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NEW HAZARD MAPS FOR THE SPANISH BUILDING CODE

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Abstract

A new estimation of seismic hazard has been developed for the Spanish territory aimed at the revision of the Spanish Building Code. The study includes geologic, seismic and strong motion data gathered in the last years, being remarkable the use of: 1) the Data Base of Quaternary Active Faults of Iberia (QAFI,v2), 2) an updated seismic catalogue homogenized to Mw, 3) a new area-source model compiling different geophysical data and 4) a ground motion prediction equation derived from local data, recommended for use in the magnitude Mw range [4 -5.5]. Its worthy to note the use of the information and lessons derived from the Lorca 2011 earthquake, which has been the most destructive event in the last 120 years in Spain.

The study has been carried out in a frame of the OPPEL project, a collaboration project between the IGN and the Technical University of Madrid (UPM, Earthquake Engineering Research Group). A probabilistic seismic hazard approach (PSHA) has been followed joining the consensus of the main specialists of the country, who have participated in the decisions around the critical aspects, such as: source model and GMPEs to be used for different magnitude ranges, values of maximum magnitude M_{max} for each zone, logic tree and weighs for uncertainty quantification, etc. As result, hazard maps in terms of PGA and spectral accelerations SA (T) have been obtained for different return periods: 475, 975 and 2475 years. In addition a map for return period of 9975 years has been derived, which may be oriented to critical facilities. Although the study over such long exposure times requires alternative methodologies and more exhaustive analysis about active faults, recurrence periods, paleoseismic data, etc, this map may be a starting point for specific assessments addressed to nuclear safety.

The new hazard maps count with the agreement of the Spanish seismological community and are presented in this communication.

Keywords: Seismic Hazard, Spain.

1. Introduction

The Hazard map included in the Spanish Building code actually in force, NCSE-02 [1], was developed at the end of the 80's decade. The improve of knowledge in different topics involved in seismic hazard in the last 25 years, make possible a new and more reliable estimation, taking into account the advance in the state of the art concerning the following topics: methodology for hazard estimation, increasing information about the active faults, update seismic catalogue, available set of strong motion records, recent ground motion prediction equations GMPEs and proposed techniques for uncertainty quantification. Therefore, a new estimation of seismic hazard has been developed for the Spanish territory including the improvements in the different topics and the geologic, seismic and strong motion data gathered in the last years.

The new study is developed in terms of PGA and spectral accelerations SA(T) in the range of structural periods [0.1-2 s], which involves the introduction of GMPEs derived from strong motion records. This point makes one of the main differences regarding the previous map of NCSE 02, which was originally computed in terms of macroseismic intensity I_{MSK} and then converted to acceleration values through a I/A relationship.

In the new estimation a PSHA is followed considering different alternatives of methods and models in different stages of the hazard estimation: method itself, zoning models, GMPEs , etc. The main issues are:

- Two variants of the probabilistic method have been adopted: the first one is based in a zoned model [2] with Poissonian distribution of seismicity while the second one adopts an zoneless model with smoothed seismicity by a Kernel Function [3] .

- For the application of the zoned method a new zonation has been proposed for the study, compiling different geophysical data [4]. This zonation is named GM12 and it has been combined in a logic tree with other extensive used in the frame of nuclear installations B&A12 [5]
- A seismic catalogue has been prepared, which has been homogenized to moment magnitude [6], corrected for completeness in different magnitude ranges and filtered of foreshocks and aftershocks.
- Regarding the GMPEs necessary for hazard estimation, a new model has been derived with local data, covering the magnitude range (Mw 3.5-5.5). This has been combined with other foreign models suitable for higher magnitudes, since we can expect earthquakes with magnitude higher than the ones covered by the strong motion data base, arriving at Mw 6.5-7 in the Peninsular territory and Mw 8.5 in the Gorringe Bank (SW San Vicente Cape).
- Finally, special attention was paid to the identification and quantification of the uncertainties involved in the whole calculation process, both of epistemic and aleatory nature. A logic tree has been built for considering the first ones requiring different models like zonation, GMPEs or the seismicity model (zoned and zoneless). A process of Monte Carlo simulation was developed for the quantification of the aleatory uncertainty in aspects such as earthquake size parameters, homogenization and declustering procedures, recurrence parameters of seismogenic sources, Maximun magnitudes, etc.

All these aspects will be explained in detail in the following sections.

