Planning in Seismic Risk Areas – The Case of Faro – Algarve. A First approach

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ABSTRACT: Algarve is an important region in the South of Portugal, with 16 municipalities including Faro, its administrative and political centre. This work aims at deepening the knowledge on the negative impact of an earthquake on an urban system. In order to achieve this goal two methodologies were developed to analyse the vulnerability of the existing housing of Faro. The first one is based on a multi-criteria decision technique involving the structural characteristics of the buildings. The second one applies the EMS-98 macroseismic scale concepts and considers the different soil layers. A simulator to determine the damage inflicted by an earthquake characterised by a magnitude and an epicentral location based on a GIS, compose the whole system. The proposed procedure is a first attempt to integrate tools and methods for assessing the expected earthquake damage, and it was mainly designed to become a support for Civil Protection and land-use planners.

SOMMARIO: L'Algarve è una regione localizzata nel Sud del Portogallo, composta di 16 comuni tra cui Faro è il centro amministrativo e politico. Questo progetto ha come obbiettivo conoscere l'impatto negativo che un terremoto può provocare nei sistemi urbani della città di Faro. Due metodologie sono state sviluppate per analizzare la vulnerabilità degli edifici esistenti. La prima è basata su una tecnica di decisione multi-criteria che include le caratteristiche strutturali degli edifici; la seconda applica il concetto della scala EMS-98. La stima del danneggiamento sismico della città, in funzione della magnitud e della posizione epicentrale, è stata realizzata attraverso l'uso di un simulatore basato su un GIS. La procedura proposta è un primo tentativo di integrare gli strumenti e i metodi per la valutazione del danneggiamento ed è stata progettata principalmente per diventare un sostegno per la Protezione Civile e per la pianificazione territoriale.

1 INTRODUCTION

The vulnerability of societies to risks and natural phenomena shows the different degree of preparation of each society to face these phenomena. It is not by chance that the same type of phenomenon, occurring with the same intensity in different societies, can provoke strong dysfunction in some cases and no dysfunction to others.

This study is intended to characterise with a certain detail the vulnerability of the built stock of the City of Faro, and to estimate the impact of earthquakes in the City (to buildings and to the main road lines). Faro is the administrative and political centre of Algarve, an important region in the South of Portugal, Figure 1.

An enormous amount of information was gathered in relation to the building stock (4334 buildings including the *Historical Centre*), which permit a good structural characterisation (between level I and II of GNDT, 1994, inquiry). Also a good description of the soil strata underneath the City was made. Faro, Figure 2, corresponds to a zone of slightly levelled morphology, marked by the existence of three mild hills, surrounded by recent alluvial sediments and plio-quaternary deposits that cover the underlying geology.

The Algarve seismicity results from the earthquake activity of the contact region of Euro-Asian and African plates (the West region of Cabo de São Vicente) and from the activity in the continental margin crossed by diverse local faults. Several potential seismic sources have been proposed, but there is not yet a tectonic model of consensus among researchers.

The methodology used on this work (Dias *et al.*, 2000) consists of the following phases:

i) characterisation of the housing park through an enquiry building by building;

ii) data treatment and identification of the most important parameters characterising the seismic behaviour of buildings;

iii) microzoning of the study area, taking into consideration the frequencies of soils and general description of surficial soil strata; and

iv) creation of a simulation model to analyse the damage inflicted to the building stock and to the population of Faro.

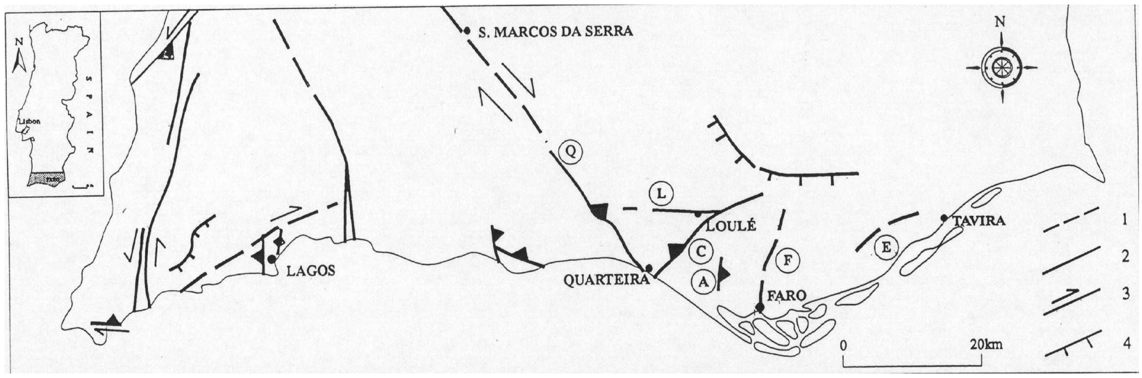


Figure 1 – Location of Algarve and Faro: main faults crossing the territory (Dias *et al.*, 1999)

Figure 2 – Faro City. Study area and classification of zones

The building survey was carried out, to identify the following main parameters: number of storeys, existence of soft story, building use, dwelling, transversal dimension of street, total area of lot, area under construction, geometry of plant, openings in the façade, stair-ways location, urban typology, number of storeys of adjacent buildings, appendages, epoch of construction (Figure 3), predominant materials, roof type and state of preservation. The main characteristics of the buildings and the structural context, as well as the indices of major or minor damages, have been identified. A GIS tool was implemented with all this information, including photos for later verifications.

