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Vulnerability assessment in Lefkada old town (W. Greece) with the use of EMS-98; comparison with the 14-8-2003, Mw=6.2, earthquake effects. First results.

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Abstract. The purpose of this paper is to assess the vulnerability to ground shaking of the building stock in the old town of Lefkada Island (Ionian Sea, W. Greece). The study area lies in the most seismically active zone of Greece region. 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. Within the context of this research we conducted an in-situ survey, of all buildings in the old town. In addition, the 2001 buildings census catalogue elaborated by the National Statistical Service of Greece was employed, as well as the damage inspection data following the 2003 earthquake. The collected data, after a detailed processing, were projected as they would have been prior to the August, 14, 2003, Mw=6.2 Lefkada earthquake. Each building was indexed by an EMS-98 vulnerability class. All results were combined in an ArcGIS scheme in order to compute the lateral vulnerability distribution and to compare it with the 14/8/2003 earthquake effects.

Keywords: EMS-98, seismic vulnerability, earthquake damage, Lefkada

1 INTRODUCTION

Lefkada, together with nearby Ithaki, Cephalonia, and Zakynthos islands is considered as the most seismically active zone in Greece. The region is dominated by the activity of the Cephalonia transform fault (Hatzfeld et al., 1995). During instrumental times (since 1900) Lefkada Island has suffered from several earthquakes with magnitude in the range 6.0-6.5. It is situated in the highest (III) seismic zone of the current Greek Seismic Design Code assigned with a peak ground acceleration of 0.36g. In Figure 1 the main tectonic features of the broader study area are presented together with epicenters of earthquakes ($M_s \geq 4.0$; Makropoulos et al., 2012) and focal mechanisms for events with $M \geq 5.8$ since 1900.

The target site, Lefkada town lies at the north-eastern part of the island at around 1-5 m above the present mean sea level. It is situated on low resistance and rigidity Holocene alluvial and lagoon deposits of a few meter thickness (Gazetas, 2004). The quasi-uniform geological settlement of the neighbouring area denotes that the whole town of Lefkada is predominantly characterized by similar formations of almost horizontal layering. The soil structure beneath the town is classified as category C according to the current Greek Seismic Design Code. Consequently, site-effects may increase the response beyond the provisions of the Seismic Design Code, due to the superficial soil quality. That was the case during the 14 August 2003 Lefkada earthquake (Mw=6.2) which caused high PGA=0.42g in Lefkada town, with a spectrum that exceeded the current and previous earthquake code design spectra, producing apart from building damage, various coseismic effects such as rock-falls, liquefaction, lateral spreading and harbour quay wall failures (Gazetas, 2004).

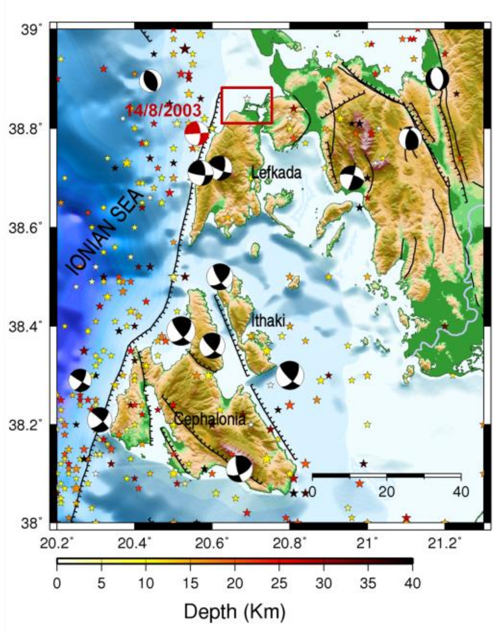

Figure 1. Seismotectonic characteristics of the broader study area. The red rectangle denotes the study area.

