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EFFECT OF THE DETAIL OF EXPOSURE DATA IN LARGE-SCALE SEISMIC RISK ASSESSMENT

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Abstract

The key components for seismic risk assessment studies include hazard characterization, inventory of exposed assets and assessment of their vulnerability. In the recent years, significant research results have been obtained regarding hazard analysis and fragility curves. However, detailed and reliable information on exposed structures to be used for large-scale seismic risk assessment is still not widely available.

The aim of this paper is to examine the influence of the level of detail of the datasets of the building stock on the results of large-scale risk assessment studies applied to urban areas in earthquake-prone regions of Europe.

Exposure data for seismic risk assessment have been collected for a number of cities around Europe, often at a high level of geographic disaggregation. Information on the building stock has been also collected within the framework of research projects aiming at the assessment of the energy performance of buildings, in this instance, aggregated at much larger areas with similar climatic conditions. Another significant source of information on the building stock, albeit not fully harmonised across countries, are the national housing censuses that may furnish an exhaustive picture of the housing stock in a region.

Firstly, the above-mentioned databases are compared in order to investigate their compatibility and to examine the possibility of using them for the seismic risk assessment of large areas in Europe.

A case study is then presented in the main part of the paper. A quantitative risk analysis is applied to a specific European country using a dataset of exposed residential buildings, with a high level of geographic detail. This dataset also offers the opportunity to classify buildings using several variables relevant for vulnerability assessment, like structural type, period of construction and number of floors. The same methodology on quantitative risk analysis is applied at a country level, using the more generic dataset of exposed buildings compiled from different sources and for larger regions.

The comparison of the results allows examining the accuracy and feasibility of seismic risk assessment of the European urban areas, making use of the information on the exposed buildings that is currently available.

Keywords: earthquake risk assessment, building stock, urban areas

1. Introduction

The key components for seismic risk assessment studies include hazard characterisation, inventory of exposed assets and assessment of their vulnerability. In the recent years, significant research results have been obtained regarding hazard analysis and fragility curves. However, detailed and reliable information on exposed structures to be used for large-scale seismic risk assessment is still not widely available.

Detailed exposure data have been collected for seismic risk assessment of a number of cities around Europe. Information on the building stock has been also collected within research projects aiming at the assessment of the energy performance of buildings. Another significant source of information are the national housing censuses that may furnish an exhaustive picture of the housing stock in a region. A major concern is the compatibility of data from different sources and the possible impact on the loss estimates. For instance, data collected by three inspectors through rapid visual observations in the city of Basel in Switzerland varied significantly in the assignment to building typologies, mainly related to the construction material and structural system, and consequently differences up to 30 % were observed in the expected damage calculated for the different datasets [1]. Similarly, important differences were observed in the distribution of reinforced concrete (RC) and masonry buildings by period of construction, as obtained from the national building census and from a detailed study of the seismic risk for the city of Catania in Italy [2]. Lastly, the comparison of two Europe-wide building inventories showed notable differences in the percentage of all building typologies and in the ratio of RC to masonry buildings [3]. These inconsistencies were also reflected in the expected damage computed with a simplified calculation for a given scenario.

The aim of this paper is to examine the influence of the level of detail of the datasets of the building stock on the results of large-scale risk assessment studies applied to urban areas in earthquake-prone regions of Europe. In Section 2 the databases are reviewed in order to investigate their compatibility and to examine the possibility of using them for the seismic risk assessment of large areas in Europe. A case study is then presented in the main part of the paper. A quantitative risk analysis is applied to a specific European country using a dataset of exposed residential buildings with a high level of geographic detail and a more generic one. Losses are computed for the seismic hazard scenario corresponding to the seismic zoning map adopted in the Portuguese National Annex for Eurocode 8 [4]. The comparison of the results allows examining the accuracy and feasibility of seismic risk assessment of the European urban areas, making use of the information on the exposed buildings that is currently available at an European level.

2. Analysis of building inventories

2.1 Exposure data in Europe

Fragility curves are developed either for individual structures or for classes thereof, which are characterised by the main attributes that are important for the seismic vulnerability of buildings. The construction material (steel, concrete and masonry are the most common in the seismic-prone regions of Europe) and period of construction, have a fundamental influence on the vulnerability of buildings. The latter currently works as a proxy for the seismic code used for the design of the building Moreover, the building height is also important, particularly for older construction, as higher buildings are in general more vulnerable to earthquakes.

There are three main sources of information on the European building stock. The first two were developed for research purposes, either regarding seismic risk assessment (mainly for individual metropolitan areas) or energy efficiency in different climatic zones. The third source of data are the national censuses that collect, at regular intervals, information on the building stock – albeit not completely harmonised across countries. Data are reported for buildings or conventional dwellings, using the Nomenclature of Territorial Units for Statistics (NUTS) which contains three main classes: NUTS 1 (groups of administrative regions), NUTS 2 (basic regions for the application of regional policies) and NUTS 3 (small regions for specific diagnoses, e.g. provinces). Within the system of Local Administrative Units (LAUs), LAU 1 roughly corresponds to cities and LAU 2 consists of municipalities or equivalent units.