Two vulnerability assessment methods were used in this study. The first one (*Method 1*) is based on a multi-criteria decision technique involving the structural characteristics of the buildings, and the second one (*Method 2*) on the European Macroseismic Scale 98 (EMS-98).

Due to the chronological aspects of the development of the work, *method 1* makes a detailed analysis of the various characteristics of each building but considers the ground motion in a simplified way, whereas the *method 2* looks to the average building type by means of the EMS-

98 classification and makes a more detailed ground motion analysis by considering the soil effects.

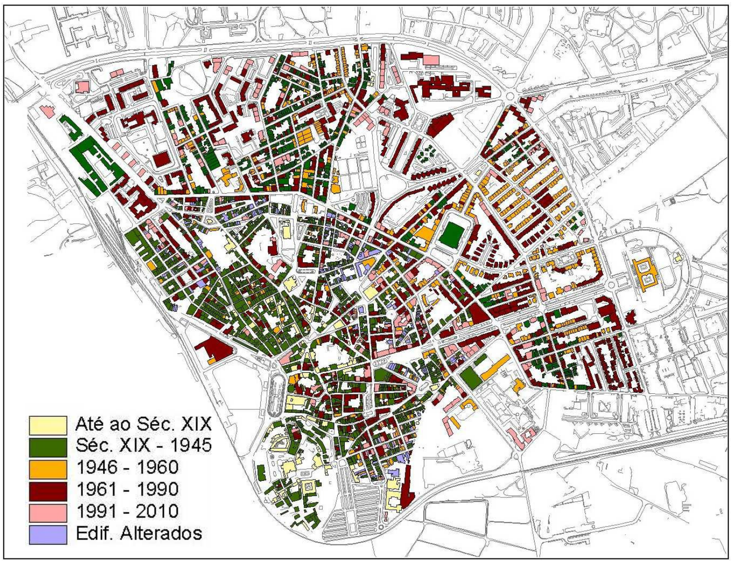


Figure 3 – Epochs of construction

2 DEFINITION OF GROUND MOTION

Attenuation laws which satisfy both the intensities of historical events and the observations of the few strong motion records existing in Portugal (PGA´s only) were used in the context of this study (Baptista and Miranda, 2002, and Oliveira, 2003a, b). They were initially adapted from Youd and Perkins, 1987, Boore *et al.*, 1994, Ambraseys and Adams, 1996, and Lopez-Casado *et al.,* 2002, for the horizontal components. A great deal of effort has been placed on trying to develop these laws, especially for the case of distant earthquakes. The three equations below try to accommodate the situations of nearby, intermediate and distant earthquakes. (They do not have continuity at the distance limits):

$$\ln a = 3.687 + 0.612M - 0.92\ln\sqrt{(d^2 + 3.5^2)} + 0.58 \quad (d<30 \text{ km})$$

$$\ln a = 3.687 + 0.612M - 0.92\ln\sqrt{(d^2 + 3.5^2)} + 0.98 \quad (30<d<100 \text{ km})$$

$$\ln a = 3.687 + 0.612M - 0.92\ln\sqrt{(d^2 + 3.5^2)} + 1.38 \quad (d>100 \text{ km})$$

where a = peak horizontal ground acceleration (PGA - cm/s^2); M = magnitude; and d = epicentral distance (km). Further studies are required not only to obtain better fitted equations to attenuation laws, as well as to define the tectonic model of the region.

Besides the above information, a predominant frequency of ground motion vibration (f_{pred}) was assigned function of distance, such that f_{pred}=5 Hz for distances below 10 km and f_{pred}=1 Hz for distance larger than 300 km, with linear variation between those distances.

Soil influence was considered looking at three main descriptors. First, the regional geological setting at a scale 1:25.000; second, a local soil description, together with the determination of shear wave velocity for the most important formations (Almeida *et al.*, 1999); and third the estimation of predominant frequencies through the use of the Nakamura method (Teves-Costa *et al.*, 2001). These elements gave rise to five categories of soil types, Figure 4, classified by predominant frequencies which vary from 1 to 4 Hz.

To consider the influence of possible resonance between the incoming ground motion and the soil, we have used the simple principle of amplification given by a one degree of freedom system, having assigned a predominant frequency of ground motion as a function of distance and magnitude. A damping ratio of ξ=50% was used.

A conversion of PGA into EMS-98 intensities was then made following Oliveira (2003a), Figure 5.

This concept of proximity of resonance can equally be applied to the buildings, as we have a very good knowledge of different building types in terms of frequencies. This will be the topic of further improvements of the present models.

