SEISMIC RISK IN ALICANTE AND ELCHE CITIES (SPAIN). A COMPARISON STUDY USING TWO SEISMIC SCENARIOS

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Abstract

The southeast of the Alicante province is one of the areas with the greatest seismic hazard in the whole country. Although this area is characterized by small to moderate earthquakes, they are very shallow (5 to 10 km) and the cities are located on soft soils, making possible to feel its effects more easily. According to the update of the seismic hazard maps carried out in 2012, seismic acceleration values in rock obtained for Alicante and Elche are 0.18 g and 0.20 g respectively. This study shows the seismic risk scenarios derived from the work carried out for both municipalities to obtain their emergency plans against seismic risk.

The seismic risk assessment has been carried out through a deterministic analysis using the SELENA software. The seismic scenarios were chosen after disaggregation of the seismic hazard and the computations were based on the capacity spectrum method, taking into account the ground effect by using several NGA ground motion prediction equations.

Soil classification (Vs30) has been carried out based on surface geology, SPT values obtained mainly from construction surveys and two microzonation campaigns carried out in the urban areas of both cities in order to obtain the predominant period of the soil in each one.

The building stock of both municipalities has been reviewed and classified according to their construction typology. Each building is assigned a predefined model building type in the literature according to the year of construction, the materials used in their construction, the number of floors and whether or not it is subject to seismic-resistant regulations. Each model building type has a corresponding capacity and fragility curves that allow to quantify the vulnerability of each of the buildings.

The results allow seeing the variation of the PGA depending on soil type across the same municipality and the damages related from both earthquakes in terms of: number of buildings with different levels of damage (light, moderate, extensive and complete), Mean Damage Ratio (MDR), number of uninhabitable buildings, economic losses and finally, the number of people affected in function of the time of day and the severity of their injuries.

Keywords: seismic risk; SELENA; deterministic analysis; fragility curves; damage scenario

1. Introduction

On April 29, 2011, the government of the autonomous Valencian region approved the “Plan Especial frente al Riesgo Sísmico” (special plan against seismic risk) through the Order 44/2011. This Order promotes that, at least, 183 municipalities have to prepare their management and emergency plans against the inherent regional seismic risk. Amongst others, the objectives of those plans should not only include a detailed seismic hazard evaluation but also the analysis of the vulnerability of the existing building stock and the computation of earthquake loss scenarios in order to better prepare for emergency situations. However, currently, none of the municipalities have completed its emergency plan and only the municipalities of Elche and Alicante have given the first steps in order to have it.

The improvement of the methodologies for the seismic risk estimation will help public authorities not only to construct according to specific regulations but also to be ready for the emergencies. This is the only way of reducing fatalities and losses.

In Spain, this situation gets more complicated. The low frequency of damaging earthquakes and the short social memory about their effects makes the population very vulnerable to this natural phenomenon (Gaspar-Escribano) [1]. The M5.1, 2011 Lorca earthquake evidenced this situation. This event was the first one causing fatalities since the implementation of modern earthquake-resistant codes in Spain. Nine fatalities, thousands of displaced people, significant damage to relatively recent buildings and elevated economic losses were the sad budget of this event. In this case, failures on construction conception and the poor performance of non-structural elements were behind this disaster.

Additionally, site effects have been demonstrated as a key factor in many of the damaging situation in our country, as for example the 1829 Torrevieja earthquake and even the 2011 Lorca earthquake.

The PSHA at the cities have been updated using the CRISIS [2] software and after a disaggregation, two main seismic scenarios have been selected. The first one, corresponding to 475 years return period assigned to a Mw 5.5 located 20 km from the capital of the province, Alicante and around 10 km from Elche. The second one, correspond to 975 years return period and is assigned to a Mw 6.5 in the same focus of the previous scenario.

After a comparison of the results, this paper show the importance of considering the site amplification in the shake maps of earthquake scenarios and the steps given to carry out the seismic ground motion and the seismic damage scenarios needed for the correct emergency planning.

1. Location

Alicante and Elche cities are located in the southeast of Spain, one of the greatest seismic areas of the country. Both belongs to the Alicante province.

Alicante coordinates are latitude 38°20'43” N and longitude 0°28'59” O and is the capital of the province. Has an elevation of 5 meters above sea level and an extension of 201,27 km².The municipality comprises a total of 12 populated areas with a total in the municipality of 331.577 inhabitants according to the 2018 census and a population density of 1.647,42 people by square kilometer (INE 2018).

In the case of Elche, its coordinates are latitude 38°16'01N and longitude 0°41'54W and it is about 32 km from the capital of the province, Alicante. Elche has an elevation around 86 meters above sea level and an extension of 326,07 km^2. In general, the municipality comprises a total of 21 populated areas with a total in the municipality of 230.625 inhabitants according to the 2018 census and a population density of 707,29 people by square kilometer (INE 2018).

