DEFINITION OF SEISMIC ACTION IN THE CONTEXT OF EC-8. TOPICS FOR DISCUSSION

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SUMMARY

The present paper summarises a few problems encountered with the application of the Eurocode 8 (EC-8), Parts 1-1 dealing with the definition of seismic action and zonation when preparing the National Document Application (NDA) in each European country. Points related to the representation of seismic action, the setting of return periods, the definition of spectral shapes and the possibility of use of more than one seismic scenario are among the most important topics presented.

The Portuguese code, in action since 1983 [9], needs to be revised in what concerns seismic action in order to include recent studies on seismicity, seismic hazard and modelling of strong motion data. This revision, opportunely assessed in the context of the EC-8, brings up several of the topics above referred and shows the proposed solutions.

INTRODUCTION

Although its intrinsic standardisation, the implementation of EC-8 requires a complex decision process that is heterogeneous among European countries, namely in what concerns hazard methods, levels of safety and policies for seismic risk mitigation and decisions. In the following, a brief discussion is made (1) on the type of representation of seismic action, (2) on the selection of the reference return period and (3) on the decisions on seismic zonation.

1. Seismic action can be represented by response spectra, by power spectral density function and duration of strong motion and by a set of time histories of acceleration. In theory, all three representations should lead exactly to the same response of any given structure. However, in practice, only approximately this objective can be accomplished, but codes should accommodate all three possibilities on an equal basis. The selection of the representation depends on the type of structure under study, and on the detailing of the analysis to be performed, but consistency for seismic action representation should always apply.

2. The common practice in the USA and other regions with high seismicity is to adopt 475 years as the reference return period for buildings design and larger periods up to ≈1,000 and ≈10,000 years for important structures and critical installations, respectively. Even though the formulation based on a common return period expresses the same probability of exceedance, important differences arise in the case of regions where the occurrence process is characterised by long recurrence intervals *vs.* regions where it is characterised by short recurrence intervals. For the second case, upper bounds are more plausible to be attained within the 475 years return period whereas, in the first case, the same will apply only for 10 000 years [3]. The first case raises the problem of non-completeness of the seismic catalogue for large return periods that could be overcome if information on historical seismicity and paleoseismicity is available. The country level of seismicity also influences the limit states to be considered. In high seismicity countries serviceability and collapse limit states must be considered, whereas in low seismicity countries serviceability limit state may be the most critical one.

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3. Seismic zonation also raises problems related to quantities, methods and classification criteria. For instance, should code seismic zones be based exclusively on hazard quantities or also on seismic risk accumulation for urban areas? Should they be based on one single parameter such as peak ground acceleration, etc., or based on an integrated measure like the effective peak ground acceleration, Housner intensity, etc? Should elastic response spectra be fitted to zone mean values, to zone mean values plus one or two sigma or to zone envelopes? And in regions influenced by different seismic scenarios the definition of seismic action must incorporate separately that reality?

4. Local soil conditions are not discussed in this work. Their influence on the definition of seismic action is of so great importance that guidance for seismic microzonation should explicitly be considered in codes.

SEISMIC HAZARD

Seismic hazard analysis followed a methodology based in probabilistic tools, as it is generally adopted in world-wide studies (*Probabilistic Seismic Hazard Analysis* – PSHA), and incorporated frequency-dependent attenuation relationships in order to estimate an *Uniform Risk Spectra* (URS) associated to a given return period. The spectral ordinates of a URS have the same probability of being exceeded during the lifetime of a facility due to the seismicity of all the sources affecting the site.

In previous studies the occurrence process in each source zone was characterised as a Poisson process and by the Gutenberg-Richter distribution of magnitudes [11, 12]. This characterisation is not the object of the present paper, so details on the reliability of the assumption of the Poisson process, on the maximum magnitude for each source zone and on the *b*-value of Gutenberg-Richter law can be found in those references. In this context a brief description of the analysed region seismic data is presented herein.

The process of seismic occurrence was based on data contained in the Seismic Catalogue of Iberian Peninsula [10]. Data on instrumental and historical earthquake catalogue, for Portuguese region, were considered. This catalogue covers a long period of observation (almost 2,000 years), allowing modelling the distribution of seismic events by time, size and location.

