Authors:

Mario A. Salgado-Gálvez, Centre Internacional de Metodes Numerics en Enginyeria (CIMNE) Universitat Politècnica de Catalunya, Barcelona, Spain. mario.sal.gal@gmail.com
Alex H. Barbat, Centre Internacional de Metodes Numerics en Enginyeria (CIMNE) Universitat Politècnica de Catalunya, Barcelona, Spain. alex.barbat@upc.edu
Omar Darío Cardona, Instituto de Estudios Ambientales (IDEA), Universidad Nacional de Colombia Sede Manizales, Manizales, Colombia. odcardonaa@unal.edu.co
Martha Liliana Carreño, Centre Internacional de Metodes Numerics en Enginyeria (CIMNE) Universitat Politècnica de Catalunya, Barcelona, Spain. liliana@cimne.upc.edu

Title: Comparing observed damages and losses with modelled ones using a probabilistic approach. The Lorca 2011 case

Contact details:

Mario Andrés Salgado Gálvez, mario.sal.gal@gmail.com, Edifici C-1, Despatx C-111 Carrer Gran Capità, S/N, Campus Nord UPC 08034, Tel. +34-603-681-219, Fax. +34-934-010-796.

Abstract:

A loss and damage assessment was performed for the buildings of Lorca, Spain, considering an earthquake hazard scenario with similar characteristics to those of a real event which occurred on May 11th 2011, in terms of epicentre, depth and magnitude while also considering the local soil response. This low-to moderate earthquake caused severe damage and disruption in the region and especially on the city. A building by building resolution database was developed and used for damage and loss assessment. The portfolio of buildings was characterized by means of indexes capturing information from a structural point of view such as age, main construction materials, number of stories, and building class as well as others related to age and vulnerability classes. A replacement cost approach was selected for the analysis in order to calculate the direct losses incurred by the event. Seismic hazard and vulnerability were modeled in a probabilistic way, considering their inherent uncertainties which were also taken into account in the damage and loss calculation process. Losses have been expressed in terms of the mean damage ratio of each dwelling and since the analysis has been performed on a geographical information system platform, the distribution of the damage and its categories was mapped for the entire urban centre. The simulated damages and losses were compared with the observed ones reported by the local authorities and institutions that inspected the city after the event.

Keywords:

Probabilistic seismic risk assessment; probabilistic seismic hazard analysis; model calibration and validation; comparison of losses; CAPRA.

1. INTRODUCTION

On May 11th 2011 a 5.1 (M_W) earthquake stroke the Murcia region in south-eastern Spain, where the city of Lorca, with almost 60,000 inhabitants, was the most affected and damaged place. The epicentre was located 5 km north of Lorca and the depth of the event was estimated at 5 km. The event was associated to the Alhama de Murcia local fault which extends over more than 100 km with a strike-slip-reverse mechanism. In spite of the moderate magnitude of the event, 9 casualties occurred, more than 300 people were injured and around 10,000 people could not return to their houses after the event due the damage to their homes. Two health centres suffered severe structural damage that endangered the security of the patients and medical staff, and were therefore evacuated. According to the damage surveys, around 80% of the inspected buildings presented some degree of damage, though it was generally classified as slight. The damage generated a chaotic situation in the post-disaster phase since there was no prior experience in implementing an emergency plan, and many of the response actions took longer than what was expected by the community (Barbat et al. 2011a).

According to the post-earthquake damage assessment made by the local municipality, 19% of the 7,852 buildings visited were not inspected from a structural engineering perspective since they only suffered very slight damage, 52% of the buildings were inspected and classified as habitable because of the lack of significant damage, 16% had no significant structural damage but limited access because of non-structural damage, 9% had forbidden access because of high structural damage, and for 4% of the buildings a mandatory demolition order was given (Ayuntamiento de Lorca 2012). At the same time, insured losses were quantified in around 490 million of euros with most of the claims related to residential and commercial units (CCS 2012). This last figure does not correspond to the total cost of the earthquake's damage in Lorca because not all insurance policies have the same conditions, and the insured limits and deductibles are not reflected in this reported amount; nevertheless, it does provide an order of magnitude of the loss.

Studies to estimate seismic damages and losses in the Murcia region have been performed in the recent past. The first one was conducted before the 2011 earthquake (Benito et al. 2005) where the probability of exceeding certain damage levels was obtained for the Murcia region. The second one was performed afterwards the earthquake, using a probabilistic approach to estimate future losses expressed in terms of a loss exceedance curve (Valcárcel et al. 2012).

In this paper the damages and losses occurred during the Lorca 2011 earthquake are quantified using a probabilistic approach, based on state-of-the-art methodologies. Seismic hazard is represented by means of the expected intensities at ground level characterized through the first two probability moments. A building by building resolution exposure database was developed considering the public and private buildings of Lorca and capturing relevant information in terms of structural and non-structural parameters that combined with updated indexes from the latest housing census (INE 2011) allow identifying and defining a set of building classes. To quantify the physical vulnerability of those, vulnerability functions that take into account the uncertainties related to the accuracy of building characteristics and seismic structural performance were used. A unique vulnerability function was assigned to each building class identified in Lorca. The convolution between the hazard and the vulnerability provided the expected losses and those values were later translated into damage levels. Only direct physical losses were accounted for in the analysis by calculating the mean damage ratio (MDR) of each building of the exposure database. Second order effects, such as business disruption, damages to cars and other indirect damage and/or socio-economic impact, were not included in the estimation. The latter can be included if complementary information is available for other vulnerability dimensions different than the physical using approaches like those proposed by Carreño et al. (2007; 2012) and Barbat et al. (2011b).

The obtained results have been compared with those gathered after the 2011 Lorca earthquake by means of field inspections and officially reported by the local authorities (Ayuntamiento de Lorca 2012). It is explored whether there are similarities in the reported losses and damage distributions among the built stock of the urban area of Lorca and also a comparison between the geographical distribution of the observed and modelled damages and losses is performed. This is done with the objective of first, exploring the capability of catastrophe risk models to reproduce damages and losses within the order of magnitude of the ones observed when similar hazard intensities are used as input data and state-of-the-art methodologies employed for the exposure and vulnerability representation and second, to compare the geographical location (at urban level) of the observed and the modelled damages and losses, an issue that is considered relevant since it is not an objective of those models but since urban maps allow the identification of individual elements, that resolution level provides a false sense of accuracy.

Several tools are available to perform a seismic risk assessment in probabilistic metrics. We have selected for this study the CAPRA[1] platform (Cardona et al. 2012; 2014; Marulanda et al. 2013; Salgado-Gálvez et al. 2014; 2015; 2016; Velásquez et al. 2014) which consists of different modules that allow the evaluation of the seismic hazard, vulnerability and risk.

The Lorca case constitutes an opportunity and a challenge to understand the strengths and weaknesses of the probabilistic seismic risk evaluation approach, highlighting the improvements required regarding exposure input data as well as for hazard, vulnerability and risk assessment. The outcome of this comparison is intended to contribute in the understanding on the capabilities and limitations of catastrophe risk models in the estimation of losses highlighting that even in cases such as this where no exact matches are found between the observed and the modelled losses, their objective of providing order of magnitudes for the expected losses is still fulfilled. Finally, a set of recommendations related to seismic safety and resilience are provided for Lorca based on not only the observed damage but some situations observed in the aftermath of the event.

