FUNDAMENTAL PERIOD OF BUILDINGS, SEISMIC SITE RESPONSE AND IMPLICATIONS ON EARTHQUAKE SEISMIC ACTION DEFINITION IN THE SIRACUSA AREA, ITALY

F. Panzera[1,3], S. D'Amico[2], G. Lombardo[3], E. Longo[3]

[1] Icelandic Met Office, Reykjavík, Iceland; [2] Physics Department - University of Malta, Msida, Malta; [3] Dipartimento di Scienze Biologiche, Geologiche e Ambientali - Università di Catania, Italy

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Introduction

The grade of building damage and its distribution during an earthquake is due to the combined effect of local site response and the dynamic features of the structures. A seismic hazard assessment (SHA), in major urban areas of south eastern Sicily, has been recently performed by several authors (Faccioli & Pessina 2000; Barbano et al. 2001; Panzera et al. 2011a; Panzera et al. 2011b), taking into account different seismic sources of the major historical earthquakes that struck the area. The seismic action on buildings is strongly dependent on their dynamic characteristics as well as on their fundamental vibration period and the engineering practice usually derives the dynamic behaviour of buildings through numerical or experimental methods. The results achieve empirical relationships that let the estimate of building resonant period as a function of either the height or the number of floors.

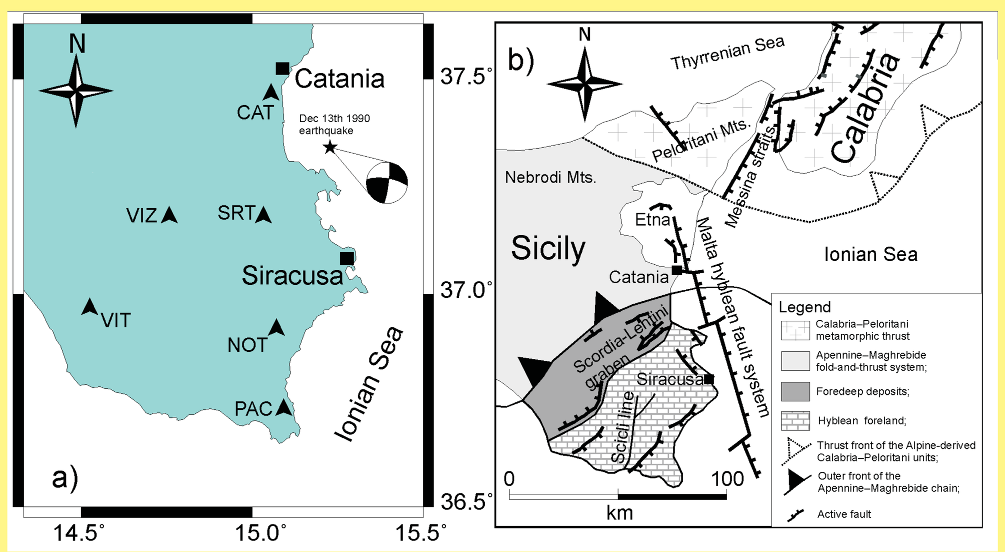

Fig. 1 - a) Recording stations and 1990 earthquake source; b) Structural map of Eastern Sicily.

Present research aims to highlight the areas in which major seismic site effects can occur as a function of the outcropping lithology. Evaluation of the dynamic response of buildings is estimated through experimental measurements based on microtremor recordings, and a deterministic study aiming to evaluate the seismic ground motion expected in the Siracusa urban area, is also performed.