The building stock of the old Lefkada town has attracted the interest of the scientific community and is designated by the European Council Cultural Heritage Unit as representative earthquake resistant constructions. Local seismic construction practices have been developed during the 17th century and are still used, to a limited extent, today. These practices demonstrate typically several principles of good seismic performance. However, knowledge degeneration, coupled with changing needs and socio-economic contexts, have imposed changes in the use and function of existing structures, often leading to critical reduction of their seismic performance (Karababa, 2007). This study describes the first stage of a multiparametric project currently being carried out by our research team aiming towards an integrated seismic risk assessment in the cultural heritage site of Lefkada town. The project comprises of three research stages.

(1) Vulnerability analysis of the buildings in the old town of Lefkada, employing a comprehensive inventory of the buildings. Vulnerability indices prior to the 2003 earthquake are established for the buildings describing the expected damage as a function of the seismic input.
(2) Simulation of strong ground motions for regional hazard assessment in Lefkada. Observed strong motion recordings and theoretical computations taking into account realistic models for wave propagation as well as possible seismic source zones are used to compute expected peak ground motion parameters (PGA, PGV, PGD) for the study area.
(3) The third stage takes into account local site effects resulting from a detailed ambient noise study conducted in 2007 in Lefkada town. In addition, available geotechnical information and in-situ measurements of the local soil properties will be employed to estimate the amplification effects with respect to the expected ground motion predicted by the regional hazard parameters in the second stage.

All obtained information, after a systematic processing and evaluation, will be incorporated into an ArcGIS scheme, for computing the lateral distribution of expected damages for different earthquake scenarios. Stages (2) and (3) are currently in progress. In this paper we focus only on the first research stage, concerning the vulnerability assessment of the existing building stock of the old Lefkada town, as it was prior to the August 14, 2003, Mw=6.3, event. Preliminarily, a comparison with the 2003 coseismic effects distribution is also discussed.

2 METHOD, DATA AND RESULTS

2.1 Method

The seismic vulnerability of a building is defined as its susceptibility to damage by ground shaking of a given intensity. The various methods for vulnerability assessment that have been proposed for use in loss estimation can be divided into two main categories: empirical and analytical. Both can be used in hybrid methods (Calvi et al., 2006). The choice depends mainly on the level of information available and on the extent of the area under examination (Dolce et al., 2003). In Greece, empirical (typological) and analytical techniques are used, although none of the above is applied on a regular basis. Typological techniques are based on data collected during macroscopic inspection. Analytical techniques are based on numerical simulations. The latter strongly depend on the characteristics of the structures being examined. The analytical procedure is computationally intensive and results cannot be easily extracted for diverse construction characteristics (Dolce et al., 2003). Such case is the building stock in the old Lefkada town, where diverse local seismic construction practices are typically common. Taking into account the available resources, applicable methods and expected results we adopted the empirical approximation as best adapted to the type and size of the target site and additionally our financial capabilities.

Within the frame of the empirical vulnerability approach two methods are used. The Damage Probability Matrices (DPM) and the Vulnerability Index Methods (VIM), each, presenting advantages and disadvantages. The concept of DPM (Whitman et al., 1973) expresses, in a discrete form, the conditional probability that a structure of given type will exhibit a damage level (e.g. collapse or serious structural damage etc.), due to a ground motion of certain intensity. This is typically not the case, mainly due to the fact that the relationship between the frequency content of the ground motions and the period of vibration of the buildings is not usually taken into account. The concept of VIM (Benedetti and Petrini, 1984) takes into account, not only the typology, but many vulnerability characteristics of the buildings and requires an expert's judgment. It is generally used in regions of strictly constrained structures typologies (i.e. reinforce concrete); it was not considered suitable for our case study, due to the diversity of the local seismic construction practices in the study area.

