SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

CORRELATION BETWEEN DAMAGE DISTRIBUTION AND SOIL CHARACTERISTICS DEDUCED FROM AMBIENT VIBRATIONS IN THE OLD TOWN OF LEFKADA (W. GREECE)

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ABSTRACT

This work is part of a multi-parametric research towards representation of damage scenarios in the Lefkada old town. The study area lies in the most seismically active zone of the Greek territory. Most of its buildings were built with local practices and have been designated by the European Council Cultural Heritage Unit as representative earthquake resistant constructions. The August 14th, 2003 (Mw=6.2) local earthquake produced several damage in the old town of Lefkada, with an inhomogeneous spatial distribution. In this paper we investigate the correlation of the observed damage pattern with soil characteristics using data collected during an ambient noise survey conducted in 2007. Those were analyzed following Nakamura's HVSR methodology and soil response was approximated by the dominant frequencies and quasi-amplification factors of the resulted HVSR curves. The latter were further inverted using a Monte-Carlo approach and best-fitting site specific geotechnical models were determined. The obtained results are reasonably consistent with borehole test data and show a remarkably good correlation with the 2003 damage distribution.

Keywords: Seismic damage, site effects, vulnerability, ambient vibrations, H/V Spectral Ratio

INTRODUCTION

The reduction of seismic risk in earthquake prone areas is of primary concern in a global policy. A seismic risk model assesses the seismic hazard at sites of interest and convolves this with the vulnerability of the exposed building stock, such that the damage distribution of the building stock can be predicted (Calvi et al., 2006). Seismic scenarios can be very powerful tools to forecast losses by investigating and quantifying the impact of a given earthquake (Dolce et al., 2003). Earthquake scenarios can be referred to different kinds of damage and losses, such as damage to constructions (buildings, bridges, etc.), casualties, economic losses, social losses, etc. The preparation of an urban damage scenario requires the following input (Dolce, 1996): (a) inventory of buildings (b) vulnerability of buildings (c) characteristics of ground shaking including site effects.

Apparently, the a priori estimation of site effects is of major significance for efficient seismic risk assessment (Panou et al 2005) as coupling between soil and building fundamental periods of vibration (soil-structure interaction) may cause resonance phenomena. Site effects can be estimated using earthquake and explosion recordings, or they can be theoretically derived. However, these

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methods are cost effective and require long time and effort in carrying out field surveys. The spectral analysis of ambient noise stands as an alternative mean to characterize the site response in urban environment. Ambient noise is composed of low amplitude high frequency signals (with periods below 2s) generated by natural disturbances such as wind, sea tides or of manmade origin (traffic, industrial machinery, household appliances, etc).

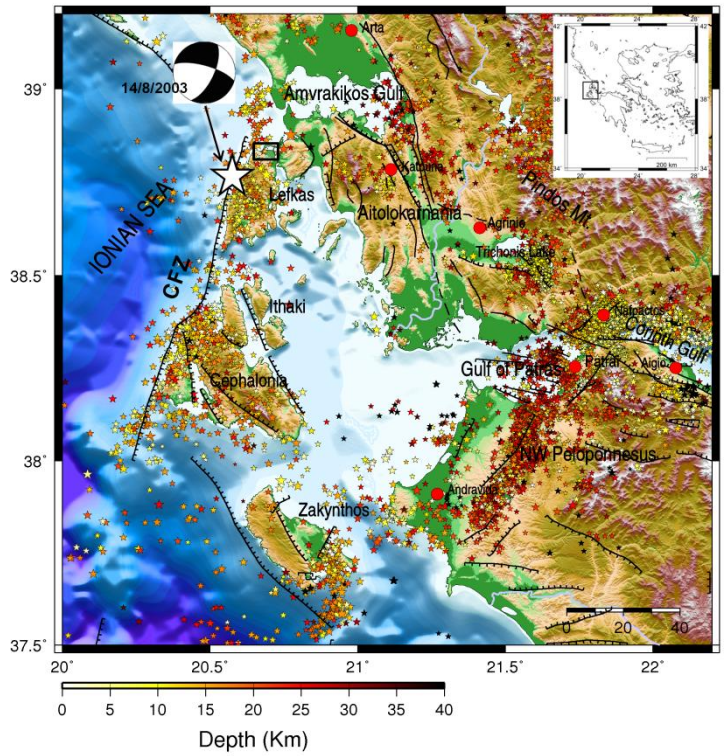

Figure 1. Map of the main tectonic features of the broader study area together with epicenters of instrumental earthquakes with $M_s \geq 3.0$ (Makropoulos et al., 2012, Hellenic Unified Seismological Network - HUSN). White star and beach-ball denote the 14/8/2003 event epicenter and focal mechanism (Papadimitriou et al., 2006), respectively. CFZ stands for Cephalonia Fault Zone. The black rectangle shows the position of the study area. The inset map at the upper right shows the location of Fig. 1 within the Greek territory.

