# Lorca earthquake May 11 2011: a comparison between disaster figures and risk assessment outcomes

**J.A. Valcárcel, G.A. Bernal & M.G. Mora**
*Universitat Politècnica de Catalunya. Barcelona. Spain*

**SUMMARY:**
In the context of Spain, the Region of Murcia has moderate to high seismicity. In 1999, 2002 and 2005 have occurred events of magnitude $M_b$ of 4.7, 5.0 and 4.8 respectively, producing considerable economic losses. Recently, in May 11 of 2011, an earthquake of $M_b$ 5.1 stroke Lorca. For risk management, questions arise about the recurrence rate of the events and its consequences, as well as the reliability of risk assessments and building codes requisites. In this work, the expected losses in the Region of Murcia are estimated considering a probabilistic approach. This analysis allows estimating the exceedance rate of losses, the probability of exceedance of a given loss in a given time frame, as well as the probability of exceedance of a given loss in the following t years. Those metrics, compared with the losses observed in the recent events, are useful in order to design risk management strategies.

*Keywords: Risk management, risk assessment, seismic risk*

## 1. INTRODUCTION

In the context of Spain, the Murcia region has moderate to high seismicity. In Table 1.1 is presented the recurrence rate of events by ranges of Magnitude. In 1977, 1999, 2002 and 2005 have occurred events, producing considerable economic losses In Table 1.2 are presented the magnitude, the maximum macroseismic intensity observed, the Peak Ground Acceleration (PGA) recorded for the events and a brief description of the damages.

**Table 1.1.** Earthquake recurrence rate (events per year) by ranges of magnitude

| Magnitude | Recurrence rate (events per year) |
|---|---|
| >7 | 0.006 |
| 6.1-7-0 | 0.033 |
| 5.1-6.0 | 1.20 |
| 4.1-5.0 | 16.6 |
| 3.1-4.0 | 219.0 |
| 2.1-3.0 | 584.0 |

Recently, in May 11 of 2011, an earthquake of $M_b$ 5.1 stroke Lorca. The PGA recorded was about 0.38 g. This acceleration is higher than the PGA estimated for Lorca in the Spanish building code for a return period of 500 years (0.12g) (Goula et al., 2011). At April 19 of 2012, the damage of buildings is described as follows: from a sample of 6419 buildings (35% of the buildings of the city), 63% were classified as habitable, 21% of the buildings had light or insignificant structural damages and 11% of the buildings suffered structural damages and its occupancy was prohibited. The remaining 5% were heavily damaged and have been demolished (Ayuntamiento Lorca, 2012). In terms of economic damages, at December 29$^{th}$ of 2011, the estimated losses, only in insured buildings, were around 332.5 millions of euros. From this amount, 256.9 millions corresponds to damages in households; 36.8 millions of damages in commerce and stores, 4.9 millions in damages in industries; 2.9 millions of damages in vehicles (Consorcio de Seguros, 2011 a).

**Table 1.2.** Most relevant Earthquakes ocurrend in the Region of Murcia

| Date | Location | Magnitude | Macroseismic intensity | PGA | Observations |
|---|---|---|---|---|---|
| February of 1999 | Mula | 4.7 | VI. | 0.012 | Near of 5000 residential buildings were affected. 18.5 % suffered significant structural damages. The damages on insured buildings were around 15.6 millions of euros. |
| August of 2002 | Bullas | 5 | V | 0.02 | Old buildings suffered light damages on architectural elements. The damages on insured buildings were around 1.6 millions of euros. |
| January of 2005 | La Paca | 4.8 | VII | 0.032 | More than 900 residential buildings were affected. The Government of Spain and Murcia delivered 4.8 million for the reconstruction. 0.3 millions were used for the management of the emergency. The damage on insured facilities was around 8.1 millions. |

*Sources: ABC.es (2012), Ayuntamiento Lorca (2012), Consorcio de seguros (2011b), Ministerio de Fomento (2002), Rinamed (2011)*

Given the seismicity of the region, seismic risk should be a matter of planning based on the analysis of the expected losses. In this regard, a probabilistic seismic hazard assessment, as well as the evaluation of seismic scenarios for return periods of 475 years have been developed in the project Rismur (Benito et al, 2006).

