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Seismic losses scenario for the municipality of Murcia

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Abstract

South and South-East of Spain are the regions with a higher seismic hazard in Spain. Therefore, the region of Murcia has been seriously affected by historical damaging earthquakes in the last 500 years. Recently, three significant events have taken place in a period of just 6 years –1999, Mula (mbLg=4.8, IEMS=VI); 2002, Bullas (mbLg=5.0, IEMS=V); and 2005, La Paca (mbLg=4.7, IEMS=VI–VII) –producing wide spread damage within the villages of La Paca and Zarcilla de Ramos and a very important social concern. Very recently, the 2011 Lorca earthquake on 11 May 2011 (Mw5.2) killed nine people, injured 300, and produced important damage in the city of Lorca. Additionally, site effects have been demonstrated as a key factor in many of the damaging situations in our country, as for example the 1829 Torrevieja earthquake and even the 2011 Lorca earthquake. Present seismicity is moderate-low with the largest magnitudes slightly over Mw5.0.

Consequently, the municipality can be affected by moderate to destructive earthquakes, so this paper provides an initial assessment of the potential impact and the consequences (in terms of structural damage, economic and human losses) if damaging earthquakes hit the region again. The study takes into account an updated of the seismic hazards maps of the region which has have been used after disaggregation to identify several seismic scenarios. Then a detailed microzonation allowed us to characterize the shear-wave velocity (Vs30) and predominant periods in the municipality of Murcia. On the other hand, the residential buildings in the municipality were classified in model building types according to their vulnerability (main structural materials, height of the buildings, seismic normative) using capacity and fragility curves [1]. The results point out that buildings damage is mainly concentrated in the soft soils areas of the city and that the non-engineered buildings, especially the oldest ones, have the highest vulnerability, and therefore, the structural damage is higher, while seismically designed structures present show a better behavior showing less damage. There is also an increase of the damage results when the vulnerability of the buildings is corrected through modifiers that take into consideration the state of conservation, number of stories, irregularities in plant, location, slope of the terrain and short columns effect.

Keywords: seismic risk, vulnerability, capacity and fragility curves, SELENA, microzonation, site effects.

1. Introduction

Murcia region is located in southeast Spain. This area belongs to the eastern part of the Betic region, an Alpine chain placed at the western most part of the Eurasian and African Plates interaction zone [2]. It is one of the most hazardous seismic area of Spain, with active faults that can frequently generate small to moderate magnitude earthquakes (generally smaller than 5.5). The Betic region is characterized by frequent earthquakes of small and moderate magnitude with moment magnitude (Mw) generally smaller than 5.5. However, most of the largest and destructive historical earthquakes occurred during the last six centuries in Spain took place in this region [3]. Among them, there were some with epicentral macro- seismic intensity $I_0 \geq$ VIII (EMS-98 scale) (European Macroseismic Scale 1998), as those of 1518 (Vera), 1522 (Almeria), 1531 (Baza), 1658 (Almeria), 1674 (Lorca), 1804 (Adra), and 1829 (Torrevieja) [3].

All these damaging earthquakes are located along the strike-slip Alhama de Murcia Fault System, which has been active during the Late Miocene and the Quaternary [4], [5]. Currently, the low-to-moderate seismic activity observed in Spain leads to a relative scarcity of sufficiently strong events for providing empirical data that can be used to constraint and reproduce local earthquake scenarios. For example, only two earthquakes with intensity VII or higher have been recorded in Spain in the past 30 years; the first one occurred in La Paca, Murcia on 29th January, 2005 [6] and the second one occurred in Lorca, Murcia on 11th May, 2011.The new seismic hazard map of the Spanish National Geographic Institute [7] shows that the region of Murcia has areas with expected peak ground acceleration (PGA) on rock greater than 0.2 g for a 475-year return period, reaching 0.23 g in Murcia city. The development of seismic risk assessment studies in the municipality of Murcia has been fomented after the events occurred in the region, such as the 1999 earthquake in Mula (Mw=4.7), 2002 in Bullas (Mw=5.0), 2005 in La Paca (Mw=4.8) or the destructive Lorca earthquake occurred in 2011 (Mw= 5.2) with catastrophic consequences in Lorca town despite being a relatively small event.

2. Local Geology and Seismic Microzonation

The regional geological framework of Murcia city corresponds to the Betic Cordillera, a set of mountain ranges originated during the alpine cycle that extends in the South of the Iberian Peninsula. From a local perspective, the city is framed in the Bajo Segura River basin, part of a tectonic accident of NE-SW tend responsible for the development of the set of Quaternary deposits distribution. This basin is inscribed in an intramontane environment of tectonic subsidence which limit coincides with important fault lines: Bajo Segura, Alhama de Murcia, Palomares and Carrascoy fault systems.

The Vega del Segura area, and especially the south bank of the river in the city of Murcia, is formed by geotechnical category V soil (Fig.1). This type of ground is mainly composed of temporarily saturated soils, such as recent soft alluvial and normally poorly consolidated (clays, silt and sand) and alluvial plain deposits. This area is especially problematic, from a seismic response point of view, due not only to the effects of amplification, which can be very high, but also to the possible development of the phenomena associated with liquefaction due to the generally shallow position of the surface of the water table.