Ambient noise is assumed to be transmitted along the bedrock-soil interface and is thus prone to amplifications by the sediment layers (Atakan, 2007). Although ambient noise has been studied since the first half of the 20th century, the number of investigations rapidly increased following the article by Nakamura (1989). The Nakamura technique is based on the horizontal to vertical spectral ratio of ambient noise recordings (HVSR hereafter) on a single site, using a three component seismograph. The HVSR of ambient noise typically approximates the fundamental frequency of the site under investigation (Nakamura 1989) indicated by a peak of the HVSR curve. It is a very popular method, mainly due to the fact that it is easily applicable with the use of simple instrumentation, it can be performed in various site conditions, and it does not have any environmental consequences. As a result, ambient noise HVSR is currently one of the most commonly applied methods for microzonation studies in urban areas (e.g. Parolai et al., 2001).

Numerous theoretical and experimental studies have been conducted on the consistency of the method, confirming the relevance between the fundamental frequency of ambient noise HVSR and the one of the superficial soil layers of the site (e.g. Field and Jacob, 1993; Konno and Ohmachi, 1998). As far as the peak amplitude of HVSR ratio is concerned, it is assumed that as a general rule, it is not able to give a good estimate of the site amplification factor, as it has been found sensitive to a variety of parameters, such as the velocity contrast, Poisson's ratio, etc (e.g. Lachet and Bard 1994; Bonnefoy-Claudet et al., 2006). However, several experimental studies revealed a good correlation on the consistency between the HVSR peak and the site amplification (e.g. Rodriguez and Midorikawa 2002).

Apart from the derivation of the fundamental resonance frequency of the subsoil, the HVSR fundamental frequency has also been widely approved for determining the dynamic properties of soil deposits at a site (e.g. Woolery and Street 2002). Several techniques using microtremors are used for gathering a variety of parameters such as depth to bedrock, Vs profile, underground heterogeneity, etc. (e.g. Konno and Ohmachi, 1998; Ibs-Von Seht and Wohlenberg, 1999; Parolai and Galiana-Merino, 2006). These methods are adopted as alternatives to the time-consuming, expensive, and extremely localized boreholes, being rapid and cost-effective means of deriving distributed information of subsurface geology (e.g. Delgado et al., 2000).

In Greece, site effect characterization using ambient noise measurements has been performed in several urban environments including Thessaloniki (Kobayashi 1973; Lachet et al., 1996; Leventakis 2003; Panou et al., 2005), Heraklion (Diagourtas et al., 2001), Mytilene (Makropoulos et al., 2004), Lefkada (Scherbaum et al., 2002; Triantafyllidis et al., 2006) and northern Greece (Apostolidis 2002); in most cases, results showed a good consistency with the geological settlement of the target site.

The present work describes the estimation and evaluation of site effects and their possible impact on the strong ground motion and, consequently, to the vulnerability of structures in Lefkada Old Town (LOT hereafter), situated at the northern part of Lefkada island (Fig. 1). Lefkada Island is part of the Ionian Island complex (western Greece) and it is located in the front of the Greek orogenic belt, at the transitional zone between the converging European and East Mediterranean tectonic plates. In the broader region of the Ionian Islands, the occurrence of earthquakes is very often, constituting it one of the most earthquake-prone areas in Europe. During the 20th century alone, the central and south Ionian Islands (Cephalonia, Lefkada, Ithaca and Zakynthos) suffered eight earthquakes of a magnitude M≥6.5. The high seismicity rate of the area is mostly associated with the NNW-SSE striking and ESE dipping right lateral Cephalonia Fault Zone (CFZ) situated off the western coast of Lefkada and Cephalonia, comprising two distinct segments, the Lefkada segment to the north and the Cephalonia segment to the south (Louvari et al., 1999) (Fig. 1). Given the geodynamics of the area, Lefkada belongs to the highest Greek seismic zone (III) of the Greek National earthquake design code which predicts a Peak Ground Acceleration (PGA) of 0.36 g. The most recent strong earthquake occurred on the 13th of August 2003 with Mw = 6.2 (Karakostas et al., 2004; Benetatos et al., 2005; Papadimitriou et al., 2006) at 10 km epicentral distance from LOT providing damage data considered in this work.

Site effects are studied using ambient noise measurements at several selected sites in Lefkada municipality (Fig. 2). Those were analyzed following Nakamura's HVSR methodology (Nakamura 1989) and soil response was approximated by the dominant frequencies and amplification factors of the resulted HVSR curves. The latter were further inverted and best-fit site specific geotechnical models were determined. In addition, geotechnical information and in-situ measurements of the local soil properties were employed. Finally, seismic damage distribution due to the earthquake on 14/8/2003 (Kalantoni et al., 2013) was employed and several correlations with the resolved subsoil characteristics were performed in order to evaluate and validate our results.

DATA AND RESULTS

Damage and geotechnical observations

In this study the damage distribution of the building stock in LOT due to the 2003 earthquake together with the buildings vulnerability were employed to investigate their possible linkage with site effects and poor soil quality. The ground motion recorded at the Lefkada Hospital during the 2003 earthquake showed a PGA value of 0.42g, with fundamental frequencies of about 0.5 s and a spectrum of about 2 s (Benetatos et al., 2007). It has been one of the greatest values recorded in Greece, significantly higher than the design spectra predicted by the current Greek earthquake code, while the maximum intensity felt was Io=VIII EMS in the municipality of Lefkada (Papadopoulos et al., 2003).