Due to the uncertainty in the estimation of the seismic hazard and the buildings vulnerability, questions arise about the recurrence rate of the events and its consequences, as well as the reliability of risk management programs based on the damage assessment of specific scenarios. Then, in order to support risk based decisions, this work presents the application of a methodology for the estimation of the expected losses in the Province of Murcia, taking into account all possible seismic events. This analysis allows estimating the probability of exceedance of the loss associated to the recent events, the probability of exceedance of a given loss in a given time frame, as well as the probability of exceedance of a given loss in the following t years. Those metrics are useful in order to highlight the relevance of the problem, influencing upon risk perception and avoidance.

## 2. SEISMIC RISK ASSESSEMENT IN THE REGION OF MURCIA

### 2.1 Exposed values

The total value of the buildings of the Region of Murcia was obtained from the data available in cadastral statistics. The exposed value is around 54000 millions of Euros. The exposed value was regionally distributed according to the population of each entity. Also, buildings have been classified into structural typologies, based on the classification by vulnerability classes (A,B,C.D) developed in the project RISMUR (Benito et al, 2006).

The typologies considered were simple stone masonry bearing walls (M12L, Low rise), unreinforced masonry walls with composite steel and masonry slabs (M33L, Low rise), unreinforced masonry walls with Reinforced Concrete - RC- slabs (M34M, mid-rise), irregular RC structures with infilled masonry walls (RC32L, Low Rise), regular RC structures with infilled masonry walls (RC31M, mid-rise) and steel moment frames with infilled masonry walls (S3M, mid- rise). This classification was developed taking into account the construction period of buildings and the classification of the population entities in urban or rural. The height of the buildings has been considered according to the statistics of number of floors (INE 2012). In Fig 2.1 (a) is presented the percentage of buildings by number of floors. In Fig 2.1 (b) is shown the percentage of the exposed value by structural typologies. Also, in Fig 2.2 (a) is presented the location of the Region of Murcia and (b), the exposed values on each population entity.

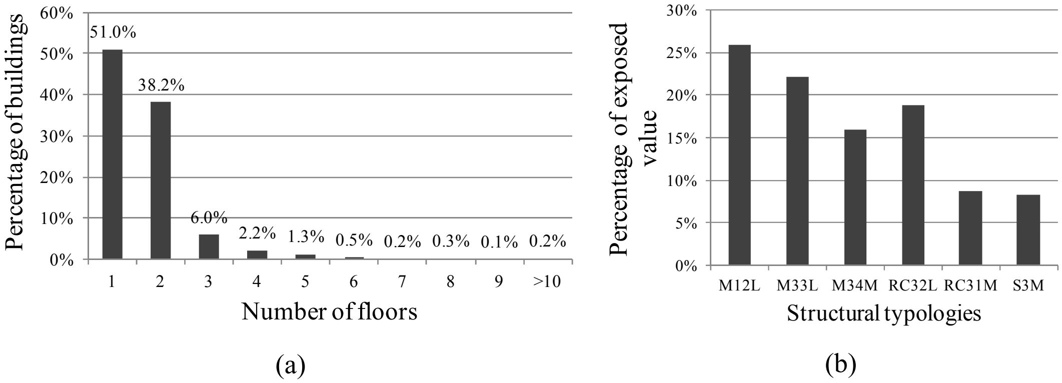



**Figure 2.1.** (a) Percentage of buildings by number of floors; (b) Percentage of the exposed value by structural typologies