The geographical area under analysis was subdivided into seismic source zones, taking into consideration the earthquake history and the knowledge about tectonic processes causing seismic activity. The model of 12 seismic source zones, illustrated in figure 1 [12], follows the revision of the neotectonic map [2], the distribution of historical and instrumental seismicity, and the principle of adjusting the zones to large geological units. Note that 5-5A means zone 5 minus zone 5A; the same applies to zone 6 and 6-6A.

In what concerns the strong motion process the frequency-dependent attenuation equations for ordinates of horizontal acceleration response spectra derived by Ambraseys *et al.* [1] were adopted. Those laws cover a range of natural periods between 0.1 and 2.0 sec and were obtained considering the influence three types of geological site conditions. To perform the seismic zonation of Portugal only rock conditions (shear wave velocities > 750 m/s) were considered.

Besides assessing seismic hazard in terms of peak ground acceleration and URS, the conditional expected values of magnitude and focal distance, given that a certain level of seismic action is exceeded, was also evaluated, following Ishikawa methodology [3, 6]. This level is related to a certain probability of exceedance by the hazard curve.

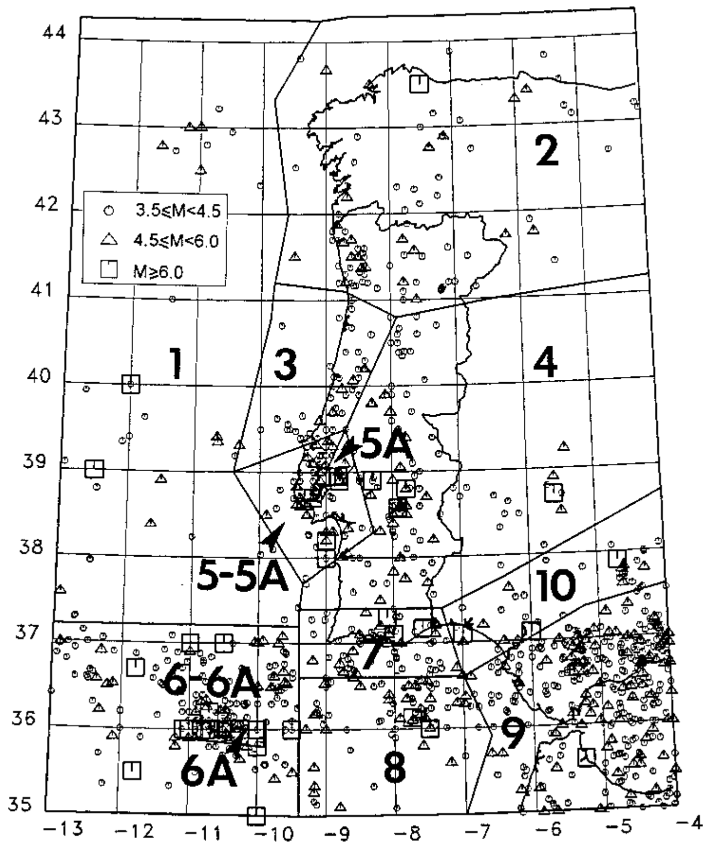

Figure 1: Earthquake epicentres, 33 AD-1991, M ≥ 3.5 [10] and seismic source model [12].

PORTUGUESE SEISMIC ACTION IN EC8

EC8 format

In the context of Eurocode 8 (EC8) [4] the earthquake motion at a given point of the surface is represented, for a reference return period, by the elastic response spectrum $S_e(T)$, where *T* is the vibration period of a linear single degree of freedom system. The elastic response spectrum is defined by the values of parameters a_g, the design ground acceleration for the reference return period, β_0, the spectral acceleration amplification factor for 5% viscous damping, T_B and T_C, the limits of the constant spectral acceleration branch, T_D, the value defining the beginning of the constant displacement range of the spectrum, k_1 and k_2, the exponents which influence the shape of the spectrum for a vibration period greater than T_C and T_D, respectively, *S*, the soil parameter and η the damping correction factor with reference value of 1 for 5 % viscous damping.

The shape of the power spectral density function must be compatible with the above definition in order to warrant consistency for seismic action used in other parts of EC-8.

Seismic hazard evaluation

This section deals with the setting of the reference return period and with the decision to use more than one seismic scenario to obtain the elastic response spectra from PSHA [7].

