrei Network

This network was reorganized and scaled back after the 1982-1984 bradyseismic episode. At early 2000 the network included five stations (3 three-components and 2 vertical) with data transmission via UHF telemetry and dedicated phone lines. Seismometer-basement coupling was poor for most of stations because the sensors were located on tiled floors or soft soil.

Ischia Network

This network was installed in the second half of 1990s. It comprised 3 stations (1 three-component and 2 vertical) transmitted by UHF telemetry. Because these stations are located on a small island they are characterized by high marine noise.

NETWORK ENHANCEMENTS

To improve the quality of the recorded data in the early 2000 the OVSN was subjected to a total reorganization with respect to site condition, instrumentation, coverage and geometry (Buonocunto *et al*., 2001).

The analog short period network (ASPN)

Knowledge of local seismogenic structures and the seismic behavior of the monitored areas allows the best configuration and tuning of the network for both geometry and instrumentation. The official task of the Osservatorio Vesuviano is to monitor the active volcanoes of the Campania Region and conduct research with the data, so the primary objective was to optimize the seismic network in these areas. Seismic stations at regional scale are useful to constrain the locations of deeper earthquakes in volcanic areas; their data are also useful to locate regional seismicity recorded by the National Seismic Network of the INGV.

At the present the ASPN comprises 28 short period stations arranged in an irregular configuration with the highest density on Vesuvio (10 stations) and Campi Flegrei (8 stations). Ischia Island is monitored by three stations, while 5 stations are deployed in the Apennines Chain, in a roughly semicircular configuration with a radius of approximately 100 km. Moreover, one station is installed on Capri Island and one on the Sorrento Peninsula (Figure 2). Station locations are shown in Table 2. Station locations were estimated from 1:25000 scale maps; these locations are being revised using a portable GPS receiver. The observed differences between the two estimates is about 10-30 m in horizontal plane and about 3-5 m in elevation.

Depending on the setting of each site, the analog stations of the OVSN are structured in two different data transmission and power supply standards. At 22 stations data are broadcast by radio in the UHF band (430-450 MHz), and transmitted by dedicate telephone line at 6 stations. Power is drawn from the local AC power line when possible, or from solar panels otherwise. Each station is instrumented with a seismometer, amplifier-VCO, lead battery, daily calibration circuit, lightning and surge protection system. For stations with radio transmission a radio apparatus with a high-gain directional antenna is used. All of these instruments require 12V DC voltage, supplied by a lead battery which is recharged using a DC power supply when possible, or using solar panels. Since the power required by the instrumentation is quite low (it spans in the range 0.5-3 W, depending on the distance and visibility between radio points), a 75 A/h battery provides sufficient power for about 3-4 days in case the power supply is interrupted, or in the worst winter weather conditions for the stations with solar panels. Of course, stations transmitting by phone line require less power and require smaller batteries.

As the monitored areas are densely populated, the cultural seismic noise is very high almost everywhere. This, as well as the poor site response due to unconsolidated deposits or soft soil, makes it quite difficult to install stations with optimum sensitivity and signal features. Many efforts have been made during the year 2000 to improve the data quality and station reliability. A seismometer installation standard has been defined to assure a good ground-sensor coupling and a reduction of the noise. It has been adopted, where possible, at all stations. Sensors are located in a PVC cylinder on rock where possible or in a cased hole of 0.5 – 1 m depth, with a concrete base. Fine sand is used to improve insulation and coupling (Figure 3). The electronics are set up in waterproof containers or in a PVC case fully grounded and lightning protected.

Two different kinds of seismometers are used in the short period stations: Teledyne Geotech S13 and Mark L4-C, both characterized by flat amplitude response for frequencies above 1 Hz. Twelve stations of the network are equipped with three-component sensors, while the remaining 16 have only a vertical component (Figure 2; Table 2).

