Seismic hazard assessment for Catalonia (Spain)

X. Goula[1], T. Susagna[1,2], R. Secanell[2], J. Fleta[1], A. Roca[1]

[1] Servei Geològic de Catalunya, Institut Cartogràfic de Catalunya, Barcelona, Spain
[2] Observatory Fabra, Barcelona, Spain

1. Introduction

Various studies on seismic hazard assessment carried out some years ago (Egozcue et al., 1991; Mayer-Rosa et al., 1993) pointed out the need for better input data, particularly in regions such as Catalonia where seismicity is moderate. With this purpose, research oriented toward the revision of the earthquake catalogue and to the definition of an "objective" seismotectonic frame was undertaken in the last years. A new regional seismic hazard assessment is proposed based on deterministic and probabilistic approaches which take into account updated data.

2. Input data

In order to analyse the seismic hazard of Catalonia a catalogue is needed made up both of information from this region and from the surroundings, including the eastern half of the Iberian Peninsula and the South of France (Figure 1).

Data from earthquake catalogues (I.G.N, 1991; BRGM-CEA-EDF, 1994; Fontserè and Iglésies, 1971; and Suriñach and Roca, 1982) have been compiled and a new working file containing the parametric data of each earthquake according to its respective information source was obtained. A critical comparison (Susagna et al., 1996) of the different information sources together with the inclusion of new specific studies, for example, Olivera et al. (1994) and Susagna et al. (1994) lead to the creation of a new revised catalogue for the area of study (Figure 1). Epicenters from this catalogue are plotted in Figure 1 together with the seismotectonic zones considered. Special effort has been devoted to the revision of earthquakes with epicenter near the border line between Spain and France.

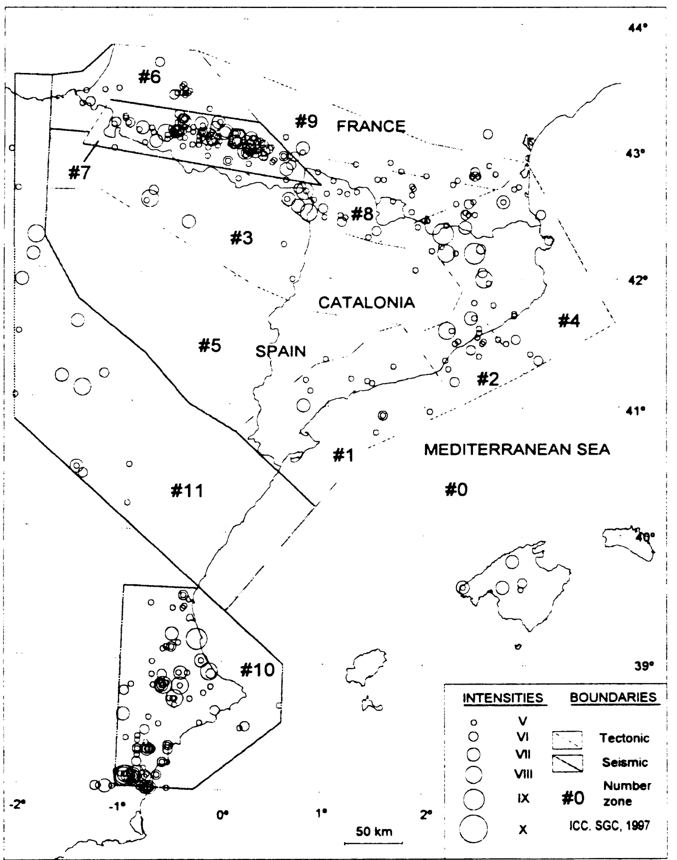

Figure 1. Seismicity and seismic zonation for Catalonia.

