SEISMIC DAMAGE SCENARIOS IN THE MUNICIPALITIES OF ELCHE AND ALICANTE (SPAIN). A FIRST STEP TO THE EMERGENCY PLANNING

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ABSTRACT

South and South-East of Spain are the regions with a higher seismic hazard in Spain. Therefore, a regional normative, focused on the importance of developing seismic emergency planning in many of the municipalities of the Valencian Community, was established in 2011. Consequently, all the municipalities in Alicante province have to develop a seismic emergency planning. However, only Elche and Alicante have completed the seismic risk analysis and they have started to prepare their emergency plans which will be finished before the end of 2019. This paper shows the main results of the seismic risk analysis carried out in both municipalities. The seismic hazard update in the region has shown that the main earthquake scenarios, which may hit both cities, correspond to the Crevillente and the Bajo Segura faults (also responsible for damaging historical earthquakes). In both cases, the urban areas are on a sedimentary deposit, which can reach hundreds of meters so site effects and possible site-building resonance can be important. Additionally, most of the building stock belongs to periods without seismic normative, increasing, therefore, their vulnerability and the obtained damage. The mean damage ratio for a magnitude of 5.5 increases from a 0.8% to a 10.3% at Alicante and Elche, respectively. Besides, if the magnitude increases to a 6.5 then the mean damage ratio increases from a 16.6% to a 60.3%. In conclusion, we recommend that the emergency planning developed for both municipalities has to take into consideration that even the occurrence of a probable earthquake (475 yrs return period) corresponding to a Mw 5.5 will affect both cities so the procedures and protocols should be written in close cooperation.

Keywords: seismic risk, emergency planning, vulnerability, site effects, seismic hazard.

1 INTRODUCTION

Great loss of human life, structural damage, and social and economic upheaval have occurred repeatedly in recent history due to natural hazards such as earthquakes, hurricanes, landslides, floods and tsunamis. Although earthquake disasters are not so frequent in comparison to other natural catastrophes, they are responsible for a 77% of fatalities and a 34% of overall losses. This is the reason why scientists have to improve the methodologies for the seismic risk estimation, which 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.

Specifically, this situation gets more complicated in Spain. The low frequency of damaging earthquakes and the short social memory about their effects makes the population very vulnerable to this natural phenomenon [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 persons, significant damage to relatively recent buildings and high economic losses were the sad budget of

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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.

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, none of the municipalities have completed its emergency plan yet. Currently, only the municipalities of Elche and Alicante have given the first steps in order to have it ready before the end of 2019.

The goal of this paper is to show the given steps to carry out the seismic ground motion and the seismic damage scenarios needed for the correct emergency planning.

2 MATERIALS AND METHOD

In general, earthquake damage and loss studies are based either on traditional empirical (or statistical) approach (i.e. macroseismic intensities) or the more recent analytical (or theoretical) approach using physical ground-motion parameters such as spectral accelerations S_a or spectral displacement S_d. 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 [2], the first is denoted as observed vulnerability, while the second represents calculated or predicted vulnerability [3], [4]. 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 [5].

In order to estimate the damage scenarios for the municipalities of Alicante and Elche, the analytical method incorporated into the software SELENA [6] has been used. The data needed to apply this methodology are:

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 [8].
b. Carry on a geological and geophysical microzonation in order to quantify the Vs30 (time-averaged shear wave velocity in the upper 30 meters, m, of the crust) and the predominant periods in both urban areas, allowing to simulate the ground motion scenario (using the source parameters above mentioned) including soil and topographic effects.
c. Classify the building stock 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 [9].

