OVERWIEV OF RECENT SEISMIC RISK ANALYSES IN SPAIN

Jorge M. Gaspar-Escribano[1] **and Belén Benito**[1]

[1] *ETSI Topografía, Geodesia y Cartografía, Universidad Politécnica de Madrid, Spain*
Email: jgaspar@topografia.upm.es, ma_ben@topografia.upm.es

ABSTRACT :

Different institutions have produced or updated regional seismic risk studies in particular regions of Spain. Despite the final purpose of all these studies is the same (to serve as basis for the development and implementation of local emergency and response plans), approaches to estimate risk to structures and individuals differ significantly from one study to another because these institutions worked independently. The technical characteristics of the different risk studies are analyzed and discussed in this presentation.

KEYWORDS: Seismic risk, Civil Protection, Emergency planning, Spain

1. INTRODUCTION

Spain is an area of low-to-moderate seismic activity, with relatively low seismic hazard in a worldwide perspective. Although several strong, damaging events have occurred in the recent past, they are not as frequent and destructive to endure in people's memory. For this reason and because other natural hazards (heavy storms, floods) are more common in Spain, seismic hazard is deemed as a secondary issue, and consequently, earthquake protection and preparedness measurements are not as developed as in other countries with higher seismicity.

The *Basic directive of civil protection planning against seismic risk* (Directriz básica de planificación de protección civil ante el riesgo sísmico, DBPPCRS, 1995, updated in 2004) is the country-wide Spanish norm that sets up the general conditions under which emergency response plans for earthquake disasters ought to be carried out, as well as their general characteristics. Three action levels may be distinguished: general, regional and local. The general level is represented by the seismic hazard map of Spain contained in DBPPCRS (2004), which gives expected MSK intensities for the 500-year return period used as reference for many preliminary evaluations. Regions displaying relatively high hazard on this map ($I_{MSK} \geq VI$, Fig 1) must develop *special regional* plans for earthquake risk. The development of these regional plans, from its design to its eventual implementation, is responsibility of the respective regional authorities. However, all regional special plans must be *accredited* by the *National Commission for Civil Protection*, implying that they are granted official normative status. After accreditation, results of regional seismic risk studies are used to establish the municipalities with high hazard levels (typically Intensity≥VII) that have to develop and eventually bring to practice *local* plans for earthquake risk and emergency response. Whilst the general plan is completed, special regional plans are under development and only a few local plans are terminated.

This paper focuses on the technical part of the respective regional seismic risk studies carried out in the last years. First, general characteristics of the seismic risk studies are commented. Subsequently, details on approaches to the different parts composing the different seismic risk studies (seismic hazard, vulnerability, damage, exposure and costs assessments), are analyzed, indicating alternative options and choices. Finally, the consequences of following alternative approaches to seismic risk assessment are discussed.

2. ACCREDITED REGIONAL RISK PLANS

Up to date, only four Spanish regions got their regional seismic risk plans accredited: Catalonia (Plan SISMICAT), the Balearic Islands (Plan GEOBAL), the Region of Murcia (Plan SISMIMUR) and the Basque Country (Fig. 1).

The plan of Extremadura is being examined for accreditation and the plans of Valencia, Andalusia and Galicia are in an advanced stage of execution.

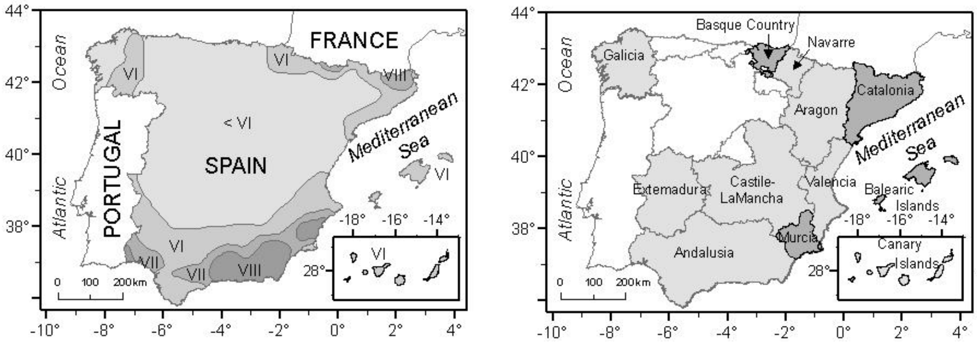

Figure 1 Left: DBPPCRS seismic hazard map of Spain (DBPPCRS, 2004); right: regions (in grey) that must develop specific regional seismic risk studies (regions with already accredited plan are shown in dark grey).