2. Seismotectonic Framewok

The Iberian Peninsula (Spain and Portugal) is located in the vicinity of the broad zone of contact between the Eurasian and African tectonic plates, which shifted from the Pyrenees to its present position during the Cenozoic. Seismicity in the Iberian Peninsula and adjacent offshore areas is related to this seismotectonic setting, concentrating along the Pyrenean fold-and-thrust belt and around the S-SE deformation zone, which includes the Betics, the Alboran Sea, the Algarve region, the Gulf of Cádiz and the Gorringe Bank. Other seismically active regions include the lower Tagus Valley and the interior of Galicia, located at West and Noth-West Iberia, respectively. The focal mechanism of the main events in the area are shown in Figure 1a, while the tectonic setting is represented in Figure 1b. Seismogenetic sources in the Iberian Peninsula are fundamentally related to faulting and located in crustal levels. Sub-crustal earthquakes take place mostly along a NNE-SSW oriented band crossing the western Betics and extending toward the western Alborán Sea, and to a lesser extent in the eastern Pyrenees, the Gulf of Cádiz and the Gorringe Bank.

With the exception of two deep earthquakes occurred in Granada province (1954, M 7.0 Dúrcal and 2010, M 6.2), no large events have taken place in mainland Spain in the instrumental times (since 1950 approximately). Consequently, the recorded m_{bLg} magnitudes by the Spanish Seismic Network (SSN), operated by IGN, don't exceed the value of mb_{Lg} 5.5. Besides, a number of moderate-high magnitude events (up to Mw 7.0) taking place in northern Morocco, northern Algeria and the Azores-Gibraltar zone (such as the 1954, 1980 El Asnam, 1969 SE S. Vicente Cape, 2003 Algiers, and 2004 and 2016 Al Hoceima earthquakes) have been also felt in Spain, some of them with important effects. Other strong events with marine epicentre also affected Spain, eventually inducing tsunamis that reached the Iberian coasts. The most important one is the 1755 Lisbon earthquake, which epicenter was located more than 100 km off the Portuguese coasts and had an estimated epicentral intensity I_{MSK} = X and estimated magnitude M ≈8.5 [7].

Table 1 lists the largest events recorded or felt in Spain, with epicentres onshore or surrounding areas ($I_{MSK} \geq$ VIII and/or $M \geq 5.0$).

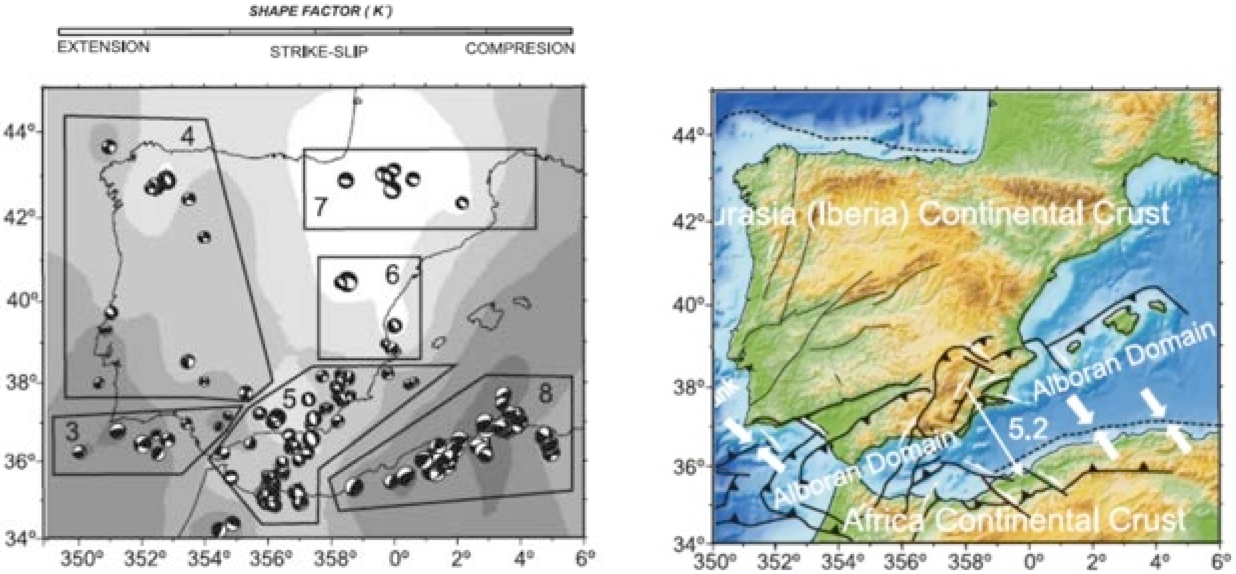


Figure 1. Left) Focal mechanisms and deformation style. Right) main tectonic features of the Africa-Eurasia plate contact according to model NUVEL-1A ***[8]****, adapted from* ***[9]***

Table 1. Largest events recorded or felt in Spain, with epicenters onshore or surrounding areas (I_{MSK} ≥VIII and/or $mb_{Lg} \geq 5.0$).