In the framework of the Prompt Assessment of Global Earthquakes for Response (PAGER) system developed by the United States Geological Survey, a global building inventory has been compiled for the purpose of earthquake loss assessment and risk management [5]. It is based on harmonised data from various sources, e.g. the World Housing Encyclopaedia, national censuses and research publications that has been rated for quality. The quality of data in the PAGER database for most of the high-seismicity countries in Europe is medium or high. The inventory provides estimates of the fractions of building types present in urban and rural regions of each country by their functional use (residential or non-residential). Building types refer to construction material, structural system, height and seismic design in the case of reinforced concrete buildings (ductile or non-ductile).

A similar objective was pursued in the framework of the NERA European research project. The housing census data in the European countries were reviewed for spotting the information that is useful for creating a building inventory for seismic risk assessment [6]. It was observed that the information is not harmonised among the countries as regards the fundamental attributes, e.g. construction material, age, number of storeys, etc. The procedure adopted in NERA was to distribute the total number of buildings in the country in cells with resolution of at least 30 arc seconds in proportion to the population density.

The same procedure was adopted for the Global Exposure Database developed by the Global Earthquake Model (GEM) Foundation [7]. The buildings database is structured at four different levels: i) country; ii) region, where statistics on the buildings are available at national or sub-national level; iii) local, where building counts are obtained by aggregating data at a building level and iv) building, with information on individual structures coming from ground surveys. Dwelling fractions (urban/rural and residential/non-residential) provided at country and region level may be used to compute the building fractions.

Europe-wide building inventories have been developed for monitoring and improving the energy performance of buildings. Data is usually extracted from previous projects and official statistics, or based on expert estimations in cases where official data is not available. The data of interest for seismic risk assessment include the total number or percentage of buildings (or dwellings) and the total floor area by use of the building, period of construction and material of construction. The information is usually aggregated in large areas that encompass several regions, i.e. NUTS 3 or higher, and in most cases refers to a limited number of European countries. The available information is quite limited for the fragility assessment of classes of buildings as construction material and number of storeys are not reported in most databanks, but the floor area may be used to estimate the current value of buildings and repair costs. Besides, there are significant divergences in the data concerning important features of the buildings, for instance their age.

A population and housing census takes place every 10 years in the member states of the European Union and the European Free Trade Association. A major advantage of census data is that they are collected for individual buildings and can therefore be aggregated at NUTS 3 or LAU areas. Furthermore, it is possible to obtain the coordinates of the areas of interest for geo-referencing, which is essential for the calculations. Fig. 1 presents the countries where information on the *construction material* and *number of floors* was collected at the 2011 censuses. The *construction period* is available in all countries. Note that the necessary information for risk assessment is recorded in most earthquake-prone areas of Europe, i.e. the majority of Mediterranean and Balkan countries and many of the countries in central and central-east Europe.

Aggregated data on dwellings from the 2011 census are available at the Eurostat Census Hub for countries, NUTS 2, NUTS 3 and LAU 2 areas. All data are available for countries and the NUTS 2 regions, but are incomplete for smaller areas. The variables of interest for seismic risk assessment available at the Census Hub are the *period of construction* of the building and possibly the *floor space* and *number of occupants* of dwellings. Data are provided in tables and can be combined in ‘hypercubes’ that intersect, for a geographic unit, two or more surveyed variables, *e.g*. number of dwellings by period of construction and per type of building (residential buildings with one, two or more than three dwellings and non-residential ones).

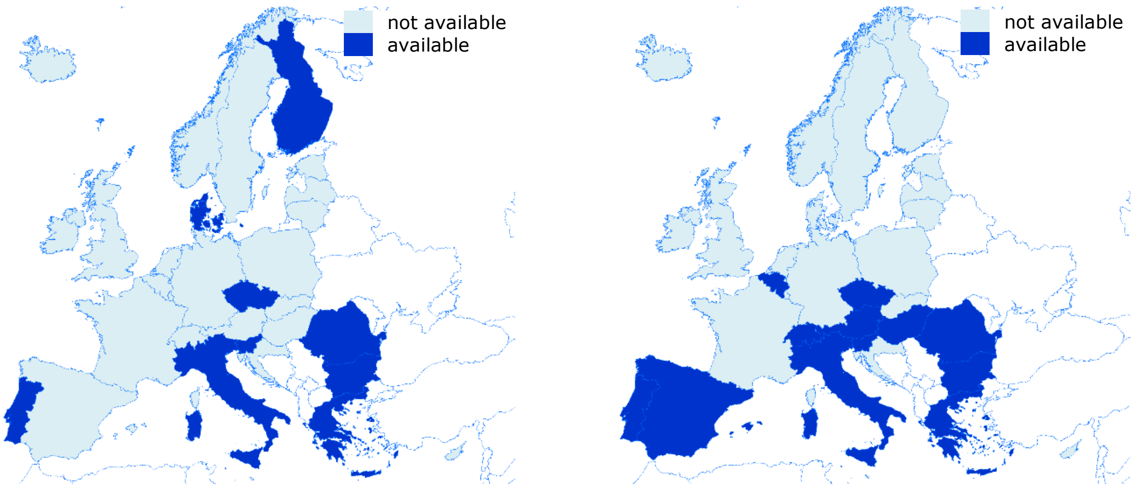


Fig. 1 – Countries where information on the construction material (left) and number of floors (right) was collected at the 2011 building census

2.2 Exposure data used in the present study

2.2.1 Detailed exposure data obtained at a national level

The Portuguese census on housing and population carried out in 2011 [8] possesses specific features that make it particularly appropriate to characterize in detail the exposure data for large-scale seismic risk assessment studies, as far as possible in a survey not specifically designed to analyse the seismic vulnerability of buildings. In addition to three basic variables that may exist in the European housing censuses, namely the *period of construction*, the *structural type* and the *number of floors*, other relevant variables are available in the 2011 survey. For instance, the “Building questionnaire” of the 2011 Portuguese housing census includes questions on (i) the repair needs of structural elements, (ii) the ground floor configuration, (iii) the position of the building within the block (corner or free-standing building) and (iv) the building height relatively to the adjacent ones.