3. Map of maximum likely felt intensities

Figure 2 shows the map of maximum likely felt intensities. For each point of the studied area this information is obtained from the location and epicentral intensity of known earthquakes since the XIII century, applying to them a law of attenuation which calculates the intensities with the distance. The Sponheuer (1960) attenuation law has been considered:

$$I_0 - I = k * \log(\sqrt{(r^2 + h^2)} / h)^s + k * \delta * \log e(\sqrt{r^2 + h^2} - h)$$

where $\mathbf{I_0}$ is the epicentral intensity, **I** the site intensity at epicentral distance **r**, **h** the focal depth, **s** the geometrical spreading parameter, δ the attenuation coefficient and κ a factor relating intensity to the logarithm of peak ground acceleration.

For each event we considered a radius of the epicentral area, $\mathbf{R_0}$, ranging between 2 and 10 km (depending on its corresponding $\mathbf{I_0}$). The anelastic attenuation value considered was $\delta \leq 0.001$ km^{-1}, obtained from the analysis of earthquakes whose different felt intensities are known (great earthquakes of the Middle Age and weaker earthquakes of this century). Focal depth values as 10-15 km for earthquakes occurred in the Pyrenees and shallower depths, between 5 and 10 km for earthquakes near to the coast.

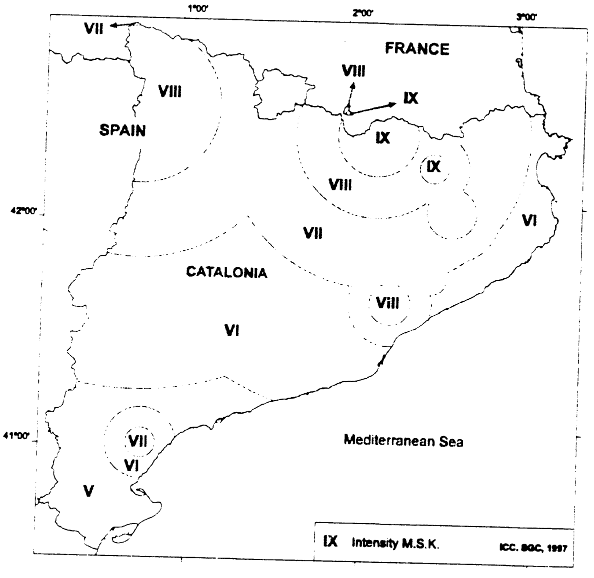

Figura 2. Maximum likely felt intensities in Catalonia.

The greatest values of maximum likely felt intensities are obtained in the Eastern Pyrenees (IX) while the lower ones are observed in the south of Catalonia (V). It is important to notice that most of the northern half part of Catalonia has felt at least an intensity of VII.

4. Probabilistic hazard assessment

The procedure used for the probabilistic assesment of earthquake hazard is essentially based on the Cornell (1968) method, later modified by McGuire (1976), and adapted for the possibility of using the Sponheuer attenuation law (Goula and Godefroy, 1985). Seismicity is considered distributed on homogeneous seismic sources, each of them characterized by the values of the parameters defining the model of earthquake occurrence.

The method calculates the probability of exceeding different intensities at given sites due to the different seismic sources, taking into account adequate attenuation laws.

4.1. Seismic sources

In areas where seismic activity is moderate, it is useful to introduce the concept of seismotectonic zones rather than active faults. The basic hypothesis is that the heterogeneity of the continental crust could explain the distribution and other characteristics of seismicity. Thus, the tectonic zonation is the first step for seismotectonic zonation, taking into account the more representative parameters of the crustal structure, mainly coming from the inherited geological structures, but not including the analysis of recent and present day tectonics (post-Miocene). For this first step, the methodology proposed by Grellet et al. (1993) has been applied with some modifications due to differences of scale and geological context. The variations of different parameters for selected themes allows us to individualize homogeneous zones (Fleta et al., 1996).

A first seismotectonic zonation may be obtained, for probabilistic analysis purposes, from the tectonic zonation, complemented by the seismicity distribution. A seismotectonic zonation with eleven zones is proposed in Figure 1. For the Pyrenees area the zones proposed are in agreement with the preliminary zones established in France (AFPS,1996). Only three zones of these eleven zones are defined by seismicity distribution criteria.