Despite the very strong ground motion recorded during the 2003 event, there were no casualties and only a small number of injuries occurred. Moderate damage was observed in villages of the central and western part of the island, as well as in the Lefkada municipality. The most prominent 2003 co-seismic effects in LOT were extensive typical ground failures like rock falls, soil liquefactions, subsidence, densification, ground cracks, and landslides. Soil liquefaction phenomena induced serious consequences at port and marine structures in the municipality of Lefkada (EERI

2003), in which the extent of the buildings damage was the largest throughout the island, attributed to its proximity to the epicentre and poor soil conditions (Karababa and Pomonis 2011).

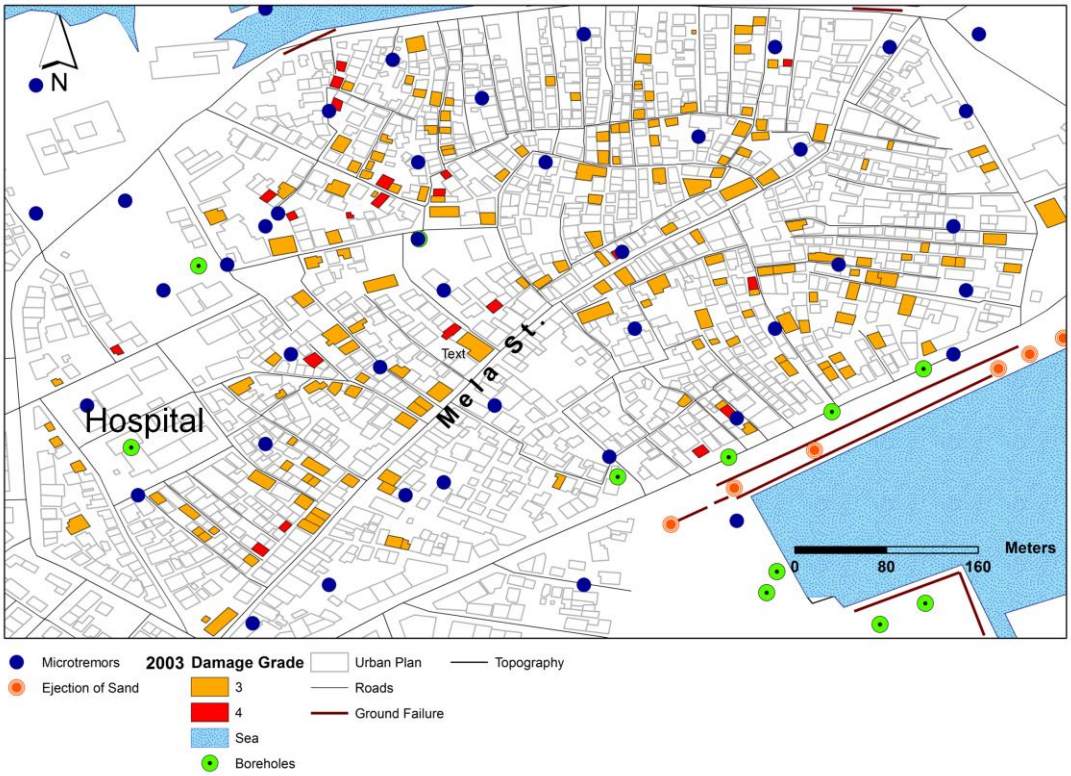

Figure 2. Map showing the locations of ambient noise observations and the damage distribution due to the 2003 earthquake (Kassaras et al., in press). Co-seismic ground failures are after EERI (2003).

The local amplification of ground motion typically depends on the soft soil deposits overlying stiff soils. The impedance between these deposits and the base amplifies the ground motion and captures the wave energy resulting to variations often observed, in the extent and intensity of the earthquake damage. According to the analysis performed on acceleration time histories and the subsoil dynamic characteristics (Gazetas 2004), the extremely high PGA was associated with local site effects.

Table 1. Average subsoil characteristics deduced from the CRI borehole datasheets in LOT. V_S is determined by empirical relations using SPT.

Soil type	SPT	V_S (m/s)	Thickness (m)	Rho (gr/cm^3)	Aquifer (m)	EC8 Category
Artificial deposits	-	-	3.2	-		
Clay	10	187	4.1	1.86		
Sand	33	236	5.2	1.94	0.6-3.1	C
Sandy silt	37	270	3.0	1.97		
Marl	>50	470	∞	2.15		

LOT is situated on low resistance and rigidity Holocene alluvial and lagoon deposits of a few meter thickness, ranging between 9 and 16m (Gazetas 2004). In accordance with the Greek Seismic Code (EAK 2000), such soils are classified under category C, and X (for soil susceptible to liquefaction), whereas according to Eurocode 8 (EC8; CEN/TC250/SC8/N317, 2002), they are classified under category D, E and S (for soil susceptible to liquefaction). 13 boreholes performed in LOT by the Central Research Institute (CRI) of the Ministry of Public Works after the 2003 earthquake provided localized subsoil characteristics at two sites, namely at the waterfront and at the north district (Fig. 2).

According to the CRI borehole reports, five soil categories are observed throughout LOT, namely artificial deposits, clay, sand, sandy silt and marl. Stiff marl of unspecified thickness is observed at each site in depth ranging between 15 and 20 m. Given the SPT and the average Vs=550 m/s implied by geophysical seismic profiling (Gazetas 2004) the marl layer is considered the "seismic bedrock" in LOT. On the other hand, the four soft soil formations are not brought onto being in all borings, whereas their overall thickness does not exceed 20 m.