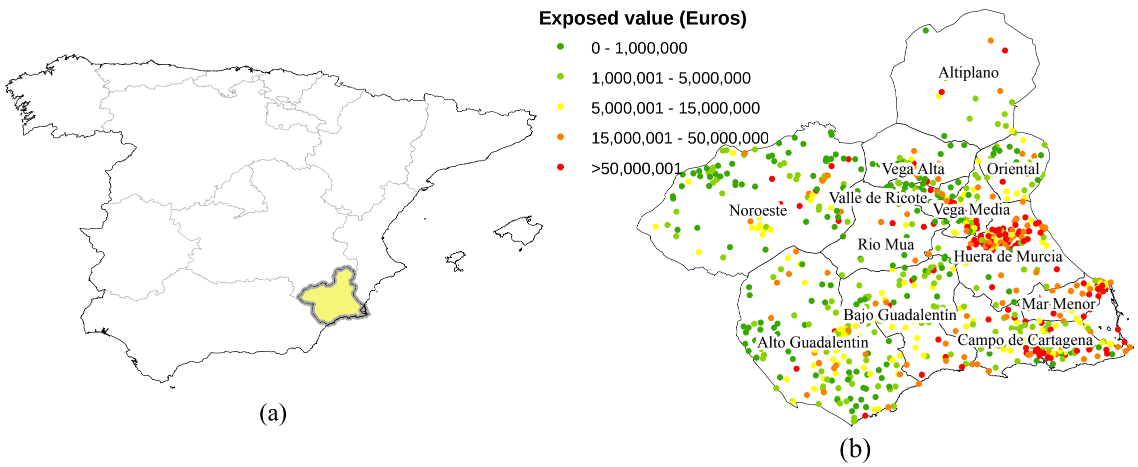



**Figure 2.2.** (a) Location of the Region of Murcia; (b) Exposed values on each population entity

## 2.2 Seismic hazard

In this work, it is considered a set of events generated based on a seismic zonation. The geometry of the sources and their seismicity parameters is defined according to the seismic zonation developed by López-Casado et al., (1995). These parameters were also considered in the project Rismur. On this basis, a set of seismic events of diverse magnitudes is generated through a sampling procedure, based on the recursive division of the sources' geometry. The seismicity parameters of each segment are assigned by weighting its area/length in relation to the total area/length of the source. Finally, the probability of each event is estimated following a Poisson magnitude recurrence relation.

Once generated the set of events, the expected spectral acceleration at any site of interest (for 5% of critical damping), is obtained through the attenuation laws defined by Ambraseys, (1996). Given the random nature of seismic ground motion, the spectral acceleration is assumed as a random variable with lognormal distribution.

This information is summarized in file composed by multiple grids of the studied territory. Each grid corresponds to the spectral accelerations calculated for each event. Those events are characterized by their magnitudes and their frequency of occurrence. A total of 56824 events are considered. This procedure is developed by using the software CRISIS 2007 Version 7.2 (Ordaz et al., 2007). In Fig. 2.3 (a) are plotted the seismic events included in the analysis. As a reference of the seismic hazard in the Region of Murcia, in Fig. 2.3(b) is presented the PGA for a return period of 500 years.