4.2. Estimation of the frequency parameters for each seismic source

To quantify the earthquake occurrence in each of the considered zones the following double truncated relation (Goula and Godefroy, 1985) is used:

$$\Pr(I \geq i) = \alpha * (\exp(-\beta * (i - i_0)) - \exp(-\beta * (i_{max} - i_0))) / (1 - (\exp(-\beta * (i_{max} - i_0)))$$

where **Pr(I≥i)** is the annual probability of exceeding a value of the intensity **i**, $\mathbf{i_0}$ is the minimum epicentral intensity considered, $\mathbf{i_{max}}$ is the maximum epicentral intensity allowable in each zone, α is the mean annual activity rate for intensities greater or equal to $\mathbf{i_0}$, and the β value is the slope related to the Guttenberg-Richter law. The minimum intensity considered in this study is V (M.S.K.) and the maximum intensity allowed in each seismic zone depends on the geological and seismic conditions of each source.

Seismicity parameters α and β have been estimated, following the maximum likelihood method proposed by Weichert (1980). The resulting frequency parameters for the different seismic zones are shown in table I:

	0	1	2	3	4	5	6	7	8	9	10	11
α	0.001	0.100	0.128	0.005	0.157	0.040	0.099	0.957	0.218	0.070	0.637	0.06
σ_α	------	0.03	0.033	------	0.03	0.014	0.025	0.09	0.04	0.02	0.059	0.016
β	1.500	1.864	1.608	1.551	1.256	1.312	1.977	1.420	1.716	1.737	1.201	0.886
σ_β	------	0.559	0.324	0.091	0.186	0.373	0.64	0.116	0.246	0.214	0.083	0.242
$\mathbf{i_{max}}$	VI	VIII	IX	VII	X	IX	VII	X	IX	VIII	XI	IX

Table 1. Mean values α and β, standard deviations σ_α and σ_β and $\mathbf{i_{max}}$ for each seismic source considered.

4.2. Seismic hazard estimation

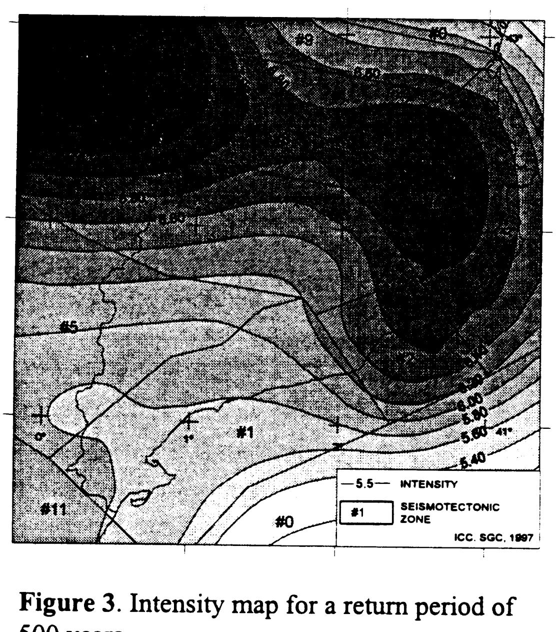

Figure 3. Intensity map for a return period of 500 years.

The seismic hazard map presented in Figure 3 was obtained using the mean values for the different frequency and attenuation parameters estimated for each seismic zone. It shows the intensity level (as a continuous parameter) corresponding to a return period of 500 years). The obtained intensities range from less than VI in the South to VII-VIII in the Northwest part of Catalonia.