2. Methodology

The damage probability for each model building type will be obtained using the analytical methodology implemented in SELENA [3]. This analytical (or theoretical) approach uses physical ground-motion parameters such as spectral accelerations Sa or spectral displacement Sd. Therefore, the loss estimation approaches differ in the way earthquake ground motion is represented and building vulnerability is treated because the loss estimation results will be provided by the convolution of both terms (expressed in terms of building damage and the corresponding economic and human losses).

According to Sandi [4], the first is denoted as observed vulnerability, while the second represents calculated or predicted vulnerability [5, 6]. Both types of vulnerability may be represented by similar means, i.e. damage probability matrices (DPMs) or fragility functions, depending on what type of data is available and which of the basic approaches is to be applied. An elaborate overview of existing methodologies for seismic vulnerability assessment is given by Calvi [7].

To apply this methodology to estimate the damage scenarios for the municipalities of Alicante and Elche, it is necessary to provide the next data:

a) Select the earthquake scenario responsible of the ground motion in both municipalities by updating the seismic hazard in the region and choosing the corresponding scenario through the disaggregation of the seismic hazard, using the software CRISIS [2].

b) Carry on a geological and geophysical microzonation in order to quantify the Vs30 and the predominant periods in both urban areas, so we will be able to simulate the ground motion scenario (using the source parameters above mentioned) including soil and topographic effects.

c) Classify the building stock of the municipalities in different model building types according to their vulnerability (using the main structural materials, age of construction, height of the buildings and seismic regulations) and represent that vulnerability through capacity and fragility curves (Lagomarsino and Giovinazzi) [8].

d) Analyze the results and discuss the sensitivity for both municipalities.

3. Results and discussion

3.1 Seismic scenarios

The seismic hazard was computed using the source zones proposed by the IGN-UPM [9] working group and the corresponding ground motion prediction equations, computing the UHS in rock for return periods of 475 and 975 years in both municipalities as shown in Figure 1. As we can see, the PGA ranges from 0.14 g to 0.05 g in Alicante and from 0.22 g to 0.10 g in Elche if the return period is 475 years (Figure 1 left) and ranges from 0.31 g to 0.11 g in Alicante and from 0.39 g to 0.18 g in Elche if the return period is 975 years (Figure 1 right). Additionally, after computing the seismic hazard disaggregation (Harmsen) [9] for both return periods at one site close to each city, we can represent the probabilities as a function of magnitude and distance. Therefore, we can easily obtain the pair (magnitude, distance) which contributes with a higher probability to the computed seismic hazard.

The active fault, which is located around 20 km from the city center of Alicante and something less from Elche, corresponds to the Crevillente Fault (CF). This fault is able to generate moderate to big earthquakes. This fault runs along to the Internal and External Betic Zones contact, representing the former limit between the Eurasian and African plates. The CF zone and associated fold is 60 km long; the fault presents reverse kinematics (with a minor sinistral component) from the Tortonian (Martin-Rojas) [10]. This fault is also responsible of moderate earthquakes in the region as the 1787 Elche earthquake, with intensity VI in the EMS-92 scale and the 1958 Fortuna earthquake (Mw 4.0 and Intensity VI) and the 2018 Albatera earthquake with a Mw 4.2 and widely felt in the city of Elche and Alicante. Besides, the maximum magnitude (Mw) from length using Stirling [11] equation derived from the instrumental dataset is 6.79 (6.67-6.79) according to García Mayordomo [12] and could even reach 6.9 according to IGME [13].

