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PRELIMINARY SEISMIC RISK SCENARIOS FOR MALAGA, SPAIN

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ABSTRACT

A preliminary seismic risk assessment is presented for the city of Malaga, one of the most important and populated cities of the southern coast of Spain. This seismic scenario is based on the seismic hazard assigned to the city by the Spanish seismic code in terms of intensity for a return period of 500 years. Soil effects in terms of intensity are evaluated using Arias Intensity computed from the ground motion obtained by a 1-D numerical method applied in different soil conditions. Damage scenarios are obtained using damage probability matrices developed for a similar region. Results indicate that a scenario with an intensity VII-VIII at rock sites can cause over 20,000 wounded persons, and more than 90,000 homeless.

Introduction

The city of Malaga, located on the south coast of Spain as shown in Fig. 1, is affected by one of the higher seismic hazard levels expected within the country. Being the capital of the Malaga province within the Andalusia region, this city is an important tourism, cultural and economical center that has experienced a population explosion in the last decades. In the past the city has been affected by strong earthquakes causing severe damages. This seismic hazard in combination to the actual population concentration and the seismic vulnerability of its building stock provide the city of Malaga with a potentially high risk of suffering severe damages is affected by strong earthquakes like those of the past.

A preliminary study of seismic microzonation is being conducted including microseismic measurements at selected sites, in order to obtain the fundamental frequency of soils. A geotechnical classification of soils was performed to evaluate transfer functions using numerical methods for characterizing the soil response that will be considered in the vulnerability analysis.

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Figure 1. Location of the municipality of Malaga.

This paper presents the preliminary results of one of the two vulnerability assessment approaches that are being applied to the city of Malaga. The results presented here correspond to the first method based on the classification of the building stock of Malaga's districts according to the EMS-98 vulnerability classes and estimates damages using the damage probability matrices in terms of intensity. The second approach classifies the vulnerability and estimate damages by implementing the vulnerability index method using the structural typologies distribution within the city.

Seismic Hazard Affecting Malaga

The seismicity of the Iberian Peninsula (Iberia) is characterized by the occurrence of earthquakes of moderate magnitude, generally lower than 5.0. The majority of the earthquakes have a shallow depth ($h<40$ km) but also intermediate ($40<h<150$ km) and deep ($h\approx650$ km) earthquakes have occurred (Buforn et al. 1995). It is known, from previous studies on historical seismicity, that the Iberian Peninsula has suffered strong earthquakes, with a maximum intensity of X degrees, like the Lisboa (1755), Torrevieja (1829) and Arenas del Rey (1884) earthquakes.

The Malaga region, located south of the Iberian Peninsula, presents a complex seismicity with the occurrence of both superficial and intermediate depth earthquakes as shown in Fig. 2. In 1494 and 1581, the city of Malaga was affected by two earthquakes with maximum intensities of VIII and VII, respectively, which caused important damages. Especially destructive was the earthquake of 1680 (Io=IX) that caused severe damages in the city of Malaga and its surroundings. Muñoz and Udías (1988) assigned a depth of 50 km to the 1680 earthquake, based on a map of isoseismal lines, and a 6.5 magnitude. Recently in 2002, two 4.3 magnitude earthquakes with depths of 70 y 90 km were felt in the city of Malaga, being recorded in the accelerometers the Instituto Geográfico Nacional has there. In order to perform a realistic seismic risk evaluation for this zone both superficial and intermediate depth destructive earthquakes should be considered.

According to the Spanish Seismic Code (NCSE-02), the seismic hazard for Malaga with a return period of 500 years implies a Peak Ground Acceleration (PGA) of 0.11g corresponding to an intensity of VII-VIII degrees (Direccion General de Protección Civil 1997). Because of its seismic hazard level, one of the goals of the ERSE (Realistic Scenarios of Seismic Risk in Spain) project is performing seismic risk scenarios for the Malaga city.

