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Earthquake loss estimation in Adra (Almería, Spain). Current impact of a repetition of the 1910 Adra earthquake

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Abstract

The town of Adra (Almería, Spain) has a population of 20,000 inhabitants and an urban area of 3.00 km^2, approximately. The number of buildings have suffered a significant increase in the last 50 years.

Adra town is situated in the SW of the Almería province (Southeast of Spain), one of the most hazardous zones of Spain from the point of view of seismic hazard. Historical seismicity data reveal that Adra was affected by near destructive earthquakes in 1522 and 1804 (IX maximum intensity, EMS scale) and in 1910 (mb = 6.2). Several small earthquakes (mb = 5.0) in the south-east of Spain, for example, in 1993, 1994 (with an epicentre near Adra) and in 1999 (with an epicentre close to Mula, Murcia) reached a VII degree of intensity (EMS scale) and a detailed macroseismic study revealed areas with different intensities within the most affected towns. In the case of two Adra earthquakes dated 23 December 1993 and 4 January 1994, the most relevant damage in Adra town occurred in reinforced concrete (RC) buildings of four or five storeys placed on recent alluvial deposits. The other RC buildings only suffered light damage or remained intact, and similar occurred with brick and masonry structures placed outside alluvial deposits. Furthermore, buildings with the same typology placed in areas underlain by similar surface geology, showed significant damage differentiation from place to place (some with moderate damages and others undamaged); the only appreciable difference amongst them was the height of the buildings (Navarro et al., 2007 [1]).

The current building stock has been classified and the typology definition and fragility functions for physical elements have been assigned following the SYNER-G project (Pitilakis et al. eds., 2014 [2]). Therefore, 27 model building types have been chosen to represent the current building stock. A simulation of the ground motion of the 1910 Adra earthquake has been used as input for structural damage computation using the analytical methodology included in SELENA (Molina et al., 2010 [3]). MASW and SPAC methods were used in order to include the site effects into the expected ground motion.

As a summary, we have obtained that 474 ±160 and 973 ± 78 buildings will suffer complete and extensive damage respectively, that is around the 40% of the buildings in the city. Approximately the 55% of the extensive damaged buildings and the 60% of the completed damaged buildings are reinforced concrete frame buildings with waffled-slabs floor pre-code. The economic losses in the city will be 43.1± 8.5 millions Euros. Finally, it has been observed an increase of the extensive damage in the mid-rise buildings that can be due to a coincidence between the period of the structure and the predominant period of the soil.

The results will be used in future emergency planning in the city.

Keywords: capacity spectrum method, seismic risk, structural damage, economic losses, predominant period.

1. Introduction

The town of Adra (Almería, Spain) has a population of 20,000 inhabitants and an urban area of 3.00 km^2, approximately. The number of buildings have suffered a significant increase in the last 70 years.

Adra town is situated in the SW of the Almería province (Southeast of Spain), one of the most hazardous zones of Spain from the point of view of seismic hazard. Historical seismicity data reveal that Adra was affected by near destructive earthquakes in 1522 and 1804 (IX maximum intensity, EMS scale) and in 1910 (mb = 6.2). Several small earthquakes (mb = 5.0) in the south-east of Spain, for example, in 1993, 1994 (with an epicenter near Adra) and in 1999 (with an epicenter close to Mula, Murcia) reached a VII degree of intensity (EMS scale) and a detailed macroseismic study revealed areas with different intensities within the most affected towns. In the case of two Adra earthquakes dated 23 December 1993 and 4 January 1994, the most relevant damage in Adra town occurred in reinforced concrete (RC) buildings of four or five stories placed on recent alluvial deposits. The other RC buildings only suffered light damage or remained intact, and similar occurred with brick and masonry structures placed outside alluvial deposits. Furthermore, buildings with the same typology placed in areas underlain by similar surface geology, showed significant damage differentiation from place to place (some with moderate damages and others undamaged); the only appreciable difference amongst them was the height of the buildings (Navarro et al., 2007 [1]).

