SEISMIC ZONATION FOR PORTUGUESE NATIONAL ANNEX OF EUROCODE 8

A. Campos Costa[1] M.L. Sousa[2] and A. Carvalho[2]

[1] *Principal Research Officer, Dept. of Structures,Laboratório Nacional de Engenharia Civil, Lisbon. Portugal*
[2] *Research Officer, Dept. of Structures,Laboratório Nacional de Engenharia Civil, Lisbon. Portugal*
Email: alf@lnec.pt luisa.sousa@lnec.pt xana.carvalho@lnec.pt

ABSTRACT :

The development of the Portuguese National Annexes of Eurocode 8 required the definition of a seismic zonation for Portugal. The goal of this paper is to present the applied methodology to perform the Probabilistic Seismic Hazard Analysis (PSHA) and to obtain seismic zonation for Portugal Mainland, Azores and Madeira Archipelagos. Similarly to the Portuguese code presently enforce (RSA, 1983), two scenarios were considered in PSHA computation: (i) a scenario labeled seismic action 1, characterizing earthquakes with their epicenters mainly offshore and (ii) a scenario labeled seismic action 2, referring to events with their epicenters mainly inland. The model of gross-source zones and the parameters defining seismic occurrence process in each source zone, like the Poissonian process and the exponential distribution of magnitudes, was adapted from Sousa (1996). Two different spectral attenuation laws were applied, consistent with the two above mentioned seismic scenarios, namely: (i) a recent regional attenuation law derived for Portuguese seismotectonic environment, based on a finite fault non-stationary stochastic seismological model calibrated for the region (Carvalho *et al.*, 2008), valid for seismic action 1 and (ii) the Ambraseys et *al*. (1996) model, valid for seismic action 2. The PSHA was performed for all Portuguese counties and for the 475 years return period. The correspondent hazard map was used as the basis for seismic zonation. Portuguese counties were sorted according to their Housner intensity, which was used as a criterion to classify each county in a pre-defined number of seismic zones.

KEYWORDS: Azores, Eurocode 8, National Annex, Portugal, Seismic zonation, Seismic hazard

1. INTRODUCTION

Within the Technical Committee CEN/TC 250 "Structural Eurocodes", it was constituted a specific working group for the Eurocode 8, that among other activities, had the mission to prepare each country National Annex, that contain the «information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works» (CEN 2004).

A team of the Structures Department of the Laboratório Nacional de Engenharia Civil was responsible for the PSHA pre-standard scientific research that was developed in order to support the decisions of the Eurocode 8 Portuguese working group. This team presented alternative zonation proposals that were discussed within Eurocode 8 working group, and that incorporated some suggestions resulting from a public presentation of that proposals to the technical and scientific community.

The main objective of this paper is to present the PSHA that was laid out to be the reference for seismic zonation and seismic action levels for the Portuguese National Annexes of Eurocode 8. At the final part of this paper it is also presented most recent Portuguese seismic zonation and elastic response spectra, bearing in mind that, those elements constitute the last draft solutions proposed by the Eurocode 8 working group, don't having, for the time being, an official approval.

2. PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)

2.1 PSHA model

Following Cornell's approach the annual frequency of exceedance of a hazard level h, $\lambda_{H>h}$, in the region characterized by N_Z seismic source zones, identified by the index k, is given by:

$$\lambda_{H>h} = \sum_{k=1}^{Nz} \nu_k \cdot \int_M \int_R \mathrm{P}(H > h | m, r)_k \, f_M(m)_k \, f_R(r)_k \, \mathrm{d}r \, \mathrm{d}m \qquad (2.1)$$

where ν_k is the mean annual rate of earthquake occurrence (with $M > m_{min}$) in source zone k, $\mathrm{P}(H > h | m, r)_k$ is the distribution of a ground motion hazard level, conditional on magnitude and distance, described by a attenuation law and $f_{.}(\cdot)_k$ is the probability density function in source zone k of the considered random variables, magnitude M (described by Gutenberg-Richter model) and distance R (uniform distributed), admitted independent.