Because of the lack of laboratory or field measurements of seismic velocities, we used boreholes datasheets available by the CRI; by employing several empirical relations (Lotzetidis et al., 1992; Kalteziotis et al., 1992; Tsiambaos and Sabatakakis 2011) we converted SPT values into Vs for each soil category and averaged the subsoil characteristics in LOT (Table 1).

Despite the poor soil conditions, the long duration (about 18 s) and the high peak ground accelerations of the ground motion, the August 14th, 2003 earthquake did not damage the traditional buildings at DG5 (total or near total collapse) in LOT, which presented satisfactory seismic behavior. According to Makarios and Demosthenous (2006), this was due to the extended use of wood and their relatively small mass. On the contrary, several modern structures situated outside LOT presented serious damage especially to infrastructures by foundation settlings (Margaris et al., 2003). Out of the 1420 buildings in LOT, 463 buildings underwent post-seismic inspection; about 60% of those were found moderately damaged and 7% heavily damaged. Most of damage concerns old buildings of traditional architecture and high vulnerability (Kalantoni et al., 2013). The damage, assessed through the available survey protocols in terms of EMS98 damage grades for each building, was employed to investigate correlations with site effects described in the next sections.

Ambient noise HVSR

Detailed description of the 2007 ambient noise survey is presented in Kassaras et al. (2008). Here we provide only a brief description for a better understanding of the later discussion. Ambient noise records were obtained during 7 – 12 October 2007 in the town of Lefkada, at certain localities, in order to achieve a dense array of measurements. 77 points were chosen, in order for the whole municipality of Lefkada (including the contemporary urban sector) to be examined. The choice of points was based on accessibility, as well as the lack of (or low) artificial signals or other unwanted noise due to the fact that most of the points were situated in residential areas. All measurements were carried out during working hours at day time. 3-channel REFTEK 72A seismic recorders were used, equipped with Guralp CMG40T seismometers with a natural frequency of 1Hz. The duration of each record was 20-25 minutes long. The sampling rate was set to 125 Hz.

HVSR curves were computed using the GEOPSY software, which was developed in the guidelines of the SESAME project (SESAME 2005). GEOPSY allows the implementation of several processing modules (filtering, smoothing, window selection, etc) enabling a quick visualization of the results. The time series were corrected for trend and were tapered with a 5% cosine function at both ends. The instrumental response correction was performed by considering the pole and zero configuration of the sensor. The Fast Fourier Transform (FFT) was calculated for each component, and the spectra were smoothed using a Konno and Ohmachi (1998) logarithmic window. The procedure was applied to variant length stationary noise windows after removing transient noise signals through STA/LTA anti-triggering. Then, the Horizontal-to-Vertical Spectral Ratios (HVSR) were calculated considering the Root-Mean-Square (RMS) spectra of the two horizontal components for each signal window. Finally, the logarithmic average of the HVSR was computed together with its standard deviation.

For a quantitative interpretation of the fundamental HVSR peak frequencies, we considered only peaks within the frequency range of 0.8 to12 Hz. The lower frequency limit was chosen close to the sensor natural frequency. The upper limit was specified due to the physical frequency threshold for site effect characterization, regarding peak frequencies above 10-20 Hz (Köhler et al., 2004). Our analysis showed that amplification factors were systematically sensitive to transients, often obscuring the frequency peaks; hence they had to be carefully removed from the signals. After rejecting outliers, the dominant (peak) frequency and its corresponding quasi-amplification factor were picked from the HVSR curves. It is worth noticing that the majority of the HVSR curves exhibited picks, showing the impedance between the superficial alluvial deposits and the underlain bedrock. Most of them have one

peak, which sometimes broadens or splits into two peaks at a higher frequency. A few recordings located southern presented almost flat HVSR curves, implying for a better quality soil formations.

For our purpose, we employed 49 out of 77 sites, located in LOT. These exhibit in general dominant frequencies (Fig. 4) ranging between 1.18 and 2.77 Hz, in agreement with results obtained by strong motion recordings (experimental and synthetics) at various locations in LOT (Gazetas 2004) and HVSR derived from both seismic and ambient noise data (Triantafyllidis et al., 2006). Amplification factors were found in range between 1.75 and 3.5. Despite the quality of our analysis, those should be considered with caution as ambient noise amplification factors have been proven lower than soil amplification in several cases.

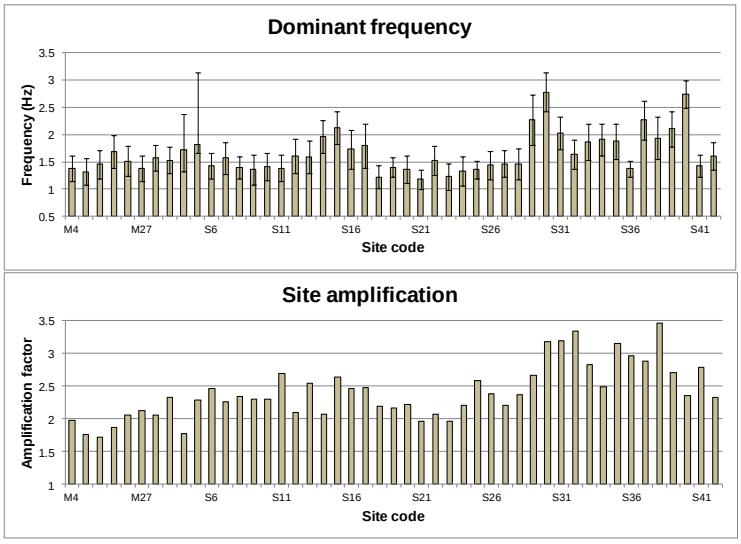

Figure 3. Ambient noise HVSR dominant frequencies and the corresponding quasi-amplification factors in the town of Lefkada (both old and new sectors).