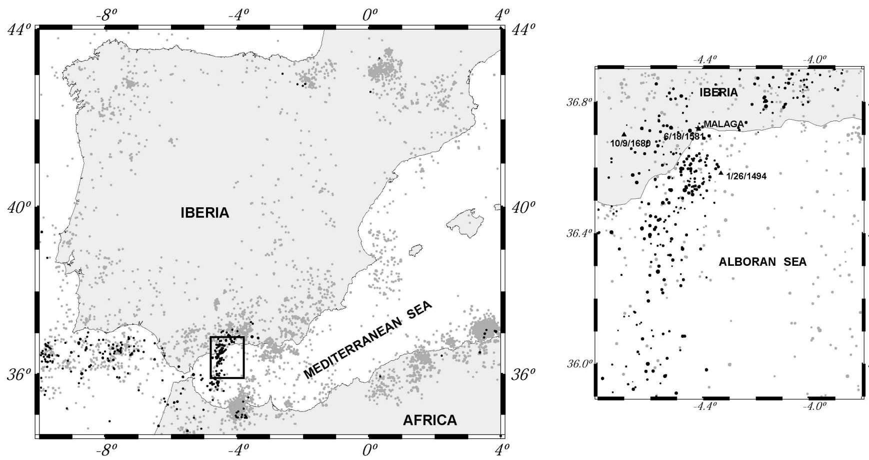


Figure 2. The left map shows the Iberian Peninsula seismicity for the 1980-2004 period and magnitudes greater or equal to 3.0. The right map shows the seismicity affecting the city of Malaga for the same period and all magnitudes. Light gray indicates superficial earthquakes (h<40 km), dark gray shows those with intermediate depth (40 km<h<150 km), and black refers to deepest earthquakes (h≈650 km).

Soil Effects for the City of Malaga

The eastern and northwest parts of the city show outcrops of Paleozoic materials belonging to the "Malaguide" complex (Betic Chain). Underlying most of the cities, quaternary materials are found along the coast, in the rivers margins, mainly at the Guadalhorce y Guadalmedina and post tectonics Pliocene materials are disposed between the quaternary and the Paleozoic outcrops. For the soil effects study, the Malaga geotechnical database, the map of the seismic microzonation of the city of Malaga based on coefficient C and the H/V ratio calculated for microtremors measurements has been considered.

Depending on the ground geotechnical characteristics, the C coefficient is defined by the NCSE-02 to consider a soil's amplification coefficient for obtaining the design seismic acceleration. The C coefficient is obtained performing a weighted average in the 30 first meters of ground, and ranges between 1 for compact rock (Vs>750m/s) and 2 for soft soils (Vs<200 m/s). The seismic microzonation map for the city of Malaga based on the C coefficient (Clavero 2005) consists of four zones as shown in Fig. 3.

In June of 2005, microtremor measurements were carried out in 74 different locations in the city. Nakamura's method (Nakamura 1989) is applied to obtain the soil's fundamental frequency in these locations. The obtained results allow us to characterize the three soft soil classes in Fig. 3 with the following fundamental frequencies: 1 Hz for soil classes 2 and 3, and 0.4 Hz for soil class 4. The obtained values show some variations that could lead to consider several more smaller zones in a future more detailed study.

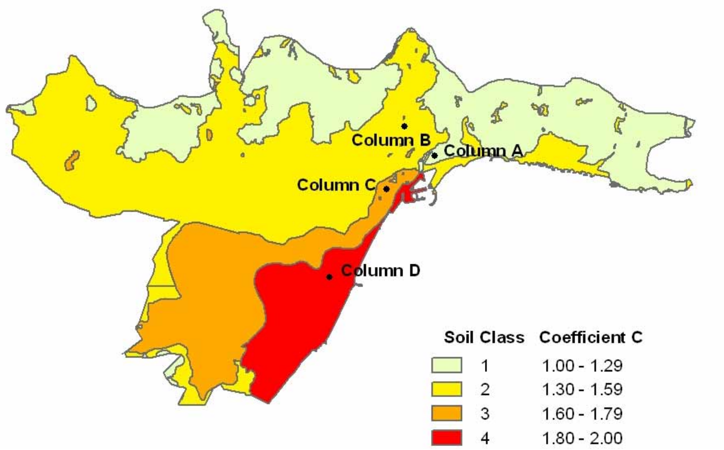


Figure 3: Seismic microzonation map for the city of Malaga; four soil classes are defined for the different values of the C coefficient. The position of soil columns is also shown.

