UPDATING SEISMIC HAZARD MAPS

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SUMMARY

Progress in engineering seismology and gathering of data taking place in recent years in the different fields related to tectonics, mechanisms of gene ration, propagation of seismic waves and historical seismicity,indicate that seismic hazard maps should be updated in a continuous manner.

This paper is dedicated to the analysis of improvements made in the last four years and studies their influence on the final hazard estimates: (i) earthquake catalogue was extended from 1900 back to 1300, (ii) earthquake source-zones slightly modified to accomodate new evidences of fault activity and (iii) attenuation curves, allowing anisothropy, fit in a better way the macroscopic observations of several quakes. A comparison with previous hazard curves is made for several sites expliciting the contributions of distant and 'nearby"earthquakes (off and onshore).

INTRODUCTION

Seismic hazard maps started being used in early seventies and became ve- ry popular by the end of this decade. They have been taken as essential ele - ments to set seismic zones in building codes and important pieces of informa- tion for a first selection of design values in large and complex structures .

With the course of time it was observed that for the same site hazard curves could vary quite considerably, not only due to interpretation of exis- ting data, but also due to successive modifications of data-base. This had led to a systematic criticism, with independent revisions, and to an evalua - tion of interval of confidance in the final hazard estimates.

The first hazard maps for Portugal were produced in 1979 (Ref. 1) and served as basis for the recently published seismic code, (Ref. 2). They were established in terms of peak ground acceleration, PGA (Fig. 1), velocity and displacement. A study of sensitivity of parameters showed that the (mean-2σ) to (mean +2σ) interval of confidance on final hazard estimates presents va - riations of 1:4 for 1000 years return period.

The present paper describes the main innovations in updating seismic ha- zard studies (see Fig. 2 for summary of important steps) and compares the re- sults of versions 1979 and 1983. A layout of main errors involved in hazard studies is discussed.

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DATA AND INHERENT ERRORS

Data-base for hazard studies fall into the following two categories:

1 - Tectonic environment: The evolution of tectonic knowledge on both active interplate regions and fault alignment of intraplate continental regions (Ref. 3) has improved the definition of generation source-zones for Portugal. However, three parameter uncertainties are still present in the identifica - tion of tectonic structures: location of fault trace, length of capable fault and activity plus mechanism of generation. In fact, in a recent study of relo cation of 55 instrumental epicenters occurred in the period 1975-1983 (Ref.4) no apparent correlation with fault traces was observed.

2 - Earthquake catalogue: The present catalogue can be divided into histori - cal (until 1900) and instrumental earthquakes (from 1900) with three sources of information: i) a collection of 1200 earthquake $M_1 > 3$ located in the grid $35^\circ - 40^\circ$ N, $4^\circ - 15^\circ$W for the period 1902-1975 (Ref. 5) which constituted the ba sis for the 1979 hazard studies, ii) historical investigation covering the pe riod 216AC to 1900DC (Ref. 6,7) and iii) catalogue from IGN in Spain with in- formation 500AC up to 1979 (Ref. 8).

Comparing these sources of information, differences on epicentral loca- tion, magnitude and intensities (MM) were observed, mainly for historical earthquakes. A first compatibilization lead to a catalogue of 392 earthquakes felt in the continent with MMI >IV, constituting the data-base for the 1983 study (Fig. 3).
An evaluation of historical earthquake parameters can only be obtained if a systematic criticism of rough data is made (Ref. 9). Uncertainties rela- ted to this evaluation, defined by a quality factor or error ε_{earthq}, are com puted as the convolution of

$$\varepsilon_{earthq} = f(\varepsilon_{date} * \varepsilon_1 * \varepsilon_2) \text{ where } \varepsilon_{earthq} \equiv \{\text{localization of focus, size and perceptibility pattern}\}$$

and : ε_{date} is the error on date of occurrence; ε_1 the error on intensity scale interpretation from historical description of effects and damage; and ε_2 the interpolation for establishing isosseismal curves. Further updating studies will quantify these uncertainties.

