Why Was It So Damaging?

The Lorca Earthquake, 2011 May 11th

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***Abstract*- The earthquake of the 11th of May 2011 that struck the town of Lorca in the region of Murcia, in the Southeast (SE) of the Iberian Peninsula has been the one with the most destructive effects in the last sixty years in Spain. Its unpredictable and devastating effects: nine victims and direct losses of 1,650,000,000 €. The monumental architectural heritage of Lorca has been severely damaged, with an estimated cost of restoration above 50,000,000 €. As one of the heads of the local government Culture Department declared: "This seism has had the most negative impact on European Heritage since the one that partially collapsed the Basilica of Asissi, in Italy, in 1997". The accelerations measured in the first event and in the second one, two hours later, were 0.24g (Mw 4.4) and 0.41g (Mw 5.1). The seismic resistant structural code in force, NCSR 02, determines a basic acceleration of 0.12g for the area. The seism was caused by the activity of the Alhama-Murcia Fault (FAM), known since 1979, on which epicentres were located, NE of the town centre. The amplifying effect of the ground under Lorca, exceeding the previsions of the ground coefficient *C* established in the NCSE 02, was one of the causes of the severe damage in the built environment.**

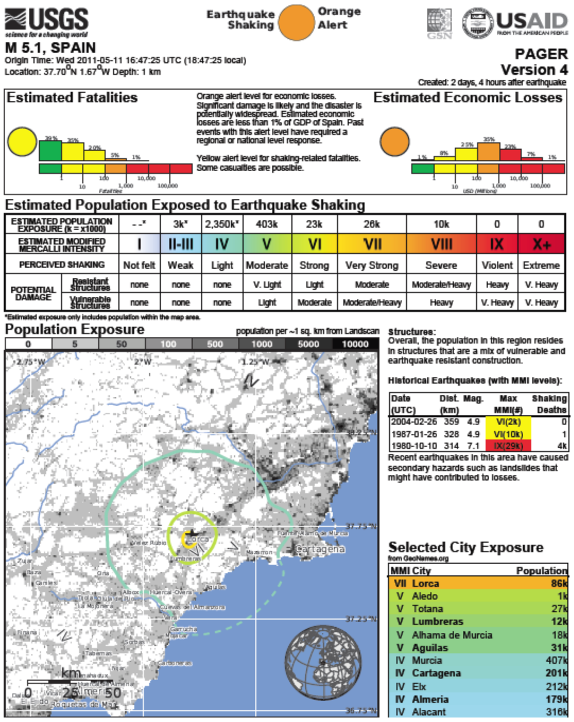
These events provide an unsurpassable opportunity to study and analyse, among other areas, the role that microzoning, urban planning and design can play in effectively mitigating hazard in the urban areas of the seismic-prone regions, where historical cities with significant heritage are sited. Planners provided with tectonic seismic local maps and detailed information of the sub-surface geology will make the right decisions in order to preserve not only lives but also the built existing environment and new buildings in future developments.

Besides the evident revision of NCSE 02, other building standards should be revised to guarantee not only a correct design but also the maintenance and retrofitting of buildings not meeting the requirement of seismic resistant design and codes in force, highlighting the need to include among them heritage structures.

Keywords*- *Earthquakes, Faults, Heritage Damages, Seismic-Resistant Structural Codes, Urban Planning in Seismic Zones

I. INTRODUCTION

The professionals related to the building sector are still not aware enough of the fact that Spain is a seismic country. The NCSE 02 needs urgent revision: nine people died under debris in the streets of Lorca, none of them due to structural collapses. Geotechnical matters such as the influence of local ground amplification should be reconsidered. Buildings with reinforced concrete (RC) structures but with set-backs, short columns, ground soft story, or incorrect anchoring of non structural elements, are examples of existing architectural and urban configurations non suitable for a correct seismic behavior. Damage of the rich heritage of the medieval and baroque buildings in Lorca evidence the need of specific inspections to determine their structural vulnerability, as well as the implementation of new reinforcement technologies for their masonry structures. Special urban planning for those historical-centre towns close to active faults is also required, but not only in Spain. Actions are to be taken in order to prevent similar effects in other Spanish historical sites with the same tectonic situation, such as Granada, Córdoba, Murcia, Alicante or Torrevieja, which are potentially laying on the same risks: Close to active faults, on grounds capable of doubling or even tripling the seismic waves. The 2009 earthquake of the Italian town of l'Aquila evidence that other European areas have the same risks. Besides, people in Europe and especially in Spain, are not as well trained as in Japan, California or South America, to follow the adequate behavior during seismic events to protect their lives.



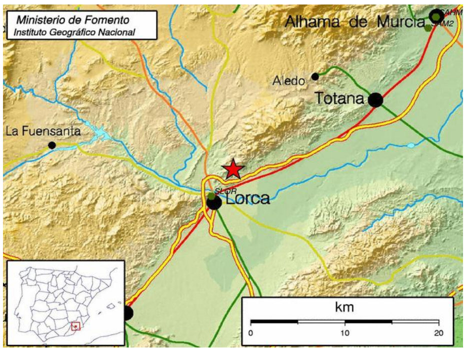


Fig. 1 Lorca's earthquake USGS chart: Data and map, above IGN chart: Epicentre (red star) and closest IGN stations (green point), under.

The municipality has an extension of 1,676 km²; the second largest in Spain, and is 353 m above sea level, located at 37 °41' N latitude and 1 °42' W longitude. It is the third most important town in Murcia, with a population of 92,869 inhabitants on January 1st 2011, according to the Spanish Statistics National Institute (INE).

Founded by the Greeks, Lorca is very well known not only for its historical and artistic architectural heritage, including one of the most important Baroque ensembles in Europe, but also for its Holy Week processions. They have been declared of International Touristic Interest and Lorca is fighting for them to be declared a World Heritage Festival by UNESCO.

The origin of most of the Baroque churches and civil buildings in Lorca is the 1674 earthquake, which destroyed all of the towers in town that were rebuilt in the style of the time.

