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Earthquake vulnerability assessment procedures for a large sized town; a case study of Cadiz city

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Abstract

Extracting and ordering information from building stock databases for earthquake vulnerability assessment is fraught with difficulties. Databases are rarely up do date, relevant information required for vulnerability classification is often unavailable, and results are often difficult to interpret.
The infra-municipal districts of the city of Cadiz have been analysed for earthquake vulnerability assessment as course of the RISTE project, dealing with tsunami and earthquake risk in the six municipalities of the Bay of Cadiz. A vulnerability assessment methodology was drawn up incorporating on-site field surveys and a multi-sourced building database analysis. The results are analysed in terms of the RISKUE vulnerability indices, the EMS98 grades, and the FEMA 78 method.
This work offers discussion on different vulnerability assessment methods, database analysis, and suitability of multi-sourcing information from different databases and on-site field surveys, as well as discussing useful and meaningful methods of conveyance.

Key-words: Seismic Risk, Urban Hazard, Vulnerability, Cadiz.

1. Introduction

The city of Cadiz has been analysed as part of the RISTE project, assessing earthquake and tsunami risk in towns bordering the Bay of Cadiz. The project is an opportunity to test different vulnerability assessment procedures against urban scale. With regard to vulnerability studies in Spain, large efforts have been undertaken at large-scale regional levels, such as the SISMICAT (2003), SISMIMUR (Murphy et al., 2006), SISMOSAN (Murphy et al.,2007), and RISNA (Murphy Et al., 2009) but there are fewer smaller scale undertakings, mostly performed by various authors for the city of Barcelona and other zones of the Pyrenean region, (Irizarry, 2004; Irizarry et al., 2004; Roca et al., 2006a & 2006b; Barbat et al., 2006; Lantada, 2007; Irizarry et al., 2007)

Cadiz is a small sized heritage city of about 5.000 buildings with a marked geographical context located on a tombolo off the SW Atlantic coast of Spain. A vulnerability study was performed during the course of 2007 and 2008 on the basis of field surveys and database analysis for risk assessment using different approaches, including EMS98 (Grünthal,1998) vulnerability types, RISKUE (Mouroux et al., 2004; Mouroux and Lebrun,2006) vulnerability indices and FEMA 78 (Federal

Emergency Management Agency USA) vulnerability codes. This paper analyses the process followed and identifies pros and cons of different methods.

1.1. Databases

The absolute minimum facts required for a successful vulnerability study are number of buildings and structural types. There are two main sources of building databases in Spain, the National Institute for Statistics (INE) including their regional agencies, and the National Cadastre Institute. None of the two agencies collect information on structural typologies of the type required for a vulnerability assessment, so this has to be inferred by other means.

1.2.1. INE databases

The INE holds the most detailed information available regarding building stocks in Spain both in terms of building description and urban scale, the information being available to a city borough level, (infra-municipal) but with the disadvantage that campaigns are held every ten years. Research conducted towards the end of a ten year period is therefore considerably outdated unless a method is devised to update the building stock information. INE databases are readily accessible online for desktop research.

1.2.2. Cadastre databases

Because the cadastre institute has a fiscal bias, databases are updated on a yearly basis and readily accessible online for desktop research, but scale is generally restricted to a provincial or municipal level. The detail of information is also limited, there is no information regarding structural types and there is often no data regarding items such as number of floors. If cadastre technicians are available for participation in research, however, a very detailed and tailored database can be drawn up. This is only likely to happen on projects that secure support from the authorities, or when regional or national authorities are the client.

1.2.3. Other sources

The Spanish Housing Ministry publishes statistics on a yearly basis, and because housing accounts nationwide for 93% of the full building stock, this information is also relevant for vulnerability studies. Again, problems arise with insufficient scale and detail. Individual town halls and architectural professional colleges also hold statistics in their respective areas but this is not readily available and considerable politics are required to gain access to this information.

1.2. Problems

A comparison between the Cadastre database and INE database for the same location for a particular year will produce different values, and over large geographical areas this can be considerable. For example, the city of Cadiz held 5.100 buildings according to the cadastre database in the year 2001 as compared to 5551 buildings according to the INE, but for the total six towns of the bay area these figures are 55.933 and 64.704. This is most likely due to different criteria in the consideration of what is considered a building, remembering that different agencies have a different bias.

When sourcing information from different town halls or national or regional agencies, it is difficult to achieve consistent information in terms of dates, scale or content. Dealing with multiple sources can therefore quickly become unmanageable. Local authorities in Spain are sometimes reluctant to disclose information because of concerns that results may compromise the authorities or the image of a location in some way.