Date	Lat.	Long.	Inten.	Mag.	Location
02/03/1373	12:00:00	0,75	VIII-IX		Ribagorça.L
18/12/1396	2:24:00	-0,2667	VIII-IX		Tavernes de la Valldigna.
15/05/1427	4:48:00	2,5	VIII-IX		Olot.GI
02/02/1428	8:24:00	2,1667	IX-X		Queralbs.GI
24/04/1431	3:11:57	-3,6333	VIII-IX		S. Granada
05/04/1504	11:35:57	-5,6333	VIII-IX		Carmona.SE
09/11/1518	5:35:57	-1,8667	VIII-IX		Vera.AL
22/09/1522	23:12:03	-2,6667	VIII-IX		W.Alhama de Almería.AL
30/09/1531	12:47:57	-2,7333	VIII-IX		Baza.GR
09/10/1680	19:12:00	-4,6	VIII-IX		NW. de Málaga
23/03/1748	0:47:57	-0,6333	IX		Estubeny.V
25/08/1804	18:24:03	-2,8333	VIII-IX		Dalías.AL
21/03/1829	1:59:57	-0,6833	IX-X		Torrevieja.A
25/12/1884	0:00:00	-3,9833	IX-X		Arenas del Rey.GR
10/09/1919	23:35:57	-0,8667	VII-VIII	5,2	W SAN MIGUEL DE SALINAS.A
18/02/1929	3:11:57	-2,1	VI-VII	5,1	TURRUNCUN.LO
14/03/1935	9:11:57	-4,5833	V	5	BENAMEJI.CO
23/06/1948	1:07:15	-1,7617	VII	5	SE CEHEGIN.MU
10/03/1951	14:16:48	-3,975	VII	5,2	W CASTILLO DE LOCUBÍN.J
19/05/1951	13:36:29	-3,917	VII	5,3	E CASTILLO DE LOCUBÍN.J
04/06/1955	3:11:57	-3,6467	VI-VII	5,1	SW ARMILLA.GR
19/04/1956	4:36:03	-3,6833	VII-VIII	5	NW PURCHIL.GR
10/02/1961	17:24:00	-6,1967	VI	5,2	ZAMORA.ZA
02/11/1962	5:35:57	2,2833	V	5,1	S JUAN DE ABADESAS.GI
24/08/1976	19:07:15	-4,62	IV	5,4	SW ALMOGÍA.MA
24/06/1984	20:07:09	-3,7383	V	5	W LENTEGÍ.GR
13/09/1984	23:33:39	-2,3417	V	5	SE TABERNAS.AL
26/05/1985	18:52:51	-4,6383	V	5,1	NW ESPEJO.CO
20/12/1989	5:24:00	-7,3917	VI	5	E AYAMONTE.H
23/12/1993	18:43:12	-2,9367	VI-VII	5	S BERJA.AL
21/05/1997	18:47:57	-7,2583	VI	5,1	NW TRIACASTELA.LU
27/10/1998	20:36:32	-2,0145	V	5,2	SE LIZARRAGA.NA
06/08/2002	21:25:12	-1,8353	V	5	SW BULLAS.MU
11/05/2011	17:13:12	-1,7114	VII	5,1	NE LORCA.MU
19/03/2013	11:20:24	-5,5197	II	5,5	NW JIMENA DE LA FRONTERA.CA

3. Methodology for definition of seismic zones

The seismic-hazard analysis has been carried out according to the well-known probabilistic seismic-hazard assessment (PSHA) approach with two variants: zoned and zoneless methods. To take into account the epistemic uncertainties linked to different stages of the process, a logic tree was formulated, while the aleatory uncertainties have been considered through Monte Carlo simulations.

The necessary inputs for the application of the zoned method have been prepared in the first phase of hazard estimation: 1) Seismic catalog, 2) Seismogenic source models, and 3) Ground Motion Prediction Equations (GMPEs). The seismic catalogue and the GMPEs have been also used in the zoneless method. All these aspect will be described in following sections.

3.1. Seismic Catalogue

A project catalogue has been preparing in a first step, starting on the IGN database, complemented with earthquake size data obtained from other agencies (Institut Geologic de Catalunya, IGC; and Instituto Andaluz de Geofísica, IAG) and specific monographies. The original catalogue contains data of 63.000 events, approximately, occurred in the period (880 A.C- 2011), covering the extension (26-45 º N, 20 W-6 E). This extensive catalogue has been filtered for obtaining the events in more restrictive area (34-45 º N, 13 W-6E), which may be consider the influence area for hazard estimation of Iberian Peninsula, Baleares island, Ceuta and Melilla (two Spanish towns located at north Africa).

In addition, the earthquakes with focal depth bigger than 65 km have been also filtering, considering that they do not present significant influence in the hazard. This involves the elimination of intermediate seismicity (50-200 km depth) located in Cadiz Gulf, Gorringe Bank, High Atlas, Granada-Malaga), as well as the depth seismicity in Granada-Durcal –Mar de Alboran. Around 1000 events belong to these ranges. After the filtering process by geographical extension and depth, a total of 56.000 events configure the selection, the first one occurred in Orihuela (Jaen) in 1048 and the last one in June, 2011. The Lorca earthquake, occurred in May 11, 2011 is therefore included in the catalogue.