II. LOSSES COST: 1,650 MILLION EUROS

The Lorca earthquake happened exactly two months after the 8.9 in magnitude earthquake that struck the Tohoku area in Japan, followed by a destructive tsunami that caused too severe damage to the Fukushima nuclear plant. What increased enormously the direct and indirect losses cost. The cost to be paid in Lorca has been estimated in more than 1,650 millions € (1 € =1.40 USD), forcing the president of the regional government of Murcia to claim from the European Commission to determine as fast as possible the amount of financial aid to be received from the European Solidarity Fund. The aid of the local, regional and national Spanish Administration will cover 50% of the costs.

The effects of the l'Aquila earthquake, with 309 victims, have been estimated at a loss cost of 3,000 million € (Fig. 7).

The number of victims in Lorca was not higher because the population was warned by an initial 4.4 event two hours before the strongest 5.1 event. Advice was given on radio, TV and Internet for the people to remain in the streets and open wide spaces, saving many lives.

TABLE I INFORMATION ABOUT EVENTS IN MURCIA IN THE LAST YEAR (OCTOBER 2010 - OCTOBER 2011)

Date	Hour (GTM)	Latitude	Longitude	Magnitude (Mw/mgLg)	Intensity (EMS)	Depth (km)	Location
From October 2010 till May 2011, there was no activity							
2011/11/05	15:05:13	37.70	-1.68	4.50 Mw	VI	2.0	NE Lorca
2011/11/05	16:47:25	37.70	-1.67	5.10 Mw	VII	2.0	NE Lorca
2011/11/05	20:37:45	37.69	-1.65	3.90 Mw	IV	4.0	NE Lorca
2001/07/30	23:49:22	38.17	-1.39	2.80 mgLg	IV	8.0	SW Blanca
2011/09/11	15:10:17	37.86	-1.79	3.10 mgLg	V	-----	NW Aledo
2011/10/02	19:39:49	37.84	-1.80	3.50 Mw	IV	2.0	NW Lorca

TABLE II INFORMATION ABOUT MURCIA AND ALMERÍA, FROM 15.00.00 TO 17.00.00 HOUR (GMT), DATE: MAY, 11TH

Hour (GTM)	Lat.	Long.	Mag. (Mw)	Int. EMS	Depth (km)	Epicentre	Stations Murcia (MU) and Almería (AL)	Dist. Epic. (km)	Max. Acceleration cm/s²		
									N-S	V	E-W
15:05:13	37.70	-1.68	4.5	VI	2.0	NE Lorca	Lorca (MU)	3.0	270.35	75.12	128.11
							Zarcilla de Ramos(MU)	24.6	6.39	8.25	10.16
							Alhama (MU) (Sports centre)	26.7	10.78	7.65	10.24
							Vélez-Rubio (AL)	35.7	3.34	1.91	2.62
							Mula (MU)	41.5	7.05	5.49	7.65
16:47:25	37.70	-1.67	5.1	VII	2.0	NE Lorca	Lorca (MU)	3.8	359.96	115.08	150.60
							Zarcilla de Ramos (MU)	24.6	35.15	26.19	3.99
							Alhama (MU) (Sports centre)	25.9	42.95	24.66	45.96
							Alhama (MU) (Library)	27.3	9.86	9.15	7.65
							Vélez-Rubio (AL)	35.9	10.76	5.97	9.32
							Mula(MU)	40.,4	35.88	20.21	41.63
							Vera (AL)	53.1	5.49	4.95	7.05
							Lorquí(MU)	55.9	8.19	4.06	8.13
							Murcia (MU)	57.3	7.17	3.46	8.36
							Cieza (MU)	63.2	2.39	1.37	2.72
							Olula del Río (AL)	67.2	2.57	1.82	4.62

TABLE III FINAL PARAMETRIC PROCESSED DATA: PGA AND PGV. IGN STATIONS MURCIA (MU), ALMERÍA (AL) AND JAEN (JA)

2011/05/11 15:05:13 Mw = 4,50 I =VI		NS Comp.		EW Comp.		Vertical Comp.	
Station	Dist. Epic. (km)	PGA (cm/sg²)	PGV (cm/sg)	PGA (cm/sg²)	PGV (cm/sg)	PGA (cm/sg²)	PGV (cm/sg)

Lorca (MU)	3.50	270.70	12.90	128.20	4.10	75.20	2.30
Zarcilla de Ramos(MU)	23.30	6.50	0.30	10.2	0.50	8.30	0.20
Alhama (MU) (Sports centre)	26.50	10.30	0.20	11.80	0.30	7.30	0.20
Vélez-Rubio (AL)	35.10	3.20	0.10	2.50	0.10	2.00	0.10
Mula (MU)	40.70	6.40	0.30	7.90	0.20	5.60	0.10
Lorca (MU)	2.90	360.0	35.70	151.70	14.70	114.10	7.20
Zarcilla de Ramos (MU)	24.40	25.40	2.20	32.10	2.10	26.20	1.30
Alhama (MU) (Sports centre)	26.70	41.10	1.30	44.20	2.10	23.60	0.80
Alhama (MU) (Library)	28.10	9.80	0.40	7.70	0.20	9.10	0.40
Vélez-Rubio (AL)	35.50	10.70	0.50	9.30	0.60	5.90	0.40
Mula(MU)	41.50	35.60	1.50	41.60	1.40	20.20	0.90
Vera (AL)	52.60	5.90	0.40	7.10	0.40	4.80	0.30
Lorquí(MU)	56.80	8.10	0.30	8.20	0.30	4.10	0.20
Murcia (MU)	58.10	7.20	0.40	8.50	0.40	3.50	0.10
Cieza (MU)	64.30	2.40	0.10	2.80	0.20	1.40	0.10
Olula del Río (AL)	66.60	2.50	0.30	4.70	0.30	1.80	0.20
Jumilla (MU)	91.80	4.10	0.30	5.40	0.40	4.40	0.20
Jaen (JA)	185.90	2.10	0.20	2.80	0.20	1.30	0.10