Previous works [9], [10], analysed the geo-referenced surveys of the residential building stock and population obtained in the 2011 Portuguese census [8] to collect data for large-scale seismic risk assessment studies. Table 1 shows the breakdown of the three variables collected in the 2011 census survey for the purpose of grouping buildings in different vulnerability classes, or typologies. According to the classification presented in Table 1, it was possible to classify the residential buildings surveyed in 350 different typologies (ten categories for the variable *period of construction*, five categories for the variable *type of structure* and seven categories for the variable *number of floors*).

Table 1 – Classes of variables selected in the 2011Portuguese census

Building structural type	Period of construction of buildings		Nb. of floors of buildings
Reinforced concrete (RC)	Before 1919	1981 - 1990	1
Masonry with RC floors	1919 - 1945	1991 - 1995	2
Masonry without RC floors	1945 - 1960	1996 - 2000	3
Adobe and rubble stone	1961 - 1970	2001 - 2005	4
Others	1971 - 1980	2006 – 2011	5 to 8
			8 to 15
			+ 15

The Portuguese municipalities were adopted as the geographic unit of analysis in which the number of residential buildings belonging to each of the 350 typologies was accounted for [10]. The Portuguese census was also examined to obtain the average number of dwellings per building and the average useful floor space per dwelling, for each municipality.

The total number of classic buildings surveyed in Portugal mainland, in 2011, was 3 353 610 and the total number of classic dwellings was 5 621 098.

2.2.2 Exposure data obtained at an European level

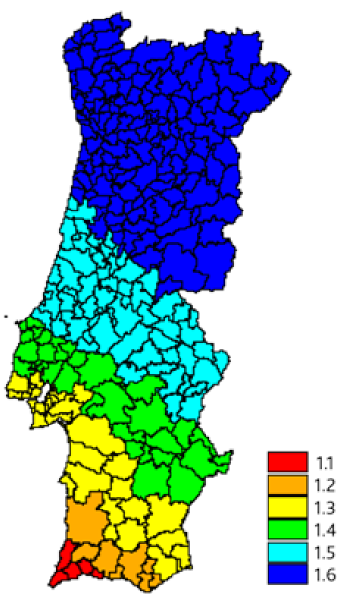
The Census Hub was investigated to obtain more generic data on exposed building assets in Portugal. The variables that were found relevant for seismic risk assessment were the number of dwellings per *period of construction* of the building and the number of dwellings per *useful floor space*. The classification of the number of dwellings by period of construction was similar to the one presented in Table 1. With this information it was possible to classify the 5 621 098 dwellings existing in mainland Portugal in 10 different typologies. The geographic unit of analysis available at the Eurostat Census Hub was NUTS 3. The average useful floor space per dwelling was also obtained per each NUT 3.

3. Seismic risk assessment

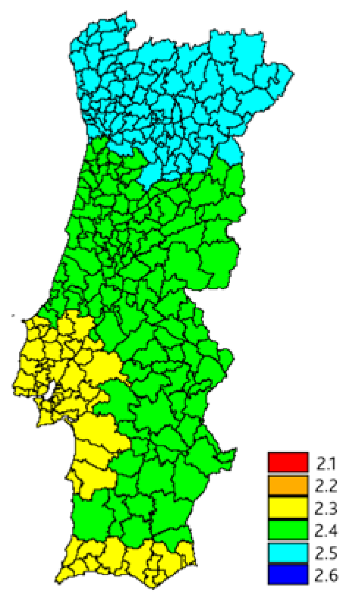
3.1 Seismic hazard

Two seismic scenarios were adopted to estimate the losses in mainland Portugal. They correspond to the two types of seismic actions prescribed in the Portuguese National Annex to EN 1998-1 [4] that were based on seismic hazard maps probabilistically evaluated for a return period of 475 years [11]. The seismic action type 1 characterizes the seismicity derived from off-shore long distance sources, including high-magnitude earthquakes. The seismic action type 2 describes short-distance, inland, moderate magnitude earthquakes.

Fig. 2 illustrates the seismic zonation present in the Portuguese National Annex to EN 1998-1 that is geographically disaggregated at a municipality level. Fig. 3 shows the corresponding horizontal elastic design spectra for seismic actions type 1 and 2.



(a)



(b)

Fig. 2 – Seismic zonation in the Portuguese National Annex to EN 1998-1. (a) Seismic action type 1; (b) seismic action type 2 [4].