The surface structure of the ground in the metropolitan area of Murcia has been determined from the combination of the results obtained with the Mini-array method [9] and the MASW method [10].

The metropolitan area of Murcia shows a very heterogeneous distribution of Vs30 values with Vs30 values growing from south to north, and between 244 m /s and 773 m /s (Fig. 2). The southern margin of the Segura river, composed of alluvial deposits of the Quaternary, shows an average value of Vs30 is 283 ± 29 m / s. The northern zone has the highest values due to the presence of conglomerates characterized by an average value of Vs30 of 588 ± 12 m / s.

Then, the obtained results has allowed to propose a soil class zonation according to Eurocode 8 [6] (Fig. 3) which will be used to amplify the ground motion when computing the damage and losses scenarios.

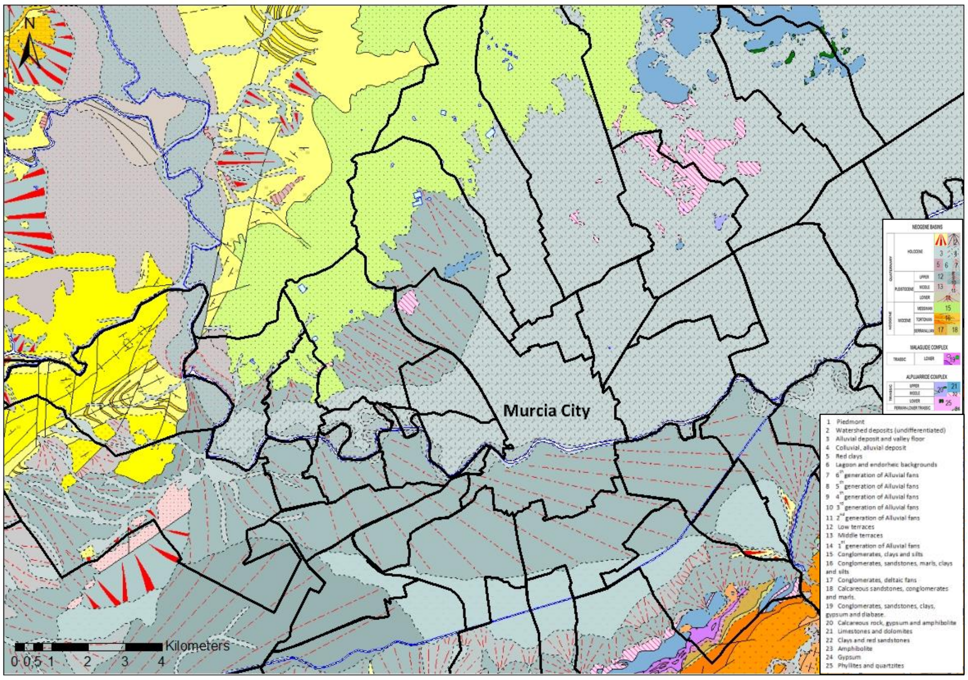

Fig. 1 - Geological map of Murcia city at scale 1:50.000 (taken from [8])