2. PROBABILISTIC SEISMIC HAZARD ASSESSMENT

Based on the characteristics of the earthquake in terms of location, depth and magnitude, spectral shakemaps were developed using the program well-known program CRISIS (Ordaz et al. 2007; 2014) which is the seismic hazard module of the CAPRA Platform (Cardona et al. 2012; 2014) in terms of a stochastic event that for each spectral ordinate considers the first two probability moments of the ground motion. Figure 1 shows the calculated shakemap of the selected event which according to the latest tectonic zonation of Spain is associated to the ESAS250 seismogenic source (Woessner et al. 2015), located beneath the urban area of Lorca. Intensities are first calculated at bedrock level using a ground motion model developed for the Mediterranean region (Ambrasseys et al. 2005), that in terms of magnitude and distances ranges is considered as suitable. Ground motion levels were compared against the automated shakemaps published by the USGS (USGS 2011) for 0.0s, 0.3s and 1.0s finding that the use of the selected ground motion prediction equation is suitable for the representation of this specific earthquake scenario.

[1] Comprehensive Approach to Probabilistic Risk Assessment (www.ecapra.org)

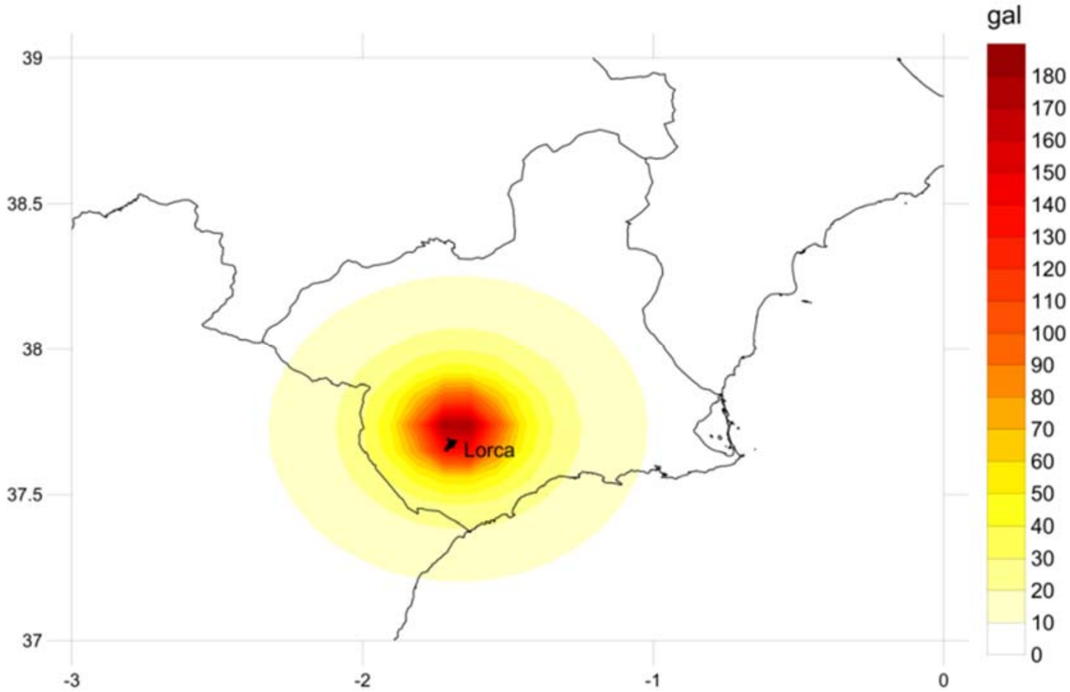

Figure 1 PGA (cm/s^2) for the selected scenario

Those obtained values are modified through spectral transfer functions, one for each homogeneous soil zone determined in the microzonation of the city proposed by Navarro et al. (2014), as shown in Figure 2, to obtain the motion intensities at ground level, used to make the damage and loss assessment.

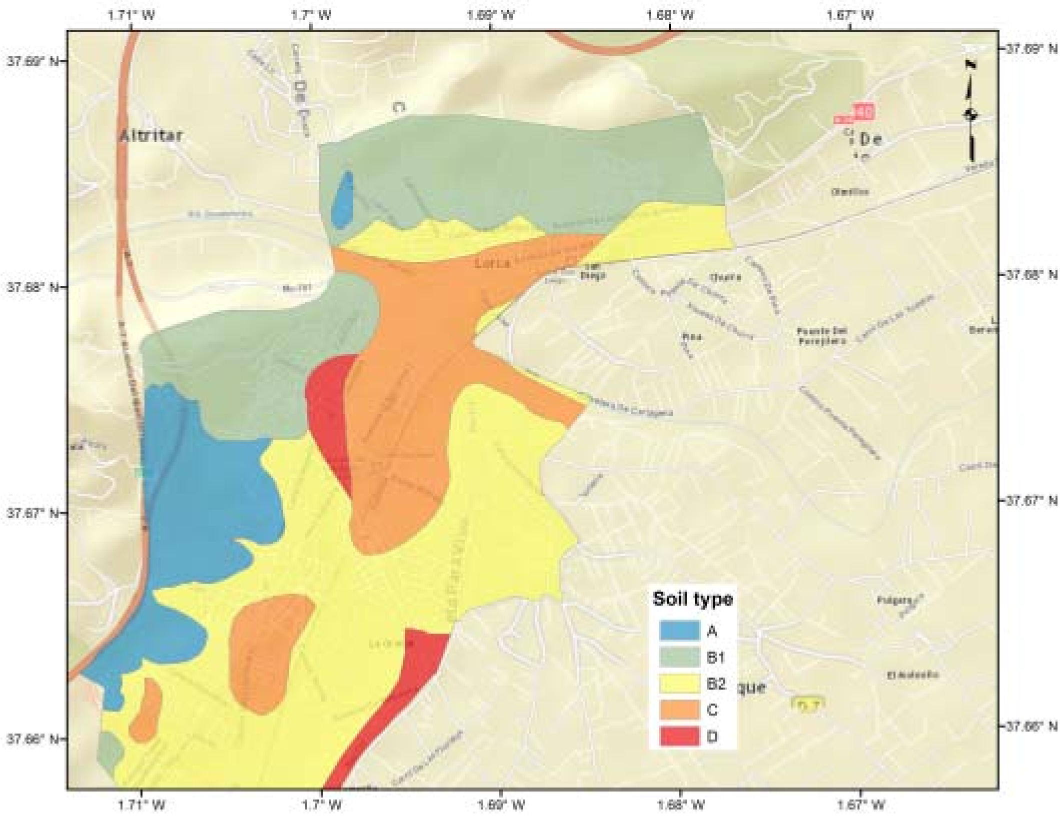

Figure 2 Homogeneous soil zones for Lorca (Navarro et al. 2014)

3. INVENTORY OF EXPOSED ASSETS OF LORCA

For this study, an exposure database that considers both the public and private buildings within the urban area of Lorca was developed. Even if exposure databases can be constructed using different resolution levels, due to the data availability in this case a detailed building by building resolution level was chosen. This process has always presented challenges in modelling since usually the required information is not available directly from a unique source and, in many cases it needs to be inferred or generated through indexes obtained from several sources. In this case, information about the geographical location and structural characteristics such as age, material, structural system, number of stories and building class is required for each element. Those parameters were assigned to each of the elements included in the final database using the data and procedure explained in this section. When conducting a probabilistic seismic risk analysis, the main assumption is related to the law of large numbers, that is, a large set of elements are to be included in the database; this is a condition that is met in this paper.