III. THE EARTHQUAKE: FIGURES AND DATA

According to the report drafted by the Geological and Mining Institute (IGME) of the Science and Innovation Ministry, a first seismic event (4.4 Mw) took place at 15:05 (GMT), followed by a series of minor events (6 tremors, magnitudes around mbLg 2.5) and a second significant shock (5.1 Mw) at 16:47, that lasted 5 seconds. Up to 200 minor events (between mbLg 0.4 and 3.9 Mw) were registered up until the 17th of May. Epicentres were located in the NE of Lorca (Fig. 1), at a distance of about 2 km, coinciding with the Northern part of the FAM. This Fault of a total length of 85 km spreads along the NW border of the Guadalentín Valley, from Alcantarilla (Murcia), to the outskirts of Góñar (Almería). Accelerations reached in the two main events were registered by the stations of the National Net of Accelerographs of ING in Table II and main events in Murcia in 2010-2011 in Table I. The final PGA and PGV processed data, in Table III, evidence that it has been the most important earthquake in magnitude of the history of the instrumental seismicity in Spain.

IV. DAMAGE: HERITAGE AND OTHER BUILDINGS

The earthquake caused 9 victims (among them two pregnant women and a fourteen year-old boy), 324 injured, and more than 15,000 people evacuated; the collapse of a multiple dwelling building in La Viña district and countless damage in 50% of the existing residential buildings. The number of seriously affected buildings in

La Viña and San Fernando districts was so especially high that the first one has become Lorca's Ground Zero (Fig. 22). The summary of the first field damage inspection, in which in no more than 6 minutes, each building was classified by colours (black, collapse or demolition; red, severe structural damage; yellow, light o moderate structural damage, requiring emergency works or non-structural severe o moderate damage; green, no structural damage, non structural severe or moderate damage) of the 6,419 RC and masonry structure buildings carried out was: 4,047 declared habitable, 1,283 slightly damaged, 723 heavily damaged and 329 to be demolished.

Two buildings were not inspected, as they had to be demolished before, and 35 remained uninspected (Table V).

Lorca Town Council implemented a geographical event viewer in its web page, to locate every inspected building in the municipality, which has proven to be a very useful tool for stakeholders (Fig.22 and 23).

The final figures obtained after a second inspection later on are reflected also in Table IV, as well as the retrofitting or rebuilding costs estimation, considering the criteria for the compensation and financial aid of the Royal Decree Law 6/2011 of Urgent Measures to Refurbish, Retrofit and Reconstruct the buildings in Lorca of the Spanish Government.

The Murcia region has a Seismic Risk Protection Plan since 2006, SISMIMUR, in which the vulnerability of each municipality has been analysed, determining the expected damage due to different intensity seisms that are susceptible to happen in the area.

TABLE IV BUILDING DAMAGE INSPECTIONS AND ESTIMATION OF THE RETROFITTING OR REBUILDING COMPENSATION COSTS

DAMAGE SCALE	FIRST FIELD INSPECTION	FINAL INSPECTION		RETROFITTING, RECONSTRUCTION OR REBUILDING COST PER UNIT				
				BLACK	RED	YELLOW	GREEN	TOTAL COST € (EUROS)
	NUMBER OF BUILDINGS	NUMBER OF BUILDINGS	DWELLING UNITS	106,000 € €/Dwelling U.	24,000 € €/Dwelling U.	20,000 € €/Dwelling U.	9,000 € €/Dwelling U.	
DEMOLISHED	2	-----	----					
BLACK	329	260	1,164	123,384,000 €				
RED	723	664	1,973		47,352,000 €			
YELLOW	1,283	1,569	4,594			91,880,000 €		
GREEN	4,047	5,383	16,124				145,116,000 €	
NOT INSPECTED	35	-----	-----					
TOTAL	**6,419**	**7,876**	**23,855**	**123,384,000 €**	**47,352,000 €**	**91,880,000 €**	**145,116,000 €**	**407,732,000 €**

TABLE V SIMULATION OF EXPECTED DAMAGE PER DWELLING UNIT IN LORCA AREA, DUE TO A VI/VII SEISM (SISMIMUR)

MUNICIPALITY	INTENSITY	COLLAPSE	VERY SEVERE DAMAGE	SEVERE DAMAGE	MODERATE DAMAGE	LIGHT DAMAGE	UNDAMAGED	TOTAL DWELLING UNITS
LORCA	VII	0	422	2,578	7,061	10,299	11,667	32,127
ALEDO	VI	0	0	0	29	111	405	545
TOTANA	VI	0	0	0	599	2,320	9,209	12,128
TOTAL		**0**	**422**	**2,578**	**7,689**	**12,830**	**21,282**	**44,800**

Fig. 2 Espolón Tower of the Castle ensemble, before and after the earthquake (left and centre), and under restoration (right). (Picture: Nandocd, www.flickr.com)

The damage was considerably minor, according to the simulation of a VI-VII intensity seism similar to the one that struck Lorca and surroundings, whose results are in Table V.

Public buildings damage has proved to be higher than initially estimated. The Hospital Rafael Méndez (built in the 80s) which had to be evacuated after the second quake and the Medical Center Santa Rosa de Lima have severe damage; the Lorca-Center Town Health Center had to be demolished, still with no determined term or economic provision for its reconstruction. The 3 Retirement Homes (Caser, San Diego and Domingo Sastre) had to be evacuated and their occupants relocated. The San Diego Home suffered serious structural damage and is still being evaluated. In relation to the educational buildings, 5 of the 23 Primary Education centre were severely damaged and 2 of the 6 institutes of secondary education had to be demolished: Institutes Ros Giner and Ramón Arcas Mecca, (built in 1972 and 1956), the last one preserving the sculptures on the main façade, were designed by the architect Miguel Fisac, who received the National Architecture Prize in 2003. In both buildings, the more recent extensions were also preserved and the cost of reconstruction is estimated at 22 million Euros. Meanwhile, a third of the students have been derived to other centers, in very precarious conditions. The amount needed to retrofit the educational buildings and rebuild both institutes included in the Budget for 2012 of the Regional Government was only 216,000 €. Other public buildings affected were the Music Conservatory Narciso Yepes, the Police Station and above all, the dwelling building of the Guardia Civil (Spanish State Police), which had to be demolished due to the severity of the damage. Regarding lifelines, preventive power and gas cut-offs took place after the seism and saturation of the mobile network was one of the biggest problems for the first field inspection technical teams.