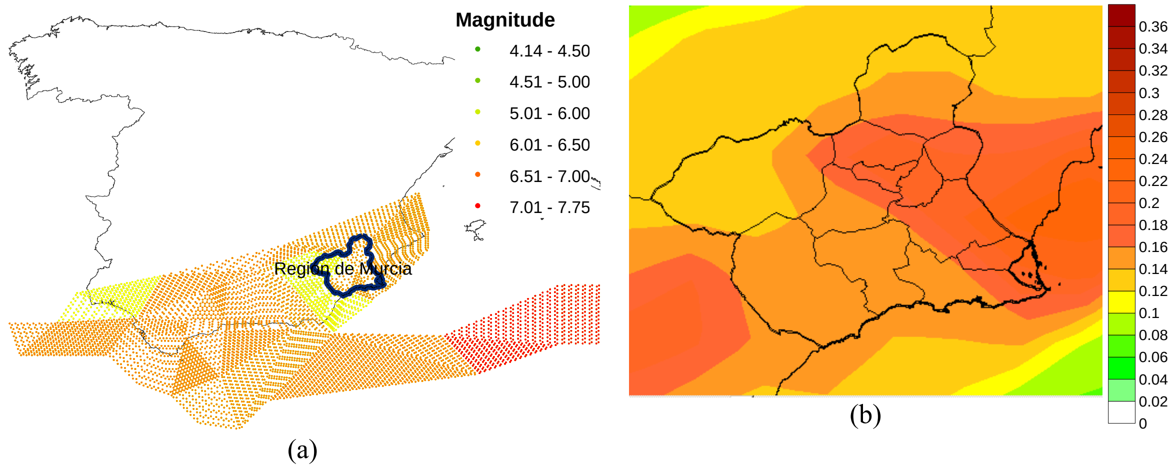



**Figure 2.3.** (a) Events considered in the analysis; (b) Peak ground acceleration for a return period of 500 years

## 2.3 Vulnerability

Each structural typology is characterized by a bilinear capacity spectrum. The spectral displacements of the yielding point and ultimate capacity are used as reference in order to define the corresponding vulnerability curve. Those curves define the expected value of loss and its standard deviation, given the spectral acceleration estimated on buildings location. The expected value of the loss (β) may be obtained following Eqn 2.1 (Miranda, 1999; Ordaz, 1998):

$$E(\beta \mid \gamma_i) = \left( 1 - exp\left[ ln(1-\beta_0)\left(\frac{\gamma_i}{\gamma_0}\right)^{\varepsilon} \right] \right) \tag{2.1}$$

Where $\gamma_i$ is the spectral displacement estimated for the building; $\beta_0$ represents the expected loss associated to the reference spectral displacement $\gamma_0$. $\beta_0$ is assumed as 5%; $\gamma_0$ is the spectral displacement at the yielding point of the bilinear capacity spectrum ($sd_y$). On the other hand, ε is a factor that is used in order to adjust the curve to the levels of loss defined for the point of ultimate capacity ($sd_u$). This value is assumed as 100%. On Table 2.1 are listed the parameters of the capacity spectrum of the typologies considered in the analysis.

**Table 2.1.** Parameters of the capacity spectrum of the structural typologies considered in the analysis

| Typology | Source | $sd_y$ (cm) | $sa_y$ (g)o | $sd_u$ (cm) | $sa_u$ (g) |
|---|---|---|---|---|---|
| M12L | Givanazzi (2005) | 0.15 | 0.15 | 1.55 | 0.15 |
| M33L | Milutinovic y Trendafiloski (2003) | 0.27 | 0.65 | 1.36 | 0.56 |
| M34M | | 0.53 | 0.3 | 3.18 | 0.3 |
| RC32L | | 0.7 | 0.13 | 5.24 | 0.14 |
| RC31M | | 0.85 | 0.81 | 2.63 | 1.13 |
| S3M | FEMA/NIBS (2003) | 0.3 | 0.1 | 3.05 | 0.2 |

Since in the hazard module the seismic action is expressed in terms of the spectral acceleration, it is necessary to convert those values into spectral displacement following Eqn 2.2 (Miranda et al., 1999).

$$\gamma_i = \beta_1 \beta_2 \beta_3 \frac{T_e^2}{4\pi^2} Sa(T) \tag{2.2}$$

Where Te is the fundamental period of the structural typology; $\beta_1$ is the relationship between the maximum lateral displacement at the roof and the spectral displacement, considering an elastic model;

$\beta_2$ describes the relationship between the maximum interstory drift and the global drift of the structure, which is defined as the maximum lateral displacement at the roof divided by the height of the structure; $\beta_3$ is the relationship between maximum lateral displacement considering an inelastic model, and the maximum displacement of the elastic model