EARTHQUAKE SOURCES. MODELLING ERRORS

Earthquake activity in the past and the tectonic structures suggest that interplate and intraplate earthquakes (mentionned here as offshore and onshore) are considered throughout hazard studies as independent identities. Fig. 4 presents the 36 source-zones modelling the seismic activity in Portugal, 8 offshore and 28 onshore. This zonation follows the main pattern developed in 1979 (Ref. 1) with slight geometrical corrections to allow a description more adapted to the present Neotectonic structural knowledge. However, we did not reduced the zone width around fault traces due to uncertainty on mechanisms of generation.Seismic characterization of each zone was based on the earthquake catalogue and on the length of main faults.
Fig. 5 presents the time and space distribution of earthquake activity by source-zones. It is clear that events are correlated in space and not sta - tionary. It is also observed that completeness of data is a function of proxi

mity and size of urban centers.Keeping in mind these facts, we determined the standard frequency laws for zones or group of zones. Several alternative situa tions, such as data referring to different epochs (ie, instrumental, histori- cal, etc), were used to obtain the values for the parameters M_o, γ, β and M_1, of the source-zones. The length of reference interval and the lower threshold value are important factors determining either the types of function that bet- ter fits the data and the correspondent parameter values. It was observed that due to the existance of on and offshore quakes, it is quite different to work with intensities or magnitudes. Also,it was observed that for a few onshore zones, frequency laws had two linear trends in the log diagram, one for fre - quent earthquakes and another, paralel to the first, for the less frequent e- vents. The inclusion of data in period 1318-1900 allowed a better characteri- zation of source-zone parameters specially for the onshore zones.

Errors involved in the determination of the above mentionned parameter values are function of errors in data-base, ε earthquake, and of number of e- vents used in regression analysis which is closely related to the choice of source-zone geometries.

The characterization of seismicity as referred previously is highly con ditionned by the number and geometry of source-zones. To investigate this de- pendence, several source-zones mapping should be analysed.

ATTENUATION RELATIONSHIPS

In 1979 studies, for reasons of structural engineering analysis,PGA was selected as the important ground motion parameter to attenuate with focal dis tance. But due to lack of strong ground motion records, isosseismal maps were used to calibrate attenuation curves after conversion of MM intensities into acceleration through the expression $\log_{10}$ PGA = I/3 - 0.5. World wide accele- ration attenuations were also considered as alternative solutions.

Separating offshore from onshore earthquakes, the two expressions were derived: $a_{offsh} = 14 \ e^{0.8M} \ (R^2+20^2)^{-1/2}$ and $a_{onsh} = 1230 \ e^{0.8M} \ (R+15)^{-2}$. Dis persion on data leads to $\sigma_{lna} = 0.4$.

In 1983 studies the MMI scale was preferred throughout the entire ana- lysis. The observation of isosseismal maps showed that 2 general patterns of non-radial attenuation were identified and represented by the following eqs.

$$I = C_1 + C_2M + C_3 \ln (R + R_o + C_4|\sin (\theta)|) \tag{1}$$

$$I = C_1 + C_2M + C_3 \ln ((R + R_o) \ x \ (1 + C_4|\sin (\theta)|) \tag{2}$$

Where C_1, C_2, C_3 and C_4 are constants to be adjusted to each source-zone and θ is a new variable measuring the angle between the azimuth of a site and the azimuth of a specific point, both in relation to the center of mass of that zo ne. Eq. 1 takes into account the phenomenon of diffraction in the transition between the oceanic and continental crust. Isosseismals of the 1755 Lisbon earthquake are an example of this type of propagation. Eq. 2 considers prefe- rential directions of propagation. Eqs. 1 and 2 are reduced to radial attenua- tion when C_4 = 0. Fig. 6 presents a plot of those three kind of attenuations relationships.

The error involved in determining constants C_1, C_2, C_3 and C_4, measured as a global error, ε_3, can be greatly reduced when separation of different me chanisms of generation is taken into consideration. However, this error cannot be reduced to zero due to the randomness existing from earthquake to earthquake. Eight attenuation curves were developed in the 1983 study. Uncertainties for the offshore source-zones were reduced quite significantly, $\sigma_I = 0.10$, but no preferencial directions of propagation were observed for the sources 12 to 36 .

If PGA is required, the conversion intensity-acceleration is made at a final stage and should account with the large uncertainties involved, ε_4. In the short range updating, formal attenuation curves will be replaced by atte- nuation scenarios in such a way that for each type of earthquake (associated to a given source-zone) the observed space distribution of intensities are as- signed. A controlling variable, for instance magnitude, will only be needed to trigger the occurrence process. This procedure will eliminate ε_2 error refer - red above and allows the consideration of microzonation aspects.