Inversion of HVSR curves

We proceeded in determining the velocity structure of the subsurface shear wave in LOT by fitting the observed HVSR at each site obtained from microtremors with a theoretical model. Techniques using HVSR to extract V_S structures of sediments are based on two different approaches. One approach is that HVSR is related at most with the fundamental mode Rayleigh waves that compose the noise (Fäh et al., 2003). The other hypothesis is that ambient noise is composed of body-waves. In this study we adopted the latter and used the code ModelHVSR (Herak 2008). One basic assumption of this approach for horizontal layering is largely valid in LOT as inferred from geotechnical data.

The ModelHVSR algorithm inverts the observed HVSR curves by Monte Carlo perturbation in order to obtain the best fitting geotechnical model. The routine randomly perturbs an initial visco-elastic model within user defined vector length, visco-elastic parameters and number of iterations. Models involved in the inversion process consist of a homogeneous and isotropic horizontal visco-elastic multi-layered soil column over a half space. Each layer is defined by thickness, velocity propagation of the body wave in question (V_P or V_S), density and the frequency dependent Q-factor which controls the inelastic properties of the wave propagation. The incoming waves are assumed to be traveling vertically. The final solution matches the observed $HVSR_{OBS}$ with the theoretical $HVSR_{THE}$ curve at frequency f_i in terms that the misfit function m is minimized (Herak 2008):

$$m = \sum_i \{[HVSR_{OBS}(f_i) - HVSR_{THE}(f_i)]W_i\}^2. \quad (1)$$

W_i is the weight defined by

$$W_i = [HVSR_{OBS}(f_i)]^E \quad (2)$$

With larger weights (for E>0) given to data around the frequencies where the observed HVSR is large.

We employed 49 experimental HVSR curves and implemented the following:

1. Inversion of the observed HVSR spectra by Monte Carlo perturbation of the initial model parameters, to obtain the best fitting models;
2. Computation of theoretical (HVSR) for body waves using estimates of both horizontal and vertical amplification of soil;
3. Computation of dynamic amplification factors of the peak-ground acceleration, velocity and displacement for the computed soil models;
4. Computation of confidence regions for the inverted model parameters.