The urban area comprises a total of 3558 buildings with different force resisting mechanisms, materials, heights, etc. The city has been divided in 71 geounits that will be used as reference unit for all the computations. As a summary 29% of the building stock was built after the first seismic design code (NCSE-94 [4] and NCSE-02 [5]) and the rest was built without any seismic code or using the firsts normatives (EH-68 [6], PGS-1-1968 [7] or PDS-1-1974 [8]). Regarding the height of the buildings, 3088 have 1 to 3 stories, 479 have 4 to 7 stories and only 29 building have 8 stories or more. Figure 1 shows an aerial view of the city with the borders of each geounit. The design of each geounit has also taken into consideration the soil distribution obtained by Martínez-Pagán et al., (2015) [9] as discussed in the next paragraph.

Fig. 1 – Aerial picture of the city of Adra (Almeria) and designed geounits.

In general, risk is defined as the expected physical damage and the connected losses that are computed from the convolution of the probability of occurrence of hazardous events and the vulnerability of the exposed elements to a certain hazard (United Nations Disaster Relief Organization). According to McGuire (2004) [10], seismic risk entails a set of events (earthquakes likely to happen), the associated consequences (damage and loss in the broadest sense), and the associated probabilities of occurrence (or exceedance) over a defined time period.

For a deterministic analysis, seismic hazard—the first component—refers to the shaking effects at a certain site caused by a scenario earthquake. While the term exposure represents the availability and inventory of buildings, infrastructure facilities and people in the respective study area subjected to a certain seismic event. Structural (i.e. physical) vulnerability stands for the susceptibility of each individual element (building, infrastructure, etc.) to suffer damage given the level of earthquake shaking. This results in structural (and non-structural) damages, which directly implicate economic losses as well as casualties.

Our main objective in this paper is to remark the need for earthquake risk mitigation policies and emergency preparedness actions in the city in order to manage the seismic risk by providing an updated computation of the damage and losses scenario due to a possible repetition of the 1910 Adra earthquake.

2. The earthquake scenario.

In Adra town, during 1993 and 1994, small earthquakes took place with a magnitude of 5.0 (Mw). Despite these earthquakes were moderate, several buildings suffered damage. The local soil conditions influenced the characteristics of the earthquake-shaking scenarios. In fact, these scenarios played a key role about the type of building damages reported and their distribution.

Martínez-Pagán et al., (2015) [9] combined Spatial Autocorrelation (SPAC) and Multichannel Analysis of Surface Waves (MASW) techniques to obtain the detailed surface shear-wave velocity (Vs^{30}) structure of the town (Figure 2). The north parth of the city shows Vs^{30} higher tan 800 m/s (type A according to EC8). However, in the south and east of the city the soils are type B2 ($360 < Vs^{30} < 500$ m/s) and type C ($180 < Vs^{30} < 360$ m/s). Finally, in the northwest of the city the soil type is B1 ($500 < Vs^{30} < 800$ m/s).

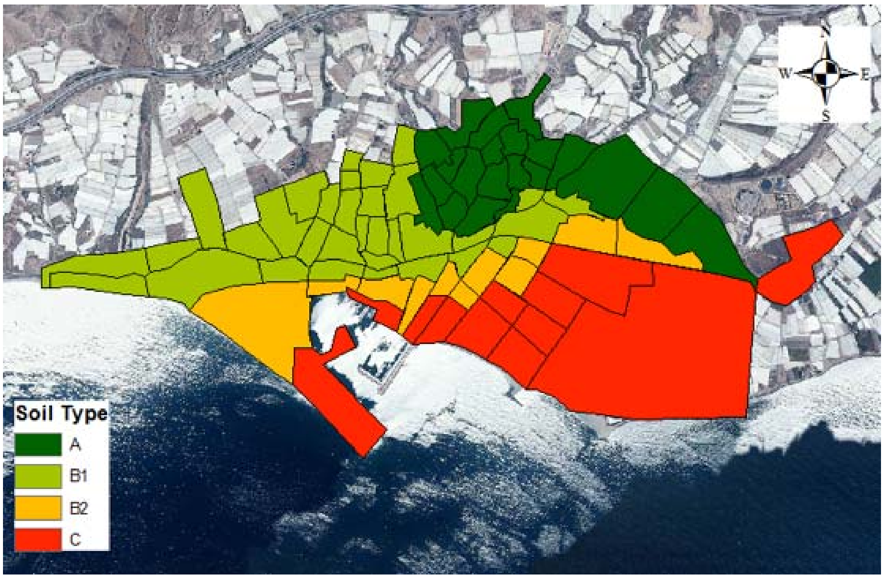

Fig. 2 – Soil distribution assigned to each geounit following Martinez-Pagan et al. (2015) [9]