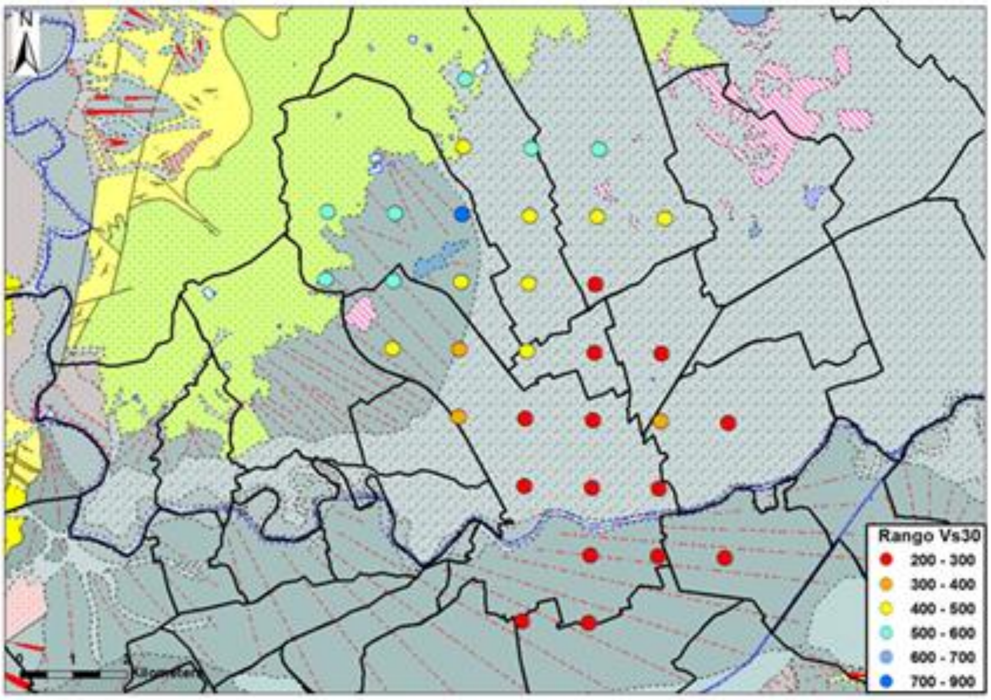

Fig. 2 - Vs30 values distribution map in Murcia city from Mini-Array

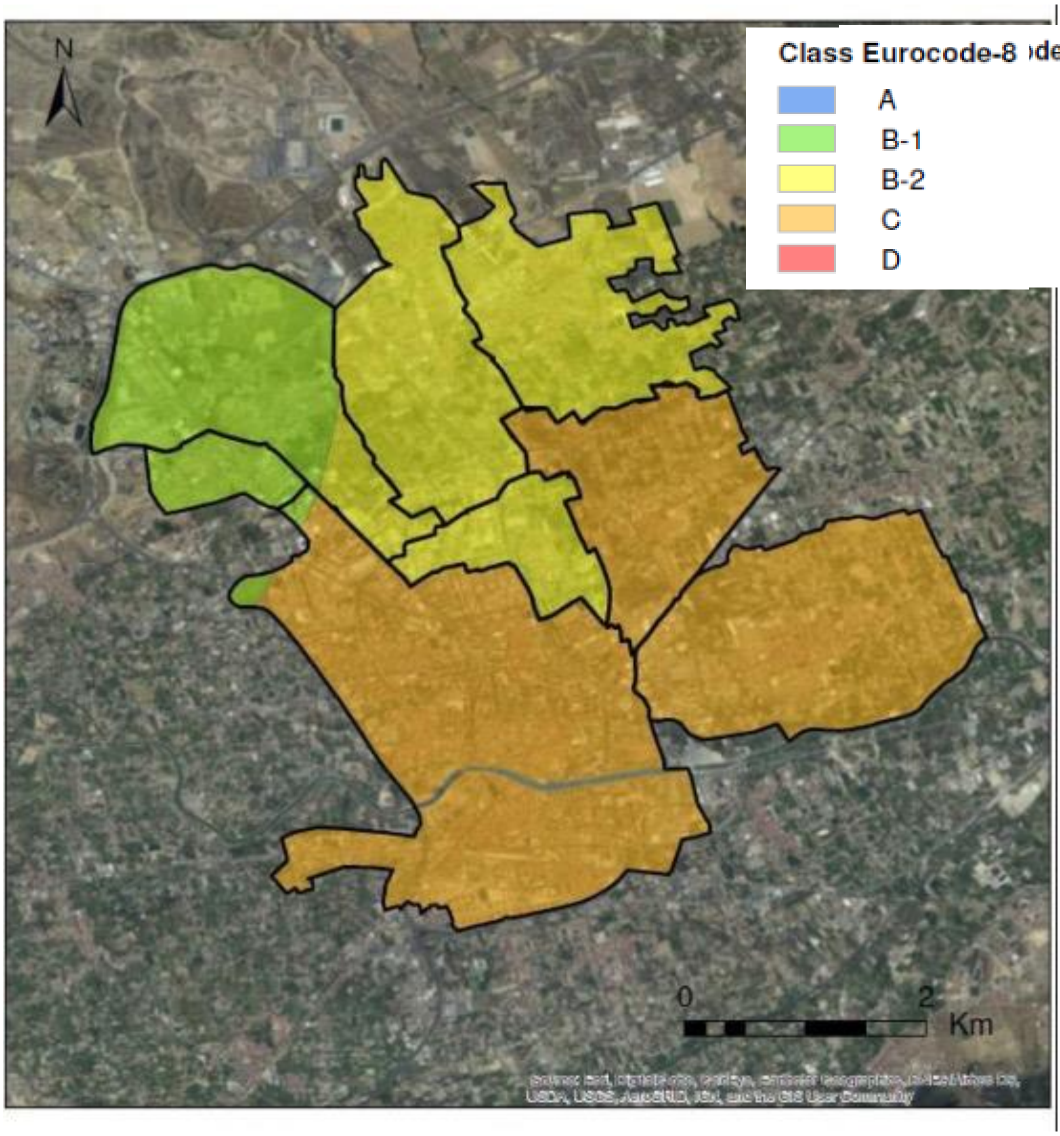

Fig. 3 - Soil class zonation proposed according to EC8

As we can see, Vs30 decrease gradually from NW to SE in the city area. The lowest Vs30 values are concentrated around Segura river. Conglomerate materials show the highest Vs30 values (588±7 m/s), while alluvial fan deposits located in the south of the city present the lowest Vs30 values (274±20 m/s). Vs30 values along the Carrascoy fault are relatively high (530 – 817 m/s), changing even in small distances. 2D S-wave velocity cross-sections obtained from MASW profiles confirm the heterogeneity of the ground. Ground predominant period distribution map shows high heterogeneity of the ground, even on the same geological formation. The obtained predominant period values using the H/V measurements indicate that the ground periods range from 0.1 s to 0.9 s.