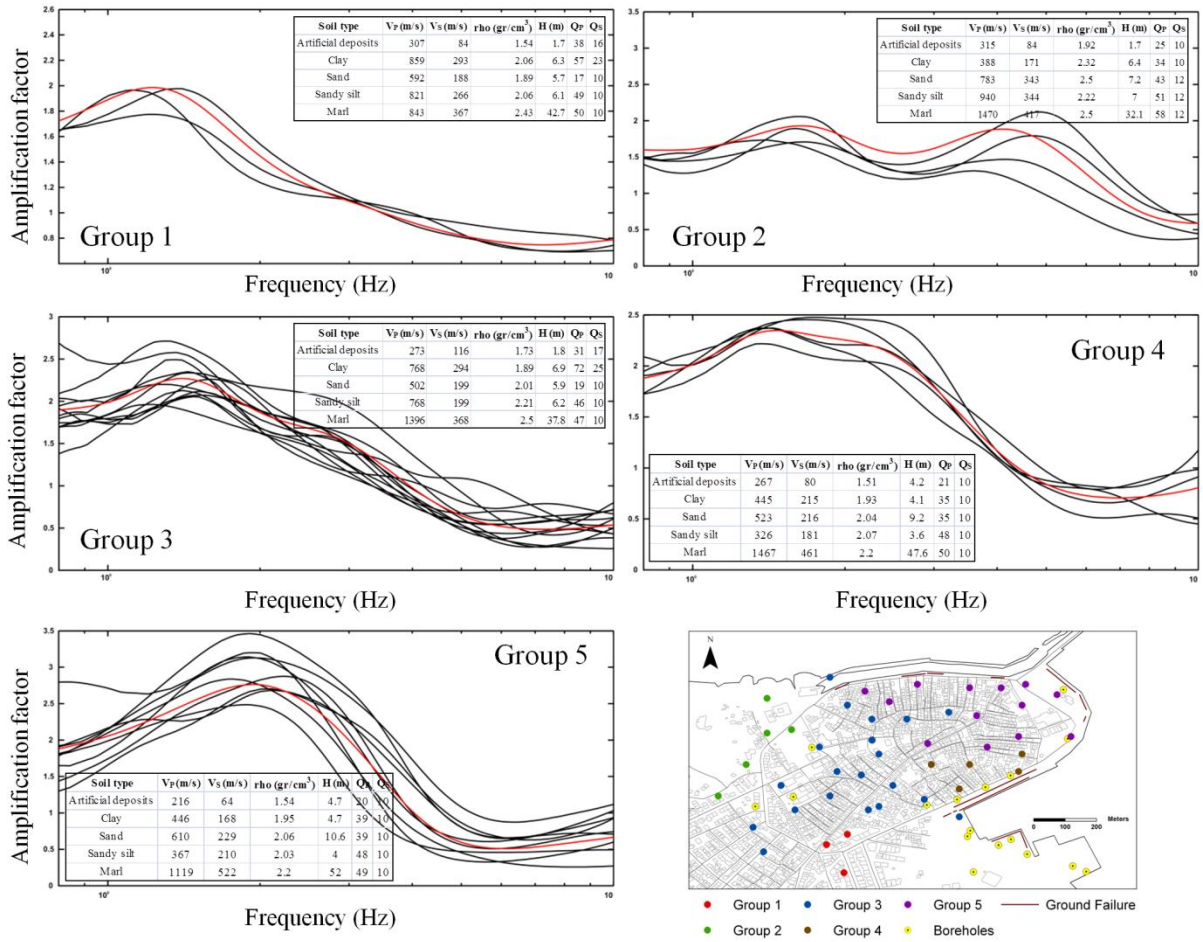

Figure 4. Classification of HVSR curves in LOT based on their shape similarity. Panels display the averaged (red) and the individual HVSR curves (black) for groups 1 to 5. Text boxes display models derived from the inversion of the averaged HVSR curves for each group. The lower right map shows the spatial distribution of each HVSR group.

At first, five different groups of HVSR curves were recognized upon their shapes (Fig. 4). For each group the average curve was computed and used to determine five representative geotechnical models in LOT using ModelHVSR software. The Monte Carlo search of the ModelHVSR inversion scheme requires a starting model whose parameters are randomly perturbed within predefined bounds. In order to minimize biases between inverted values, bounds were assumed according to our experimental data, theoretical constraints and several coherency tests as following:

a) The average thicknesses (H) and density (rho) of the soil categories, available from borehole measurements were perturbed by 30% of the initial values.
b) Vs, which was indirectly determined using empirical relations and Vp, constrained by an arbitary constant V_P/V_S=1.73, were 100% perturbed.
c) Average Q_P and Q_S, adopted by Triantafyllidis et al. (2006), were perturbed by 100% of their initial values. Those were found not significantly affecting the results.

d) Minimum H was set to 1 m, with respect to the minimum average thickness of the artificial deposits (1.6 m). Given the lack of information on the velocity structure, an initial value of 100 m/s was used, based on literature.

e) Minimum V_P/V_S was set 1.73 (Poisson medium). A maximum limit V_P/V_S = 4 was set, suitable for soils susceptible to liquefaction, which is likely in LOT (Gazetas 2004; Papathanassiou et al., 2005).

The average model comprising 5 layers with *Vs*, *rho* and thickness (*H*) derived from the CRI borehole data (Table 1) was input for the inversion of the 5 average HVSR curves. The inversion yielded 5 best-fit models overlying a half-space (text boxes in Fig. 4). The latter were used as starting models for inverting individual HVSR curves belonging to each group and 49 site-specific soil columns were resolved. V_S columns at two sites were proven incompatible with the generic patterns, hence they were rejected and finally 47 sites were employed for further analyses. Following, V_{S30} was calculated as the time for a shear wave to travel from a depth of 30 m to the ground surface and accordingly EC8 soil quality assessment was performed showing poor quality soil structure beneath LOT, classified in EC8 C and D categories (Fig. 5).

As mentioned above, Model HVSR is based on the theoretical assumptions regarding the body-waves composition of the noise, horizontal layering, vertical incidence, etc. When those assumptions are suspected to be significantly violated, the derived results should be used with caution (Herak 2008). This may be often encountered in cities where a considerable part of ambient noise is of local anthropogenic noise and local sources largely consist of horizontally propagating surface waves (Bonnefoy-Claudet et al., 2006). On the other hand, the restriction of vertical incidence is a valid approximation only when there is a strong velocity contrast between soft shallow and stiff deeper structures. The probability for such violations was investigated by correlating the inverted models with borehole data.

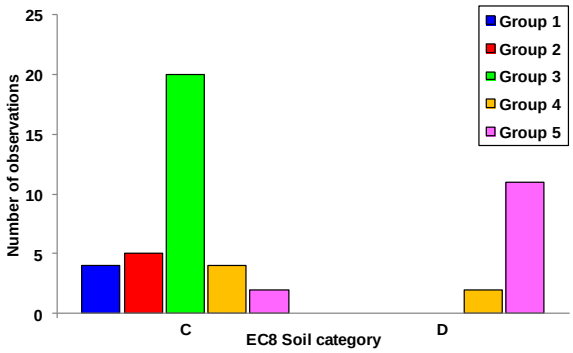

Figure 5. EC8 classification of soils in LOT derived from inverted HVSR. The location of each group is displayed in Fig. 4.

Fig. 6A presents the distribution of inverted and borehole concluded V_S with depth. When looking at individual observations, a relatively fuzzy pattern is seen. To distinguish possible systematic distributions we computed best fit trend lines for each population of observations. As it can be clearly seen in Fig. 6A, borehole V_S lie within the bound of the inverted ones for the whole depth range, with exemptions at depth >15 m; V_S at depth >15 m concerns marl, for which the empirical relations used for their indirect assessment were likely proven incompatible and hence a re-evaluation of such formulae is needed.

