Probabilistic assessment of the seismic risk of Barcelona

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SUMMARY:
A probabilistic methodology is used to obtain an actualized estimation of the seismic risk of Barcelona. The main steps of this methodology are: 1) a probabilistic seismic hazard assessment (PSHA); 2) a probabilistic assessment of the seismic vulnerability and; 3) the estimation of the seismic risk. According to the results of the PSHA analysis, which has been done using the CRISIS2008 code, the macroseismic intensity of VI-VII has a return period of 475 years. On the other hand, a probabilistic version of the methodology of the vulnerability index was used to assess the seismic vulnerability of 69982 buildings of Barcelona. According to the results, Ciutat Vella is the more vulnerable district in Barcelona. In this district the probability that the vulnerability index of the buildings will be greater than 1.0 range between 18.76% and 44%, with a mean value of 30.43%. In this case, values close to 1 of the vulnerability index represent high levels of seismic vulnerability. On the other hand, according to the seismic risk results, the districts of Ciutat Vella and the Eixample have the higher levels of seismic risk of Barcelona.

Keywords: Seismic Risk, Seismic Hazard, Seismic Vulnerability, Barcelona.

1. INTRODUCTION

The damage that occurred in several buildings in Spain due to the 2011 Lorca earthquake, and the damage that was related to the 2010 Haiti earthquake, were considered socially inacceptable. These cases are examples of the importance of executing adequate assessments of the seismic risk in any urban areas, with the purpose of improving the seismic management of the cities. In the case of Barcelona is possible to affirm that there are a solid group of academics and public authorities, which consider as an important task to do periodical evaluations of the seismic risk of Barcelona. Some of these persons have been the responsible of the main part of the databases related to the buildings in Barcelona that were used in the present work (Aguilar-Meléndez, 2011).

2. SEISMIC RISK OF BARCELONA

2.1. Methodology

In order to assess the seismic risk of Barcelona the LM1_P methodology (Aguilar-Meléndez, 2011) was chosen. The main steps of this methodology are: 1) the probabilistic seismic hazard assessment, 2) the seismic vulnerability analysis and, 3) the estimation of the seismic risk.

2.1.1. Seismic hazard in the LM1_P Methodology
In the LM1_P methodology it is recommended the use of the code CRISIS2008 (Ordaz et al, 2011). This code allows estimating the seismic hazard according to the Esteva-Cornell approach (Esteva, 1970; Cornell, 1968). The CRISIS2008 code and its previous versions have been widely validated in different international projects. The new version of this code has significant improvements. For instance, now it is possible to assess the seismic hazard using attenuation laws in terms of peak ground

acceleration (PGA), or in terms of macroseismic intensities. In the LM1_P Methodology seismic hazard curves in terms of macroseismic intensities versus frequencies of exceedance are required.

2.1.2. Seismic vulnerability in the LM1_P Methodology

In this methodology the seismic vulnerability is considered as a property of the building. This vulnerability depends on the characteristics and the properties of the building, but also depends on the environment where the building is located. Particularly, the level of the seismic vulnerability of each building, describes the level of its weakness to resist properly the effects that some earthquakes can produce to the building (Aguilar-Meléndez et al, 2010a; 2010b).

The vulnerability index is the parameter that contributes to describe the level of seismic vulnerability of each building. Values close to 0 of this index mean low seismic vulnerability and values close to 1 mean high seismic vulnerability. According to the LM1_P methodology (Aguilar-Meléndez, 2011), the seismic vulnerability of each building is represented though a probability density function (pdf), beta type. That pdf describes the probabilities that different values of the vulnerability index can occur, and at the same time this pdf allows to represent the important uncertainties related to the assessment of the seismic vulnerability of each building.

In order to estimate the seismic vulnerability, each building must be classified into some of the typologies defined in the LM1 methodology of the Risk-UE project (Milutinovic and Trendafiloski, 2003). The Table 2.2 include examples of the kind of typologies that were mentioned.

Table 2.1. Examples of building typologies (Milutinovic and Trendafiloski, 2003).

	Building Typology
M.3.4.	Unreinforced masonry bearing walls with reinforced slabs – without or low earthquake resistant design (E.R.D.)
R.C.1.2.	Concrete moment frames with moderate E.R.D.

2.1.3. Seismic risk in the LM1_P Methodology

According to the LM1_P methodology the convolution between the seismic hazard and the seismic vulnerability allows to estimate the seismic risk. For this purpose, a function damage in terms of the seismic vulnerability index and the seismic macroseismic intensity is used. This function is mainly represented by the Eqn. 2.1, which allows estimating a mean damage grade, and then the complete distribution is obtained using the Equation 2.2. In these expressions, the scale of the damage grade corresponds to the description of the Table 2.2.

$$\mu_D = 2.5\left[1+\tanh\left(\frac{I+6.25V-13.1}{2.3}\right)\right] \tag{2.1}$$

where μ_D is the mean damage grade, I is a macroseismic intensity, V is the seismic vulnerability index.