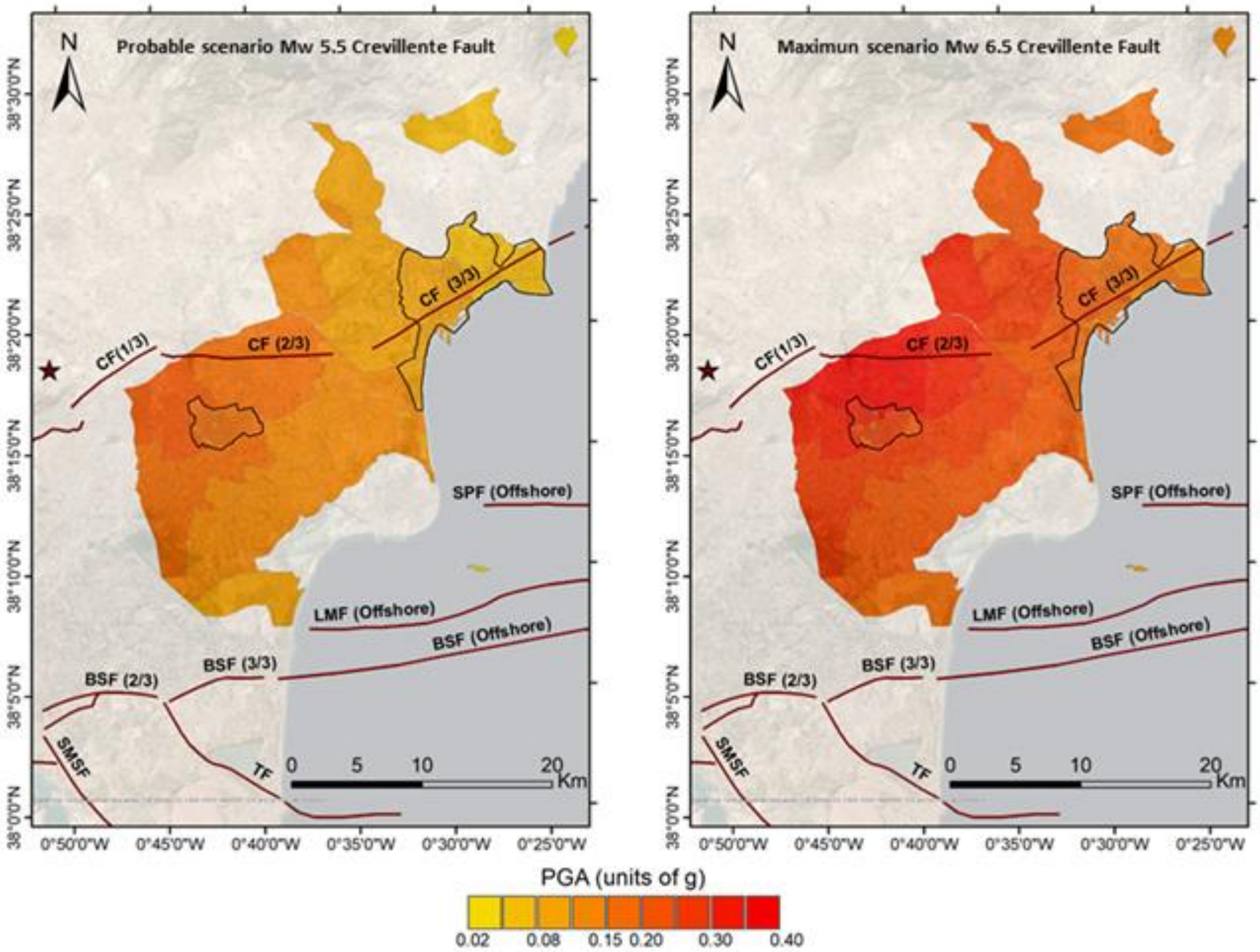

Figure 1. Seismic hazard for 475 years return period (left), 975 years return period (right) and active faults of the regions (dark red lines).

The Table 1 shows the source parameters of the main seismic scenarios chosen after disaggregation and used in the computation of the structural damage and economic and human losses in both municipalities simultaneously. The first one will be considered as the probable scenario and the second one as the maximum scenario, both of them located in Crevillente Fault.

Table 1. Seismic scenarios proposed after seismic hazard disaggregation

Scenario	Latitude	Longitude	Depth (km)	Mw	Mechanism	Strike	Dip
Probable (10% in 50 yrs)	30.309	-0.50	11.0	5.5	Reverse	250	65
Maximum (5% in 50 yrs)	30.309	-0.50	11.0	6.5	Reverse	250	65

Additionally, Figure 1 shows the epicenter of the proposed rupture in the Crevillente Fault (red star) with the urban area of each municipality where most of the residential buildings are located.

3.2 Seismic microzonation and ground motion scenarios

For both municipalities, a seismic microzonation campaign was carried out after studying the geological data. The geophysical microzonation campaign was carried out in both cities around the urban areas using a 500x500 meters grid with 90 measurement points in Elche and 123 in Alicante. These measurements were recorded using Mark L-4C-3D 1 Hz sensors connected to Reftek and Geophonino [14] digitizers. Additionally, array measurements were also taken at two different sites of Elche city by three circular arrays composed of five VSE-15D sensors surrounding a sixth similar. These sensors measured the vertical component and were connected to a SPC-35 digitizer. At the same time, a Güralp 6TD was used for H/V measurements.