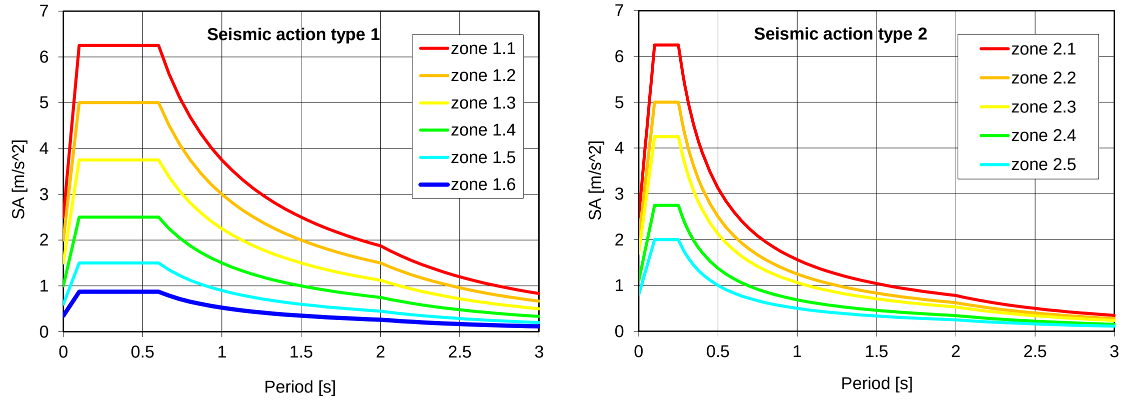


Fig. 3 – Horizontal elastic response spectra for seismic actions type 1 and 2 (5% damping) in the Portuguese National Annex of Eurocode 8 (based on [4]).

3.2 Modelling building damage

Damage to RC and masonry buildings was modelled by means of fragility curves that have been recently produced considering the specific characteristics of Portuguese buildings. RC building classes were defined for three periods of construction and six classes of building height [14]. The three periods of construction were defined by the date of entry into force of the Portuguese seismic codes introduced in 1958 and 1983. The buildings with date of construction later than 1960 were built after the entry into force of the first modern Portuguese seismic resistant code [13], while the buildings with date of construction later than 1985 should have been built under the current Portuguese seismic resistant code [12]. However, it is not possible to assure that the buildings constructed after the enforcement of the codes followed any seismic design requirement [10].

Fragility curves were based on the results of nonlinear dynamic analyses of two-dimensional models of infilled frames, where the cross-sections of elements were discretised in fibres and the infills were modelled by diagonal compression struts [14]. The authors used 100 acceleration time-histories recorded at regions with geological and tectonic characteristics similar to those in Portugal. The variable parameters considered for the definition of the buildings to be analysed included the number of storeys, storey height, column and beam cross-section dimensions, slab thickness, mechanical properties of concrete, steel and masonry, and period of construction. Spectral acceleration was used as earthquake intensity measure and the fragility curves were considered to follow a lognormal distribution. Four damage states (slight, moderate, extensive and collapse) were defined from the results of pushover analysis using global and inter-storey drift as the engineering demand parameter [14].

Masonry building typologies were defined for two types of masonry (one for masonry with concrete or timber floors and another for weak masonry comprising adobe, rubble stone or rammed earth blocks) and five classes of building height (corresponding to 1, 2, 3, 4 and 5-7 storeys) [15]. Masonry buildings with concrete or timber floor were further subdivided by three periods of construction (delimited by the 1958 and 1983 building codes). The fragility curves were derived using the capacity spectrum method, wherein the demand spectrum intersecting the capacity spectrum of each building type at the global drift threshold of each limit state was used to obtain the corresponding value of peak ground acceleration [15]. This design spectrum and peak ground acceleration were used in the following to calculate the spectral acceleration at the yield period of the building representative of each class, taken as the median of the lognormal cumulative function [15]. In the absence of detailed information, the conventional value of standard deviation β = 0.6 was used for the fragility curves for all classes.

The fragility curves for the most common types of RC and masonry buildings are indicatively shown in Fig. 4. These are one-storey RC buildings constructed between 1958 and 1983, that correspond to 11 % of the total stock of residential buildings, and two-storey masonry buildings constructed in the same period, that correspond to 9 % of the total stock. The fragility curves show that RC buildings have higher probabilities of exceeding the slight and moderate damage states than masonry buildings. On the other hand, masonry buildings are more vulnerable as regards the extensive damage and collapse states.

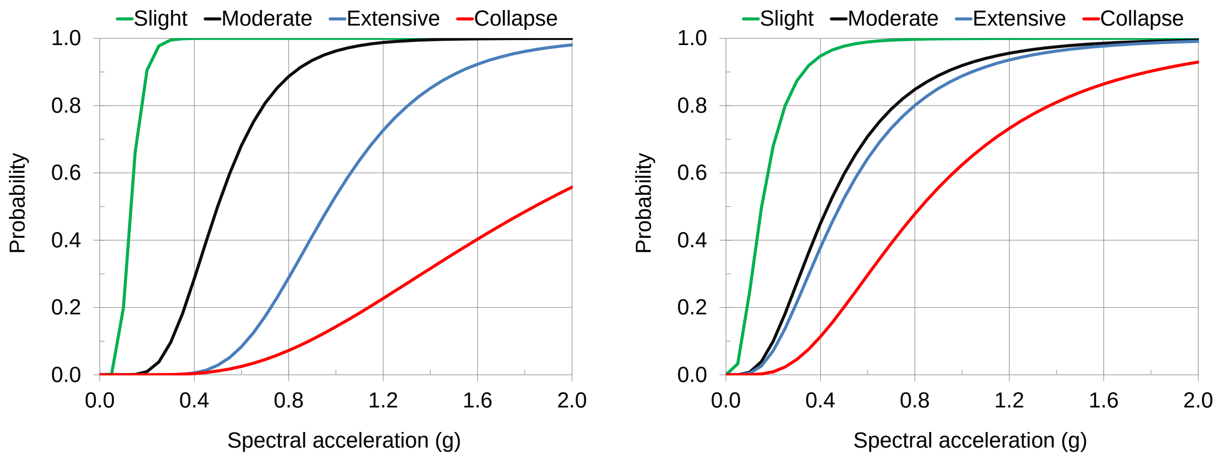


Fig. 4 – Fragility curves for one-storey RC buildings in seismic zone A [14] (left) and two-storey masonry buildings [15] (right) constructed between 1958 and 1983