The European Macroseismic Scale (EMS-98) (Grünthal G. (Ed.), 1998), which, more than any of the previous intensity scales gives emphasis to the performance of existing buildings to accurately assess the intensity and incorporates new types of buildings, especially those including earthquake-resistant design features and commonly found in Greece and Lefkada Island. Building structures of various types (load-bearing masonry, reinforced concrete frames etc.) are broadly classified into 6 classes (A to F) according to their vulnerability to ground shaking (the level of earthquake design is also taken into account). In addition, clear definitions are given for the various levels of damage (damage grades) for masonry and reinforced concrete structures respectively (five Damage Grades, from DG-1 for negligible to slight damage to DG-5 for destruction). In the range of intensities that by definition are capable of causing damage to buildings (V and above) the likely ranges in the proportions of the buildings in each vulnerability class to suffer a certain damage grade are clearly defined. Most importantly, it is probabilistic in its approach to damage; as for any type (strength) of building at a particular level of intensity, damage can be considered as a distribution of damage grades (Musson, 2000). It was adopted in this study, as the most appropriate reference for the classification of the existing building vulnerability potential in Lefkada town. Its main disadvantage, of neglecting the ground-structure natural frequencies will be encountered by incorporating eigenfrequencies of buildings, through an in-situ survey for ambient noise measurements in a later stage of our research programme.

Local Seismic Construction Practices (LSCP) in Lefkada comprise: (A) Load-bearing stone masonry structures (LSCP-SM). They are one or two storey buildings consisting of stone masonry walls of thickness 0.60-1.00 m. They have pitched roofs made of timber trusses covered with tiles. (B) A dual system of stone masonry and timber frame structures. Typical buildings consist of two to three storeys, with stone masonry on the ground level and timber frame on the upper storeys. The upper storeys are supported by the stone masonry of the ground level, as well as an additional set of timber columns in the interior of the ground storey. This system of support is locally known as "*pontelarisma*" (LSCP-P). Most of buildings of these two types were erected during the 19th century. (C) After the 1825 severe earthquake (M=6.5) that destroyed the town of Lefkada the new houses adopted a masonry infilled wooden frame structure of the type also known as "*casa baraccata*" (LSCP-TF-CB), a method applied by the Venetians from the 18th century (Makropoulos and Kouskouna, 1994). Many of these buildings survive to this day. Their timber frame is filled with masonry (usually rubble stone) and covered with metal sheets to protect the wood. Their floors are made of timber joists covered with wooden planks. Their roofs are timber trusses similar to those of building types A and B. Figure 2 illustrates typical examples of the LSCP. We note that in our figures we have used the abbreviations SM, P and TF-CB for the building types A, B and C.

Apart from the local type constructions, several reinforced concrete frame structures exist in Lefkada town. Those were built in the period 1961 up to the present. Their roofs are either reinforced concrete flat slabs or low pitch roofs constructed with timber frames covered with tiles. In some of these buildings the second and sometimes the third storey are constructed with timber frame. Their roofs are timber trusses covered with tiles. The timber frame storeys are probably constructed later than the reinforced concrete frame ground floor. Pure reinforced concrete frame structures are classified as type (RCF) structures and those with reinforced concrete frame ground floor with timber frame storeys above as type (RCF-TF) structures.

Figure 2. Local seismic construction practices (LSCP) in the old Lefkada town.

2.2 Buildings inventory

The high costs and the long time necessary, to obtain detailed buildings inventory are among the most challenging factors in the preparation of a damage scenario. For this reason, in most studies related to regional risk assessment the inventory is frequently based on census data. Following this practice, we initially considered the available catalogue from the 2001 National Statistical Service (NSSG) buildings census carried-out in December 2000. For each individual structure, the following information was available: code of building block, construction material, age of construction, roof cover type, plan regularity, number of storeys, plan area and perimeter.

However, apart from artefacts detected for an important number of buildings, the prevalent disadvantage of the NSSG census was the lack of the direct linkage between the buildings typology information and their precise location, as each building was only assigned with the code of its relative building block. Consequently, only median vulnerability estimation per building block could be possible, far below the desired scale for our scope, being the vulnerability assessment of each individual building. To overcome this problem, two research stages were employed:

(1) Exploitation of available digital aerial photos of the area provided by the National Cadastre Organization. Using the aerial photos we measured the footprint of each building and, where possible, we evaluated the type of roof and in some cases the type and material of the constructions. Furthermore, we associated our measurements and macroscopic observations with the relative information included in the NSSG census. By applying this procedure, we managed to identify the exact location for a large part of the building stock. The obtained data were mapped using ArcGIS. The evaluation of the mapped information though, yielded numerous uncertainties that needed to be removed. For this purpose, we conducted the second stage.