d. Compute the damage results, analyze the results and discuss the sensitivity

3 RESULTS AND DISCUSSION

3.1 Seismic Scenarios

The seismic hazard was computed using the source zones proposed by the IGN working group [9] and the corresponding ground motion prediction equations, computing the UHS at 10% and 5% probability of exceedance in 50 years on a firm-rock site condition with V_S30 = 760 m/s (return periods of 475 and 975 years, respectively) as shown in Fig. 1. As can be seen, the PGA ranges from 0.172 g (north of Alicante municipality) to 0.207 g (south of Elche municipality) if the return period is 475 years (Fig. 1a) and ranges from 0.23 g to 0.28 g (following the same spatial distribution) if the return period is 975 years (Fig. 1b). Additionally, after computing the seimic hazard disaggregation [10] for both return periods at one site close to the city center of Elche (Figs. 2 and 3), the probabilities as a function of magnitude and distance can be represented. Therefore, the pair (magnitude, distance) which contributes with a higher probability to the computed seismic hazard can be easily obtained.

Figure 2a reveals that the magnitude–distance combinations with a higher contribution to the seismic hazard are the corresponding to earthquakes with magnitude ranging from 5.4 to 5.8 and distances between 16 and 21 km, for a 475-year return period. The maximum probability is assigned to a magnitude 5.7 and distance 18 km with a value of 0.00135. On the other hand, for the 975-year return period, Fig. 2b reveals that the magnitude–distance combinations with a higher contribution to the seismic hazard are the corresponding to earthquakes with magnitude ranging from 6.0 to 6.5 and distances between 16 and 21 km. The maximum probability is assigned to a magnitude 6.4 and distance 18 km with a value of 0.0066.

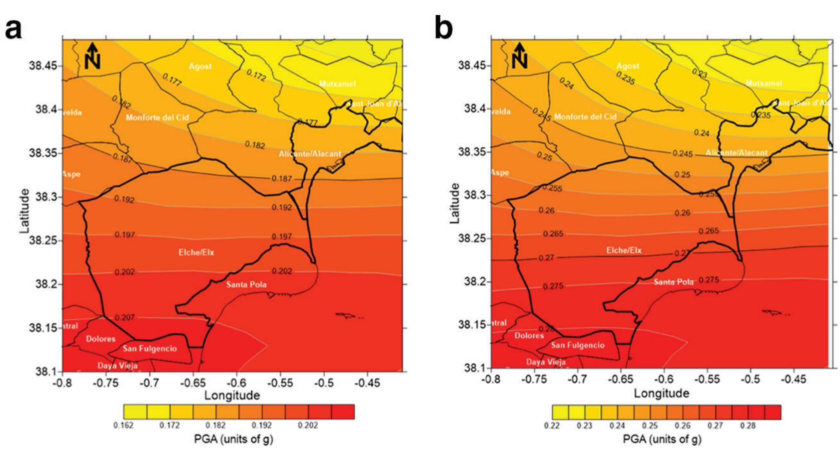

Figure 1: Seismic hazard in terms of PGA for a return period of 475 years (a) and 975 years (b). The thick borders surround the municipalities of Elche (South) and Alicante (North).

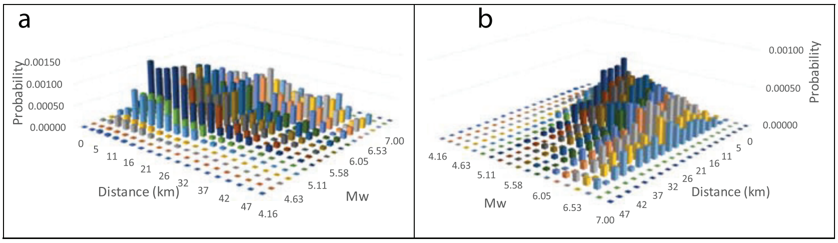

Figure 2: Disaggregation of the seismic hazard for a return period of 475 years (a) and 975 years (b).

The abovementioned information can be combined with the active faults in the area (Fig. 3). As can be seen, the active fault which is located around 20 km from the city center of Alicante and can generate moderate to big earthquakes is the Crevillente Fault (CF). This fault runs along to the Internal and External Betic Zones contact, representing the former limit between the Eurasian and African plates. The CF fault zone and associated fold is 60 km long; the fault presents reverse kinematics (with a minor sinistral component) from the Tortonian [11]. This fault is also responsible of moderate earthquakes in the region as the 1787 Elche earthquake, with intensity VI in the EMS-92 scale, the 1958 Fortuna earthquake (Mw 4.0 and Intensity VI) and the 2018 Albatera earthquake with a Mw 4.2 (widely felt in the city of Elche and Alicante). Besides, the maximum magnitude (Mw) from length using empirical relationships [12] is 6.79.

