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# EVOLUTION OF EARTHQUAKE LOSSES IN PORTUGUESE RESIDENTIAL BUILDING STOCK

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## ABSTRACT

The objective of this paper is to analyse the evolution of expected earthquake losses in Portuguese residential buildings, to determine if their natural regeneration originates the mitigation of the seismic risk, although exposure in the region increased over time.

To achieve this goal, the evolution of quantified risk measures was evaluated, based on the surveys of the residential building stock obtained in the 2001 and 2011 Portuguese census.

This study provides a global perspective of the seismic risk on the Portuguese mainland, and makes possible the comparison of risk levels between different regions and epochs.

The comparison of economic losses obtained in these two different moments in time, took into consideration the inflation rate, and led to the conclusion that the natural regeneration of the residential housing stock contributed to the mitigation of seismic risk, even if there was a significant increase in the exposure.


## INTRODUCTION

The seismic risk analysis of a large population of buildings is an expensive and time consuming process, mainly due to the required survey of the elements exposed. Consequently, the number of studies on the evolution of seismic risk is not so frequent and the process of seismic risk management often includes mitigation proposals that do not consider this issue.

The objective of this paper is to analyse the evolution of expected earthquake losses in Portuguese residential buildings, to determine if their natural regeneration originates the mitigation of the seismic risk, although the exposure in the region increased over time.

The surveys of the residential building stock obtained in the 2001 and in the 2011 Portuguese census were used to characterize the vulnerability of the Portuguese building stock in two different moments in time.

The comparison of five different metrics to characterize losses in two different moments provides a global perspective of the evolution of the seismic risk in the Portugal mainland.

## METHODOLOGY FOR LOSS ASSESSMENT

The expected value of losses, E($L$), for a given time interval is given by (Sousa, 2008):

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$$\mathrm{E}(L) = \int_H \mathrm{E}(L \mid h)\, f_H(h)\, dh \qquad (1)$$

where, $f_H(h)$ is the probability density function of the seismic hazard, with seismic hazard here defined as the annual exceedance probability of a level *h* of the seismic motion at a site, approximating the annual exceedance frequency of *h*.

If the expected losses are analyzed in terms of the equivalent lost building area, then the expected annual loss value, conditioned by a seismic hazard level, $\mathrm{E}(L \mid h)$ may be obtained by the following expression:

$$\mathrm{E}(L \mid h) = Ne_T \cdot \sum_d \sum_v A_v \cdot DF_d \cdot \mathrm{P}_D(D = d \mid h) \cdot \mathrm{P}_V(V = v) \qquad (2)$$

where:

- $Ne_T$ is the number of buildings in the studied region;
- $A_v$ is the average floor area of the buildings belonging to a typological class, with vulnerability *v*, in the studied region;
- $\mathrm{P}_D(D = d \mid h)$ is the damage probability matrix considered as the percentages of buildings, belonging to a typological class with vulnerability *v*, that are in a damage state *d*, after being subject to a seismic action with severity *h*;
- $\mathrm{P}_V(V = v)$ is the probability of a buildings belonging to a typological class that has vulnerability $V = v$, and it is assumed to be equal to the frequency of that typological class, in the studied region.

Different measures of earthquake impacts were considered, namely the expected annualised economic earthquake losses, referred to as the *AEL*, and the expected annualised human earthquake losses, called the *AHL*, by analogy with the *AEL*. The Coburn and Spence (2002) model was used to evaluate the human loss as a consequence of earthquakes. To estimate the human casualties, it was assumed that most people were indoors at the time of the earthquake, i.e., only night-time earthquake scenarios were contemplated, because the mobility of the population was not considered. Three other parameters, or risk metrics, were used to characterise the specific risk. They were obtained normalising *AEL* and *AHL* with respect to exposure (buildings and inhabitants, respectively). The first parameter, the *AELR*, is the expected *AEL* ratio, which «represents the *AEL* as a fraction of the replacement value of the local building inventory» (FEMA, 2001), $Ne_T$ ,whereas the second parameter, the *AELC*, expresses the *AEL per capita*. The third parameter, the *AHLR*, results from normalising the *AHL* with respect to the total resident population in the region, $Np_T$ . Table.1 exhibits the risk indicators used in this study.

Table.1 Expected annualised earthquake loss parameters.

| Risk | Absolute | Specific |
|---|---|---|
| Economic | *AEL* | $AELR = AEL / Ne_T$<br>$AELC = AEL / Np_T$ |
| Human | *AHL* | $AHLR = AHL / Np_T$ |

## SEISMIC HAZARD AND VULNERABILITY

The risk was evaluated based on previous seismic hazard studies for the region (Sousa, 2006) and on the damage model of Giovinazzi and Lagomarsino (2003, 2004).

The seismic hazard maps adopted in the evaluation are shown in Figure 1.

The study of the seismic vulnerability of the region followed three main steps: (i) analysis of a survey of the exposure, available as a geo-referenced inventory, (ii) classification of the vulnerability of assets at risk in different typologies; and (iii) characterization of their vulnerability according to damage models.