New instruments are being introduced to replace the older and obsolete ones. New modulators (an amplifier-VCO circuit named MARCAP with 430, 1050, 2200, 3200 and 4750Hz carrier frequencies) were designed and are being installed at the OVSN Laboratory (Capello, 1996). They are low-cost instruments with modular architecture and have the frequency transfer function displayed in figure 4. Up-to-date synthetized UHF NBFM radio transmitters have replaced quartz-crystal oscillator apparatuses. The transmission frequency is programmable by a RS-232 port over the operative frequency band (430-450 MHz). The radio power emission can be adjusted and the instruments are lightning protected.

In the year 2000 the most significant upgrades of the OVSN have been in the Campi Flegrei area, where three short period stations have been added (ASE, ASO and DMP; figure 2). Moreover, the sensor installation, as well as the other instrumentation, has been modified at some old stations (BAC, POZ and SFT; figure 2). During 2001 special efforts were made on the network at Vesuvio with the conversion of two stations (BKE and CPV; figure 2) from vertical to three-components to improve the quality of event locations. Finally, other stations (e.g. HR9, NL9, OTV and SSB; figure 2) and the RF radio repeaters have been upgraded.

The Receiving Data Center (RDC) is located in the Osservatorio Vesuviano service building on Posillipo Hill (Napoli; figure 2), a position that guarantees good visibility towards the monitored areas. The Center houses high-gain directional antennas and UHF receiving radios for signals transmitted by radio, and phone lines for stations connected by cable. Receiving radios are lightning protected with gas arresters. Frequency modulated signals are demodulated using Lennartz Electronic mod.7222 demodulators, low-pass filtered for antialiasing and then digitized using a 16 bit A/D converter at 100 sps together with an absolute time signal (77.5 kHz German time signal DCF). All data are stored continuously on hard disks in IASPEI SUDS format, while some channels are also recorded on paper drums. All of the instruments of the Receiving Data Center require 12V DC voltage, supplied by power voltage suppliers and lead batteries in case of power drop. Computers are equipped with large capacity UPS.

Signals are broadcast from the RDC to the near (less than 1km) Monitoring Center for analysis and archive throughout data-communication network (Giudicepietro *et al*., 2000) by a couple of routers primarily connected through a dedicated numerical line at 2 Mb/s. A secondary connection is activated automatically by the routers in case of failure of the main connection. A further connection is provided by a 2.4 GHz radio modem (spread spectrum; 1.5 Mb/s) that ensures data transmission during interruptions of the data-communication network. At the Monitoring Center data are acquired on a network of personal computers and continuously monitored on 19” video-terminals in multi-monitor configuration (Giudicepietro, 2001). The daily signals from each station are also printed on laser printer.

Calibration techniques and controls

Since the seismic signal undergoes several transformations from the seismometer to the acquisition center, a calibration of the entire instrumental chain is needed to determine the transfer function that relates the seismogram amplitude expressed in counts to the ground velocity.

The stations are periodically calibrated using a calibration coil. The analysis of data produced by the seismometer for a series of pulses (on/off and off/on transitions of the current in the calibration coil) furnishes the dynamical calibration constant G, as well as the amplitude and phase response of the instrument (*Mathcad* program; Del Pezzo, 2000). To improve the signal-to-noise ratio the calibration is realized with minimum gain of the amplifier circuit. Each station is also equipped with an electronic circuit that provides a daily calibration. It consists of two calibration pulses, the first one up (current on in the calibration coil) and the second one down (current off), and is used for a check of the polarity and the station status.

The daily calibration pulse is also used for a control of the power status of the instruments. A circuit checks the battery power level and inhibits the calibration pulse if the voltage falls under 12.2V for any reason (DC power supply failure, activation of surge protections, utility failure, etc.). With this alert it is possible to restore the power supply before the buffer battery exhausts its charge. Moreover, in case of power failure, a low voltage cutoff switch turns off the battery power to all instruments when the battery voltage fall under 11.5V to preserve the battery from overdischarge.