South of the Alicante province, the Bajo Segura Fault (BSF) is found. According to [13], the Bajo Segura Fault Zone, located at the NE end of the Eastern Betic Shear Zone, has been the site of some of the most intense seismic activity on the Iberian Peninsula in the historical and instrumental time periods. This structure is an active blind fault that does not show any surface rupture. It is characterized by a set of ENE-WSW trending blind thrust faults that offset the Triassic basement and cause active folding of the Upper Miocene-Quaternary sedimentary cover. The main active structures of this fault zone are two ENE-WSW striking reverse blind faults, the Torremendo and the Bajo Segura Faults, and several secondary NW-SE striking dextral faults (San Miguel de Salinas, Torrevieja and Guardamar Faults). These structures continue offshore to the east. From geological, geomorphological and geodesic data, fault slip rates between 0.2 and 0.4 mm/year have been obtained, whereas other authors have proposed higher values ranging between 0.75 and 1 mm/year. The fault zone can generate earthquakes with maximum estimated magnitudes (Mw) from 6.6 to 7.1 and has approximate recurrence intervals between 4.500 and 21.500 years.

Therefore, Table 1 shows the source parameters of the chosen seismic scenarios used in the computation of the structural damage and economic and human losses in both municipalities simultaneously. Figure 3 also shows the epicentral location of the earthquakes using a red star. This paper has focused on two of the seismic scenarios: the likely earthquake with a magnitude Mw 5.5 and the maximum deterministic earthquake with a magnitude Mw 6.5 scenario, both in the Crevillente Fault.

3.2 Seismic microzonation and ground motion scenarios

A seismic microzonation campaign was carried out after studying the geological data. The geophysical microzonation campaign was carried out using a 500×500 meters grid with 90 measurement points for the urban area of Elche and 123 measurements for the urban area of

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 the city of Elche 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.

Table 1: Seismic scenarios proposed after seismic hazard disaggregation.

Scenario	Latitude	Longitude	Depth (km)	Mechanism	Strike	Dip
Frequent (10% in 10 years)	38.3090	–0.50	11.0	5.0	Reverse	250°
Likely (10% in 50 yrs)	38.3090	–0.50	11.0	5.5	Reverse	250°
Maximum (5% in 50 yrs)	38.3090	–0.50	11.0	6.0	Reverse	250°
Maximum CF (Deterministic)	38.3090	–0.50	11.0	6.5	Reverse	250°
Maximum BSF (Deterministic)	38.0800	–0.68	5.00	6.5	Reverse	77º