2.2 PSHA for Mainland Portugal

2.2.1 Seismic source model and catalogue

A model of 11 seismogenic zones, adapted from Sousa and Oliveira, 1997, was considered to re-evaluate seismic hazard for Mainland Portugal. The seismogenic zonation was designed taking into consideration the Portuguese seismotectonic environment, but mainly the distribution of historical and instrumental seismicity with epicentral map shown in figure 2.1 and the principle of adjusting source zones to large geological units. Figure 2.1 also illustrates the delineated model of seismogenic (or seismic source) zones.

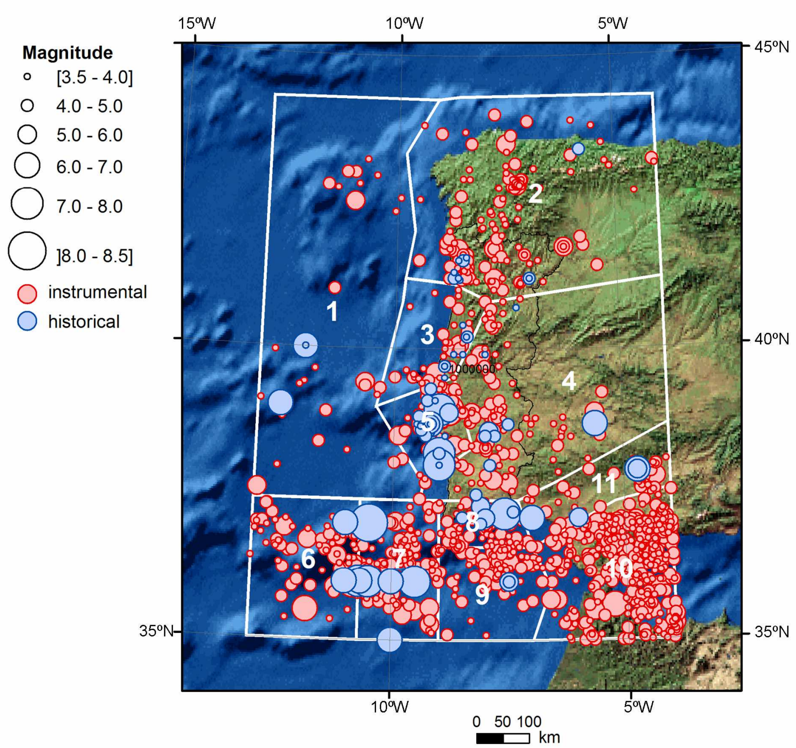

Figure 2.1 Epicentral map, 33 AD-1999, M ≥ 3.5, historical and instrumental earthquakes (Sousa and Campos Costa, 2008) and the seismic source zones (adapted from Sousa and Oliveira, 1997)

To estimate the parameters that characterize the seismic occurrence process, the historical and instrumental catalogue was considered (figure 2.1). The used catalogue covers a time period of approximately 2 000 years and suffered a variable time interval completeness treatment and an aftershock removal process (Carvalho and Sousa, 2001).

2.2.2 Characterizing seismic occurrence process

The complete catalogue, without aftershocks, was used as the base information to estimate the parameters of the Poissonian process and of the exponential distribution of magnitudes for each seismogenic zone, i.e., the upper bounded Gutenberg-Richter model. Further details may be found in Sousa, 1996 or in Sousa and Oliveira, 1997). Table 2.1 presents, for each zone, the upper bound magnitude of Gutenberg-Richter model, the *b*-value estimated by a maximum likelihood method for different magnitude completeness intervals (Weichert, 1980), and the mean annual rate of earthquake occurrence.