The three main vulnerability methods adopted were the EMS 98 vulnerability types, RISKUE vulnerability indices and FEMA 78 vulnerability codes.

1.3. EMS98

The EMS98 scale identifies 6 vulnerability types of which three types (D; E and F) correspond to engineered structures incorporating earthquake resistant design. (ERD)

1.4. RISK-UE Vulnerability Index (VI)

This method, devised for European cities identifies 23 basic structural types, but differentiated in low, medium and high-rise groups, totaling 65 vulnerability types. For engineered buildings incorporating earthquake resistant design architects consider this is a controversial issue, because for a specific hazard value, all buildings have to meet the same code stability standards whatever their geometry or number of floors. It is therefore controversial to state that code-compliant buildings are more vulnerable simply because they are taller.

The IV method also allows for considerable refinement of the index values by considering building geometry, placement, irregularity, conservation state, and other factors which are best suited to a case by case building study.

This methodology has been applied to the city of Barcelona (Roca et al., 2006b) as part of the RISK-UE project both for dwelling buildings (Lantada, 2007) and monumental buildings (Irizarry et al., 2004). Within the ISARD project (Goula et al., 2007). The Risk-UE vulnerability index method was also implemented for the development of seismic risk scenarios for the French and Spanish sides of the Cerdanya Valley and Andorra (Irizarry et al., 2007; Gonzalez et al., 2007).

1.5. FEMA

The Federal Emergency Management Agency FEMA 178 NEHRP Handbook for the seismic evaluation of existing buildings (FEMA 1992) of the USA defines 16 structural types similarly divided in to building height brackets, resulting in 36 vulnerability types. These types make specific reference to North American building types. An important characteristic for the relevance of this method in Europe is that all unreinforced masonry types are rolled into one label, causing a considerable loss of detail for these types.

1.6. Field Survey

Regardless of the source, no database in Spain holds consistent information regarding structural types of buildings. These must be inferred through some method and a field survey is the best way to identify them.
Field surveys are time consuming and require extensive manpower to be statistically significant. However, useful information can be obtained with brief surveys. Architects can exercise confident judgment of the structural composition and approximate age of a building at a glance, and are best appointed to perform this type of work.

1.7. Fieldwork methodology

Observers often make direct EMS98 or VI evaluations from buildings on the field, but it is best to prepare an inventory of the main structural types existing in the field and make conversions later. This ensures transparency in the process and allows an inventory of structural types specific and contextual to a region. For Cádiz, a total of 7 structural types were defined as best representing the building stock of the town (Irizarry et al., 2008). These were identified with a project code as shown in Tab 1.

Tab 1 Building types identified during the field survey for the city of Cadiz.

Code	Description
EMPOFM	Limestone simple stone masonry with no diaphragm action from wooden floors
EMLFM	Brick masonry with no diaphragm action from wooden floors
EMMOFM	Fieldstone masonry with no diaphragm action from wooden floors
EMLFH	Brick masonry with rigid reinforced concrete floor slabs
EHP	Reinforced concrete frame with masonry infill walls before 1976
EHP74	Reinforced concrete frame with masonry infill walls after 1976 and before 1996
EHP94	Reinforced concrete frame with masonry infill walls after 1996

For each structural type, a characteristic model was drawn up identifying the main parameters of the building type, as shown in Fig 1.

Fig 1 Two of the building type models defined in Tab 1

The project types were then analysed in light of the different vulnerability methods, and conversions made with a matrix table. This allowed the project types to be analysed in different ways without loss of original information. Tab 2 shows the conversion of the EMPOFM model to the EMS 98, RISK-UE and FEMA vulnerability types.

Tab 2 The EMPOFM model as seen by different vulnerability methods

Name	Equivalence	Nº Floors	Value
EMPOFM	EMS 98	All	B
	I_V RISK UE	1-2	0,72 M12L
		3-5	0,76 M12M
		+6	0,80 M12H
	FEMA -178	1-2	34-URML
		3+	35-URMM

1.8. Building Age

Many European cities have experienced continuous occupation for centuries resulting in a varied building stock, but many building tendencies are time dependant. Breaking down the building stock into time windows will reveal common construction characteristics prevailing in different times. A time-based analysis will also reveal keystone changes like the appearance of technical codes, earthquake resistant codes or the appearance of new structure types such as reinforced concrete.