Geology, Tectonics and Seismicity of the study area

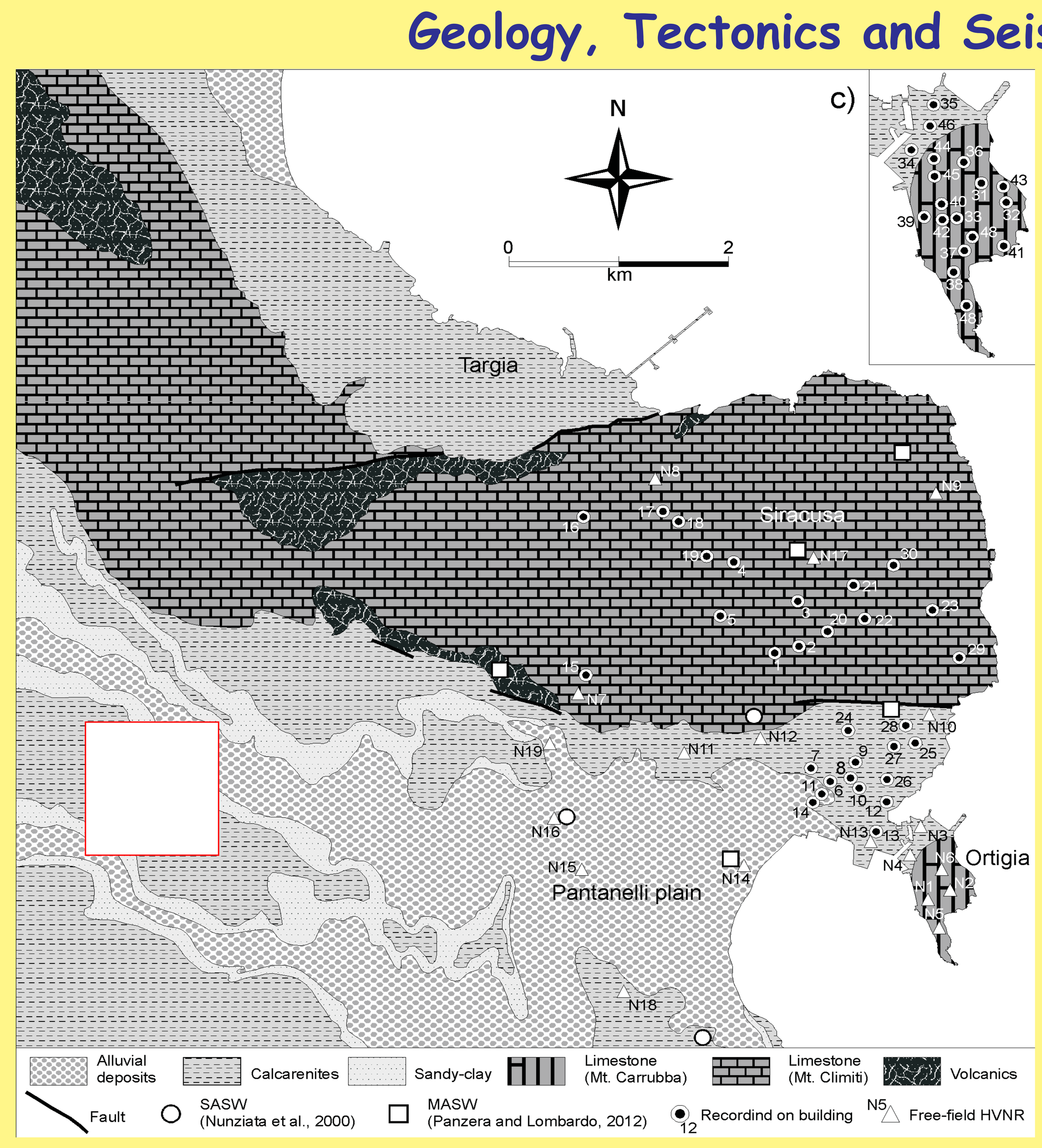

Fig. 1 - c) Geolithologic map of Siracusa urban area.

The town of Siracusa is located in the Hyblean foreland (see Fig. 1b). At regional scale, the tectonics of south eastern Sicily is characterized by a NE-SW striking normal fault system, located inland (Scicli line) and the Malta-Hyblean escarpment, trending NW-SE, located offshore in the Ionian sea (Fig. 1b). Seismotectonic information and interpretations available suggest that both fault systems can be identified as possible sources for the seismic activity that affected in historical time the town of Siracusa. In any case, relations between the main offshore fault segments and the historical earthquakes coupled with tsunamis occurring in this region suggests that the Malta–Hyblean Escarpment represents one of the major seismogenic sources of the whole southern Italy (Monaco & Tortorici 2007). In the study area the substratum outline a horst structure formed by a Meso-Cenozoic carbonate sequence with interbedded volcanics (Grasso and Lentini, 1982) cropping out in the northern part of Siracusa (Fig. 1c). The Cretaceous volcanics, having thickness up to 500 m, locally represent the deepest term. Such sequence, in some sites is directly overlaid by sub-horizontal poorly consolidated calcarenites up to 20 m thick whereas, in the southern part of the study area, sands and sandy clays, up to 20 m thick, overlay the bedrock. Finally, alluvial deposits fill out the graben of the "Pantanelli" plain (see Fig. 1c) whilst detritus, having thickness of about 6-8 m due to anthropic activity and historical ruins, is mainly outcropping in the downtown Ortigia area.

The area is affected by a moderate seismicity. However, the potentially most hazardous event, witnessed by the seismic history of the area, is represented by an earthquake that occurred in 1693 that reached a MW of 7.4 (Rovida et al. 2011). The most important moderate size instrumental seismic event occurred in south eastern Sicily on December 13th 1990. Although its moderate magnitude (MW=5.68), it caused the collapse of a few buildings and it was felt throughout Sicily with a maximum seismic intensity of VII-VIII (Locati et al. 2011). This event shows a dominant right-lateral strike slip solution (Amato et al. 1995) and appears to be located along a 5 km long transverse segment separating two sub-parallel segments of the Malta-Hyblean fault scarp.