Table 2.1 Maximum magnitude (m_{max}), estimates of b value of Gutenberg Richter law and mean annual rate of earthquake occurrence with M >3.5, for each source zone k

Source Zone	m_{maxk}	b_k	ν_k
1	7	-0.68	0.418
2	6	-0.66	1.224
3	5.6	-0.86	0.447
4	7	-0.82	1.207
5	7.2	-0.71	0.840

Source Zone	m_{maxk}	b_k	ν_k
6	7.5	-0.72	0.798
7	8.75	-0.72	1.087
8	7.8	-0.77	0.7057
9	7.1	-0.81	0.9547
10	6.2	-0.79	4.474
11	7	-0.84	0.566

2.2.3 Seismic ground motion attenuation

In what concerns the seismic ground motion attenuation process two frequency-dependent attenuation equations for ordinates of horizontal acceleration response spectra were adopted. For inland source zones 2, 3, 4, 5, 8 and 11 the Ambraseys *et al*. (1996) model, for rock sites, were used and for offshore source zones 1, 6, 7, 9 and 10 source zones new earthquake ground-motions relations for Portuguese seismotectonic environment recently developed, based on a finite fault non-stationary stochastic seismological model calibrated for the region [Carvalho et al., 2008] were applied.

2.2.4 Probabilistic seismic hazard maps

Similarly to Portuguese code presently enforce, and due to seismotectonic characteristics of this region, two scenarios were considered in PSHA computation: (i) a hazard scenario labeled seismic action 1, characterizing long distance severe magnitude earthquakes, with their epicenters mainly offshore and evaluated with seismicity of source zones 1, 6, 7, 9 and 10 and (ii) a hazard scenario labeled seismic action 2, characterizing short distance moderate magnitude earthquakes, with epicenters mainly inland and evaluated with seismicity of source zones 2, 3, 4, 5, 8 and 11.

Figure 2.2 shows the hazard maps correspondent to the reference return period of 475 years. This return period is one the Nationally Determined Parameter (NDP) adopted within Eurocode 8 working group and is the seismic action for which current structures should verify the no-collapse requirement. Notice that in the Portuguese code presently enforce (RSA, 1983) the adopted return period was 975 years.

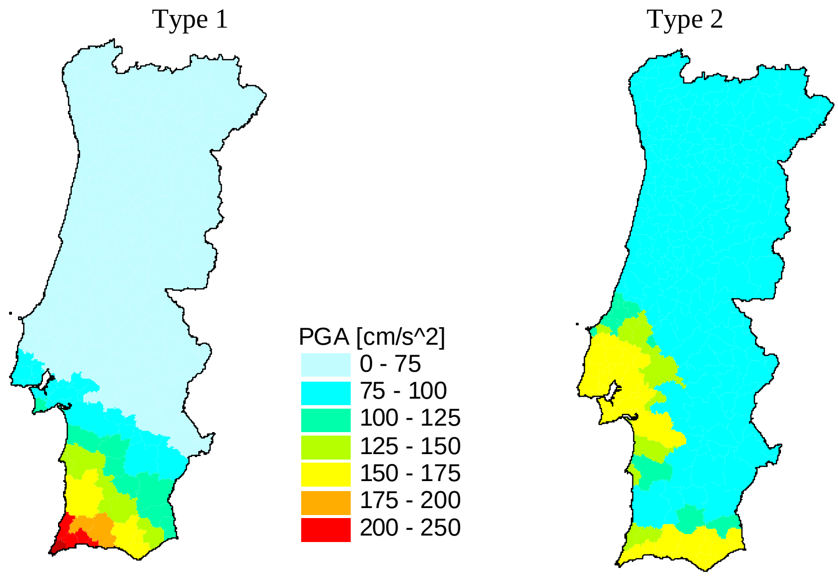

Figure 2.2 Mainland Portugal hazard maps for a exceedance probability of 10% in 50 years

2.2 PSHA for Azores and Madeira Arquipelagos

PSHA for Azores Archipelago was already published at an international periodic review (Carvalho *et al.*, 2001), so it will not be addressed in this paper. Figure 2.3 shows the 475 years return period map that was one of the results of that study and that support the decisions of the Eurocode 8 Portuguese working group.