3. Seismic and ground motion scenarios

A detailed seismic hazard analysis has been carried out in the city. Therefore, ground motion including site effects has been computed for return periods of 475 and 975 years. Then, after disaggregation of seismic hazard (Fig.4), we have identified the seismic scenarios which contribute mostly for both return periods. Furthermore, a Mw 5.5 at a distance of 10 to 20 km from the urban area of Murcia has been related to the return period of 475 years and a Mw 6.5 at a similar distance is related to the return period of 975 years. Using the active faults database [11], three earthquakes scenarios related to its specific fault (Fig. 5) were chosen in order to carry out the earthquake losses scenarios (Table 1).

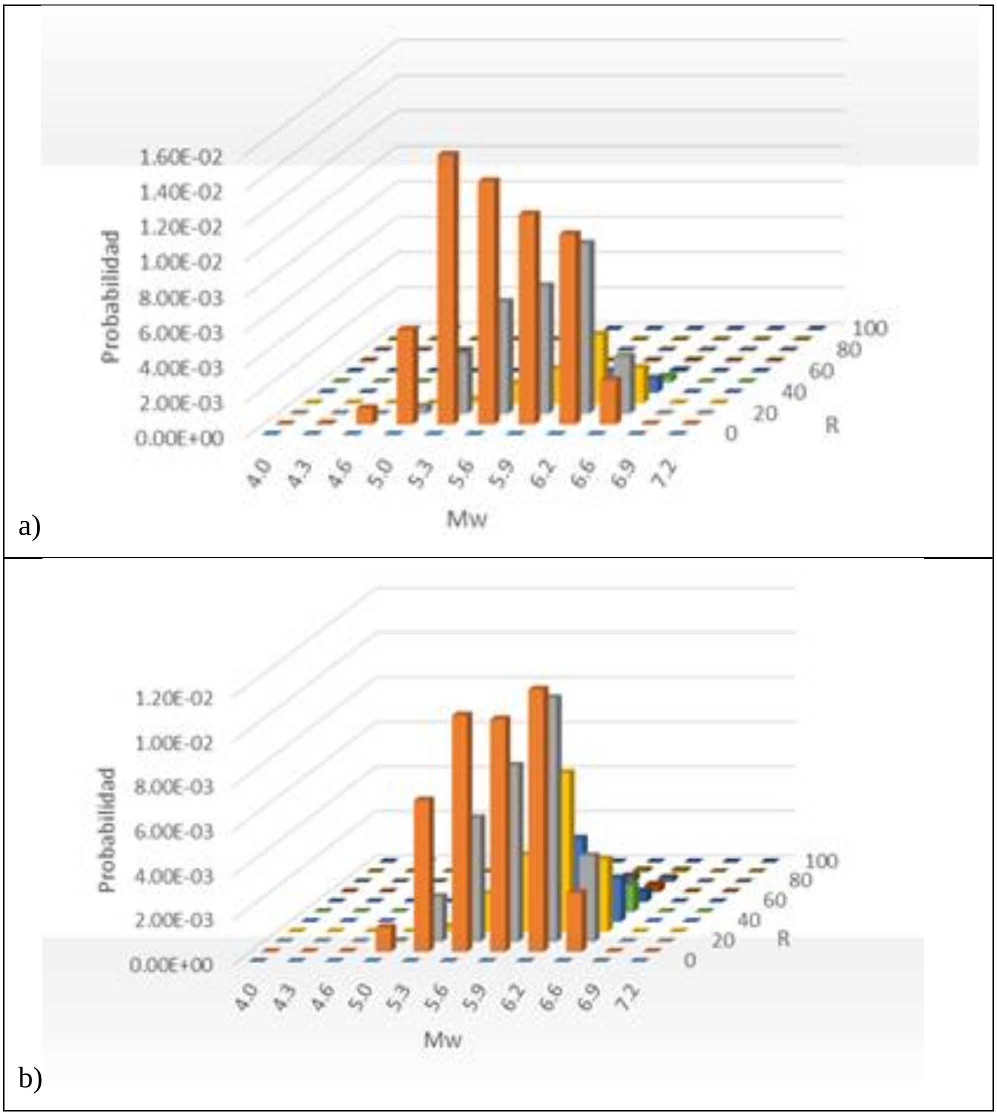

Fig.4- Seismic disaggregation for a return period of: a) 475 year and b) 975 years.

Table 1. Seismic scenarios used to compute damage and losses in the studied area.