1-D method (Shake) was used to obtain the transfer function and the ground motion for all the defined soil classes shown on Fig. 3. A characteristic soil column was defined for each zone from geotechnical data of Malaga provided by LIDYCCE (Laboratorio del Instituto de Investigación, Desarrollo y Control de Calidad de Edificación). This database contains information of about 400 drills.

As input motion at rock one acceleration record was selected from the European Strong Motion Database (Ambraseys et. al. 2000) whose spectral content is similar to the response spectrum defined by NCSE-02. This acceleration record is scaled to a PGA of 0.11g that corresponds to the PGA value proposed in the NCSE-02 for Malaga. The two computed transfer functions with the fundamental frequencies previously obtained from Nakamura's method are shown in the Fig. 4 for column C (soil class 3) and column D (soil class 4).

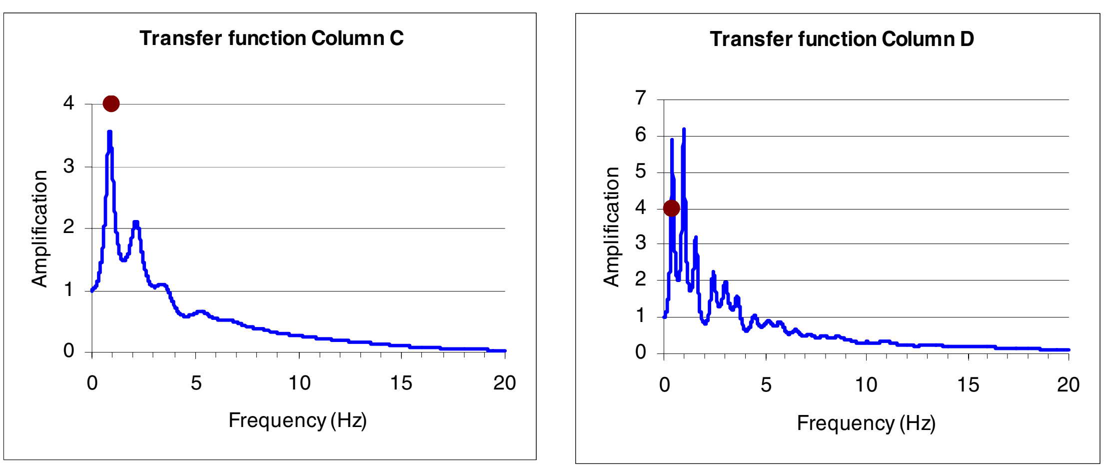


Figure 4: Transfer functions for columns C (soil class 3) and D (soil class 4) together with fundamental frequencies (big dot) obtained by Nakamura's method in sites located near the drillings.

The PGA and Arias Intensity (AI) values of the different synthetic acceleration records obtained for the soil columns have been calculated. Their values are shown in Table 1. Soil classes 2 and 3, characterized by soft thin soils, show a similar amplification for PGA an AI. It was observed that soil class 4 has a higher amplification for AI than for PGA. This observation can be due to the presence of a deep basement (fundamental frequency of 0.4Hz) that produces a longer acceleration records and in consequence a higher AI. So, Arias Intensity seems to be more representative of the whole soil response than PGA.

Arias Intensity and macroseismic intensity can be related from empirical observations, as for example the relation proposed by Cabañas et al. (1997) for the Mediterranean area. In this way, the intensity increment (ΔI_i) representative of each soil class can be obtained, using Eq. 1, from the soil to rock ratio of the Arias Intensity (AI_i/AI_R). The macroseismic intensity increment obtained for each soil class is shown in Table 1. These values will be used to increase the intensity value proposed for a reference soil for the city of Malaga.