The technical part of these plans has been carried out in almost all cases by university departments or research institutes. As the DBPPCRS does not provide detailed specifications over technical aspects of risk studies, approaches to seismic hazard, structural vulnerability and expected damage assessments differ from one regional plan to another. A general trend to use probabilistic methods (eventually combined with deterministic methods, as in the regional plans of Catalonia, Balearic Islands and Basque Country) and to present hazard maps in terms of macroseismic intensity (similar to the DBPPCRS) is observed (Roca et al., 2006; Benito et al., 2008). The main characteristics of accredited risk studies are shown in Table 1.

At this point, it is worth mentioning the joint initiative of Civil Protection and the National Geographic Institute of developing a GIS-based, freeware application for simulating seismic scenarios, which calculates estimated losses in residential buildings and casualties at the affected municipalities (SES, Barranco and Izquierdo, 2002). SES is amply used for the production of preliminary studies and can be considered as a reference tool for seismic risk assessment studies in Spain.

2.1. Approaches to seismic hazard evaluation

The low seismic activity of Spain determines the characteristics of seismic hazard assessments at Spanish sites, which are affected by strong limitations on seismogenic source characterization and on instrumental data availability. This leads to great epistemic uncertainties on the entire analysis. The main characteristics of the basic approaches to seismic hazard evaluation are shown in Figure 2: the SISMIMUR approach (in blue) and the SISMICAT approach (in red/magenta), also followed in GEOBAL.

2.1.1. Seismic sources characterization

Studies on characterization of seismogenic sources for hazard estimation purposes are limited in Spain and usually refer to specific faults and not to faults covering an entire region. There are some exceptions in which seismic parameters have been provided, such as the work of Sanz de Galdeano et al. (2003, 2006) in some Tertiary basins of southern Spain, García-Mayordomo (2005) in southeast Spain, and Perea et al. (2006) in Catalonia. For this reason, most seismic hazard studies in Spain use the standard zoning method, which assumes homogeneous spatial distribution of earthquakes, to model source activity.

This is also the case of all the regional hazard studies presented in this paper. Only the seismic hazard study of Murcia ~~also~~ includes specific faults as seismic sources in addition to seismogenic zones (García-Mayordomo et al., 2007). The zoning model usually adopted in the regional hazard studies is either a newly developed zoning model (Secanell et al., 2004), either a combination of regional and general zoning models integrated into a logic tree

(García-Mayordomo et al., 2007). In all cases, seismicity is modelled with a Gutenberg-Richter distribution. The size parameter is either macroseismic intensity or moment magnitude (Mw).

Table 1 Characteristics of seismic risk studies contained in accredited regional plans

	SISMICAT (Catalonia)	GEOBAL (Balearic Islands)	SISMIMUR (Murcia Region)	Basque Country Plan
SEISMIC HAZARD				
Method	Probabilistic (Deterministic)	Probabilistic (Deterministic)	Probabilistic	(pseudo-Probabilistic, Deterministic*)
Size parameter	MSK Intensity	MSK Intensity	Magnitude Mw	Intensity
Ground motion parameter	Intensity	Intensity	PGA and SA	Intensity
Source definition	Region-specific Zoning	Region-specific Zoning	National and Region-specific Zoning, Faults	None (maximum event related to mapped faults)
Magnitude distribution	Gutenberg-Richter model	Gutenberg-Richter model	Gutenberg-Richter model	Gutenberg-Richter model
Attenuation	Constrained with local data	National standard	Combination of three models	National standard
Uncertainty	Monte Carlo (Seismic param.)	None	Logic tree (zoning and attenuation)	None
VULNERABILITY				
Classification	Several (adapted to EMS 92)	None	EMS 98	None
Method	Statistical and Expert-based	None	Statistical and Expert-based	Qualitative
Proxies	Age, number of stories, location	None	Age, location. seismic-code renovations	Number of buildings per unit area, location
DAMAGE TO STRUCTURES				
Classification	EMS 92	None	EMS 98	Ad hoc
Method	Damage Probability Matrices	None	Damage Probability Matrices	Qualitative
REPRESENTATION				
Geographic Working Unit	Municipality	Municipality	Municipality and smaller	Municipality and smaller