Name	Type	RP	Mw	R (km)	Fault
E1	Probable Earthquake	475	5.5	10-20	Alhama de Murcia (segment Alhama-Alcantarilla)
E2	Probable Earthquake	475	5.5	10-20	Carrascoy (segment Southeast, Algezares- Casas)
E3	Maximum Earthquake	975	6.5	10-20	Carrascoy (segment southeast, Algezares-Casas Nuevas)

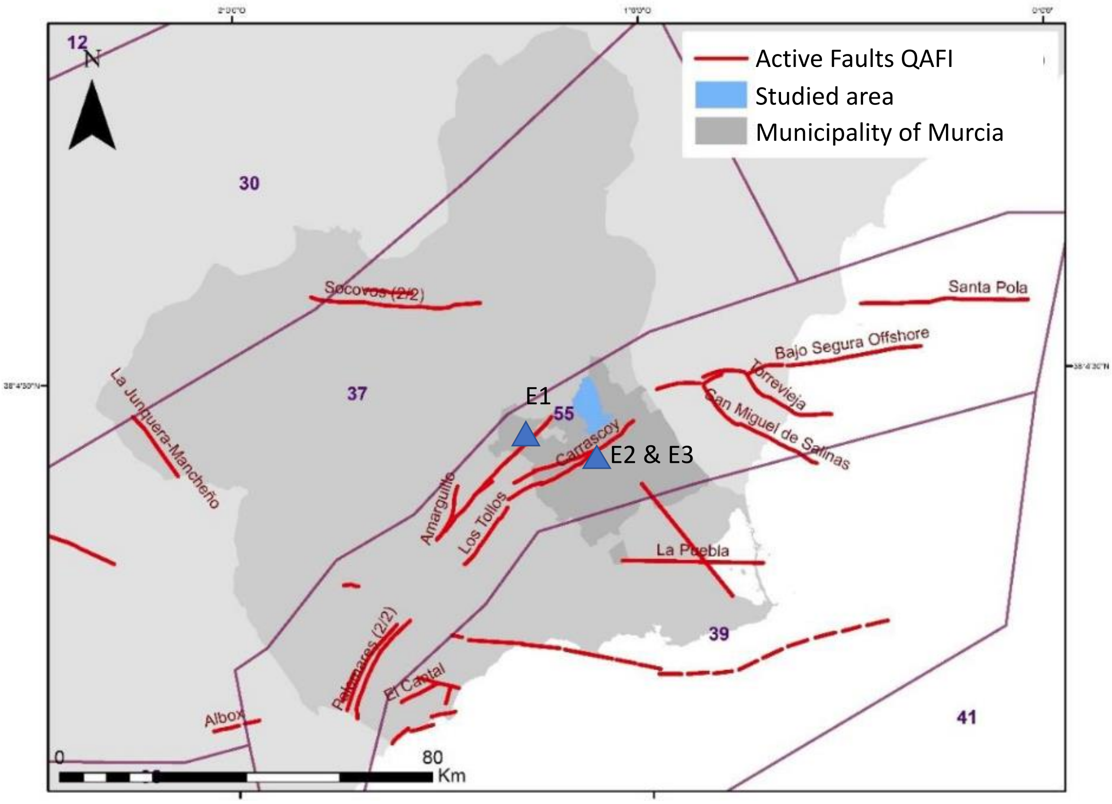

Fig. 5 - Geographical location of the seismic scenarios and corresponding active faults

4. Vulnerability and Exposure

The building and exposure database was compiled using the databases from the National Statistic Institute which provides social information and the General Directorate of the Cadastre which provides information about the number of buildings classified by age of construction, number of stories and condition, according to the INSPIRE directive.

Therefore, after the compilation of the database, the urban area of Murcia has 18007 residential buildings and 108400 dwellings. Fig.6 shows the distribution of residential buildings and dwellings. The current building stock has been classified according to the main structural components (masonry / reinforced concrete), the height of the building (low, mid and high rise) and the year of construction (no code, pre-code and low code). Fig. 7 represents the distribution of typologies in the studied area and Table 2 summarize the description and vulnerability according to [1].

Table 2. Description of the building typologies and their vulnerability according to [1].

Tipologies	Vulnerabilty EMS-98	Vulnerability Index (V)	Vulnerability function
M11: Rumble Stone L (1 to 2 stories) and M (3 to 5 stories)	A	0.77 0.85	M1.w_L M1.w_M
M31: Unreinforced masonry with wooden floors L (1 to 2 stories) and M (3 to 5 stories)	B	0.62 0.70 0.78	M5.w_L M5.w_M M5.w_H
M34: Unreinforced masonry with concrete floors L (1 to 3 stories) and M (4 to 7 stories) and H (>7 stories)	C	0.57 0.65 0.73	M6_L-PC M6_M-PC M6_H-PC
RC31-pre: Reinforced concrete with masonry walls and no code L (1 to 3 stories) and M (4 to 7 stories) and H (>7 stories)	C	0.57 0.59 0.63	RC3L-pre RC3M-pre RC3H-pre
RC31-low –DCL: Reinforced concrete with masonry walls, low seismic code and low ductility L (1 to 3 stories) and M (4 to 7 stories) and H (>7 stories)	D	0.61 0.59 0.59	RC3L-III-DCL RC3M-III-DCL RC3H-III-DCL
RC31-low-DCM: Reinforced concrete with masonry walls, low seismic code and moderate ductility L (1 to 3 stories) and M (4 to 7 stories) and H (>7 stories)	D	0.47 0.49 0.51	RC3L-III-DCM RC3M-III-DCM RC3H-III-DCM