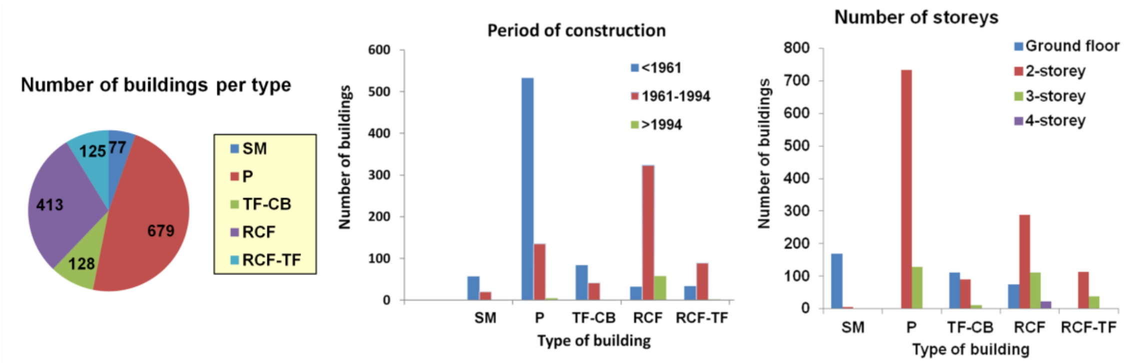

Figure 3. The buildings inventory of the old Lefkada town regarding the type, height and construction period.

(2) An in-situ building by building survey in Lefkada town between 10 and 20 July, 2012. During the field investigation, we verified the dataset provided during the first stage, corrected erroneous observations, filled out any gaps and photographed each individual building. In addition, a unique identification code was adapted to each building, including its reprocessed and corrected inventory data together with its photo imagery. Figure 3 shows the buildings inventory summary, regarding the type, construction period and height (according to the NSSG census).

As mentioned above, the macroseismic scale selected for the classification of the structures vulnerability does not account for the relationship between building natural frequency and the frequency content of the ground motions. For this, we measured ambient noise vibrations at several types of constructions, in order to obtain their eigenfrequencies, to be considered when constructing future earthquake scenarios. This will be discussed in a future publication.

In order to adapt an EMS-98 vulnerability class (A to F) to each individual structure, the building stock of the town was categorized considering the following generalized criteria:

1. Use. As is typical in urban environments, three categories of buildings are distinguished: Residential, public and monuments (see description in Table 1). In this study only residential buildings are considered. Public and monumental structures are exempted and will be separately investigated in another phase of this project.
2. Earthquake Resistant Design (ERD). For reinforced concrete buildings in Greece the level of ERD depends on the period of the construction, given that the National Seismic Design Code improved over the years, following the lessons learnt from earthquakes in Greece and worldwide. In

Lefkada, three building categories are distinguished. Those built prior to 1961 (no ERD), between 1961 and 1994 (moderate ERD) and post 1994 (modern ERD).

Table 1. Summarized typological criteria adopted for the buildings empirical vulnerability classification using EMS-98. (R: Regular, I: Irregular).

Type	Criteria	Vulnerability Class by Plan or Vertical Irregularity		Description/Level of Maintenance
Reinforced Concrete Frame (RCF and RCF-TF)	Period of construction & irregularity	C (R)	B-C (I)	Buildings without ERD or with low ERD (<1961)
		D (R)	C-D (I)	Buildings with moderate ERD (1961-1994)
		E (R)	D-E (I)	Buildings with high ERD (>1994)
LSCP-SM	Maintenance and Irregularity	B (R)	A-B (I)	Good
		A-B (R)	A (I)	Moderate
		A		Poor or abandoned
LSCP-P		B-C (R)	B (I)	Good
		B (R)	A-B (I)	Moderate
		A		Poor or abandoned
LSCP-TF- CB		D (R)	C-D (I)	Good
		C (R)	B-C (I)	Moderate
		B		Poor or abandoned