$$\Delta I_i = 0.66*Ln(AI_i/AI_R) \quad (1)$$

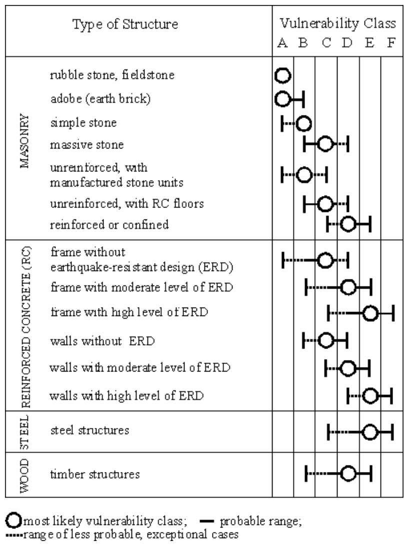
Table 1: PGA and AI values computed for each soil class together with the adopted values of macroseismic intensity increment.

Soil Class	PGA(g)	AI (cm/s)	ΔI MSK
1	0.11	19.4	+0.0
2	0.14	36.7	+0.5
3	0.14	38.9	+0.5
4	0.14	63.7	+1.0

Seismic Vulnerability of Malaga

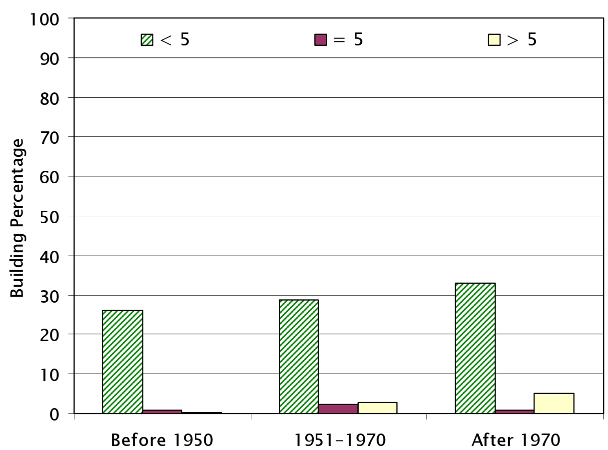
Malaga's vulnerability assessment is based on the classification of the building stock of the municipality according to the EMS-98 (Grünthal 1998) vulnerability classes using the methodology developed by Chávez (1998) and exposed by Roca et al. (2005). Fig. 5 shows the vulnerability classes assigned by the EMS-98 to common structures of masonry, reinforced concrete, steel and wood. Chávez (1998) established the distribution of the vulnerability classes according to the age, height and location of the building stock. To obtain the number of buildings in each vulnerability class, the age and height distribution must be known for both the urban and rural areas of the municipality. The vulnerability classes distribution by Chávez (1998), also shown in Fig. 5, was defined based on the expert judgment of architects who knew very well the construction history of the Catalonian region in Spain.

The building height and year of construction data for each district of Malaga was obtained from the National Institute of Statistics of Spain. The building distribution of Malaga according to height and year of construction periods proposed by Chavez (1998) is shown in Fig.6. As can be seen the majority of buildings have less than 5 levels; higher levels correspond to recent construction. Then, the vulnerability classes' distribution percentages are applied to obtain the vulnerability class distribution shown in Fig.6. Vulnerability classes A and D have the lower percentages, while vulnerability classes B and C present almost equal percentages.

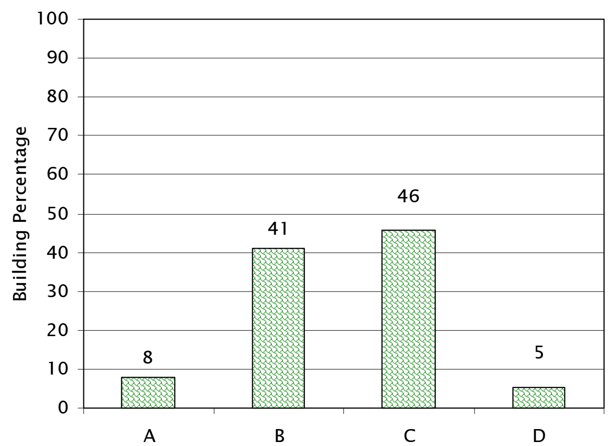


	Vulnerability Classes Percentages by Chavez (1998)					
	Until 1950		1951-1970		After 1970	
Levels	Urban	Rural	Center	Dissem	Center	Dissem
< 5	20A 80B	30A 70B	5A 50B 45C	15A 70B 15C	85C 15D	5A 20B 65C 10D
= 5	20A 80B	40A 60B	10A 60B 30C	20A 70B 10C	5A 20B 65C 10D	10A 30B 55C 5D
> 5	40A 60B	60A 40B	15A 70B 15C	30A 65B 5D	8A 27B 60C 5D	15A 45B 40C

Figure 5. EMS-98 Vulnerability Classes and its distribution according to Chávez (1998).