These seismic results have been applied to simulate the earthquake ground motion scenario corresponding to the 1910 Adra earthquake (M_w 6.1), which is given in terms of peak ground acceleration (PGA). As the PGA follows a continuous distribution for all the city, and each geounit has to be assigned one PGA value, we have used three different seismic scenarios: the mean value for each geounit (with a weight of 0.60) and the minimum and maximum PGA value for each geounit (with weight of 0.2 and 0.2 respectively). Therefore, our seismic damage and losses scenario will be computed by means of a logic tree with three branches and the results will be shown as mean values and corresponding percentiles (Molina et al., 2010 [3]). In Figure 3a we represent the mean PGA value for each geounit. There are four geounits without any colour because there aren't buildings in those geounits, so PGA has not been represented. As we can see nearly the half of the city will be affected by PGA values between 0.26 and 0.32 g. Besides, Figure 3b shows the mean, maximum and minimum ground motion for the geounit with the highest PGA value (0.3215 g), using the EC-8 spectral shape (CEN, 2002 [11]). Besides, in Figure 3b we have also included the spectral acceleration according to the NCSE-02 spectral shape using the 475 year return period acceleration (PGA of 0.19 g) obtained by I.G.N (2013) [12] and amplified using the soil type C.

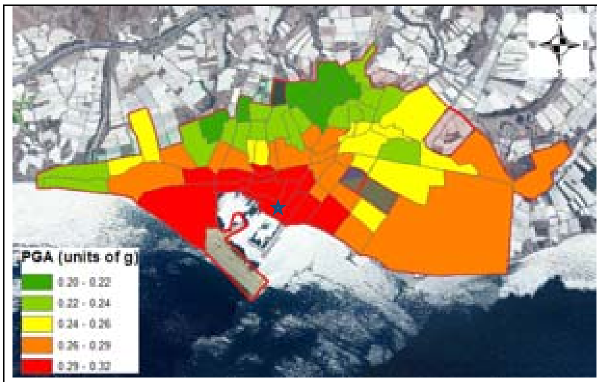

Fig. 3 a– Mean PGA assigned to the centroid of each geounit.

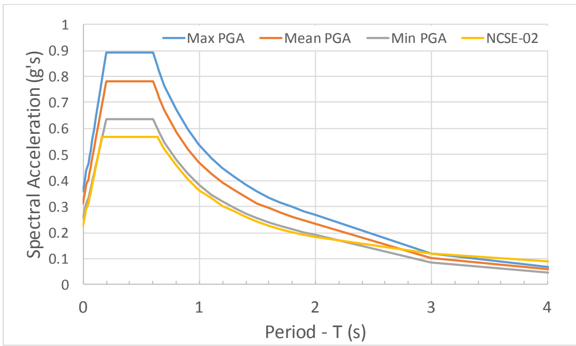

Fig. 3 b – Spectral shape of the ground motion for a geounit (blue star in Fig. 3a)

3. Building types in the urban area of Adra.

With the aim of simplifying the seismic risk assessment, the building stock exposed to earthquakes in the city under study has to be classified into Model Building Types (MBT). Each MBT represents a group of buildings with similar behaviour under earthquake shaking. The classification has to be detailed, to guarantee realistic outcomes; as well as generic, to allow the classification of buildings into categories.

Recently, Pitilakis et al., (2014) [2] presented a detailed review of the fragility function in Europe and their classification using the SYNERG- building taxonomy. Each building typology is defined taking into consideration the force resisting mechanism (FRM1), the force resisting mechanism material (FRMM1), Plan (P), Elevation (E), Cladding (C), Detailing (D), Floor System (FS), Roof System (RS), Height Level (HL) and Code Level (CL).

