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Active and Passive Experiments for S-Wave Velocity Measurements in Urban Areas

C. Nunziata, G. De Nisco and M.R. Costanzo
Dipartimento di Scienze della Terra,
Univ. Napoli Federico II
Italy

1. Introduction

One of the key parameters for the study of the effects of local site conditions is the S-wave velocity structure of unconsolidated sediments and the S-wave velocity contrast between bedrock and overlying sediments.

Detailed V_S profiles with depth can be measured with standard borehole logging and hole measurements, like down-hole and cross-hole. Such measurements are expensive, very local (point measurements) and may be not representative of large areas. Powerful methods for V_S measurements, that do not need drillings, are all based on the dispersion properties of Rayleigh wave phase and group velocities. Methods for phase velocity measurement of surface waves need recordings along dense arrays, with small geophone spacing, to avoid spatial aliasing, or, in case of 2 receivers, there is the problem of getting the right number of cycles and, hence, the analysis may lead to wrong values (Nunziata, 2005). Instead, the group velocity dispersion curve of the fundamental mode of Rayleigh waves can be extracted from the recorded signal at a single station by using the FTAN (Frequency Time Analysis) method (Nunziata, 2010 and references therein).

FTAN is appropriate to process surface wave data both for the identification and the separation of signals and for the measurement of signal characteristics other than phase and group velocities, like attenuation, polarization, amplitude and phase spectra. When not only the fundamental mode but also the higher modes are excited, FTAN method lets to estimate the gross Q values too. In fact, the comparison between synthetic seismograms computed with extreme Q values and experimental data is based on the relative amplitude of fundamental and higher modes (Nunziata et al., 1999). FTAN method is successfully employed both in seismological and engineering field (e.g. Nunziata et al., 2009; Nunziata, 2010). At urban sites, the impossible use of explosive sources or heavy masses blows, limits the penetration depth to the uppermost 20-30 m, depending upon the rock velocities. Recently, cross correlations of long time series of ambient seismic noise have been demonstrated to recover surface wave dispersion (Green function) over a broad range of distances, from a few hundred metres to several hundred kilometres (e.g. Weaver & Lobkis, 2001; Bensen et al., 2007; Nunziata et al., 2009). Detailed V_S profiles with depth are then obtained from the non linear inversion (Hedgehog method) of the average dispersion curve of the fundamental mode of Rayleigh group velocities.

Aim of this paper is to present examples of the FTAN and Hedgehog methods applied to both active and passive experiments, to obtain reliable V_S profiles to depths of 2 km in a complex urban area like Napoli, with high seismic and volcanic risk.

2. Methodologies

In the FTAN analysis, signal is passed through a set of narrow-band Gaussian filters with central frequencies varying in the frequency band of interest. The combination of all so filtered signals is a complex function $S(\omega_c, t)$ of two variables, filter central frequency ω_c and time, called frequency-time representation of a signal. A FTAN image is produced by displaying the logarithm of the square of the contour map of $|S(\omega_c, t)|$ amplitude and, for ω fixed, it represents the signal envelope at the output of the relevant filter. The group arrival time as a function of the central frequency of the Gaussian filter is determined from the peak of the envelope function. Typically period replaces filter central frequency and, being known the source-receiver distance, group velocity replaces time. One example of the FTAN analysis on a signal recorded with active seismic experiment at Napoli (Italy) is given in Figs. 1a-e.
An average dispersion curve of Rayleigh group velocities with errors is computed, from FTAN analysis made on a few (4-5 or more) signals, which can be inverted to determine V_S profiles versus depth. A non-linear inversion is made with the Hedgehog method (Panza et al., 2007 and references therein) that is an optimized Monte Carlo non-linear search of velocity-depth distributions. In the inversion, the unknown Earth model is replaced by a set of parameters (V_P, V_S, density and thickness) and the definition of the structure is reduced to the determination of the numerical values of these parameters. In the inversion V_S and thickness are variable parameters, while density is fixed and V_P is dependent on V_S through an assigned V_P/V_S ratio. In the inversion problem of V_S modeling, the parameter function is the dispersion curve of group velocities of Rayleigh fundamental mode.
Given the error of the experimental phase and/or group velocity data, it is possible to compute the resolution of the parameters, computing partial derivatives of the dispersion curve with respect to the parameters to be inverted (Panza, 1981). The parameterization for the inversion is defined so that the parameter steps are minima, subject to the condition $\sum_j \left(\partial V(T_i) / \partial P_j \right) \partial P_j = \sigma(T_i)$ where σ is the standard deviation of measurements, V is phase or group velocity, T_i is the i-th period, and P_j is the j-th parameter; in this way each parameter step represents a satisfactory measure of the uncertainty affecting each parameter. The theoretical phase and/or group velocities computed during the inversion with normal-mode summation are then compared with the corresponding experimental ones and the models are accepted as solutions if their difference, at each period, is less than the measurement errors and if the r.m.s. (root mean square) of the differences, at all periods considered, is less than a chosen quantity (usually 60–70% of the average of the measurement errors). All the solutions of the Hedgehog inversion differ by no more than ±1 step from each other. A good rule of thumb is that the number of solutions is comparable with the number of the inverted parameters.
From the set of solutions, we accept as a representative solution the one with the rms (root mean square) for phase and group velocities closest to the average rms for all the solutions, reducing in this way the projection of possible systematic errors into the structural model (Panza, 1981). Other selection criteria could be followed as described by Boyadzhiev et al. (2008). An example is shown in Fig. 2.

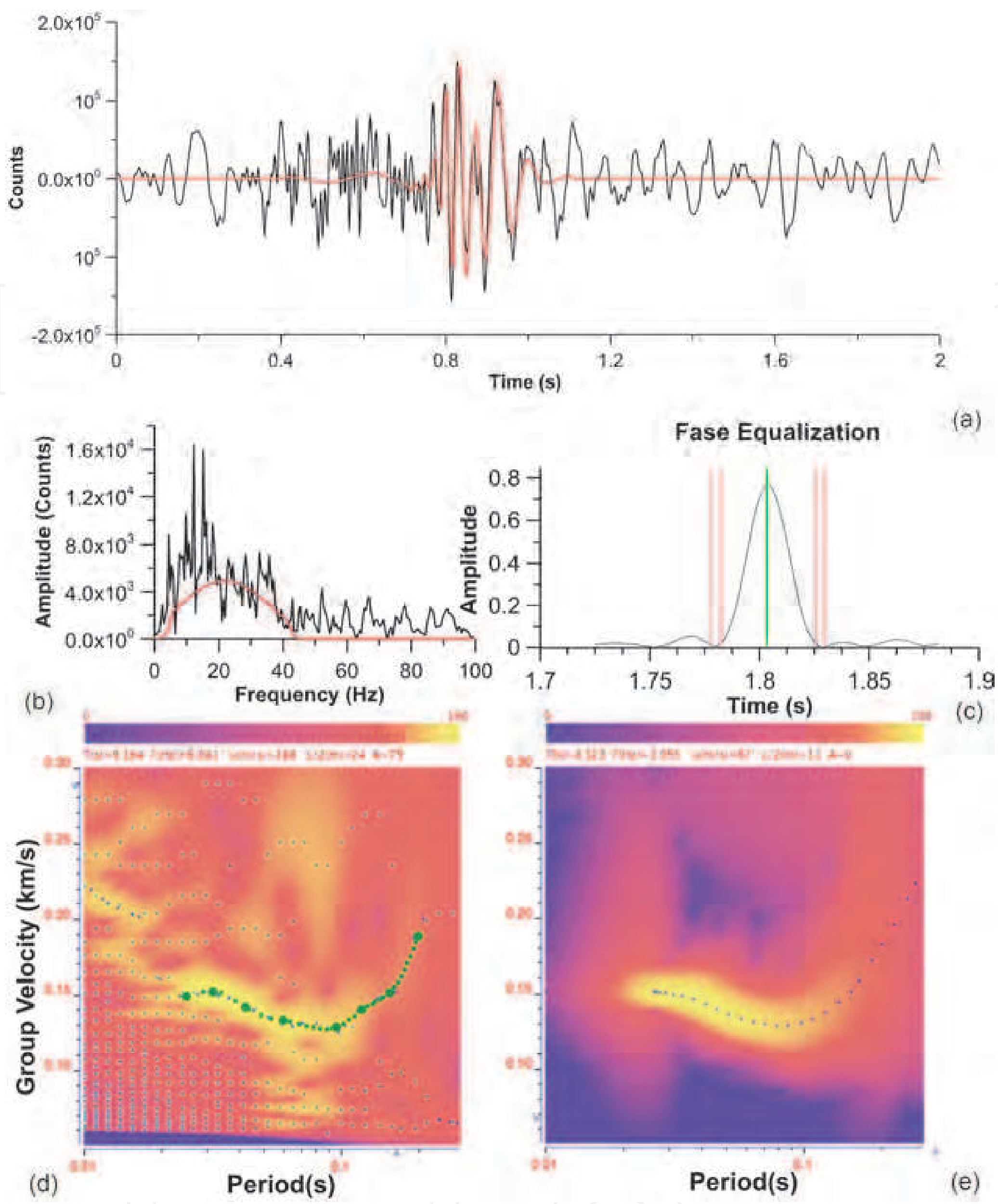

Fig. 1. Example of FTAN analysis on a signal of active experiment at Napoli (Scampia, located in Fig. 3) with 120m offset: (a) the raw waveform (black line); (b) Fourier spectrum amplitude of the signal; (c) a raw group velocity curve (green dots) is chosen by the analyst by picking maxima on the FTAN map. This raw group velocity dispersion curve is back Fourier transformed to get the dispersed signal. Phase-matched (anti-dispersion) filtering is performed on the chosen period-band to remove dispersion. (d) The anti-dispersed signal will collapse into a single narrow spike. Such operation has the only effect to alter the initial phase of the resulting signal, so it can be shifted to a convenient instant of time, for example, to the midpoint of the record. The collapsed waveform is then cut (vertical lines) from the surrounding time-series and re-dispersed to give the clean waveform. (e) The FTAN image of the cleaned waveform is computed and, using the same process applied to the raw waveform, the cleaned group velocity curve (blue dots) and fundamental mode waveform (red line in (a)) are obtained.