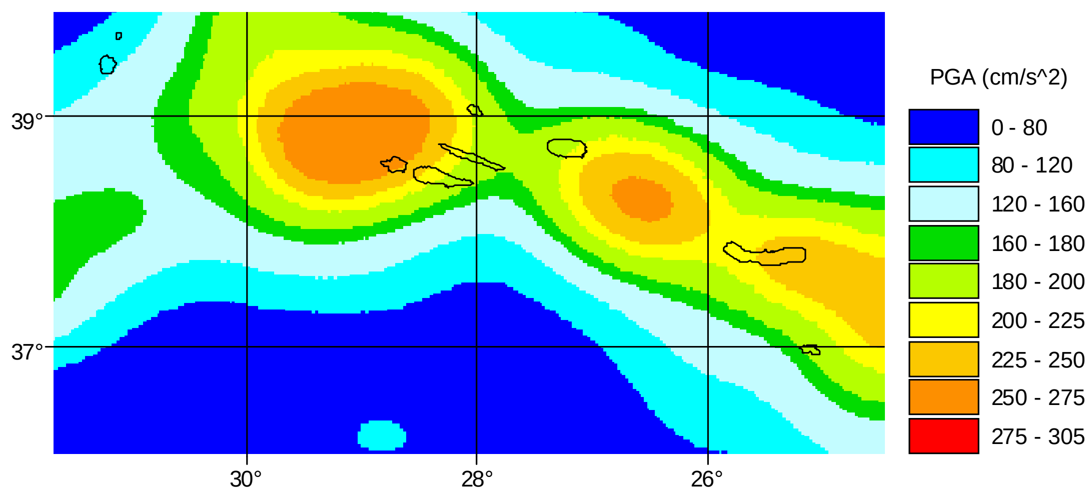

Figure 2.3 Central group of Azores islands hazard map for a exceedance probability of 10% in 50 years (Carvalho *et al.*, 2001)

Regarding Madeira Archipelago, it wasn't done a specific PSHA for this region, and it was included, following the same approach of the Portuguese seismic code (RSA, 1983) presently enforce, in the less severe seismic zone of a long distant scenario.

3. SEISMIC ZONATION

3.1 Mainland Portugal

In EN 1998-1 the country seismic zonation is one of the Nationally Determined Parameters (NDP). Seismic zonation should be established for a reference peak ground acceleration on type A ground[1], a_{gR}, correspondent to the reference return period T_{NCR} of seismic action for the no-collapse requirement, i.e. 475 years (figure 2.2).

In a first stage, it was proposed for discussion a territory seismic zonation with the same number of zones as the code presently enforce (RSA, 1983), i.e. 4 seismic zones. Housner intensity (Housner, 1952), for 5% damping ratio, was used as the criterion to classify each county seismic hazard. The 278 Mainland Portuguese counties were sorted by Housner intensity evaluated for short distance and long distance scenarios and for the 475 years return period. The counties limiting zones were chosen according to a least square criterion based on an iterative process that minimizes the sum of quadratic errors between Housner intensity of each county and the average Housner intensity of a first guess seismic zone.

As already mentioned in the Introduction, this initial proposal was discussed within Eurocode 8 working group, and incorporated some suggestions resulting from a public presentation for the technical and scientific Portuguese community. In accordance to those discussions, the initial proposal progressed to a 5 seismic zones territory division, for the long distance scenario, and a 3 seismic zones division, for short distance scenario. Regarding the former scenario one intends to obtain a smoother acceleration transition between consecutive zones, mainly in Algarve region, and in the latter scenario some zones with approximate peak ground acceleration were eliminated (Carvalho, 2007).

Table 3.1 presents the reference peak ground acceleration, a_{gR} for the considered seismic zones and for the two scenarios.