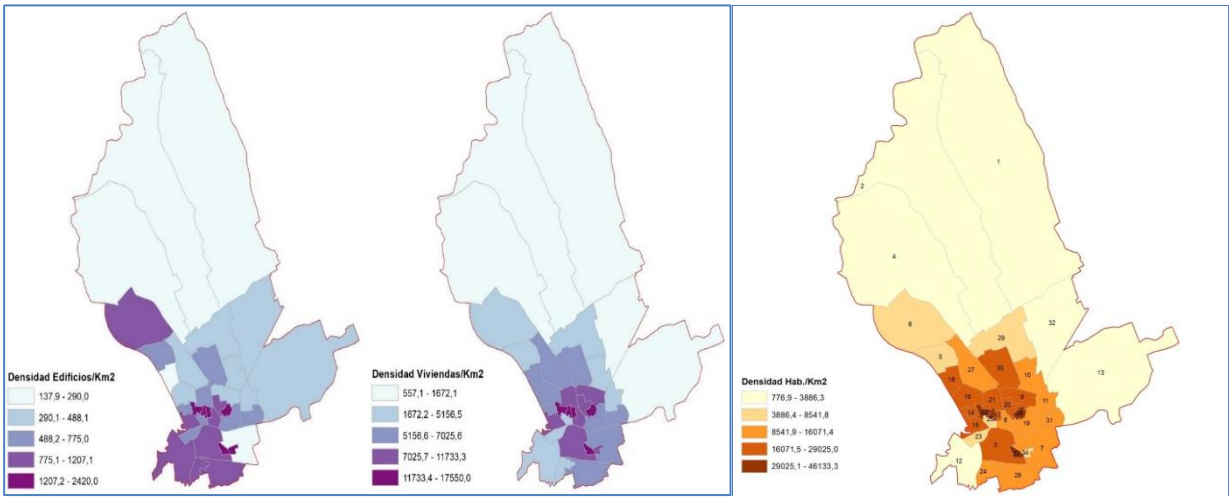

Fig. 6- Geographical distribution of buildings, dwellings and population expressed as density.

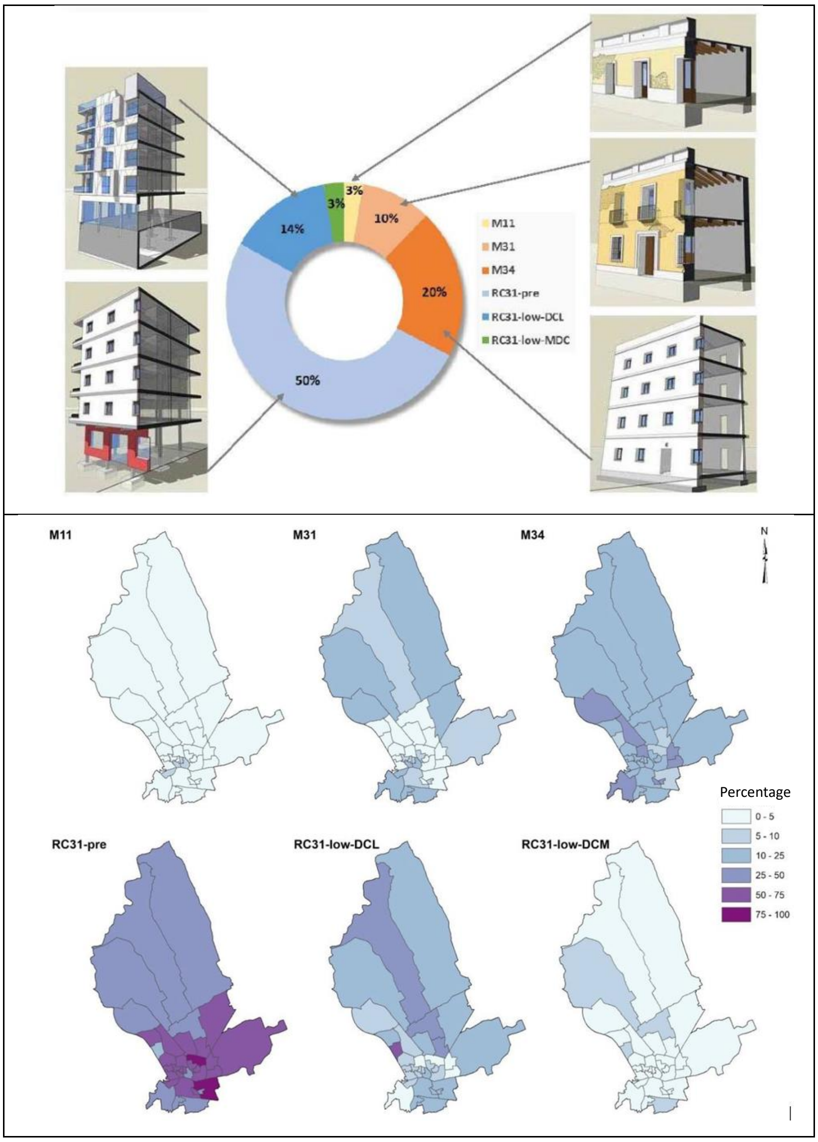

Fig. 7- Building typologies for the studied area

Additionally, the vulnerability index provided in Table 2 can be fine-tuned using modifiers [13]: regional (using the year of construction) and urban behavior (location of the building in the block, number of stories, irregularity in height and floor). Therefore, we have applied those modifiers and Fig. 8 shows a comparison between the vulnerability index before and after using the modifiers. As we can see, most of the buildings have now vulnerability index values higher than 0.7, that is, similar to vulnerability of masonry buildings. Furthermore, the vulnerability increase in the most of the districts after using the urban modifiers, pointing out the importance of taking them into consideration in any seismic risk analysis.