The heterogeneity concerning the size parameter has required a careful process for converting the values of the different parameters and /or scales to a common magnitude. The moment magnitude Mw has been chosen as more suitable for the homogenization purpose. The relationships estimated for the homogenization process are described in detail in [6]. Particular attention was paid to uncertainties quantification over the original and the final data, including errors propagation for giving, in a last step, the value of $Mw \pm \sigma$. The resulting range of σ values is (0.1-0.5). The highest value corresponds to the case of intensity as original size parameter.

The completeness analysis over the previous catalog was also carried out taking the seismicity clustered in intervals of 0.5° magnitude. Examination of the temporal distribution for each interval provides the reference year from which we can consider that the seismicity is complete inside the interval. In this analysis, we distinguished different geographic areas taking into account the regional variability of the amount and quality of data in the Iberian Peninsula and north Africa.

In a last step the catalog was filtered for fore- and after- shocks to accomplish the basic hypothesis of our zoning models: the seismicity of each zone fits to a Poisson model. Details of the issues for preparing the catalogue are described in [6,10].

As result of the homogenization, completeness and clustering process, a final project catalogue contains 6999 events in the ranges of magnitude Mw (3.5- 8.5), depth (0-65 km) and covering the period (1048-June 2011). Figure 2 shows the epicenters of the final project catalogue.

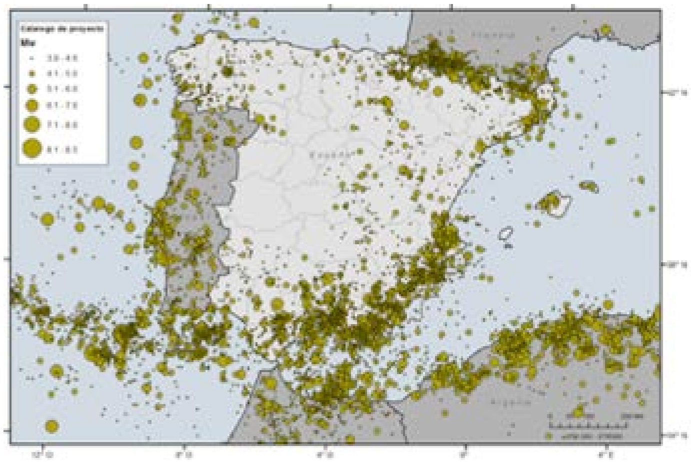


Figure 2. Epicenters distribution in Iberian Peninsula and surrounding areas, according the final catalogue of the project.

3.2. QAFI Data Base: Quaternary Active Faults of the Iberia

The knowledge of active tectonics in the Iberian Iberica has increased during the last years notably due to different projects developed at national and international level (Iberfault, FaseGeo, Share, etc). With the information generated in these projects the Instituto Geológico y Minero de España (IGME) and the Iberfault Working Group have led the initiative of elaborating a Data Base of Quaternary Active Faults of Iberia (QAFI) [11]. It compiles data of Neotectonic activity and seismic parameters of Quaternary faults, including uncertainty ranges. Figure 3 shows the faults which are included in QAFI. This Data Base presents a valuable information to improve seismic hazard studies in Spain. However, the information that contains about active faults of the Iberian Peninsula is not homogeneous, which makes it difficult the possible inclusion of faults as independent units in the seismic hazard computation at national scale.

In this work, the active faults have been taken into account for the identification of the limits of the seismic area-sources and their maximum magnitudes, which imply an innovation and improvement with respect to previous work, thanks to the information contained in the QAFI.

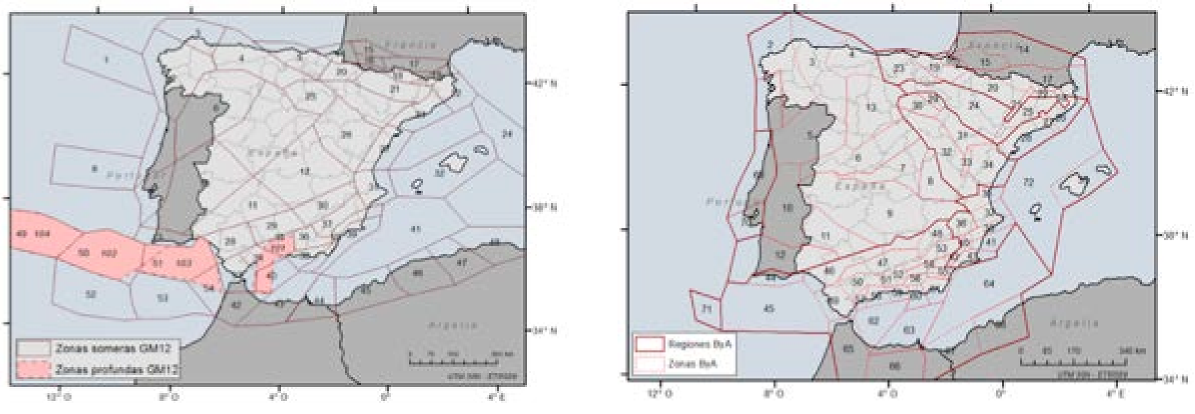
Figure 3. Quaternary faults contained in the QAFY Data Base [11]