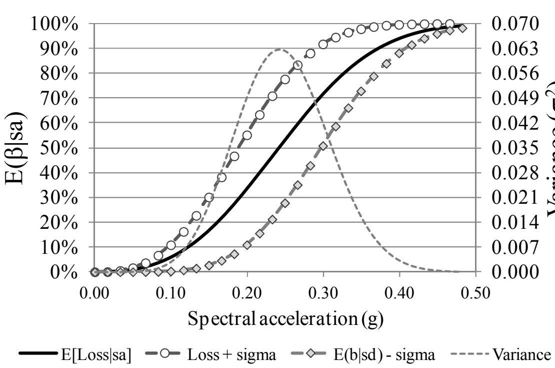
It is assumed that the loss follows a Beta distribution function (see Eqn. 2.3) The parameters of the distribution may be computed following Eqn 2.4 and Eqn 2.5, based on the estimation of the expected value of loss, (See Eqn 2.1), and the coefficient of variation of the loss $C^2$ (β). This coefficient has been adopted following the ATC (1985) and Graf & Lee (2009). It is considered that the variance of loss has a maximum at the 50%.

$$P_{\beta|\gamma_i}(\beta)=\frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)}\beta^{a-1}(1-\beta)^{b-1} \tag{2.3}$$

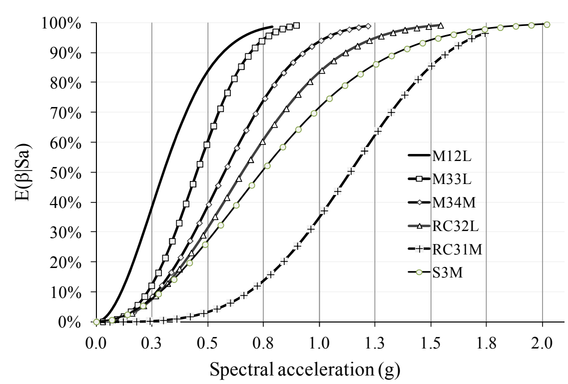
$$a=\frac{1-E(\beta|\gamma_i)-E(\beta|\gamma_i)C^2(\beta)}{C^2(\beta)} \tag{2.4}$$

$$b=a\left[\frac{1-E(\beta|\gamma_i)}{E(\beta|\gamma_i)}\right] \tag{2.5}$$

Once established the expected value of the loss and its variance, it is possible to estimate its probability distribution, given a specific spectral acceleration. As an example, In Fig. 2.3 (a) is shown the vulnerability curve of buildings of unreinforced masonry walls with composite slabs of steel and mansonry. In Fig. 2.3 (b) are shown the vulnerability curves of the typologies considered in the study.



(a)



(b)

**Figure 2.4.** (a) Vulnerability curve of the typology M33L (b) Vulnerability curves in the analysis

## 2.**4. Risk assessment**

*2.4.1 Loss Exceedance curve*

The Loss Exceedance Curve (LEC) specifies the frequencies (also known as the exceedance rate), usually annually, of the events that may exceed a specific loss value. The exceedance rate is obtained according to Eqn (2.6)

$$\nu(p)=\sum_{i=1}^{events}P(P>p|i)F_A(i) \tag{2.6}$$

Where ν(p) is the exceedance rate of the loss p, and this is the sum of the losses that may occur in all exposed values. $F_A(i)$ is the annual frequency of the event i. P(P>p|i) is the probability that the loss be greater than p, given the occurrence of the event i. The exceedance rate is then obtained as the sum of all the potential harmful events. The inverse of ν(p) is the loss return period. Each point of this curve is known as the Probable Maximum Loss (PML) for the correspondent return period.

The procedure to estimate the ν(p) is as follows: (i) for a given scenario of the hazard module, estimate the probability distribution of the loss for each municipality and structural typology; (ii) estimate the probability distribution of the addition of the losses of all elements exposed, following the loss-aggregation rules proposed by the National Commission for Insurance of Mexico (CIRCULAR S-10.4.1.1); (iii) estimate the probability that the total loss in the scenario exceeds a certain value p. (iv) multiply the probability estimated in the previous step by the annual frequency of occurrence of the event i. This procedure must be repeated for each event i included in the hazard module. In Fig. 2.5 is presented the LEC obtained for the region of Murcia. From this Figure it is possible to observe that the loss excedance rate, for losses of 300 million of euros (similar to the losses of the recent earthquake of Lorca) is near to 0.1 (per year).