Following, we examine the probability that discrepancies occur due to low impedance between the deep and the shallow structures, related with low amplification factors of the HVSR curves. Fig. 6B displays inverted V_{S30} versus amplification factors of the respective HVSR curves implying for a general trend of decrease of the dispersion of V_{S30} values with the increase of amplification factors. Apparently, three families of soil columns are distinguished, namely Groups 3, 4 and 5. Groups 1 and 2 exhibit the largest V_{S30} dispersion and a quite vague pattern. Given the small number of observations (9) for the latter families, a robust interpretation is unlike, yet those are clearly linked with low amplification factors, likely attributed to low impedance and/or waves diverged from vertical incidence due to contamination from very local urban sources.

SUMMARY AND CONCLUSIONS

This study describes the effects of local geological conditions on seismic ground motion in Lefkada Old Town (LOT), Ionian Islands, Greece, which is the most seismically prone area within the eastern Mediterranean region. The most recent local strong earthquake on August 14th 2003 (Mw=6.2) provoked several reconnaissance campaigns including geological, geotechnical and seismic downhole surveys, implying for a poor quality soil susceptible to liquefaction. However, those were not sufficient enough for a detailed subsurface exploration due to their extreme localization and uneven distribution in LOT. For this reason, we used data from a microtremors survey conducted by our research team in 2007. By applying Nakamura's technique we computed HVSR curves distributed in a grid with cell dimensions ~150×150 m^2 which adequately samples the study area. 47 HVSR curves were classified in 5 groups according to their shape type and were inverted using a Monte Carlo perturbation of an initial visco-elastic model in order to find the best-fitting models. We used the Model HVSR software (Herak 2008).

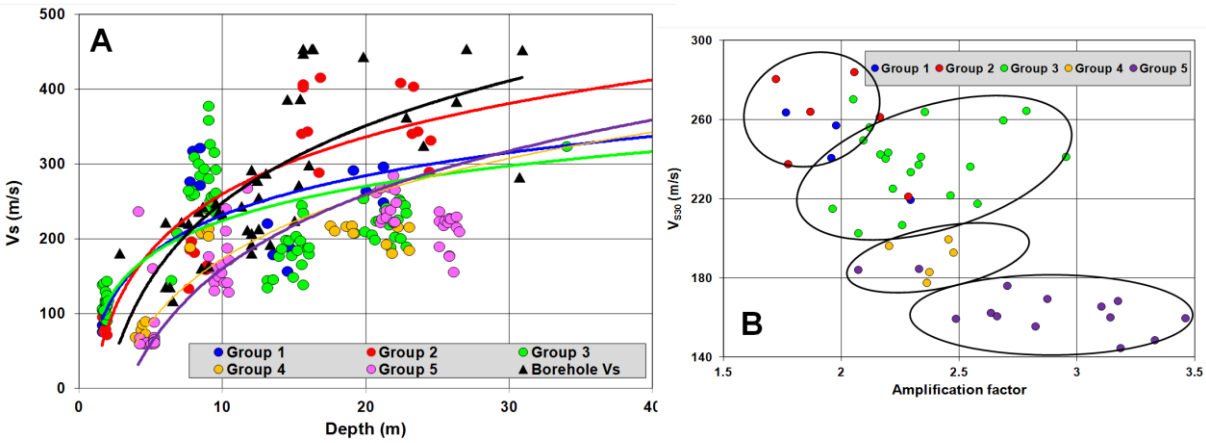

Figure 6. (A) Comparison between V_S derived from HVSR modelling and borehole SPT measurements at various depths; (B) Comparison between Model HVSR V_{S30} distribution with the amplification factor of the respective HVSR curves. Solid lines represent regression lines. Ellipses contain HVSR families.

Information from 13 geotechnical drillings provided a general description of the subsurface of the study area, used to construct a starting visco-elastic model for the inversion of the HVSR curves. The inversion provided 47 1-D velocity models exhibiting a reasonable consistency, both laterally and with respect to the velocities derived empirically from borehole test data. Various uniformity from generic patterns could be attributed to the empirical relations used to determine V_S, the different localization between boreholes and HVSR curves, the magnitude of impedance between regolith and the seismic bedrock, and the presence of transient noise inducing other than vertically incident waves required by the inversion scheme. In a general trend, the V_S and thickness acquired by Model HVSR modeling of microtremors are about 25% lower and larger, respectively, than the values acquired by downhole surveys. However, such differences are acceptable for a Vs modeling and have no significant influence on the inferred pattern. The analyses led us to conclude that the sites having high HVSR amplitudes and clear peaks yield more consistent results with low misfit functions.

The site was classified according to EC8 provisions, corresponding to classes C and D. Fig. 7 illustrates the most prominent results. It is evident that the soil formations seem to have played an important role to the 2003 damage pattern. V_{S30} ranges between 145 and 284 m/s with the lowest values observed beneath the eastern part of the town and the largest values beneath the western district (Fig. 7A). Low V_{S30} is associated with damage observed at the southeastern part; at the eastern sector (lowest V_{S30}) no damage is observed, most likely because of the low vulnerability of buildings situated in this part (hotels, well preserved residences).