Evaluation of Building Dynamic Properties

The seismic performance of a building obviously depends on the progression of the frequencies along the input time-history, nevertheless the knowledge of its fundamental frequency at low amplitude values and the associated damping are of primary importance to characterize the initial seismic behaviour of a structure. In the present study, the horizontal to vertical noise ratio (HVNR) and the standard noise spectral ratio (SSNR) techniques were used to identify the building's frequencies. Measurements were performed in 48 buildings distinguished according to their construction typology 20 masonry buildings (MA) and 30 reinforced concrete (RC) edifices (see examples in Fig. 2). The fundamental period of the building is obtained by computing the ratio between the amplitudes of the Fourier spectrum of horizontal (longitudinal and transverse) components recorded on the top floor and the same components registered on the ground floor (Parolai et al. 2005) to observe the influence of the geometry. Ambient noise was recorded using a three-component velocimeter (Tromino) sampling the signal at a frequency of 128 Hz. The damping ratio was computed using the nonparametric analysis (NonPaDAn) Matlab routine (Mucciarelli & Gallipoli, 2007). The fundamental period and damping experimentally obtained through noise measurements were also compared with the ones obtained by empirical formulas that calculate the fundamental period as a function of the buildings geometry and the damping versus period (Table 1).

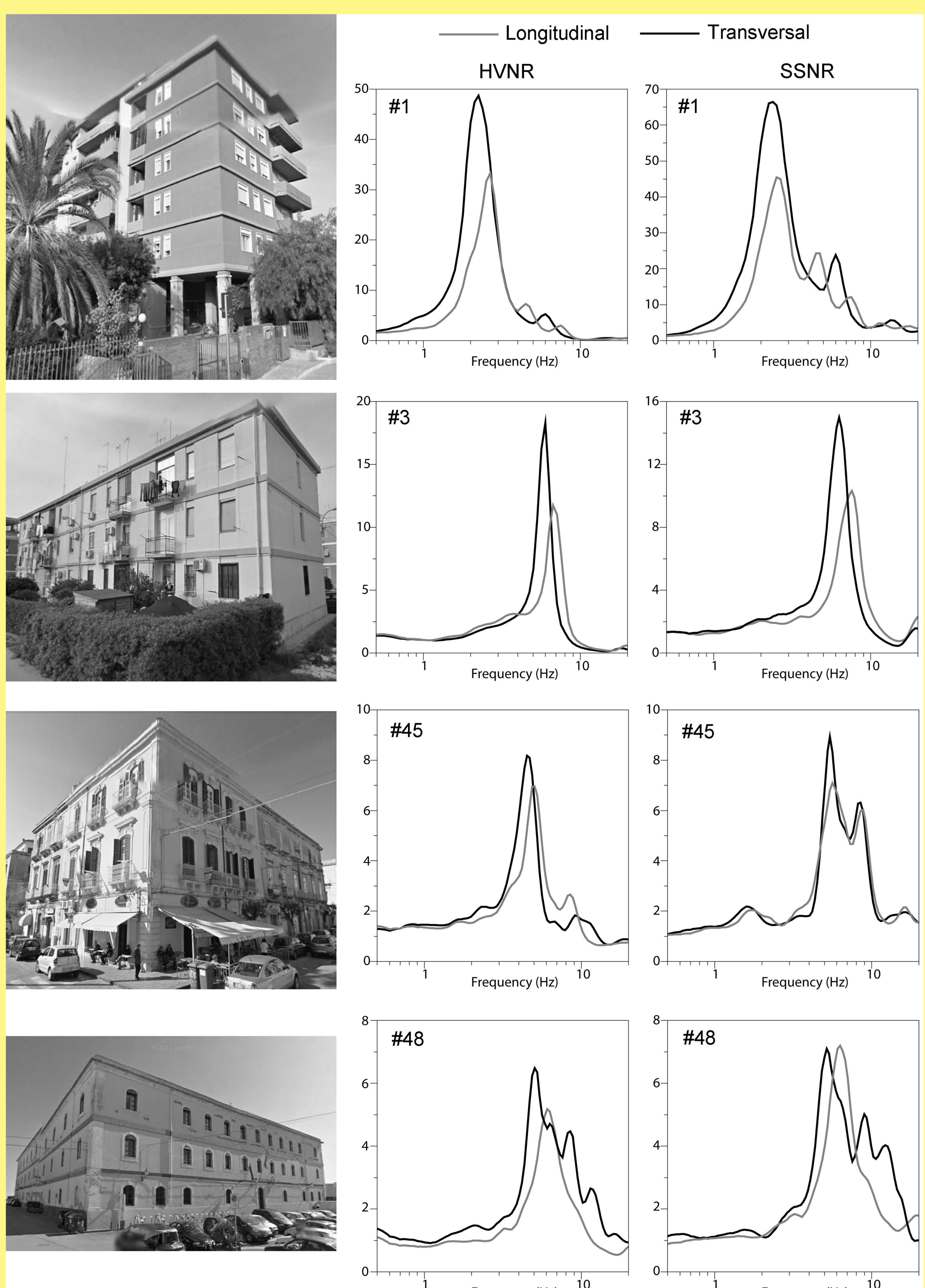

Fig. 2 - Examples of HVNR and SSNR in RC and MA buildings

Table 1

Authors	Country	Period-Height	Damping-Height
Lagomarsino *et al.* (1993)	-	-	* $D(\%) = 0.724T + (0.703/T)$
Enamoto *et al.* (1999)	Spain	$T = 0.05N$	$D(\%) = 0.8/T$
Satake *et al.* (2003)	Japan	$T = 0.015h$	$D(\%) = 1.4/T$
Navarro & Olivera (2004)	Spain	$T = 0.045N$	$D(\%) = 1.1/T$
Eurocode8	Europe	* $T = 0.075h^{0.75}$ ** $T = 0.050h^{0.75}$	-
Gallipoli *et al.* (2009)	Italy	$T = 0.016h$	-
Panzera *et al.* (2013)	Italy	$T = 0.018h^{0.928}$	-

Tab. 1 - Numerical relationships to evaluate the fundamental period and damping of buildings.

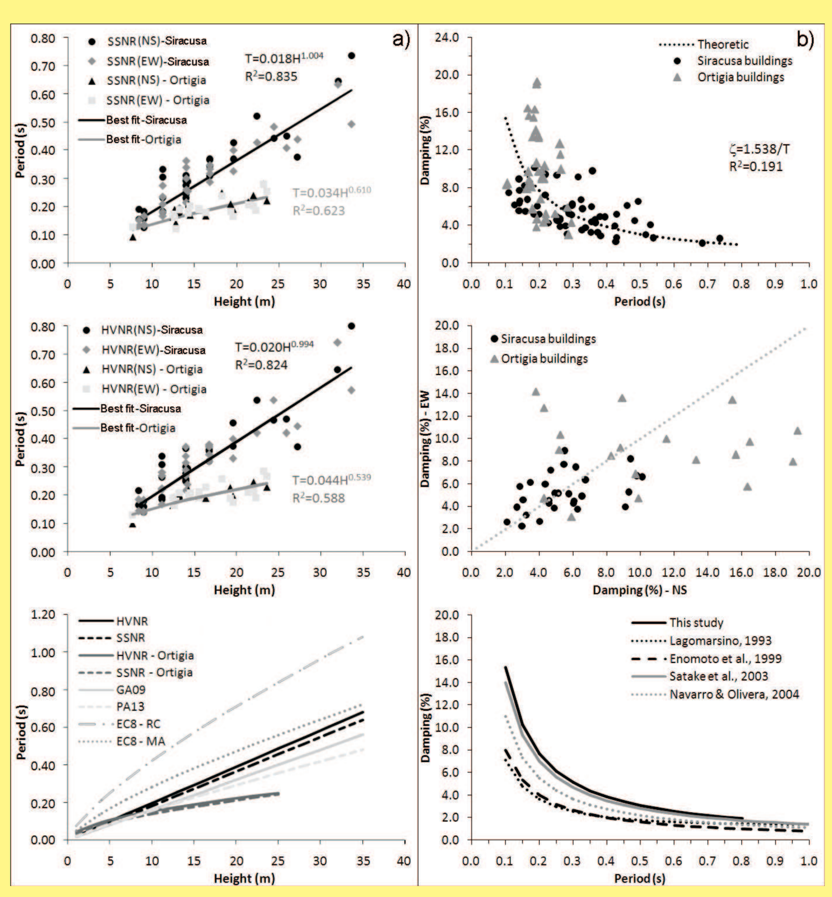

Fig. 3 - a) Period – Height relationships; b) Damping vs. Period from experimental values obtained through NonPaDAnv technique.