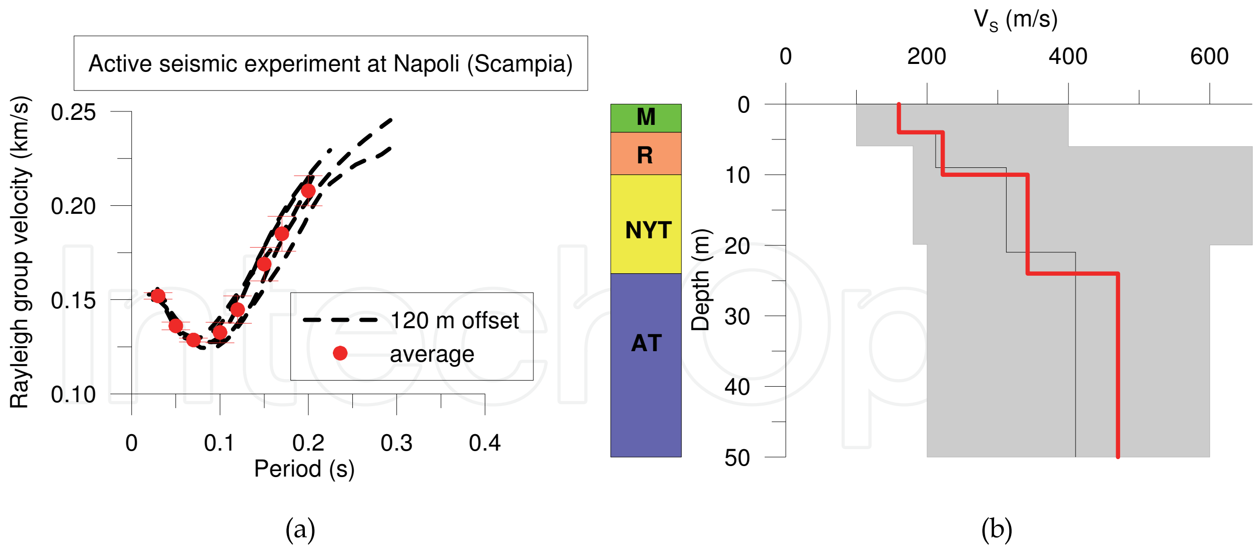

Fig. 2. (a): Dispersion curves of group velocity relative to receivers with 120m offsets at Napoli (Scampia, located in Fig. 3). (b): Shear wave velocity models: the grey area indicates the searched part of the parameter's space, while the accepted models are represented by the solid lines. The chosen solution has been selected as the closest to the known stratigraphy (red line). Legend: M man made ground; R recent pyroclastic products; NYT Neapolitan Yellow Tuff (soil facies); AT ancient tuff.

3. Active experiments

FTAN measurements have been successfully performed, at engineering scale, in italian urban areas with different soil and rock environments (e.g. Nunziata et al., 2004; Nunziata, 2005). A weight drop of 30 kg is used as source and one or more low frequency 4.5-1 Hz vertical geophones are used as receivers for offsets less or greater than 50 m, respectively. Only one receiver is requested, or, alternatively, a seismic refraction spreading, in order to evaluate an average group velocity dispersion curve from 4-5 receivers or 4-5 sources.
In the following some examples are reported at the neapolitan area to show the main advantages of FTAN method in complex geological settings of noisy urban areas.

3.1 FTAN measurements at Napoli

Several measurements have been performed at the urban area of Napoli for which, taking into account the stratigraphies, six geologically homogeneous zones have been recognized (Nunziata, 2004) (Fig. 3). The geological setting of Napoli is mainly characterized by pyroclastic materials, soil (pozzolana) and rock (tuff), produced by different eruptive centres at Campi Flegrei and Somma-Vesuvio volcanoes. The most widespread lithotype is the Neapolitan Yellow Tuff (NYT, 15 ka) which constitutes the skeleton of the historical urban area. FTAN-Hedgehog V_S models represent average values over distances of 50-100m and are more suitable than down-hole (DH) and cross-hole (CH) point measurements for seismic response analysis. Beside this, the good agreement of FTAN-Hedgehog with CH measurements (Nunziata et al., 2004), has allowed to enrich database and to acquire experience enough to select, for each zone, some V_S models for the evaluation of the spectral amplification (Nunziata, 2004). In fact, because of the lack of recordings of strong ground motion at Napoli, the only way to estimate site effects is to compute them. Starting from the

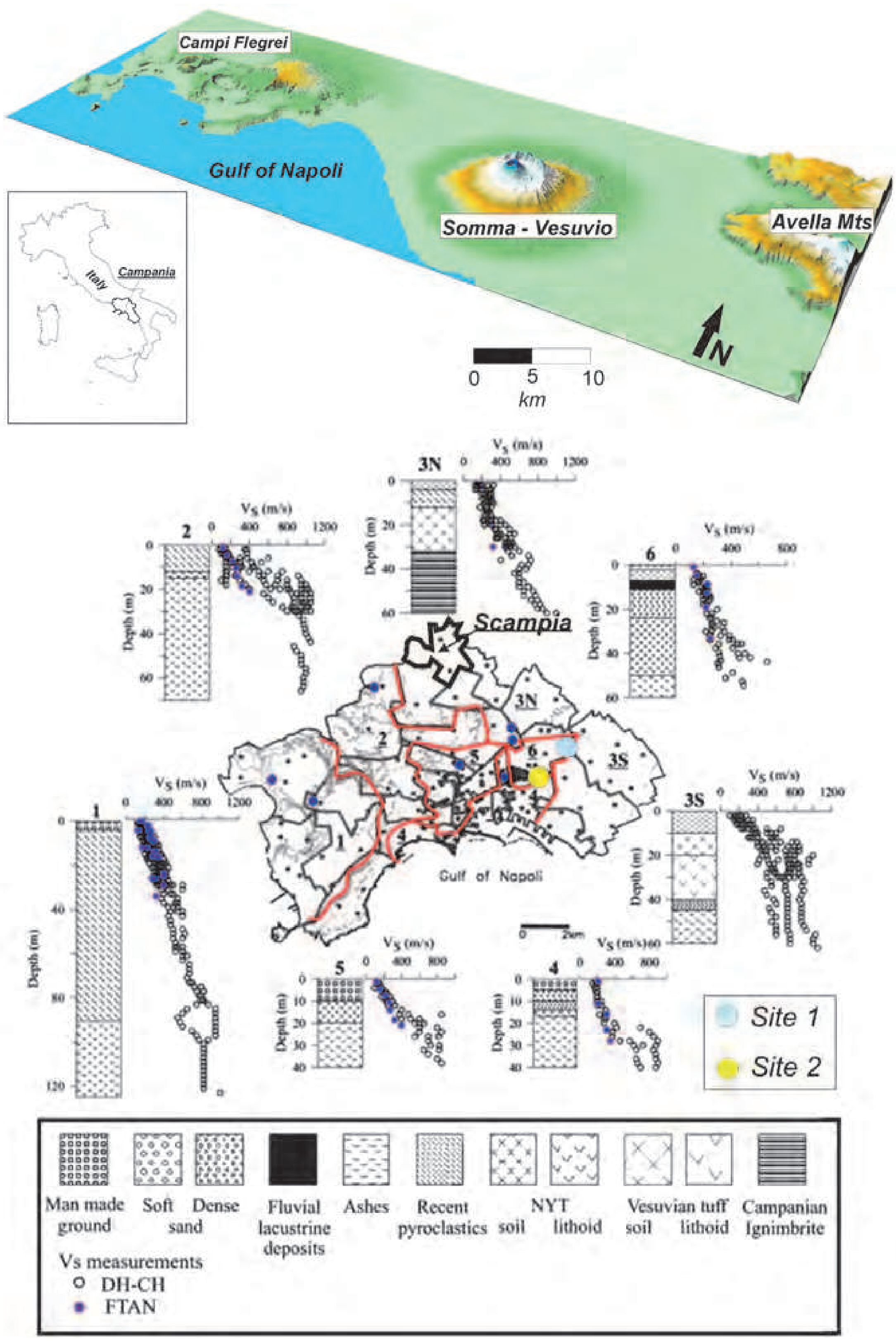

Fig. 3. Urban map of Napoli showing the quarter limits and the representative stratigraphic column for each of the six geological zones (bold underlined numbers), together with drillings (black dots), FTAN measurement sites (blue dots) and all available V_S measurements (modified after Nunziata et al., 2009).