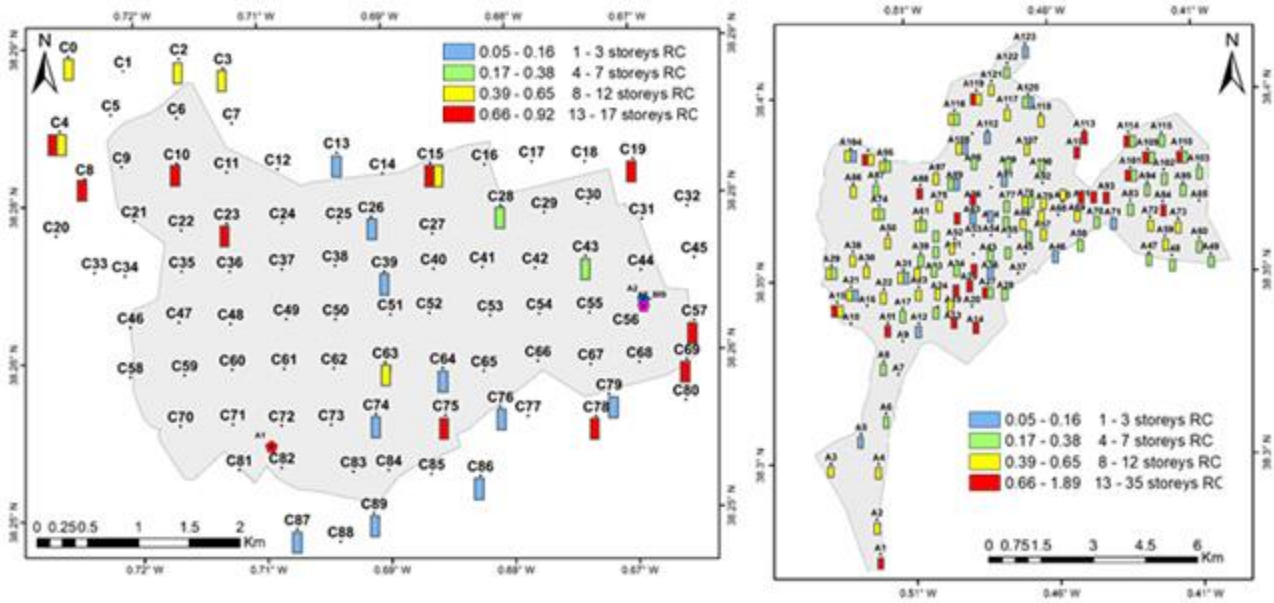

Figure 2. Seismic microzonation carried out in the urban area of Elche (left) and Alicante (right).

Figure 2 shows a summary of the results obtained after microzonation in the urban area of Elche and Alicante. Geological data corresponds to Quaternary deposits composed mainly of conglomerates and clays, followed by silt and marl, being able to form a deposit of great power, according to the boreholes carried out in the study area and in zones close to it. The basement has hundreds of meters and is formed by limestones and dolomites. In Alicante area some resistant materials emerge with respect to Elche.

After analyzing the data of seismic noise taken in the urban area of Elche, a fundamental frequency is observed in all the measurement stations whose average value is 0.3 Hz and which is probably due to the impedance contrast between the basement of the basin and a sedimentary deposit, which can reach hundreds of meters. Shallower contrasts could produce resonance effects in some reinforced concrete buildings. If we apply the empirical relationship between fundamental period and number of stories of reinforced concrete buildings [15] then we can see coincidences for the northwest of the city, occupied mostly by industrial buildings, between the soil period and the corresponding to buildings from 1 to 3 stories. The west part of the city has mainly buildings with 4 to 7 stories, but the soil period is not the same. Only the buildings close to the river have heights close the soil periods found. Finally, the east part of the city shows again a match between the soil periods and building with 1 to 3 stories.

On the other hand, the results obtained in Alicante shows a fundamental frequency ranging between 0.25 to 0.5 Hz in most of the municipality, but to the east and north of the municipalities we have found fundamental frequencies of 2.7 to 6 Hz and 1.5 to 2.7 Hz. These frequencies could be like reinforced concrete building with 8-12 stories and 4-7 stories, in the area.

3.3 Vulnerability and exposure

The area of Alicante municipality has 24162 buildings. 4672 buildings are old buildings made of rubble and simple stone or unreinforced masonry with old brick constructed before 1950, that is without any seismic consideration (No Code). In the period 1950-1977 the buildings used as main structural materials mix masonry and concrete but also without any seismic consideration (9006 buildings). The period 1977-1997 was the starting point of the structures made with masonry and reinforced concrete or only with reinforced concrete (6054 buildings) using some construction guidelines so we called this period as Pre-Code. Finally, the periods 1997-2004 and >2004 correspond to the two Spanish seismic regulations: NCSE-94 [16] and NCSE-02 [17] which is our current seismic normative. All the buildings associated to these periods (4430) are reinforced concrete buildings constructed applying seismic regulations (Code).

A similar distribution of the buildings according to the period of construction is found in the urban area of Elche (Figure 3). The area of Elche municipality has 34395 buildings. As in Alicante city, 5493 buildings are old buildings made of rubble and simple stone or unreinforced masonry with old brick constructed before 1950, that is without any seismic consideration (No Code). In the period 1950-1977 the buildings used as main structural materials mix masonry and concrete but also without any seismic consideration (10199 buildings). The period 1977-1997 includes 10643 buildings using the Pre-Code guidelines. Finally, all the buildings (8060) associated to the periods 1997-2004 and >2004 are reinforced concrete buildings constructed applying the Spanish seismic regulations, NCSE-94 [16] and NCSE-02 [17], respectively.