The seismicity of the Portuguese region is induced by complex seismotectonic structures in which two important source mechanisms may be distinguished:

1. The earthquakes originated by the movement between the Eurasian and African plates designated by interplates events. In particular, in the Gorringe Bank the movements associated to this boundary caused severe events, which affected the Iberian Peninsula and the Northern Africa, such as 1755, and 1969 earthquakes (macroseismic maximum intensity X and Richter magnitude 7.9-8.0, respectively).

2. The earthquakes originated in faults inside the Eurasian plate designated by intraplate events. The Benavente earthquake of 1909, and probably the 1531, January 26 earthquake, are examples of intraplate events (Richter magnitude 6.9 and macroseismic maximum intensity IX-X , respectively).

One may expect that location, magnitude, time duration and frequency content of events originated at interplates and intraplate sources are different: distant epicentre, large magnitude, long duration and lower frequency content for the former and short to distant epicentres, moderate magnitude, short duration and higher frequency content for the latter. Low period response spectra ordinates are induced by low magnitude and short distance earthquakes, whereas high period ordinates are influenced by higher magnitude and longer distance earthquakes, meaning that the computed spectrum is not physically linked to an unique seismic scenario and the independence of each frequency component of the seismic ground movement, that is a basic criterion underlying an uniform risk spectra approach, is disregarded.

In order to avoid that type of inconsistencies, two scenarios were considered in PSHA computation: (i) the "intraplate scenario" generated by earthquakes with their epicentres mainly inland (source zones 2, 3, 4, 5A, 5-5A, 7 and 10 in figure 1) and (ii) the "interplates scenario" originated by events with their epicentres mainly offshore (source zones 1, 6A, 6-6A, 8 and 9 in figure 1).

Considering both scenarios the PSHA and URS were computed for the 278 Portuguese counties. For seismic action definition and territory zonation it was chosen the 95% fractile for a 50 years structure lifetime (975 return period) in accordance with the Portuguese seismic code, presently enforced.

Figure 2 presents the 975 years return period URS envelope for Portuguese counties, and for the intraplate and interplates scenarios. This figure illustrates how the response spectra shapes are significantly influenced by the two considered scenarios associated to different magnitudes and epicentral distances as referred before. Figure 2 highlights the contribution of long distance scenario (interplates) on long period components of spectra. Figures 3 and 4 present the correspondent expected values of magnitude and focal distance.

Figures 3 and 4 evidence that the intraplate scenario should be better circumscribed. In fact, the expected values of magnitude and focal distance in those left figures change considerably with natural period. A possible solution could be splitting the intraplate scenario into short and long distance scenarios. From figure 4 and previous studies [11, 12] it can also be concluded that interplates scenario is conditioned by the events generated in the Gorringe Bank (source zone 6A). Figure 4, right, shows the average distance variation of each county to that source zone.

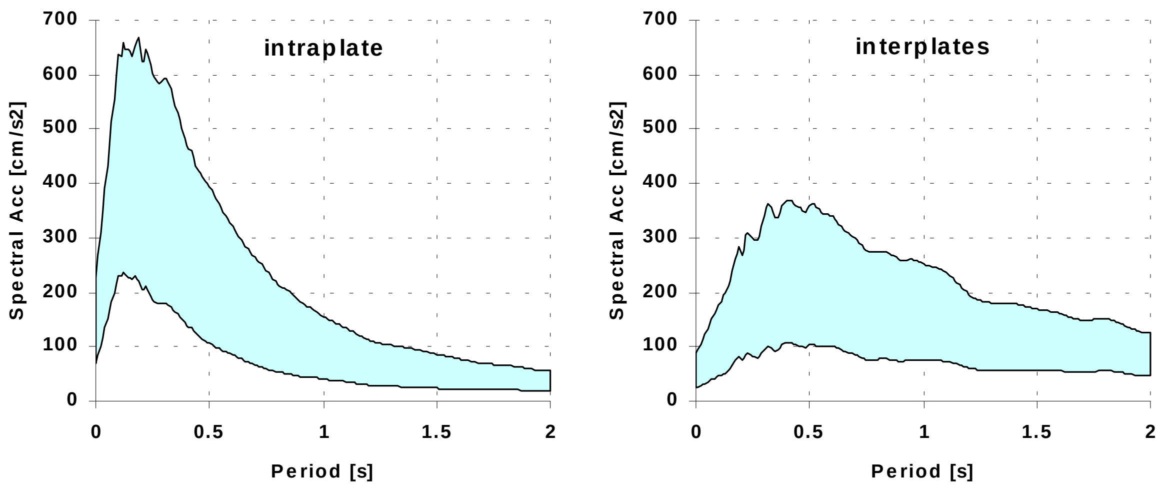

Figure 2: Envelop of URS; 975 return period.