Table 3.1 Reference peak ground acceleration, a_{gR}

Type 1 seismic action		Type 2 seismic action	
Seismic zone	a_{gR} [m/s^2]	Seismic zone	a_{gR} [m/s^2]
1.1	2.5	2.1	2.5
1.2	2.0	2.2	2.0
1.3	1.5	2.3	1.7
1.4	1.0	2.4	1.1
1.5	0.5	2.5	0.8

Figure 3.2 illustrates seismic zonation for the Portuguese National Annex of NP EN 1998-1 where, in what concerns Mainland Portugal, the two scenarios are distinguished. Seismic zonation was geographically disaggregated for each of the 278 Portuguese counties.

[1] In EN 1998-1 stratigraphic profile of type A ground is defined as: Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.

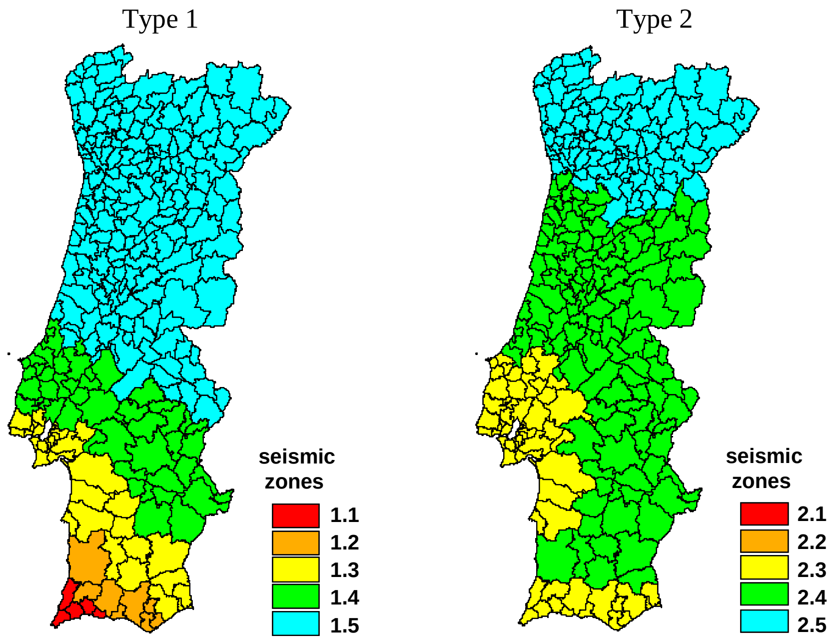

Figure 3.2 Mainland Portugal seismic zonation for Portuguese National Annex of NP EN 1998-1

3.3 Azores and Madeira Archipelagos

Figure 3.3 illustrates Azores archipelago seismic zonation for Portuguese National Annex of NP EN 1998-1. For this archipelago only type 2 seismic action scenario should be considered.