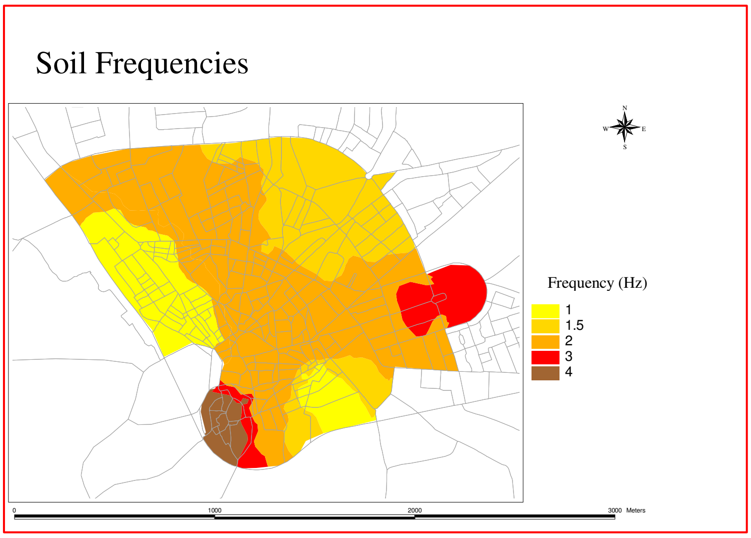


Figure 4 – Soil classes according to predominant frequency of vibration of upper layers (units: Hz)

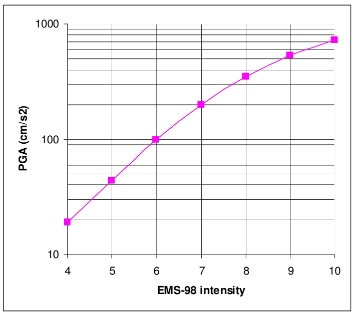


Figure 5 – Conversion of PGA to EMS-98 intensity

3 THE "MULTI-CRITERIA" MODEL OF SEISMIC VULNERABILITY (*METHOD 1*)

3.1 Generalities

In this method we introduced the concept of Point of View (PV) which is a parameter in the survey used to quantify the vulnerability. Six PV´s were considered in the analysis: epoch of construction, number of floors, state of preservation, discontinuity with adjacent buildings, soft-storey, and openings. To obtain a scale value for each PV a "Direct Rating method" (Bana and Costa, 1986) was used.

3.2 Points of View

PV 1 – Epoch of construction - This point of view evaluate the building behaviour in function of the epoch of construction, to which material of construction and constructive techniques are related. During years this was the only used point of view for the elaboration of risk maps. Five categories were identified (Figure 3): (i) Before 1900; (ii) 1900-1945; (iii) 1946-1960; (iv) 1961-1990 and (v) 1991-2001. They correspond essentially to the main periods of construction types, the first of pure masonry wall structures, the second with the initiation of the reinforced concrete (RC) slabs and few beams, the third with a more general application of RC elements, the fourth using the first seismic code, and the last with full use of present RC techniques. Figure 3 shows that the City of Faro was built by concentric almost circular segments, around the historical zone A, but with a great mixture of epochs. Statistics about the epoch of construction (Figure 6 a) clearly indicate a dominance of older construction, prior to 1945, for which the traditional masonry materials predominate.

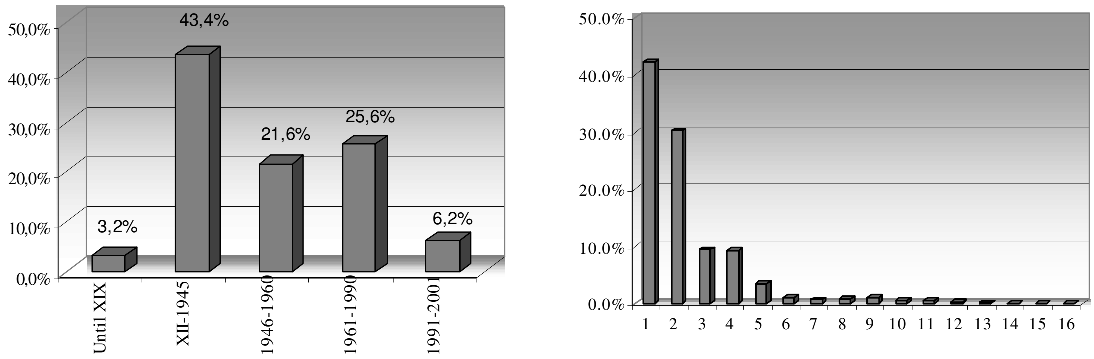
PV 2 – Number of floors – It is an important parameter which should be considered for seismic vulnerability. The most unfavourable scenario for the building is the one that provokes a predominant frequency nearby to the building vibration frequency. Statistics about the number of floors, Figure 6 b), show a predominance of 1 to 2 storeys, which are observed in the older parts of the City.

PV 3 – State of preservation - Four alternatives were used to describe the state of preservation: good, reasonable, bad and ruin. A building in state of ruin was directly assigned to the worst vulnerability class.

PV 4 – Discontinuity with adjacent buildings - This point of view pretends to measure the influence of adjacent buildings by considering the different heights, and consequently the different frequencies exhibited by those buildings. Based on the lateral stiffness of the contacting buildings and on the distance between them either a stiffening effect or pounding may occur.

PV 5 – Soft-storey - Two situations were considered: an opening space used frequently for accommodating shops, restaurants, etc., and a divided space made by using infill brick panels.

PV 6 – Openings – The front façade was considered as a wall with a large portion of openings (windows or doors) or with a small percentage of openings. (For more details see Dias *et al*, 2000).



a) b)

Figure 6 – Percentages of buildings according to: a) the epoch of construction; b) the number of floors

Many interesting characteristics were observed in the analysis of the collected information, related to all Points of View, individually or jointly, such as the existence of a large number of lateral discontinuities of adjacent buildings, but this subject cannot be developed here.

