A GIS based seismic risk scenario of the cities of Santa Fé and Atarfe in Andalucía, Spain

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Abstract: This paper applies a GIS -based methodology to a case study in the cities of Atarfe and Santa Fé in Anadalucía (Spain) which recently suffered a seismic series with six magnitude 4 earthquakes. The framework for estimating the risk scenario essentially relates each housing building in the cadastral, to the probability of reaching different levels of seismic damage, namely negligible, slight, moderate, extensive given the seismic hazard in the area under study. It is built on the python toolbox pandas and QuantumGIS. Although only minor to light damages were observed and reported during the seismic series, this study reveals that there is a high-risk scenario in the area if the 475-year design earthquake occurred nowadays.

Keywords: Seismic loss assessment, Push over curve, N2 method, GIS, seismic risk, cadastral data

1. Introduction.

Predicting future losses due to earthquakes in hazardous regions is always a complex problem, especially if we consider that losses imply not only physical damage to buildings but also social, economic, and psychological aspects, which are difficult to objectivize. Nevertheless, it is paramount in seismic areas to understand the risk in order to: i) Inform people and policy makers; ii) Grant governments with tools to make informed decisions; and iii) implement mitigation and emergency plans, among other. To this end the seismic risk scenarios, as the case study presented in this paper, are helpful tools to understand the problem. There are currently several procedures to estimate seismic damage scenarios worldwide: RADIUS (UN 1999) from the United Nations, The ATC-13 (Applied Technology Council 1985) and the ATC-21 (Applied Technology Council 1996; McCormack and Rad 1997) together with HAZUS (Federal emergency management agency 2018; Kircher, Whitman and Holmes 2006) in United States, the project Risk-UE (Moroux and Le Brun 2006) in Europe.

When evaluating a risk scenario two main issues need to be addressed: First an estimation of the seismic hazard in site, and second a vulnerability analysis of the building stock exposed. Regarding the estimation of the vulnerability part, the state-of-the-art methodologies nowadays assume that the characteristics and performance of any individual building in the area under study can be represented by a benchmark structure that represents all the structures alike. However, this assumption masks the particularities of each individual building within the corresponding typology group. Therefore, a certain level of uncertainty should be acknowledged and accounted when applied to vast areas. Another issue when estimating vulnerability in large is the enormous effort required to characterize each individual building, since it is time consuming and requires specialized workforce. In this regard, researchers have contributed to the development of tools such as geographic information systems (GIS), computer models, data mining, or deep learning to overcome these issues (Rajarathnam and Santhakumar (2015), Gentile and Gallaso (2020), Flores, Escudero and Zamora-Camacho (2021), Kim et. al (2020), Gonzalez et al. (2020) , Riedel et al. (2015), Borzi et al. (2011)).

In the last decade in Europe GIS systems have increasingly evolved. Nowadays, anyone can access massive geospatial data, such as the digital cadastral databases (Directive INSPIRE 2007; Van Loenen and Grothe 2014). In the case of buildings, three databases collect information on the location, geometric attributes, and temporal information, and the authors support that there is alreay enough information to produce simple structural models and predict the seismic performance of each building. This paper applies a GIS-based methodology to a case study in the cities of Atarfe and Santa Fé in Andalucía (Spain) which recently suffered a seismic series with six magnitude 4 earthquakes. Although only minor to light damages were observed and reported during the seismic series, this study reveals that there is a high-risk scenario in the area if the 475-year design earthquake occurred nowadays.

2. GIS procedure

The framework for estimating the risk scenario essentially relates each building item of the cadastral data (Directive INSPIRE 2007; Van Loenen and Grothe 2014), to the probability of reaching different levels of seismic damage, that is negligible, slight, moderate, extensive given the seismic hazard in the area under study. It is built on python toolbox pandas (McKinney 2015) and QuantumGIS (2021) and comprises five steps explained below:

Step I – Definition of the seismic hazard. The seismic hazard in a particular site will be determined with conventional elastic response spectra. In this study the provisions given in Eurocode 8 (European Committee Normalization 2004) and its national annexes are employed.