3.1 Available information from the cadastral data

Updated cadastral information is available for Lorca with a building by building resolution level (MHAP 2013). Since that data was generated for cadastral and tax purposes, several properties other than buildings such as terraces, squares and balconies are originally included, having the city a total of 42,062 elements in the raw database. After a depuration process, intended to remove all entries different than buildings, 17,017 elements remained (buildings classified as ruins before the 2011 earthquake by the cadastral office were also removed since those were not inspected in the aftermath of the event by the local authorities). The cadastral information contains data about the geographical location and number of stories of each building. Building footprints were compared with an aerial image (ESRI 2010) and additional elements were included in the database for a total of 17,064 buildings. Figure 3 shows the map with the buildings in Lorca according to the number of stories attribute, which is an attribute available from the cadastral data. As shown, most of the buildings in Lorca are classified as low-rise from a structural point of view; i.e., buildings of 1 to 3 stories.

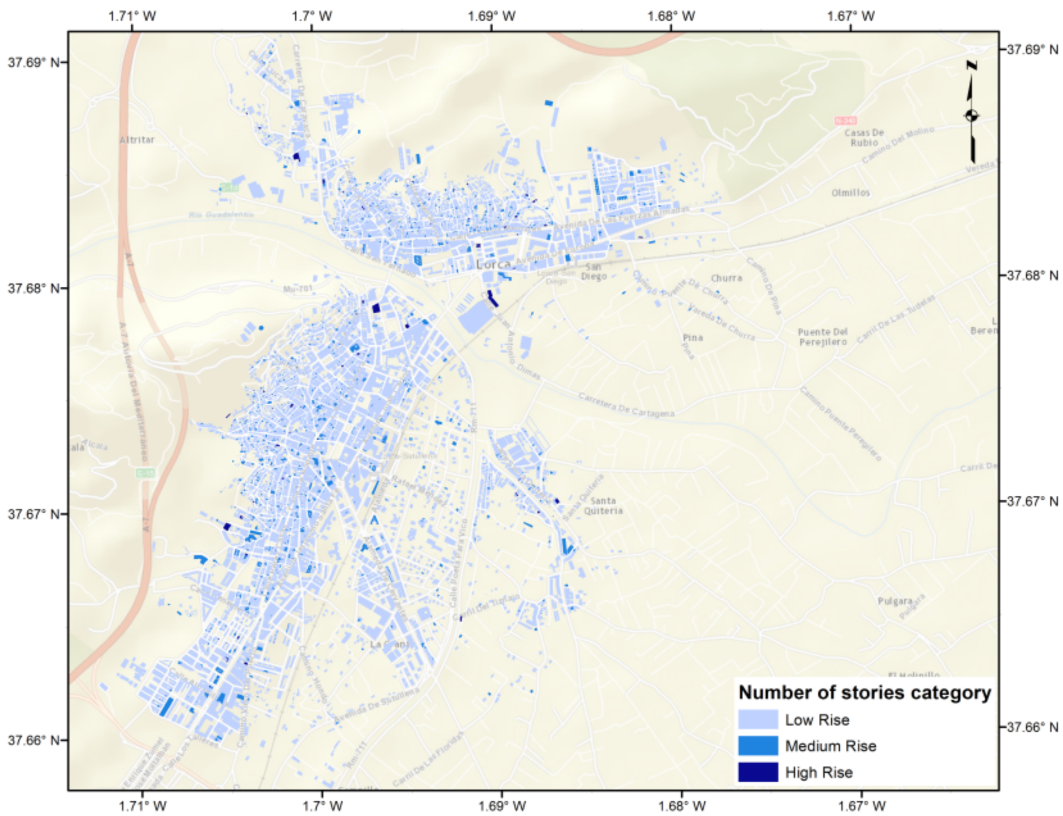

Figure 3 Map of the number of stories of the buildings in Lorca

3.2 Vulnerability classification of the building portfolio

From the most recent Spanish population and housing census (INE 2011), it is possible to define the age distribution of the buildings in Lorca. Using the data of Table 1, this parameter was distributed to the entries of the database. Since these data in the housing census is not geo-located, the assignation of the age parameter to each dwelling was done after performing a comprehensive field visit in the urban area of Lorca.

Table 1 Age distribution for the buildings in Lorca

Age	Distribution
Before 1900	4.4%
1900-1920	2.8%
1921-1940	4.0%
1941-1950	4.8%
1951-1960	11.1%
1961-1970	13.5%
1971-1980	19.4%
1981-1990	13.3%
1991-2001	13.1%
2002-2011	13.6%

Also, based on previous studies (Benito et al. 2005) and making use of the age distribution, a vulnerability classification based on the EMS-98 scale (Grünthal 1998) using the data of Table 2 was prepared. It can be seen from the table that structures are classified in categories between A and D on said scale. These data was useful for the assignation and distribution of building classes among the built stock, which at the same time, was validated by means of field visits to the urban area of Lorca. Anyhow, since some of the data used for the characterization of the buildings in Lorca is not originally geo-located, it is important to bear in mind that for this exposure database despite the field visits for data validation purposes, there may be cases of specific buildings that do not have assigned their particular structural characteristics but, on the other hand, the overall age, height, vulnerability class and building class share is representative of Lorca, which for these kind of analyses based on the law of large numbers is acknowledged to be suitable.

Table 2 EMS 98 vulnerability classes for the buildings in Lorca according to age ranges

	EMS98 vulnerability class	A	B	C	D
Age	Before 1900	80%	20%	-	-
	1900-1920	72%	28%	-	-
	1921-1940	72%	28%	-	-
	1941-1950	69%	28%	3%	-
	1951-1960	46%	49%	5%	-
	1961-1970	18%	38%	44%	-
	1971-1980	5%	40%	55%	-
	1981-1990	-	38%	57%	5%
	1991-2001	-	28%	62%	10%
	2002-2011	-	18%	69%	13%

Figure 4 shows the geographical distribution of the vulnerability classes for the buildings of Lorca from where it is clear that the oldest buildings, located in the historical centre and in the northern area of the city are the most vulnerable from the seismic performance point of view.

