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Seismic hazard-consistent studies for Portugal

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ABSTRACT: This paper presents the last developments on seismic hazard analysis directed to the computation of strong ground motion parameters to be applied to nonlinear structural analysis (Campos-Costa, 1992). It follows the Ishikawa and Kameda approach (1988), and makes an application to the Lisbon site. Inhere, the methodology and the most probable seismic scenarios are presented. In an accompagning paper (Duarte *et al*, 1992), time series generation is obtained for a long distance and short distance earthquake scenarios.

1 INTRODUCTION

The purpose of this paper is to present the latest developments in the determination of the strong ground motion parameters compatible with the seismicity in Portugal. These parameters are obtained for the most likely earthquake scenario given a certain probability of exceedance.

The methodologies used in previous studies, for the definition of strong ground motion parameters, were based on hazard analysis for a single parameter and a spectral shape. Those studies did not allow a full description of ground motion compatible with the physics of the process, since the non-stationarity in amplitude and frequency content were not assessed.

The necessity of performing non-linear analysis of civil engineering structures for code makers or structural designers requires a more detailed description of ground motion input. For instance, the recent Eurocode 8 (1989), prescribes time series as input seismic action.

Several techniques have been widely used for the generation of time series compatible with a given spectral shape and modulating functions (Duarte *et al*, 1992). For the identification of the above mentioned entities, one should know at least the expected values of magnitudes, M, and focal distance, R_f (Kameda *et al*, 1980). In fact, with any pair (M, R_f) and the knowledge of source characteristics and soil conditions, one can obtain an almost full description of the most likely ground motion using stochastic, deterministic or mixed methods.

The pairs of (M, R_f) values to be considered for a resonable solution of the underlying complex stochastic process of the occurrence and attenuation of ground motion, must be characterized in a probabilistic framework. An optimal characterization of the process would require the knowledge of the joint probability distribution functions of M and R_f.

To overcome the difficulties induced from the scarcity of data, and of the large number of computations, the hazard scenarios are only drawn for the expected values of those random variables, which are thought to be independent.

In this paper a brief description of updated input data on seismic and tectonic environment is presented. The criteria for designing seismic zones follows the general guide lines presented by Oliveira (Oliveira *et al*, 1984) with some recent improvements, which are briefly described. Secondly, the standard mathematical model of hazard analysis for a given site is applied (McGuire, 1976). The generalized concept of hazard-consistent analysis is outlined with the additional assessment of the expected values of magnitudes, M, and focal distance, R_f, by means of Baye's theorem, following Ishikawa's proposal (Ishikawa *et al*, 1988). Finally, an application of the above mentioned methodology for Lisbon site is presented.

The most relevant achievement of this study is the rationality behind the methodology which is both hazard and phenomenological consistent.

2 SEISMO-TECTONIC ENVIRONMENT

Earthquake activity and the portuguese tectonic environment induce a complex situation in which interplate and intraplate earthquakes may occur.

Data for hazard analysis studies include the available knowlegde of three different aspects of the earthquake phenomenon, namely:

- Seismic activity compiled in earthquake catalogues;
- Neotectonic and geological structures which consider the morphology (geometry and type) of main faults and their potencial as seismic source zones (degree of seismic activity);
- Wave propagation from source-to-site regarding the identification of the general attenution pattern.

In Figure 1 the seismic activity for the studied region is presented, according to the compilation of earthquake catalogues for Iberian region (Sousa *et al*, 1992). It can be seen that earthquakes occur in a rather random pattern, not exhibiting, for the time being, a clear alignement with geological structures (see Figure 2).

This diffuse pattern is due to the regional intermediate seismicity associated with the intraplate activity (*e.g.* Benavente 1909 earthquake, with epicenter in lower Tagus valley). Moreover, the portuguese continental territory was stroke by scarce but intense earthquakes with their origin in interplate source zones (*e.g.* 1755 Lisbon Earthquake, Gorringe bank).

These features where considered in the design of the seismic zones (Figure 3) to be used in seismic hazard models and according to the following criteria:

- For the, inland activity, essentially intraplate, main zone alignments were drawn in accordance to the fault traces. Zone widths were selected in order to cover most earthquake epicenters.
- For the offshore activity, mostly interplate, the tectonic structures are not well known and so the zones were dimensioned wider, considering the concentration of epicenters.