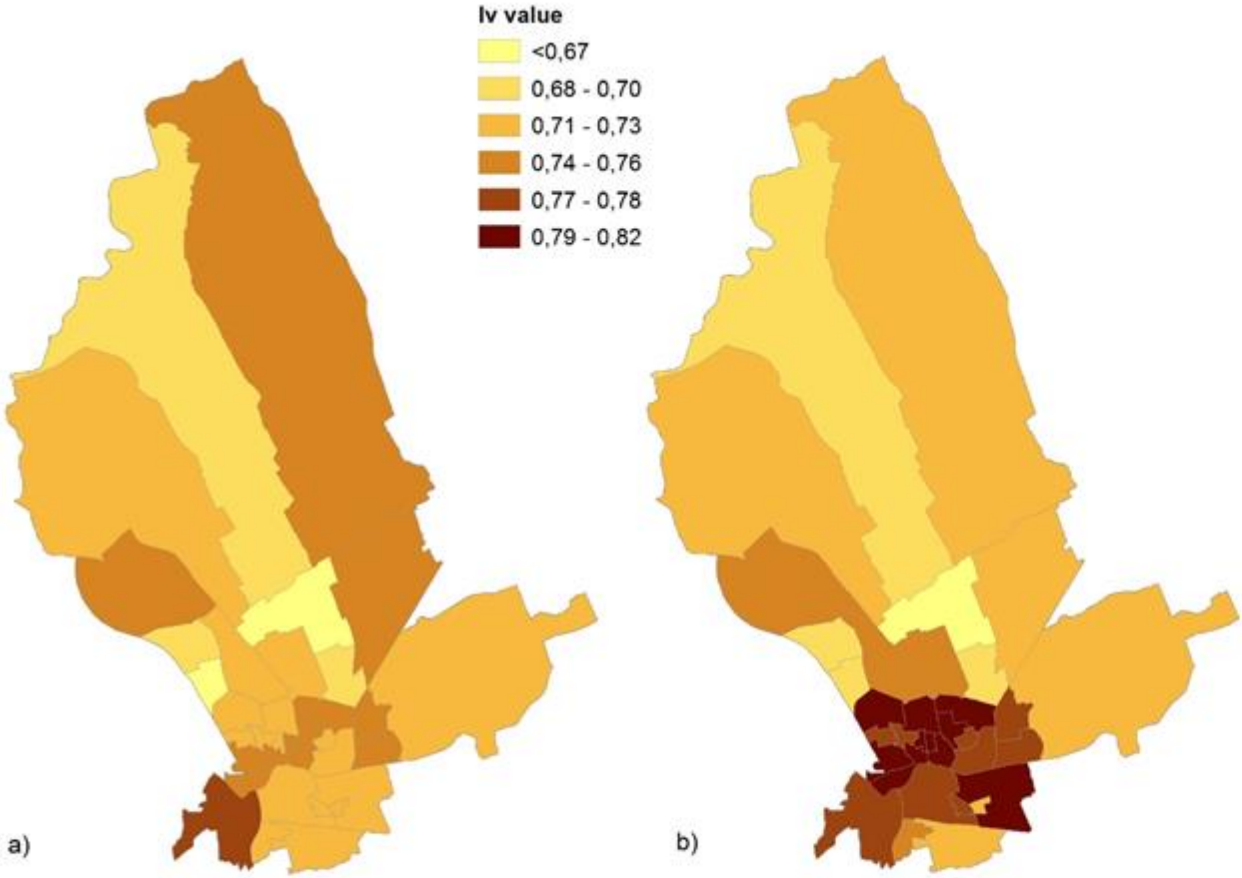

Fig. 8 - Comparison of the vulnerability index in the studied area: a) before and b) after including regional and urban modifiers

5. Damage and Losses results

The damage and losses have been computed using the software SELENA [14]. Taking into consideration the large difference in vulnerability when using vulnerability modifiers, the damage has been computed weighting the results 80% without modifiers and 20% with modifiers. Fig. 9 summarize the main results in terms of mean damage and human losses.