State infrastructures were not so badly damage as buildings in general. The viaducts and tunnels of the Mediterranean motorway A-7 withstood, only suffering small damage, although A-7 was cut for 24 hours after the earthquake for evaluation of the cracking that appeared in the viaduct. The RM 701, a secondary road, was also cut between kilometric points 0.6 to 2.7 due to detachments. In rail infrastructures, Lorca-Sutullena Station was the biggest victim with serious damage on the top floor, which was demolished for safety. The public water authority, the Hydrographic Confederation of the Segura River Basin reported no damage in the reservoir dams of Valdeinfierno and Puentes apart from the collapse of the distribution water booths.

Lorca's Town Hall evaluated the direct impact of the earthquake in the municipality income in 841 million Euros, derived from the significant number of companies and businesses that have been affected and thus, prevented or limited in their activity, with the consequent loss of revenue. From a total of 1,181 shops, 59.94% (708) have been damaged, with an estimated loss of profits of 6,297,744.65; 58.8% (50) of the 85 artisanal enterprises too, with a loss of profits of 325,132 €. 71.6% (210) of the 293 hotel establishments present damage, ascending their profit losses to 4,071,506.48 €. The Town Hall launched the Plan Ayuda (Aid PLAN), with a budget of 1,500,000 € for financial compensation of the repairs to be carried out in the establishments, with a maximum of 8,000 € per business premise.

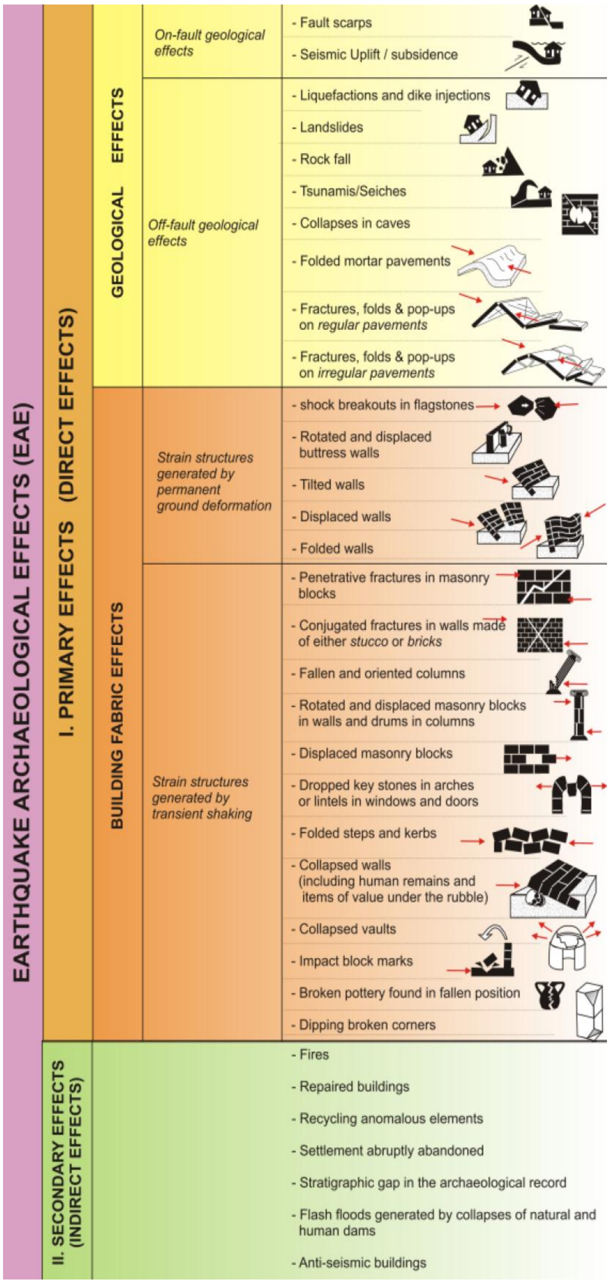


Fig. 3 Earthquake Archaeological Effects (EAE) Rodriguez-Pascua et al. (2011)

Structural geology techniques were used in the study of the historical building damage included in the IGME Report. More than a hundred effects were identified and classified in 33 masonry structural buildings, according to what Giner-Robles et al. (2009) and Rodriguez-Pascua et al. (2011) defined as Earthquake Archaeological Effects (EAE), depending on whether they are direct or indirect effects (Fig. 3). After analysing the global damage extent, the provisional budget was 50 millions €. Final figure, according to the Framework Plan for the Lorca's Cultural Heritage Recovery, drafted in July 2011, is 51,287,076.93 €. Complete restoration is scheduled to be completed in five years, if funds are available; too long taking into account the importance of tourism in Lorca's economy.

Fig. 4 Inside damage, Convent of the Virgen de Huertas (Authors own archive)

Fig.5 Damaged top of the tower, Church of Santiago (Scheme of the IGME Final Report)

Besides, only 60% of the required total sum is available for the moment. The restoration cost of the most significant buildings is the following:

- **Espolón Tower (XIIIth c.) San Antonio Porch, San Clemente Hermitage, medieval walls of the Castle and the National Parador** (public-owned luxurious hotel in historical site), near the synagogue. The Castle is a fortress built throughout Xth and XVIth centuries, declared Protected Cultural Asset in 1931. The Historical Centre of Lorca, including the Castle, was declared a Historical-Artistic Ensemble in 1964. Damage in the tower shows evidence of the main direction of the horizontal shakes, due to the NE location of the epicentre. Most damaged corners are those in the NE-SW diagonal of the plan (Fig. 2).