The complete distribution of the damage is obtained using the Eqn. 2.2.

$$PDF: p_{D_x}\left(\frac{D_x+1}{6}; p,q,0,1\right) = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)}\left(\frac{D_x+1}{6}\right)^{p-1}\left(1-\frac{D_x+1}{6}\right)^{q-1}; 0 \le \frac{D_x+1}{6} \le 1 \tag{2.2}$$

where PDF is the probability density function that is required to estimate the damage distribution, Γ is the gamma function, D_x is the damage grade, which value is a number between 0 and 5 (Table 2.2). The values of the parameters p and q are obtained through the Eqn. 2.3 and 2.4, respectively.

$$p = t(0.007\mu_D^3 - 0.052\mu_D^2 + 0.2875\mu_D) \tag{2.3}$$

$$q = t - p;\ \ t = 8 \tag{2.4}$$

Table 2.2 Damage grades that are used in the LM1_P methodology to describe the level of seismic damage (Aguilar-Meléndez, 2011).

	Damage grade	Structural damage	Non-structural damage
1	Negligible to slight damage	None	Slight
2	Moderate damage	Slight	Moderate
3	Substantial to heavy damage	Moderate	Heavy
4	Very heavy damage	Heavy	Very heavy
5	Destruction	Very heavy	

2.2. Seismic Hazard of Barcelona

The seismic hazard of Barcelona was assessed using the CRISIS2008 code (Ordaz et al, 2011). This code allows obtaining directly the seismic hazard curve of macroseismic intensities versus exceedance rates. In order to estimate the seismic hazard of Barcelona the seismic sources of the Fig. 2.1 were considered. On the other hand, the attenuation laws used to compute the seismic hazard were proposed by López-Casado et al (2000). These attenuation laws describe the attenuation of the macroseismic intensity with the distance.

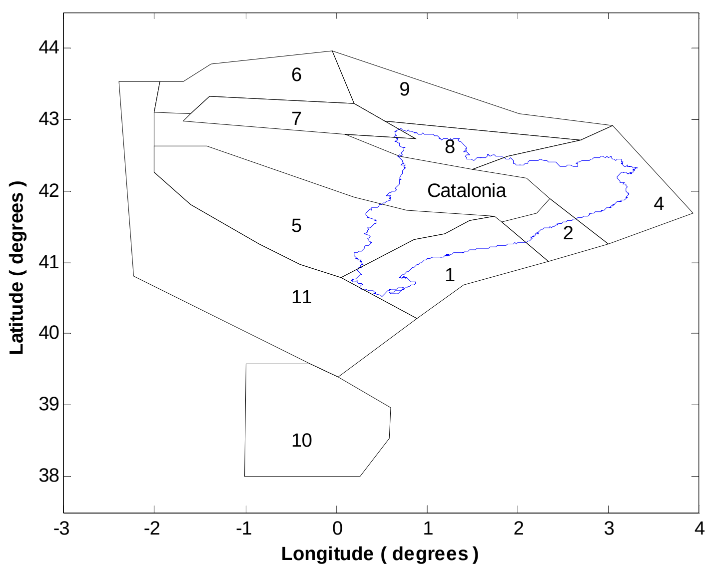

Figure 2.1. Geometry of the seismic sources considered to estimate the seismic hazard of Barcelona.

It is important to mention that the uncertainty related to different parameters that are involved in the PSHA were considered. For instance, the attenuation laws used were considered with its respective standard deviation. This kind of estimation of the seismic hazard is possible in the recent version of the CRISIS2008 code (Ordaz et al, 2011). The seismic hazard curve obtained for Barcelona is shown in the Fig. 2.2. According to this curve, the macroseismic intensity that has a return period of 475 years corresponds to a value between VI and VII.

The seismic hazard results that were obtained in the present work have important coincidences with the results that were obtained in previous studies. For instance, Secanell et al (2004) obtained a mean value of 6.5 for the macroseismic intensity related to a return period of 475 years. Similar value was estimated by Goula et al (1997).

On the other hand, a disaggregation study was included as a part of the PSHA. According to this study, the seismic source that has the higher contribution of the seismic hazard of Barcelona is the seismic source that in the Fig. 2.1 is identified with the number 2.