Digital broadband network (DBBN)

Recently the network has been further improved with the installation of 3 broadband three-component stations. The broadband seismometers are very important for the identification and the analysis of seismic signals from volcanic areas that are characterized by low frequency spectral content (e.g. tremor, long-period events). These stations are located on Vesuvio and Campi Flegrei (see figure 2) and are equipped with three-axial force balance Guralp CMG-40T seismometers with a frequency range of 60s – 50Hz.

Seismic data are digitized at 100 sps by an on-site acquisition system (Kinemetrics *Altus* K2) whose A/D converter furnishes 19 significant bit data. Digital data output via RS-232 port at 9600 baud rate are broadcast real-time by UHF radio to the receiving center (RDC). Since the dynamic range of the transmitting instrument chain is 96 dB, corresponding to 16-bit data, the three least significant bits are dropped in the transmission. Data are thus received and acquired on a personal computer at 16-bit. The acquisition system is based on a 16 ports RS-232 interface board (DigiBoard PC/16e) and the XRTPDB IASPEI software (Tottingham and Mayle, 1994). The data transmission between the Receiving Data Center (RDC) and the Monitoring Center, as well as the visualization of the signals, is realized using the same procedures of the Analog Network (Giudicepietro *et al*., 2000; Giudicepietro, 2001).

The installation of broadband seismometers follows a procedure similar to that described for analog stations (see figure 3), but the sensor is insulated thermally to reduce the daily temperature variations according to the worldwide standard (Uhrhammer *et al*., 1998). If the installation is outdoor (e.g. SOB station, figure 2), an underground vault (about 1.0-1.5 m deep) with a heavy plastic case is used to help keep the temperature stable. The sensor is placed on the concrete floor of the vault inside a PVC tube. To insure an effective heat insulation of the sensor the space between the plastic case and the PVC tube is filled with granular polystyrene. Moreover, the tube is filled with fine sand to completely cover the seismometer and to improve insulation and coupling. Top insulation is provided by a tight thermal cover made of 15-20 cm thick polystyrene slices. Finally the vault is closed with a heavy plastic watertight lid. In interior installations the method is the same, but further insulation of the outer surfaces of the plastic case is provided with polystyrene slices faced with aluminium foil. The data-logger, power supply instruments and UHF transmitter are located in waterproof containers or in a PVC case and are lightning protected.

During 2001-2002 five additional digital broadband stations will be installed on volcanic and tectonic zones of the Campania region. Although at present both Vesuvio and Campi Flegrei are in a period of repose, special effort will be directed to improve the DBBN on these volcanic areas to recognize and analyze any seismic events that could signal a resurgence of volcano unrest. In the meantime, to assure a wide coverage of digital broadband stations at Vesuvio, 3 Lennartz Mars-lite stations equipped with Guralp CMG-40T seismometers have been installed temporarily. These instruments are maintained by the Mobile Network Group of the Osservatorio Vesuviano. These stations provide local recording on long duration magneto-optical disks and their data are processed jointly with data from DBBN stations.

A major initiative to modernize the network is underway. In the next few years (2002-2003) the broadband instruments will be upgraded with 24-bit digital encoders designed to replace most of the short period (vertical and three components) stations operated by the Osservatorio Vesuviano Seismic Network. Moreover, new stations will be installed to improve the spatial coverage and redundancy criteria will be applied to the telemetry system (ordinary telemetry and digital phone lines and/or satellite comunication) to guarantee the continuous data acquisition.

CONCLUDING REMARKS

It is a difficult task to install and maintain a seismic network in a highly urbanized area. Cultural noise and electro-magnetic fields produce high background noise and transmissions/receptions with interference and spikes. In spite of these problems, the new criteria for sensors installation and the upgrade of the instruments have provided clear improvement in the signal-to-noise ratio and the general quality of data recorded by the OVSN. By means of adequate surge and lightning protections the network reliability has become very high, with few failures and fast emergency maintenance (typically within 24-36 hours).