3.3 Vulnerability Index

The vulnerability of the structures has been evaluated by a survey of 4334 buildings in Faro town. Four vulnerability classes were defined: Very High (VHV), High (HV), Medium (MV) and Low (LV). The "Swing Weights method" (Bana and Costa, 1986) was used to quantify the weight of contribution of each PV to the building vulnerability.

The Very High class of vulnerability was obtained using the "Screening Method" (Bana and Costa, 1986), and all buildings in state of ruin were placed there.

Then, all other buildings were classified into one of the other three vulnerability classes through a "compensatory model" using the Simple Addition Technique (Bana and Costa, 1986). This model attributes a global number in a 1 to 100 scale to each building, by using a weighted average of the partial punctuation obtained in each point of view.

3.4 Damage classes

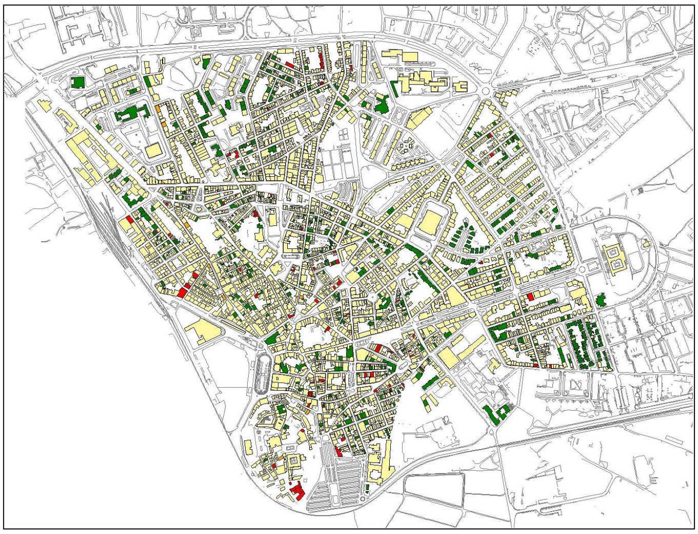
Given the classification 1-100 for each building it was necessary to introduce limits for the definition of "good", "neutral" and "poor". At this stage the number of storeys was introduced to differentiate the "low" from the "tall" buildings differently affected by the two extreme scenarios (*nearby* and *distant scenario)*, through the proximity or not between the predominant frequencies of ground motion and the frequencies of buildings. In consequence we derived two vulnerability types, one to be applied in the case of *nearby scenario,* and another in the case of *distant scenario.*

For a better comprehension of the meaning of vulnerability classes VHV, HV, MV and LV, we have used the descriptions assigned to reinforced concrete and masonry structures by the "*Hazus99 Technical Manual*": the extension and severity of damage in the structural and non-structural components of a building is described by five degrees: no damage; light damage; moderate damage; severe damage; and collapse. In Portugal, following the construction traditions we assign the above referred typologies to two categories, as follows:

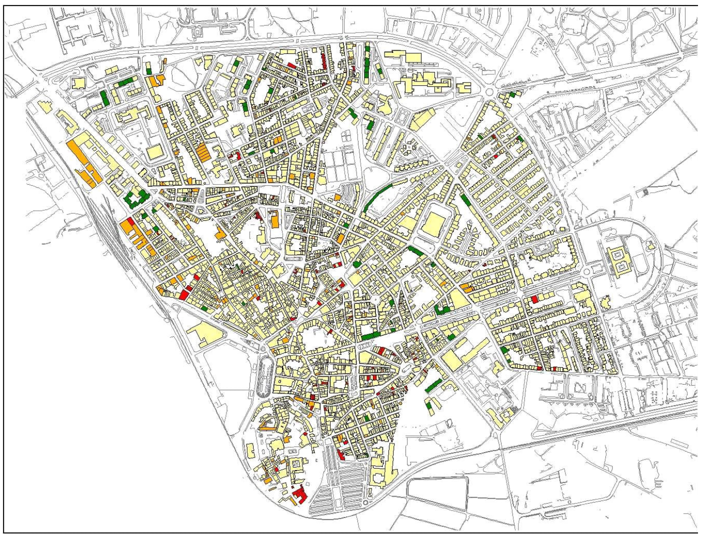
URM - *Unreinforced Masonry Bearing Walls* – buildings constructed until approximately 1940. They are made of masonry walls with wooden floors.

C3 - *Concrete Frame Buildings with reinforced Masonry Infill Walls* – buildings constructed after 1940, with the application of RC frames. They have plenty of clay-brick infill walls.

Figure 7 a) and b) presents the vulnerability index according to *method 1*, building by building, for both typical *distant* and *nearby scenarios*.



Distant scenario



Nearby scenario

Figure 7 – Vulnerability index (*method 1*): a) *distant scenario*; b) *nearby scenario*

4 THE EMS-98 MODEL FOR SEISMIC VULNERABILITY

4.1 Vulnerability evaluation

The vulnerability analysis of the stock of buildings was made following the concepts described in the EMS-98 scale (Grunthal, 1998), and implemented by Giovinazzi and Lagomarsino (2002 and 2003). We used the basic vulnerability functions adapted to the reality of Faro (Table 1). Application of penalizing functions considering the number of floors, plan and vertical irregularities, state of preservation, and other factors will be the subject of further studies. All the necessary data for this analysis is available through the GIS data-bank.