(a)



(b)

Figure 6. (a) Distribution of building stock according to Malaga's City Council and (b) vulnerability class distribution for the city of Malaga according to Chavez (1998).

Fig. 7 shows the vulnerability classes distribution and to population for each district in the city of Malaga. Most of the districts show low percentages of vulnerability class A. The highest vulnerability class A is shown by district 1, Malaga's historical center. The majority of the districts have important percentages of vulnerability classes B and C, except districts 9 and 10 with a low percentage of vulnerability class B and district 1 with low presence of vulnerability class C. Districts 8, 9 and 10 exhibit the larger percentages of buildings with vulnerability class D. The districts with higher percentages of the most vulnerable classes A and B, are those having high population.

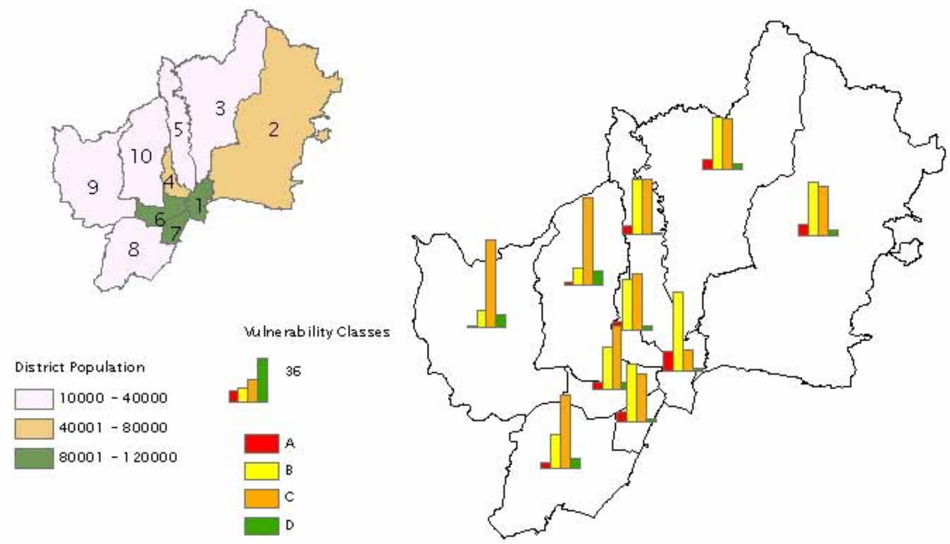
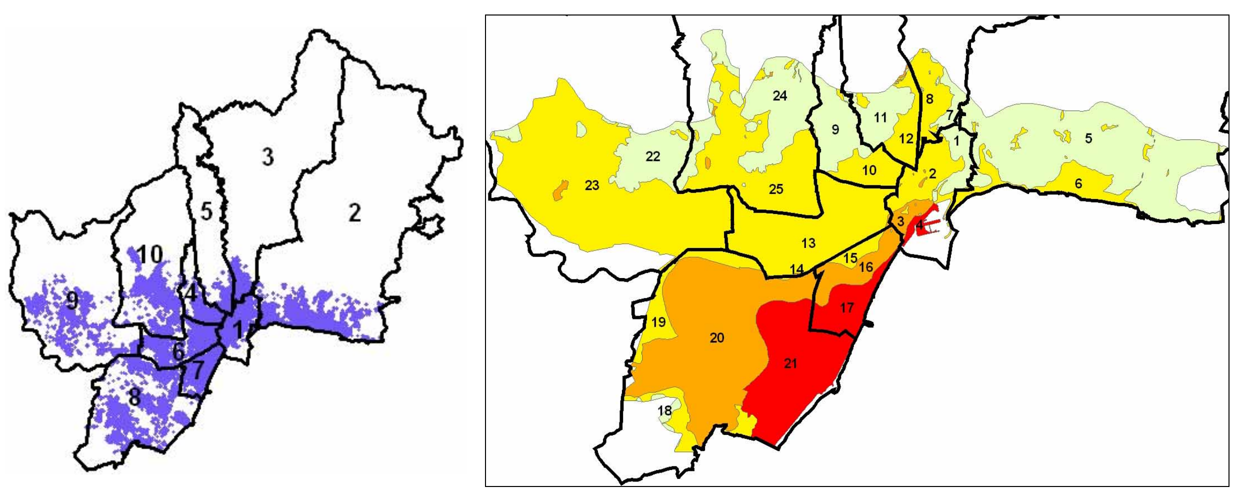