The improvement and standardization of the Analog Short Period Network and the installation of the first group of Digital BroadBand Stations provides a good network geometry and improves the quality of the hypocentral locations, focal mechanisms solutions, and the other source parameters. Such a seismic surveillance system, together with geodetic and geochemical information, provides a good data base for quantification of volcanic activity with the aim of a useful eruption forecast.

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FIGURE CAPTIONS

Figure 1. Map of the Campania Region monitored areas. Black dots represent the seismicity recorded in the last five years (1996-2000). Circles show the location of the largest earthquakes occurred in the last centuries according to Table 1 (data from Image Processing Facilities Osservatorio Vesuviano – INGV; Vilardo *et al*., 2001).

Figure 2. Location map of the OVSN short-period and broadband stations. Data acquisition and processing center (black square) is also shown.

Figure 3. Layout of a standard seismometer installation.

Figure 4. Transfer function of the MARCAP amplifer-VCO.

TABLE 1

Strongest historical and recent earthquakes in the Southern Apennines

Date	Intensity MCS	Magnitude	Reference number in Figure 1
1456	I ≥ X MCS	--	1
1688	I = X MCS	--	2
1694	I ≥ X MCS	--	3
1805	I ≥ X MCS	--	4
1857	I ≥ X MCS	--	5
1930	I ≥ X MCS	$M_S = 6.7$	6
1962	I = IX MCS	$M_S = 6.2$	7
1980	I = X MCS	$M_S = 6.8$	8

TABLE 2

Station book of the Osservatorio Vesuviano Seismic Network

Code	Location	LAT-N	LONG-E	Elevation (m asl)	Sensor[1]	Date[2]
AN9	Capri Island	40°33.07′	14°13.01′	250	SP-3C	1998
ASE	Astroni Crater	40°50.46′	14°09.55′	100	SP-1C	2000
ASO	Astroni Crater	40°50.41′	14°08.46′	200	SP-1C	2000
BAC	Baia Castle	40°48.58′	14°04.96′	15	SP-1C	1970
BKE[3]	Vesuvius-Bunker Est	40°49.07′	14°26.33′	863	SP-3C	1992
CAI	Ischia Island	40°43.88′	13°57.92′	80	SP-1C	1996
CPV[4]	Vesuvius-Cappella Nuova	40°46.93′	14°25.33′	190	SP-3C	1992
DMP	Pozzuoli	40°50.10′	14°06.85′	46	SP-3C	2000
FO9	Forio d’Ischia	40°42.65′	13°51.32′	234	SP-1C	1995
HR9	Ercolano	40°48.30′	14°20.93′	34	SP-1C	1987
MSC	Mt. Massico	41°11.49′	13°58.28′	109	SP-1C	1979
MT9	Mt. Stella	40°14.22′	15°03.90′	1125	SP-1C	1988
NIS	Nisida	40°47.81′	14°09.80′	3	SP-3C	1983
NL9	Nola	40°55.23′	14°32.70′	75	SP-1C	1992
OC9	Ischia Island	40°44.75′	13°54.05′	123	SP-3C	1993
OTV	Ottaviano	40°50.35′	14°27.98′	363	SP-1C	1996
OVO	O.V. Historical building	40°49.65′	14°23.80′	584	SP-3C	1971
OVB	O.V. Historical building	40°49.65′	14°23.80′	584	BB-3C	2000
PE9	Pescosannita	41°14.00′	14°50.00′	395	SP-1C	1999
POB	Vesuvius-Pollena	40°51.13′	14°23.00′	170	BB-3C	2000
POZ	Pozzuoli	40°49.22′	14°07.23′	3	SP-1C	1982
SFT	Solfatara Volcano	40°49.79′	14°08.31′	90	SP-3C	2000
SGG	Mt. Matese	41°23.20′	14°22.75′	880	SP-3C	1977
SMC	Vesuvius-Mt. Somma	40°51.12′	14°26.08′	406	SP-1C	1995
SOB	Solfatara Volcano	40°49.65′	14°08.66′	175	BB-3C	2000
SOR	Sorrento Peninsula	40°34.92′	14°20.10′	497	SP-3C	1976
SSB	Vesuvius	40°50.47′	14°22.23′	175	SP-1C	1993
STH	Agnano Crater	40°49.78′	14°09.00′	100	SP-3C	1983
TDG	Torre del Greco	40°48.35′	14°23.53′	300	SP-1C	1995
TR9	Trevico	41°02.75′	15°13.92′	1094	SP-3C	1980
TRZ	Terzigno	40°48.42′	14°28.52′	175	SP-1C	1994