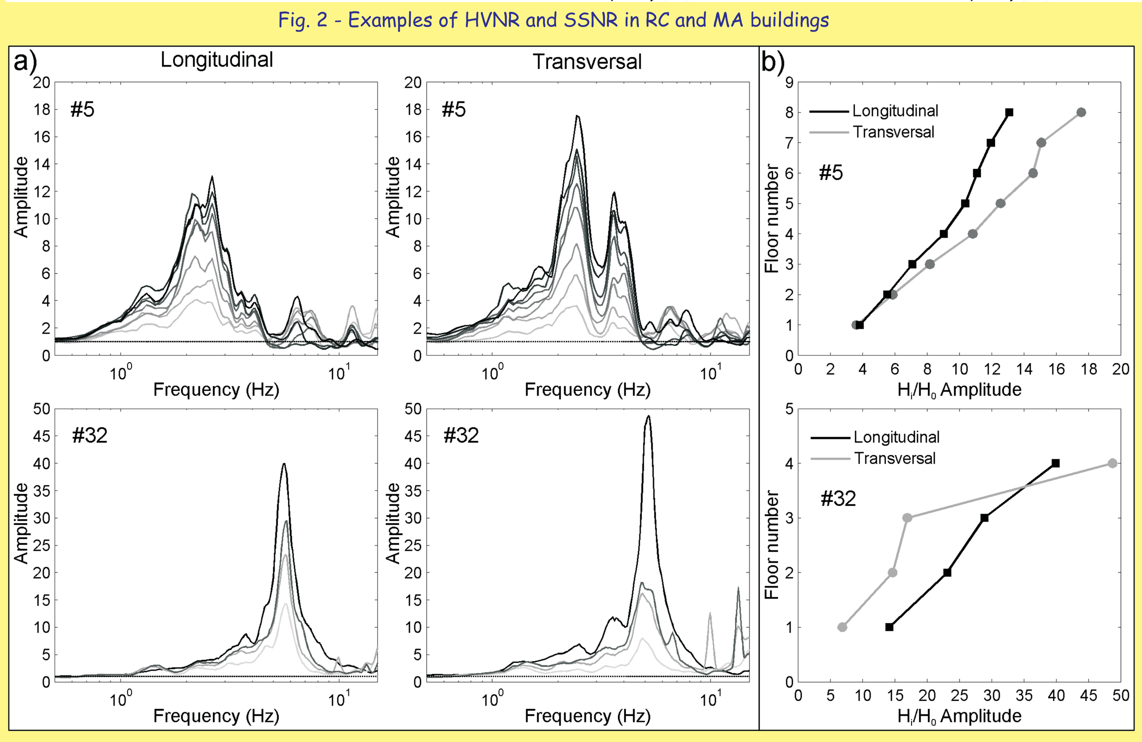

Fig. 4 - SSNR (a) and modal shapes (b) from seismic noise data recorded in each floor of two selected buildings in RC (Building n. 5) and MA (Building n. 32). The curves in (a) are plotted using a grey color scale; the light grey curve corresponds to the lower floor measurements while black curve refers to measurements taken on the top floor.

Earthquake Ground Motion Scenario

In order to predict the expected ground motion parameters in terms of peak ground acceleration (PGA) peak ground velocity (PGV), and Spectral Acceleration (SA) as a function of distance and magnitude we used the latest version of EXSIM program (Boore, 2009). The simulations were carried out by using the regional propagation parameters for southeast Sicily (Scognamiglio et al., 2005) and rectangular faults having length and width proportional to the moment magnitude according the relationship proposed by Wells and Coppersmith (1994). Moreover, considering the potential seismic effect due to the local geology (Nunziata et al. 2000; Panzera & Lombardo, 2013), we produced a reliable earthquake scenarios by simulating the Mw=5.8 earthquake that occurred on 13th December 1990 off-shore of eastern Sicily (about 20 km north the study area). All the input parameters necessary for the simulations are summarised in Table 2. In order to test the performance of our simulations we computed the Fourier Amplitude spectra and compared them with the observed data at the strong motion stations, of the Italian seismic network, located in South eastern Sicily (Fig.5), obtaining a good agreement.

Figures 6, 7, and 8 show the contouring of PGA, PGV and the PSA (at 5% critical damping) for periods of 0.2, 0.4, 0.6 and 1.0 sec. To validate the ground motion results, free-field HVNR spectral ratios obtained in the most important lithotypes outcropping in the Siracusa area were used (Fig. 8). We observe that HVNRs in the Ortigia area show spectral ratio peaks in the frequency range 1.0-3.0 Hz and 4.0-10.0 Hz (see N1, N2, N3, N4, N5, N6 in Fig. 8). Since the Ortigia area is characterized by the outcropping of a limestone formation, we think that the observed resonance frequencies can be ascribed to the local site response linked to topographic effects and to the vibration of small blocks that can imply the existence of resonant frequencies at high values. The ground motion scenario results can instead be well correlated with the features of the outcropping geology in areas where either limestone or calcarenites, as well as volcanics, outcrop (see N7, N8, N9, N10, N11, N12). The HVNRs obtained from measurements performed in the Pantanelli plain (see N13, N14, N15, N16) show pronounced spectral ratio peaks in the range 1.0-2.5 Hz, which can be related to the presence of thick (40–50 m) alluvial deposits and soft sandy-clay sediments. We have also to mention that in some spots within the limestones and calcarenites formations (see N17, N18, N19 in Fig. 8), we observe the presence of significant peaks in the spectral ratios. This suggests that a detailed zonation of limestone should be performed.