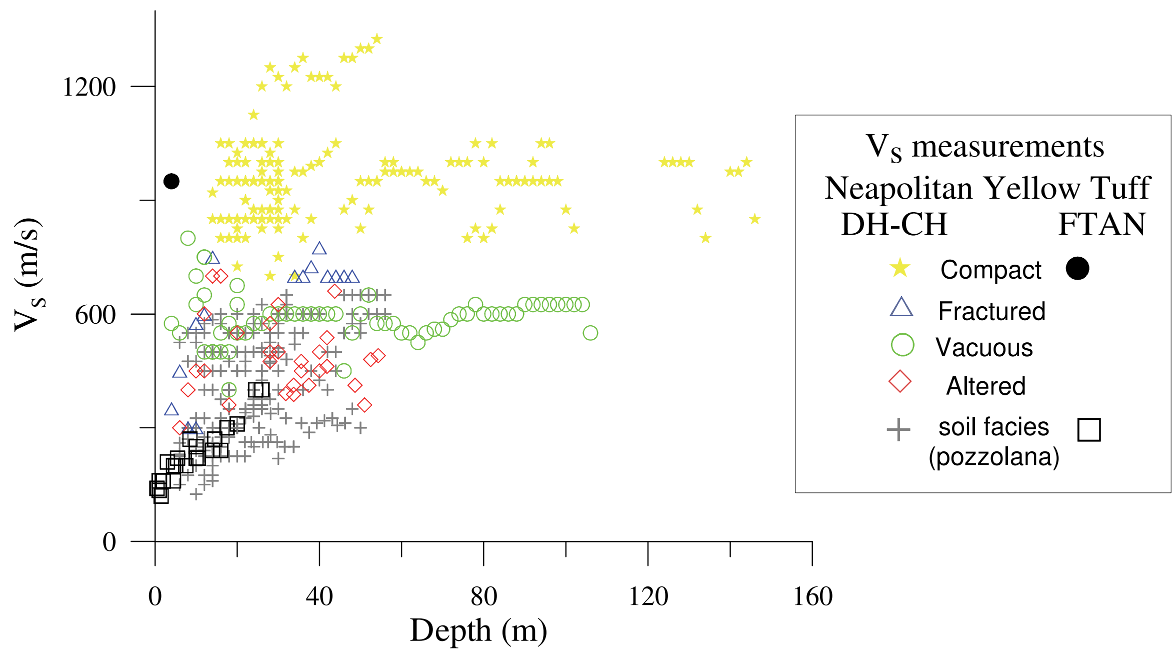

Fig. 4. V_S velocities of Neapolitan Yellow Tuff, both soil and lithoid facies (modified after Nunziata et al., 2004).

good fit between the first strong event recorded close to Napoli (about 20km far), that is the 1980 earthquake (Ms=6.9), and seismograms computed with mode summation technique, the detailed geological and seismic information of the neapolitan subsoil were used to compute quite realistic ground motion at Napoli for the 1980 earthquake (Nunziata, 2004) and the 1688 scenario earthquake (Nunziata et al., 2011). The propagation of the waves from the source to the complex laterally varying structure is computed with the mode summation technique, and in the laterally heterogeneous structure, it is computed with the finite difference method (Panza et al., 2001 and references therein). Site amplification effects were estimated in terms of spectral amplification, defined as the response spectrum at a site in the 2-D structural model, normalized to the response spectrum computed for the 1-D average reference model. Average and maximum response spectra and spectral amplifications were computed for all V_S models at each zone and proposed for zoning purposes. The need of doing robust V_S measurements vs. depth in volcanic settings is strictly dependent on their wide ranges of variations. They are the consequence of the profound differences in the physical properties and textural conditions that can be found even in the same formation. An additional important factor responsible for the observed scatter in the V_S values is the different hardening degree, due to the diagenetic process. As an example, V_S measurements relative to NYT, both in soil and lithoid facies, are shown in Figure 4.

3.2 FTAN measurements at Portici (Somma-Vesuvio)

Somma-Vesuvio is a very densely populated area, and accurate V_S measurements are requested for the volcanic and seismic hazards. FTAN measurements performed at the Royal Palace of Portici, famous town for the highest population density in Italy, have given detailed V_S models for the shallower 40 m (Fig. 5). These results are important for seismic zoning and give precious volcanological information in terms of thickness of the erupted products. In fact, taking into account the stratigraphy of a close drilling, it resulted that a Vesuvio shallow lava (medieval or 1631 eruption) is characterized by V_S of 500 m/s, which is higher than that of Somma lava at 30 m of depth, and that pyroclastic deposits have low V_S velocities around 200-300 m/s.

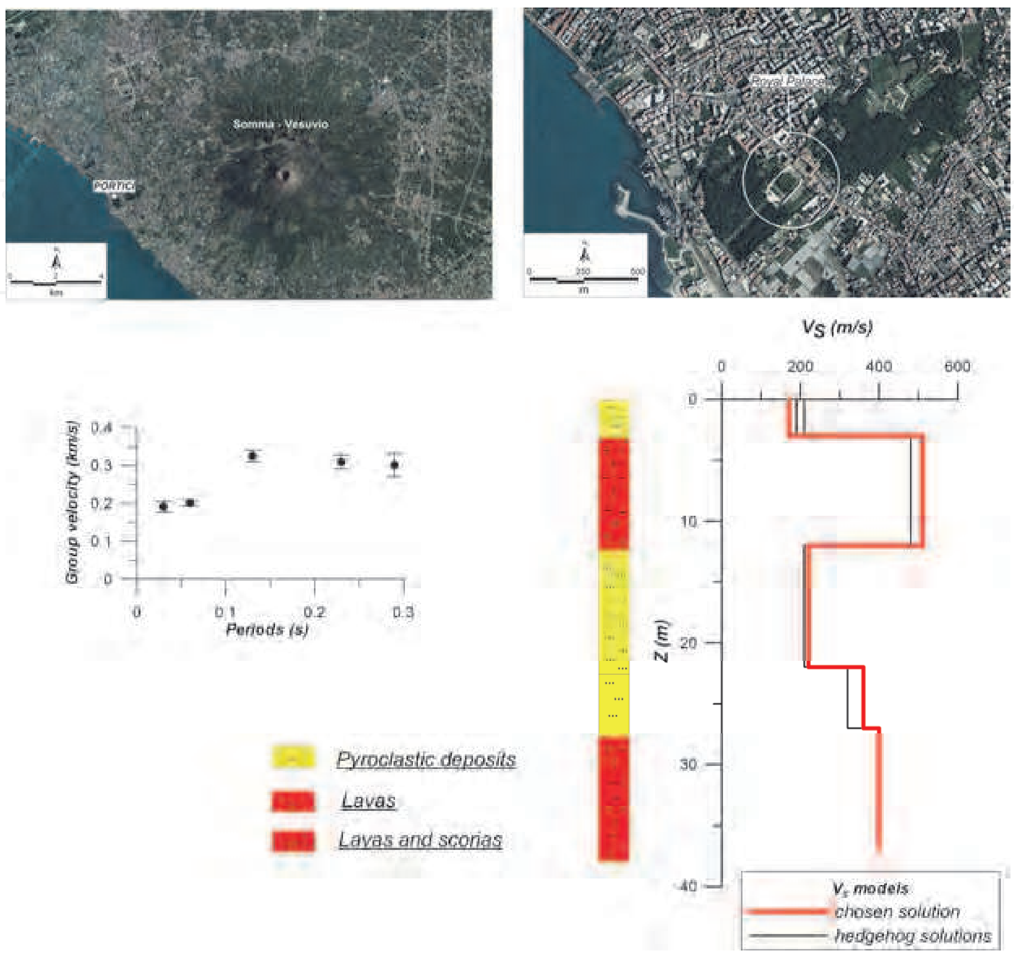

Fig. 5. Results of nonlinear inversion (Hedgehog method) of the average dispersion curve of Rayleigh group velocities, with error bars, together with a close drilling stratigraphy.

4. Passive experiments

Passive methods are based on ambient vibrations or microtremors and can be used to infer V_S profiles vs. depth. One method is the H/V method of Nakamura (1989), defined as the ratio between the mean of the Fourier spectra of the horizontal components and the spectrum of the vertical component, which has proven to be a convenient technique to estimate the fundamental frequency of soft deposits (e.g. Lermo & Chavez-Garcia, 1994). Another method is the Noise Cross-correlation Function (NCF) based on the cross correlation of simultaneous noise recordings at two sites, which allows to recover surface wave dispersion (Green function) over the site distance.