2.1.2. Attenuation model

Another key element is the choice of the ground-motion attenuation model. Again, the type of size parameter adopted determines the type of model used. Using intensity as earthquake size parameter allows using attenuation relations constrained with local data. The resulting seismic hazard map is expressed in terms of expected intensity, which despite being a damage parameter; it is used as ground motion parameter (SISMICAT, GEOBAL). A more complete characterization of expected ground motions can be obtained by means of attenuation relations that use magnitude as size parameter and predict the entire response spectrum (SISMIMUR). However, there are no such equations derived with local data (at least for the range of expected motions of interest).

2.1.3. Treatment of uncertainties

The importance and treatment conferred to this issue is also highly variable amongst the respective seismic hazard studies of the different accredited plans. Whereas some plans (GEOBAL, Basque Country) simply do not mention it, others focus on estimating the epistemic uncertainty related to different choices of zoning models and non-local attenuation relations (SISMIMUR) or the aleatory variability associated to different seismic parameters through a Monte Carlo experiment (SISMICAT).

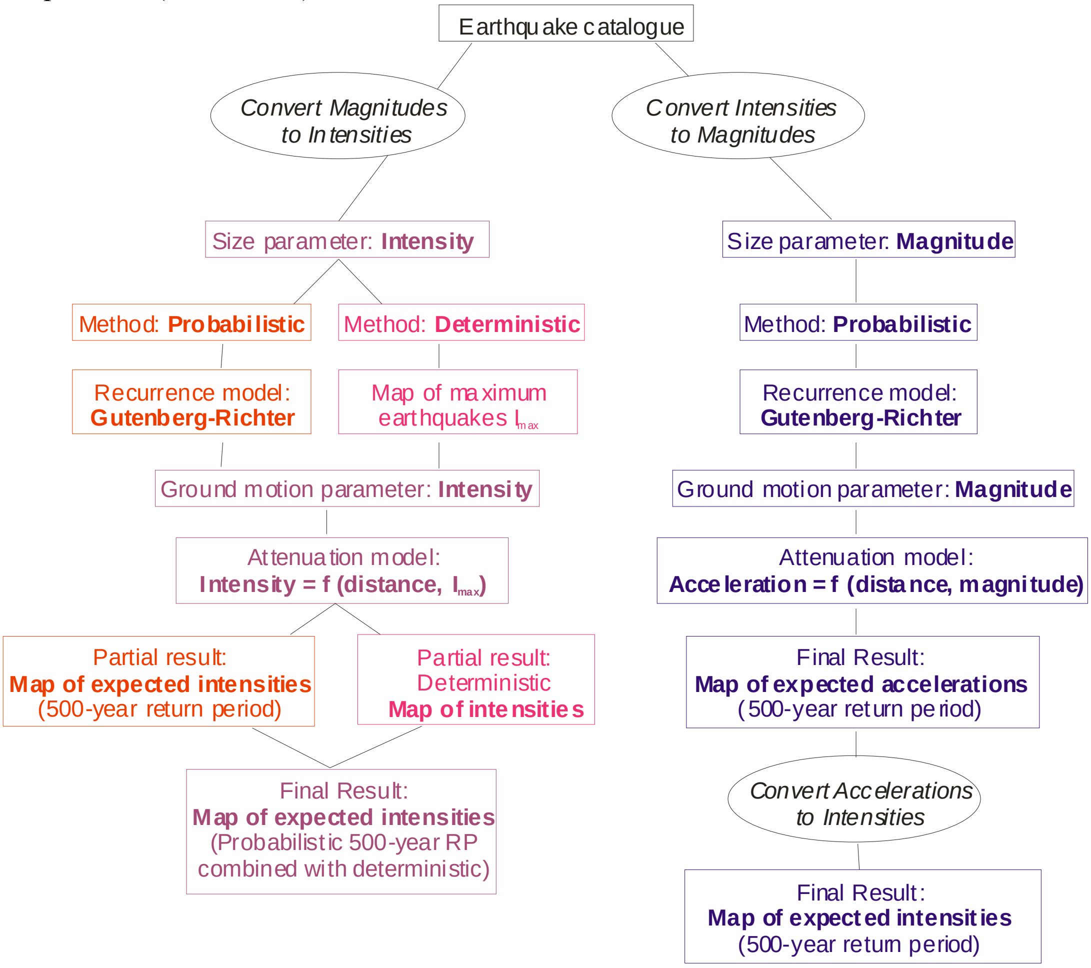

Figure 2. Steps of regional seismic hazard analyses in SISMIMUR approach (in blue) and in SISMICAT and GEOBAL approach (in red/magenta).

2.2. Approaches to seismic vulnerability assessment

Due to the regional nature of the analysis, approaches to seismic vulnerability characterization are rather general. Vulnerability classifications of extended use in Europe (MSK and EMS scales) and with a notable qualitative character are preferred. Factors such as building age, number of stories, geographical location (urban or rural), renovations of seismic-code specifications, maintenance or gross (visual) constructive classifications, are utilized as proxies to seismic vulnerability. Part of these data is available from urban planning administrations and technical reports and part is collected during field surveys. A rational combination of *in situ* vulnerability assessments to particular, limited groups of buildings, with general vulnerability assessments (based on distributions of data proxies available for the entire building stock of the region) serves