In relation to the source-to-site attenution laws, no instrumental information concerning major events is available. On the other hand, the information on historical events is quiet good, allowing the identification of two general patterns of nonradial attenuation functions from isoseismal maps (Oliveira *et al*, 1984).

3 HAZARD ANALYSIS METHODOLOGIES

Due to differences on source mechanisms of earthquakes that affect portuguese sites, distant sources (R > 50 km) were separated from near sources (R < 50 km), as two different scenarios. In fact, one may expect that time duration and frequency content of strong ground motion are different: long duration and lower frequency content for the former and short duration and higher frequency content for the latter scenario. Each case induces distinct damage in civil engineering structures.

3.1 *Standard hazard analysis*

Previous studies (Oliveira, 1980 and Oliveira *et al*, 1984), present the first steps towards the portuguese hazard analysis, using the methodology proposed by Cornell (Cornell *et al*, 1975) and implemented by McGuire (1976).

Hazard maps for 10 000 years of return period are presented in Figure 4, where it can be seen the area of influence of long distance and short distance scenarios zonation.

Specifically for Lisbon site, it was computed the *annual probability of exceedance - inverse of return period* - for several levels of MM intensity (I), Figure 5.

On the basis of an intensity analysis, it must be concluded that short distance earthquakes affect more severely the town of Lisbon, although the well known 1755 Lisbon earthquake has its epicenter in a long distance source zone. The fact is that most of the distant earthquakes are not enough intense to exceed the effects of the short distance large events.

3.2 *Hazard-consistent analysis*

Using Ishikawa approach (Ishikawa *et al*, 1988), the expected values of magnitude M, and focal distance R_f, as selected strong motion parameters, could be assessed by the Bayes theorem. For a pair (M, R_f) it can be written:

$$E[M \mid I \geq i] = \\ = \frac{\int_m \int_{r_f} m P[I\geq i|m,r_f] f_M(m) f_{R_f}(r_f) dm dr_f}{\int_m \int_{r_f} P[I\geq i|m,r_f] f_M(m) f_{R_f}(r_f) dm dr_f} \quad (1)$$

$$E[R_f \mid I \geq i] = \\ = \frac{\int_m \int_{r_f} r_f P[I\geq i|m,r_f] f_M(m) f_{R_f}(r_f) dm dr_f}{\int_m \int_{r_f} P[I\geq i|m,r_f] f_M(m) f_{R_f}(r_f) dm dr_f} \quad (2)$$

where $f_M(m)$ and $f_{R_f}(r_f)$ are the probability density distribution functions of magnitude (Gutemberg-Richter law) and focal distance, respectively; the values $E[M \mid I \geq i]$ and $E[R_f \mid I \geq i]$, express the conditional expected values of magnitude and focal distance given that a certain level of MM intensity, i , is exceeded. The level i is related to a certain probability of exceedance p_0, $i = i(p_0)$, by the hazard curve.

Those values were computed by implementing expressions (1) and (2) on the aforesaid standard McGuire algorithms.

The analysis of structural reliability is a possible application of hazard-consistent results (Campos-Costa, 1992). For this purpose it would be convenient to express the MM intensity in terms of Peak Ground Acceleration - PGA. There are several relationships to do this conversion; the well known formula of Gutemberg-Richter,

$$\log_{10} PGA = IMM/3 - 0.5 \tag{3}$$

was used in this work.

In order to assess the frequency content of strong ground motion at a given site, one can use the empirical relations derived by Triffunac (Triffunac *et al*, 1989) for which the response spectra is computed in terms of the MM intensity, soil condition and vertical or horizontal component of the ground motion.

The envelope in each frequency of the strong motion can also be derived by the empirical expressions computed by Kameda (Kameda *et al*, 1980), as function of any pair (M, R_f).

From this point onwards it is possible to generate any strong motion record using the values of M, R_f, and the previously obtained site response spectra.