4.1 Single station

If V_S models representative of average geological structures are available, the measured main peak of the average H/V spectral ratios is in agreement with the ellipticity computed, from the models, of the fundamental mode Rayleigh wave (Nunziata, 2007). The ellipticity at each frequency is defined as the ratio between the horizontal and vertical displacement

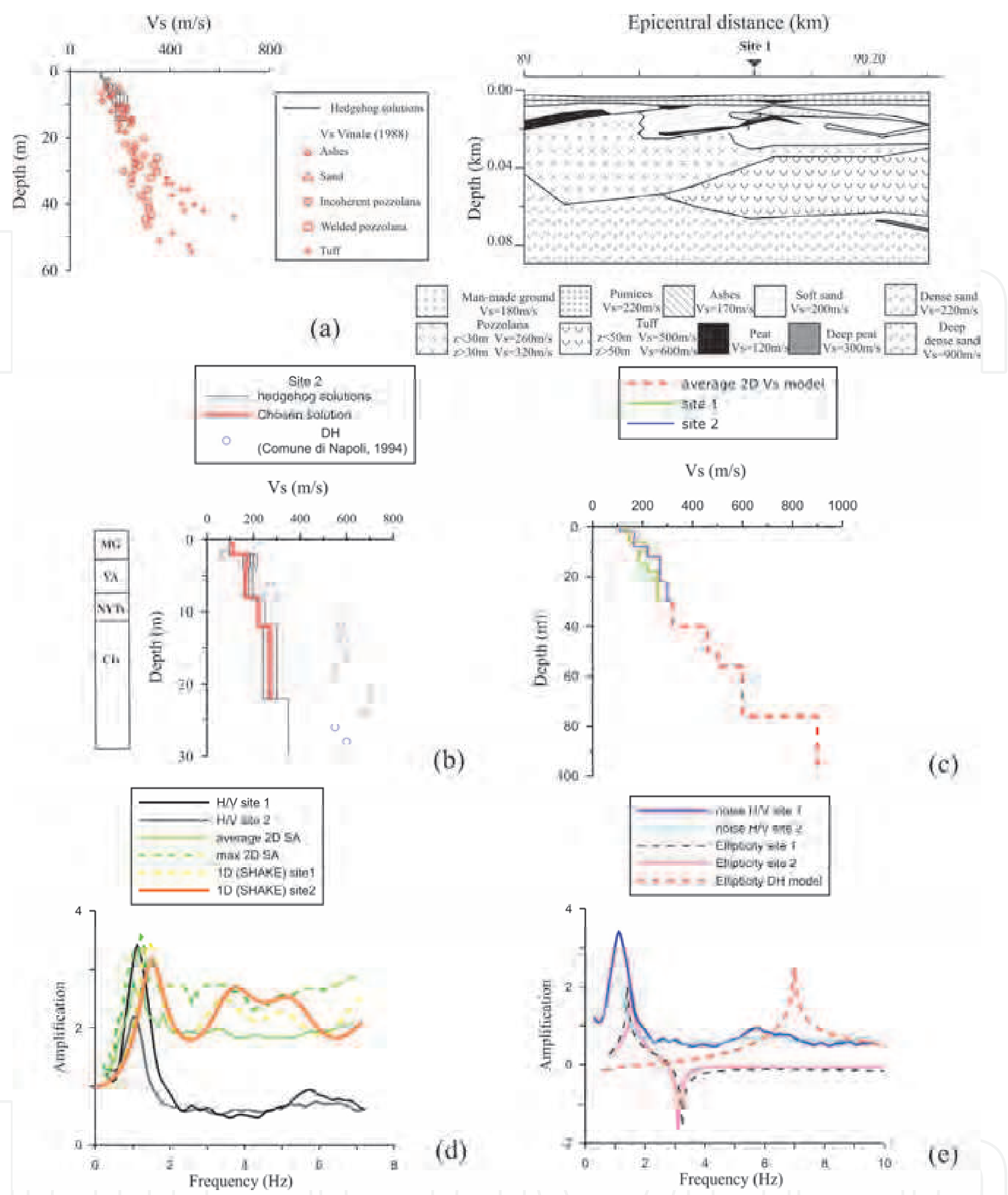

Fig. 6. Interpretation of noise H/V ratio at Napoli (zone 6 in Fig. 3). (a) Geological cross section representative of site 1 and shear velocities of the soils assigned based on Hedgehog solutions and DH and CH measurements. (b) Comparison between DH V_S measurements (circles) and the velocity range defined from the Hedgehog non-linear inversion of FTAN measurements at site 2. Legend: MG=Man made Ground; VA=Vesuvius Ashes; NYTs=Neapolitan Yellow Tuff (soil facies); CIs=Campanian Ignimbrite (soil facies). (c) V_S models (chosen Hedgehog solutions) at sites 1 and 2. At depths greater than 30m, V_S have been attributed on average DH-CH measurements (Vinale, 1988) as shown in (a). (d) Noise H/V ratios, synthetic 2D (hybrid method along the cross section in (a)) and 1D (SHAKE program) spectral amplifications at sites 1 and 2. 1D amplification computed for the DH velocity profile nearby site 2 is also shown. (e) Noise H/V ratios and logarithm of ellipticity absolute values computed for the V_S profiles shown in (c) and the DH velocity profile in (b).

eigenfunctions in the P-SV case, at the free surface. The ellipticity of the fundamental mode of Rayleigh waves computed for the V_S velocity models obtained by FTAN-Hedgehog methods, integrated at greater depths, down to the seismic bedrock, both by geological information and eventual down- and cross-hole measurements, has been compared with the ambient noise H/V ratio (Nunziata, 2007). The interpretation of noise measurements, carried out with Kinemetrics Quanterra Q330 station and a 3 component Episensor broadband sensor, has been also done through the comparison with the computed SH wave spectral amplifications, both 2D (Nunziata, 2004) and simplified 1D with SHAKE program (Schnabel et al., 1972).

As an example, we show the interpretation of noise measurements performed at two sites, 2km apart, at Poggioreale quarter, zone 6 (Figs. 6 a-e). Site 1 is located at the Centro Direzionale area with many skyscrapers built after 1980 earthquake and very detailed geological and geophysical information. The area was a marsh recently drained both for urban development and for the reduction of water supply. The subsoil is mainly formed by man-made ground, alluvial soils (ashes, sands, peat), loose and slightly cemented pozzolanas, NYT tuff and marine sands (Fig. 6a). Taking into account several DH and CH measurements, a good agreement has resulted with FTAN measurements and it has been possible to attribute V_S velocities at depths greater than 30m along a cross section through noise measurement site 1 (Nunziata, 2004 and references therein).

Instead, at site 2, strong discrepancy resulted between the V_S profiles vs depth obtained with FTAN-Hedgehog methods and the Down-hole measurements (Comune di Napoli, 1994) in a nearby drilling, despite the very good agreement between the representative Hedgehog solutions at the two sites since peat is characterized by similar velocities of host pyroclastics (Fig. 6b). At greater depth, average velocities increasing from 320 m/s, typical of tuff soils, up to 900 m/s, at 76m of depth, have been assigned on the basis of DH and CH measurements in the nearby Centro Direzionale (Fig. 6c). Hence, the seismic cross section through site 1 can be considered representative of site 2 as well. Two-dimensional spectral amplifications (5% damping) computed along the cross section are characterized by main peaks at about 1 Hz for the transverse component. H/V noise measurements show a good agreement with the average and maximum 2D spectral amplifications, while 1D amplifications have the first main peak at frequencies a little bit higher than H/V noise (Fig. 6d). Instead, the 1D amplification computed for the V_S profile measured in the drilling close to site 2 has a very high frequency content with the main peak at about 7 Hz. Agreement is also observed between H/V noise and ellipticity computed for the V_S models attributed at sites 1 and 2 as shown in Fig. 6c (Fig. 6e), whereas ellipticity computed for DH velocity profile has a peak at very high frequency (about 7 Hz).

4.2 Two stations

Cross correlations of long time series of ambient seismic noise have been demonstrated to recover surface wave dispersion (Green function) over a broad range of distances, from a few hundred meters to several hundred Kilometers (e.g. De Nisco & Nunziata, 2011 and references therein). This approach is based on earlier theoretical studies after Weaver and Lobkis (2001), who demonstrated that the cross correlation of a diffuse wavefield is related to local transient response. A diffuse field Φ in a finite body, in the point *x* at the time *t*, may be expressed as:

$$\Phi(x,t) = \Re \sum_{n=1}^{\infty} a_n u_n(x) \exp\{i\omega_n t\} \tag{1}$$

Where a_n are the complex modal amplitudes and u_n the real orthogonal mode shapes and $\Re$ indicates the real part of a complex quantity.
The cross correlation of the diffuse field at points x and y is:

$$\left\langle \Phi(x,t)\Phi(y,t+\tau)\right\rangle = \frac{1}{2}\Re\sum_{n=1}^{\infty}F(\omega_n)\ u_n(x)\ u_n(y)\exp\{-i\omega_n\tau\} \tag{2}$$

If F is almost constant, i.e. $F(\omega)\simeq$const, it turns out that the cross correlation is equivalent to the time derivative of the Green's function of the medium between x and y:

$$G_{xy}(\tau) = \sum_{n=1}^{\infty}u_n(x)\ u_n(y)\ \frac{\sin\omega_n\tau}{\omega_n} \qquad (\text{for } \tau > 0,\ \text{otherwise } 0) \tag{3}$$