3. Plan or Vertical Irregularity. It refers to the degree of the structure's divergence from the ideally earthquake resistant cubic or regular rectangle shape but also the presence or not of other structural irregularities. A case is the existence of a ground floor with columns supporting the upper stories but without infill walls (piloti or soft storey) which is used as a car parking facility, or a store (both a rare practice in Lefkada). On the contrary, common is the conversion of the ground floor of an old masonry building into a shop, by knocking down walls to accommodate wider openings. The latter, often carried out without an official plan, may drastically reduce the seismic resistance of the whole structure.
4. Maintenance. This criterion mainly refers to vulnerability classes A, B and C. Buildings with poor maintenance or visibly abandoned may be significantly more vulnerable.

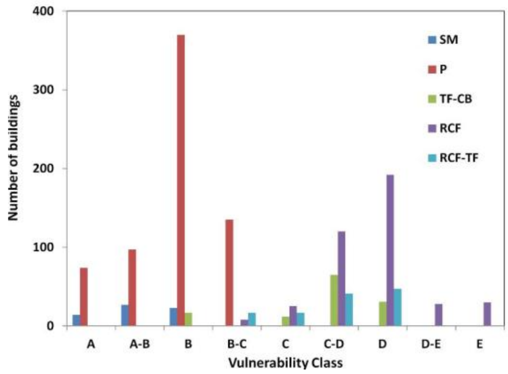

Figure 4. Distribution of the old Lefkada town building stock to EMS-98 vulnerability classes with respect to the buildings types (2012) (see text and Table 1).

The scheme proposed by EMS-98 was adopted in order to assign each individual building to a vulnerability class. Apart from vulnerability classes A to E, interim classes (A-B, B-C and so on) were also used based on the structural irregularity and state of maintenance criteria as described in Table 1. Figure 4 presents the resulting distribution of vulnerability classes per type of structures. Figure 5 presents the spatial distribution of the proposed vulnerability classes across the study area. Those, concern the 2012 buildings inventory. All processed data during this phase were incorporated in an ArcGIS building-per-building scheme (Figure 6).

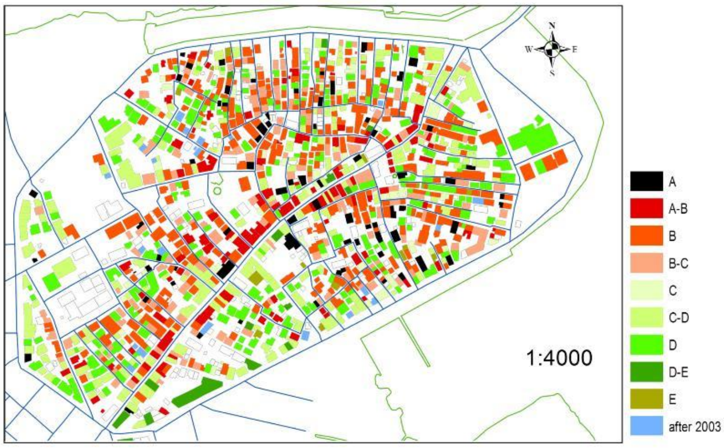

Figure 5. Map of spatial distribution of the proposed vulnerability classes (2012). Buildings erected after 2003 earthquake are also shown.

ESYE_CODE	8
id_build	726
Address	I.Valaoriti & Marinou26
Type of constuction	**RCF**
Period of construction	1961-1994
Soft storey	
Regularity	**no**
Type of roof	Timber frames covered in tiles
Number of floors	2 storey
State of preservation	moderate
vulnerability class	**C-D**

Figure 6. Screenshot example of the integrated GIS scheme including ~1500 constructions in old Lefkada town.