Step II – Characterization of building stock. The cadastral geodata following the specifications of the INSPIRE directive (Directive INSPIRE 2007; European Commission Joint Research Centre 2014) was used to obtain a mechanical model of the buildings in the case study area. The database gathers the following information: i) A vector defining external building boundaries and internal building boundaries, and ii) descriptive data such as the number of floors, building parts, gross area per floor, building use, and year of construction. The cadastral data provides several fundamental parameters to define a probable structural model and its mechanical and dynamic characterization as follows:

- The year of construction provides the standard that ruled the design of the structure, hence the shear coefficient, i.e: the lateral strength of the building.

- The structural type. Construction standardization and code regulation over the last decades, resulted in a strong homogenization of building technology. Hence, the building stock can be sorted in a few typological groups with common construction practices, which would share similar performance levels. In this study the building stock was categorized based on the height and year of construction.

- Mass distribution. The area per floor together with the weights of materials allows for an estimation the mass vector, fundamental for the determination of the dynamic properties.

- Fundamental period. Which can be approximated considering the building height and structural typology.

Step III – Determination of probable capacity curve. Based on the castral data obtained in step II, we can define a simplified elastic perfectly plastic capacity curve by defining the ultimate capacity, F_u, and the yield lateral displacement, D_y as follows: To obtain F_u, the design base shear F_d is increased by two overstrength factors, γ_1 & γ_2, that relate the design force to the yielding force and the yielding force to the ultimate respectively (i.e. $F_u = \gamma_1 \cdot \gamma_2 \cdot Fd$). *Fd* can be easily estimated by multiplying the design base shear coefficient *c*, given by the design code at the construction year, and the effective mass of the building for the first mode of vibration, obtained from the mass vector in step II of each individual building. To obtain D_y the usual drift values (as a percentage of the total building height) proposed in the literature (American Society of Civil Engineers ASCE 2000; Federal emergency management agency 2018; Kircher, Whitman and Holmes 2006) were adopted, which in RC and masonry buildings falls within the range $D_y \in [0.15\%,0.25\%]$ as proposed in HAZUS and FEMA 356. Finally, to account for the uncertainty when defining the capacity curve, a random Monte Carlo simulation proposing 50 capacity curves was carried out varying F_y and D_y within reasonable bonds (±30% and ±20%) depending on the year of construction as recommended in HAZUS (Federal emergency management agency 2018, Kircher, Whitman and Holmes 2006).

Step IV – Estimation of the seismic performance. The seismic performance in this study is defined on terms of the maximum probable displacement expected, as it is an engineering demand parameter closely related to damage in structural and non-structural components (Fardis 2009; SEAOC Seismology Committee 2006; Calvi, Priestley and Kowalsky 2007;) The N2 method proposed by Fajfar (1996) and adopted in Eurocode 8 (2004) annex B is implemented in this study to obtain the target displacement or performance point.

Step V – Prediction of the probable damage level. Finally, once determined the engineering demand parameter in the form of probable target displacement, damage can be readily categorized into the five different damage levels defined in HAZUS: no damage (DS0), light (DS1), moderate or immediate occupancy (DS2), extensive or life safety (DS3) and complete (DS4). Limits between different damage levels are defined by means of a lateral drift for each specific structural system. The probable damage that an individual would reach given the hazard level will be most likely damage obtained for the 50 capacity curves defined in step IV.

3. Case Study: the cities of Santa Fé and Atarfe

Atarfe and Santa Fé are two residential towns in the metropolitan area of the historic city of Granada, southern Spain (see Table 1 for relevant information). Geologically they locate in the basin of Granada. This basin is filled with upper Miocene to quaternary detrital sediments, and it is bounded by normal faults to the east and north which are responsible for some of the seismic activity in the area. These faults have been responsible of several destructive ground motions (Montilla, de Galdeano and Casado 2003) which are the largest expected in Spain with magnitude up to 5. Figure 1 shows the location map together with the active faults in the area (García-Mayordomo, J et al, 2012). As can be seen several active faults cross both localities, which makes both cities highly vulnerable to earthquake and being also prone to site effects due to the proximity to fault and soft soil. The recently updated seismic hazard and the Spanish seismic standard NSCE-02 assign a PGA of 0.23g (stiff-soil) for the 475-year return period earthquake.