The basic idea of the method is that a time-average cross correlation of a random, isotropic wavefield computed between a pair of receivers will result in a waveform that differs only by an amplitude factor from the Green function between the receivers. Ambient seismic noise can be considered as a random and isotropic wavefield both because the distribution of the ambient sources responsible for the noise randomizes when averaged over long times and because of scattering from heterogeneities that occur within the Earth. Several researchers have used the noise cross correlation instead of the time derivative (e.g. Campillo & Paul, 2003; Shapiro & Campillo, 2004). This assumption is acceptable from the ambient noise recorded on broadband seismic stations, typically with relatively small bandwidth, being the difference between the cross correlation and its derivative a phase shift.
The assertion that the impulse response (Green's function) can be retrieved from cross correlation of the diffused fields (noise) in two receiving points is based on the time-reversal symmetry of the Green's function (Derode et al., 2003). Thus, for a perfectly homogeneous distribution of sources surrounding the two points, fully immersed in the scattering medium, the exact impulse response can be recovered from either the causal (t>0) or the anticausal (t<0) part of the cross correlation stacked for all sources, that is the cross correlation is symmetric. However, considerable asymmetry in amplitude and spectral content is typically observed, which indicates differences in both the source process and distance to the source in the directions radially away from the stations (Larose et al., 2004; Bensen et al., 2007). Yet, in the seismic experiments described by Campillo and Paul (2003) and Sabra et al. (2005), the Green's function was reconstructed from one-sided cross correlation because of a preferential direction. Many authors, using the spatial reciprocity of the Green's functions (De Nisco & Nunziata, 2011 and references therein), average positive and negative parts of NCF and impose symmetry. In most cases, this procedure enhances the signal to noise ratio (SNR) and effectively mixes the signals coming from opposite directions, which helps to homogenize the source distribution. If the signature of the Green function is recognized in only one part of the NCF or if there is a large time shift between the positive and negative part, seismic noise could have a preferred orientation source, and it is not possible to design the geometry of the array so that correct wave velocity can be computed. If the possible preferred orientation source is identified and the array is installed perpendicular to it, the Green function is obviously seen only in one part of NCF.
Experiments of noise cross correlation have been successfully conducted at Napoli over distances ranging from 50 m to about 4 km (Fig. 7). Two broadband Kinematrics Quanterra

Q330 stations equipped with 3-component Episensor broadband FBA (Force Balance Accelerometer) sensors have been employed.

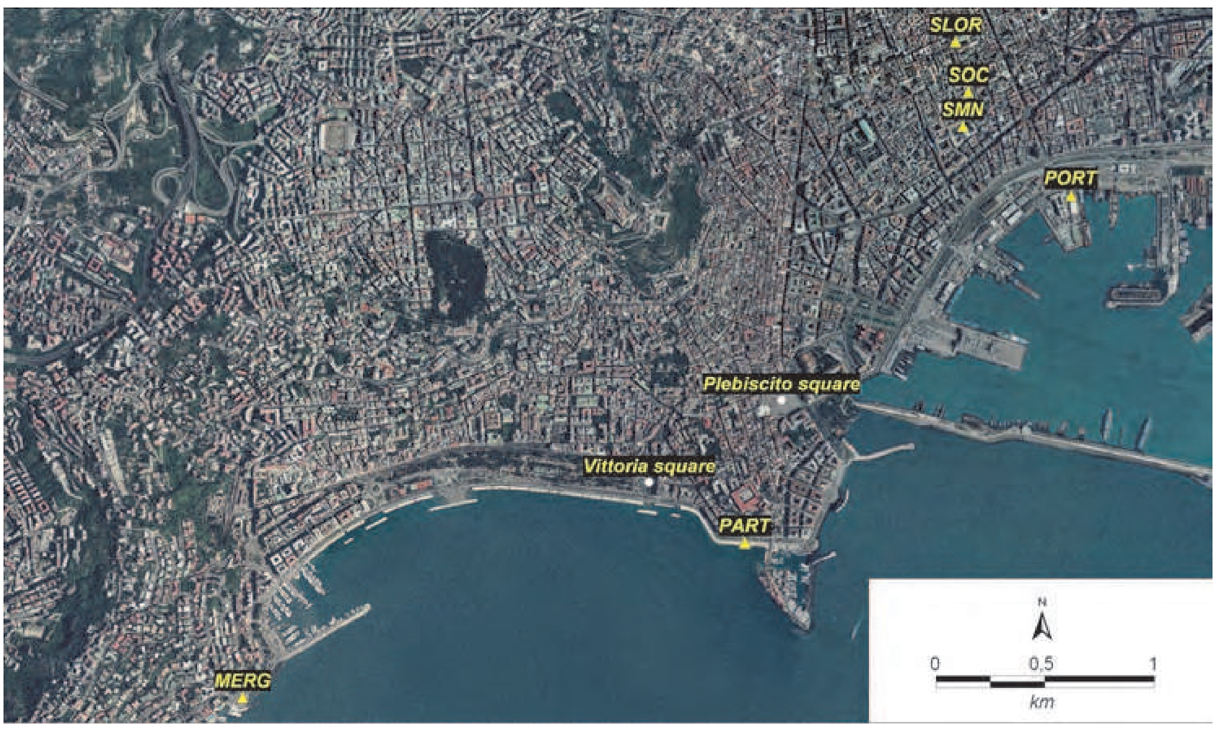

Fig. 7. Location of the seismic stations employed in the cross correlation experiments at the urban area of Napoli.

4.2.1 Signal analysis

The analysis of noise cross correlation consists of the steps that are illustrated in Figure 8 and refer to measurements at 4 km receiver spacing (path MERG-PORT located in Fig. 7). A one-bit normalization is applied to the vertical components of the recorded noise (Fig. 8A), which retains only the sign of the raw signal by replacing all positive amplitudes with a 1 and all negative amplitudes with a −1, in order to increase the signal-to-noise ratio. After average removal, power spectra are evaluated to discern the frequency band of interest (Fig. 8B). Signals are iteratively band-pass filtered (Butterworth filters) to enhance the dispersed wave trains in the cross correlation (Fig. 8C). The cross correlations are computed and then stacked with the Seismic Analysis Code (SAC) (Goldstein et al., 2003). One-sided cross correlations have generally resulted indicating differences in both the source process and distance to the source in the directions radially away from the stations (Larose et al., 2004; Bensen et al., 2007), or the presence of a preferential direction (Campillo & Paul, 2003; Sabra et al., 2005). Then FTAN analysis is performed to extract the fundamental mode of Rayleigh waves (Figs. 8 D-E).