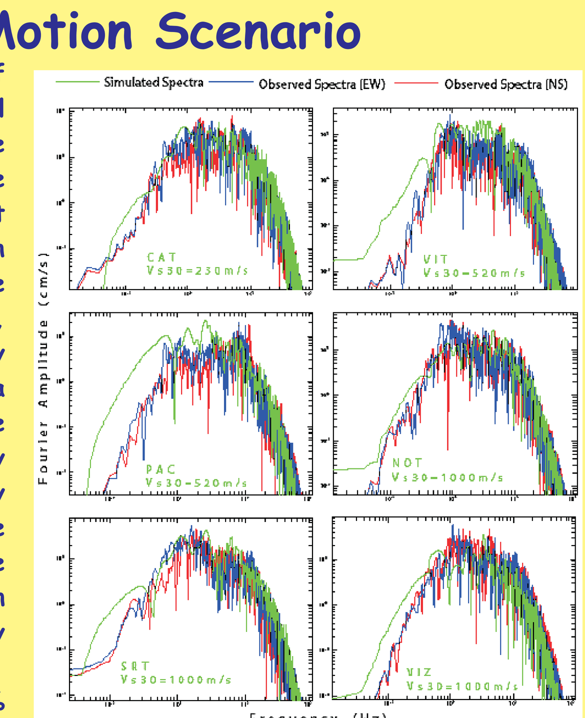

Fig. 5 - Simulated and observed spectra.

Tab. 2

Parameter identification	Parameter value
Hypocentral Location	Latitude: 37.27 Longitude: 15.32 Depth = 10 km
Fault orientation and Moment Magnitude	Strike = 94 Dip = 84 $M_w = 5.8$
Fault dimension (Wells & Coppersmith 1994) Number of sub-sources Pulsing area	Length = 8 km Width = 5 km, 8 (strike) x 5 (dip) 50 %
Crustal shear wave velocity Density (crustal) Rupture velocity Anelastic attenuation $Q(f)$ (Scognamiglio *et al.* 2005)	3.5 km/s 2.8 g/cm³ 0.8 × shear wave velocity $Q(f) = Q_0(f/f_{ref})^{\eta}$ with $f_{ref} = 1.0$; $Q_0 = 400$ and $\eta = 0.26$
Kappa (sec)	0.035
Geometrical spreading (Scognamiglio *et al.* 2005)	$g(r) = \begin{cases} 1/r, & r \le 40 \\ (1/40)(40/r), & r > 40 \end{cases}$
Windowing function	Saragoni–Hart
Stress drop (Di Bona *et al.* 1995)	$\Delta\sigma = 210$ bar
Site class in term of $V_{s,30}$ (Eurocode8 2003)	$\begin{cases} A = 1000\ m/s \\ B = 520\ m/s \\ C = 230\ m/s \end{cases}$
Damping factor	5%