3.3 Classifying seismic vulnerability of buildings

In seismic risk studies the evaluation of the distribution of the building stock by vulnerability classes (see $\mathrm{P}_V(V=v)$ in Eq. 1) should meet, simultaneously, three requirements: (i) match the inventory of building available, which was described in section 2.2.and 2.3 (ii) be in accordance with the adopted models to calculate damage on buildings, described in section 3.2 and (iii) comply with the existing built environment.

In this section it is described how buildings and dwellings existing in 2011 in mainland Portugal were classified according to the fragility models selected for the study.

The fragility models proposed by [14] and [15] consider, respectively, 48 and 15 RC and masonry building classes, for different seismic codes, date of construction and number of storeys. The authors also proposed [15] five classes of weak masonry buildings for different number of floors. The fragility models were specifically developed to match the inventory of buildings surveyed in the 2011 Portuguese census, so the distribution of the building stock is naturally adapted to the damage models.

In what concerns the generic inventory obtained from the Eurostat Census Hub, the buildings were classified only by period of construction and disaggregated geographically by NUTS 3, as information on the building structural type and number of floors was absent. In this case, the distribution of dwellings by vulnerability classes was based on expert opinion, taking into account that the Portuguese stock is mainly composed of low rise buildings and has a large amount of masonry structures, whose incidence is decreasing in the latest periods of construction.

3.4 Modelling economic losses

The following equation describes the model used to estimate the expected economic losses in dwellings, given a seismic hazard scenario with severity *h* [10]:

$$\mathrm{E}(L\,|\,h) = Nb \cdot RV \cdot \sum_d \sum_v A_v \cdot DF_d \cdot \mathrm{P}_V(V=v) \cdot \mathrm{P}_D(D=d\,|\,h) \cdot \qquad (1)$$

where:

Nb is the number of dwellings in the studied region;

RV is an indicative average construction price, per square meter, adopted to estimate the building's replacement value;

A_v is the average useful floor space per dwelling belonging to a vulnerability class $V = v$;

DF_d are loss ratios defined as the ratio of building repair cost (or loss), to the building replacement value at the time of the earthquake, representing, in this case, a rough estimate of the percentage of the building's lost area, when the building is in a given damage grade *d*;

$\mathrm{P}_V(V=v)$ is the probability of a building belonging to a certain class of vulnerability $V = v$, assumed to be equal to the frequency of that class in the studied region;

$\mathrm{P}_D(D=d\,|\,h)$ is the damage probability matrix defined as the percentage of buildings, belonging to a class of vulnerability $V = v$, being in a damage state *d* after being subject to a seismic action with severity *h*. These discrete probabilities of the buildings being in each of the five damage states were approximately obtained differentiating the cumulative probabilities given by the fragility curves presented in section 3.2.

In the current study the building's replacement values, *RV*, were estimated in a simplified way in accordance with the ordinance no. 1172 applied to the housing stock inventoried in 2011. The ordinance distinguishes the construction prices for three different building clusters in the Portuguese territory, namely the district capitals and other major cities (744 €/m^2), the municipalities located in urban areas (650 €/m^2) and the municipalities located in rural areas (589 €/m^2) [10]. The consideration of the average useful floor space in Eq. 1 multiplied by the replacement value mentioned herein leads to the evaluation of exposure in economic terms, as follows:

$$Exposure = Nb \cdot RV \sum_v A_v \cdot \mathrm{P}_V(V=v) \tag{2}$$

On the other hand, the relation between levels of damage and losses is a major source of uncertainty in seismic risk studies [16], [17]. A damage-to-loss function recently developed for Portuguese RC buildings [17], was adopted in this study [17]. Martins et al. [17] attempted to model the loss ratio probabilistically, but could not fit the most common distributions to this variable, for more than two damage states. Hence, a deterministic approach was followed in the current work, using the average loss ratios proposed in [17], *i.e*, the values of 0.056, 0.282, 0.522 and 0.825, respectively for Slight, Moderate, Severe and Collapse damage states.

In the case of detailed exposure, data was obtained directly at a municipality level from the national census. In the case of data obtained from the Census Hub, the number of dwellings obtained per NUTS 3 was uniformly distributed per the municipalities integrated in each NUTS 3. So, in both cases, losses were estimated at a municipality level, to take advantage of the detail of the seismic hazard assessment at the same municipality level.

A conservative approach was adopted when aggregating losses, as between the seismic actions of type 1 and 2 was selected the scenario able to generate the highest loss value for each municipality.