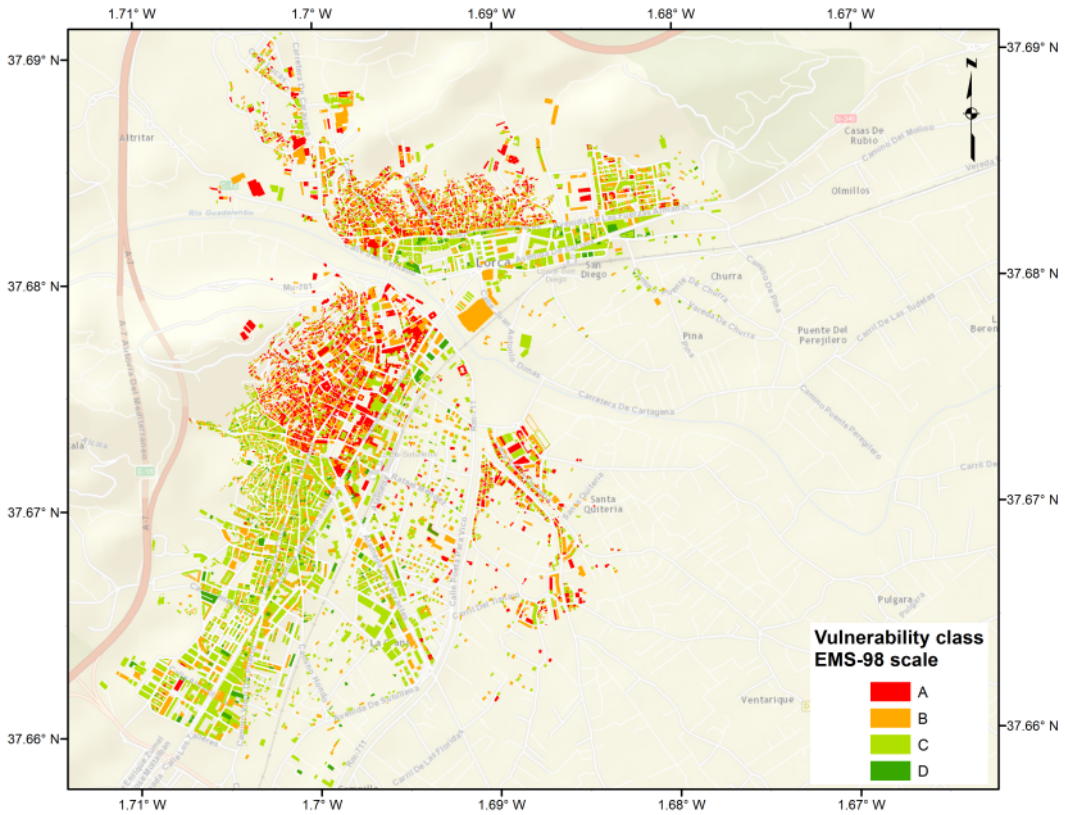

Figure 4 Spatial distribution of the vulnerability classes for the buildings of Lorca

3.3 Building portfolio appraisement

No cadastral price information was available in the database and for that reason an index based on the total constructed area was obtained to capture the replacement value of each element. The replacement cost is intended to capture the repair or replacement cost of the buildings to bring them to exactly the same conditions as of today. The main objective of this appraisal is to establish an order of magnitude for the replacement cost of the buildings in Lorca as a whole. In this study, replacement costs do not take into account historical or heritage values of the structures.

Based on data from INE (2011) a base value of 1,247 euros per constructed square meter was established for the city. In addition to this, and in order to take into account the fact that all elements do not have the same price, age was selected as a differentiation parameter. Since repairing stone and brick masonry buildings is more expensive than repairing reinforced concrete buildings due to the necessity of specialized manpower, a factor that increases with the age was assumed (see Table 3).

Table 3 Replacement costs and age factors for Lorca

Age	Age factor	Cost per constructed m2
Before 1900	2.00	2,494 €
1900-1920	2.00	2,494 €
1921-1940	1.75	2,182 €
1941-1950	1.75	2,182 €
1951-1960	1.50	1,871 €
1961-1970	1.50	1,871 €
1971-1980	1.50	1,871 €
1981-1990	1.25	1,559 €
1991-2001	1.25	1,559 €
2002-2011	1.00	1,247 €

By using this approach, the total replacement cost of the public and private buildings in Lorca has been established in around 7,000 million euros.

3.4 Definition of building classes in Lorca

By having defined the age and vulnerability class distribution, several building classes were identified from the information collected by Benito et al. (2005). A vulnerability class according to the EMS-98 scale has been assigned to each building class. Buildings in Lorca are mostly made of different types of masonry (bricks and stone) for the low-rise structures whereas for medium- and high-rise buildings reinforced concrete (R/C) waffled slab buildings are mostly used. Steel frames and prefabricated R/C structures are found mostly in the industrial facilities of the city.

By combining the above mentioned two parameters for all the elements, a unique building class was assigned to each element, with a total of 10 building classes used for the analysis. Table 4 shows the building classes which were identified and assigned for this study together with the vulnerability classes proposed by Benito et al. (2005). In the second column an abbreviation code is included whereas in the third column the classification according to the EMS-98 vulnerability scale is shown. Figure 5 shows the geographical distribution of the building classes of Lorca. A careful review of the assigned building classes was performed with the aim of avoiding unrealistic typologies such as reinforced concrete framed buildings built before 1900 or high-rise masonry dwellings.

Table 4 Building classes, abbreviation codes and EMS 98 vulnerability levels

Building class	Abbreviation code	Vulnerability class (EMS-98)
Stone masonry	M-PP	A
Earthen	M-TA	A
Toledo masonry	M-ET	B
Brick masonry	M-L	B
Masonry walls and R/C slabs	M-H	C
Pre 1995 R/C frames	E-H	C
Post 1995 R/C frames	E-H2	D
R/C frames with steel braces	E-HX	D
Prefabricated R/C structures	E-HF	C
Steel buildings	E-MT	D

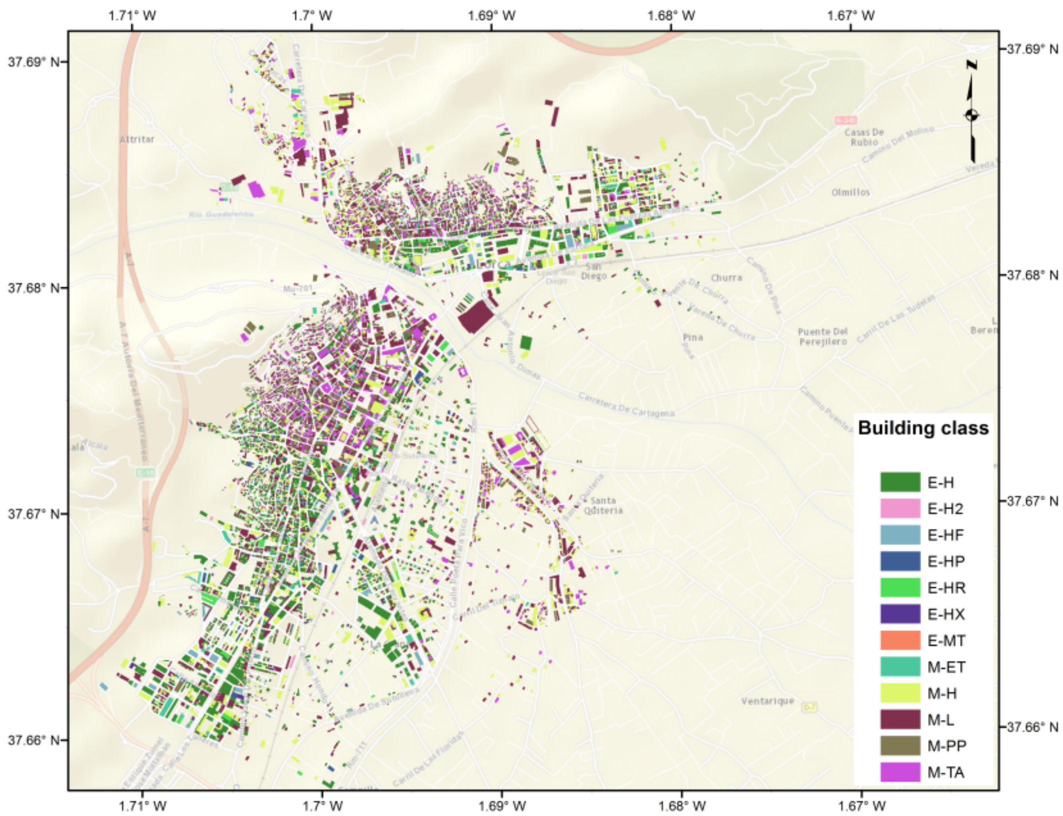

Figure 5 Building class distribution of Lorca

Table 5 shows a summary of the exposed assets in terms of building classes, number of elements and replacement values of each of them.