3.3 Zoning models of Seismogenic zones

Different zoning models have been proposed for seismic hazard studies in the Iberian Peninsula. After the compilation and revision of all these models, two of them have got the general consensus for the actual analysis by use the zoning method. These have been the ones proposed by [4] and [5], hereafter referred to as GM12 and B&A12, respectively. Both are composed by seismic area-sources - named seismogenic zones- defined as geographical areas of uniform seismic conditions and equal probability of earthquake occurrence within their limits.

Zoning model (GM12). This model is the result of a careful revision of a previous model developed by a working group composed by Spanish geologists who compiled data about geology and tectonic cartography, morphology, crustal thickness, thermal flux, historical and instrumental seismicity and paleoseismicity. Through an expert judgement a preliminary model was defined and published in the first Iberia meeting (Iberfault 2010). about Active Faults and Seismicity [11]. The model was redefined in the frame of the European Project Share (Seismic HAzard Harmonization in Europe, 2011) with participation of French and Portuguese experts. New changes and fit of zones were proposed after the compilation of the QAFI Database. A final adjustment were done in order to get suitable recurrence laws for the seismicity of each zone. The final model [4] contains 55 zones modeling surface seismicity and 4 zones including the depth seismicity located S and SW Iberian Peninsula (Figure 4A). The complete description of these zones may be found in [5].

Zoning model (B&A12). This zoning model finds its antecedents in a number of seismic hazard studies developed by the authors in the period 1999-2009, aimed at security of different nuclear power plants and waste deposal in Spain. A final fit of the zones was done in the frame of this new study taking into account the opinions of the expert committee and joining the necessary consensus. The model B&A12 is composed by 8 big seismogenic regions: Macizo Hesperico, Pirineos, Cordillera Iberica, Cordillera Costero Catalana, Levante, Orla Mesozoica y Neogena Occidental Portuguesa, Cordilleras Beticas-Valle Guadalquivir y Banco de Gorringe. These big regions contain 72 smaller area sources, represented in figure 4B. The complete description of this model is included in [5].



(A)

(B)

Figure 4. Zonings model adopted in the study. A) GM12 model. B) B & A12 model

3.4 Seismic Source Parameters

Two different approaches are aimed at characterization of sources depending of the method to be followed in our hazard estimation: zoned and zoneless method. In the case of use the zoned method, the seismicity is distributed in the seismic area sources according the two models described in previous section: GM12 and B&A12. For each zone the seismicity is fit to a Gutenberg–Richter model truncated to a minimum magnitude m_0 4.0, given by the equation $log N(m \geq m_0) = a - bm$ .Therefore, the annual rate of events with $m \geq m_0$, $N(m_0)$, and the parameters of the Gutenberg–Richter relation (a and b) are estimated for characterizing the recurrence of each zone. The computation of the parameters a and b was done by two independent methods, least- squares (as in former studies) and maximum likelihood (more suitable for the proposed adjustment).

In addition of the parameters a and b inherent to the recurrence, a maximum magnitude must be defined for characterizing the source activity in each case. At this regard, the information of the QAFI Data Base has been taken into account, together with the historical and instrumental seismicity. Fault data are used to calculate a distribution of Mmax values from the population of surface fault lengths. In those cases in which the population of reported active faults is not sufficient to derive a Mmax distribution in this way, the Mmax distribution is derived from the seismic catalog. Activity rates and b-values depend on the geometry of the area-sources and the epicenters located within their limits. Activity rates range (Mw ≥ 4.0) from 0.015 to 1.127 event per year and b-values range from 0.38 to 2.27.

3.5. Development and selection of GMPE's

One of the most critical aspects in the study is the selection of GMPEs, due to differences in crustal characteristics and scarcity of strong-motion data recorded in Iberian Peninsula. More concretely, the calibration and selection of models required to consider the next issues:

- The influence area includes different tectonic domains corresponding to active shallow crust (Iberia and northern Africa), and another one for the Azores-Gibraltar region and Deep sources in the Alboran sea. Maximum magnitudes reach values Mw of 6.5- 7 in the first case and 8.5 in the second one, concretely in the Gorringe bank, where the 1755 Lisbon earthquake took place.
- A strong motion database of IGN is available. It contains records from 530 events occurred in the Iberian Peninsula and adjacent areas, mostly in the southern part of the country, with distance and magnitude ranges R [5-100 km] and M [2-5]. Recorded PGA values in the three components oscillate in the ranges NS [0.26-360 cm/s^2] ; EW [0.24-151 cm/s^2] and Z [0.22-183 cm/s^2], where the highest values corresponding to the Lorca earthquake (11 may 2011, Mw 5.1, recorded at a source-site distance of 3 km).
- There are no GMPEs developed with local data covering the complete magnitude and distance ranges. Most strong motion data correspond to distance R >10 km and magnitudes Mw < 5. Thus it is not viable developing model to calculate a GMPE with local data for the maximum expected magnitudes.
- Moderate events (4 < M <5) present a high contribution to the expected hazard (with return period of 475 years). So it is important to use GMPEs covering this magnitude range.