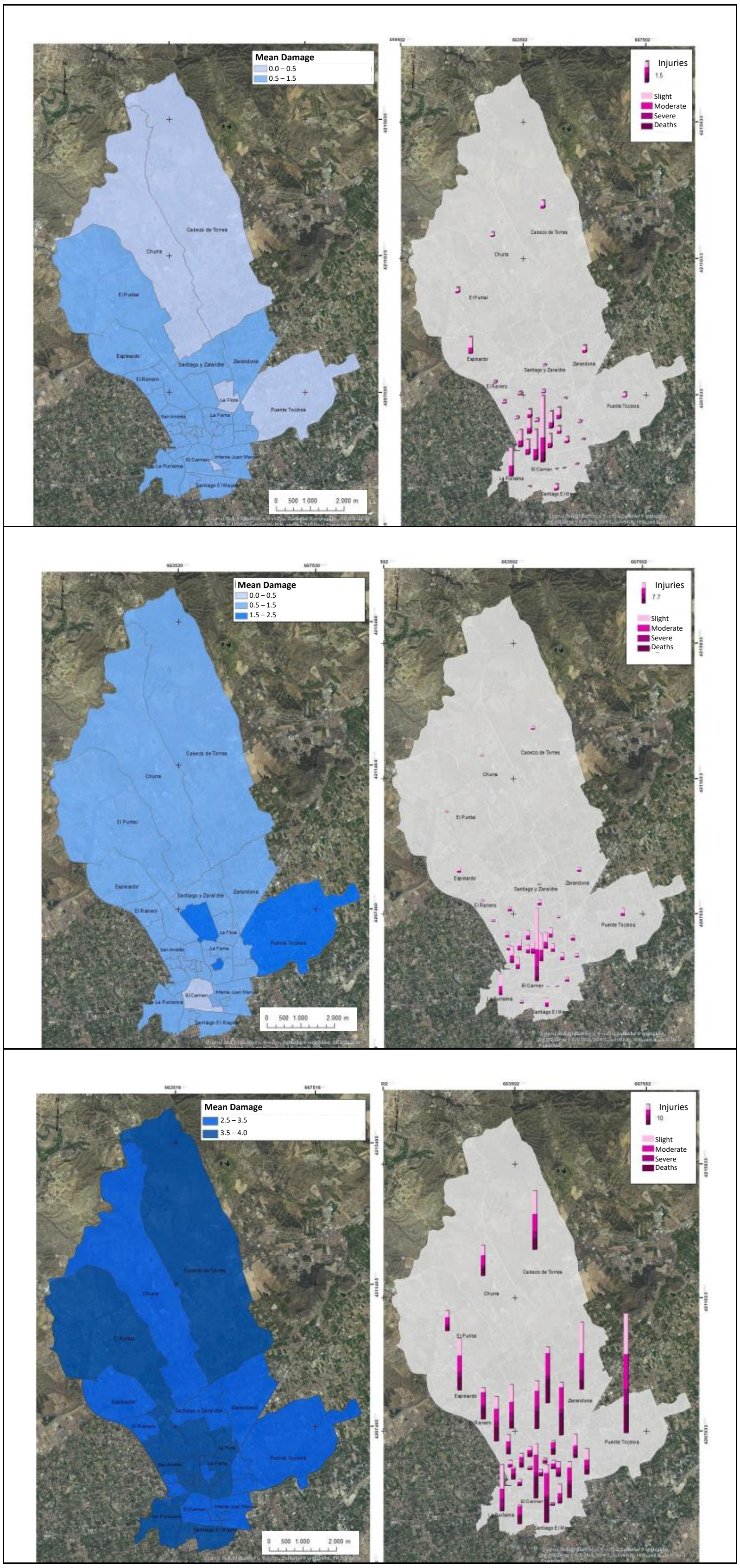

Fig. 9 - Mean damage and human losses for scenario E1(top), E2 (middle) and (E3) bottom.

5. Conclusions

We have computed earthquake damage and losses scenarios for three different earthquake scenarios for the municipality of Murcia. From the obtained results, we can conclude:

a) The surface ground of Murcia city is composed mainly by Quaternary alluvial deposits with different sediment thicknesses. The Vs30 distribution shows a gradually decrease from NW to SE in the city area. Lowest Vs30 values are concentrated around Segura river. Conglomerate materials show highest Vs30 values (588±7 m/s), while alluvial fan deposits located in the south of the city present lowest Vs30 values (274±20 m/s). Ground predominant period on the city shows high heterogeneity of the ground, even on the same geological formation. The predominant period values range from 0.1 s to 0.9 s.

b) The seismic hazard in the area including site effects ranges from 0.20 to 0.24 g for a 475 yr return period and 0.26 to 0.34 g for a 975 yr period. The disaggregation indicates that the seismic scenarios related with the hazard are close (10-20 km) and with magnitudes from 5.5 to 6.5.

c) The vulnerability in the city is high mainly in the historical center where the main typologies are masonry buildings. Besides, if we include vulnerability modifiers, the vulnerability also increases in many reinforced concrete buildings which can be assigned a vulnerability index similar to masonry.

d) The lowest damage is obtained for the E1 scenario (Mw 5.5 in the Alhama de Murcia fault). Only a 2% of complete damage and 5%-6% of extensive damage is found in the historical center. The damage increase for the E2 scenario (Mw 5.5 in the Carrascoy fault) with 8% to 9% of complete damage in the historical center. Finally, the highest damage is found for the scenario E3 (Mw 6.5 in the Carrascoy fault) with a 63% of complete damage.

Finally, this study will be very valuable for the public authorities of the city and civil protection being the starting point for a detailed emergency planning for a future earthquake affecting the city.

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