2.3 Comparison with building damages during the 14/8/2003 Mw=6.2 earthquake

On 14 August 2003, Lefkada Island was strongly affected by an Mw=6.2 earthquake (Karakostas et al. 2004). The maximum intensity has been evaluated Io=VIII-IX (EMS) at Lefkada municipality. The most characteristic macroseismic effects on the island were extensive typical ground failures, such as rock falls, soil liquefaction, subsidence, densification, ground cracks and landslides, similar to the pattern reported from some historical Lefkada earthquakes (e.g. 1704, 1914, Ms=6.3; 1948, Ms=6.5) (Papathanassiou et al. 2005). Generally, the damage experienced was moderate with the highest level of damage occurring in Lefkada town, partly owing to the local geology (Karababa and Pomonis, 2011) but also to its proximity to the epicentre. Several studies concerning the 2003 buildings damage distribution in Lefkada town (EERI, 2003; Karababa and Pomonis, 2011) provided a damage percentage on buildings of each category. None of them however, addressed sufficiently the earthquake effects as a function of the buildings typology, the seismic wavefield characteristics and the local site-effects.

In order to refine the earthquake effects observations, during our field survey in Lefkada (10-20 July 2012), we visited the local Organization for Restitution of Earthquake Victims and obtained original records regarding the degree of damage and the exact location of each of the affected buildings in Lefkada town. The buildings inspected soon after the earthquake for their safety and usability, were characterized by the Organization as: Green (without structural or with slight no structural damage, suitable to use); Green–Yellow (slight or moderate damage of the upper storeys); Yellow (moderate structural damage and heavy no structural damage); Red (heavy structural damage). The damage distribution and related EMS98 damage grades (Kouskouna and Malakatas 2000), supports the intensity VIII-IX assigned for Lefkada municipality.

Table 2. Distribution of damage due to the 2003 earthquake with respect to the EMS-98 vulnerability classes and damage grades.

Vulnerability Classes	Green (Damage Grade 1)		Green-yellow (Damage Grade 2)		Yellow (Damage Grade 3)		Red (Damage Grade 4-5)	
	(%)	Number of buildings	(%)	Number of buildings	(%)	Number of buildings	(%)	Number of buildings
A	49.35	76	2.6	4	38.31	59	9.74	15
A-B	77.24	95	4.88	6	15.45	19	2.44	3
B	80.34	335	3.6	15	16.07	67	0	0
B-C	85.52	124	4.83	7	9.66	14	0	0
C	72.97	81	2.7	3	24.32	27	0	0
C-D	88.34	144	3.07	5	8.59	14	0	0
D	96.28	259	1.12	3	2.6	7	0	0
D-E	100	19	0	0	0	0	0	0
E	100	18	0	0	0	0	0	0

Two inspections took place, a preliminary and a final inspection. The data used here are those after the second-final inspections. The damage data were processed and compared with the compiled existing buildings database, excluding the buildings erected after the 2003 earthquake. Table 2 shows the 2003 distribution of damage in the old Lefkada town with respect to the buildings vulnerability class, determined in this study. As it can be observed in Table 2, the amount of damage is higher for the highest vulnerability classes A, A-B and B, except for the case of the vulnerability class C buildings, which present a larger percentage of moderate damage with respect to classes A-B, B, B-C. This effect, however, is an artefact due to the small number of C vulnerability class existing buildings as well as due to the fact that some of these are the old (in poor maintenance) *casa baraccata* buildings that need further consideration as to the appropriate vulnerability class. From Figure 7 it is inferred that dual loading structures (P) and stone masonry (SM) buildings were the most damaged. The spatial distribution of damage per proposed vulnerability class is presented in Figure 8.

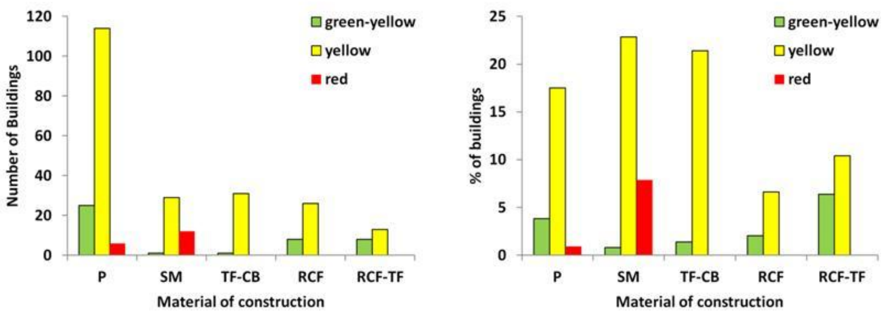

Figure 7. Damage distribution with respect to the structural class of the damaged buildings.