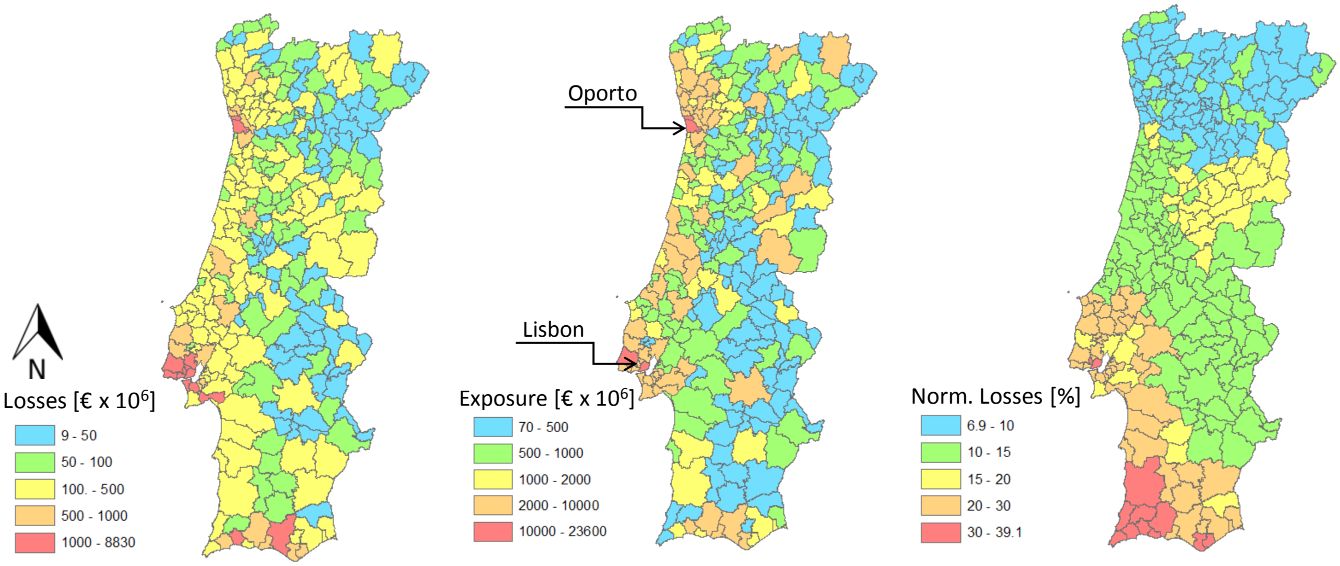
It is also worth mentioning that the spatial correlation of losses was not considered in this study. The effect of neglecting a positive spatial correlation in probabilistic loss assessment is the underestimation of the standard deviation of the portfolio loss, resulting in a lower probability estimation of the extreme values of losses, *i.e.*, small and large loss values become less likely to occur [10], [18], [19], [20]. Still, the estimation of a probabilistic loss curve is beyond the objectives of this study and for comparison purposes only losses estimates for a 475 years return period scenario were analysed.

Lastly, it should be pointed out that the losses estimates due to earthquakes in the Portuguese building stock are significantly underestimated in this study, since the census only takes into account the residential buildings and because the floor area adopted for a building is the average useful floor space estimated of all building's dwellings. However, these two simplifications were adopted in both analysed cases and therefore will not influence the comparisons.

4. Effect of the detail of exposure data on losses

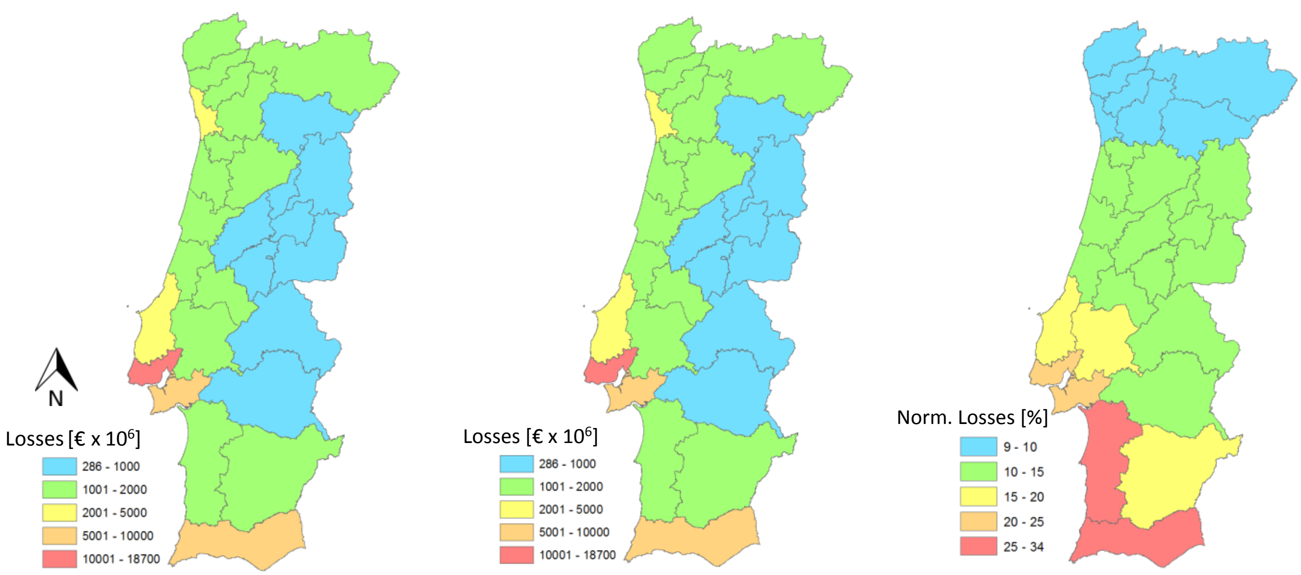
Fig. 5 and Fig. 6 present the maps of exposure, losses and normalized losses for a 475 years return period seismic scenario. Also indicated in Fig. 5 are the locations of Lisbon and Oporto that are the municipalities associated with the largest urban areas in the country.