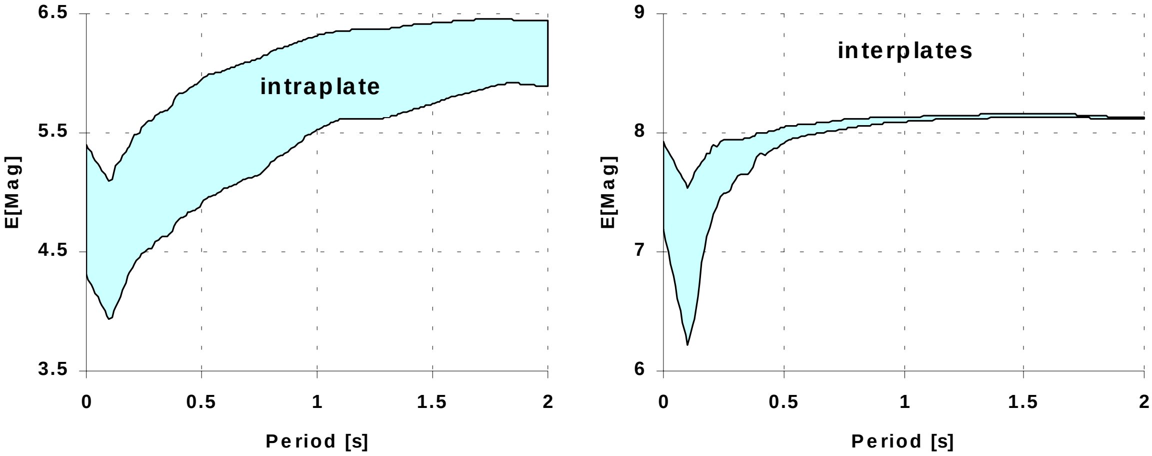

Figure 3: Envelop of expected magnitude, *Mag*; 975 return period.

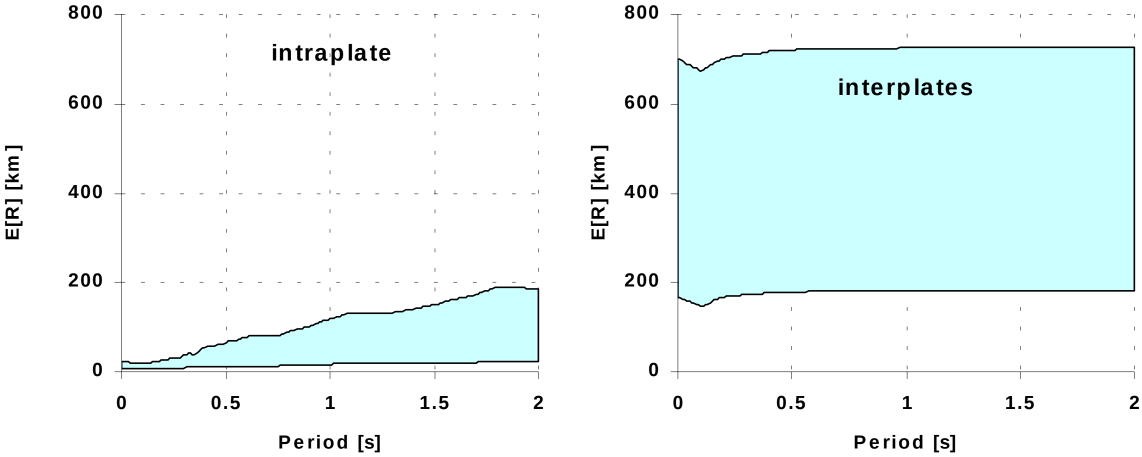

Figure 4: Envelop of expected focal distance, *R*; 975 return period.

Hazard consistent zonation and seismic action

The Portuguese seismic code [9] divides the country in 4 different seismic zones. That number of zones was maintained in order to simplify the practice of a revised code.