A sensitivity analysis is now in progress for investigating the influence of the uncertainty of parameters values on the stability of the results. Figure 4 shows the mean seismic hazard curves in the following towns: Barcelona, Tarragona, Lleida, Girona, Viella and Olot; the last two towns are located in the epicentral areas of the two greatest known earthquakes which have occurred in Catalonia. In the same figure the maximum

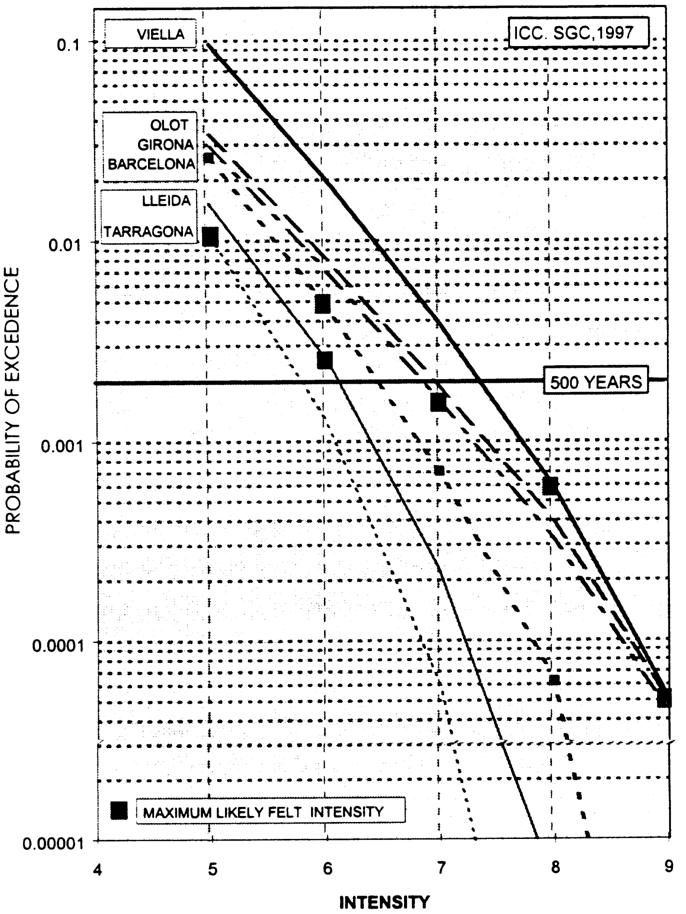

Figure 4. Hazard curves for 6 towns.

likely felt intensities for each city are also presented.

For Tarragona, the maximum likely felt intensity is one degree lower than the value corresponding to a return period of 500 years. Lleida, Barcelona and Girona show maximum felt intensities very similar to the values corresponding to a return period of 500 years. On the other hand, for Viella maximum felt intensity is greater than the 500 years intensity and Olot shows a difference of two degrees.

5. Conclusions

A new seismic hazard assessment for Catalonia has been carried out, taking into account a recently revised earthquake catalogue and a seismotectonic zonation defined by tectonic zonation and seismicity distribution.

Two approaches are proposed, one based on maximum felt (likelihood) intensities and another on mean intensities corresponding to a return period of 500 years.

The felt intensities result to be greater than the intensities corresponding to a return period of 500 years for the northern part of Catalonia. This result may indicate a particular situation for this region, in the sense that the big earthquakes which occurred in the Middle age may correspond to return periods larger than 500 years.
In order to propose a seismic zonation to be used in a construction code, this fact must be taken into account and the intensities corresponding to a return period of 500 years need to be modified considering maximum felt (likelihood) intensities.
An ongoing sensitivity analysis of the uncertainty of hazard parameters will allow us to have a control of the stability of the probabilistic results.

Acknowledgements

We want to thank CEA/IPSN for providing seismic and geological data of the French territory; to J.Escuer and GEO-TER s.a.r.l. for their participation in the seismotectonic zonation; to the Association Française de Génie Parasismique (APFS) for discussions concerning seismotectonic zonation on the Pyrenees area; to the Instituto Geográfico Nacional (IGN) for supplying seismicity data; to the Direcció General d'Arquitectura i Habitatge of the Generalitat of Catalonia for supporting the study; to the GIS section of the ICC for assisting on data processing and mapping. The tasks of revision of the earthquake catalogue have been partially founded by CEC Project BEECD (Contract number EV5V-CT94-0497).

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