[1] SP=Short Period; BB=Broad Band; 1C=vertical component; 3C=three components

[2] Date of installation

[3] Converted in 3C on March 2001

[4] Converted in 3C on June 2001

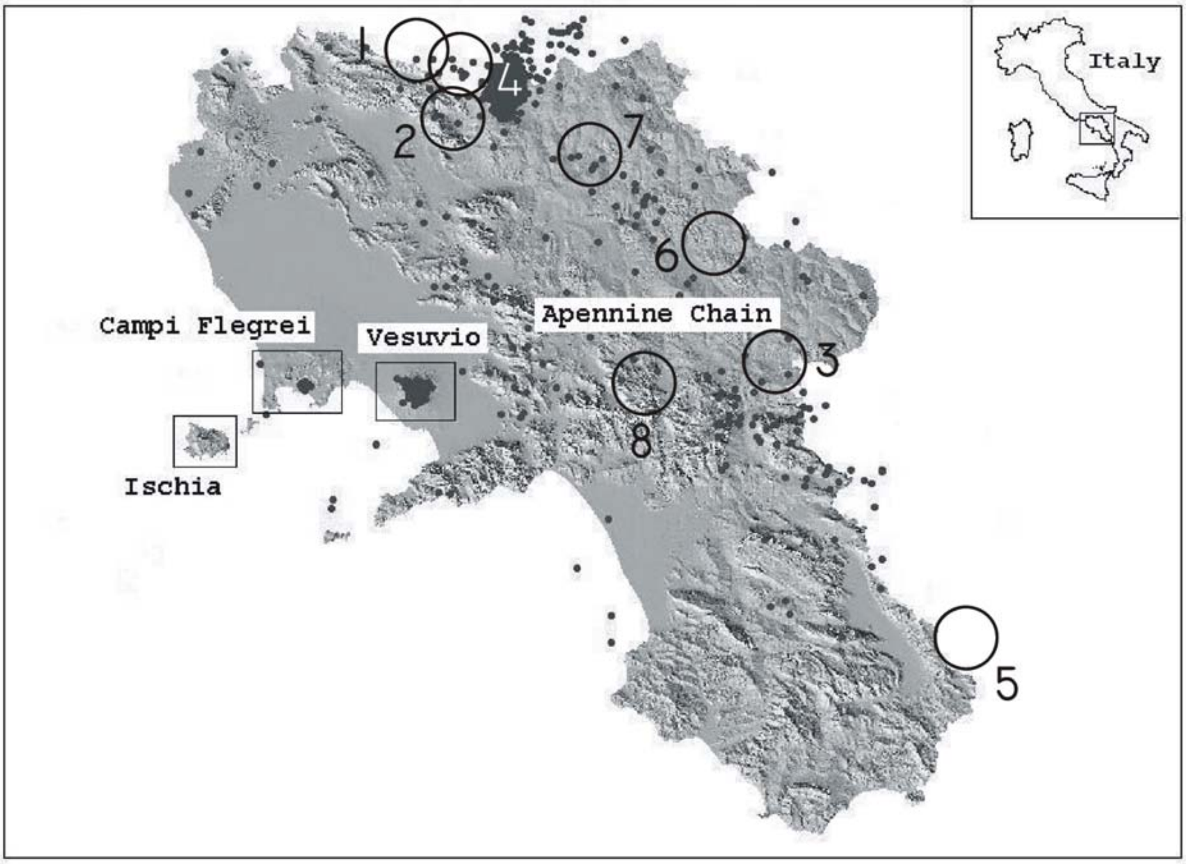

Italy
1
4
2
7
6
Apennine Chain
Campi Flegrei
Vesuvio
3
8
Ischia
5

Figure 1.