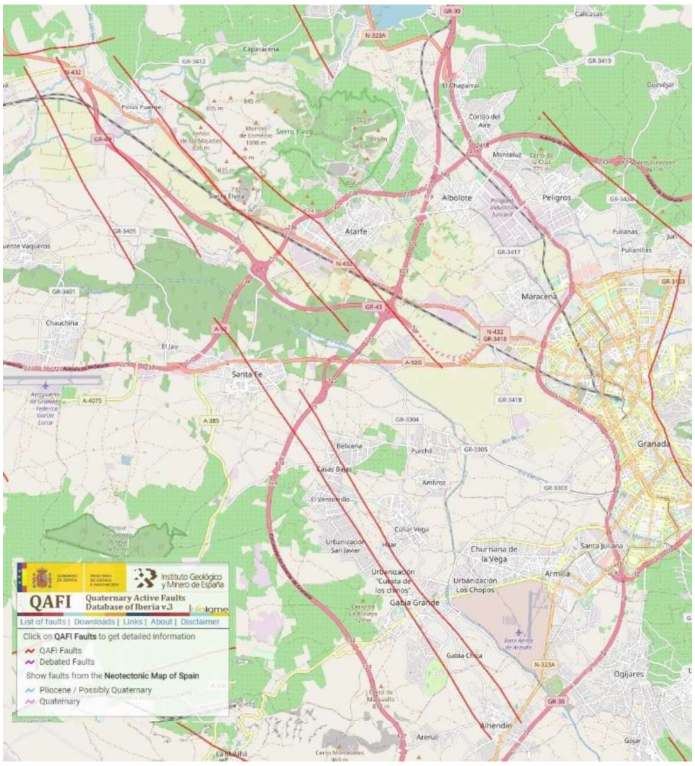

Fig. 1. quaternary Active faults at the iberian peninsula (IGME, 2009)

Table 1: Relevant data of Atarfe y Santa Fe

City	Population	Area	Buildings	Housing buildings
Atarfe	18960	47,22 km2	5173	3988
Santa Fe	15222	38,17 km2	5030	4394

3.1.1. The seismic series of 2021.

Since October 2018 it has been observed a seismic activity more intense than usual in the area, starting with a magnitude 4 and intensity V (EMS) earthquake on the nineth of October, 2018. Since then, a low seismic activity was recorded until December, 2^{nd} 2020, when a 3.5 Mw stroke the metropolitan area of Granada. After this event the Andalusian seismic network recorded and processed 3961 seismic events until January, 23rd 2022. Among all earthquakes it is worth mentioning six magnitude ≥ 4.0, which reached intensity VI (EMS) resulting in minor damages in constructions (grade 1 & 2 in EMS scale) in Santa Fé and Atarfe. Further information on the seismic series is available in IGN (2021). Figures 2 & 3 show the epicentres and temporal evolution of the seismic series,