to estimate the vulnerability distribution in the target region. Other methods for damage estimation, such as the capacity spectrum method (ATC-40, 1996) or its modified version (ATC-55, 2005) and the vulnerability index method (Lagomarsino and Giovinazzi, 2006) have not been used in regional earthquake risk studies in Spain so far (they have been used in local risk assessments).

The relevance given to vulnerability assessment in the regional studies is varied. In one hand, in GEOBAL it is just mentioned, but not analyzed scientifically, and in the Basque plan, vulnerability is estimated through the density of buildings and the location, but no reference to building typology is done. On the other hand, the regional plans of Catalonia and Murcia present a more elaborated vulnerability analysis: Four different vulnerability classifications are contrasted in SISMICAT (Roca et al., 2006) and a through description of Murcian building typologies in EMS 98 terminology is accomplished in SISMIMUR.

2.3. Approaches to damage estimation

The only cause of damage to individuals and structures considered in all regional seismic risk plans is ground shaking, hereby excluding indirect effects such earthquake-triggered landslides, fires, etc.

As there are limited quantitative local data on earthquake-related damage to structures (Gaspar-Escribano et al. 2005), data from other regions with similar constructive habits, materials and techniques are used (Murphy Corella, 2005). In this sense, damage data from Italian earthquakes (Irpinia earthquake, 1980; see Braga et al. 1986; Chávez 1998) are taken to infer damage probability matrices (PDMs) relating macroseismic intensity with degree of damage for each vulnerability class. This is a method widely used in Spain for regional-scale seismic risk analyses, including the seismic risk plans of Catalonia and Murcia, and the software SES-2002. These PDMs apply to residential buildings. Damage to persons and damage to singular structures, such as hospitals and lifelines, are estimated making use of published relations that are extensively accepted (Coburn et al., 1992; ATC, 1985; 1991). Again, the lack of damage data related to earthquakes occurred in the study regions is supplemented with information of extraneous events.

The regional plans of the Basque Country and of the Balearic Islands do not estimate damages to persons and to structures.

