

Uncertainty assessment for the seismic hazard map of Spain



J.M. Gaspar-Escribano ^{a,*}, A. Rivas-Medina ^{a,1}, H. Parra ^{a,c}, L. Cabañas ^b, B. Benito ^a,
S. Ruiz Barajas ^a, J.M. Martínez Solares ^b

^a ETSI en Topografía, Geodesia y Cartografía, Universidad Politécnica de Madrid (UPM), Spain

^b Instituto Geográfico Nacional (IGN), Madrid, Spain

^c Universidad de las Fuerzas Armadas – ESPE, Sangolquí, Ecuador

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ABSTRACT

The uncertainty assessment for the development of the new seismic hazard maps of Spain is explained in this work. A detailed description of how uncertainties are considered in the different phases followed for the probabilistic seismic hazard assessment study is presented. Special emphasis is given to the characterization of the uncertainty of earthquake size parameters contained in the catalog, and their propagation to subsequent phases of the analysis such as catalog homogenization, completeness and declustering. Aleatory and epistemic uncertainties are examined and assessed using Monte Carlo simulations and a logic tree, respectively. The final impact of uncertainty in hazard estimates is evaluated through coefficient of variation maps, showing the areas where larger and lower variability is obtained. The hazard maps developed in this work are intended to be the basis for the future revision of the Spanish seismic code.

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1. Introduction

Seismic hazard maps constitute a tool for identifying areas with larger and lower expected hazard that may lead informed decisions about risk mitigation. Specifically, most seismic codes contain a seismic hazard map that is the basis for developing earthquake-resistant design of buildings and infrastructures. Hazard maps must be renovated as new significant earthquake data and hazard models are available to improve seismic hazard assessment analyses.

Seismic hazard assessment studies involve many uncertainties. Some of them are related to the intrinsic randomness of natural earthquake processes (aleatory variability). Other uncertainties are due to the incomplete knowledge about such processes (epistemic uncertainty). Both must be addressed and quantified, in order to capture the variability of the final hazard results and to establish their probability and confidence levels, which are needed for informed decision making on design levels and thus, safety thresholds. Hence, the analysis of the impact on uncertainties on the final results must be accomplished to fully understand the significance of the results obtained (Budnitz et al., 1997).

The uncertainty involved in hazard calculations is usually divided into an epistemic and an aleatory component. Different treatment is adopted for quantifying each one.

The epistemic uncertainty reflects the lack of complete knowledge about the process leading to earthquake shaking and the approaches

used to model them. For instance, the real models of wave propagation are unknown and the ground motion prediction models considered as more realistic is usually adopted. An epistemic uncertainty is inherent to the selected model for reproducing the reality case, and in principle, it can be reduced as improved models are elaborated. The epistemic uncertainty can be assessed using a logic tree. It is composed by several nodes that represent alternative input choices (branches steaming from the nodes). Each branch is given a weight that represents the degree of verisimilitude assigned by the analyst (or panel of analysts).

Aleatory uncertainty refers to the natural random variability that is inherent to earthquake processes. It can be quantified and it is typically modeled by means of probability functions. In this work, the aleatory uncertainty model of seismic parameters (beta-values, Mmax values) is explained below. In addition, the aleatory uncertainty of ground motion models, which has a strong impact of estimated ground motion values, is also included in hazard integral.

This paper presents the assessment of the uncertainties involved in the new seismic hazard map of Spain (IGN-UPM Working Group, 2013). This map is the end result of a project carried out by the Spanish National Geographic Institute (IGN) and the Earthquake Engineering Research Group of the Technical University of Madrid (UPM) and it is intended to be the basis for the future revision of the Spanish seismic code.

Below, sources of uncertainties are identified and quantified for different factors, including earthquake size parameters contained in the catalog, catalog homogenization and declustering procedures, seismic parameters of seismogenic area sources, uncertainties incorporated in the hazard calculation and in the final hazard results.

* Corresponding author.

E-mail address: jorge.gaspar@upm.es (J.M. Gaspar-Escribano).

¹ Presently at: Dep. Ciencias de la Tierra y de la Construcción, Universidad de las Fuerzas Armadas – ESPE, Sangolquí, Ecuador.

2. Catalog uncertainties

The seismic catalog is one of the key element for a seismic hazard study, as it contains the earthquakes that occurred in the past and information on (at least) their location, occurrence date and size.

As geological time frames are much longer than historical records, a seismic catalog represents a very short sample of the entire seismic history of an area. A challenge is faced when using this information to construct recurrence models that can apply for the entire seismic history of the study area and not only the period covered by the catalog. This challenge is bigger when the active faults of the study area move at slow rates (Newman et al., 1999). This typically implies that earthquake recurrence periods (especially of strong events) are much longer than the period covered by the catalog. Additionally, evidence for paleo-earthquakes occurrences is harder to find and to date in these slow moving faults (Ortuño et al., 2012).

Uncertainties in earthquake location are included in the catalogs. The continued development of seismic networks leads to a progressive reduction of source coordinate errors. Whereas this issue is very important for hazard source models strongly relying on earthquake location, it has a secondary significance for hazard models based on area-sources (see below for details).

A first process is carried out in order to produce a catalog usable for a conventional seismic hazard assessment study, which is the *homogenization* of the earthquake size parameter.