Because building databases in Spain do not record structural types, the field survey is the right time to correlate building types to specific ages. For this reason it is best to identify areas or boroughs of a town that correspond to a specific urban expansion period. In Cadiz, surveys were conducted in the historical town centre, and the 19th and 20th century expansion belts. In Tab 3 is the type of information that was recorded during the survey.

Tab 3 Sample of Information collected for specific buildings in the historical quarter of Cadiz

Code	Nº	F	Age	Project type	EMS 98	RISK-UE VI
CA-CORRALÓN CARROS	48-50	3	<1900	EMLFMP	A	11
	52	3	<1900	EMLFMP	A	11
	54	4	C.1960	EHP	C	35
	56	3	<1900	EMPOFMP	A	4
	58	5	C.1965	EHP	C	35
	60	3	C.2000	EHP-94	D	35
	62-64	3	2007	EHP-02	D	35
	66	2	<1900	EMPOFM	B	3
CA-CRISTO MISERICORDIA	3	5	<1900	EMPOFMP	A	4
	5	5	C.1965	EHP	C	35
	26	3	<1900	EMLFM	B	11
CA-LA PALMA	7	3	C.1950	EMLFH	C	20
	9	3	<1900	EMLFM	B	11
	11	3	<1900	EMPOFM	B	4
	13	3	<1900	EMPOFM	B	4
	15	4	<1900	EMPOFM	B	4
	17	3	<1900	EMPOFM	B	4
	19	3	<1900	EMPOFM	B	4
	21	4	C.1950	EHP	C	35
CA-SAN FELIX	2	3	C.1970	EHP	C	35

Other relevant information was also recorded, such as the incidence of structural refurbishments which are difficult to detect in a database, and have a positive impact in vulnerability estimates. The classification of the building stock into relevant dates coinciding with major structural changes such as the introduction of reinforced concrete or the publication of a specific mandatory earthquake resistant code allows a time-dependant matrix to associate building types to the building stock database. As shown in Fig 2.

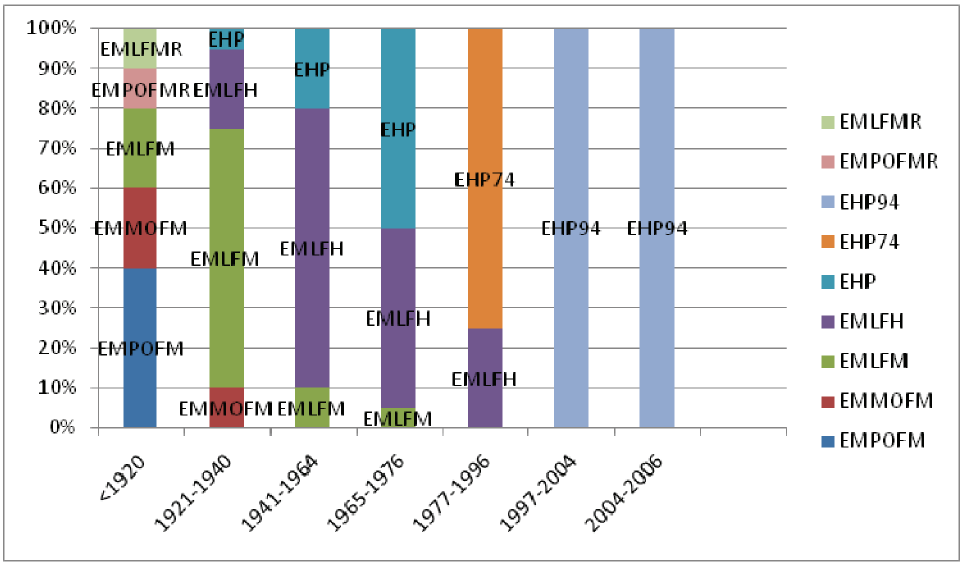

Fig 2 The time – dependant matrix relating project types to specific date brackets

1.9. Growth Index

The use of a growth index has proved to be a valuable tool for rapid database update. For the case of Cadiz, there is detailed information in the INE database regarding number of floors, building height and detailed geographical locations until the year 2001. From the cadastre database we can complete the absolute number of buildings until 2007, but we do not have the same detail regarding number of floors or geographical location.

A growth index was devised which allowed to complete the estimate of the building stock to the year 2007 based on replicating the urban tendencies observed regarding building height during the last years of the INE database.

2. Results

Although vulnerability studies are typically performed as an intermediary step between hazard and risk assessments, valuable independent information can be obtained from those results. A colour based pie was chosen to display the global results, using a range of red tones for traditional structures and blue tones for engineered structures, allowing the viewer to grasp at a glance an immediate feel for the building composition of the study area, as shown in Fig 3.