Final budget: 11,169,293.13 €. In restoration

- **Church of Santiago (XVIIIth c.)** Baroque style building, its dome collapsed after the second event (Fig. 7).

Fig.6 Damaged top of the Santo Domingo's towers, before partial demolition

The collapse analysis revealed that restoration works carried out in 1994, reinforcing the masonry structure with too rigid RC elements, did not reduce the structural vulnerability but even increased it, possibly causing the collapse. The bell tower shows also evidence of damage due to rotation (Fig. 5).

Final budget: 2,100,256.00 €. Unrestored.

- **Church of San Francisco (XVIth c.)**. Built in the Renaissance period, with a beautiful Classical main fa çade and Baroque interior, declared BIC, the provisional budget estimated for its restoration (2,500,000.00 €) in the preliminary report was the only lower than the final figure.

Final budget: 4,340,771.16 €.

- **Santo Domingo Ensamble (XVIIth-XVIIIthc.).** In the Main Street of Lorca, comprise the convent or church and the Rosario Chapel. Only three cloister fa çades reamined standing.

Final budget: 2,727,256 €. Under restoration.

Fig.7 Church of Santiago in Lorca (Spain), after dome collapse and similar damage in the Duomo of San Massimo in L'Aquila (Italy) (Photographs: Atlas Agency, 201-05-13 and AP/Alesandra Tarantino, 2009-04-07)

Fig.8 View of the West fa çade of the dwelling building that collapsed during the earthquake, located in La Vi ña Square

- **Church of San Patricio (XVIth-XVIIth c.**) Renaissance interior, Baroque fa çade, declared Historical-Artistic Ensemble in 1941.

Final budget: 2,960,000.00 €.Under restoration.

- **Guevara Palace (XVIIth-XVIIIth c.)** Also called the Columns House, originally was a luxurious Baroque residence, with a noble cloister. Declared BIC in 1984, it is one of the most representative buildings of civil architecture in town.

Final budget: 1,163,392.00 €.Under restoration.

- **Convent of the Virgen de Huertas (XVth c.)** Baroque ensemble, partly rebuilt in the XVIIth century, recently restored (Fig. 4).

Final budget: 2,525,000.00 €.Under restoration.

Fig.10 View from the main fa çade of the building that completely collapsed after the second event (Southern side)

Fig.9 One of the victims, under debris (Phtotograph: Globovisi ón)

Apart from historical buildings and others damaged in the historical town centre, all with masonry load-bearing wall structures, very vulnerable to seismic activity, a high number of buildings in the districts of La Vi ña (at the SW, with a population of about 4,900 people) and San Fernando (SE) were devastated, although, recently built in the 70s - 80s, with RC structures.

All of the victims were killed in the streets, by falling fa çades or non-structural construction elements broken loose from buildings. Roof and others parapets fell because of the inertial or shaking horizontal forces on the elements themselves (Fig. 9).

Other ornamental cantilever elements fell down because they were insufficiently or incorrectly anchored or tied to structural elements.

Portions of outer double-leaves traditional facades, due to the distortions imposed by the RC structure, swayed back and forth, or suffered separation-pounding at the interface between the adjacent structures (Fig. 12, facade building in demolished block, called San Mateo Residence).

A three story multi-dwelling building with ordinary moment frame RC structure collapsed after the second shock, because of the incorrect configuration of the basement columns.

Fig.11 View from the central area of the main fa çade of the same collapsed building of the former Figure.

Fig.12 Scheme of the difference between the theoretic model and the real behaviour, pillars of former pictur

Columns with shorter or variable effective height to that of the other regular ones within the same storey, called short pillars, are stiffer, and hence have increased seismic demand: higher values of induced horizontal forces during the earthquake than their counterparts; they are highly vulnerable. Brittle failure of short columns caused the collapse of the aforementioned building. A scheme of its ordinary moment frame RC configuration is presented in third place in Fig. 17. Other configurations including short columns, frequent in existing buildings in seismic-prone zones, due to the disposition of staircase landing beams between two floors or variation of column height with different ground floor levels, are included in first and second place in the same figure. Different pictures and a scheme of the collapsed structure in Fig. 8, 10, 11, and 13 to 16. Other short column structures in buildings in the same street did not collapse, but were severely damaged (Fig.16).

Masonry walls in direct contact with ground floor columns suffer an undesirable short storey effect, increasing the shear demand in columns accordingly, causing severe damage (Fig. 18).

Fig.13 View from the main street of the building collapsed (north part)

Fig.14 Irregular and not uniform distribution of masses, stifness, strength and ductility, combined with inexistance of masonry under first floor spans and different height of columns (soft story)

The inexistence of a sufficient gap between masonry and the columns restrains their free movement, causing the damage.

In recent buildings, damage in the RC structures are those to be expected in structures designed to support a peak of acceleration three times smaller than the value registered (soft-story scheme in Fig. 18). This explains why a number of structures remained standing but with such severe damage that they had to be knocked down as fast as possible after the quake.

Fig.15 Aerial view of the building that collapsed (detail of the north part)

In older structures, the effects can also be attributed to incorrect seism-resistant design, including columns, joints and others as well as lack of maintenance.

V. SPANISH SEISMIC-RESISTANT CODE: NCSE 02

In Spain, In Spain, the seismic-resistant design and construction structural code in use is NCSE 02. This is a result of the revision of the former NCSE 94 that substituted PDS-1/1974. This, in turn, had only been preceded by the first Spanish seismic-resistant standard, dating from 1968, PGS-1. That code did not include a seismic risk map, but referred to the one in MV 101, the building loads code in force at that moment. NCSE 02 is based on previous knowledge and includes the analysis of the most relevant earthquakes registered in Spanish history. It also applies new criteria and the lessons learnt from the latest destructive earthquakes such as Mexico (1985), Armenia (1988), Loma Prieta (1989), Kobe (1995), Izmit (1999) or Taiwan (1999) considering also, the rest of the European (Eurocode 8) and International standards, that have also been revised and renewed recently.