Damage at the northern part is correlated neither with high velocity, nor with the thickness of regolith (Fig. 7C). It is though well correlated with the thickness of the two topmost soil layers (artificial deposits and clay, Fig. 7B), showing that those formations certainly contributed the most to the amplification of the seismic wavefield during the 2003 earthquake. In the central part of the town

(along Mela St.) damage unlikely correlates with low velocity and/or thickness of loose formations. Nevertheless, it is correlated with relatively high vulnerability of buildings reported in this area (Kalantoni et al., 2013); several two- and three-storey buildings with a highly vulnerable soft ground storey due to structural modifications in order to be used as stores, failed during the earthquake.

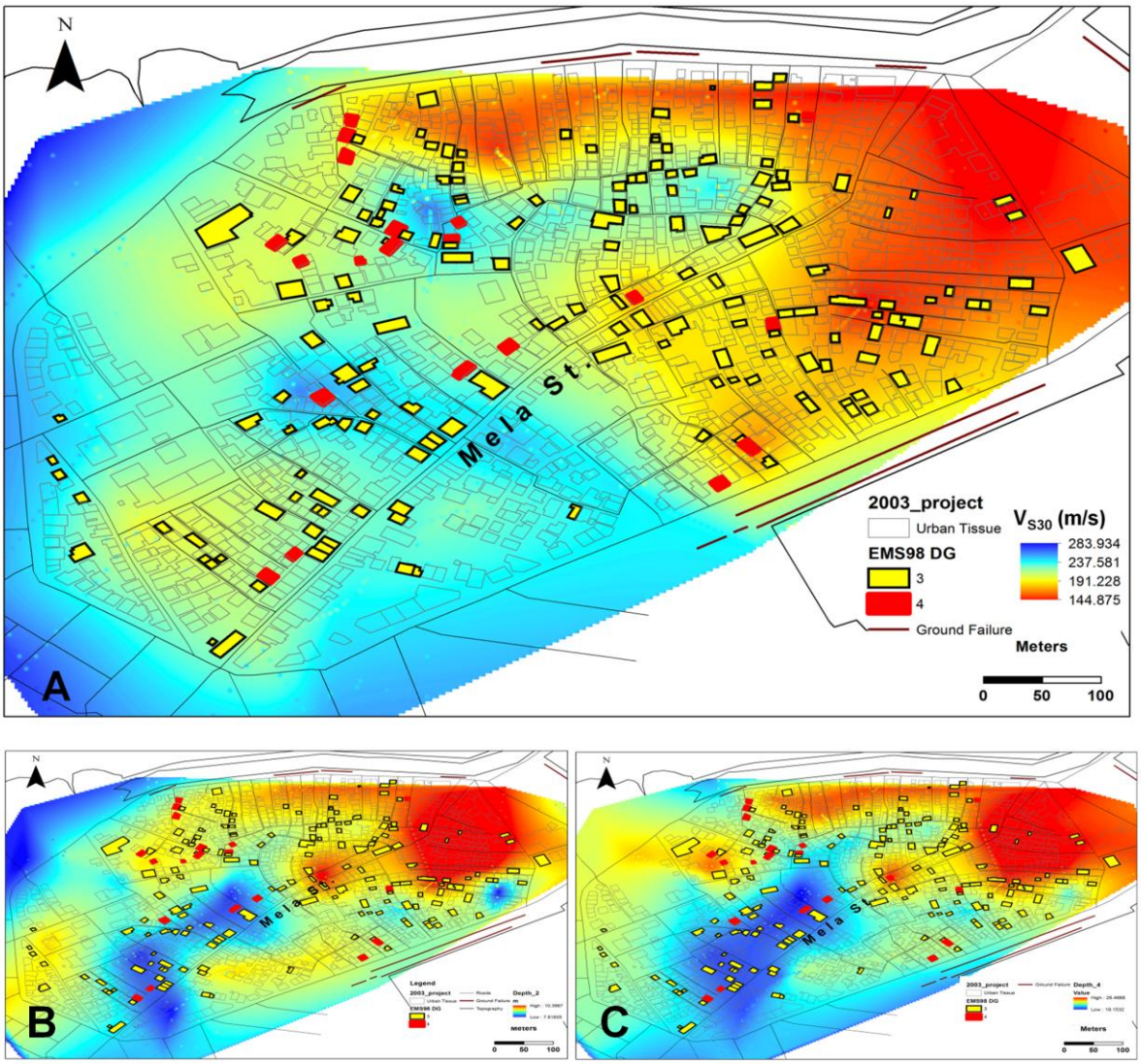

Figure 7. (A) Inverted V_{S30} lateral distribution and buildings damage distribution due to the 2003 earthquake in LOT. Damage is expressed in EMS98 (Grünthal 1998) Damage Grades (DG, Kalantoni et al., 2013); (B) Depth distribution of the first two soil layers (artificial deposits and clay) derived from the inversion; (C) Depth distribution of the regolith derived from the inversion.

In conclusion, despite some variance due to data and/or method uncertainties our results converge towards a poor quality and laterally a strongly inhomogeneous soil, which correlates very well with the 2003 buildings damage. The latter provides a promising context for the next step of our research that is to generate realistic loss scenarios in the study area.

ACKNOWLEDGMENTS

We are grateful to Dr Nikolaos Malakatas, Director of CRI for making available the borehole test data and Mrs Ioanna Vasileiou for helping us with their manipulation. This work was partially funded by SARG-UoA.

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