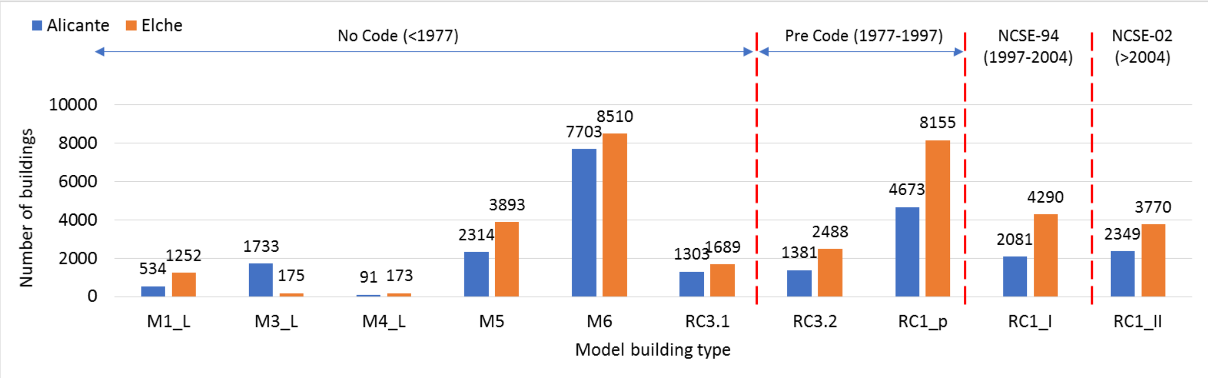

Figure 3. Model building type distribution in Alicante and Elche.

Table 2 presents the building classification and the corresponding vulnerability function according to Lagomarsino and Giovinazzi [8].

Table 2. Building classification

Model Building Type	Period of construction	Vulnerability function
M1: Rubble stone. L (1 to 2 stories) to M (3 to 5 stories)	< 1950	M1.w_L M1.w_M
M3: Simple stone with wood floors. L (1 to 2 stories) to M (3 to 5 stories)	< 1950	M3.w_L M3.w_M M3.w_H

M4: Massive stone. L (1 to 2 stories) to M (3 to 5 stories)	< 1950	M4.w_L M4.w_M M4.w_H
M5: Unreinforced masonry with Wood floors L (1 to 2 stories) to M (3 to 5 stories)	< 1950	M5.w_L M5.w_M M5.w_H
M6: Unreinforced masonry with R.C. floors L (1 to 2 stories), M (3 to 5 stories) y H (> 5 stories)	1950 - 1977	M6_L-PC M6_M-PC M6_H-PC
RC31: Reinforced/Confined Masonry L (1 to 2 stories), M (3 to 5 stories) y H (> 5 stories)	1950 - 1977	M7_L-PC M7_M-PC M7_H-PC
RC32-p: Reinforced concrete frame with unreinforced masonry infills without seismic code L (1 to 3 stories), M (4 to 7 stories) y H (> 7 stories)	1978 - 1977	RC1L-pre RC1M-pre RC1H-pre
RC1-p: Reinforced concrete frame with unreinforced masonry infills without seismic code but in the period Pre-Code L (1 to 3 stories), M (4 to 7 stories) y H (> 7 stories)	1978 - 1996	RC3L-pre RC3M-pre RC3H-pre
RC1-I: Reinforced concrete frame with unreinforced masonry infills with low seismic code and low ductility L (1 to 3 stories), M (4 to 7 stories) y H (> 7 stories)	1997 - 2004	RC3L-III-DCL RC3M-III-DCL RC3H-III-DCL
RC1-II: Reinforced concrete frame with unreinforced masonry infills with low seismic code and moderate ductility L (1 to 3 stories), M (4 to 7 stories) y H (> 7 stories)	> 2004	RC3L-III-DCM RC3M-III-DCM RC3H-III-DCM

Figure 4 shows the vulnerability distribution in both urban areas depending on its classification as No Code (<1978), Pre- Code (1978 to 1996) or Code (>1996). Alicante has 13678 buildings classified like No Code (<1978), 6054 buildings of Pre- Code (1978 to 1996) and 4430 buildings with Code (>1996). Elche has 15692 buildings classified like No Code (<1978), 10643 buildings of Pre- Code (1978 to 1996) and 8060 buildings with Code (>1996).

3.4 Structural Damage and Losses

Using the software SELENA [3] and the previously collected information the structural damage in both cities has been computed. The performance point has been computed using three analytical methods: N2 [18], [19] IDCM and MADRS [19].

As a summary, we have found that 5.6 % in Alicante and 35.6 % in Elche would be inhabitable after a Mw 5.5 earthquake (72 % in Alicante and 88 % in Elche for a Mw 6.5).

Additionally, if we focus the description of the results for the probable scenario of Mw 5.5, the values for structural damage in Alicante are, 102 buildings are expected to show complete damage (it is possible to see the distribution of this level of damage in the figure 5), 559 extensive damage, 2109 moderate damage and 9977 slight damage. For Elche the structural damage values are, 2353 show complete damage (Figure 5), 4727 extensive damage, 7702 moderate damage and 14747 slight damage

On the other hand, the impact of a Mw 6.5 rupture in the Crevillente Fault in Alicante, 8500 buildings are expected to show complete damage (figure 5), 6218 extensive damage, 5351 moderate damage and 4311 slight damage. The structural damage values for Elche are, 20454 with complete damage (Figure 5), 7652 extensive damage, 5262 moderate damage and 2706 slight damage.