The maps on Fig. 5 display exposure and losses geographically disaggregated by municipality and used a municipality-based exposure data obtained at a national level, whereas the maps on Fig. 6 outline exposure and losses geographically disaggregated by NUTS 3 and used NUTS3 based exposure data obtained in the Census Hub.



(a) (b) (c)

Fig. 5 – Exposure (a), losses (b) and normalized losses (c) based on detailed national data (municipality level)



(a) (b) (c)

Fig. 6 – Exposure (a), losses (b) and normalized losses (c) based on European data

The comparison of the maps on the left side of the figures with the maps on its central part indicates that the highest losses are mainly concentrated in urban regions and on coastal line regions. It is also clear that losses are largely influenced by exposure. On the other hand, the normalized losses on the right side of the figures are higher in the south part of mainland Portugal due to the influence of a more severe seismic hazard of the region (see Fig. 2). The normalized losses are also higher in the southwest part of the country do to the low levels of exposure and to the severe seismic hazard of the region.

Table 2 and Table 3 present the values of exposure, losses and normalized losses, aggregated by NUTS 2, based, respectively, on the data obtained in the Census Hub and on the detailed exposure data at a national level. A map with the classification of territorial units for statistics at level 2 and 3, for mainland Portugal, is illustrated in Fig. 7. Also shown are the losses due to long and short distance 475 years return period hazard scenarios, indicating that, with the models selected in this paper, the long distance scenario causes globally lower losses than the short distance one.

Table 2 – Losses per NUTS 2 based on detailed national data (municipality level)

	NORTE	CENTRO	LISBOA	ALENTEJO	ALGARVE	Total
Loss [€×10^9]	14	11	36	4	8	73
Loss [€×10^9] Long distance scenario	5	3	32	3	8	52
Loss [€× 10^9] Short distance scenario	14	11	29	3	5	62
Exposure [€× 10^9]	143	83	147	23	27	423
Norm. loss [%]	10%	13%	24%	16%	31%	17%

Table 3 – Losses per NUTS 2 based on European data (NUTS 3 level)

	NORTE	CENTRO	LISBOA	ALENTEJO	ALGARVE	Total
Loss [€×10^9]	13	10	32	4	8	67
Loss [€×10^9] Long distance scenario	5	3	29	3	8	48
Loss [€× 10^9] Short distance scenario	13	10	29	3	5	60
Exposure [€× 10^9]	134	77	139	22	25	396
Norm. loss [%]	10%	13%	23%	18%	34%	17%

Fig. 7 – NUTS 2 and 3 in Portugal mainland (www.ine.pt)

The estimate aggregated economic losses for the region is larger than the one anticipated by Silva et al. [15], that are the authors of the damage models used in this paper. Such discrepancy cannot be explained by the assumptions made to evaluate building replacement values, but may be influenced by the differences in the hazard scenarios used in both studies. In the present study a conservative approach was adopted when aggregating losses, since two seismic scenarios were considered and the one able to generate higher loss values was selected for each municipality. Moreover, in the Portuguese National Annex to the Eurocode 8 the design spectra are generally more conservative than the correspondent uniform hazard spectra derived from probabilistic seismic hazard analysis (PSHA) studies (see an example in [21]).

As regards the effect of the detail of exposure data on losses, the comparison of Table 2 and Table 3 shows that the less accurate inventory originates an error of 8% on losses estimates relatively to the more detailed dataset, whereas the normalized losses do not differ significantly. The values quantifying exposure on the two datasets have a relative percentage difference of 6% contributing to the error above mentioned. In addition to the differences in the geographic detail of the data, the variation in the exposure may be explained as follows: (i) the exposure for the detailed inventory was evaluated on the basis of the number of buildings, multiplied by the average number of dwellings per building and by the average useful floor space per dwelling, (ii) the exposure for the more generic inventory the number of dwellings was collected directly and simply multiplied by the average useful floor space per dwelling.

5. Conclusions

The analysis of building inventories in Europe used in seismic risk assessment studies showed that they fully comply with the required taxonomy of exposed buildings and with the spatial variability of the seismic hazard. Furthermore, they accurately represent the building stock in the area of interest. Their main drawback is that they refer to rather small geographic areas and are not representative of other similar areas. As a matter of fact, a number of case studies highlight the significant differences in the building stock between urban and rural areas, between towns in the same country and even between districts of the same town. It is demonstrated that these differences may affect the losses estimated in small-scale risk studies. Such observations are not surprising, still their relevance should be investigated in large-scale risk assessment studies.

This article aimed to investigate the accuracy and feasibility of seismic risk assessment at European urban areas, making use of the information on the exposed buildings in large datasets, available at an European level, but not specifically designed to analyse the seismic vulnerability of buildings.