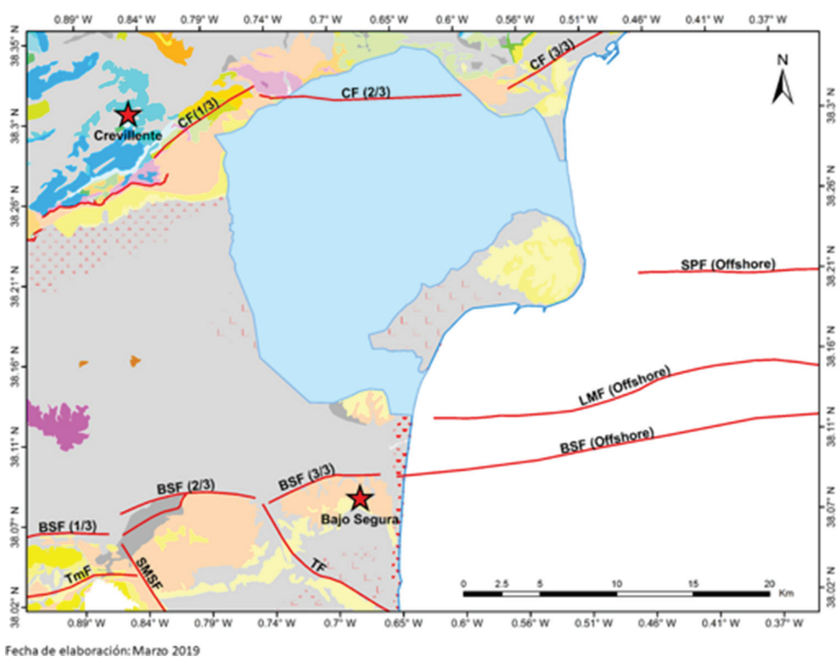

Figure 3: Main active faults in the Alicante province and epicentral location of the earthquakes after disaggregation (see Table 1).

Figure 4a shows a summary of the results obtained for the urban area of Elche. 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, found around 1000 meters deep, is formed by limestones and dolomites. After analyzing the seismic

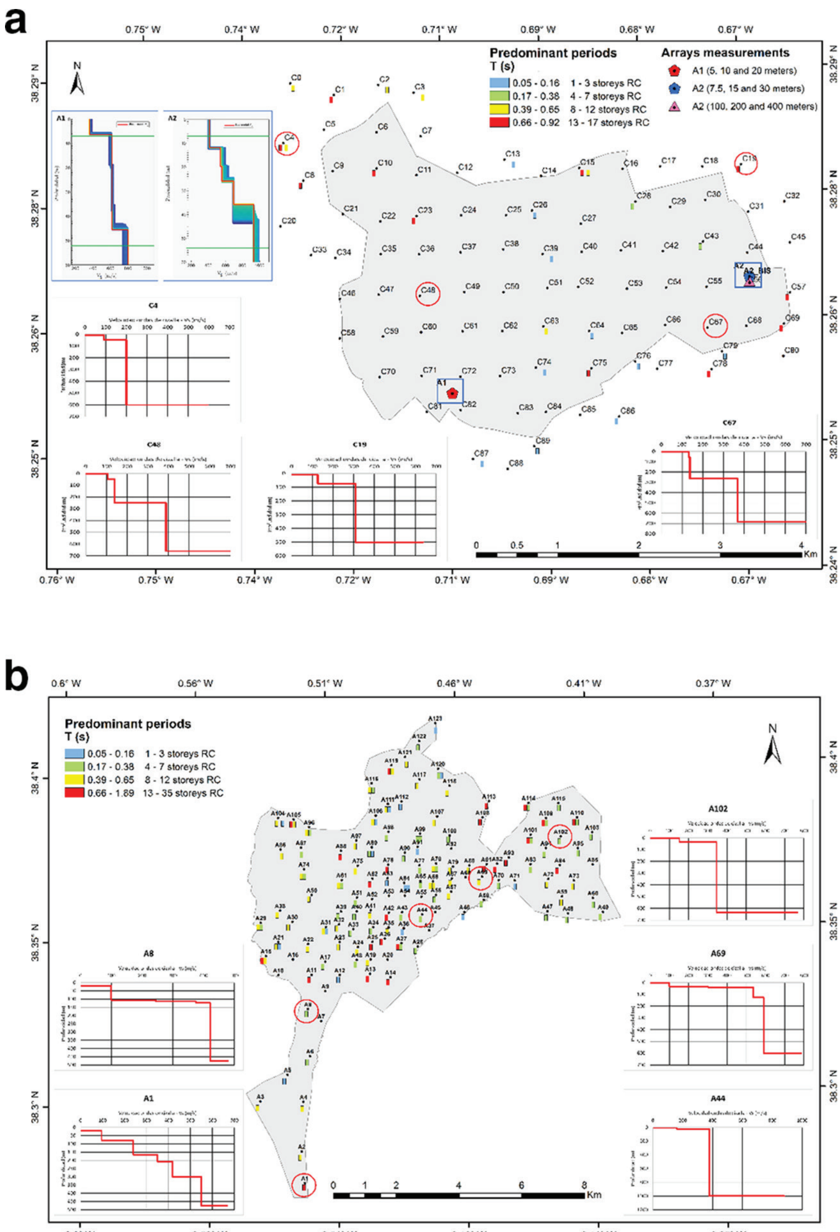

Figure 4: Summary of the seismic microzonation carried out in the urban area of Elche (a) and Alicante (b).