Mean damage ratio by administrative blocks of buildings, minimum and maximum values of damage, were obtained. Number of collapsed and seriously damaged buildings were also computed. A few of these values are presented for typical earthquake scenarios.

Table 1. Correspondence between EMS-98 typologies, Faro typologies and Vulnerability index (Giovinazzi and Lagomarsino 2002).

EMS-98 Typology	Faro Typology	Vulnerability Index
M2	Before 1900	0.840
M5	1900-1945	0.740
-	1946-1960	0.553
RC2	1961-1990	0.447
RC3	1991-2000	0.287

4.2 Population at risk

Residents and population dynamics for different periods of the day and epochs of the year were estimated based on the population Census of 1991 and 2001 and on several indexes connected to commercial activities, leisure and population concentration. The information unit is by zone A to I, as referred in Figure 2, in a total of 19578 permanent residents.

Vulnerability of the population was obtained using the proposals of Coburn and Spence (2002), which indicate the number of dead, seriously injured, trapped people, homeless, etc.

5 EARTHQUAKE SIMULATON

A GIS simulator was built using *ArcView®* software, with data supported in a data-base containing all the information on soils and buildings. Any kind of earthquake scenario can easily be developed given the epicentral location and magnitude.

Output includes all kind of variables from ground motion PGA and Intensities, to damage to buildings, people affected, building by building or by groups of buildings such as blocks.

To analyse the vulnerability and the damages provoked by earthquake loading, and compare the two different methods, we used three distinct seismic scenarios to represent the most probable occurrences affecting the City of Faro. They are quite different in magnitude and epicentral distance (see Figure 1):

Scenario 1 – *Nearby Earthquake* - epicentre located in the Loulé Fault, 15 km North from Faro, with Richter magnitude 5.5; this event causes EMS-98 VI/VII for the case of no soil differentiation and V to IX with soil differentiation (predominance of VI).

Scenario 2 – *Intermediate Earthquake* - epicentre located in the range of 30 to 100 km from Faro, occurring in the São Marcos da Serra Fault to NW of Faro, or in the Atlantic Ocean 70 km SE of Faro, with Richter magnitude 6.5; this event causes an average EMS-98 VII.

Scenario 3 - *Distant Earthquake*- epicentre located at around 150 km SW from Faro (Fault in the Atlantic Ocean), with Richter magnitude 7.5; this event causes an average EMS-98 VII for the case of no soil differentiation and VI to VIII with soil differentiation (predominance of VIII).

Table 2 presents a summary of PGA and EMS-98 intensities for the several cases above referred.

Table 2. Peak horizontal ground acceleration for different magnitudes and different epicentral distances. Correspondence in Intensities and return period (T). Probability of liquefaction for susceptible soils.

Distance	Magnitude	PGA (cm/s^2)	Intensity	T (years)	Probability of
	5	122	VI	200	0%
15	5.5	166	VI/VII	500	
	6	225	VII	1000	60-90%
	6.5	84	VI	50	
150	7	113	VI/VII	150	
	7.5	154	VII	400	

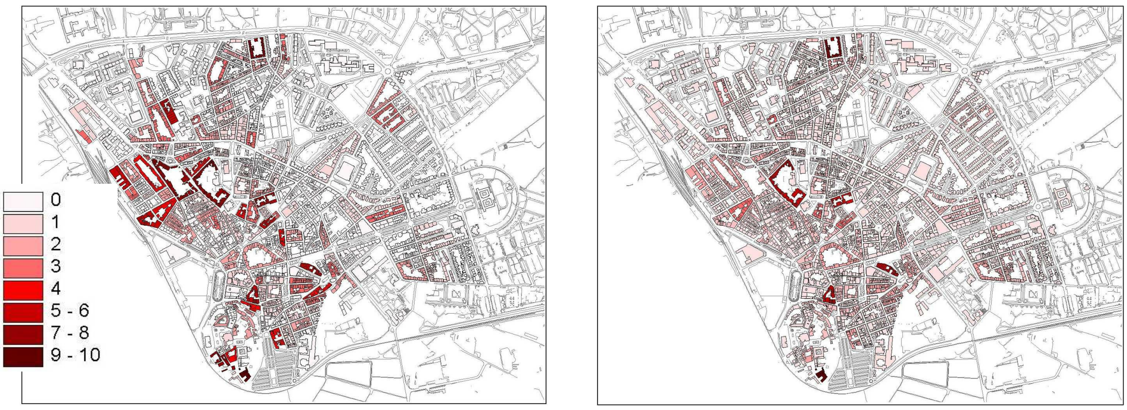
Other less probable scenarios (but inflicting larger damages) were also developed for detecting possible anomalies and for calibration purposes such as comparing effects in historical events.

The intensities obtained for these cases are very different if we include or not the effect of soil. Using *method 1* we neglected the soil, but considered the influence of height of buildings to relate resonance with ground motion from distant sources. In this method we also considered the above referred Points of View. In *method 2* we developed the soil influence to act over EMS-98 intensities, but so far did not consider the possibility of resonance of buildings, or other penalizing functions. In both cases the epoch of construction was the main base for vulnerability assessment.