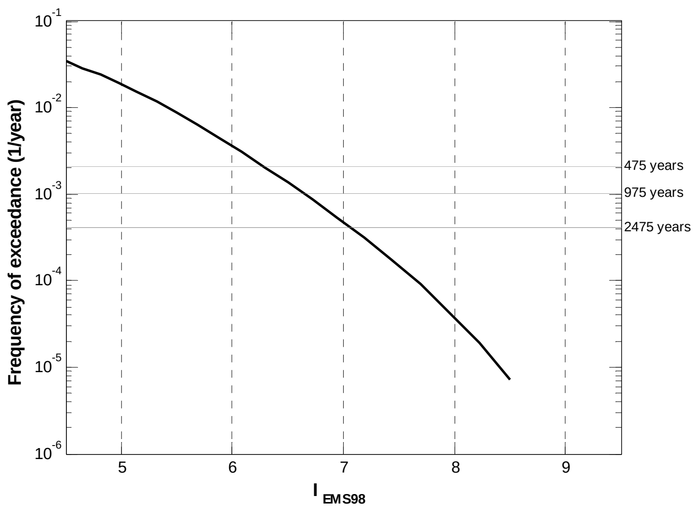

Figure 2.2. Curve of seismic hazard of Barcelona.

2.3. Seismic vulnerability of Barcelona

For administrative purposes the city of Barcelona has been divided into 10 districts (Fig. 2.3). In this work 69982 buildings were studied. The data of these buildings has been mainly provided by the Barcelona Council and this information has been processed by a research group of the Technical University of Catalonia, during the last decade (Aguilar-Meléndez, 2011). In the Fig. 2.4 is possible to observe a distribution according to the main structural material of the buildings of each district of Barcelona. According to this information, near of the 90% of the buildings of the district of Ciutat Vela are of unreinforced masonry.

Figure 2.3. Administrative division of the city of Barcelona.

In this study, the seismic vulnerability was estimated for each one of the 69982 buildings. Particularly, three vulnerability curves were obtained to describe the seismic vulnerability of each one of these building. For this purpose, the code USERISK2011 (Aguilar-Meléndez et al, 2011), was used. Additionally, average curves of the vulnerability, were obtained for each neighbourhood, each district and even for the whole city. The Fig. 2.5 shows the average of the best vulnerability curves of the districts of Barcelona. Similarly, the Fig. 2.6 shows the average curves of the seismic vulnerability of Barcelona.

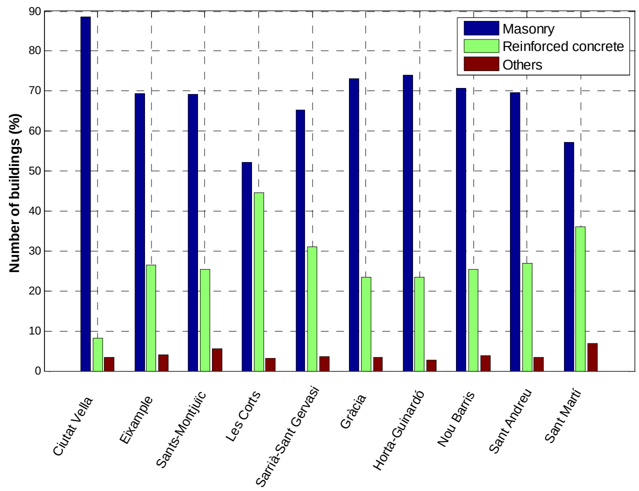

Figure 2.4. Distribution of the buildings according to its main structural material in each district of Barcelona.

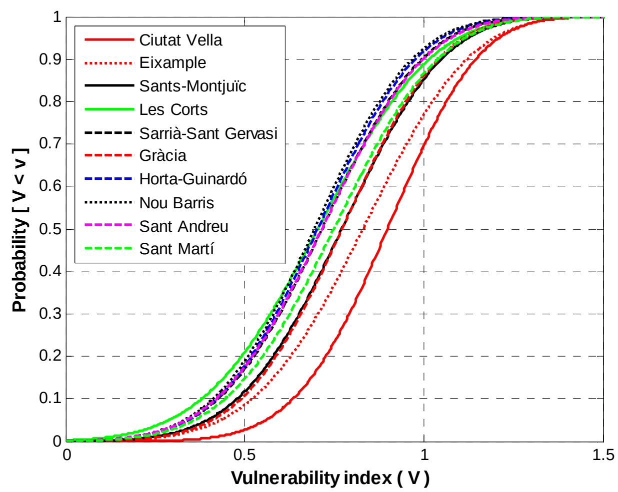

Figure 2.5. Average curves of the best seismic vulnerability of the districts of Barcelona.

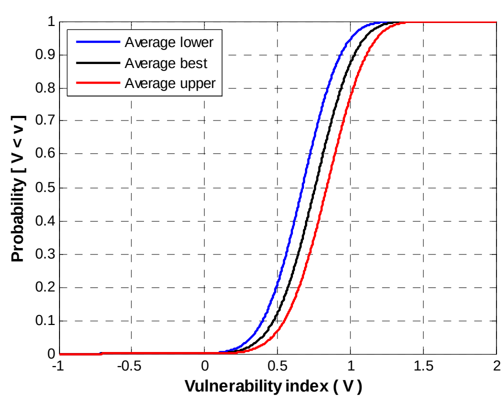

Figure 2.6. Average curves of the seismic vulnerability of Barcelona.