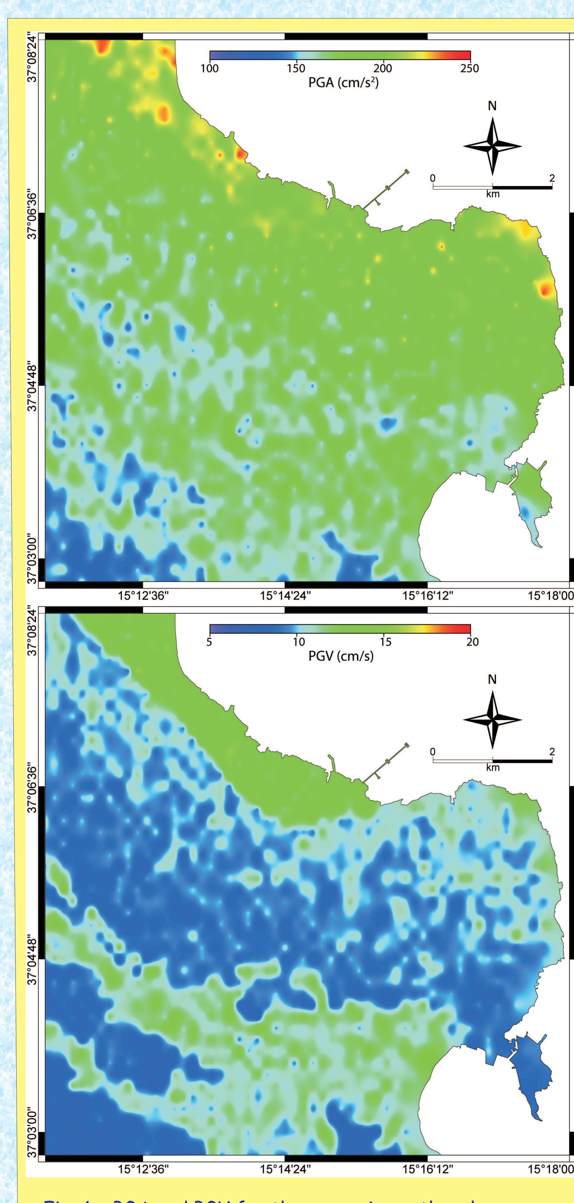

Fig. 6 - PGA and PGV for the scenario earthquake.

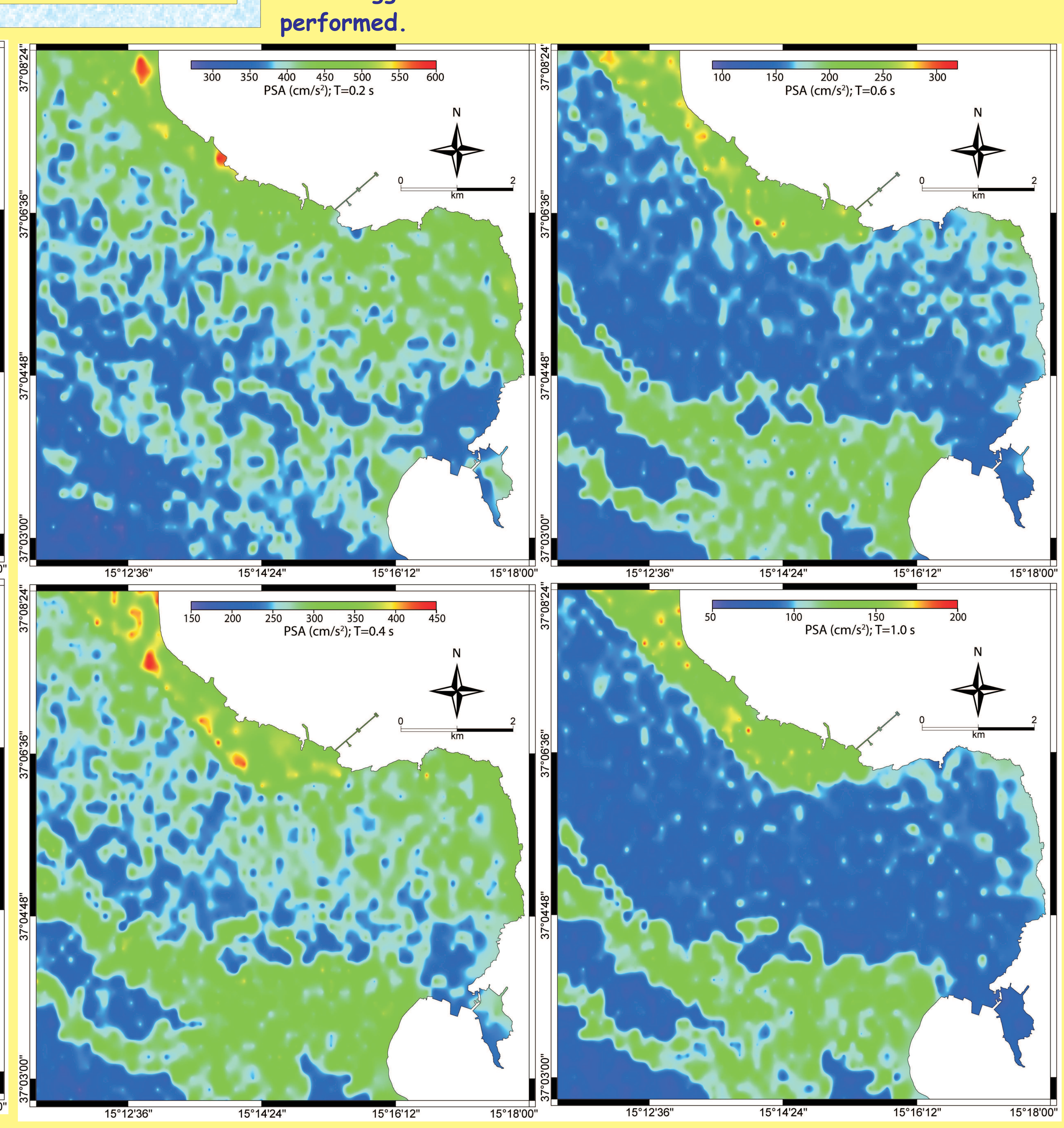

Fig.7 - Contour in term of acceleration response spectral ordinates at period of 0.2, 0.4, 06 and 10 s