Fig. 16 Short column that did not collapse

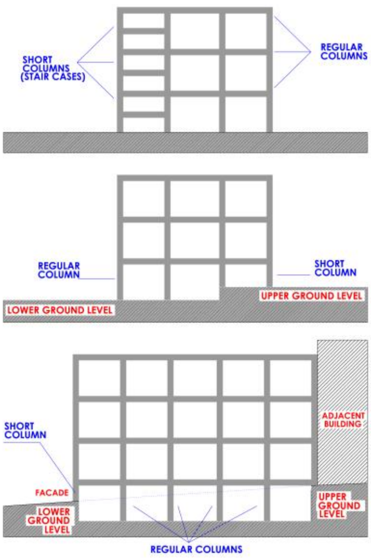


Fig. 17 View from the main street of the building that collapsed (detail of the north part)

Fig. 18 Soft-story damage and scheme (P. Murphy) and induced short column by masonry walls (A. Aretxabala)

The NCSE 02 map establishes a macrozonification for the basic acceleration values a_b (Fig. 19), the basis to obtain the design seismic acceleration, fundamental data required to design any seismic-resistant structure. The basic acceleration for Lorca is 0.12*g*. Granada and Alicante areas have values over 0.16*g*, being the highest 0.24*g* in the town of Santa Fe, in Granada. However, the most harmful recent seismic movements in Spain have been located in Murcia, which suffered five important seisms in the last 12 years: Mula (1999), Bullas (2002) y La Paca (2005, magnitude 4.4 Mw, 40 km away from Lorca) and the last one in Lorca (2011), all of them related to the FAM.

The seismic design acceleration resultant in Lorca, multiplying the basic by the rest of parameters to consider (four coefficients: contribution k = 1.00, ground type C =1.60, risk =1.00 and ground amplification, S =1.27) is 0.15*g*, clearly minor than the maximum acceleration registered, 0.41*g*. The fact that the hypocentre was so superficial and the epicentre so close to the town centre were crucial for the disaster. The crust structure of the ground in Murcia, like in the rest of the SE of Spain, is similar to an assembly of domino pieces horizontally laid: when one of them moves, all the others are affected.

Eurocode 7 Parts 1, 2 and 3 (General Rules/Ground investigation and testing) and Eurocode 8, Parts 1 and 5 (General rules, seismic actions and building rules/Foundations and geotechnical aspects) are Spanish Standards UNE in force (UNE-EN).