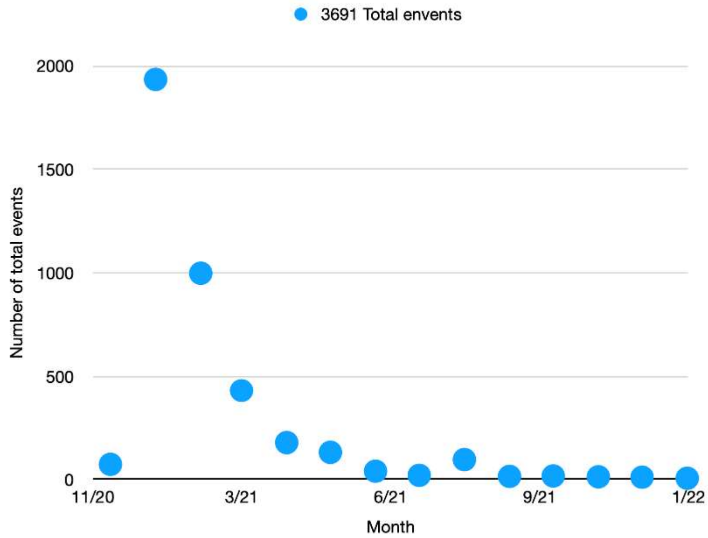

Fig. 2. Evolution of the seismic series

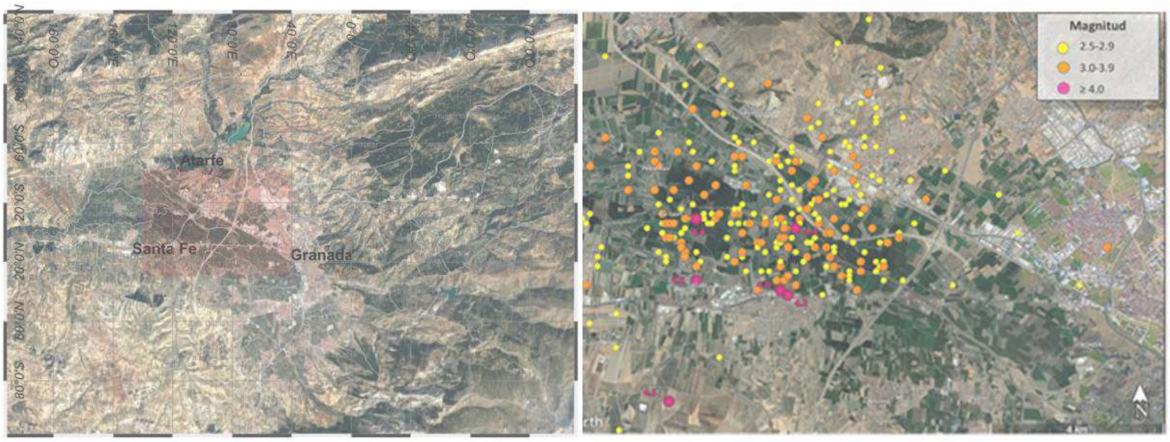

Fig. 3: Location of epicentres

3.2. Building stock characterization

Table 2 summarises the main typological groups in which the building stock in the area under study can be categorised. And Figure 4 shows two maps of the typological distribution in Atarfe (top) and Santa Fé (bottom). As can be observed the predominant types are P.CODE.MA.L and M.CODE.RC.M, that is low rise masonry buildings and medium rise reinforced concrete buildings designed with an inadequate seismic standard.

Table 2: Building Stock Categorization

year	Code	Structural typology	Number of flors
year< 1968	Pre-code (PCODE)	Masonry (MA)	Low (L)
1969< year <1994	Medium-code (MCODE)	Reinforced Concrete Frame (RC)	Medium (M)
>1994	High-code (HCODE)		High (H)