2.4. Exposure and costs

The DBPPCRS specifies that municipalities where the expected seismic intensity equals or exceeds degree VII must count with a catalogue of exposed elements, i. e., elements at risk, whose destruction (for a *reasonable* probability) may involve human casualties, disrupt essential services or enhance indirect damage. From the accredited seismic risk plans, only SISMIMUR and SISMICAT present such an inventory, and it is integrated in a geographic information system that contains data about lifelines and critical infrastructures. At the regional scale utilized in these analyses, there is no detailed mapping of residential buildings at risk, just overall estimates. Exposure of people as a function of time of the day and variations of population density related to vacation days (Murcia, Catalonia and the Balearic Islands are top tourist destinations) and building use is commented but not tackled in detail.

None of the accredited seismic risk plans contains any estimation of costs: reinforcement, retrofitting, repair, specific insuring, debris removal, demolition of uninhabitable structures and other eventual costs are not contemplated in these plans.

2.5. Geographic working unit

The geographic working unit used in regional risk studies must be small enough to provide detailed information about the actual risk of the region without increasing the amount of information to a level that is impossible to manage. Common choices are the zip code and the smallest administrative subdivision. The accredited plans of the Balearic Islands and Catalonia follow this second option: the *municipality*, which is also the smallest territory with specific local government in Spain. This choice is attractive because if a local seismic risk study is to develop (as derived from the regional risk study) then the local government should receive the undisputed competence to accomplish it. Whereas the choice of the municipality as geographic working unit is convenient for practical reasons, there are cases in which the territories corresponding to different municipalities present strongly dissimilar sizes. This is the case of Murcia and of the Basque Country, where a further subdivision of broad municipalities needed to be performed. Then, in these plans the geographic working unit adopted is a combination of municipalities and *pedanías* or subdivisions of the former ones (Fig. 3). Although this approach may seem confusing for the end-user of the plan, it is necessary in order to avoid crude generalizations that could bias seismic hazard, vulnerability and expected damage estimates.

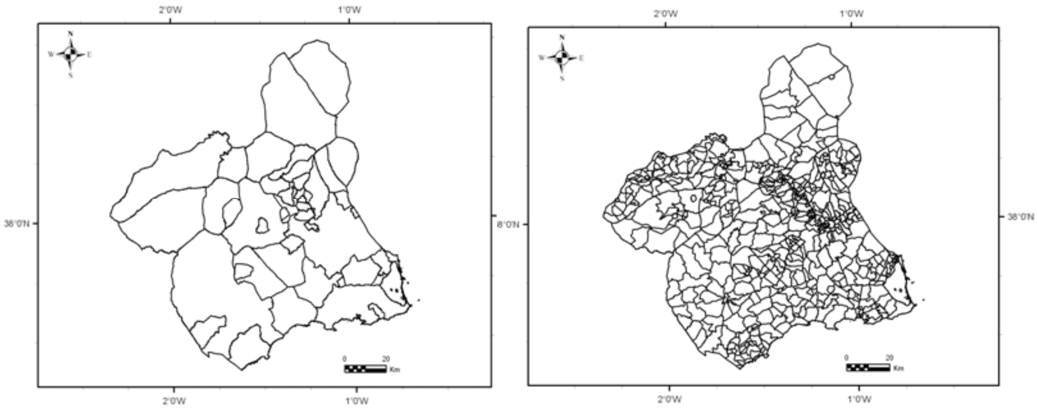

Figure 3. Administrative subdivisions of the region of Murcia: municipalities (left) and *pedanías* (right)

3 NON-ACCREDITED REGIONAL RISK PLANS

Although non-accredited regional risk plans are under development and hence may still be subjected to changes, some non-confidential characteristics may be advanced.

The regional seismic risk plans of Andalusia (SISMOSAN) and Navarre (SISNA) follow a similar approach than the SISMIMUR plan of Murcia. Minor differences appear in the definition of source zones: whereas in SISMOSAN the local seismogenic zoning model of Murcia is disregarded and several zones covering the northern African coast and part of the Atlantic Ocean are included in the analysis, in SISNA a new, local zoning is elaborated and integrated into a logic tree scheme for hazard analysis.

The regional seismic risk plan of Galicia (SISMIGAL) is largely inspired in the simulator of earthquake scenarios SES-2002, increasing the degree of detail of the geographical working unit considered for the analysis. Nevertheless, the regional government of Galicia has approved two seismic risk plans for the provinces of Orense and Lugo (approximately half of the territory of Galicia), which are based on the results of SES-2002 for two scenarios reproducing the largest events affecting the target sites ever.