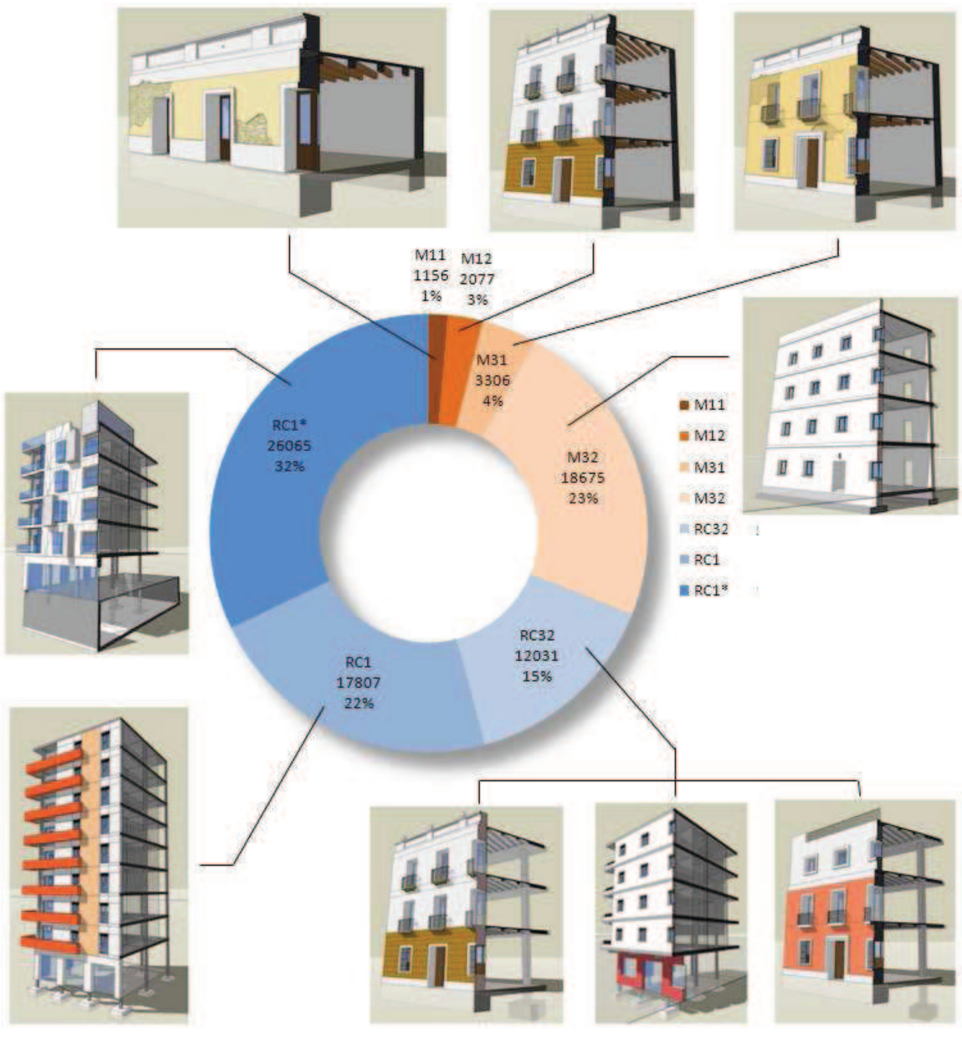

Fig 3 Vulnerability results for all the buildings in the study area of the Bay of Cadiz. In shades of blue, traditional building types. In shades of red, engineered structures. Each pie sector has the total estimated number of buildings and their proportion regarding *the* whole. Codes correspond to the RISK-UE vulnerability index types, the preferred method chosen for Cadiz.

At a smaller scale, the information for the city of Cádiz is displayed at an infra-municipal level with bar charts following the same colour code for all buildings in the town boroughs. An immediate and easily comprehensible building distribution can be seen, with the inner city boroughs 1 – 5 showing a heavily aged building stock, whereas the peripheral boroughs 7-10, occupied during this last century has a larger proportion of modern engineered buildings, as shown in Fig 4.