Table 5 Summary of exposed assets statistics

Building class	Number of dwellings	% of dwellings	Exposed value (million €)	% of exposed value
Stone masonry	1,838	10.8%	848	12.2%
Earthen	1,955	11.5%	978	14.1%
Toledo masonry	528	3.1%	203	2.9%
Brick masonry	5,207	30.5%	2,057	29.7%
Masonry walls and R/C slabs	2,963	17.4%	1,156	16.7%
Pre 1995 R/C frames	3,432	20.1%	1,293	18.7%
Post 1995 R/C frames	485	2.8%	161	2.3%
R/C frames with steel braces	35	0.2%	8	0.1%
Prefabricated R/C structures	593	3.5%	216	3.1%
Steel buildings	28	0.2%	8	0.1%
TOTAL	**17,064**	**100**	**6,928**	**100**

From Table 5 it can be clearly seen that most of the buildings in Lorca are made of masonry, concentrating more than 60% of the total both in number and in exposed value. Moreover, waffle slab buildings constitute the majority of the R/C structures in the city (more than 20% of the buildings in the city).

4. PHYSICAL SEISMIC VULNERABILITY OF THE BUILDINGS

Vulnerability of an urban area can be expressed considering several dimensions such as physical, economic, social and cultural among others (Birkmann et al. 2013). For this study only the physical vulnerability quantification is of interest. A vulnerability function approach (Ordaz et al. 1998; Miranda 1999) was selected for the damage and loss calculation process. Damage is represented through a continuous function that relates hazard intensities which in this case is the spectral acceleration for 5% damping, to the mean damage ratio (MDR), also considering its variance to account for the uncertainties. The value of the dispersion of the MDR changes along the intensity levels, being equal to zero at the extreme values of the interval and taking its maximum value for the intensity corresponding to a mean damage equal to 50%. MDR in this case corresponds to the ratio between the direct economic loss and the total exposed value of each building.

Vulnerability functions are a description of the variation of the first two statistical moments of loss with respect to the hazard intensity. A Beta probability distribution function is assigned and, in this case, the mean value and the standard deviation correspond to the mentioned statistical moments. Once this distribution function is computed, all the parameters required to compute risk in a probabilistic way are available (Ordaz 2000). This approach is compatible with the probabilistic risk assessment approach selected for the study. Each of the building classes has an associated vulnerability function. The replacement cost of each asset is needed to quantify the expected losses in monetary units since what it is obtained at each intensity level is the ratio of the repair cost relative to the total value of the building.

Structures with different characteristics behave and might be damaged in a different way when subjected to the lateral forces imposed by the same event and, therefore, hazard intensities for different spectral ordinates are calculated. This difference in the behavior of the buildings can be accounted using the fundamental period of each building class. Each vulnerability function has also an associated spectral ordinate that corresponds to the typical elastic fundamental period of the building class whose expected damage is being characterized, establishing the link between the vulnerability functions and the building classes.

A total of 22 vulnerability functions were used in the analysis, that based on the authors' opinion capture the characteristics of all the considered building classes in Lorca and capture the most relevant structural characteristics of the building stock in the city and were developed using the framework proposed by CIMNE et al. (2013). Figures 6 and 7 show the vulnerability functions used in this study. The codes of Table 4 are used to denote the vulnerability functions and the height of the structures is included in the analysis through three different categories: low-rise (L) for buildings between 1 and 3 stories, medium-rise (M) for those that have 4 to 7 stories and high-rise (H) for 8 and more; these abbreviations are also included in the notation used in Figures 5 and 6.

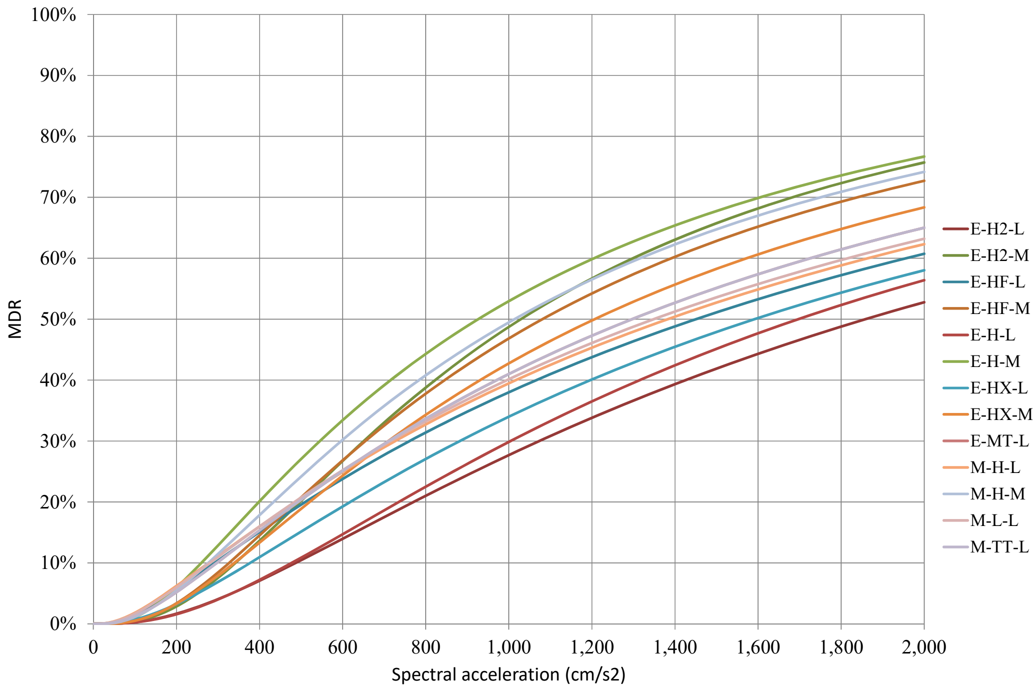

Figure 6 Vulnerability functions used for the flexible building classes in Lorca (L=Low-rise; M=Medium-rise; H=High-rise)

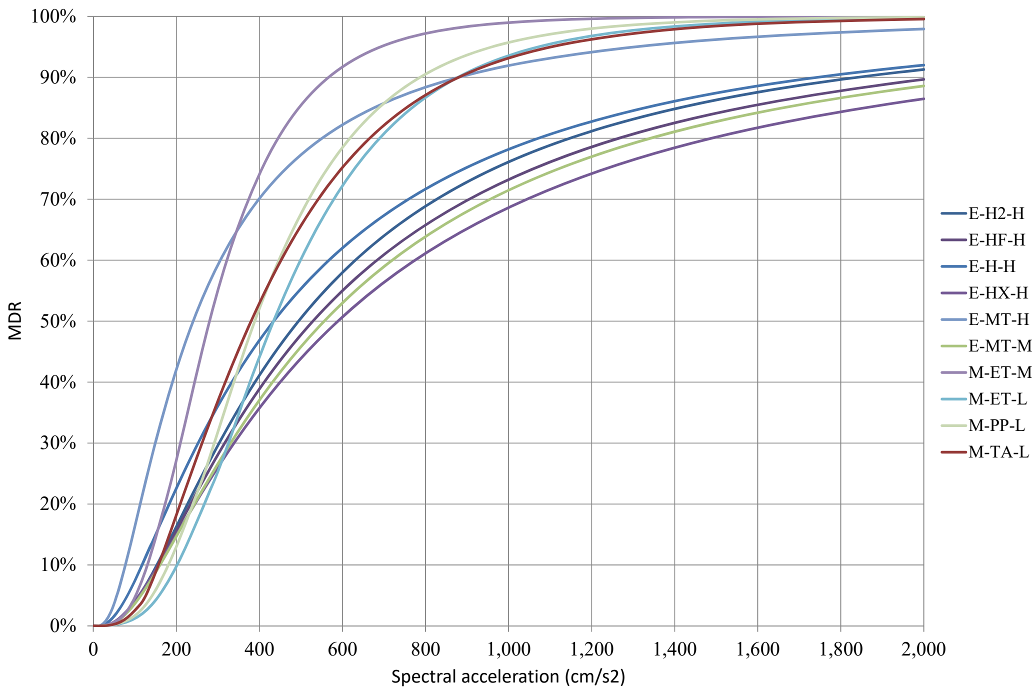

Figure 7 Vulnerability functions used for the rigid building classes in Lorca (L=Low-rise; M=Medium-rise; H=High-rise)