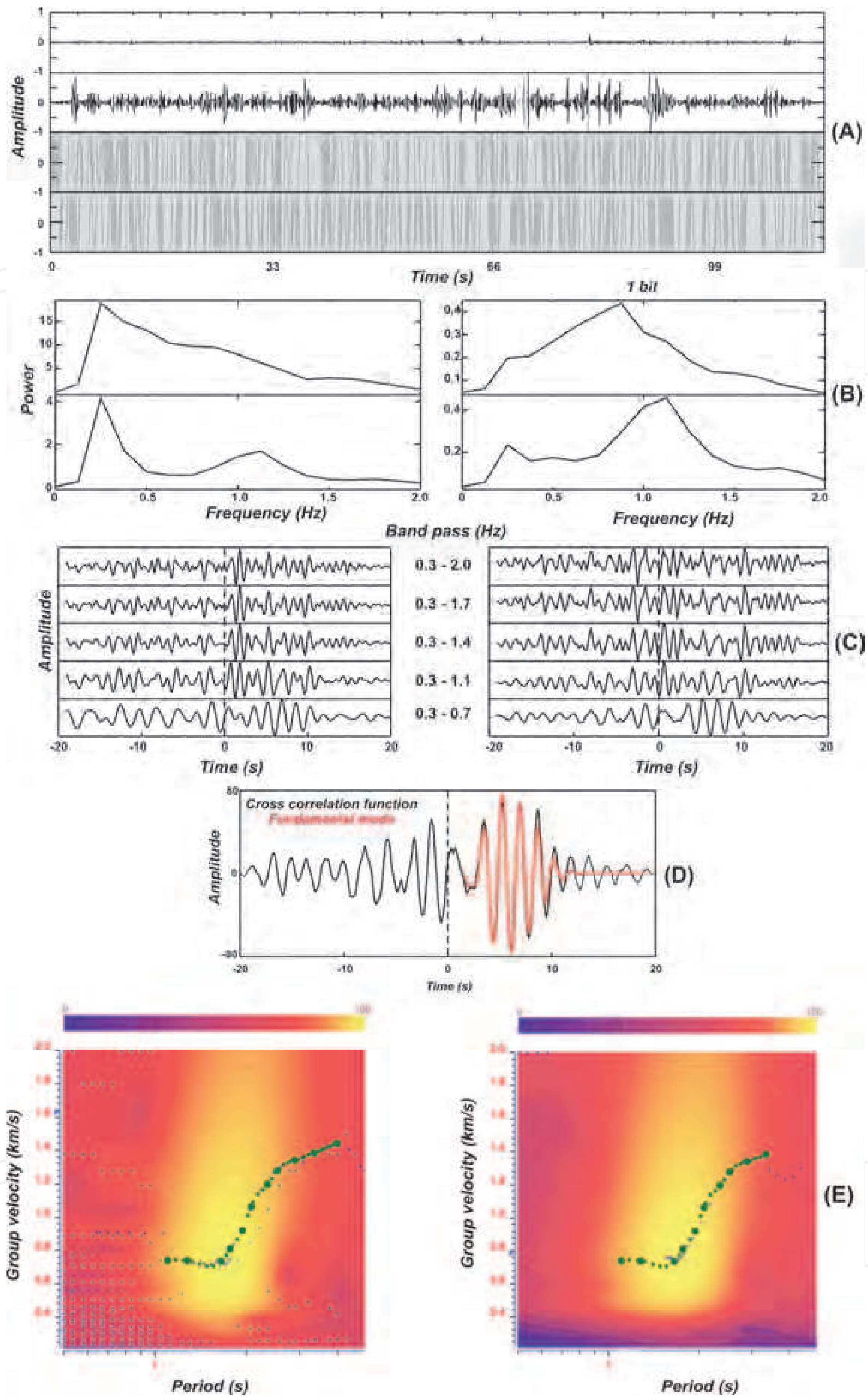

Fig. 8. Example of NCF analysis: (A) noise recordings with 1 Hz vertical geophones 4 km apart (1 and 2 receivers) at Mergellina (MERG) and harbour (PORT) (located in Fig. 7) and 1-bit normalized signals; (B) power spectra of noise recordings (on the left) and 1-bit normalized signals (on the right); (C) cross correlation of signals shown in (A) and band-pass filtered; (D) Cross correlation of 1-Bit 0.3-0.7 Hz band-pass filtered signals and the fundamental mode Green function extracted with FTAN method (red line). (E) Raw and cleaned FTAN maps of the cross correlation [bottom of (C)].

Three experiments have been conducted at the historical centre of Napoli (SMN, SOC and SLOR in Fig. 7) being one (SMN), permanently installed and continuously recording at the rock foundations of the SS. Marcellino and Festo monumental complex (www.geosism.unina.it). The other Q330 station was mobile and recorded ambient noise, for at least 1 hour, using a 100-Hz sampling frequency, at S. Lorenzo Maggiore basilica (SLOR) and the Sociology Faculty of University (SOC). The SMN-SOC and SMN-SLOR distances are 260 m and 400 m, respectively.

The retrieved V_S models (shown along the SMN-SLOR in Fig. 9) clearly show at 20-35 m below ground level a V_S increase to about 600 m/s. According to stratigraphies and velocity ranges for NYT tuff (Fig. 4), it can be argued that such V_S values are consistent with the presence of altered NYT tuff, typically found on the top of compact tuff and called "cappellaccio". Compact NYT tuff (V_S of about 800 m/s) is found 10-15 m deeper. The average thickness of the NYT tuff formation is 50m. At greater depth, a further increment of V_S is observed, to 970 m/s at 70-150 m of depth. This V_S distribution versus depth is very consistent with the stratigraphy of a deep borehole (400 m) drilled in the Plebiscito square, in front of the Royal Palace, and close to the investigated area. In fact, in the shallower 160 m, layers of NYT tuff, 80 m thick, and Whitish tuff, 80 m thick, were found. Then an important stratigraphic result can be deduced: the thickening of the NYT tuff layer moving towards west, that is in the direction of the eruptive centre (Nunziata et al., 2009).

Another experiment has been performed at the Partenope street (PART in Fig. 7), with highly chaotic traffic, by noise recordings with a 24 bit Geometrics StrataVisor seismograph and 1 Hz vertical geophones (Geospace GS-1), along a spreading with geophone distance of 180 m. The V_S distribution vs. depth is very consistent with the stratigraphy of a deep borehole at Vittoria square (Fig. 7), close to the investigated area (Fig. 10). It turns out that the investigated area is characterized by fractured and compact tuffs below a shallow layer of man made ground material, laid to construct and protect the street from sea actions.

Very recently, a further experiment has been performed over a distance of 4 km in order to define the thickness of the tuff cover. Two 24 bit digital tromographs with a wide frequency range (0.1-200 Hz) have simultaneously recorded noise for 1 hour at Mergellina (MERG) and harbour (PORT) (for their location see Fig. 7). The results are very important as, for the first time, structures have been defined below Napoli at 2 km of depth (Fig. 11). The obtained V_S models are in agreement with V_S velocities obtained by Nunziata (2010) along the Vesuvio-Campi Flegrei path, crossing Napoli and its gulf. The agreement with the data relative to Mofete (Campi Flegrei) drillings, that is V_S computed from V_P sonic log measurements (AGIP, 1987) by assuming a reasonable V_P/V_S ratio of 1.8, and ultrasonic measurements on saturated specimens (Zamora et al., 1994) is quite impressive and the following interpretative structural model can be formulated.

The first 0.5 km consists of tuffs while tuffs and tuffites are present at 0.5-1.2 km depth; tuffs and tuffites with lava interbedding, probably thermometamorphic, might be present at depths of 1.2-2 km. At these depths, both the agreement with ultrasonic velocity measured on a conglomerate sample (Bernard & Zamora, 2003) and the stratigraphy at Plebiscito square (Fig. 9), suggest that the presence of highly fractured sedimentary rocks cannot be escluded. The compact sedimentary horizon, with a V_S of 3.6-3.7 km/s, has been found below the Neapolitan area at about 3 km of depth (Nunziata, 2010).

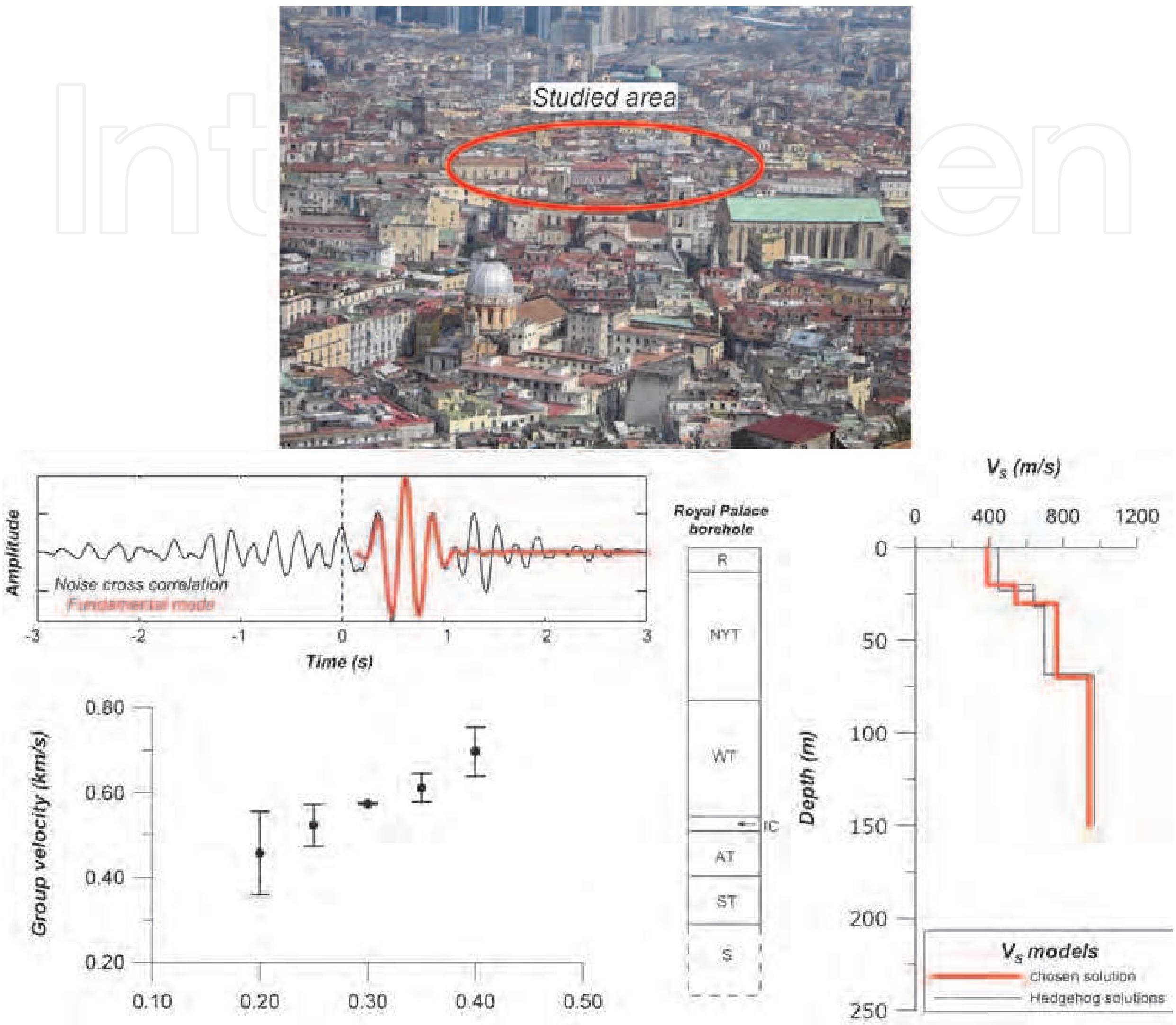

Fig. 9. The V_S solutions and the chosen solution (red line) for SMN-SLOR path obtained from the non-linear inversion with Hedgehog method of the average dispersion curve of the fundamental mode, with error bars, are compared with the stratigraphy of the deep drilling at Plebiscito square (located in Fig. 6). Legend: R=man made ground material and recent pyroclastic deposits; NYT=Neapolitan Yellow Tuff; WT=Whitish tuff; IC= Campanian Ignimbrite; AT= Ancient Tuffs; ST= Tuffs and sedimentary rocks; S= Sedimentary rocks. The cross correlation of 1-Bit 3-6 Hz band-pass filtered signals and the fundamental mode Green function extracted with FTAN method (red line) are also shown.