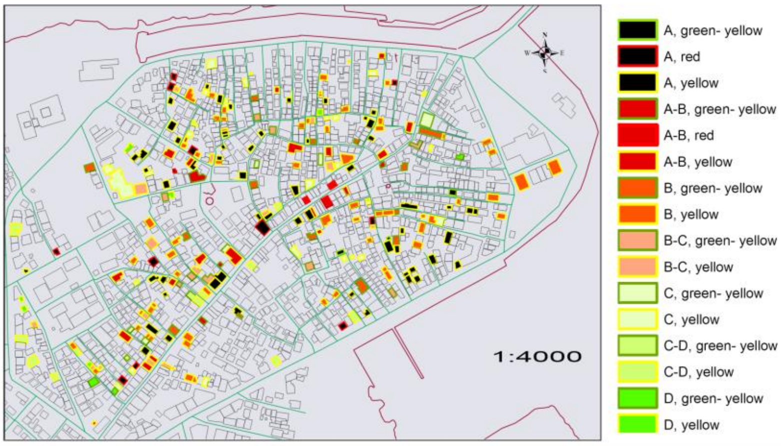

Figure 8. Spatial damage distribution with respect to the proposed vulnerability classes of buildings (2003 earthquake's final damage inspection data).

3 DISCUSSION – CONCLUSIONS

Towards constructing a pivot scheme on the seismic damage in urban areas, we selected the old Lefkada town as a target site for the following reasons: (1) it belongs to the highest seismic hazard zone in Greece; (2) its building stock has been designated as representative earthquake resistant constructions by the European Council Cultural Heritage Unit; (3) new information regarding the local geotechnical conditions and the seismic performance of the individual buildings obtained after the recent strong earthquake of 14/8/2003 (Mw=6.2); (4) the availability of the 2001 NSSG census data; (5) numerous experimental HVSR (Horizontal-to-Vertical-Spectral-Ratios) (Nakamura, 1989) obtained by an ambient noise campaign conducted in 2007, which provided a high resolution image of the superficial geology response characteristics. The goals of this scientific attempt are to improve the assessment of seismic hazard, to investigate the vulnerability of the built environment and to combine the results, in order to carry out damage scenarios. In this study we present results from the first stage of the multi-parametric scientific project, regarding the building stock inventory, and the individual buildings empirical vulnerability assessment. Finally, we compare the buildings damage distribution during the 2003 earthquake with the proposed vulnerability classes. Summarizing, the following tasks have been implemented:

- The catalogue of 2001 census elaborated by the NSSG was processed, corrected, completed and evaluated. This was accomplished by an in-situ survey which allowed peer-inspection of the individual constructions. Each building was assigned a unique code followed by its inventory data.
- A complete archive of photographic material of the building stock was constructed.
- A complete catalogue of the damage degree due to the 2003 earthquake was compiled.
- A vulnerability class was assigned to each structure, using EMS-98 and applying various criteria depending on the particular characteristics of the local architecture.
- All information was employed in a multilayer GIS scheme (topography, digital urban map, buildings typological characteristics, vulnerability class, 2003 damage).

In general, the seismic behaviour of the buildings during the 2003 earthquake is considered sufficient. Constructions classified in A and B categories were mainly damaged (moderately or heavily). Those were mostly single storey and 2-storey buildings. The spatial distribution of damaged buildings implies that those were concentrated in the central part of the town (market place) and along the southern promenade, where an overall dock failure took place (Figure 8). The first observation could be related with the existence of several soft-storey buildings in the central market district, due to the use alteration of residences into stores. The second might be related with ground liquefaction phenomena (Papathanassiou et al., 2005). In addition, the amount of damage is related with the position of buildings within the block, with those located at the edges-corners presenting partially systematic failures. Apparently, the future stages of the project regarding the detailed study of soil and seismic wavefield characteristics, is expected to shed light on whether coseismic effects were solely due to the buildings seismic behaviour, or to soil-structure interaction, or a combination of the both.