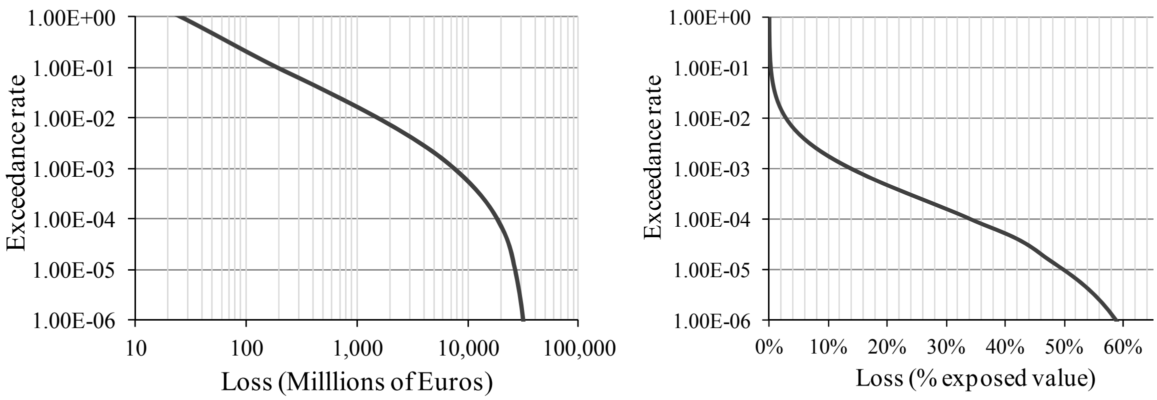



**Figure 2.5.** Loss Exceedance Curve (a) in millions of Euros. (b) in percentage of exposed value

*2.4.2 Average annual loss*

The area under the LEC is known as the Average Annual Loss (AAL). The AAL is the expected value of the annual loss and represents, in a simple insurance scheme, the actuarially fair insurance premium. It could be obtained following Eqn 2.7 or by integration of the ν(p). In Table 2.1 are presented the results of the analysis in terms of the AAL, as well as the PML for different return periods. In Fig. 2.6 are shown the AAL estimated for each population entity.

$$AAL = \sum_{i=1}^{events} E(P \mid i) F_A(i) \tag{2-7}$$

**Table 2.2.** Summary of results. Average Annual Loss and Probable Maximum Loss for different return periods

| | | | | |
|---|---|---|---|---|
| AAL (millions of Euros) | | | | 168.07 |
| Exposed value (millions of Euros) | | | | 54,052.67 |
| AAL/exposed value | | | | 0.0031 |
| Murcia-Gross Regional Product-GRP- (millions of Euros) | | | | 27957.7 |
| Return period | Exceedance rate | PML (millions of Euros) | PML (% exposed value) | PML (% GRP) |
| 50 | 2E-02 | 674 | 1.2% | 2.4% |
| 100 | 1E-0.2 | 1,170 | 2.1% | 4.2% |
| 250 | 4E-03 | 2,700 | 5.0% | 9.7 |
| 500 | 2E-03 | 4,700 | 8.7% | 16.8 |
| 1000 | 1E-03 | 6,200 | 11.5% | 22.2 |