6 RESULTS

6.1 Method 1

The results for scenarios (M=5.5; d=15 km) and (M=7.5; d=150 km) based on *method 1* are presented in Figure 8 a) and b), and summarized in Table 3 and constitutes a first contribution to the vulnerability analysis of buildings in Faro.



a) **(M=5.5; d=15 km)** b) **(M=7.5; d=150 km)**

Figure 8 - Damage scenarios by the block (*method 1*). (Number of buildings which collapse per block).

Table 3. Number of buildings affected to each damage class (*method 1*)

Class	Distant earthquake (M=7.5; d=150 km)		Nearby earthquake (M=5.5; d=15 km)	
	Buildings	% of Total	Buildings	% of Total
A	107	2,5 %	107	2,5 %
B	16	0,4 %	169	3,9 %
C	3590	82,8 %	3981	91,9 %
D	621	14,3 %	77	1,8 %
Total	4334	100%	4334	100%

A few comments can be made in relation to these results.

For the distant earthquake (epicentral distance: 150 km; magnitude: 7.5), causing EMS-98 intensity VII in Faro, we observe that the majority of buildings belong to vulnerability class C, which corresponds to Moderate Damage. The more affected are higher buildings for which a better match of frequencies with ground motion exists.

Buildings in zones D and F are typically 1 to 2 storeys high, and fall in Class D. Class A, with higher vulnerability, is assigned to buildings in very poor state of conservation.

6.2 Method 2

The results for *method 2* are presented in Figures 9 and 10 with a summary of main values in Table 4. The selective EMS-98 intensities taking into consideration the predominance of soil frequency and of ground motion are also presented.

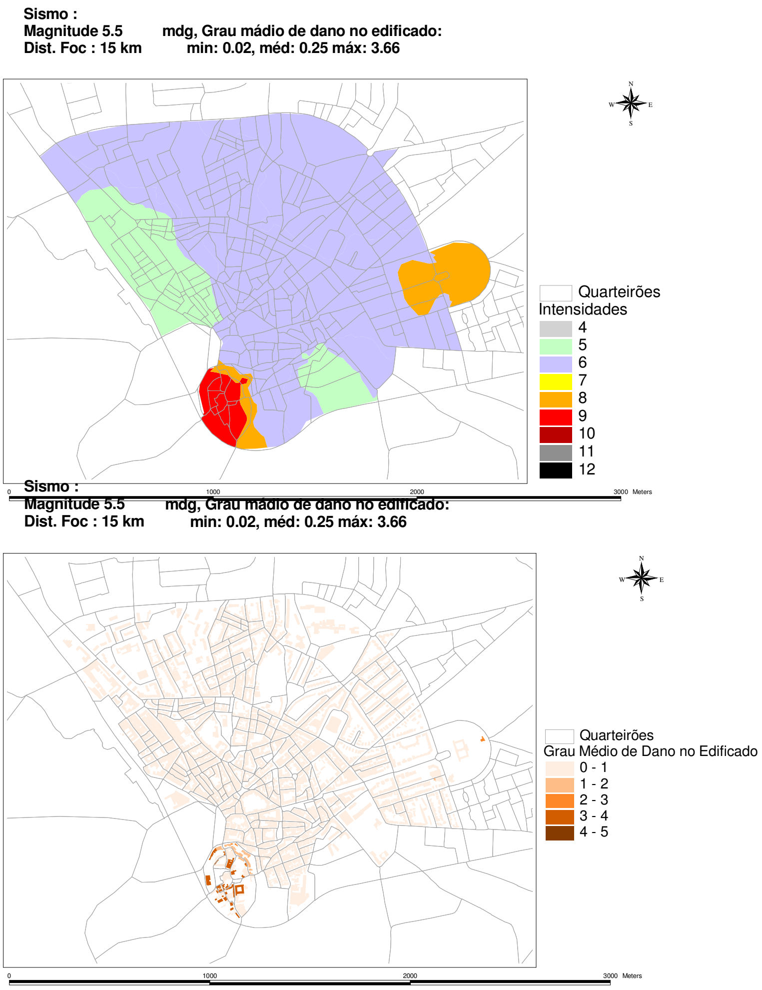


Figure 9 – Intensities and damage scenarios block by block, *nearby scenario* (*method 2*). (scale 1-5).

Comparing the two approaches, we observe that results do not differ very much in general terms, but present great differences in the detail. We have mixed various techniques of evaluation to understand the influence of options. Much further work has to be developed in order to reduce the variability in the final product.

We think this is a first tentative to put several tools to work together. However, the final results are not calibrated with historical data, the only way capable of measuring the rightness of the models, at least for the old type of masonry. According to our experience the values obtained are quite below what we would anticipate from previous studies made in Lisbon an in the Greater Metropolitan Area of Lisbon (Oliveira 2004), for similar intensity values. Therefore, while all information gathered points to moderate damage, great caution should be exercised until more confidence can be placed in the present results.

As seen in Table 4, many differences are observed for each scenario, not only in total number but also in the geographical location (Figures 9 and 10).

From our past experience with the studies done in Lisbon (Oliveira, 2004), where classical vulnerability analysis as made by Tiedemann (1992) and Coburn and Spence (2002) was performed, the final results for similar ground motion intensities and similar building stock were slightly more pessimistic than the ones with the Giovinazzi and Lagomarsino (2002) technique. However, in relation to the victims (deaths, injures and homeless) the present numbers are in the order of 20 times less than in the Lisbon model. Even though we know the great dispersion in these variables, no explanation has been found for this important discrepancy.