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REFERENCES

Benedetti D, Petrini V., (1984). Sulla vulnerabilitá sismica di edifici in muratura: Proposte di unmetodo di valutazione. L'industria delle Construzioni, 18: 66-78.

Calvi, G.M., Pinho, R., Magenes, G., Bommer, J., Restrepo-Velez, L.F., Crowley, H., (2006). Development of seismic vulnerability assessment methodologies over the past 30 years. *Indian Society Journal of Earthquake Technology*, **43**(3):75–104.

Dolce, M., Masi, A., Marino, M., Nova, M., (2003). Earthquake Damage Scenarios of the Building Stock of Potenza (S. Italy) Including Site Effects. *Bulletin of Earthquake Engineering*, **1**: 115–140.

Earthquake Engineering Research Institute (EERI) (2003). Learning from Earthquakes: Preliminary Observations on the August 14, 2003, Lefkada Island (W. Greece) Earthquake. Oakland, USA.

Gazetas, G., (2004). Geotechnical aspects of the Ms 6.4 Lefkada Island, Greece, 2003 earthquake: preliminary assessment, *Proc. of the 5th Int. Conf. on Case Histories in Geotechnical Engineering*, 13–17 April 2004, New York, paper no. 13.

Grünthal, G., (ed.) (1998). "Cahiers du Centre Européen de Géodynamique et de Séismologie: Vol. **15**, European Macroseismic Scale 1998", Europ. Center for Geodyn. and Seism., Luxembourg.

Hatzfeld, D., Kassaras, I., Panagiotopoulos, D.G., Amorese, D., Makropoulos, K., Karakaisis, G.F., Coutant, O., 1995. Microseismicity and strain pattern in NW Greece. *Tectonics*, **14**: 773–785.

Karababa, F., Pomonis.A., (2011). Damage data analysis and vulnerability estimation following the August 14, 2003 Lefkada Island, Greece, Earthquake. *Bull Earthquake Eng.*, **9**: 1015–1046.

Karababa, F.S., (2007). Local seismic construction practices as a means to vulnerability reduction and sustainable development. The case-study of Lefkada Island, Greece, *PhD*, Cambridge University.

Karakostas, V.G., Papadimitriou, E.E., Papazachos, C.B., (2004). Properties of the 2003Lefkada, Ionian Islands, Earthquake Seismic Sequence and Seismicity Triggering. *B.S.S.A.*, **94**: 1976–1981.

Kouskouna, V., N., Malakatas, 2000. Correlation between EMS98 with damage reported of the earthquake of 7th September 1999. *Ann. Géol. des Pays Helléniques*, **38**(B), 187-196.

Makropoulos, K., Kaviris, G., Kouskouna, V., (2012). An updated and extended earthquake catalogue for Greece and adjacent areas since 1900. *Nat. Hazards Earth Syst. Sci.*, **12**: 1425-1430.

Makropoulos, K.C., Kouskouna, V., (1994). The Ionian Islands earthquakes of 1767 and 1769: seismological aspects. Contribution of historical information to a realistic seismicity and hazard assessment of an area. In: P. Albini and A. Moroni (eds), *Materials of CEC Project Review of Historical Seismicity in Europe.* CNR, Milano, **2**: 254 pp.

Musson, R., (2000). Intensity-based seismic risk assessment. *Soil Dyn. Earthq. Eng.*, **20**: 353-360.

Nakamura Y., (1989). A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface. *Quart. Report of Railway Tech. Research Institute*, **30**, No.1.

Papathanassiou G., Pavlides S., Ganas A., (2005). The 2003 Lefkada earthquake: Field observations and preliminary microzonation map based on liquefaction potential index for the town of Lefkada. *Engineering Geology*, **82**: 12– 31.

Whitman, R.V., Reed, J.W., Hong, S.T., (1973). Earthquake Damage Probability Matrices. *Proc. 5th World Conference on Earthquake Engineering*, Rome, Italy, **2**: 2531-2540.