Taking into account these conditions, we require models that consider active shallow crust and with a magnitude range of Mw [4-7] and others for the deep and the Azores-Gibraltar areas covering magnitudes Mw of [4-8.5]. Specifically, for the Iberian Peninsula and Northern Africa, a local model has been derived from 140 records of magnitude Mw [4-5.5] and distance R[3-360 km]. In addition, several foreign models have been tested and calibrated with local data using the approach of [12], in order to be used for M > 5.5. The models with a best fit to our data have been finally selected: [13] and [14]. Therefore, in the hazard estimation different combinations of Local model (M< 5.5) + Foreign model (M ≥5.5) are used for Iberian Peninsula and North Africa. For the Azores-Gibraltar area and deep zones, a selection of models covering large distances (R> 400 km) and high magnitudes (up to Mw 8.5) was done. Only 19 records from the Atlantic Ocean of magnitudes between 4 and 6.3 were available for the calibration. The models that seem to reproduce the attenuation better are [15] and [16]. Table 2 summarizes the GMPEs finally selected for the two tectonic environments that will be integrated in the logic tree for account the epistemic uncertainty inherent to the attenuation model.

Table 2. Main characteristics of the GMPEs used in this study: type and range of applicability in distance and magnitude, component and units of predicted ground motion parameter.

MODEL	*Magnitude Range*	*Type of Magnitude*	*Distance Range*	*Type of Distance*	*Horizontal Component*	*Predicted variable (units)*
Akkar & Bommer (2010)	5.0 - 7.6	Mw	≤100km	Rjb	Geometrical mean	Ln (g)
Boore & Atkinson (2008)	4.2 - 7.9	Mw	<200 km	Rjb	GMRotI50	Ln (g)
Cotton et al (2008)	4.0-7.3	Mw	<100 km	Rjb	Geometrical mean	log(cm/s^2)
Cauzzi & Faccioli (2008)	5.0-7.2	Mw	15-150 km	Rhyp	Geometrical mean	log (m/s^2)
Bindi et al. (2011)	4.0 - 6.9	Mw	>200 km	Rjb	Geometrical mean	log cm/s^2)
Zhao et al. (2006)	5.0 - 8.2	Mw	10-300 km	Rrup	Geometrical mean	ln (cm/s^2)
Youngs et al (1997)	5.0 - 8.2	Mw	10-500 km	Rrup	Geometrical mean	ln (g)
This work	4.0-5.5	Mw	1-370 km	Repi	Geometrical mean	log (g)

3.6. Uncertainties quantification: Logic tree and Monte Carlo simulation

A crucial issue on any seismic hazard assessment is the identification and quantification of uncertainties, which are usually divided in two groups: epistemic and aleatory uncertainties. Different treatment is adopted for quantifying each one. In order to quantify the epistemic uncertainty in this work we have configured a logic tree with five nodes (Figure 5), corresponding to the following items:

- Method of hazard estimation, with two branches representing the two alternatives (both probabilistic): zoning and zoneless method.
- Zonning model : GM12 or B&A12
- Estimation of the “b” parameter at regional or local scale, depending on the zoning model adopted: B&A12 or GM12, respectively.
- Method for obtaining the recurrence parameters of the zones: minimum squares method or maximum likelihood.
- Combinations of GMPE´s for different magnitude ranges and two tectonic environments: Iberian Peninsula -North Africa and Atlantic and deep zones.

On the other hand, three sources of aleatory uncertainty have been considered, inherent to variability given by the GMPE´s, the magnitude Mw of each event in the catalogue, and the maximum magnitude Mmax for each zone.

- In the first case, possible values of the ground motion parameter are considered through a normal distribution according to the sigma value of each GMPE, which involves a probability density function included in the integral for the hazard estimation.
- Regarding the uncertainty linked to the magnitude of each event, we must consider that, although our catalogue has been homogenized to a Mw, different size parameters are contained in the original catalogue (Intensity Io, Mb, mD, mbLg, etc). We have taken a σ value for the original size parameter as well as the σ of the relationships used for the conversion to Mw, in order to obtain the Mw $\pm \sigma$ for each event by errors propagation. Then the possible values of Mw are taken into account through a triangular distribution and 500 synthetic catalogues are developed by Montecarlo simulations, considering the variability of Mw.
- Lastly, a distribution of values is considered for the expected maximum magnitude of each zone, M_{max}, instead of an individual value. The distribution was obtained taking into account two kind of data: the actives faults and the seismic catalogue. Then the density function f(Mmax) is included in the hazard integral for modeling this uncertainty.