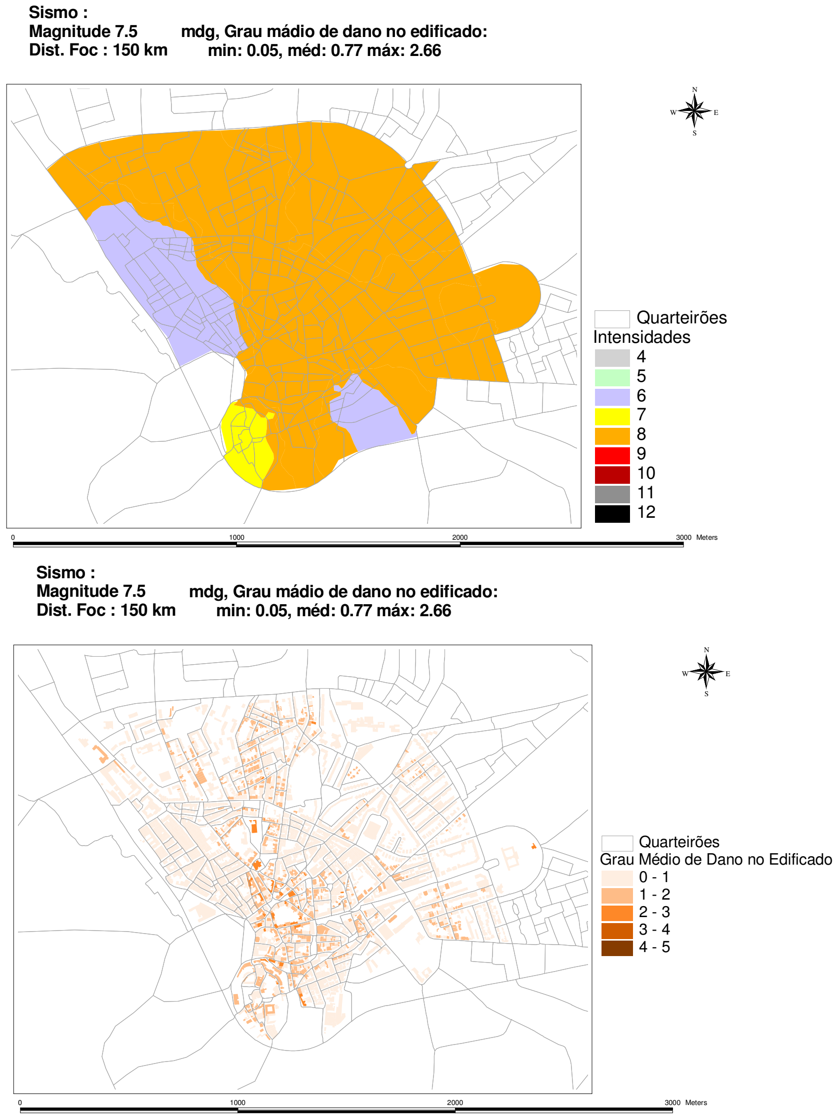


Figure 10 – Intensity and damage scenarios block by block, *distant scenario* (*method 2*). (scale 1-5).

Table 4. Estimation of variables for different scenarios (magnitudes and epicentral distances), including the large 1755 earthquake.

Earthq	Magni-tude	Focal dist. [km]	Trapped popula-tion	Death	Injures	Home-less	Colla-pses	Severe damage	Mean damage grade (0-5)		
									min	mean	max
1755	8.75	229	854	207	495	1495	115	635	0.27	1.49	3.66
-	7.5	150	169	39	99	490	10	289	0.05	0.77	2.66
-	5.5	15	36	8	22	82	10	43	0.02	0.24	4.33

6.3 Liquefaction Analysis

A preliminary analysis of liquefaction was also performed. Because zones C, D, part of zones B and F, and all the northern part of the City of Faro is laying on alluvial soils with high water level, the potential for liquefaction of these sediments, when saturated, varies between high and moderate, according to Youd and Perkins (1987). An earthquake with M=6 at 15 km from Faro produces a PGA=225 cm/s^2, and the probability of liquefaction in those areas vary from 60 to 90%, according to the criteria defined by Liao, *et al.* (1988). Table 2 summarizes several other situations that may arrive in Faro.

7 SEISMIC RISK PLAN AND FINAL CONSIDERATION

7.1 Microzoning maps

Even though many uncertainties are still present in these preliminary studies, the maps produced are already great tools for the authorities to visualize the potential losses that can occur in the eventuality of the above mentioned seismic scenarios. We know the areas possibly more affected, where the concentration of cases requires the presence of the agents of the Civil Protection for a more rapid and efficient intervention. We also know the zones of liquefaction, the amount of injuries, deaths, homeless. We know the streets more prone to obstruction, the routing to use in case of emergency.

7.2 Strategies for Risk Mitigation

Beyond the parameters above analysed, the following items are important for future studies: important structures, such as hospitals, schools, governmental offices, lifelines, structures of cultural and patrimonial value, etc. Among these play a very important role the accesses to the City, both by car and by train, because all lines cross liquefiable areas. The presence of industrial plants and the continuous gas transportation from storages and the airport facilities by large trucks put an important threat in case of earthquake.