Housner intensity [5], for 5% damping ratio, was used as the criterion to classify each county seismic hazard. Figure 5 shows the 278 Portuguese counties sorted by Housner intensity evaluated for intraplate and interplates scenarios and for the 975 years return period. Vertical solid lines in that figure show the divisions among the 4 seismic zones. The counties limiting zones were chosen according to a least square criterion based on an iterative process that minimises the sum of quadratic errors between Housner intensity of each county and the average Housner intensity of a first guess seismic zone.

Figure 6 presents a possible seismic hazard consistent zonation for Portugal according to the intraplate and interplates scenarios and Figure 7 illustrates the envelopes of hazard curves for each zone and scenario.

For both scenarios, zones 1 are the ones of worst seismic hazard, whereas zones 4 are the ones of less severe seismic hazard for both scenarios. The seismic zoning criterion was exclusively hazard consistent; however, if the hazard was weighted accordingly to the geographic distribution of the housing stock, some dense urbanised counties, like Lisbon, would natural move to a more severe seismic zone.

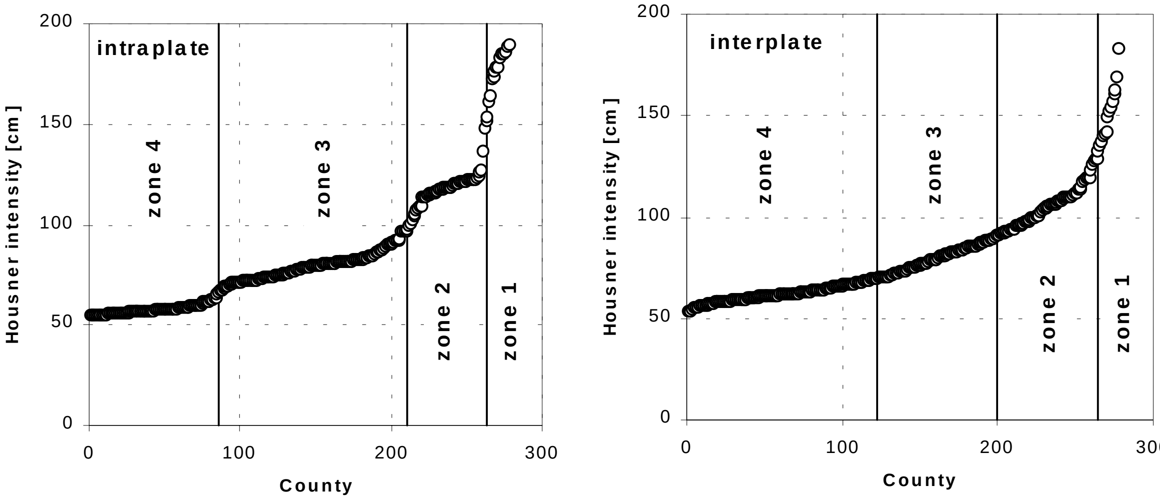

Figure 5: Portuguese counties sorted by Housner intensity.

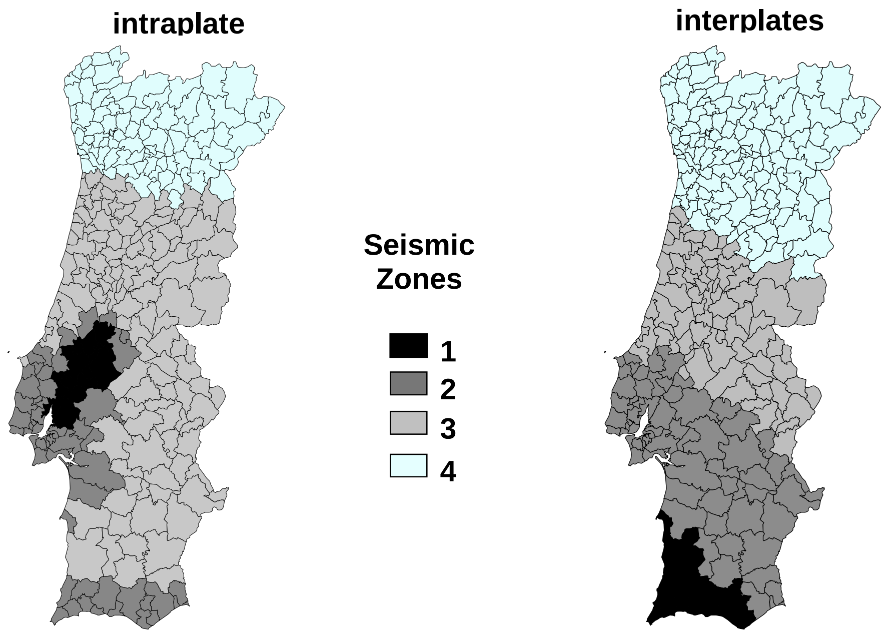

Figure 6: Portuguese seismic hazard zonation.