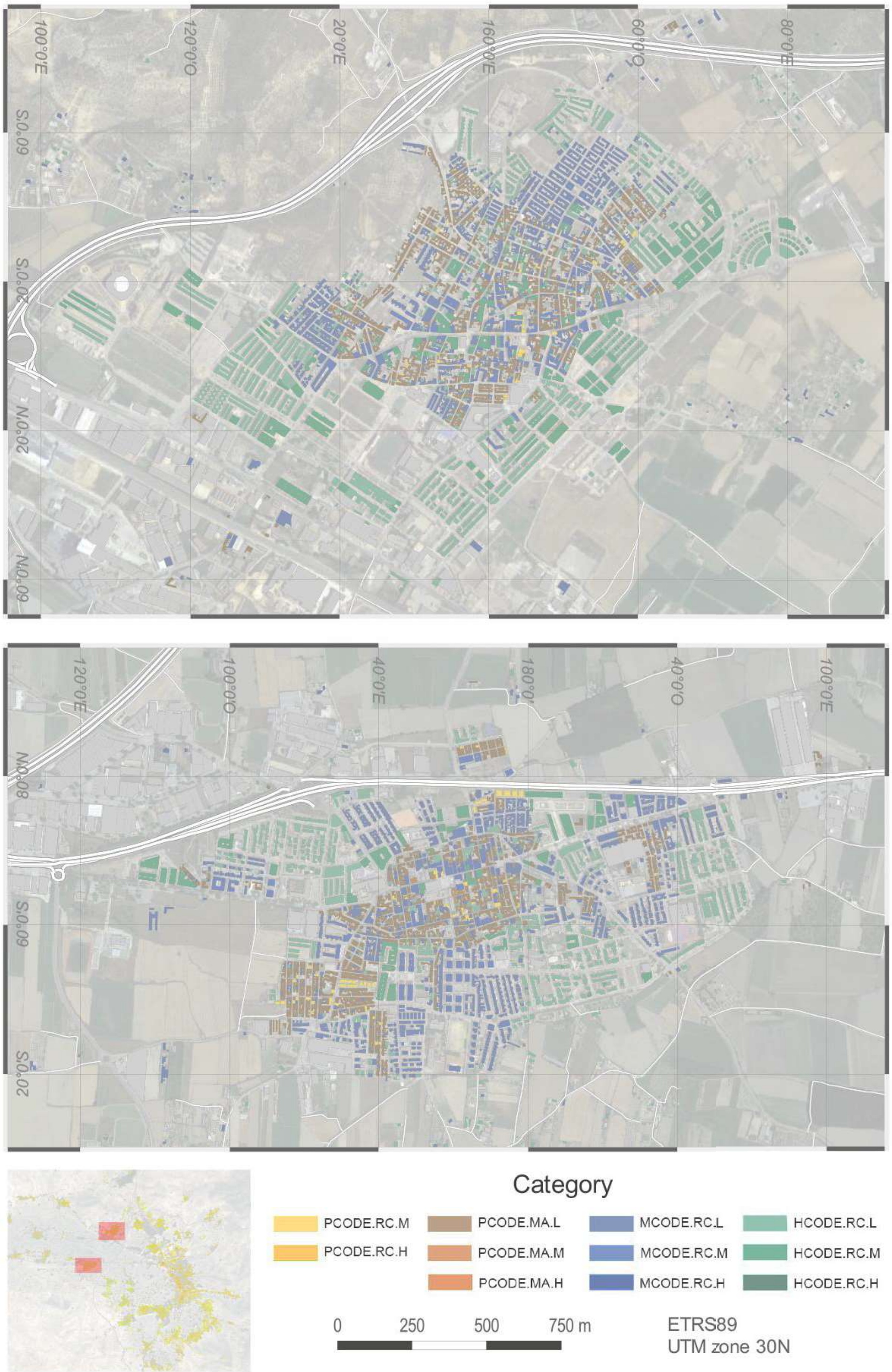

Fig. 4: Building categories in Atarfe and Santa Fé

3.2. Seismic Performance

Following the procedure in section 2, fifty probable target displacements were obtained for each building, hence obtaining a probabilistic estimation of the individual seismic performance. The median target displacement obtained is represented in figure 5 for the area under study. As can be observed the predominant categories P.CODE.MA.L and M.CODE.RC.M show a maximum displacement, in terms of drift, ranging between 0.9 to 1.5%.