For the city of Adra we have used the cadastral database obtained from the Spanish Statistic Institute updated to 2014. This database has been complemented with other databases from previous research projects and with random field trips around the city. The data first was classified by building age taking into consideration that the Code Level and force resisting mechanism has evolved with that age. Additionally, the height of the buildings has been classified as Low (1-2 stories); Mid (3-5 stories) and High (+6 stories) for building without reinforced concrete frames and Low (1-3 stories), Mid (4-7 stories) and High (+8 stories) for building with reinforced concrete frame.

Therefore 27 model building types have been defined for the city that has been summarized in Table 1.

Table 1 – Classification of the building stock in Adra town.

Label	Period of Construction	Height	Seismic Design Level	Description	Number of buildings
T1	< 1926	1-2	No Code	Old buildings using timber-framed masonry and blocks of rubble/adobe/soft stones. Floor system uses timber	92
T2	<1926	1-2 (T2M) 3-5 (T2L)	No Code	Old buildings using unreinforced masonry of blocks of soft stones or fired bricks. Floor system uses timber.	287
T3	1926 to 1945	1-2	No Code	Old buildings using brick masonry with wooden slabs and timber floor system.	85
T4	1926 to 1945	1-2 (T3L) 3-5 (T3M)	No Code	Old buildings using brick masonry with poor concrete floor system.	44
T5	1946 to 1960	1-2 (T5L) 3-5 (T5M)	No Code	Buildings using brick masonry with reinforced concrete floor system	412
T6	1961 to 1976	1-2 T6	No Code	Buildings using confined masonry with concrete blocks and reinforced concrete floor systems	263
T7	1961 to 1976	1-3 (T7L) 4-7 (T7M) +8 (T7H)	Pre-Code	Reinforced concrete frame structures with embedded or emergent beams	531
T8	1977 to 1996	1-3 (T8L) 4-7 (T8M)	Pre-Code	Reinforced concrete structures with waffled-slabs floor	891
T9	1977 to 1996	4-7 (T9M) +8 (T9H)	Pre-Code	Reinforced concretes structures with embedded or emergent beams	85
T10	1997 to 2004	1-3 (T10L) 4-7 (T10M) +8 (T10H)	Moderate Code	Reinforced concrete structures with waffled-slabs floors	46
T11	1997 to 2004	1-3 (T11L) 4-7 (T11M) +8 (T11H)	Moderate Code	Reinforced concrete structures with flat or emergent beams	485
T12	> 2004	1-3 (T12L)	Moderate Code	Mixed masonry-reinforced concrete-steel buildings	135
T13	> 2004	1-3 (T13L)	Moderate Code	Reinforced concrete structures with waffled-slabs floors	43
T14	> 2004	1-3 (T14L) 4-7 (T14M) +8 (T14H)	Moderate Code	Reinforced concretes structures with flat beams	189

The distribution of buildings (number and built area) according to each one of the defined MBT is shown in Figure 4. As we can see it prevails the unreinforced masonry structures and the reinforced concrete buildings with waffled-slab floors, designed and built previously to the NCSE-94.

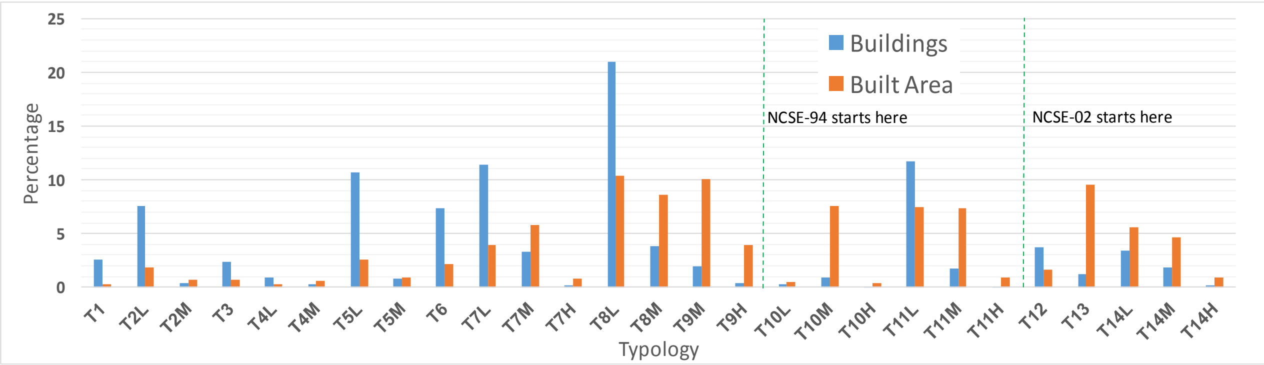

Fig. 4 – MBT distribution in the city of Adra.