Figure 7. Vulnerability classes distribution and population for each district of Malaga city.

Seismic Scenarios for Malaga

Almost all the population of Malaga is concentrated near the coast as can be seen in part (a) of Fig. 8, so the population obtained for each district from the Malaga's City Council was concentrated over the urbanized area of the city. When the districts are superimposed over the soil zonation, a total of 25 subdivisions are created because most of the districts are affected by various soil zones. A number of buildings and population was defined for each district subdivision proportional to its area contribution within the district. Finally the intensity with soil effects was defined for each district subdivision by adding the intensity increment for each corresponding soil class to the intensity at rock of VII-VIII.



(a) (b)

Figure 8. (a) Populated zone map where numbers indicate districts and (b) district subdivisions

for Malaga.

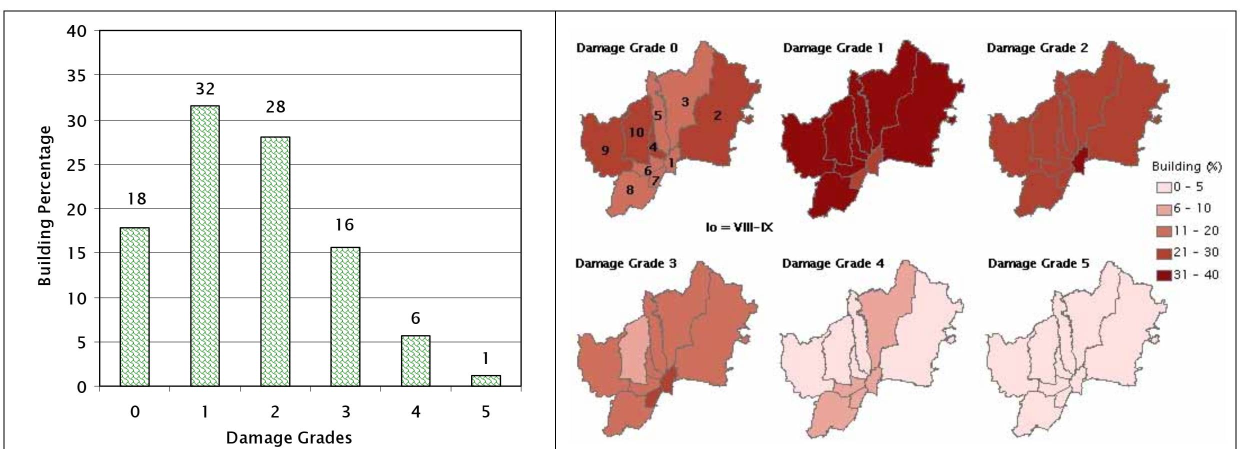
Damage distributions for each of the subdivision were obtained using the damage probability matrices, developed by Chávez (1998) for each vulnerability class, that give the ratio of buildings with different damage grades for a set of given intensities. An example of the damage probability matrix for vulnerability class C is shown in Table 2. With the damage distribution for each district subdivision, a damage distribution was obtained for each district and for the whole Malaga city.

Table 2. Damage probability matrix for vulnerability class C.