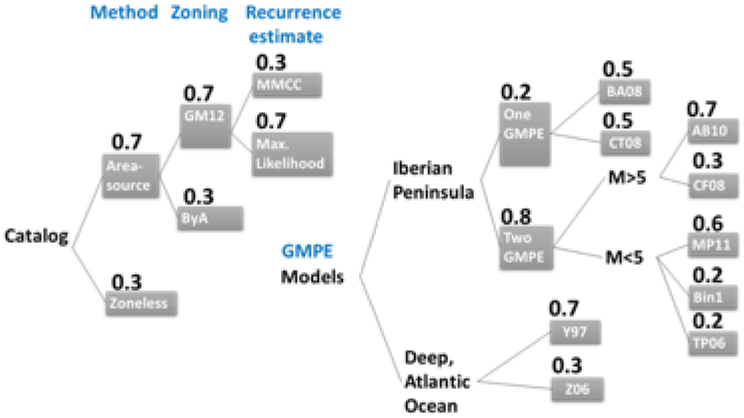


Figure 5. Logic tree adopted for the PSHA

3.7. Hazard Estimation

The hazard has been estimated in a grid of points covering the Spanish Peninsular territory composed by 150º*90 nodes, equispaced 0.1º in longitude and latitude. The software used is CRISIS 2007 [17]. In each point of the grid, the hazard curves have been obtained for the ground motion parameters in rock conditions: PGA, SA (0.1s), SA (0.2s), SA (0.5s), SA (1s), and SA (2s). In all cases the annual probability of exceedance has been evaluated for 10 ground motion levels equispaced in a logarithmic scale between 10 and 1000 cm/s^2. The values in each point have been obtained for return period of 475, 975 and 2475 years, and the maps of the corresponding iso-lines have been drawn [5].

4. Results

A set of maps for the different ground motion parameters and return periods has been obtained as global result of the study, included in [5]. Figure 6 shows the map of PGA (mean of the logic tree and Montecarlo simulation) for return period of 475 years. In addition, with the zoning method we have developed the map of PGA for return period of 9975 years (Figure 7). Although is evident that the catalogue used cover only a period of 600 years, not enough to be extrapolated to long periods, however the maximum magnitude has been estimated from geologic criteria, and the uncertainties have been taken into account. Then the map shown for a return period of 9975 yrs may give a first approximation to the expected motion for the long return periods, and may be useful as starting point for studies aimed at critical facilities.

The map of return period 475 years will be used for the revision of the Spanish Building code. The maximum values of PGA (on rock conditions) are observed in SE Spain, arriving to PGA= 0.24 g in Granada and Bajo Segura. Values lower than 0.04 g are shown in Central plateu and some points of the Ebro Basin.

Figure 7 shows that the expected PGA values exceed 0.20 g in the largest part of Spain, reaching maximum PGA values of up to 0.5-0.6 g in SE Spain and of up to 0.40 g along the Pyrenees. The lowest PGA values are found in the northern Meseta and the Ebro basin. These values may seem too high, but it should be born in mind that they are expected ground motions with a probability of 0.005 in 50 years. Also considering that a M 5.1event such as the 2011 Lorca earthquake produced a PGA of 0.36 g, the PGA values reflected by the hazard map of RP 9975 years are not disproportioned, given the existence of sources capable of generating higher magnitudes (about Mw 6.5-7) in the Spanish territory.

Figure 6. Hazard map derived in the study in terms of PGA (g) mean of the logic tree and Montecarlo simulation for a return period of 475 yrs .

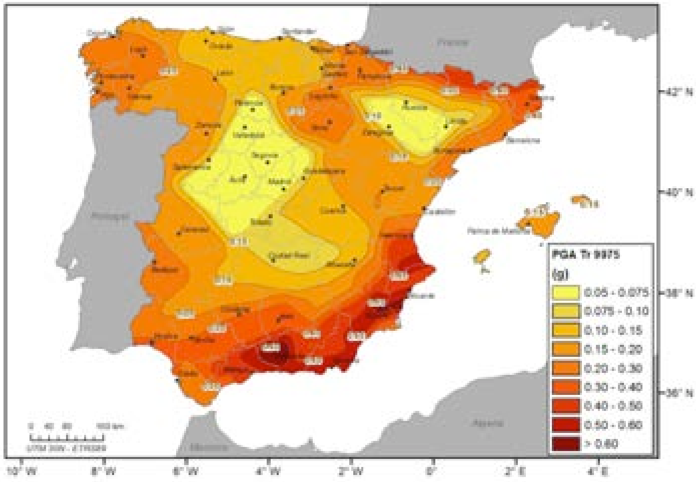


Figure 7. Hazard map derived in the study in terms of PGA (g) mean of the logic tree and Montecarlo simulation for a return period of 9975 yrs.