The damage functions (capacity and fragility functions) used in this study were taken mainly from Lagomarsino and Giovinazzi (2006) [13] and they are presented in Table 2.

The fragility functions defined by the corresponding limit states, Sd, (Median and Beta values in Table 1) were derived using the lognormal cumulative probability function.

Table 2 – Damage functions for the typologies defined in Adra.

Label	Capacity Curve				Sd – Slight (m)		Sd– Moderate (m)		Sd –Extensive (m)		Sd- Complete (m)	
	Ay(g's)	Dy(m)	Au(g's)	Du(m)	Median	Beta	Median	Beta	Median	Beta	Median	Beta
T1	0.155	0.0028	0.155	0.0111	0.00196	0.24	0.0042	0.24	0.00695	0.24	0.0111	0.24
T2L	0.263	0.0024	0.263	0.0124	0.00168	0.29	0.0036	0.29	0.0074	0.29	0.0124	0.29
T2M	0.208	0.0054	0.208	0.0187	0.00378	0.22	0.0081	0.22	0.01205	0.22	0.0187	0.22
T3	0.279	0.0028	0.279	0.014	0.00196	0.28	0.0042	0.28	0.0084	0.28	0.014	0.28
T4L	0.324	0.0036	0.324	0.0171	0.00252	0.27	0.0054	0.27	0.01035	0.27	0.0171	0.27
T4M	0.256	0.008	0.256	0.026	0.0056	0.2	0.012	0.2	0.017	0.2	0.026	0.2
T5L	0.358	0.004	0.358	0.0236	0.0028	0.31	0.006	0.31	0.0138	0.31	0.0236	0.31
T5M	0.283	0.0088	0.256	0.035	0.0062	0.24	0.0132	0.24	0.0219	0.24	0.0350	0.24
T6	0.508	0.003	0.508	0.0233	0.0021	0.36	0.0045	0.36	0.01315	0.36	0.0233	0.36
T7L	0.24	0.0174	0.24	0.0523	0.01218	0.19	0.0261	0.19	0.03485	0.19	0.0523	0.19
T7M	0.143	0.0259	0.143	0.0781	0.01813	0.19	0.03885	0.19	0.052	0.19	0.0781	0.19
T7H	0.083	0.0352	0.083	0.106	0.02464	0.19	0.0528	0.19	0.0706	0.19	0.106	0.19
T8L	0.227	0.0108	0.227	0.0324	0.00756	0.19	0.0162	0.19	0.0216	0.19	0.0324	0.19
T8M	0.164	0.0168	0.164	0.0504	0.01176	0.19	0.0252	0.19	0.0336	0.19	0.0504	0.19

T9M	0.19	0.0195	0.19	0.0584	0.01365	0.19	0.02925	0.19	0.03895	0.19	0.0584	0.19
79H	0.134	0.0277	0.134	0.083	0.01939	0.19	0.04155	0.19	0.05535	0.19	0.083	0.19
T10L	0.426	0.0203	0.426	0.0735	0.0142	0.22	0.0305	0.22	0.0469	0.22	0.0735	0.22
T0M	0.282	0.0288	0.282	0.1187	0.02016	0.25	0.0432	0.25	0.07375	0.25	0.1187	0.25
T10H	0.187	0.0387	0.187	0.1592	0.02709	0.25	0.05805	0.25	0.09895	0.25	0.1592	0.25
T11L	0.54	0.0257	0.54	0.082	0.0180	0.20	0.0386	0.20	0.0539	0.20	0.0820	0.20
T11M	0.357	0.0365	0.357	0.1324	0.0256	0.22	0.0548	0.22	0.0845	0.22	0.1324	0.22
T11H	0.237	0.049	0.237	0.1776	0.0343	0.22	0.0735	0.22	0.1133	0.22	0.1776	0.22
T12	0.625	0.0297	0.625	0.095	0.0208	0.20	0.0446	0.20	0.0624	0.20	0.0950	0.20
T13	0.401	0.0191	0.401	0.089	0.0169	0.25	0.0363	0.25	0.0618	0.25	0.0994	0.25
T14L	0.508	0.0242	0.508	0.0994	0.01694	0.25	0.0363	0.25	0.0618	0.25	0.0994	0.25
T14M	0.286	0.0292	0.286	0.1453	0.02044	0.28	0.0438	0.28	0.08725	0.28	0.1453	0.28
T14H	0.189	0.0392	0.189	0.1949	0.02744	0.28	0.0588	0.28	0.11705	0.28	0.1949	0.28