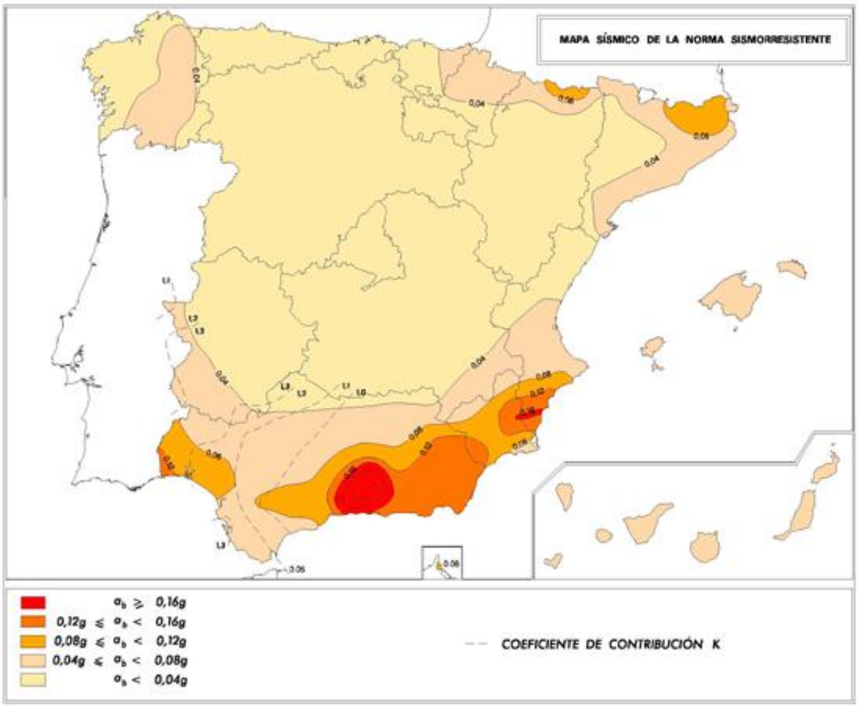


Fig. 19 NCSE 02 seismic risk map

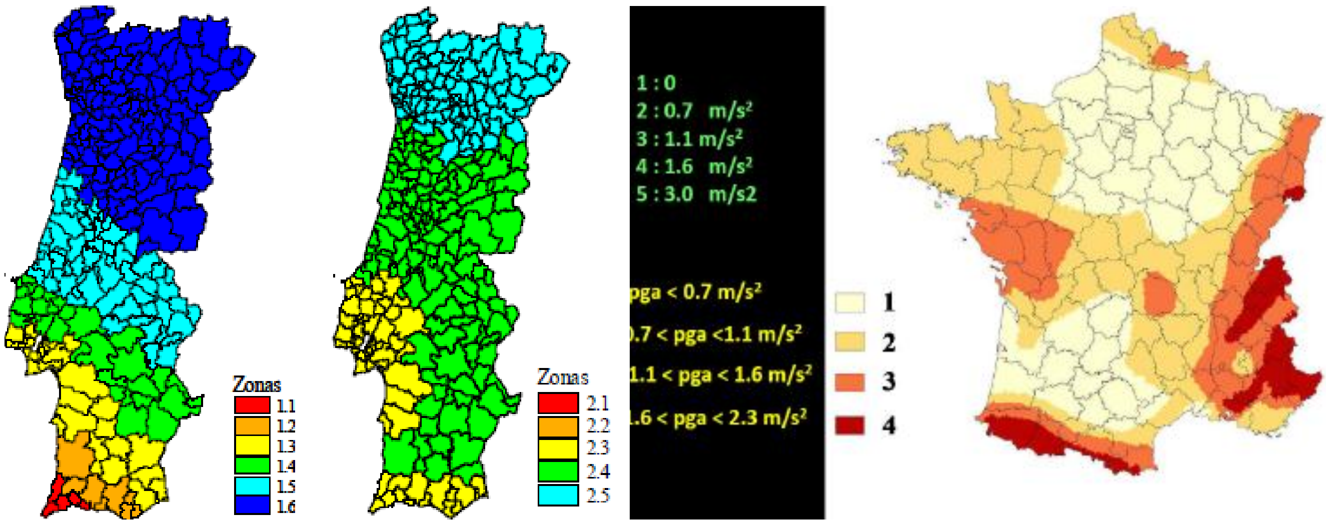


Fig. 20 Eurocode 8. Part 1. Risk maps of the nads of Portugal (above) and France (under)

A report on the proposal for the UNE-EN 1998-1 (EC 8, Part 1) National Application Document (NAD) was published in 2011, drafted with the collaboration of experts from Portugal, Italy and France, and having also analysed working papers from other European countries (such as Belgium and Germany).

This report includes the NCSE 02 map, highlighting the urgent need to modify its content in order to adapt basic seismic acceleration values to the maps of other countries around Spain, specifically in border areas like the Pyrenees (Fig. 20), with the values on the other side of the border being considerably higher.

The Ministry of Town and Regional Planning and Public Works of the Murcia Regional Government, together with the Lorca Town Hall are involved in publishing two documents, drafted by FECHOR Engineering, a very well known Spanish consultant on structural engineering: a Guide for the Definition of a Seismic-resistant Strategy for New Buildings and another volume, which will include examples, among them a building close to the one that collapsed, in La Viña, designing a new structure without short columns, substituted by RC walls. Both texts will include far more criteria for the structural seismic resistant design and the possibility of forbidding the design of short-columns not matter how they are reinforced is under consideration, as well as quoting as many preventive design details as possible in order to reduce the soft story effect. A revision of NCSE 02 should be considered anyway, but officially there has not been any information on the matter.

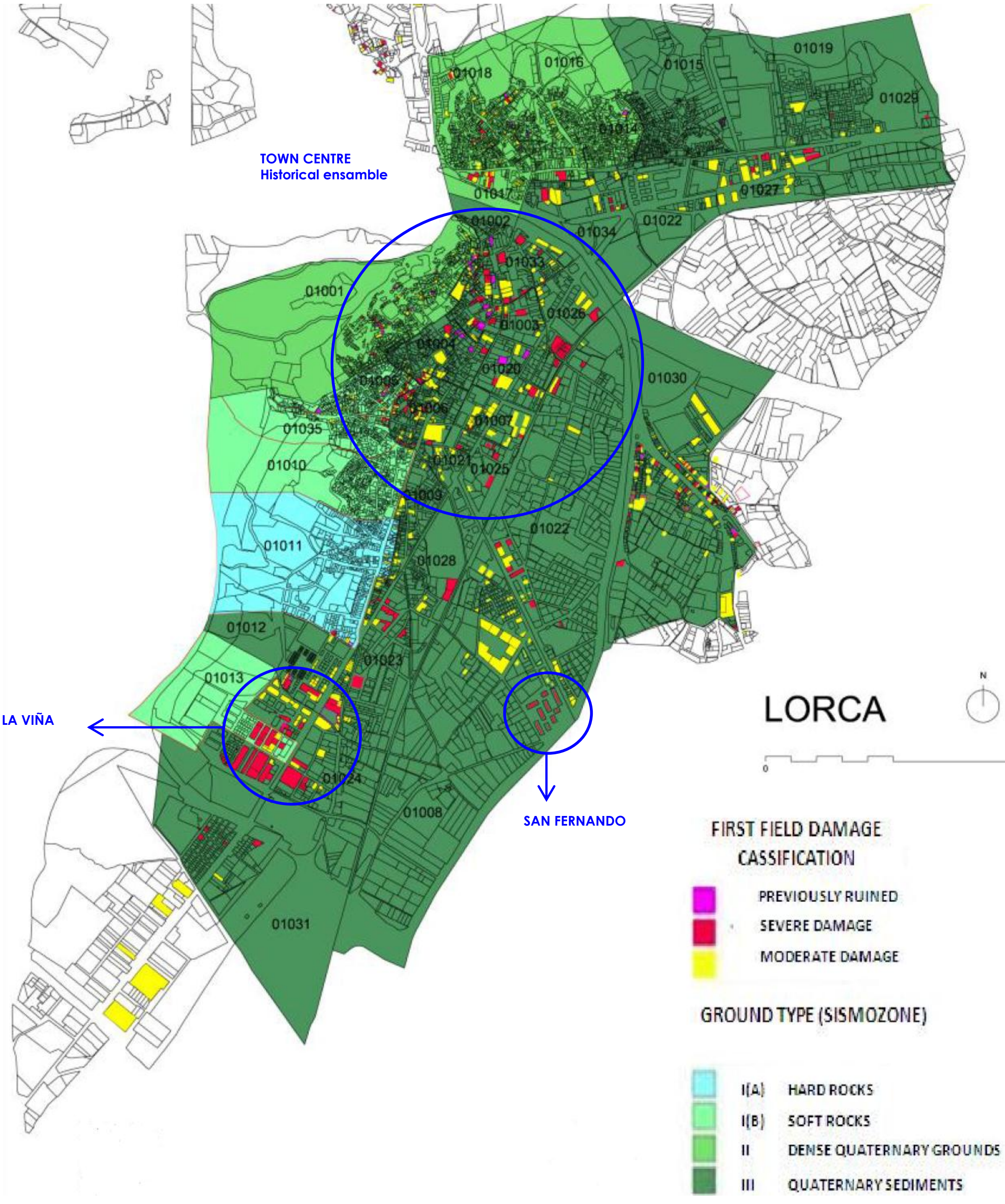


Fig. 21 Lorca first field damage classificaton and ground type (IGN, INFORME DEL SISMO DE LORCA DEL 11 DE MAYO DE 2011)