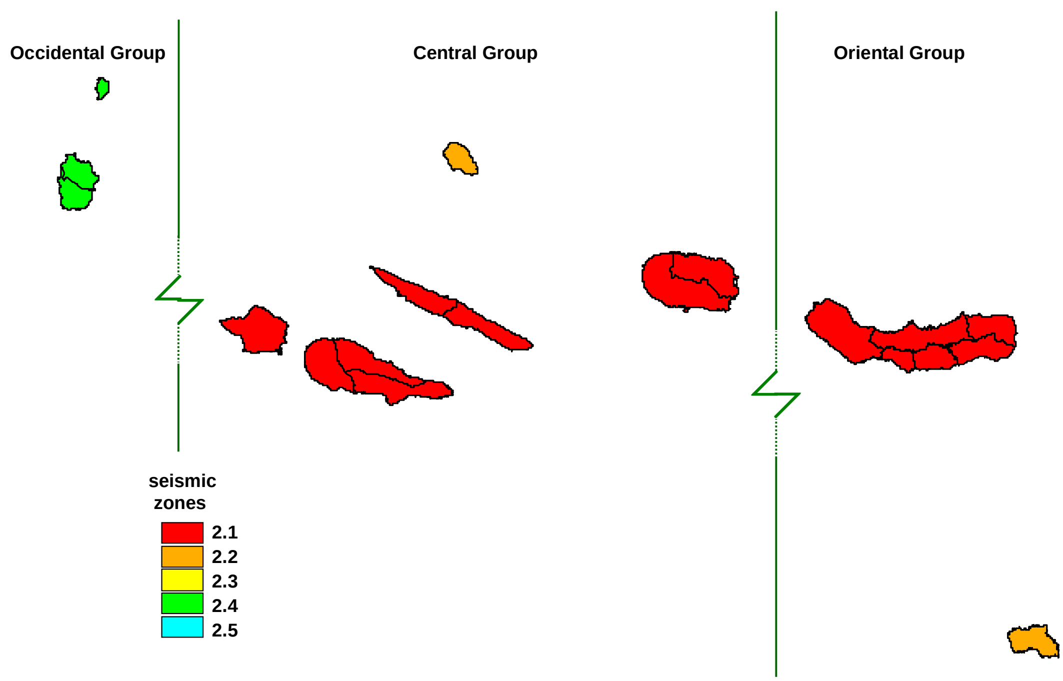

Figure 3.3 Azores Archipelago seismic zonation for Portuguese National Annex of NP EN 1998-1

Regarding Madeira archipelago only Type 1 scenario should be considered and all counties were included in seismic zone 1.5.

4. ELASTIC RESPONSE SPECTRA

For the horizontal components of the seismic action, the elastic response spectrum *Se*(*T*) is defined in EN 1998-1 by the well known following expressions:

$$0 \le T \le T_B: \qquad S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 2.5 - 1)\right] \qquad (4.1)$$

$$T_B \le T \le T_C: \qquad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \qquad (4.2)$$

$$T_C \le T \le T_D: \qquad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \cdot \left[\frac{T_C}{T}\right] \qquad (4.3)$$

$$T_D \le T \le 4s: \qquad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \left[\frac{T_C T_D}{T^2}\right] \qquad (4.4)$$

where *Se*(*T*) is the elastic response spectrum, *T* is the vibration period of a linear single-degree-of-freedom system; a_g is the design ground acceleration on type A ground ($a_g = \gamma_I . a_{gR}$ and γ_I is the importance factor); T_B is the lower limit of the period of the constant spectral acceleration branch; T_C is the upper limit of the period of the constant spectral acceleration branch; T_D is the value defining the beginning of the constant displacement response range of the spectrum; *S* is the soil factor; η is the damping correction factor with a reference value of η=1 for 5% viscous damping.

Table 4.1 presents the values that describe the elastic response spectra adopted in the last draft of the Portuguese National Annex of Eurocode 8.

Table 4.1 Values of the parameters describing the elastic response spectra

	Type 1 spectra, T_B = 0.1s and T_D = 2.0s					Type 2 spectra, T_B=0.1s and T_D=2.0s		
Ground type	T_C [s]	*S*				T_C [s]	*S*	
		Zone 1.1	Zone 1.2	Zone 1.3	Zones 1.4 and 1.5		Zones 2.1, 2.2 and 2.3	Zones 1.4 and 1.5
A	0.6	1.0	1.0	1.0	1.0	0.25	1.0	1.0
B	0.6	1.2	1.2	1.2	1.3	0.25	1.35	1.35
C	0.6	1.3	1.4	1.5	1.6	0.25	1.5	1.6
D	0.8	1.4	1.6	1.8	2.0	0.30	1.8	2.0
E	0.6	1.4	1.5	1.7	1.8	0.25	1.6	1.8

Figure 4.1 illustrates the elastic response spectra for Portuguese seismic zones and for ground type A.