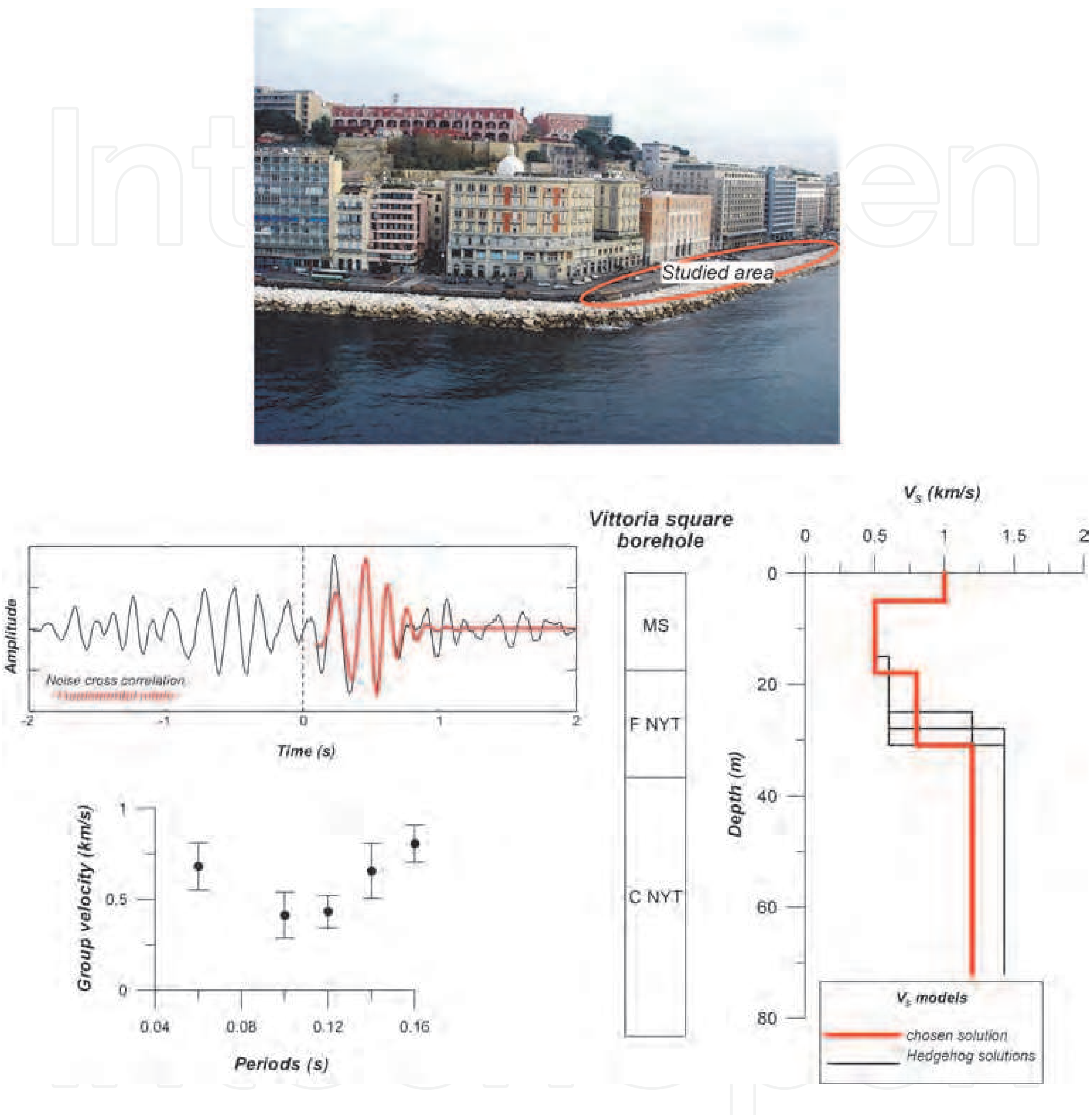

Fig. 10. The V_S solutions and the chosen solution (red line) for the spreading at Partenope st. with geophone distance of 180 m. The statigraphy is relative to Vittoria square borehole (located in Fig. 7). The photo of the investigated area, the cross correlation of 1-Bit 6-25 Hz band-pass filtered signals, the fundamental mode Green function extracted with FTAN method (red line), and average dispersion curve of the fundamental mode, with error bars, are also shown. Legend: MS = Marine sands; F NYT = Fractured Neapolitan Yellow Tuff; C NYT = Compact Neapolitan Yellow Tuff.

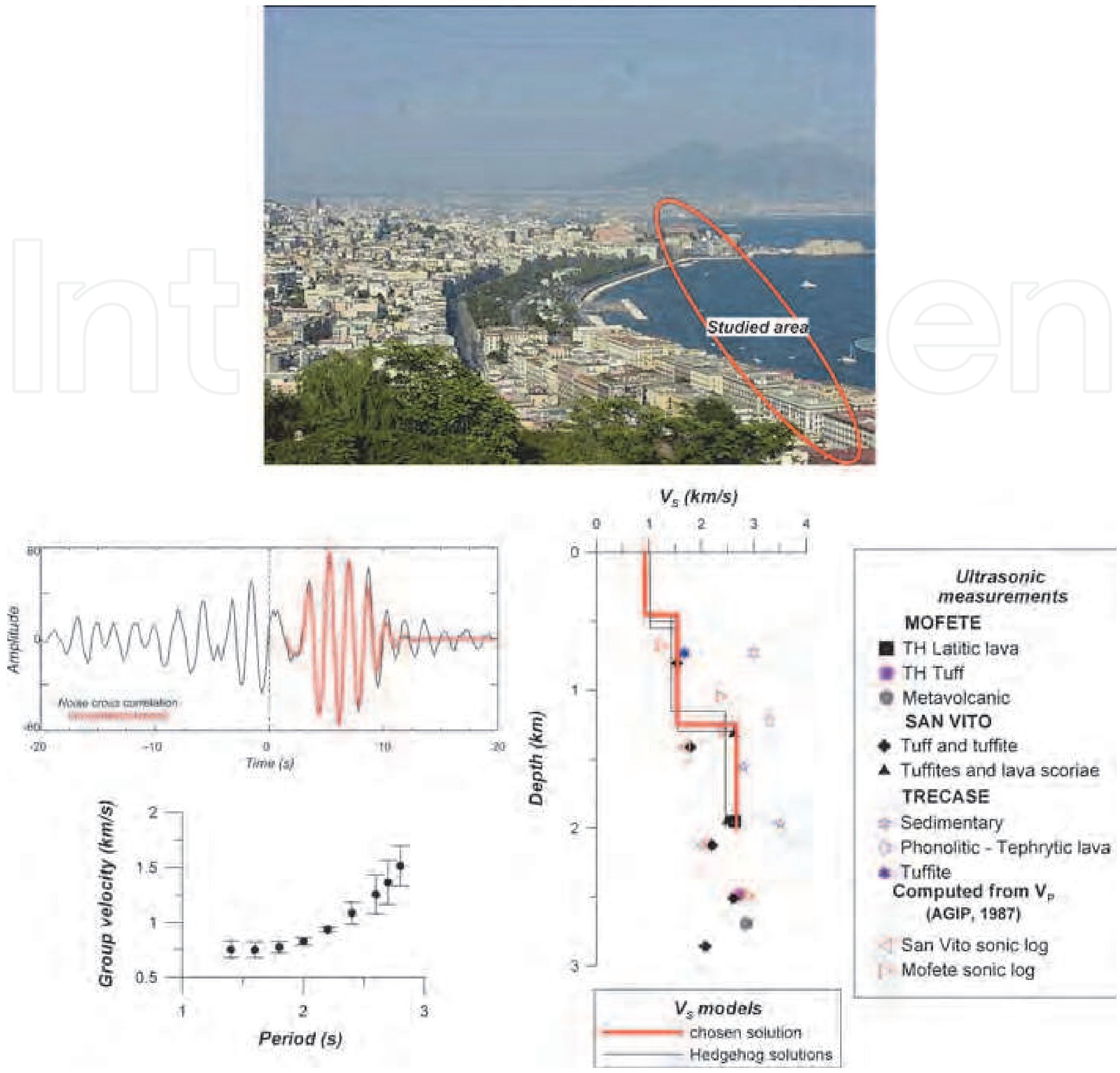

Fig. 11. The V_S solutions and the chosen solution (red line) for the MERG-PORT path (Fig. 7) are shown together with the average dispersion curve of the fundamental mode, with error bars, and comparison between 1-Bit 0.3-0.7 Hz band-pass filtered signals cross correlation and the fundamental mode Green function extracted with FTAN method (red line). Ultrasonic measurements on specimens from Campi Flegrei (Zamora et al., 1994) and Vesuvio (Trecase drilling) (Bernard & Zamora, 2003) are reported together with V_S values computed from V_P sonic log measurements (AGIP, 1987).