4. Earthquake loss scenario for the 1910 Adra earthquake

In order to compute the damage probability, the analytical risk and loss assessment tool SELENA was used (Molina et al., 2010 [3]) using the improved displacement coefficient method I-DCM (ATC, 2005 [14]) to obtain the performance point.

Figure 6 shows the number of damaged buildings for each one of the MBT (in % of the total number of that typology). As we can see the non-engineered buildings have a higher vulnerability and therefore the structural damage is higher. In particular, typology T1, T2 and T5 reach easily the complete damage. Also the typologies T8, which is one the most numerous reach easily the extensive and complete damage. A similar behaviour can be seen in typology T7 and T9.

On the other hand, seismic designed structures show a better behaviour showing less damage although mid and high rise buildings have more extensive damage than low rise buildings.

As a summary, we observe from Figure 7 that 474 ±160 and 973 ± 78 buildings will suffer complete and extensive damage respectively that is around the 40% of the buildings in the city. As we can see the number of damaged buildings is very high and this is probably due to the damage functions used to represent the most common buildings, that is T8 (Reinforced concrete frames using waffled-slabs floors) and T7 (Reinforced concrete frames with embedded or emergent beams) and, both pre-code. From the 973 buildings with extensive damage, approximately the 55% correspond to the typology T8 and 25% to typology T7. Also the 60% of the complete damaged buildings belongs to typology T8.

Moreno et al. (2010) [15], Vielma et al. (2010) [16] and Vargas et al. (2013) [17] also pointed out that this waffled-slab floors typology is more vulnerable, so, therefore, special care has to be taken when interpreting these losses because they are mainly due to these two typologies which, probably, should be better characterized with more specific damage functions.

Fig. 5 –Percentage of Damaged Buildings in the city of Adra classified by MBT.

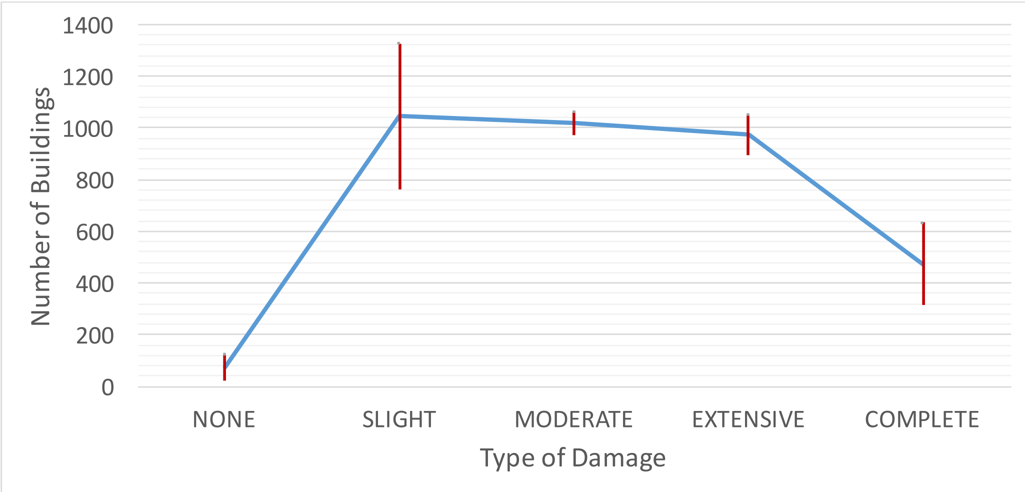

Fig. 6 – Total number of damaged buildings in the city of Adra

On the other hand, we have quantified the impact of this structural damage in terms of economic losses and we have estimated around 43.1± 8.5 millions Euros needed to repair or reconstruct all the damaged buildings. This estimation has been obtained using the construction value (Vc) criteria (Equation 1) given by the the cadastral databases:

$$Vc\ (euros/m^2) = MBC*OCCUPANCY*QUALITY*YEAR\ OF\ CONSTRUCTION \quad (1)$$

where MBC has a given value for each Spanish city, i.e. 650 euros/m^2 for Adra, OCCUPANCY ranges from 0.65 to 1.7, i.e. 1.15 for Residential use; QUALITY ranges from 0.60 to 1.40, i.e, 1.20 for medium-high construction quality; YEAR OF CONSTRUCTION ranges from 1.0, for buildings constructed in the last 5 years to 0.32 if they were constructed more than 70 years ago.

Therefore, for example, a Residential building (typology T14) constructed in 2014 will have a construction value Vc= 650 x 1.15 x 1.20 x 1.0 = 897 euros/m^2. This value is assumed to be the the cost per square meter of reconstruction of a complete damaged building. The cost of repair of extensive, moderate and slight damage will be assumed 50%; 10% and 2% of complete damage (FEMA 2003 [17]). Note that the economic loss is not including the demolition and/or debris removal cost that will increase this quantity.

In Figure 7 we represent the distribution of economic losses for each geounit as a percentage of the total economic losses. As a result, we have a view of the impact of the earthquake in each geounit. The most of these geounits with the higher economic losses have also a predominant period of the soil layer between 0.20 to 0.30 s which is also the predominant period of the RC buildings with 4 to 7 stories according to Navarro et al. (2007) [15].

Fig. 7 – Economic losses distribution for each geounit in the city of Adra.

Finally, if we compare the damage distribution of the seismic series 1993-1994 in the city of Adra (Figure 8), we can see that the damaged buildings in that seismic series are located in the geounits with highest economic losses, that is, there is good correlation between the scenario computed for the 1910 Adra earthquake with recently observed damage scenarios.

Fig. 8 – Damaged buildings in the city of Adra during the 1993-1994 seismic series (taken from Martinez-Pagán et al., 2015 [9])

5. Conclusions

From the previous results, the following conclusions can be addressed:

- Soil effect is very important in the city of Adra and a repetition of the 1910 Adra earthquake will affect the most of the buildings with PGA values higher than 0.26 g, significantly higher than the 0.19 g predicted by the new seismic hazard map (developed for Spain for a return period of 475 yrs) (I.G.N., 2013 [12])

- A repetition of the 1910 Adra earthquake will suppose a dramatic impact in the city of Adra due to the high vulnerability of its current building stock (the most of the buildings are non-engineered ones constructed without any seismic design criteria)
- From the damage distribution, a relationship between the increase of the extensive damage for mid to high rise RC buildings and the predominant period of the soil can be established addressing the point that the new buildings have to try avoid a predominant period closer to the predominant period of the soil
- The most of the damage buildings are unreinforced masonry buldings and reinforced concrete frame pre-code mainly with waffled-slabs floors.
- The use of a logic tree has allowed to obtain the damage and losses results taking into consideration the uncertainties of averaging the ground motion for the centroid of each geounit instead of a continuous distribution.

Finally, taking into consideration that waffled-slab floors structures are predominant in the city an additional effort has to be given to estimate specific damage functions for this structure in Adra.

4. Acknowledgements

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5. Copyrights

5. References

[1] Navarro, M., Vidal, F., Enomoto, T., Alcalá, F. J., García-Jerez, A., Sánchez, F. J., & Abeki, N. (2007). Analysis of the weightiness of site effects on reinforced concrete (RC) building seismic behaviour: The Adra town example (SE Spain). *Earthquake Engineering & Structural Dynamics*, *36*(10), 1363–1383. http://doi.org/10.1002/eqe.685

[2] Pitilakis, K. Franchin, P., Khazai, B., Wenzel, H. (Eds) (2014): *SYNER-G: Systemic Seismic Vulnerability and Risk Assessment of Complex Urban, Utility, Lifeline Systems and Critical Facilities*. Springer, 1st edition.