The catalog is subjected to two more processes that are related to the use of poissonian-like models of earthquake occurrence for seismic hazard assessment studies: catalog declustering and analysis of completeness. The adoption of a poissonian seismicity model implies that the occurrence of one earthquake is independent of the occurrence of another event, and that earthquake occurrence rates remain constant (they are time-independent) in the period and within the area considered. This approach involves two conditions for using a seismic catalog in seismic hazard analysis. The first one is that the catalog must not contain earthquakes that have a cause–effect relation between them. This requires deleting from the catalog events such as fore-shocks, after-shocks and swarms. The process to achieve this is called *catalog declustering*. The approach of Gardner and Knopoff (1974) to identify seismic series by finding the events that are related within a common time and space frame, is followed in this work. The second condition is that the catalog must include the complete collection of earthquakes that have actually occurred in the time period considered in order to compute time-independent occurrence rates. This is achieved after developing the *analysis of completeness*.

2.1. Earthquake size parameters

The seismic catalog of Spain and adjacent areas is elaborated mainly from the IGN database and it is complemented with earthquake size data obtained from other agencies (Institut Geològic de Catalunya, IGC; and Instituto Andaluz de Geofísica, IAG) and specific publications.

The IGN catalog contains six different earthquake size parameters: macroseismic intensity plus five magnitude definitions. The macroseismic intensity estimates (*I*) are reviewed and updated into the EMS98 scale by Martínez-Solares and Mezcua (2002) for events that occurred up to year 1900. This catalog contains maximum intensity estimates (associated to epicentral intensities for onshore sites) and felt intensities (for onshore and offshore epicentral locations). For each intensity estimate, a quality index that accounts for the confidence on the source documentation and interpretation is assigned in that study. Intensity is the prevalent size parameter up to 1923. From 1924 through 1962, the progressive deployment of seismic stations allows using a duration-based magnitude scale (m_D), which coexists with the macroseismic intensity as size parameters in the IGN catalog. From this year on, the IGN routinely used seismogram data to calculate a m_{bLg} magnitude through formulae adapted to the Spanish territory

conditions, following the procedure of Mezcua and Martínez-Solares (1983) for the period 1962–2002 (m_{bLg} (MMS) magnitude) and the study of López (2008) from 2002 up to date (m_{bLg} (L) magnitude). In addition to this magnitude estimate, two more magnitude scales are implemented and incorporated to the IGN catalog from 2002: a body-wave magnitude scale and moment magnitude scale. The body-wave magnitude (m_b (VC) magnitude) is calculated following the approach of Veith and Clawson (1972) and it is the preferred scale for events with deep hypocenters (>30 km) or with epicenters that are located relatively far away from the Spanish territory, such as the offshore areas of the north Atlantic Ocean, Alboran Sea and the Moroccan and Algerian mainland. The M_w magnitude is determined for relatively large events using the algorithm of Dreger and Helmberger (1993).

The IGN catalog is complemented with historic data from IGC (Susagna and Goula, 1999), which also contains a quality index, and with the moment magnitude catalog of the IAG (Stich et al., 2003). The distribution of the different size parameters through time since year 1900 is illustrated in Fig. 1.

The calculation of a size parameter estimate contains uncertainties due to a number of factors: quality of source information and amount of data, instrument sensitivity and accuracy, station coverage, etc. In this work, a criterion to assess earthquake size uncertainty in relation to earthquake date is followed. The basic idea is that the older the event, the higher the uncertainty. This is complemented with further knowledge about the network coverage and magnitude definition. For instance, events with epicenters in northern Africa are mostly expressed in m_b (VC). As network coverage is less complete in this area than in Spain, a higher uncertainty value is assigned for these events than to the events with epicenter in the Iberian Peninsula.

Size of historic earthquakes (pre-1923 occurrence date) is estimated through macroseismic intensity, which is by far the parameter presenting the greatest uncertainty because it is not derived from instrumental data, but from observations and written reports that include significant subjectivity. An uncertainty value ranging from 0.5 to 1.5 intensity degrees is established for intensity estimates of earthquakes with epicenter inland, according to the quality index assigned (higher uncertainty to lower quality index, see Table 1). Earthquakes which epicenter is estimated to be located offshore are penalized with an extra uncertainty of 0.5 intensity degrees.

The uncertainty assigned to magnitude scales ranges from sigma values of 0.4 to 0.1. Sigma values of 0.4 are assigned to m_D magnitude estimates, which were obtained from a relatively short amount of measurements of analog instruments. Magnitude m_{bLg} (MMS) is assigned lower uncertainties because it is derived using equations relating amplitude and period of body-wave arrivals and with different coefficients in function of the epicentral distance. The m_{bLg} (MMS) sigma value of 0.3 for the period 1962–1985 is reduced to 0.2 after this year due to the progressive implantation of digital stations and the geographical densification of the network. From year 2002 onwards, the magnitude estimates are more accurate and accordingly, the associated sigma values are

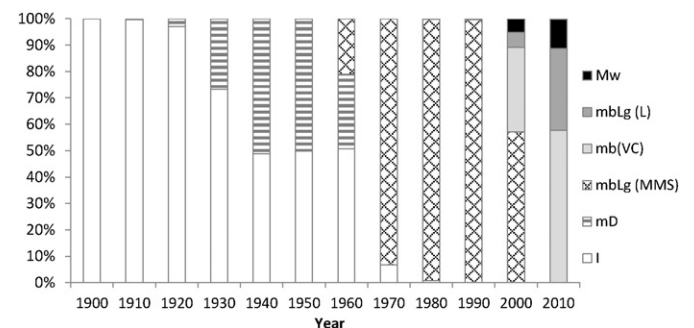


Fig. 1. Percentage of events with different size parameter scales contained in the IGN catalog since 1900.

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