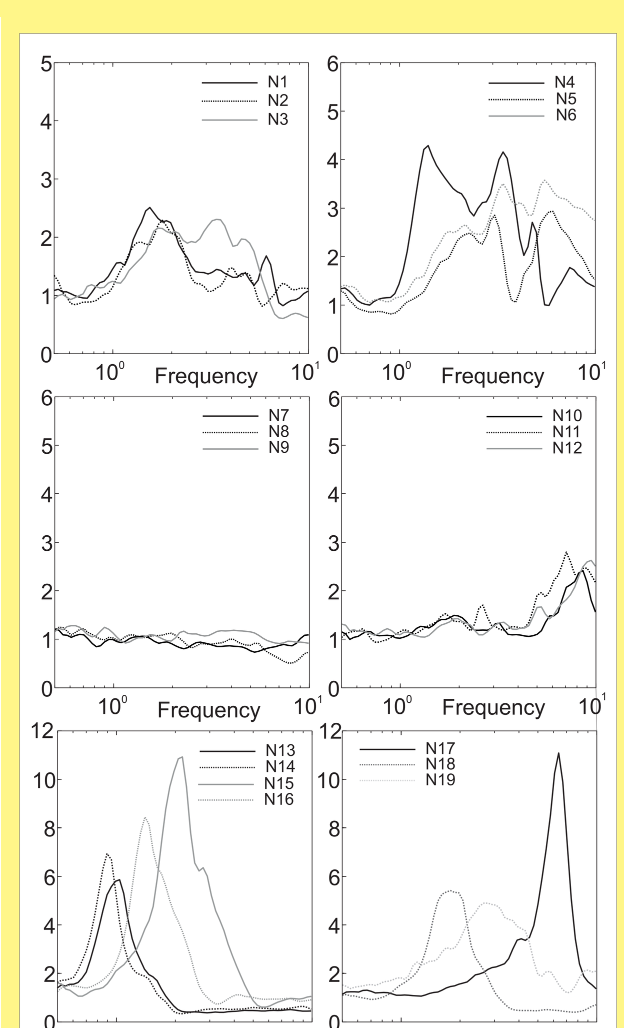

Fig. 8 - Free-field HVNR obtained on main outcropping lithology in the Siracusa area.

CONCLUDING REMARKS

The evaluation of the dynamical properties of buildings and of the ground motion scenario in the Siracusa area gave significant suggestions about potential critical conditions due to soil-structure interaction. The results obtained can be summarized as follow:

- Ambient noise spectral ratios provided reliable estimates of the fundamental period of analyzed buildings. The period-height relationships obtained set into evidence that the experimental values are lower than those postulated by Eurocode8 (2003). Such finding could be explained by considering the contribution of the infill walls that modern codes do not consider adequately.
- Significant differences were observed between the fundamental periods of RC and MA buildings, the former being usually higher than the latter. This appear related, as suggested by the results of damping estimates, to the different stiffness of the structures and to the presence of connected adjacent buildings, especially in the historical centre of the town.
- The ground motion parameters, highlighted that the areas where amplification effects take place, match up to sites where sedimentary terrains outcrop.
- Contour maps of PGA values appear affected by the site-to-source distance whereas whereas, the PGV seems a reliable indicator of the role played by the lithology.
- H/V spectral ratios performed on the main outcropping lithotypes, show a good agreement with results coming from the analysis of the scenario earthquake. These outcomes validate indeed the presence of local amplification effects on thick sedimentary terrains, pointing also out some critical behavior especially in Ortigia and in sites where detritus outcrops.
- The results of the simulated scenario confirm the observed major damage during the 1990 earthquake, which were located in the Ortigia downtown area. This can be considered as the consequence of both the poor quality of some buildings and the local amplifications taking place on the sedimentary terrains. It was indeed observed that considering buildings having height of about 20 m, a MA building will oscillate with a period of about 0.2 s whereas a RC building will oscillate with a period of about 0.4 s. In terms of spectral accelerations, the MA building will be subject to an effect that is about 1.5 times greater than the RC one (PSA ranging between 250-600 cm/s2 and 150-450 cm/s2, for 0.2 s and 0.4 s, respectively).

Finally, the used methodologies in our opinion represent the preliminary steps for a fast, practical and inexpensive procedure aiming to determine the regional vulnerability and the mitigation priorities, for large cities like Siracusa that in the past have been affected by destructive earthquakes. Moreover this kind of study may be useful to governmental agencies tasked with emergency response and rescue.

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