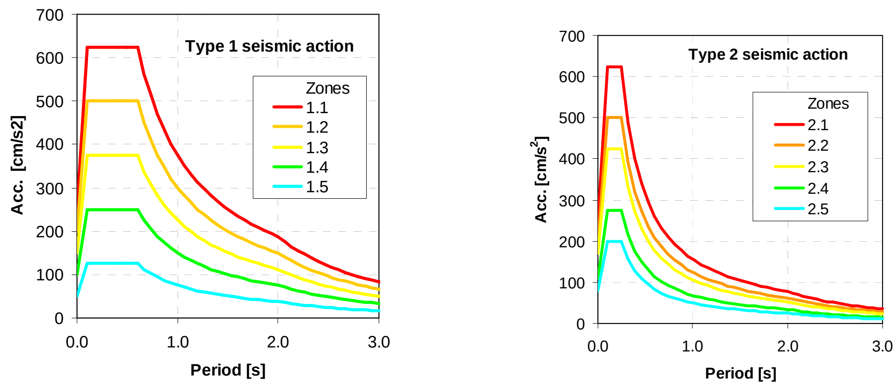

Figure 4.1 Elastic response spectra for Portuguese seismic zones (ground type A)

5. FINAL CONSIDERATIONS

The present paper presents the Probabilistic Seismic Hazard Analysis developed to be the reference for seismic zonation and seismic action levels of the Portuguese National Annexes of Eurocode 8 (NP EN 1998-1). The applied criteria for seismic zonation are also presented. The last part of the paper includes the last proposal for seismic zonation and the levels of seismic action to be used for the design of buildings and civil engineering works. Notice that seismic zonation and levels of seismic action may be subjected to further improvements, as they constitute the last operational draft of the Eurocode 8 working group.

As a final consideration one may say that pre-normative studies for seismic Portuguese Standard should be supported by continuous research projects that incorporate up to date seismic hazard and risk knowledge and that allow a more frequent revision of this Standard.

REFERENCES

Ambraseys, N.N, Simpson, K.A. and Bommer, J.J. (1996) Prediction of Horizontal Response Spectra in Europe. EESD, **45**: 371-400.
CEN. (2004) EN 1998-1 Eurocode 8: Design of structures for earthquake resistance -Part 1: General rules, seismic actions and rules for buildings. Brussels, Belgium
Carvalho, A., Zonno, G. Franceschina, G., Bilé Serra J. and Campos Costa A. (2008) Earthquake shaking scenarios for the Metropolitan Area of Lisbon. Soil Dyn. and Earthq. Eng. In print: Elsevier.
Carvalho, A. & Sousa, M.L. (2001) Análise estatística do catálogo sísmico de Portugal Continental. Technical Report nº2/2001 – G3ES. LNEC, Lisbon. Portugal.
Carvalho, A., Sousa, M.L., Oliveira, C.S., Campos Costa, A., Nunes, J.C. and Forjaz, V.H. (2001) Seismic hazard for the Central Group of Azores Islands. Bolletino di Geofisica teorica ed applicata, **42**: 89-105.
Carvalho, E.C. (2007) Anexo nacional do eurocódigo 8. Consequências para o dimensionamento sísmico em Portugal. Proceedings 7º Congresso de Sismologia e Engenharia Sísmica, FEUP, Porto, Portugal.
Housner, G.W. (1952) Spectrum Intensities of Strong Ground Motion. Symposium on Earthquake and Blast Effects on Structures, Earthquake Engineering Research Institute, Los Angeles, USA.
RSA, 1983. Regulamento de Segurança e Acções para Estruturas de Edifícios e Pontes. Decreto-Lei nº 235/83 de 31 de Maio e Decreto-Lei nº 357/85 de 2 de Setembro. INCM, 1986. Lisbon. Portugal.
Sousa, M.L. (1996) Modelos probabilistas para avaliação da casualidade sísmica em Portugal Continental. MSc thesis. IST, UTL. Lisbon. Portugal.
Sousa, M.L. and Oliveira, C.S. (1997) Hazard assessment based on macroseismic data considering the influence of geological conditions. Natural Hazards. **14**: 207-225, Kluwer Academic Publishers.
Weichert, B.H. (1980) Estimation of the Earthquake Recurrence Parameters for Unequal Observation Periods for Different Magnitudes. Bulletin of The Seismological Society of America, **70 (4)**: 1337-1346.