4 DISCUSSION

4.1. Regional seismic risk studies of accredited emergency plans

The characteristics of the several regional seismic risk studies are outlined above. The absence of actual, local data constraining expected ground motions and the consequent damage to individuals and to structures constitute important limitations to the analyses. In this respect, the use of foreign data, supported with local data when available, is necessary. Another important constraint is imposed by the regional character of the study, which makes unviable reaching the detail of urban risk studies. Qualitative approaches to structural vulnerability are appropriate at this scale.

Main differences among the different risk studies concern seismic hazard evaluation and vulnerability and damage assessment. Whereas in SISMICAT and SISMIMUR vulnerability and damage assessments are fairly complete at the scale adopted, in the other accredited plans they are very simple (Basque Country plan) or just void (GEOBAL). Concerning seismic hazard evaluation, the preference of most plans for using intensity data as size and as ground-motion parameter (as in SISMICAT, GEOBAL and the Basque Country plan) has the advantage of obtaining hazard results that relate finely with expected damage, avoiding unnecessary acceleration-intensity conversions. By contrast, the choice of magnitude as size parameter and of peak and spectral accelerations as ground motion parameter allows a better ground motion characterization in the spectral domain, which could present an additional interest for engineers and designers.

4.2. Potential consequences of the present risk assessment system

The DBPPCRS is conceived to provide a reference frame for establishing operative seismic emergency plans. As regional authorities have complete legal attributions on earthquake risk planning and response management, it is reasonable that they get this responsibility instead of national or local administrations. Practical issues related to data availability, update and property evidence the convenience of such arrangement. However, the variety on approaches to estimate earthquake risk (as shown in this paper) may lead to significantly dissimilar results between neighbour regions, which could present unwelcome consequences specially along bordering areas. Imagine the case of two neighbour regions which earthquake risk plans give high and low expected risk over the same area. Apart from the apparent inconsistency, several negative consequences are foreseen: One is that the amount and availability of response resources could be inadequately distributed, making the entire response system results unbalanced and unable to manage an eventual earthquake disaster. Another negative consequence is that as earthquake protection measurements (earthquake-resistant construction requirements, reinforcement priorities, obligation of property insurance) differ in both regions, companies would favour undertaking new developments in the regions where seismic-protection exigencies carry lesser costs. The economical impact of such circumstance may imply significant (perhaps, unjustified) unbalances between the economies of both regions. Finally a more important negative consequence is related to the doubts about the reliability of earthquake risk results that may arise to end-users (including individuals). If two results appear to be unjustifiably and exaggeratedly dissimilar, they may be rendered useless and hence obliterated from public consciousness. This is just the scenario that risk mitigation planners want to avoid and should be combated.

4 CONCLUSIONS

Regional seismic risk studies help delimitate areas with higher and lower expected earthquake damage and hence can be used for defining prevention and response strategies. Despite the development of these studies in low and moderate seismic areas such as Spain is hindered by the absence or limited availability of data, their results are valuable and must be promoted by public administrations. However, efforts to seismic risk assessment should be placed in the same direction. Present regulations in Spain delegate seismic emergency planning in regional administrations. Whereas this approach is practical and to some extent logical, the lack of guidelines on how to carry out the respective seismic risk studies may lead counterproductive consequences, such as an unreasonable variability on results leading to a likely misallocation of resources for pre- and post-event risk reduction measurements and a decrease of confidence in administrative planning efforts. Accordingly, it would be recommendable the development of a detailed set of guidelines for performing regional risk studies with uniform characteristics and approaches by the competent authority.

ACKNOWLEDGEMENTS

The authors wish to thank Gregorio Pascual (Spanish Civil Protection) for providing information on regional seismic risk plans and María José García Rodríguez (UPM) for Figure 3.

REFERENCES

Applied Technology Council (ATC) (1985). Earthquake damage evaluation data for California, Report ATC-13, Redwood City, California.

Applied Technology Council (ATC) (1991). Seismic Vulnerability and impact of disruption of lifelines in the conterminous United States. (ATC-25). Redwood City. California. 440 pp.