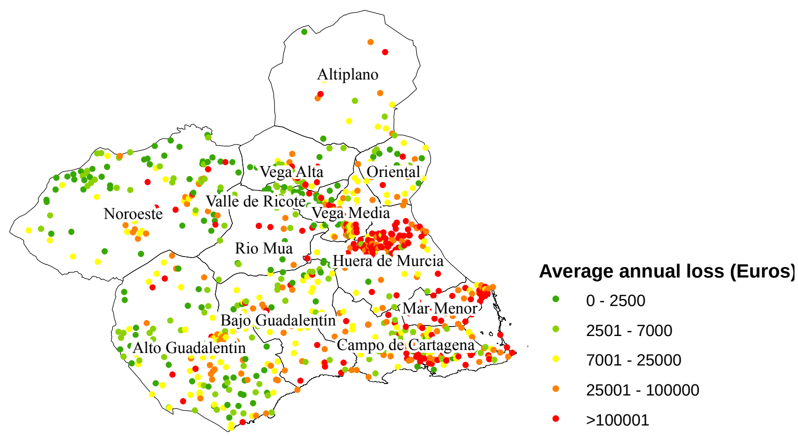



**Figure 2.6.** AAL by population entity

If it is considered a return period of 500 years as a reference for the seismic safety requisites of buildings, from Table 2.2 it is observed that the PML, for this return period, is around 16.8% of the GRP of Murcia, (8.7% of the exposed value) which is a significant value. Then, it should be remarked that the safety requisites should not be defined only in terms of the frequency of the hazardous events, but in terms of the expected losses.

Regarding the geographical distribution of losses, from Fig.2.6 it is possible to identify the regions of higher concentration of losses. Those are located near to the city of Murcia (province of Huera de Murcia), the capital of the Region, where the concentration of exposed values (see Fig 2.2 b), as well as the seismic hazard (see Fig 2.3) are higher.

*2.4.3 Probability of exceedance of loss*

The Loss Exceedance Curve represents the frequency of occurrence of events with losses higher (or equal) than a given loss p. If it is assumed that the occurrence of loss events follows a Poisson distribution, then it is possible to estimate the probability of exceedance of a given loss p, in a time frame T (in the next T years), following Eqn. 2.8:

$$Pe(p,T) = 1 - e^{-\upsilon(p)T} \tag{2.8}$$

Where Pe(p,T) is the probability of exceedance of the loss P in the next T years. By using the loss exceedance rates estimated in the LEC, In Fig. 2.7 are shown the loss exceedance probabilities, taking into account the following time frames (T): 10, 25, 50 and 100 years. Similarly, on Fig. 2.8 are shown the loss exceedance probabilities, taking into account losses of 50, 100, 250, 500 and 1000 million during the next T years.