2.4. Seismic risk of Barcelona

The results of seismic risk can be obtained into different scales: building scale, neighbourhood scale, district scale or city scale. In order to estimate the seismic risk of Barcelona the code USERISK2011 (Aguilar-Meléndez et al, 2011) was used. The Fig. 2.7 shows the seismic risk curves for Barcelona and the Fig. 2.8 shows the seismic risk curves for the districts of the city.

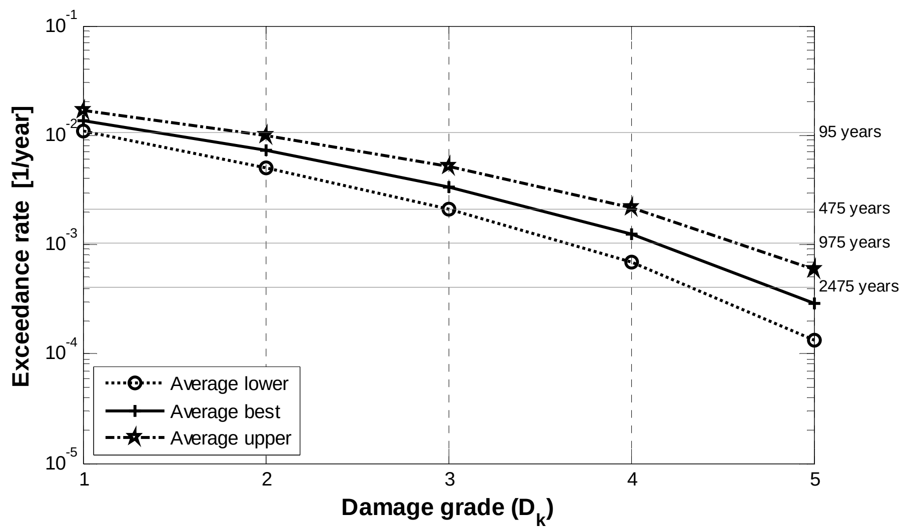

Figure 2.7. Average curves of the seismic risk of Barcelona.

According to the results (Fig. 2.8), the district with the highest level of seismic risk is the district of Ciutat Vella. And the same time, one of the districts with the lower seismic risk is the district of Horta-Guinardó (Fig. 2.8).

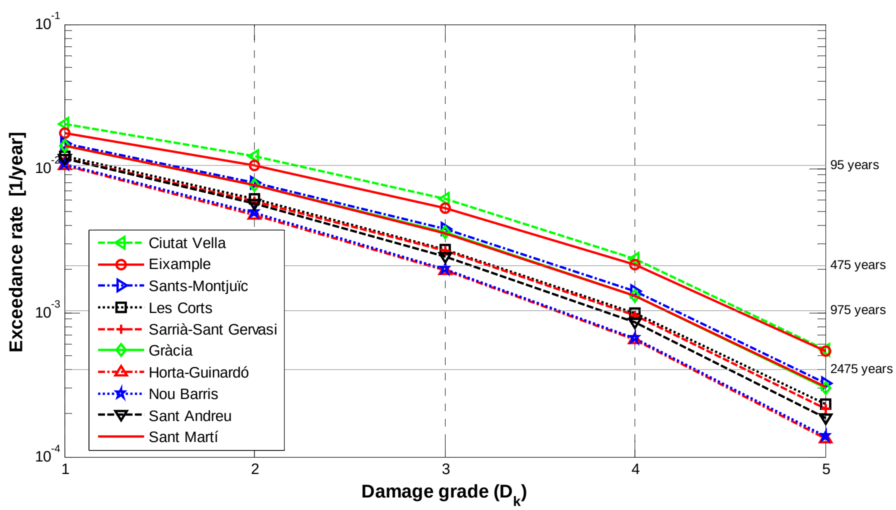

Figure 2.8. Average curves of the seismic risk of the districts of Barcelona, related to the best vulnerability curves.

3. CONCLUSIONS

According to the results in Barcelona there are significant levels of seismic risk. This condition is mainly due to buildings with high levels of seismic vulnerability, located in a place with a moderate seismic hazard. The results obtained in this study are in agreed with the results obtained by Irizarry, et al (2010). The methodology applied allows to obtained valuable information about the seismic hazard, the seismic vulnerability and the seismic risk of a high percentage of the buildings of an important city as Barcelona. Therefore, the LM1_P methodology is appropriated to estimate the seismic risk in many urban areas of the world.

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