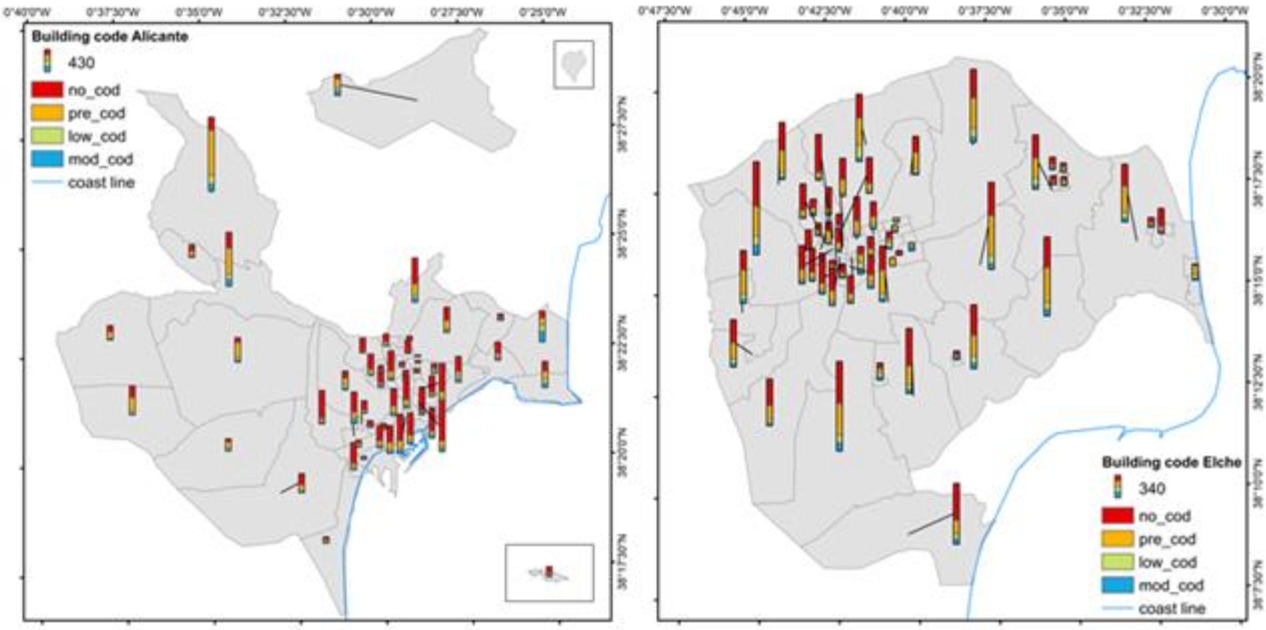

Figure 4. Building distribution according the seismic code design.