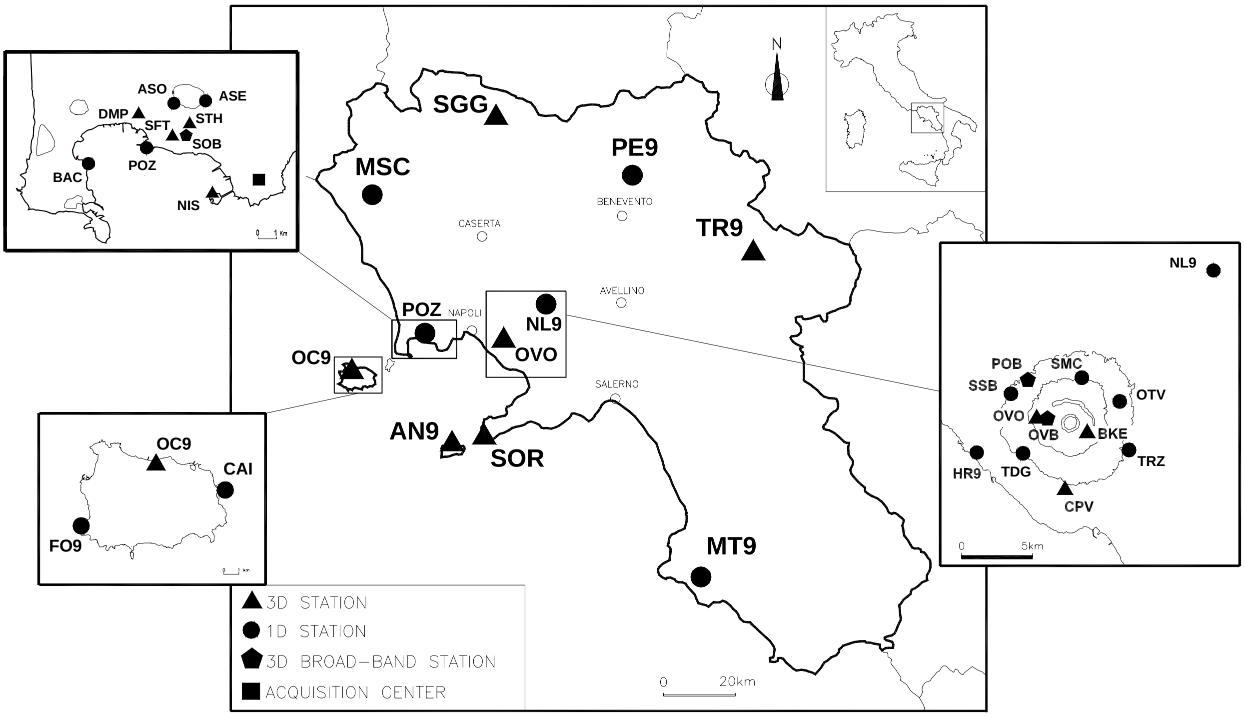

ASO
ASE
DMP
SFT
STH
SOB
POZ
BAC
NIS
SGG
MSC
PE9
BENEVENTO
CASERTA
TR9
AVELLINO
POZ
NAPOLI
NL9
OVO
OC9
SALERNO
AN9
SOR
MT9
OC9
CAI
FO9
NL9
POB
SMC
SSB
OTV
OVO
OVB
BKE
HR9
TDG
TRZ
CPV
0
5km
N
3D STATION
1D STATION
3D BROAD-BAND STATION
ACQUISITION CENTER
0
20km

Figure 2.