noise data recorded 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 get to produce resonance effects in some reinforced concrete buildings. Then, applying the empirical relationship between fundamental period and number of stories of reinforced concrete buildings [15] it can be seen coincidences between the soil period and the corresponding to buildings from 1 to 3 stories for the northwest of the city, occupied mostly by industrial buildings. The west part of the city has mainly buildings with 4–7 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 1–3 stories.

On the other hand, the results obtained in Alicante (Fig. 4b) point to a fundamental frequency ranging between 0.25 to 0.5 Hz in the most of the municipality. However, fundamental frequencies of 2.7–6 Hz and 1.5–2.7 Hz are found to the east and north of the municipality. These frequencies could be similar to reinforced concrete building with 8–12 stories and 4–7 stories, in the area.

Therefore, taking into consideration the Vs30 obtained through the seismic microzonation and the source parameters of the seismic scenarios, the spectral acceleration for both municipalities using the ground motion prediction equations proposed by Abrahamson *et al*. [16] and by Campbell and Bozorgnia [17] has been computed. Figure 5 shows the obtained ground motion in terms of PGA. As it can be seen, the ground motion decreases from north to south in Elche. On the other hand, the ground motion is lower in Alicante, due to the higher distance to the rupture but the variations in the soil conditions introduce, also, important variations in the PGA in the municipality. The PGA has a maximum of 0.23 g and 0.41 g for a Mw 5.5 and 6.5, respectively in Elche and ranges from 0.11 g to 0.24 g in Alicante.

3.3 Vulnerability and Exposure

Alicante municipality has 24162 buildings while Elche municipality has 34452. 57% in Alicante and 46% in Elche are old buildings made of rubble and simple stone or unreinforced masonry with old bricks constructed before 1950, or constructed in the period 1950–1977 using as main structural materials mix masonry and concrete (without any seismic consideration in both cases and named No Code). The period 1977–1997 was the starting point of the structures made with masonry and reinforced concrete or only with reinforced concrete (25% in Alicante and 31% in Elche) using some construction guidelines so this period has been named as Pre-Code. Finally, the periods 1997–2004 and >2004 correspond to the two Spanish seismic regulations: NCSE-94 [18] and NCSE-02 [19] which is our current seismic normative. All the buildings associated to these periods (18% in Alicante and 23% in Elche) are reinforced concrete buildings constructed applying seismic regulations (named Code). Table 2 and Figure 6 represent the building classification and the corresponding vulnerability function according to [8].

3.4 Structural damage and losses

Using the software SELENA [6] and the previously collected information the structural damage in both cities has been computed. The performance point has been computed using two analytical methods: N2 [20] and IDCM [21].