Figure 8 presents, for each zone, the upper envelopes of uniform risk spectra and the elastic response spectra according to EC8 format. The values of parameters defining this format were obtained by a conjugate gradient optimisation method [8]. Note that the fitted elastic response spectra presents PGA values slightly above the PGA values of the envelopes and that the deviation occurring for periods larger than 0.8 sec., for intraplate scenario, comes from fixing the parameter k_1 at the default value of 1.0.

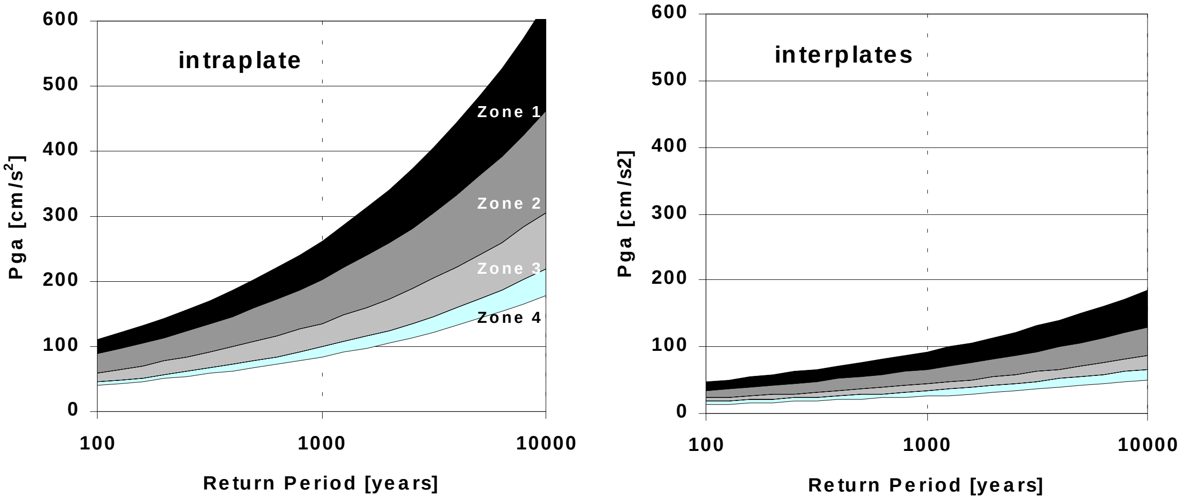

Figure 7: Envelopes of hazard curves.

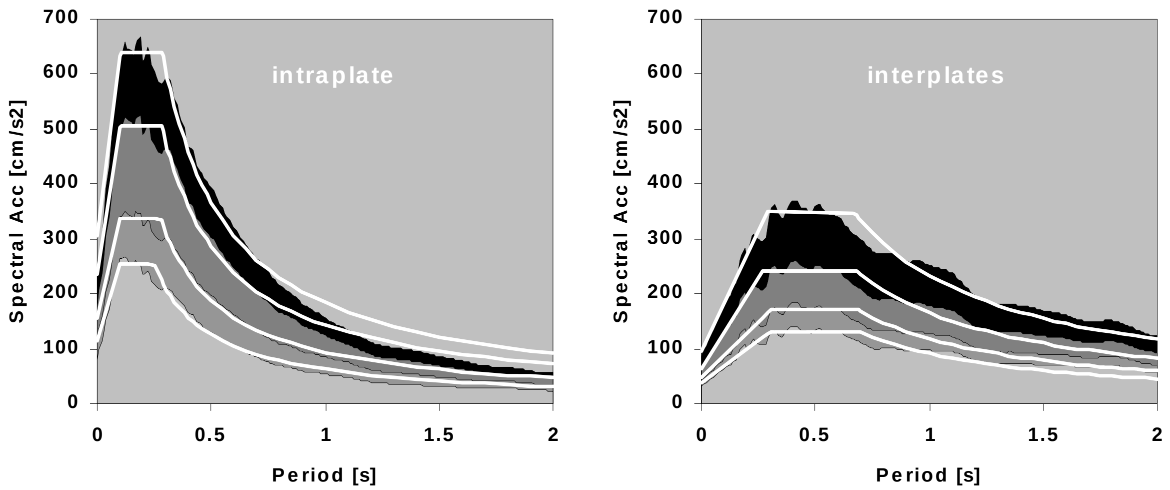

Figure 8: Upper envelopes of uniform risk spectra and fitted elastic response spectra; zones of figure 6 and 975 return period.