5. Discussion: comparison with previous results in Spain and neighboring country maps

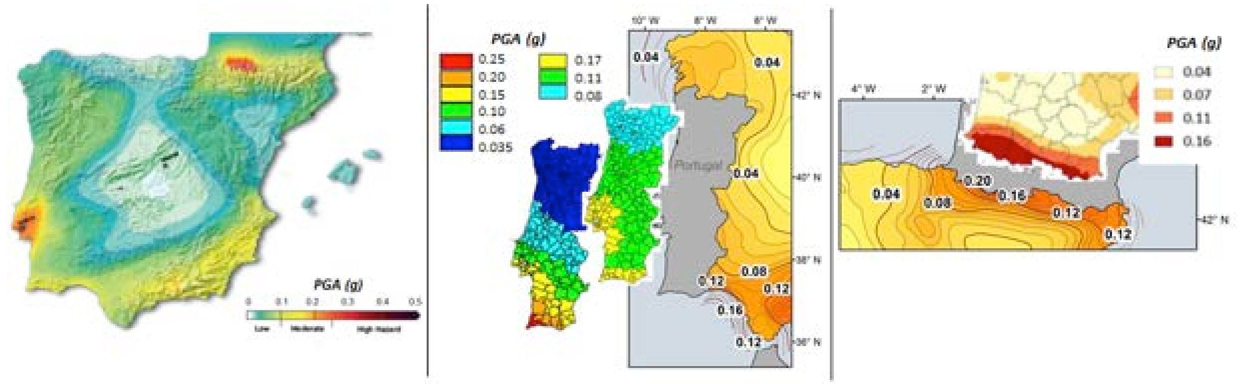
In general the seismic hazard increases according the new map with respect to the previous map of the building code NCSE-02 [1], arriving the difference to 20 % in some places. The biggest increments, around 0.1g to 0.13 g, are found in some parts of Andalusia, Murcia, Alicante, Valencia and Pyrenees. The central part of the Peninsula presents the minor variations. However, the area where PGA is minor than 0.04 g, in which building design is no required according NCSE-02, is reduced in the new map. This fact involves that many municipalities of Castilla, Leon and Extremadura, which in the previous map lied below than 0.04g, are included now inside the isoline of 0.04 g, being compulsory the building design. This aspect has also implications in the Autonomies that are obligated to prepare emergency plans according to Civil Defense.

A comparison of the map obtained for RP 475 with other maps has been done, in particular with the map of the Share project and the ones of the codes for France and Portugal in the boundaries with Spain.

Regarding the Share project [18], the map derived for the Iberian Peninsula (Figure 8A) show a quite homogeneous hazard in all the territory, with maximum values around 0.25 g near Lisbon, followed by the S and E Spain with PGA around 0.15 g. The rest of Spain and Portugal takes values minor than 0.1 g. This map is completely different with respect the ones of the codes in both countries and other published maps. The expected motion according Share map is quite low and don´t reflect the more zones active zones.

In the comparison with the map of the French Building Code [19], the PGA values obtained in this study for Pyrenees are closer to the French hazard map (Figure 8C) than those of the Spanish code NCSE-02. Even that our values in the boundary are in the range 0.16-0.20 g, while the French code gives values of 0.3 g.

Portugal adopts the national Annex to EC-8 [20] with two maps (Figure 8 B) , one for the action of local zones and other for the Atlantic more distant zones (included Gorringe Bank). The first represent the hazard for the near earthquakes and give values of 0.11 g in the east part (boundary with Extremadura, Castilla-Leon), 0.08 in the north (Galicia) and 0.17 g in the south (Huelva). These are even highest than the ones of our new map.



(A) (B) (C)

Figure 8. A.) Hazard map for the Iberian Peninsula derived in the frame of the Share Project, in terms of PGA for RP 475 years. B) Comparison of the PGA obtained in this study for RP 475 years with the ones given by the Portugal Building Code for Atlantic earthquakes (left) and local earthquakes (right). C) similar comparison with the PGA values of the French Building Code.

In conclusion, the increment of hazard presented in this work leads to a higher convergence with the hazard maps contained in the Portuguese and French codes along the borders. In general, the previous hazard map of the NCSE-02 presented notably lower values in the boundaries than the other codes, doubling the expected acceleration in some locations. The values obtained in the present work are closer to the ones proposed by these codes, but they are even below that the values given in the boundaries by the French and Portuguese codes. Results of this work are important for the definition of the seismic action required for the development of seismic risk assessment studies. In addition, the map of RP 9975 years provides PGA values arriving at 0.5-0.6 g in some parts of SE and 0.4g along the Pyrenees. These low-probability, large ground motion levels should be considered in the design of structures requiring the assumption of a very low risk level, such as critical facilities.

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