Intensity	**Damage Grades**					
	0	**1**	**2**	**3**	**4**	**5**
VII-VIII	0.325	0.388	0.211	0.064	0.011	0.001
VIII	0.209	0.384	0.283	0.104	0.019	0.001
VIII-IX	0.144	0.324	0.314	0.165	0.047	0.006

The damage distribution obtained for the city of Malaga, shown in part (a) of Fig. 9, is centered over damage degrees 1 and 2 indicating that the majority of the buildings would show slight to moderate damages. A lower but significant 7%, over 2000 buildings of the city's building stock, can suffer severe damages. Part (b) of Fig. 9 shows the distribution of damage grade by district.

The district identifying numbers are only shown for damage grade 0 to clarifying the figure. As can be seen the probability of having no damage (damage grade 0) is lower in the center and older districts, while the probability of suffering damages grade 1 and 2 is more or less evenly distributed among the districts. Districts 1 and 7 show the higher probability of suffering moderate grade 3 damages, while most of the center districts have the higher percentages of buildings having severe damages of grade 4.



(a) (b)

Figure 9. (a) Damage grade distribution for the city of Malaga and (b) distribution of the damage grade by district.

The losses estimation included the uninhabitable buildings, the number of homeless, the mortal victims and the persons slightly and severely injured for each district. The uninhabitable buildings and homeless persons were calculated as done by Chavez (1998) and are shown in Fig.10. The wounded persons and mortal victims were estimated as recommended by the ATC-13 (1985). As can be seen the higher number for all these losses estimated concentrate in the central districts. The considered scenario is expected to cause almost 5000 uninhabitable buildings in Malaga, that is, a 15% of the total building stock of the city, and more than 20,000 wounded persons. This building loss would leave over 90,000 persons without home.

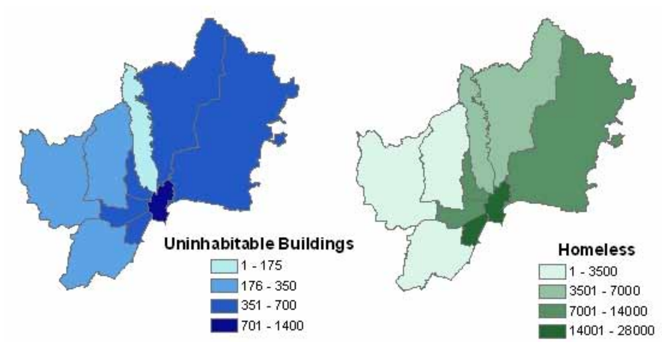


Figure 10. Estimation of uninhabitable buildings and homeless.

Conclusions

Malaga is a highly populated city located in one the most active seismic regions of Spain. The preliminary results obtained for the scenario based on the NCSE-02, an intensity of VII-VIII at rock sites, show that the city is very vulnerable to suffer seismic damage especially in its old historical center. In addition most of the population is concentrated near the coast where the soil amplifications are more critical. The consequences of such a scenario can cause a state of emergency for which a lot of resources will be required and a good coordination of the emergency management will be essential.

In a preliminary soil effects study, the soil response of soft soil sites is better characterized using the AI than the PGA. Several synthetic acceleration record have been obtained in different soil sites, using geotechnical data and their AI computed and correlated with the macroseismic intensity in order to obtain, for each soil class, an intensity increment value to consider the soil effects in the seismic risk scenarios. As a result the intensities from the seismic scenario considered varied from VII-VII at rock sites to VIII-IX for soil class 4. A more detailed study will be conducted to characterize all the soil conditions in Malaga city using 1D method to obtain the transfer function and the expected ground motion for a greater density of soil columns distributed by the city.

The seismic vulnerability analysis showed that the most vulnerable districts of Malaga city are unfortunately those having a higher population. As a consequence the seismic scenario proposed can cause approximately 5000 uninhabitable buildings, leaving over 90,000 homeless, and over 20,000 wounded persons. The work on the seismic risk assessment for the city will continue with the application of the vulnerability index method for the evaluation of the vulnerability based on the structural typologies of the building stock. More seismic scenarios will be considered based on historical earthquakes and the current seismicity.

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