FINAL CONSIDERATIONS AND FURTHER WORK

The definition of a seismic action in the context of EC-8 was made for a given region showing the feasibility of the method proposed. The application to Portugal is an exercise evidencing the need for further development in the following subjects:

1. Lack of reliable models to characterise the attenuation of movement generated by long distance large magnitude events.

2. Need to perform sensitivity studies on a number of parameters and methods including attenuation, scenario features and decision process on zoning.

3. Conversion of elastic response spectra presented in figure 8 into power spectral density functions. This is essential to warranty consistency of seismic action used in all parts of EC-8, such as the ones dealing with bridges, pipelines, etc.

A number of other topics related the definition of ground motion deserves further work: long period components, displacement base design, spatial variability, wave polarisation, interdependence between horizontal and vertical components and artificial simulation *vs*. databank ground motion records. Finally, in many different items above discussed, the relation between Engineering Seismology and Earthquake Engineering should be clarified. The latter should incorporate all information provided in recent years by the former like empirical data related to strong motion records and the simulation of source and wave propagation based on physical modelling. However, it should not be forgotten that Earthquake Engineering needs a definition of seismic action for design of structures, which is a set of elements representing all possible events that can struck those structures during its lifetime.

REFERENCES

1. Ambraseys, N.N; Simpson, K.A. and J.J. Bommer (1996), "Prediction of Horizontal Response Spectra in Europe", *Earthquake Engineering and Structural Dynamics*, 45, pp. 371-400, John Wiley & Sons.

2. Cabral, J. (1993), "Neotectónica de Portugal Continental", PhD thesis in Geology, Lisbon University, Lisbon, Portugal (in Portuguese).

3. Campos-Costa, A. (1993) "A Acção dos Sismos e o Comportamento das Estruturas" PhD thesis in Civil Engineering, Oporto University, Oporto, Portugal.

4. CEN (1994), "Eurocode 8: Design of Structures for Earthquake Resistance of Structures - Part 1-1: General rules – Seismic Actions and General Requirements for Structures", ENV 1998-1-1. Brussels, Belgium.

5. 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.

6. Ishikawa, Y. and Kameda, H. (1988), "Hazard-Consistent Magnitude and Distance for Extended Seismic Risk Analysis", *9th World Conference on Earthquake Engineering*, vol. II, pp. 95-100, Tokyo, Japan.

7. McGuire, R.K. (1995), "Probabilistic Seismic Hazard Analysis and Design Earthquakes: Closing the Loop", *Bulletin of Seismological Society of America*, 85, pp. 1275-1529.

8. Press, W.H., Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P. (1992), "Numerical Recipes in Fortran. The Art of Scientific Computing", 2nd Edition, Cambridge University Press, Victoria, Australia.

9. RSA (1983), "Regulamento de Segurança e Acções para Estruturas de Edifícios e Pontes", Decreto-Lei nº 235/83, Imprensa Nacional - Casa da Moeda, Lisbon, Portugal (in Portuguese).

10. Sousa, M.L., Oliveira, C.S. and Martins, A.M. (1992), "Compilação de Catálogos Sísmicos da Região Ibérica", Report LNEC, 36/92, NDA, 250 pp., Proc. 036/11/9295, Lisbon, Portugal (in Portuguese).

11. Sousa, M. L. (1996), "Modelos Probabilistas para a Avaliação da Casualidade Sísmica em Portugal Continental", MSc thesis in Operational Research and System Engineering, Lisbon Technical University, Lisbon, Portugal (in Portuguese).

12. Sousa, M. L. and Oliveira, C.S. (1997), "Hazard Mapping Based on Macroseismic Data Considering the Influence of Geological Condition", *Natural Hazards*, 14, pp.207-225, Kluwer Academic Publishers.