The risk of a catastrophe can be reduced with actions which include prevention, urban planning and good organization of emergency. The importance of a national code regulation for different types of constructions is a first step towards this ultimate objective. Its appropriate application in terms of design and construction is a second step.

Faro with its location close to the ocean should also look into the potential for the tsunami run-up, and other risks of flooding.

Planning the use of the urban land is another tool in the mitigation of earthquake risks. The simple change of implantation of certain activities may reduce damage.

For the system of the "escape streets" and the "safe spaces", the Urban Plan will have to increase the alternative ways, increase the accessibility to the "safe" spaces and reduce the direct and induced vulnerability ways. These improvements will have to be led according to the urban drawing and the characteristics of the existing buildings.

As a final conclusion it can be said that the reduction of the structural vulnerability by a preventive reinforcement and by good use of code regulations, the correct use of the land, and a good educational campaign are the most important aspects for mitigation of earthquake risk, independently of the efforts to reduce the existing uncertainties. Specific measures should also be applied to other matters, such as fire following the earthquake, local landslides, etc.

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References

Ambraseys, N. N.; Adams, R. D. 1996. Large Magnitude Central American Earthquakes 1898-1994, Geophysical Journal International, v.127, pp 665-692.

Almeida, F.; Moura, R.; Teves-Costa, P.; Oliveira, C. S. 1999. Caracterização Dinâmica das Areias de Faro através de Ensaios Sísmicos, Proceedings, 4º Encontro Nacional de Sismologia e Engenharia Sísmica, pp. 233-243, Universidade do Algarve, Faro. (in portuguese).

Bana e Costa, C. A. 1986. Avaliação de Projectos e Decisão Pública, Sebentas, 11/1986, IST, Lisboa. (in portuguese)

Baptista, M. A.; Miranda, J. M. 2001. Atenuação da Intensidade Sísmica na Península Ibérica, Proceedings, 5º Encontro Nacional de Sismologia e Engenharia Sísmica, pp. 49-56, Laboratório Regional de Engenharia Civil, Ponta Delgada. (in portuguese).

Boore, D. M.; Joyner, W, B.; Fumal, T. E. 1994. Ground Motion Estimates for Strike and Reverse-Slip Faults, in Hazus99.

Census-1991. INE, Lisbon.

Census-2001. INE, Lisbon.

Coburn, A.; Spence, R., 1992. Earthquake Protection, UK.

Dias, C.; Ferreira, M.; Oliveira, M.; Pestana, P. 2000. Planeamento em Zonas de Risco Sísmico na Cidade de Faro, Projecto Final de Curso, IST, Lisboa. (in portuguese)

Dias, R; Cabral, J; Terrinha, P. 1999, Sismotectónica da Região de Faro, Proceedings, Laboratório Regional de Engenharia Civil, Ponta Delgada, pp. 11-18. (in portuguese)

Giovinazzi, S.; Lagomarsino, S. 2002. A Method for the Vulnerability Analysis of Built-up areas, Proceedings, International Conference on Earthquake Losses and Risk Reduction, Bucharest.

Giovinazzi, S.; Lagomarsino, S. 2003. Seismic Risk Analysis: a Method for the Vulnerability Assessment of Built-up areas, Proceedings, European Safety & Reliability Conference, Maastricht.

GNDT, 1994. Scheda di esposizione e Vulnerabilità di Primo Livello e di Rilevamento Danni, Gruppo Nazionale per la Difesa dai Terremoti, CNR, Roma.

Grunthal, G. 1998. European Macroseismic Scale 1998. Cahiers du Centre Européen de Geodynamique et de Séismologie , Vol 15, Luxembourg.

Hazus 99. 1999. Technical and Users Manuals, FEMA. Washington, D.C.

Liao, S. S.; Veneziano, D.; Whitman, R. V. 1988. Regression Models for Evaluating Liquefaction Probability, Journal of Geotechnical Engineering, vol. 114, No.4.

Lopez-Casado, C. *et al*. 2002. Geotechnical and Structural Effects During El Salvador Earthquakes of January and February 2001, Proceedings, 3ª Assembleia Luso-Espanhola de Geodesia e Geofísica, Valência, pp 1937-1943. (in spanish).

Oliveira, C. S. 2003a. Conversion of Intensity into PGA for the Iberian Peninsula, Report in progress, Lisboa.

Oliveira, C. S. 2003b. Catálogo de Registos dos Movimentos Fortes em Portugal. Report in progress, Lisboa.

Oliveira, C. S. 2004. The Influence of Scale on Microzonation and Impact Studies, Chapter 2, in Recent Advances in Earthquake Geotechnical Engineering and Microzonation, Ed. Atilla Ansal, Kluwer Publishing.

Teves Costa, P.; Vales, D.; Vicêncio, H. 2001. Estudo de Ruído Ambiental na Cidade de Faro, Proceedings, Sísmica 2001, LREC, Ponta Delgada, pp. 251-260. (in portuguese)

Tiedemann, H. 1992. Earthquakes and Volcanic Eruptions: A Handbook on Risk Assessment, Swiss Re, Zurich.

Youd, T. L., Perkins, D. M. 1987. Maping of Liquefaction Severity Index, Journal of Geotechnical Engineering Division, ASCE, vol. 118, no.11, pp. 1374-1392.