3.3 *Application to Lisbon site*

As an application of the aforesaid probabilistic consistent methodology, some results are presented for Lisbon site, Figures 6 to 8.

From the analysis of these figures, one may observe several trends of utmost importance concerning the definition of seismic input and subsequent reliability analysis, and the characterization of the hazard scenarios for Lisbon.

4 FINAL CONSIDERATIONS

The following considerations apply to Lisbon site:

- Short distance earthquake scenarios must be more severe then long distance ones. For return periods > 200 years, the total hazard is completely controlled by the former.

- Values of intensity, magnitude and focal distance associated with large return periods, > 1 000, denote a similar assimptotic trend. This feature comes from the upper limit of earthquake activity considered for each zone, which is decisive for the definition of the upper tails in reliability analysis.

- For the short distance scenario the increase of magnitude is associated with a decrease of focal distance and for the long distance one, the increase of magnitude is associated with an increase of focal distance. Moreover, considering the seismotectonic environment it can be stated that the global seismicity for Lisbon site is controlled by two main source-areas: Gorringe and Benavente zones.

- This study could be generalized for several strong motion parameter, like time duration, epicentral azimuth, or even structural damage. Particularly, it would be interesting to improve the model, by the inclusion of the azimuthal dependence θ, as third important parameter. The computation of $E[\theta \mid IMM]$, will eventually contribute to the identification of a specific neotectonic structure, allowing the use of more refined seismological strong motion generating models.

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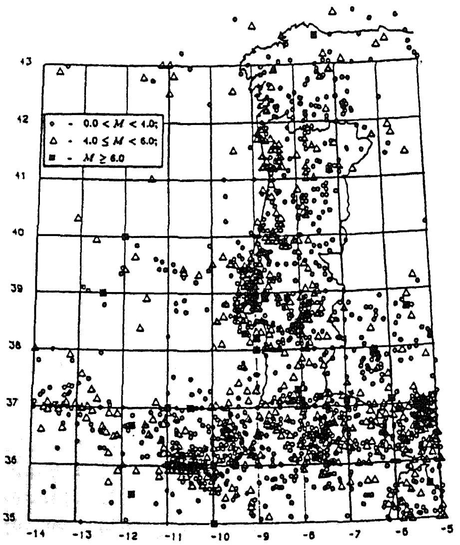

Figure 1: Earthquake occurrences after Iberian compilated catalogue (adapted from Sousa *et al*, 1992).

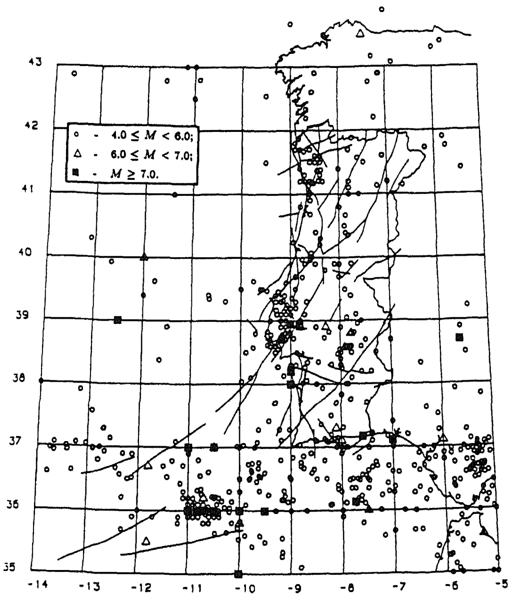

Figure 2: Main neotectonic structures (Cabral *et al*, 1988) and epicenters with $M \geq 4.0$ (adapted from Sousa *et al*, 1992).