5. Conclusions

The results obtained in Napoli metropolitan area, with the non linear inversion of Rayleigh wave group velocity dispersion curve of the fundamental mode extracted with FTAN method from both active seismic surveys and noise cross correlation, show that the procedure is a powerful and reliable instrument to get V_S profiles versus depth in urban areas. The proposed methodology is low cost, as one (active experiments) or two (passive experiments) receivers are requested on ground surface and is particularly suitable for urban areas as doesn't require spreadings. The depth of penetration is mainly controlled by the distance and the soil velocities.

A new intriguing prospective is open by noise cross correlation as deep structures can be investigated in absence of specific energy sources. This is promising in terms of both seismic zoning and, even more, of volcanological zoning as stratigraphies can be reconstructed whereas they would be blind because of unaccessible outcrops in densely urbanized areas. Stratigraphic correlations can be assessed and used for volcanic hazard scenarios.

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7. References

AGIP, 1987. Geologia e geofisica del sistema geotermico dei Campi Flegrei. Internal Report, pp. 17.

Bensen, G.D.; Ritzwoller, M.H.; Barmin, M.P.; Levshin, A.L.; Lin, F.; Moschetti, M.P.; Shapiro, N.M. & Yang, Y. (2007). Processing seismic ambient noise data to obtain reliable broad-band surface wave dispersion measurements. *Geophysical Journal International* No.169, pp. 1239-1260.

Bernard, M. L. & Zamora, M. (2003). Mechanical properties of volcanic rocks and their relations to transport properties, In the CD of: *The internal structure of Mt. Vesuvius*, P. Capuano, P. Gasparini, A. Zollo, J. Virieux, R. Casale & M. Yeroyanni (Eds)., Liguori Editore.

Boyadzhiev, G.; Brandmayr, E.; Pinat, T. & Panza, G.F. (2008). Optimization for non-linear inverse problems. *Rendiconti Lincei,* Vol.19, No.2, pp. 209.

Campillo, M. & Paul, A., (2003). Long-Range Correlations in the Diffuse Seismic Coda. *Science*, Vol. 299, No. 5606, pp. 547-549.

Comune di Napoli (1994). Indagini geologiche per l'adeguamento del P.R.G. alla legge regionale 07.01.1983 n. 9 in difesa del territorio dal rischio sismico.

De Nisco G. & Nunziata, C., (2011). V_S profiles from noise cross correlation at local and small scale. *Pure and Applied Geophysics*, Vol.168, No.3-4, pp. 509-520.

Derode, A., Larose, E., Tanter, M., de Rosny, J., Tourim, A., Campillo, & M., Fink, M. (2003). Recovering the Green's function from field–field correlations in an open scattering medium. *Journal of the Acoustical Society of America,* Vol.113, pp. 2973–2976.

Goldstein, P.; D. Dodge; M. Firpo & L. Minner, 2003. SAC2000: Signal processing and analysis tools for seismologists and engineers, In: *International Handbook of Earthquake and Engineering Seismology*, W.H.K. Lee; H. Kanamori; P.C. Jennings; & C. Kisslinger (Eds.), Academic Press, London, United Kingdom.

Larose, E.; Derode, A. ; Campillo, M. & Fink, M. (2004). Imaging from one-bit correlations of wideband diffuse wavefields. *Journal of Applied Physics*, Vol.95, pp. 8393–8399.

Lermo, J. & Chávez-García, F. J. (1994). Are microtremors useful in site response evaluation?. *Bulletin of the Seismological Society of America*, Vol.84, No.5, pp. 1350-1364.

Keilis-Borok V. I. (1989). *Seismic Surface Waves in a Laterally Inhomogeneous Earth,* Springer.

Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, *QR of RTRI,* Vol.30, pp. 25-33.

Nunziata, C.; Costa G.; Natale, M.; Vuan, A. & Panza, G.F. (1999). Shear wave velocities and attenuation from Rayleigh waves, In: *Pre-failure Deformation Characteristics of Geomaterials*, 365-370, Balkema.

Nunziata, C. (2004). Seismic ground motion in Napoli for the 1980 Irpinia earthquake. *Pure and Applied Geophysics*, Vol.161, No.5/6, pp. 1239-1264.

Nunziata, C.; Natale, M. & Panza, G.F. (2004). Seismic characterization of neapolitan soils. *Pure and Applied Geophysics*, Vol.161, No.5-6, pp. 1285-1300.

Nunziata, C. (2005). FTAN method for detailed shallow V_S profiles. Geologia *Journal of technical & environmental geology*, No.3, pp. 25-43, Available from www.consiglionazionalegeologi.it.

Nunziata, C. (2007). A physically sound way of using noise measurements in seismic microzonation, applied to the urban area of Napoli. *Engineering Geology*, Vol.93, No. 1-2, pp. 17-30.

Nunziata, C.; De Nisco, G. & Panza, G.F. (2009). S-waves profiles from noise cross correlation at small scale. *Engineering Geology*, 105, No.3-4, pp. 161-170.

Nunziata, C. (2010). Low shear-velocity zone in the Neapolitan-area crust between the Campi Flegrei and Vesuvio volcanic areas. *Terra Nova,* Vol.22, No.3, pp. 208-217.

Nunziata C.; Sacco C. & Panza G.F. 2011. Modeling of ground motion at Napoli for the 1688 scenario earthquake. *Pure and Applied Geophysics,* Vol.168, No.3-4, pp. 495-508.

Panza G.F. (1981). The resolving power of seismic surface wave with respect to crust and upper mantle structural models, In: *The solution of the inverse problem in Geophysical Interpretation*, R. Cassinis (Ed.), 39-77, Plenum Press, New York, USA.

Panza, G.F.; Romanelli, F. & Vaccari, F. (2001). Seismic wave propagation in laterally heterogeneous anelastic media: theory and applications to the seismic zonation. *Advances in Geophysics,* Vol.43, pp. 1-95.

Panza, G. F.; Peccerillo, A.; Aoudia; A. & Farina, B. 2007. Geophysical and petrological modelling of the structure and composition of the crust and upper mantle in complex of geodynamic setting: The Thyrrenian Sea and surrounding. *Earth-Science Reviews,* Vol.80, pp. 1-46.

Sabra, K. G.; Gerstoft, P.; Roux, P. & Kuperman, W.A. (2005). Extracting time-domain Green's function estimates from ambient seismic noise. *Geophysical Research Letters,* Vol.32, No.2 L03310.

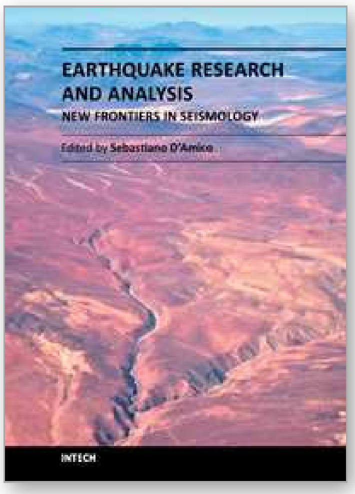
Schnabel B.; Lysmer J. & Seed H., 1972. *Shake: a computer program for earthquake response analysis of horizontally layered sites,* E.E.R.C. 72/12, Earthquake Engineering Research Center, University of California, Berkeley, USA.

Shapiro, N.M & Campillo, M. (2004). Emergence of broadband Rayleigh waves from correlations of the ambient seismic noise. *Geophysical Research Letters* Vol.31, L07614.

Vinale, F. (1988). Caratterizzazione del sottosuolo di un'area campione di Napoli ai fini di una microzonazione sismica. *Rivista Italiana di Geotecnica,* Vol.22, pp. 77-100.

Zamora, M.; Sartoris, G. & Chelini, W. (1994). Laboratory measurements of ultrasonic wave velocities in rocks from the Campi Flegrei volcanic system and their relation to other field data. *Journal of Geophysical Research*, Vol.99 pp. 13553–13561.

Weaver, R. L. & Lobkis, O. I. (2001). On the emergence of the Green's function in the correlations of a diffuse field*Journal of the Acoustical Society of America,* Vol.110, pp. 3011-3017.



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The study of earthquakes combines science, technology and expertise in infrastructure and engineering in an effort to minimize human and material losses when their occurrence is inevitable. This book is devoted to various aspects of earthquake research and analysis, from theoretical advances to practical applications. Different sections are dedicated to ground motion studies and seismic site characterization, with regard to mitigation of the risk from earthquake and ensuring the safety of the buildings under earthquake loading. The ultimate goal of the book is to encourage discussions and future research to improve hazard assessments, dissemination of earthquake engineering data and, ultimately, the seismic provisions of building codes.