The paper compared the loss estimates obtained with two datasets of different levels of accuracy applied to a specific European country. On the one hand, the losses were obtained using a dataset of exposed residential buildings, with a high level of geographic detail. On the other hand, the loss estimates were based on a more generic dataset compiled for larger regions. The case study shows that both at large geographic regions (NUTS 2) and at a country level the assessment based on the generic data captures the order of magnitude of the losses estimated on the basis of the detailed data. However, the difference in the absolute values of total losses, calculated with the two datasets, shows a non-negligible difference in the values of total losses for the mainland country, although it may be justified by the uncertainty in quantifying exposure.

In conclusion, considering the low level of observed variability of losses (8%), the readily available data extracted from the Eurostat Census Hub can be used to assess with acceptable accuracy the seismic risk for all European countries. The opinion of local experts on the distribution of the set of buildings per different vulnerability classes is of great importance in such studies.

Accordingly, there are still some questions left unanswered that deserve further studies, namely the need for a sensitivity analysis on the impact of the opinion of local experts on results and the analysis of the influence a full probabilistic risk study, rather than a single scenario.

References

[1] Steimen S, Fäh D, Giardini D, Bertogg M, Tschudi S (2004): Reliability of building inventories in seismic prone regions. *Bulletin of Earthquake Engineering*, **2**(3), 361-388.

[2] Frassine L, Giovinazzi S (2004): Basi di dati a confronto nell'analisi di vulnerabilità sismica dell'edilizia residenziale: un'applicazione per la città di Catania. *XI Congresso Nazionale 'L'ingegneria Sismica in Italia'*, Genoa, Italy.

[3] Spence R, Foulser-Piggott R, Pomonis A, Crowley H, Guéguen P, Masi A, Chiauzzi L, Zuccaro G, Cacace F, Zulfikar C, Markus M, Schaefer D, Sousa ML, A. Kappos (2012): The European building stock inventory: creating and validating a uniform database for earthquake risk modelling. *15th World Conference on Earthquake Engineering*, Lisbon, Portugal.

[4] IPQ (2010): *Portuguese Annex to Eurocode 8: Design of structures for earthquake resistance - Part 1: general rules, seismic actions and rules for buildings*. Instituto Português da Qualidade, Caparica, Portugal.

[5] Jaiswal K, Wald D, Porter K (2010): A global building inventory for earthquake loss estimation and risk management. *Earthquake Spectra*, **26**(3), 731-748.

[6] Crowley H, Özcebe S, Spence R, Foulser-Piggott R, Erdik M, Alten K (2012): Development of a European building inventory database. *15th World Conference on Earthquake Engineering*, Lisbon, Portugal.

[7] Gamba P (2014): *Global Exposure Database: scientific features*. GEM Technical Report 2014-10, GEM Foundation, Pavia, Italy.

[8] INE (2012): *Censos 2011- Resultados definitivos - Portugal*. Instituto Nacional de Estatística, Lisbon, Portugal.

[9] Sousa ML (2008): Annualized economic and human earthquake losses for mainland Portugal. *14th World Conference on Earthquake Engineering, Beijing*, China.

[10] Sousa ML, Campos Costa A (2015): Evolution of earthquake losses in Portuguese residential building stock. *Bulletin of Earthquake Engineering*. DOI 10.1007/s10518-015-9809-z.

[11] Campos Costa A, Sousa ML, Carvalho A. (2008): Seismic zonation for Portuguese National Annex of Eurocode 8. *14th World Conference on Earthquake Engineering*, Beijing, China.

[12] RSA (1983): *Regulamento de Segurança e Acções para Estruturas de Edifícios e Pontes*. Decreto Lei nº 235/83 de 31 de Maio e Decreto Lei nº 357/85 de 2 de Setembro. Imprensa Nacional - Casa da Moeda, 1986. Lisbon, Portugal.

[13] RSCCS (1958): *Regulamento de Segurança das Construções Contra os Sismos*. Decreto nº 41 658. Imprensa Nacional. Lisbon, Portugal.

[14] Silva V, Crowley H, Varum H, Pinho R, Sousa L (2015): Investigation of the characteristics of Portuguese regular moment-frame RC buildings and development of a vulnerability model. *Bulletin of Earthquake Engineering*, **13**(5), 1455-1490.

[15] Silva V,·Crowley H, Varum H, Pinho R (2015): Seismic risk assessment for mainland Portugal. *Bulletin of Earthquake Engineering*, **13**(2), 429-457.

[16] Martins L, Silva V, Marques M, Crowley H, Delgado R (2014): Evaluation of analytical fragility and damage-to-loss models for reinforced concrete buildings. *2nd European Conference on Earthquake Engineering*, Istanbul, Turkey.

[17] Martins L, Silva V, Marques M, Crowley H, Delgado R (2014): Modelo de consequência para edifícios de betão armado em Portugal. *JPEE2014*, Lisbon, Portugal.

[18] Wesson RL, Perkins DM (2001): Spatial correlation of probabilistic earthquake ground motion and loss. *Bulletin of the Seismological Society of America*, **91**(6), 1498-1515.

[19] Chen WF, Scawthorn C (2003): Earthq*uake Engineering Handbook*. CRC Press.

[20] EERI (2000): *Financial management of earthquake risk*. EERI Endowment Subcommittee on Financial Risk Management.

[21] Sousa ML, Campos Costa A, Caldeira L (2010): Apreciação do risco sísmico em Lisboa. Revista Portuguesa de Engenharia de Estruturas (RPEE), Thematic number on risks (ISSN 0870 – 984X), Lisbon. Portugal.