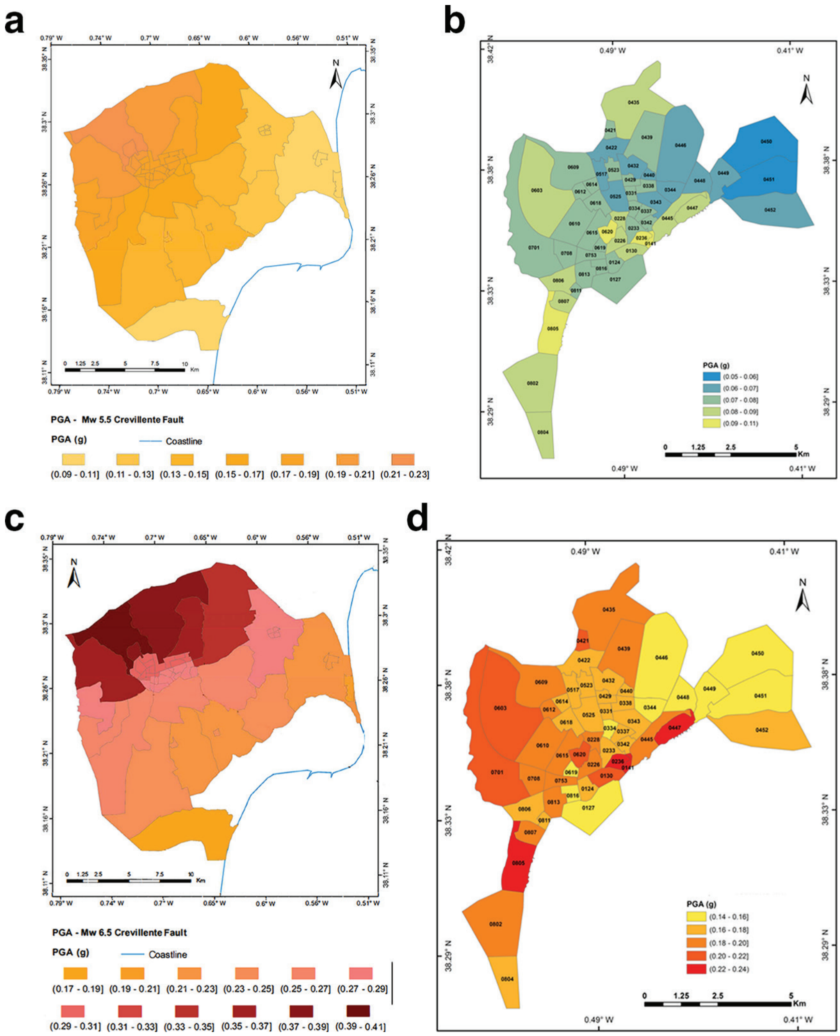

Figure 5: Ground motion scenarios of a magnitudes of 5.5 and 6.5 at the Crevillente Fault for Elche (a,c) and Alicante (b,d).

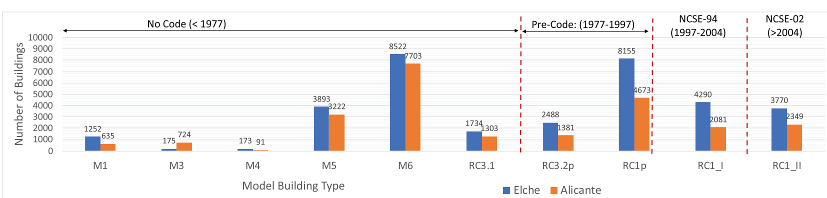

Figure 6: Building typologies distribution in the municipalities of Elche and Alicante.

Table 2: Proposed building typologies and vulnerability functions.

Building Typology	Period of Construction	Vulnerability Function (*)	Seismic Normative
M1: Rubble stone. L (1 to 2 stories) to M (3 to 5 stories)	< 1950	M1.w_L M1.w_M	None
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	
RC3.1: 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	
RC3.2-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	Pre-Code
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	NCSE-94
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	NCSE-02

(*) According to [8].

Table 3: Summary of the seismic loss results.

Scenario	Municipality	Uninhabitable Buildings	Homeless	People Injured	Economic Losses (millions €)	Mean Damage Ratio (%)
5.5	Elche	4576	40013	1900	2300	10.3
	Alicante	178	1300	96	228	0.8
6.5	Elche	25534	190085	15800	13500	63.0
	Alicante	4362	25784	5304	6190	16.6