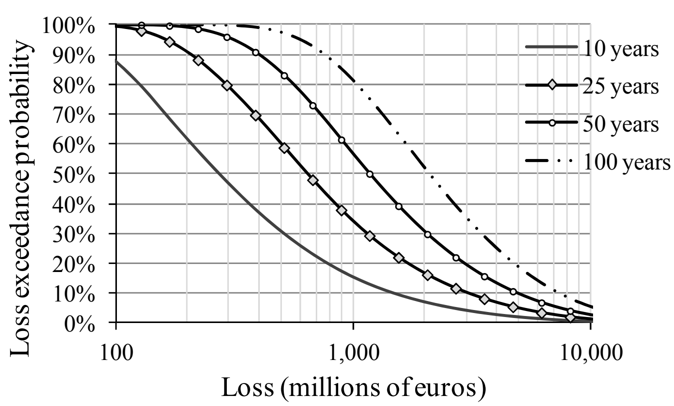



**Figure 2.7.** Loss exceedance probability in 10, 25, 50 and 100 years

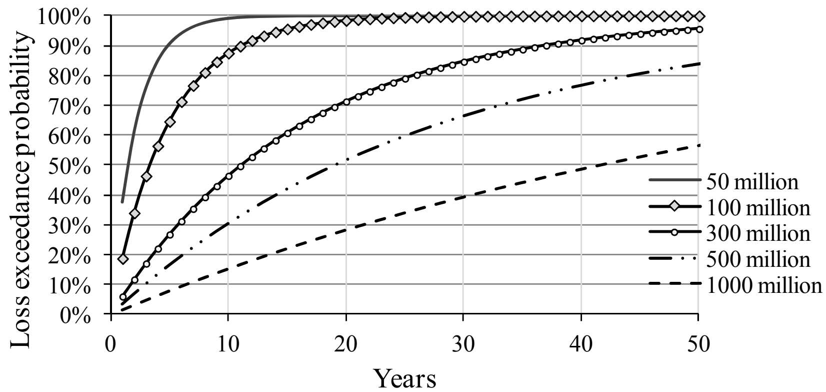



**Figure 2.8.** Probability of exceedance of losses of 50, 100, 250, 500 and 1000 million during the next T years

From Fig. 2.7 and 2.8 it is possible to observe that if it is considered a loss of 300 millions of euros, the probabilities of exceedance, in a given time frame are as follows: around 45% during the next 10 years, 80% in 25 years, and more than the 90% for T≥50 years. Those values reflect that loss events such as the observed during the recent earthquake of Lorca (in insured assets) are not extreme events. Those losses are related to the seismicity of the region (See Table 1.1) and the vulnerability of the buildings Then, as a complement of risk reduction activities, risk financing programs should be promoted, based on probabilistic risk estimates, in order to design risk financing alternatives.

In Spain, those risk financing alternatives are of special interest for the Consortium of Compensation of Insurance (Consorcio de Compensación de Seguros, CCS), which is a public institution of the Ministry of Economics. During catastrophic events, (i.g earthquakes, floods), the CCS works as a reinsurer of the private companies when the losses are not covered. Then, probabilistic risk estimates would be useful in order to design emergency funds, reconstruction funds, as well as catastrophic risk insurance mechanisms.

## 3. CONCLUSIONS

In Spain, the Region of Murcia has moderate to high seismicity. On the last 20 years have occurred events producing considerable economic losses. Recently, in May 11 of 2011, an earthquake of $M_b$ 5.1 stroke Lorca. At December 29th of 2011, the estimated losses, only in insured buildings, were around 332.5 millions of Euros. In order to design risk management strategies, in this work are estimated the expected losses in the Region of Murcia.

The exposed value of the buildings of the Region of Murcia was estimated from cadastral statistics. This value was geographically distributed by population entities according to the number of inhabitants. Buildings have been classified into structural typologies, based on the construction techniques of the Region and the buildings description developed on previous studies. Each structural typology was characterized with specific vulnerability curves that relate, for a given ground motion intensity, the expected value of loss and its standard deviation. The expected losses were estimated taking into account set of random events generated according to the seismicity of the country.

This analysis allows estimating the exceedance rate of losses, the probability of exceedance of a given loss in a given time frame, as well as the probability of exceedance of a given loss in the following t years. From the results, it is observed that the loss excedance rate, for losses similar to those observed in the recent earthquake of Lorca, is near to 0.1 (loss events per year). Also, the probabilities of exceedance, in a given time frame are as follows: around 45% during the next 10 years, 80% in 25 years, and more than the 90% for T≥50 years. Those values reflect that loss events, such as the observed in the recent earthquake of Lorca (in insured assets) are not extreme events; those losses are related to the seismicity of the region and the vulnerability of the buildings.

Regarding the seismic safety requisites of the buildings, if it is considered as a reference a return period of 500, it is observed that the probable maximum loss, for this return period, is around 16.8% of the gross regional product of Murcia, (8.7% of the exposed value) which is a significant loss. Then, it should be remarked that the safety requisites should not be defined only in terms of the frequency of the hazardous events, but in terms of the expected losses.

In this work are compared the losses observed (in insured buildings) during the earthquake of Lorca and the losses estimated for all possible seismic scenarios in the Region of Murcia. For risk management, it must be remarked that observed and calculated risks are two quite different things (Elms, 2004). Therefore, the design of risk reduction programs, as well as risk financing alternatives, should be supported on probabilistic risk estimates, taking into account aspects related to risk perception, judgments of experts and groups of representatives from various interested parties, in order to build trust and consensus (Aven & Kristensen 2005).

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