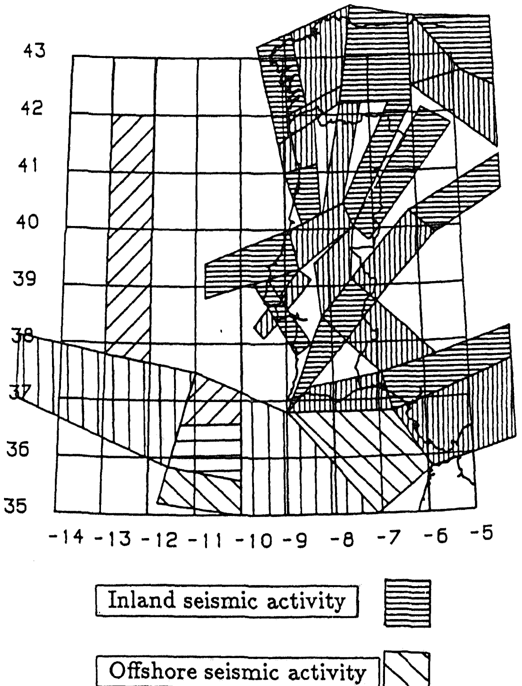

Figure 3: Designed source-areas for inland and offshore seismic activity (after Oliveira *et al*, 1984).

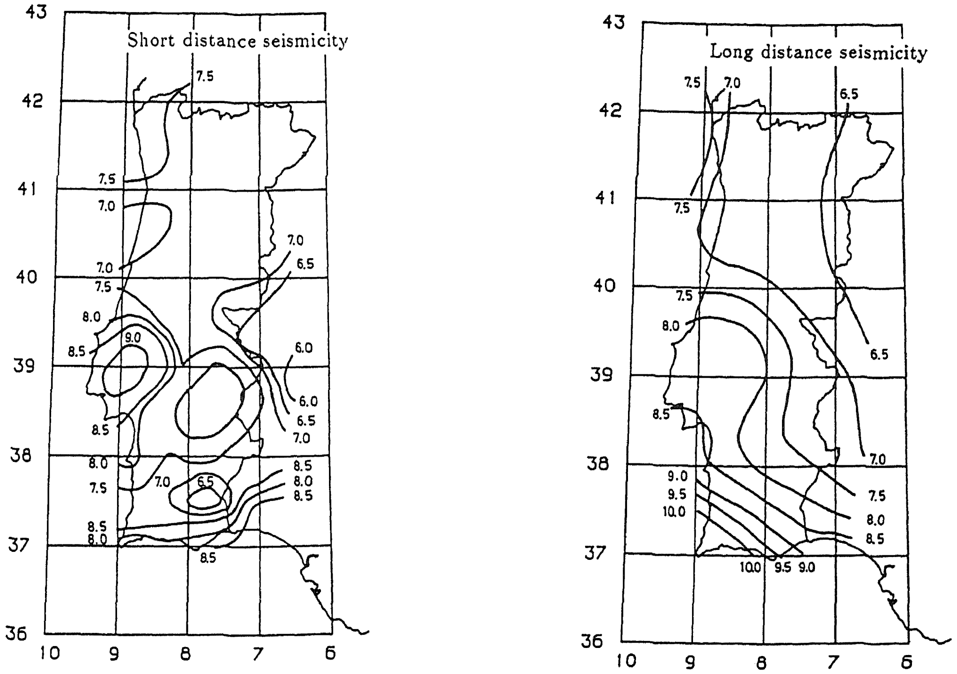

Figure 4: Hazard maps for 10,000 years return period - short and long distance scenarios.

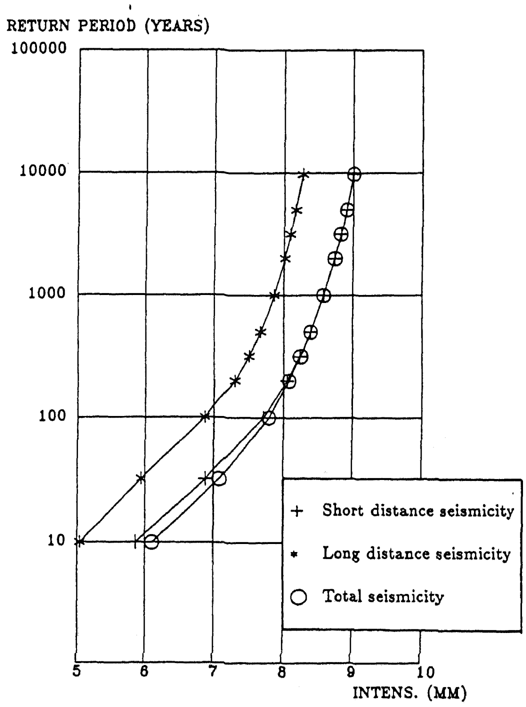

Figure 5: Hazard curve estimate for Lisbon site.