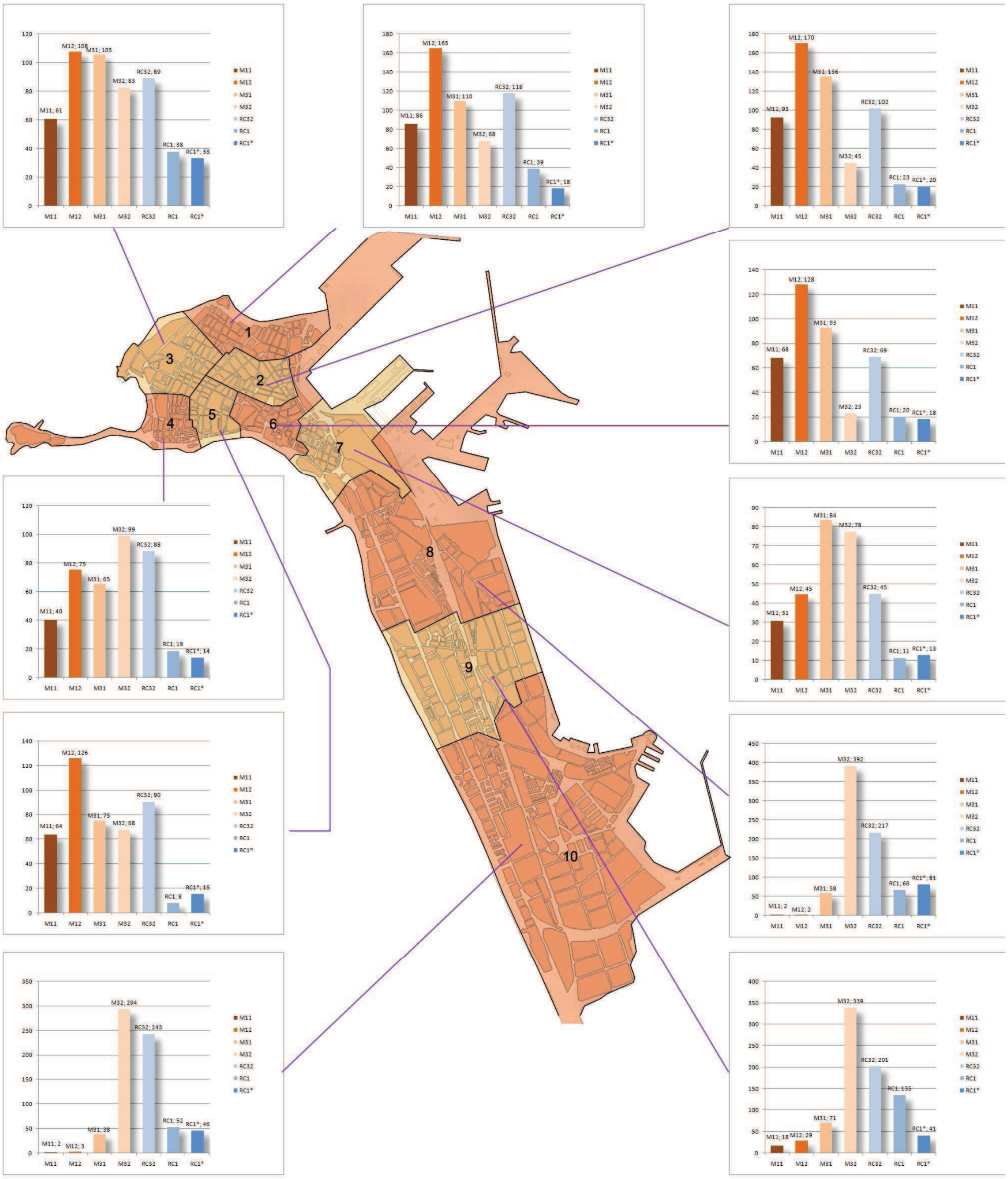

Fig 4 Vulnerability results for all buildings in the 10 urban boroughs of the city of Cádiz in 2007. In shades of blue, traditional building types. In shades of red, engineered structures. Each histogram has the total estimated number of buildings and their vulnerability assessment referred to the total for each borough. Codes are the RISK-UE vulnerability index types, the preferred method chosen for Cadiz.

3. Discussion

Vulnerability is the constantly changing factor in the Hazard – Risk equation. Hazard is constant through time, but building stocks change in a daily basis. Buildings are replaced, retrofitted, new codes are published, and continuous urban expansions result in a constantly changing building stock.

Risk assessments take a snapshot of the state of the building stock dating from the latest database entry, but the relevance of the results will become quickly out of date over a few years.

The growth index proved to be a useful tool for the database completion and its use may allow Risk studies to be quickly updated by scientists and authorities without the cost and manpower of repeating full hazard and risk studies.

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