[3] Molina, S., Lang, D. H., & Lindholm, C. D. (2010). SELENA – An open-source tool for seismic risk and loss assessment using a logic tree computation procedure. *Computers and Geosciences*, 1–13. http://doi.org/10.1016/j.cageo.2009.07.006

[4] Ministerio de Obras Públicas, Transporte y Medio Ambiente. (1995, 8 de febrero). Real Decreto 2543/1994, de 29 de diciembre de 1994, por el que se aprueba la NCSE-94 Norma de Construcción Sismorresistente: parte General y de Edificación. *Boletín Oficial del Estado*, nº 33, pp. 3935-3980. España.

[5] Ministerio de Fomento. (2002, 11 de octubre). Real Decreto 997/2002, de 27 de septiembre de 2002, por el que se aprueba la NCSE-02 Norma de Construcción Sismorresistente: parte General y de Edificación. *Boletín Oficial del Estado*, nº 244, pp. 35898-35967. España.

[6] Presidencia del Gobierno. (1968). Decreto 2987/1968, de 20 de septiembre de 1968, por el que se aprueba la EH-68. Instrucción para el proyecto y la ejecución de obras de hormigón en masa o armado. *Boletín Oficial del Estado*, nº 290, pp. 17257-17291. España.

[7] Presidencia del Gobierno. (1969, 4 de febrero). Decreto 106/1969, de 16 de enero de 1969, por el que se aprueba la PGS 1-1968 Norma Sismorresistente: parte A. *Boletín Oficial del Estado*, nº 30, pp. 1658-1675.

[8] Ministerio de Planificación del Desarrollo. (1974, 21 de noviembre). Decreto 3209/1974, de 30 de agosto de 1974, por el que se aprueba la PDS-1-1974 Norma Sismorresistente: parte A. *Boletín Oficial del Estado*, nº 279, pp. 23585-23601. España.

[9] Martínez-Pagán P., Navarro M., Pérez-Cuevas J., Vidal F. (2015). Application of SPAC and MASW Techniques to Earthquake-shaking Scenarios. The Case of the 1993-1994 Adra Earthquakes. *21st European Meeting of Environmental and Engineering Geophysics- Near Surface Geosciences*, Turin, Italy.

[10] McGuire RK (2004) *Seismic hazard and risk analysis*. In: EERI Publication No. MNO-10, Earthquake Engineering Research Institute, Oakland, CA

[11] CEN (European Committee for Standardization) (2002). In: prEN 1998-1:200X, Eurocode 8: Design for Structures for Earthquake Resistance, Part 1: General Rules, Seismic Actions and Rules for Buildings. Building Code, European Committee for Standardization, Brussels, Belgium 224 pp.

[12] I.G.N. (Instituto Geografico Nacional) (2013). *Actualización de Mapas de Peligrosidad Sísmica de España 2012*. Edita CNIG, ISBN. 978-84-416-2685-0, 267 pp.

[13] Lagomarsino S, Giovinazzi S (2006) Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. *Bull Earthq Eng 4*:415–443. doi:10.1007/s10518-006-9024-z

[14] ATC-Applied Technology Council (2005) *Improvement of Nonlinear Static Seismic Analysis Procedures*, FEMA-440, California, United States

[15] Moreno-González R. and Bairán-García J.M: (2010). Curvas de fragilidad para evaluar el daño sísmico en edificios de concreto armado con losas reticulares. *Revista de la Facultad de Ingeniería U.C.V.*, Vol. 25, 4, 61-71.

[16] Vielma, J. C., Barbat, A. H., & Oller, S. (2009). Seismic safety of low ductility structures used in Spain. *Bulletin of Earthquake Engineering*, *8*(1), 135–155. http://doi.org/10.1007/s10518-009-9127-4

[17] Vargas, Y. F., Pujades, L. G., Barbat, A. H., & Hurtado, J. E. (2013). Evaluación probabilista de la capacidad, fragilidad y daño sísmico de edificios de hormigón armado. *Revista Internacional De Mètodos Numèricos Para Cálculo Y Diseño en Ingeniería*, *29*(2), 63–78. http://doi.org/10.1016/j.rimni.2013.04.003

[18] FEMA (2003) *HAZUS-MH: multi-hazard loss estimation methodology*. Federal Emergency Management Agency, Washington, D.C., United States.