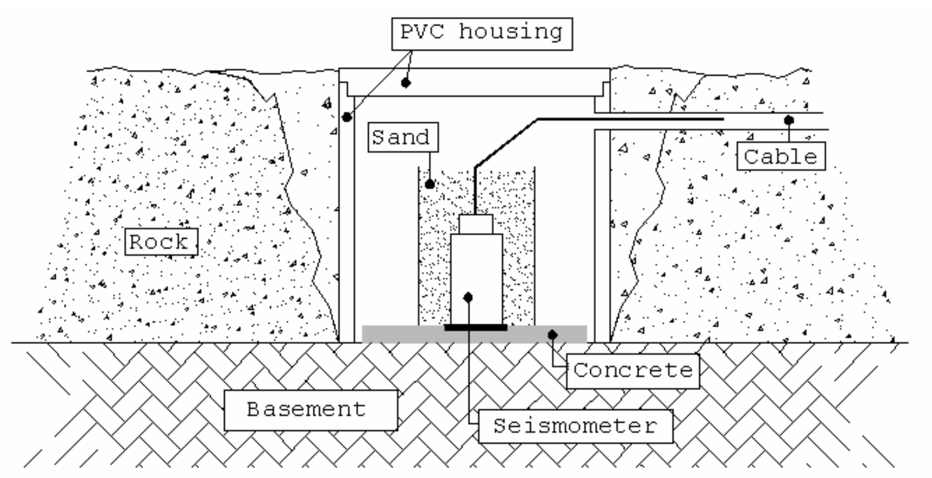
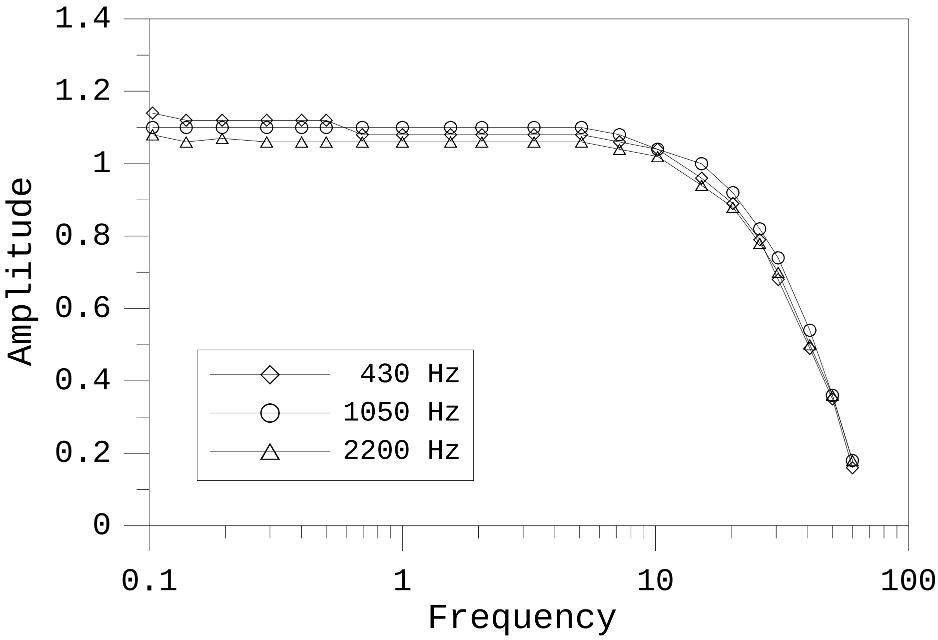

PVC housing
Sand
Cable
Rock
Concrete
Basement
Seismometer

Figure 3.



1.4
1.2
1
0.8
0.6
0.4
0.2
0
Amplitude
430 Hz
1050 Hz
2200 Hz
0.1
1
10
100
Frequency

Figure 4.