Applied Technology Council (ATC) (1996). Seismic Evaluation and Retrofit of Concrete Buildings, Report ATC-40, Redwood City, California.

Applied Technology Council (ATC) (2005). Improvement of Nonlinear Static Seismic Analysis Procedures. FEMA-440, California, USA.

Barranco, L. and Izquierdo, A. (2002) Preliminary rapid estimate of potencial earthquake damage in Spain: Simulation of Seismic Scenarios (SES 2002). Dirección General de Protección Civil, Instituto Geográfico Nacional, CD ROM.

Benito, B; Gaspar-Escribano, J. M., Martínez-Díaz, J. J., García Rodríguez, M. J., Jiménez Peña, E., Canora, C. and Álvarez-Gómez, J.A. (2008). The RISMUR Project: Seismic Risk assessment of the Murcia province (SE Spain). *Bolletino di Geofisica Teorica e Applicata* **48**.

Braga, F., M. Dolce, and Liberatore, D. (1986). Assessment of the relationships between macroseismic intensity, type of building and damage, based on the recent Italy earthquake data. *Proceedings of the 8th ECEE*. Lisbon 1986.

Chávez, J. (1998). Vulnerability evaluation and seismic risk at regional scale: Application to Catalonia. PhD Thesis, Universitat Politècnica de Catalunya, Barcelona, 343 pp. (In Spanish).

Coburn, A.W., Spence, R.J.S. and Pomonis, A. (1992) Factors determining human casualty levels in earthquakes: Mortality prediction in building collapse. Proceedings of the 10th World Conference on Earthquake Engineering, Madrid, 5989–5994.

Directriz básica de planificación de protección civil ante el riesgo sísmico (DBPPCRS) (1995) Boletín Oficial del Estado **124**, 15294-15304. (In Spanish)

Directriz básica de planificación de protección civil ante el riesgo sísmico (DBPPCRS) (2004) Boletín Oficial del Estado **238**, 33205-33208. (In Spanish)

García-Mayordomo, J. (2005). Characterization and Seismic Hazard Analysis in Southeast Spain, PhD Thesis, Universidad Complutense de Madrid, Madrid, 379 pp. (In Spanish)

García-Mayordomo, J. Gaspar-Escribano, J. M. and Benito, B. (2007) Seismic Hazard Assessment of the Province of Murcia (SE Spain): Analysis of Source Contribution to Hazard. *Journal of Seismology* **11**, 453–471.

Gaspar-Escribano, J. M., Murphy, P., and Benito, B. (2005). Study of ground motions and damage trends in different building types caused by recent low-magnitude earthquakes in SE Spain. Lessons for defining seismic design criteria. Proceedings 250th Anniversary of the 1755 Lisbon Earthquake, Lisbon, 548-554.

Lagomarsino, S. and Giovinazzi, S. (2006). Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. *Bulletin of Earthquake Engineeering* **4**, 415–443.

Murphy Corella, P. (2005). Building performance during recent earthquakes in the Iberian Peninsula and surrounding regions. Proceedings 250th Anniversary of the 1755 Lisbon Earthquake, Lisbon, 446-450.

Perea, H., Masana, E. and Santanach, P. (2006). A pragmatic approach to seismic parameters in a region with low seismicity: the case of Eastern Iberia. *Natural Hazards* **33**, 451–477.

Sanz de Galdeano, C., Peláez, J. A. and López Casado, C. (2003). Seismic potential of the main active faults in the Granada Basin (southern Spain). *Pure and Applied Geophysisics* **160**, 1537-1556.

Sanz de Galdeano, C., Peláez, J. A. and López Casado, C. (2006). Active faults and seismic potential of the Guadix Baza Basin. In: The Guadix-Baza Basin, Sanz de Galdeano, C., Peláez, J. A. (eds.). Granada, 283-299 (In Spanish).

Secanell, R., Goula, X., Susagna, T., Fleta, J. and Roca, A. (2004). Seismic hazard zonation of Catalonia, Spain, integrating random uncertainties. *Journal of Seismology* **8**, 25-40.