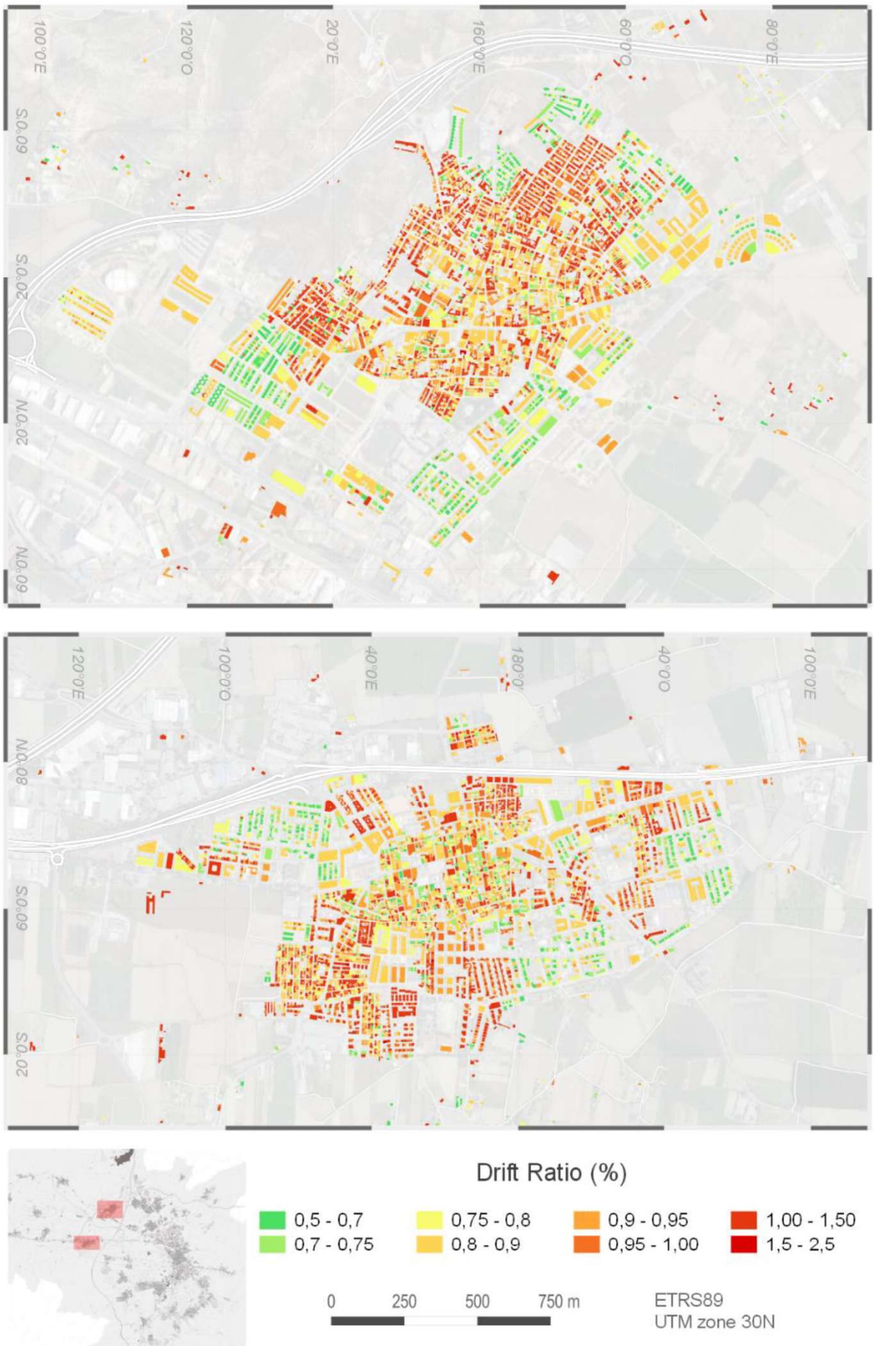

Fig. 5: Median target displacement in Atarfe (top) and Santa Fé (Bottom)

3.3. Damage levels

Figure 6 shows the translation of maximum lateral displacement into damage by means of the fragility curves defined in HAZUS. The results are also represented in a disaggregated by building category in Figure 7 and by building code in Figure 8. As observed the damage State 2 or moderate damage is predominant in the map with scarce samples reaching Damage State 3 or extensive damage. This is expected, since the predominant building categories P.CODE.MA.L and M.CODE.RC.M have similar response and are prone to damage. On the other hand most of the modern buildings designed with current standards present a damage level DS1 or minor damage.