HAZARD ANALYSIS. RESULTS

We used the methodology proposed by Cornell with non-radial attenuation functions. The computer algorithm is based on McGuires. Other approaches such as extreme value analysis of observed intensities was not explored.

Three sites (Fig. 7) were selected for comparison of 1983 studies with 1979 (Ref. 1) where a detailed sensitivity analysis took place. Hazard curves show the relative influence of on and offshore seismicity in each site. Unfor- tunately no upper and lower bounds were assign to the recent curves. The as - signment of probability density function to each random variable, ε_1 to ε_3, re ferred above will allow a detailed assessment of intervals of confidence on fi nal hazard. In any case one can say that uncertainties on final estimates are significantly reduced in relation to 1979 studies specially due to the decrea- se in uncertainty associated with attenuation relationships. If we had worked with acceleration the uncertainties would have been larger due to the poor cor relations between structural behaviour and PGA.

Hazard maps for 1000 years of return period are presented in Fig. 8 whe- re we can see which is the area of influence of offshore and onshore quakes and compare with results in Ref. 1. The 1983 study show good agreement with the shape of the map of maximum observed intensities in the last 400 years. The intensities assigned are also in agreement with the return periods that histo- rical observation indicate.

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Peak acceleration (cm/s^2)
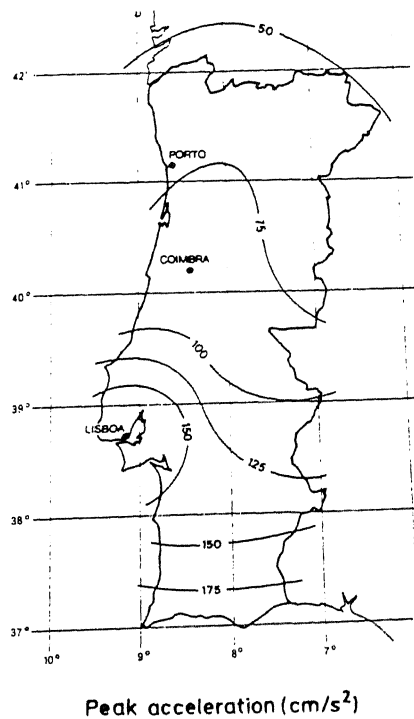
Fig. 1 – Hazard map for Portugal according to 1979 studies. (1000 years return period)

	A	B	C	D	E	
1958	1	1	1	3	2	CODE
1972	1	2	2	1	1	
1976	2	2	2+3	1+4	1	
1979	3	2	2+3	1+4	1	CODE
1983	3	1+2	3	3	2+3	

A – TECTONICS
1 – Geological map
2 – Tectonic alignements
3 – Active structures

B – CATALOGUES
1 – Historical
2 – Instrumental

C – MATHEMATICAL MODEL
1 – Deterministic
2 – Empirical distributions
3 – Source-zones

D – ATTENUATION
1 – Accel.,Vel.
2 – Radial intensities
3 – Non-radial intensities
4 – Regional strong motion recording

E – MAPPING
1 – Acceleration (cm/s^2)
2 – Intensities for offshore zones
3 – Intensities for onshre zones