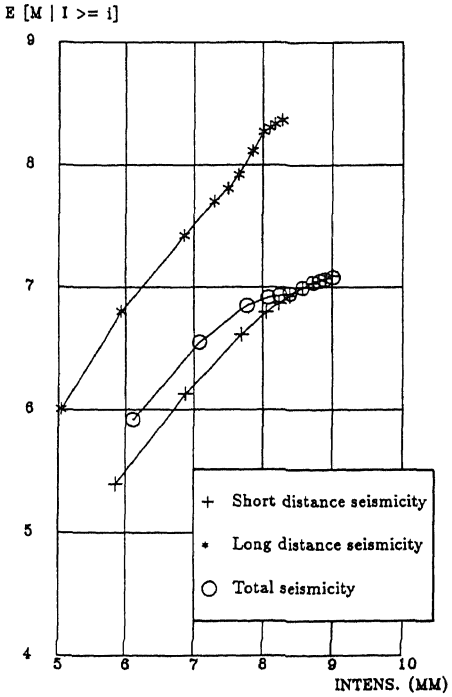

Figure 6: Expected values of magnitude, M, for given intensities.

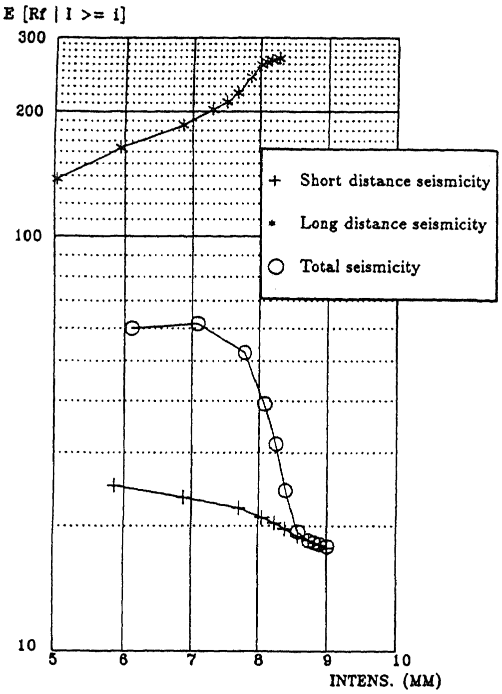

Figure 7: Expected values of focal distance, R_f, for given intensities.

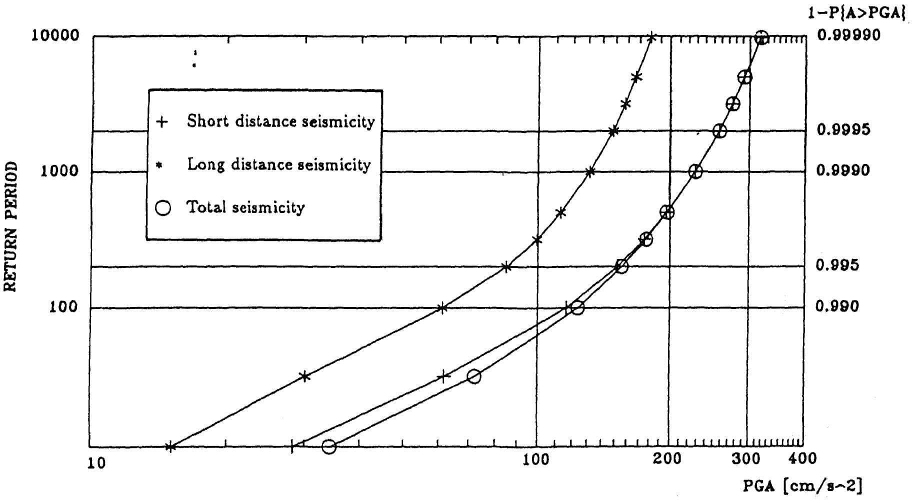

Figura 8: *PGA* probability distribution function for Lisbon site.