5. SEISMIC RISK ASSESSMENT

5.1 Methodology

A probabilistic risk analysis is usually conducted for the complete set of stochastic events that are the outcome of a probabilistic seismic hazard assessment. Nevertheless, if it is required, the analysis can be performed for a single event. Using the methodology proposed by Ordaz (2000) and implemented in the CAPRA-GIS software (ERN-AL 2011), the probability density function is $f(loss_j | Event_i)$ which allows calculating the loss on the j^{th} exposed asset, conditional to the occurrence of the i^{th} event. However, since it is not possible to calculate this probability distribution directly, a chaining process between two different conditional probability distributions is required, being them:

$$f(loss_j \mid Event_i) = \int_0^{\infty} f(loss_j \mid Sa) \cdot f(Sa \mid Event_i) dSa \qquad \text{(Eq. 1)}$$

where $f(loss_j|Sa)$ has to do with the vulnerability (the expected loss given a hazard intensity) and $f(Sa|Event_i)$ with the hazard (the hazard intensity given the occurrence of the event). Since loss is computed as a random variable, it has to be aggregated in a rigorous way. Also, it is important to bear in mind that since uncertainties from the ground shaking and the physical vulnerability are propagated to the loss results, spatial correlation has been taken into account.

The following expressions are used for the expected value of the loss, $E(p|Event_i)$, and its corresponding variance, $\sigma^2(p|Event_i)$, for each event:

$$E(p \mid Event_i) = \sum_{j=1}^{NE} E(p_j) \quad \text{(Eq. 2)}$$

$$\sigma^2(p \mid Event_i) = \sum_{j=1}^{NE} \sigma^2(p_j) + 2 \sum_{\substack{k=1 \\ k<j}}^{NE-1} \sum_{j=2}^{NE} \mathrm{cov}(p_k, p_j) \quad \text{(Eq. 3)}$$

where NE is the total number of exposed assets, $E(p_j)$ is the expected value of the loss at the j^{th} exposed element given the occurrence of the i^{th} event, $\sigma^2(pj)$ is the variance of the loss at the j^{th} exposed element given the occurrence of the i^{th} scenario, and $\mathrm{cov}(p_k,p_j)$ is the covariance of the loss of two different exposed elements. The covariance is calculated using a correlation coefficient $\rho_{k,j}$ set equal to 0.3 and taking into account the standard deviations for losses in different assets:

$$\sigma^2(p \mid Event_i) = \sum_{j=1}^{NE} \sigma^2(p_j) + 2 \sum_{\substack{k=1 \\ k<j}}^{NE-1} \sum_{j=2}^{NE} \rho_{k,j} \sigma(p_k) \sigma(p_j) \quad \text{(Eq. 4)}$$

Seismic risk, when calculated in a probabilistic way, is usually expressed in terms of a loss exceedance curve that relates the frequencies with which losses exceeding a certain amount occur. It is usually computed in terms of the annual exceedance rate and calculated by using the following expression:

$$v(l) = \sum_{i=1}^{N} \Pr(L > l \mid Event_{\,\mathrm{i}}) \cdot F_A(Event_{\,\mathrm{i}}) \quad \text{(Eq. 5)}$$

where $v(l)$ is the rate of exceedance of loss p, N is the total number of hazard scenarios, F_A $(Event_{\mathrm{i}})$ is the annual frequency of occurrence of the i^{th} hazard event, while $\Pr(L>l|Event_{\mathrm{i}})$ is the probability of exceeding l, given that the i^{th} event occurred. When a single event approach is selected, as in this case, N takes a value equal to 1, while at the same time the frequency of occurrence, F_A is set to 1.0. For the selected event, the intensities are first calculated for the area under analysis, and then for each asset included in the exposure database the loss and its variance are calculated using the vulnerability functions associated to each element (based on its geographical location and the hazard intensity value at that point). This process is repeated in this case for the 17,064 buildings included in the exposure database. When the risk assessment is performed for a single hazard event, it can be said that a deterministic approach is chosen for the temporal perspective whereas a probabilistic approach still remains for the hazard intensity calculation, vulnerability representation and loss calculation.

5.2 Simulated earthquake event for Lorca

In the case of a single event approach, the MDR for each building is obtained and aggregated for all the buildings of the city. Results can be disaggregated in terms of building classes to see which classes concentrate higher risk levels as it has been also done for previous fully probabilistic risk assessments in Lorca (Salgado-Gálvez et al. 2015; 2016).

Table 6 shows the risk results in terms of the aggregated MDR for all the building classes of Lorca considered in this study; from this it is clear that the masonry building classes concentrate the higher physical risk values. Furthermore, it can be seen that the building class with higher MDR corresponds to earthen structures, which have proven to have poor performance under the seismic demand due to the poor construction practices and materials. Masonry structures have the highest MDR values, showing the fact that the stone masonry buildings present the highest risk. R/C slabs also have an important contribution to the modeled losses due to their high seismic vulnerability.

Table 6 MDR by building class in Lorca

Building class	Damage (million €)	MDR
Stone masonry	108.5	12.8%
Earthen	157.5	16.1%
Toledo masonry	33.4	16.5%
Brick masonry	159.3	7.7%
Masonry walls and R/C slabs	97.6	8.4%
Pre 1995 R/C frames	40.1	3.1%
Post 1995 R/C frames	1.3	0.8%
R/C frames with steel braces	0.4	4.9%
Prefabricated R/C structures	16.1	7.4%
Steel buildings	0.5	6.1%
TOTAL	**614.7**	**8.9%**

According to the simulated scenario, a global MDR equal to 8.9% is expected for the buildings of Lorca, which in monetary units and using the replacement cost approach selected for this study corresponds approximately to 615 million of euros of direct losses. With the input data used for the risk modelling for this specific earthquake scenario, the standard deviation is approximately 45%. The MDR obtained if the value reported for the insured losses (490 million of euros) is used, corresponds to 7.1%.

Since the risk assessment has been performed on a geo-coded database, the geographical distribution of the damage can also be geo-referenced and risk maps, in terms of the MDR, can be obtained for Lorca (see Figure 8).