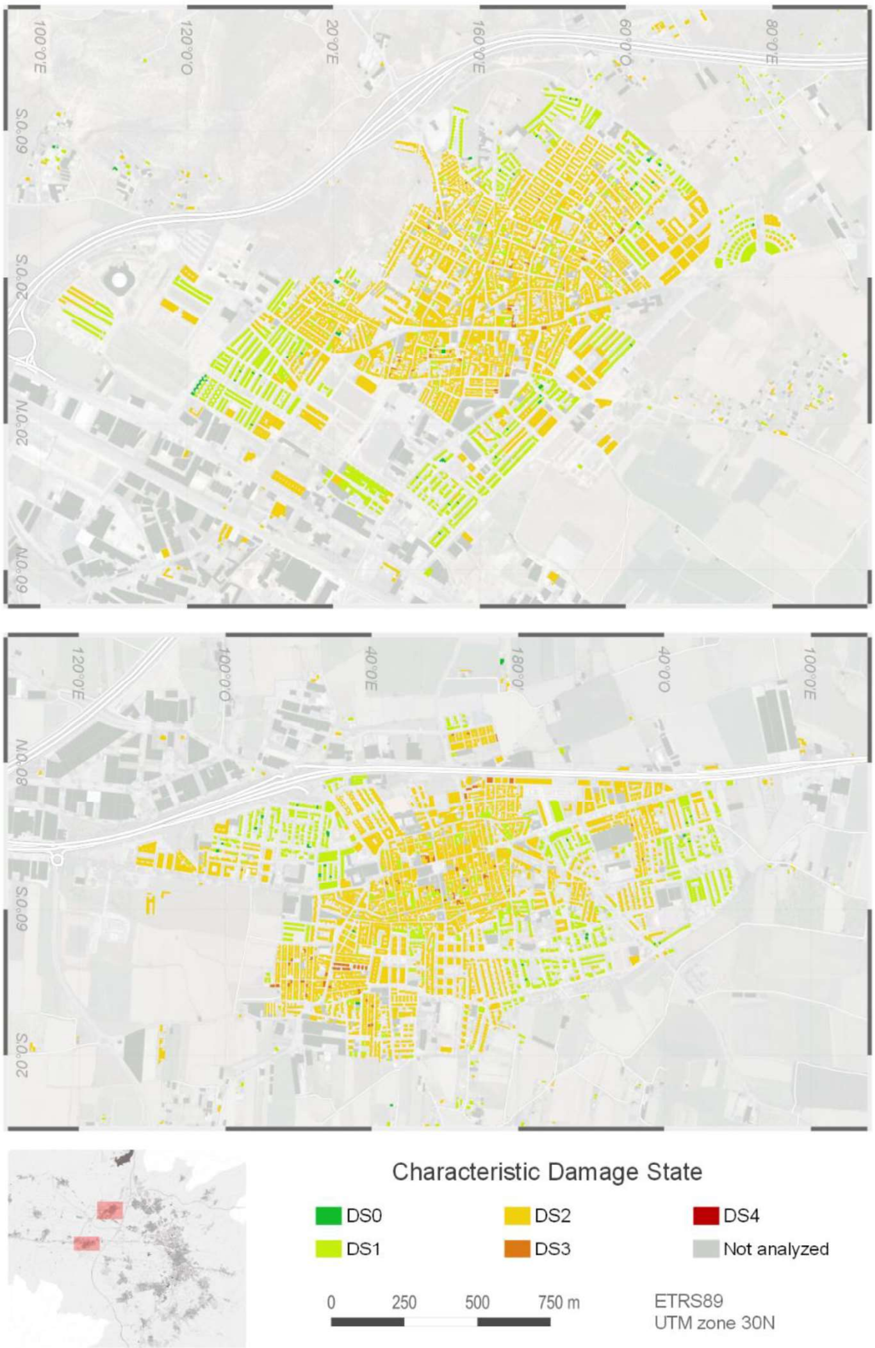

Fig. 6: Median seismic damage

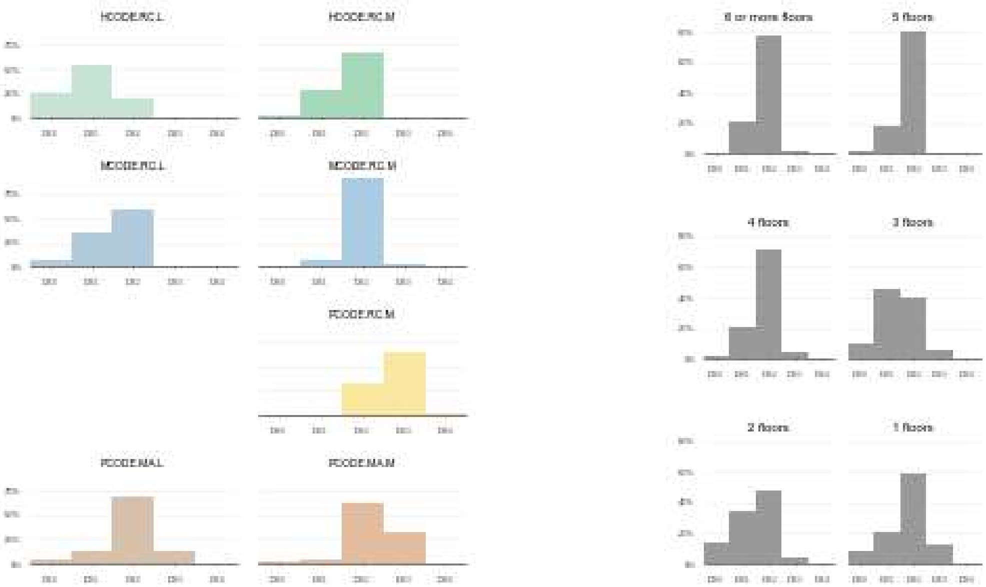

Fig. 7 : Histograms of seismic damage by building category

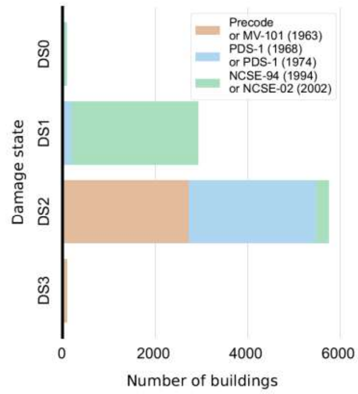

Fig. 8: Distribution of damage states and building codes

4. Conclusions

Between October 2018 and January 2022, a seismic series occurred, whose epicentres were near the cities of Atarfe and Santa Fé in Andalucía, southern Spain. Around 4000 events were recorded, six of which had magnitude larger than 4.0. This seismic series reached intensity VI (EMS) resulting in minor damages in constructions (grade 1 & 2 in EMS scale), raising awareness of the latent seismic hazard and the need for a deeper seismic assessment of the seismic risk in the area. This paper presents the results of a seismic risk scenario in the cities of Atarfe and Santa Fé in Andalucía, southern Spain for a return period of 475 years. From the results presented the following conclusions can be drawn:

- The predominant building categories in the area are low rise masonry buildings and medium rise reinforced concrete buildings designed without seismic provisions or with an inadequate seismic standard. That is a vulnerable building stock against earthquakes.

- Based on a GIS assessment, the most likely expected damage is between moderate (DS2) and extensive (DS3) for masonry budlings, between light (DS1) to moderate (DS2) for low code RC buildings, and between no damage (DS0) to light (DS1) for high code buildings.
- It is estimated that a 65% of the total building stock is exposed to generalised moderate damage under the design earthquake. Most of the vulnerable stock consists of under designed reinforced concrete frames (M.CODE.RC.M), with rather limited lateral strength and energy dissipation capacity.

Although only minor to light damages were observed and reported during the seismic series, this study reveals that there is a high-risk scenario in the area if the 475-year design earthquake occurred nowadays. Some recommended retrofitting strategies are the combination of dampers with FRP reinforcement, and measures to improve the seismic performance of non-structural components.

Acknowledgements

Grant PID2020-120135RB-I00 funded by MCIN/AEI/ 10.13039/501100011033 and by the “European Union”. Programa Operativo FEDER 2014-2020/Junta de Andalucía/Consejería de Transformación Económica, Industria, Conocimiento y Universidades/Proyecto B-TEP-306-UGR18.

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