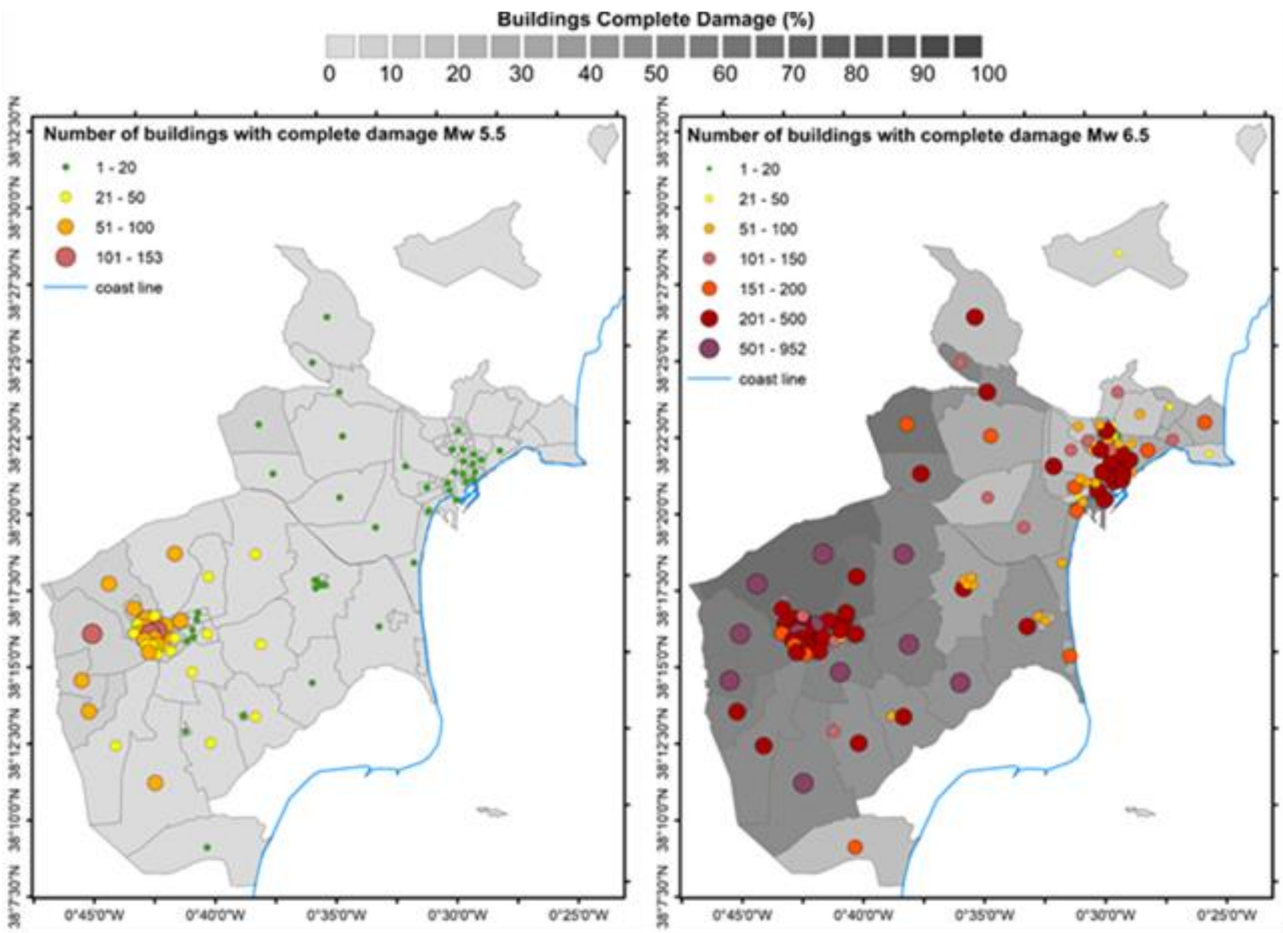

Figure 5. Number of buildings with complete damage for both scenarios.

The Figure 6 shows the distribution of the Mean Damage Ratio. This index allows to see the impact on each division (in this study the division correspond to the neighborhoods) that we have established when made the computations. This value shows the average damage ratio in percent, whatever be the number of buildings or typologies present and allowing to compare which are the areas that have suffered the greatest impact.