Fig. 2 – Summary of important steps in the evolution of hazard studies
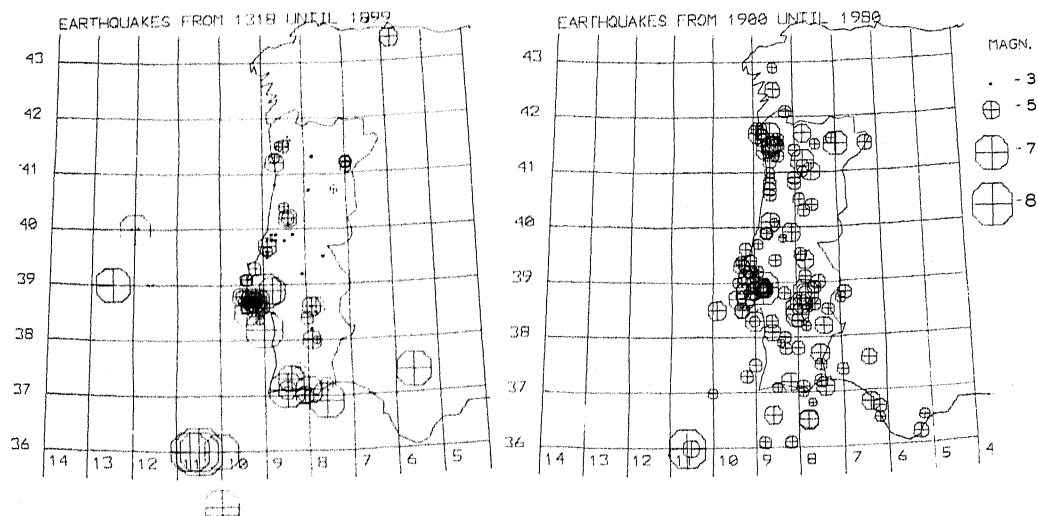
Fig. 3 – Earthquake epicenters with MMI$\geq$IV: a) Period 1318–1899; b) period 1900–1983

Fig. 5 — Time and space distribution of earthquake activity
(Vertical scale ≡ magnitude M_l)

Fig. 4 — Source-zones adopted
in the 1983 study

ZONE No. 1

$20^{\circ}-37^{\circ}$ $19^{\circ}-37^{\circ}$

$20^{\circ}-36^{\circ}$ $19^{\circ}-36^{\circ}$

1755 LISBON EARTHQUAKE
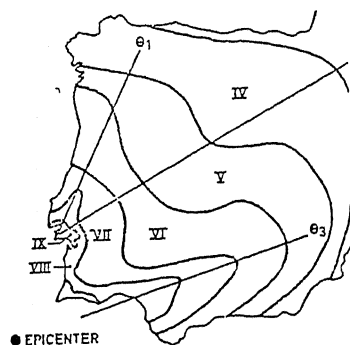
GORRINGE ZONE (No 5)
C_1=11.9 C_2=1.6 C_3=-3.19 C_4=-200
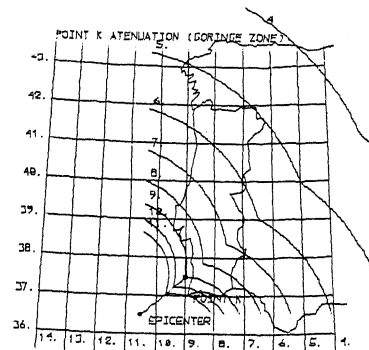
Sept 4,1962
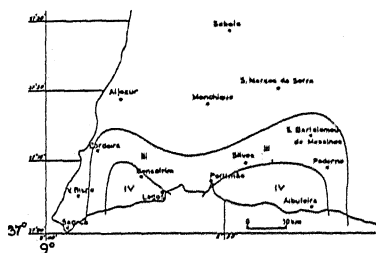
ALGARVE ZONE (No 11)
C_1=6.8 C_2=1.13 C_3=-2.2 C_4=0.5
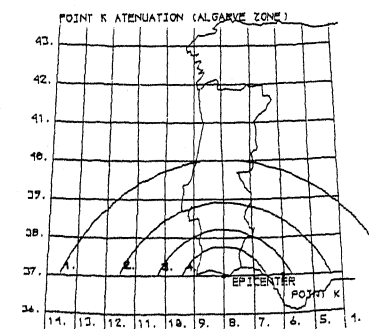
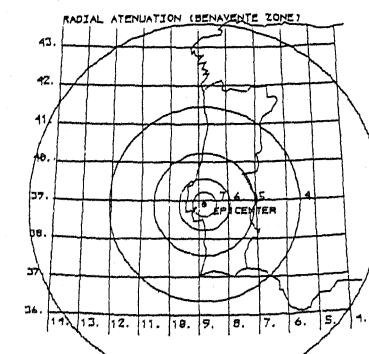## 1909 BENAVENTE EARTHQUAKE

a)
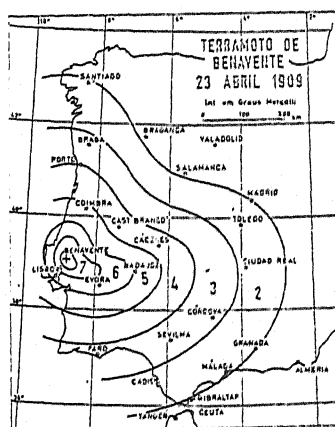
BENAVENTE ZONE (No 19)
C_1=6.8 C_2=1.13 C_3=-1.68 C_4=0

b)