VI. Damage Explanation: The Ground

Lorca is placed on the axis of the FAM, both seismic movements that 11th of May were very superficial and the second was only 3 km NE from town centre. This explains the high number of minor events registered months after, located across the segments in which the FAM is divided into. Similar configurations exist not only in the region of Murcia but also in other in Spain (Navarra, Basque Country, Aragón and Cataluña) as well as in their counterparts on the north side of the Pyrenees, in the French Departments of the Pyrenées Atlantiques and Orientaux. Each segment of the faults has an average recurrent activity of a thousand years, and there are lots of them. This means that the probability of a similar earthquake every hundred years in other urban areas in the mentioned regions is high. It is also important to underline the fact that Lorca lays on a very rich geotechnical site, regarding the soil textures and specimens, underneath the municipality. The sediments of the Guadalentín River have generated a "cuvette" capable of amplifying the seismic waves, as it occurred. Due to the fact that part of these materials can be qualified as collapsible, the consequences are difficult to foresee. The year before the earthquake, the FAM was in an inter-seismic period with no activity at all except a few months before, (Table I) thus, it was quite predictable, with the obvious limitations that something could happen; some tectonic experts even announced it. The real unexpected issue was not the earthquake itself but the top basic acceleration generated.

VII. CONCLUSIONS

The earthquake consequences require a deep multidisciplinary analysis, in order to establish the lessons-learnt for seismologists, geologists, engineers, architects and stakeholders and taking into account not only building design in seismic risk areas, but also construction, use and maintenance of existent and new buildings.

After the seism, classified VII, it has been the first opportunity to apply the article 1.3.3 of NCSE 02 that requires that "*...in areas with intensity equal o higher than VII a report should be drafted, in order to analyze the consequences of the earthquake on buildings, as well as to determine the kind of measures to be taken*.". Furthermore, it has been very useful to evidence the significant lack of building standards and codes on building retrofitting, restoration or even structural reinforcement, so often underlined by the professionals. Thus, the criteria adopted in the urgent reinforcement of the most damaged buildings, generate serious doubts about the future behaviour of the structures, because in most of them damaged pillars or beams have been reinforced, but not their unions, the real key factor.

Actions must be taken in order to raise public awareness. It is essential to raise the awareness of the population, especially the building sector agents, regarding the existence in Spain of areas highly vulnerable to earthquakes. Preventive actions to face a high magnitude seism's striking in the future as well as the procedures to follow after should be determined before, instead of just implementing corrective measures after damage is caused. The Administration should transmit a clear message: Spain is a country with seismicity capable of killing people, damaging buildings and infrastructures and paralysing the economic activity of a whole region. The economic losses in Lorca are today socially unacceptable: a seism is not seen any more like an inevitable natural tragedy to accept but to be prepared for, in order not just to guarantee safeness of the people, but also of the property and urban environment itself, meaning an important change of mind.

Urban planning. Tectonic and/or seismic research should be coordinated with micro-zoning and urban planning development, in order to make the location, volume, number and height of buildings and other of their significant characteristics, consistent with the geological and seismic ground information available, as well as with the seismic resistant structural approach. Furthermore, urban development of areas with high seismic risk should require the previous elaboration of local maps, including among other natural risks, the seismic risk, as we do currently with floods in order not only to prevent building in flooding areas but also analyzing its impact in the existing buildings, in order to adopt specific measures.

National Heritage. Spain is the second country in the world in total number of National Heritage sites, only after Italy and before China. It is urgent to be conscious of the need of making an important investment in the future of Spain, one of the most important countries regarding cultural tourism. Spanish Heritage should be promoted to the highest level in the scale of priorities, providing the regions with the most important cultural or historical richness with special plans related to seismology and Heritage preservation. Possibly, one of the most ambitious tasks for the future may be to plan the retrofitting of all the historical buildings. This requires not only foreseeing their structural behaviour during an earthquake, but also to provide the economic and technical means to carry it out. Other ways, we should be aware of the fact that there is a high risk that a significant number of them may have to be demolished if damaged by an earthquake, like it happened in New Zealand after the 2010-2011earthquakes.

Constructive non-structural elements. There is a lot to do regarding their design and construction, in their specific building codes, but in a coordinated matter with the seismic resistant codes, especially in relationship with masonry elements like roof parapets and façade walls.

Local seismotectonic zoning. Revision of the maps in zones where seisms of L'Aquila or Lorca type could happen is required, as well as a new approach to the response spectrums from waves generated by shallow or superficial faults' activity. Once the CPNS, the Spanish Committee responsible for the seismic resistant codes, finishes the new macroseismic risk map (in which the acceleration values for certain areas are the double of those of NCSE 02), the values of the NCSE 02 ground contribution coefficient k should be reconsidered too.

Fig. 22 La Viña district building damage, Lorca's Town Hall Visor

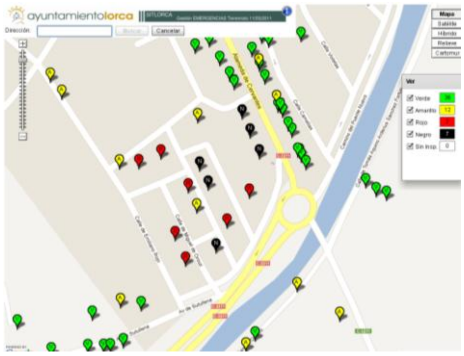


Fig. 23 San Fernando district building damage, Lorca’s Town Hall Visor

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