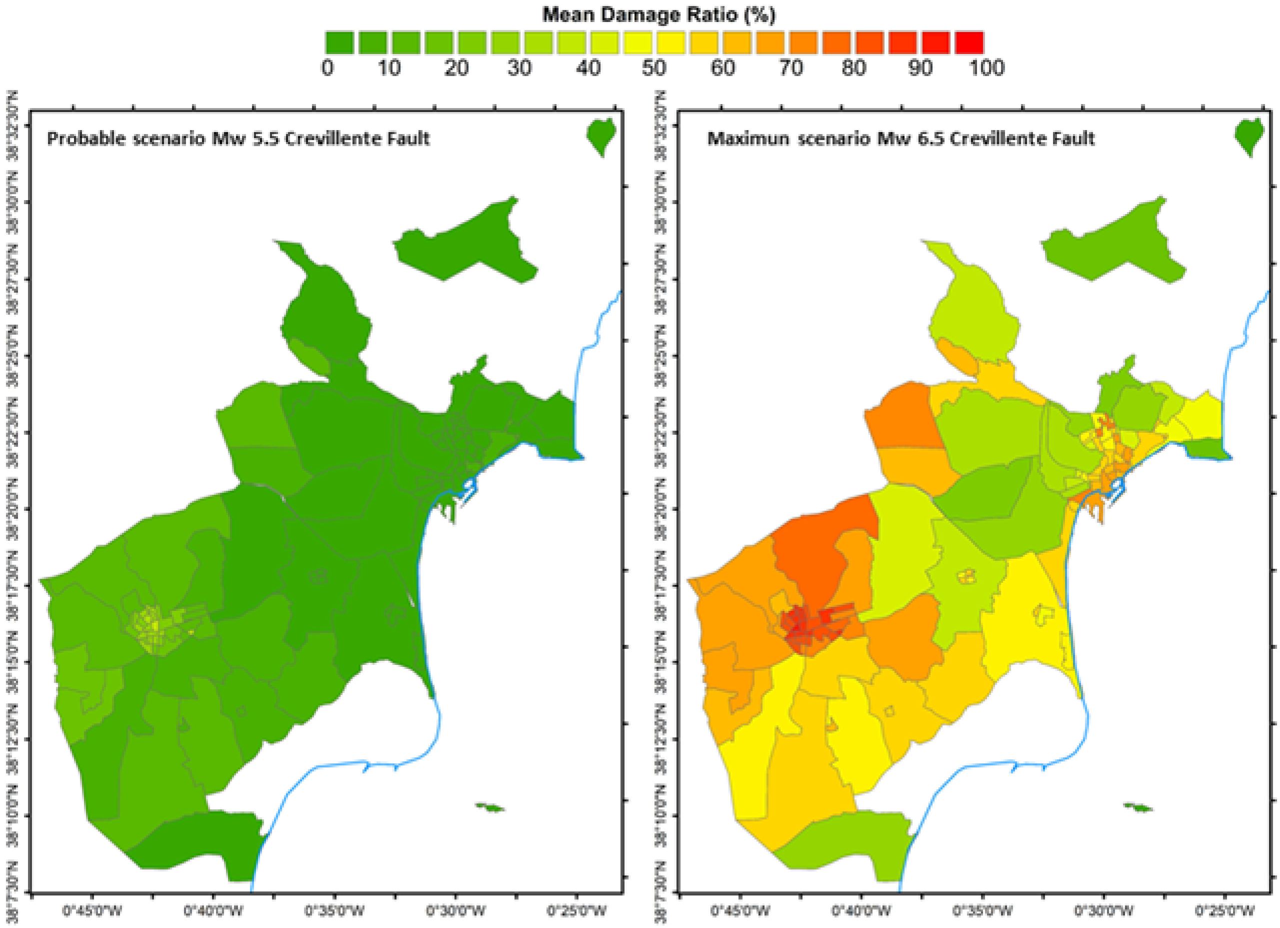

Figure 6. Mean Damage Ratio value distribution.

The maximum average damage ratio that has been obtained in Alicante for the Mw 5.5 scenario varies between 1 and 12 %. In Elche the values ranges from 2 to 39 %.

For the maximum scenario with a Mw 6.5 the MDR in Alicante varies from 3 to 75 % and in Elche the values for this scenario varies between 26 to 90 %.

In both cases the greatest MDR is obtained for the earthquake of 6.5, but the damage in Elche is significantly more important due to the proximity of the urban area to the focus of the earthquake.

The structural damage caused by the probable scenario (Mw 5.5) will have an economic impact in Alicante of 1151 ± 3 million Euros (only repair and reconstruction). The impact on the population will depend on the time in which the rupture happens. Therefore, at night when a largest number of people are into the buildings, 237 ± 1 people will suffer slight injuries, 63 ± 1 moderate injuries, 22 ± 1 severe injuries and 17 ± 1 will suffer very severe injuries and even death.

For Elche the economic impact is around 2818 ± 10 million Euros (repair and reconstruction) and the impact on the population at night will be 1627 ± 19 persons will suffer slight injuries, 879 ± 1 moderate injuries, 441 ± 2 severe injuries and 447 ± 3 will suffer very severe injuries and even death.

If the maximum scenario took place the economic impact in Alicante of this earthquake means 10560 ± 1600 million Euros (repair and reconstruction). If the earthquake happens at night then 6148 ± 1348 persons will suffer slight injuries, 4338 ± 1030 moderate injuries, 2113 ± 589 severe injuries and 2660 ± 589 very severe injuries and even death.

Finally, in the case of Elche for this maximum earthquake scenario the economic impact means 9263 ± 4200 million Euros (repair and reconstruction). In this case, if the earthquake happens at night then 5851 ± 748 persons will suffer slight injuries, 5259 ± 698 moderate injuries, 2139 ± 300 severe injuries and 3931 ± 540 very severe injuries and even death.

Tables 3 and 4 show a resume, in absolute terms, of the losses as a consequence of both scenarios. It can see how Elche is most affected in both scenarios, however Alicante also suffered the consequences of both situations.

Table 3. Resume of the losses in both municipalities.

Scenario	Municipality	Uninhabitable dwellings	Homeless	Economic Losses (M€)	Mean Damage Ratio
Probable (Mw 5.5) (10% in 50 yrs)	Elche	40355	89222	2818	9 %
	Alicante	10300	18582	1151	2 %
Maximum (Mw 6.5) (5% in 50 yrs)	Elche	100019	208205	9263	39 %
	Alicante	132250	239210	10560	26 %

Table 4. Resume of the injured people during the night.

Scenario	Municipality	Slight injuries	Moderate injuries	Serious injuries	Severe injuries
Probable (Mw 5.5) (10% in 50 yrs)	Elche	1627	879	441	447
	Alicante	237	63	22	17
Maximum (Mw 6.5) (5% in 50 yrs)	Elche	5851	5259	2138	3931
	Alicante	6148	4338	2113	2660

4. Conclusions

From the previous results, it is observed that even the Mw 5.5, which cause important damages in the municipality of Elche, affects also the municipality of Alicante. Old buildings without seismic regulation would be the most affected by the site effect, which has a great effect on the distribution of damage.

The consequences for both cities because any damaging earthquake show the importance of the close collaboration between the two municipality governments when planning the emergency response in order to know the means available if it will be necessary. This will obviously affect the number of available hospitals to send the injured people, the places to settle the homeless, and so on.

5. Acknowledgements

The research presented has been benefited from funding of the Ministerio de Economía, Industria y Competitividad through research project CGL2016-77688-R, the Generalitat Valenciana through the research project AICO/2016/098 with the collaboration and funding provided by Elche and Alicante municipalities.

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