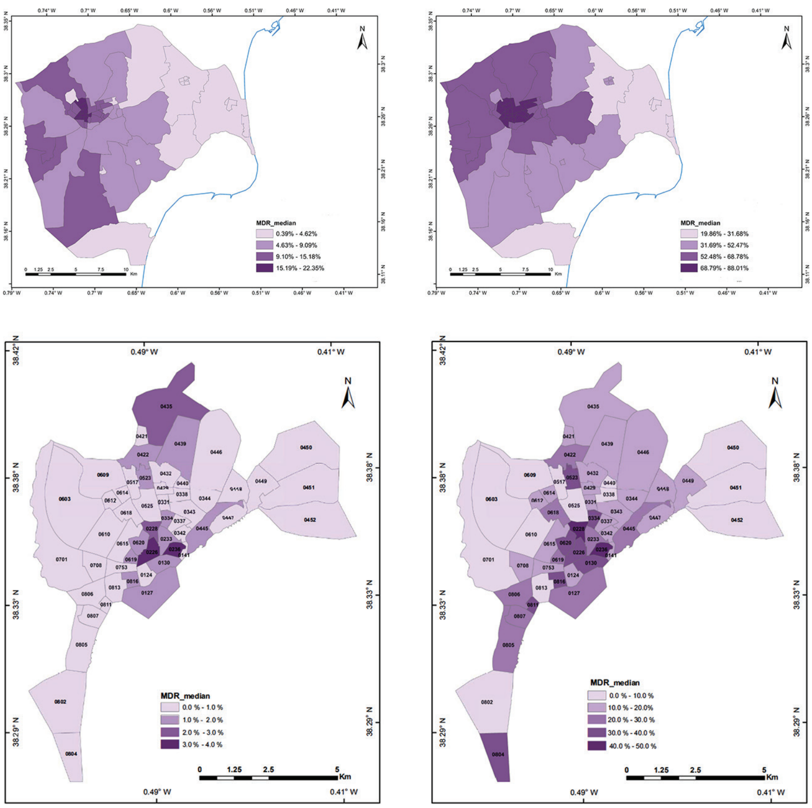

Figure 7: Impact of the magnitude 5.5 and 6.5 (Crevillente Fault) in terms of Mean Damage Ratio in Elche (a,b) and Alicante (c,d).

As a summary, it has been found that 13% of the building stock in Elche and 0.7% in Alicante would be inhabitable after a Mw 5.5 earthquake (74% in Elche and 18% in Alicante for a Mw 6.5). The homeless will range from 0.4% in Alicante to 17% in Elche for a Mw 5.5 and 8% to 82% for a Mw 6.5. The people injured (from slight injuries to even death) also range from 0.03% in Alicante to a 0.8% in Elche for a Mw 5.5 and from 1.7% to a 7% for a Mw 6.5. The economic losses will increase from 0.6% of the constructed value in Alicante for a Mw 5.5% to 45% of the constructed value in Elche for a Mw 6.5. Table 3 summarized these results in terms of absolute values.

Figure 7 represents the mean damage ratio (MDR in percentage) in each of the geounits corresponding to both municipalities. Figures 7a and 7b show the impact for the magnitude 5.5 (a) and 6.5 (b) so it can be seen that some districts of the urban area are widely affected in both cases although the damage ratio is obviously higher for a magnitude 6.5 (MDR of 68% to 88 %) than for a magnitude 5.5 (MDR of 15% to 22%).

Regarding the municipality of Alicante (Figure 7c,d) the same behavior is observed although the MDR distribution is quite heterogeneous due to the soil effect and vulnerability distribution in the municipality. For both magnitudes, the old urban area has the highest MDR ranging from 3% to 4% for the Mw 5.5 to 40%–50% for the Mw 6.5.

4 CONCLUSIONS

From the previous results, it is observed that even the Mw 5.5, which causes important damages in the municipality of Elche, affects also the municipality of Alicante. Therefore, the seismic emergency planning for each municipality has to be done in close cooperation because any damaging earthquake will affect both municipalities at the same time. This will obviously affect the number of available hospitals to send the injured people, the places to settle the homeless, and so on.

The oldest districts of the city with buildings constructed without any seismic regulations will be the most affected additionally soil effects has also an important effect on the damage distribution.

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