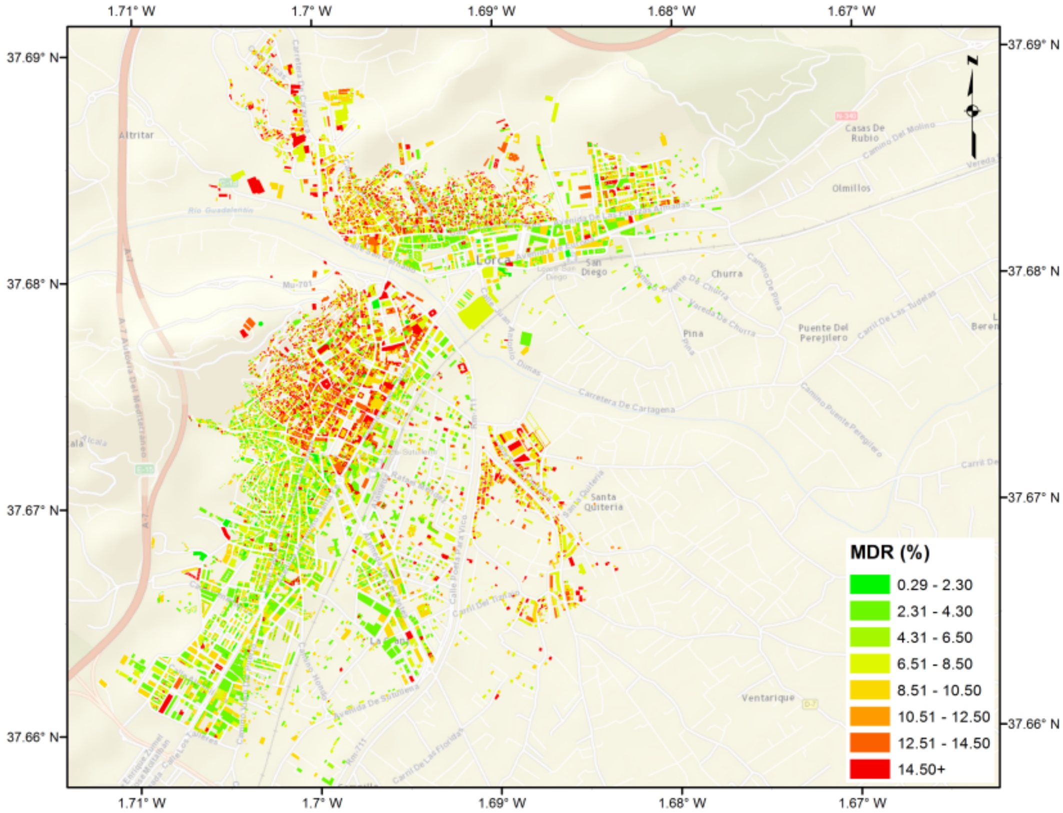

Figure 8 MDR distribution obtained for Lorca

5.3 Comparison between the simulated and the observed losses in Lorca

Damage due to shear stresses was observed for a large number of buildings made of masonry walls which, as was mentioned, constitute the majority of the building portfolio in Lorca. For the R/C waffled slabs and frame structures the same damage was observed, but mainly in non-structural elements such as façades and division walls (these walls were constructed mostly with brick masonry). Damage due to the presence of short columns was widely observed in R/C frame structures. The only building that collapsed during the earthquake, a 4 story R/C columns-and-slabs structure failed because of this effect.

A comparison between the damage observed in Lorca according to the official report of the local authorities (Ayuntamiento de Lorca 2012) and the scenario simulated in this work was made. According to the inspections, the damaged buildings were classified in four categories: 1) habitable, without significant damage; 2) with restricted access due to non-structural damage endangering the safety of the occupants; 3) with forbidden access because retrofitting actions were required; and 4) buildings with mandatory demolition orders.

A total of 7,852 buildings were inspected, accounting for 44.5% of the buildings in Lorca, and it was observed that 19% of those did not suffer any significant damage. The distribution of damage among the four categories is shown in Table 7. These results have the same order of magnitude than other damage surveys conducted in the city by other experts and institutions (Benito et al. 2012; IGN et al. 2011, Barbat et al. 2011b, Álvarez et al. 2013; Menéndez et al. 2012).

Table 7 Observed damage statistics in Lorca

Damage category	Number of buildings	% of buildings
No damage	1,492	19.0
Habitable	4,083	52.0
Non-structural damage	1,256	16.0
Structural damage - forbidden access	707	9.0
Demolition order	314	4.0
Total damaged buildings	**7,852**	**100**

The damage survey was geo-located and a damage map is available online (Ayuntamiento de Lorca 2012). The number of inspected buildings can be considered as statistically significant and useful for establishing damage distributions along Lorca.

Since the reported damages were classified into categories, in order to compare the observed damages with the simulated ones, MDR levels were set, using the authors' judgment, for the different damage categories. Since in this case, both the observed losses and damages are of interest for comparison purposes, vulnerability functions instead of fragility curves have been used. For the first to provide damage levels, different MDR's were assigned based on the author's opinion as explained next. A demolition order is needed if MDR is higher than 40%; a building has forbidden access if MDR is between 16 and 39.9%; it has restricted access if MDR is between 10 and 15.9%; is considered as habitable if MDR is between 4 and 9.9%; and has no damage if MDR is lower than 4%. According to these levels, the statistics for all buildings in Lorca is presented in Table 8.

Table 8 Damage categories statistics from the simulated scenario

Damage category	MDR (%)	Number of dwellings	Dwellings share
No damage	0.0 - 3.9	2,163	12.7%
Habitable	4.0 - 9.9	6,306	37.0%
Non-structural damage - restricted access	10.0 - 15.9	8,067	47.3%
Structural damage - forbidden access	16.0 - 40.0	528	3.1%
Demolition order	40.0+	0	0.0%
TOTAL		**17,064**	**100.0%**

The percentage values of the simulated scenario are similar in all damage categories with the exception of the buildings with demolition order and restricted access. For the first case it is important to mention that in Lorca many buildings were not demolished because they presented a high level of damage but due to social, institutional and insurance reasons. Figure 9 shows the simulated results grouped in damage categories whereas for the second case, the inflicted damage in the structures was suffered mostly in non-structural elements and contents which behavior is acknowledged to not be well captured with the vulnerability functions used herein.