Fig. 6 - Isosseismal maps corresponding to different mechanisms of attenuation: a) observed; b) according to eqs 1) and 2)
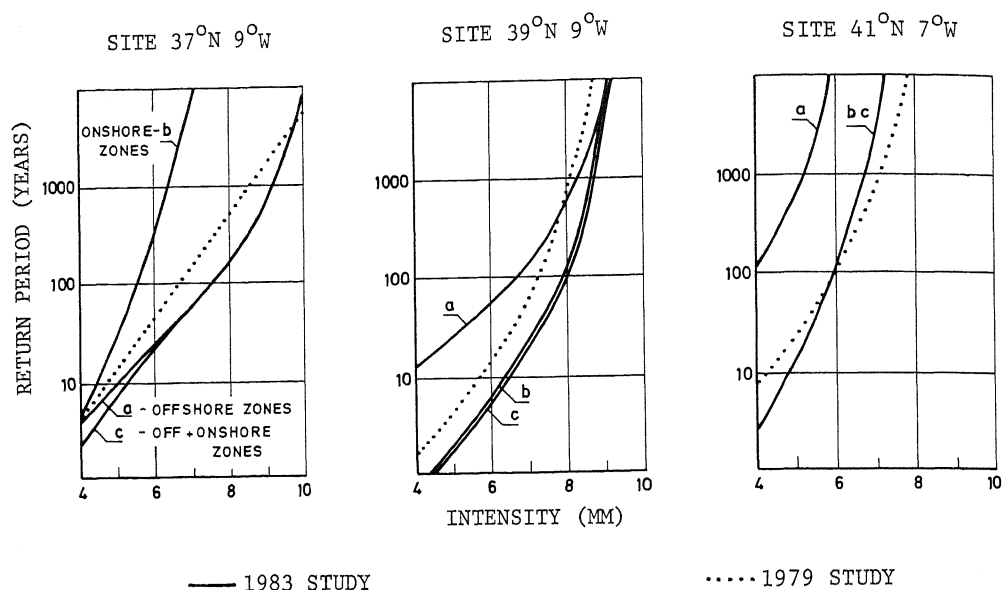
SITE 37°N 9°W   SITE 39°N 9°W   SITE 41°N 7°W

Fig. 7 - Comparison of hazard estimates for three different sites, according
         to the 1979 and 1983 studies

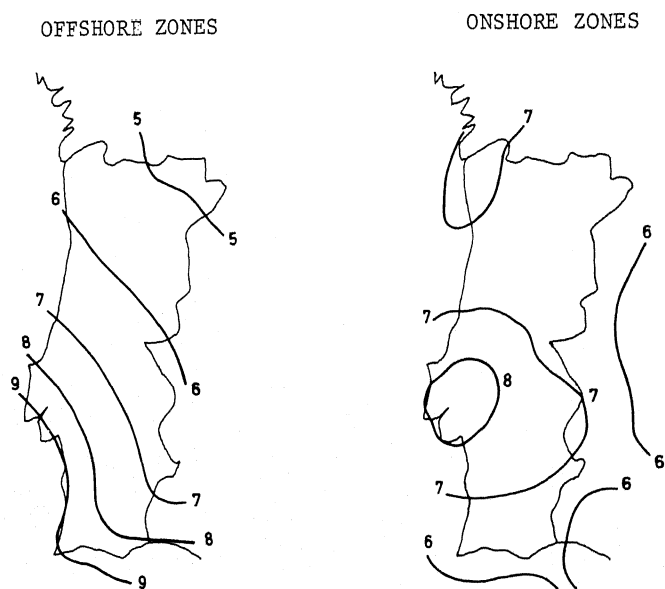OFFSHORE ZONES   ONSHORE ZONES

Fig. 8 - Hazard maps obtained in the 1983 study for 1000 years return period: a)
         offshore zones; b) onshore zones (units in MMI)