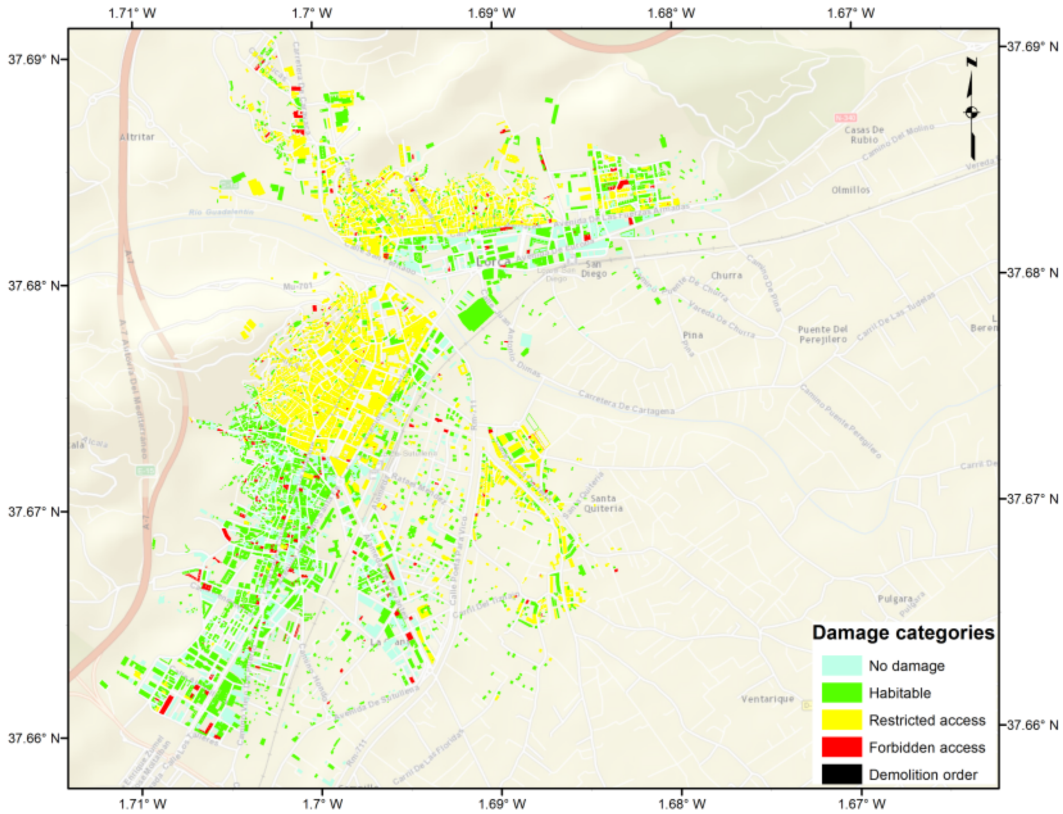

Figure 9 Simulated damage categories for the urban area of Lorca

As it is well known, physical risk estimations are intended to provide an order of magnitude of the expected losses and their average frequency of occurrence if a loss exceedance curve is computed, and to predict the exact damage and its geographical location in the area under analysis. The objective of this article is to compare the results of observed and simulated damage and loss. A model calibration is not possible from a methodological point of view because it cannot be based on a unique observed damage case. Since catastrophic risk models are mostly intended to work on a global basis, a single event is clearly not statistically significant. Moreover, catastrophic events have low occurrence frequencies and thus there are no sufficient observed damage and loss records available which can be used in a comprehensive calibration process. Obviously, even if a catastrophic risk model is adjusted to match the observed damage for a unique event, this does not guarantee the reliability for a different event at a different location with different characteristics.

From our perspective, instead of a model calibration, what is needed is a model validation from the methodological perspective, making sure that seismic hazard, physical vulnerability and their convolution to obtain damage and loss are included in an appropriate manner into the probabilistic calculation algorithm. The methodology employed in this study accounts for the uncertainties related both hazard and physical vulnerability; assuming that input data in terms of hazard, exposure and vulnerability can be considered as reliable, a good estimation in terms of physical risk have been obtained in the case of Lorca..

6. RECOMMENDATIONS FOR SEISMIC RISK REDUCTION STRATEGIES IN LORCA

The fact that an earthquake with moderate magnitude caused important damages and disruption in the affected area, mostly in the city of Lorca, has been a concern for engineering, civil defense, emergency attention and disaster risk management practitioners since it highlighted not only the high levels of vulnerability of different building classes but also the lack of preparation at a societal level to cope with this kind of events.

From a structural point of view, the poor performance under earthquake solicitations of reinforced concrete structures with the short column and weak floor typologies were observed; in fact, the only building which collapsed because of the earthquake in the south of Lorca did so due to the first reason. Even though that Spain has had different earthquake resistant building codes, those are not of mandatory use and the misperception of a negligible seismic hazard in many regions due to the low recurrence rates of the seismic activity has contributed to an increase and accumulation of physical vulnerability. In the building codes, the use of those typologies is strongly recommended against and, therefore, the use of said documents by architects and engineers should be mandatory and a stronger enforcement needs to be put in place in order to stop the increase of vulnerable dwellings.

In terms of the emergency attention, since no plans were previously arranged for earthquakes it was observed a chaotic situation for several days which affected Lorca's inhabitants, from the users of the hospital which was evacuated, to those who owned structures with forbidden access and did not have prompt access to habitable spaces. An emergency plan accounting for different earthquake scenarios that involves the participation of local and regional experts in the disaster risk management field is required in order to estimate the required public spaces for attention, number of professionals to be involved in the emergency attention and the kind of machinery required for the rescue operations by knowing in advance the type of materials required to work with as present in Lorca.

Finally, ex-ante strategies based on fully probabilistic risk analyses of the city (Salgado-Gálvez et al. 2016) such as alternative financial protection activities and/or probabilistic benefit-cost analyses for structural retrofitting can be developed in order to have at hand and in a timely manner the required resources not only for the emergency but also the reconstruction phase whereas at the same time achieving different goals toward the seismic vulnerability and risk reduction.

7. CONCLUSIONS

Earthquake risk models at urban level provide overall estimations that can be useful for decision-makers in terms of required resources and expected damages and losses of the portfolio even if their exact location cannot be established. Therefore, if the results are mapped, a building by building resolution level risk assessment can be misleading since those could be interpreted as an exact prediction for each building, whilst they only represent mean values that are representative as long as the number of elements complies with the requirements of the law of large numbers. Therefore, results in the best case should be grouped by categories, such as building classes, neighborhoods, counties, etc.

In terms of the exposure database used in this study, many parameters could be captured without an individual survey and, therefore, a grouping process among building classes was followed. Data gathering processes should be encouraged at different resolution levels so that the collected and organized information can be used to refine and improve the damage and loss estimations. Continuous updates on the cadastral databases capturing parameters that are of interest to activities different than the taxation ones should be promoted in order to connect said data with the development of ex-ante seismic risk studies that allow a proper quantification of the human, economic and operational resources in order to cope with the needs after the occurrence of earthquake events.

This study presents a comparison between the observed and simulated damage in Lorca for an earthquake which characteristics have been defined similar to that occurred on May 2011 and also considered the local soil response by using the information derived from the seismic microzonation of the city. Damage levels have the same order of magnitude, showing that probabilistic approaches, such as the selected for this assessment, are useful for the risk quantification process, though they do not match exactly the actual observed values.

An estimation of the direct losses in monetary terms has been made in this study and a gross value of the insured losses is also available. Whereas for the modelled losses a variability can be reported after taking into account the uncertainties related to the seismic hazard and vulnerability aspects, for the observed and reported losses said variability is unknown; nevertheless, it is known that it can be large and that again, the reported values are only intended to be reference values of the orders of magnitude. Even if these figures are not intended to match since the latter consider only the insured buildings and only take into account the insured amount, leaving out of the value corresponding to the layers associated to deductibles and insured limits, this case shows that an estimation within the order of magnitude of the losses exists which at the end is the main objective of these models.

Although the reported variability in this study may sound large, it is important to understand that within the scope and limitations of probabilistic catastrophe risk models it can be considered as acceptable (Woo 2011) and that again, the purpose of this comparison is not to find an exact matching between the reported and modelled figures but to see whereas or not orders of magnitude agree.

From the observed damage point of view, there are several challenges regarding how damage was recorded and classified if a loss evaluation calibration process is performed. Usually qualitative damage scales are used, and therefore, no formal ways to translate those observed damage into loss exist. It is also difficult to capture the damage cost since usually after a large event strikes a city, price increases driven by inflation and scarcity of materials occur and are not easy to be distinguished and included in risk assessment.

Finally it is worth mentioning that after a disaster event there are decisions made not necessarily following technical reasons but economic and urban planning ones. Disaster events may trigger economic boost initiatives, generate new open public space areas and/or promote and encourage the stock replacement (even more when resources are available through an insurance consortium). Those actions are not predictable since they depend in each case on the economic circumstances of the event's occurrence.

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