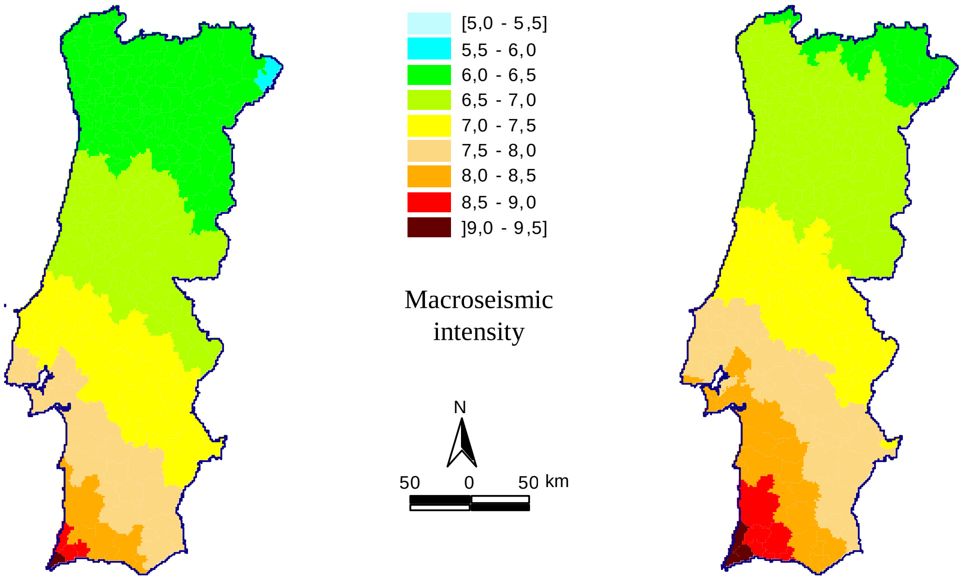


Figure 1. Hazard maps for Portugal [Sousa, 2006]. Left: probability of exceedance of 10% in 50 years. Right: probability of exceedance of 5% in 50 years.

Using the variables surveyed in the Portuguese census of 2001, it was possible to classify and to characterize the vulnerability of the housing stock in 315 different typologies, considering nine periods of date of construction, per five classes of structural type, and per seven classes of number of floors. The same 315 different typologies apply to the housing stock surveyed in the Portuguese Census of 2011, aggregating the buildings constructed between 2001 and 2011 to the buildings constructed between 1986 and 2001. These buildings were constructed after the date of entry into force of the current earthquake code (RSA, 1983). The Portuguese census also surveyed the population present in residential buildings assigned to the above mentioned vulnerability typologies.

Figure 2 shows an illustration of common building typologies existing in Portugal mainland.

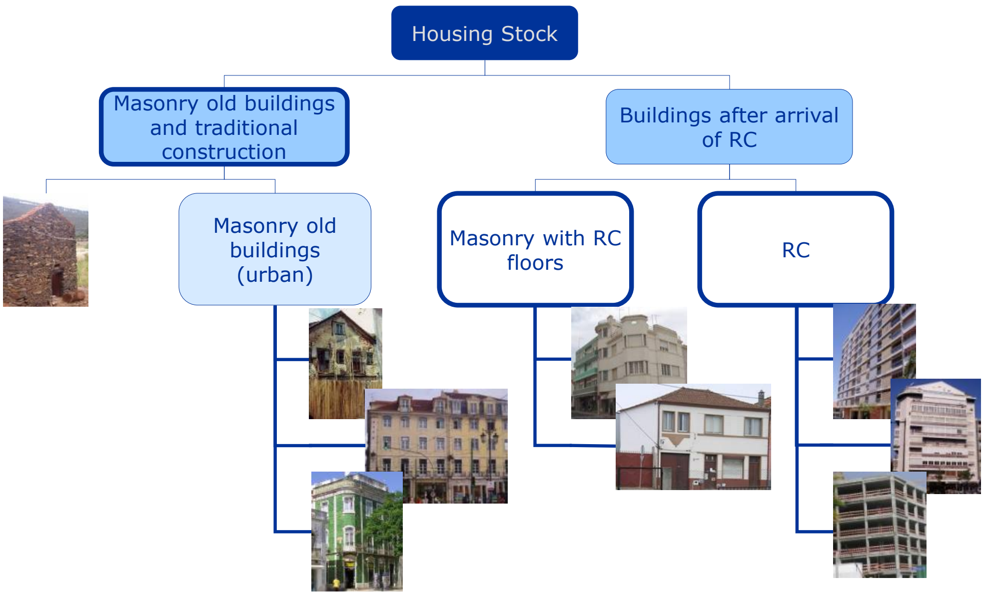


Figure 2. Illustrated synthesis of building construction in mainland Portugal

The damage model proposed by Giovinazzi and Lagomarsino (2003 and 2004) was applied to evaluate the building damage. The seismic vulnerability of the elements at risk belonging to a given building typology is described by the Vulnerability Index, which varies between 0 and 1 and is independent of the hazard severity level. The average vulnerability of a region is obtained by weighting the typology Vulnerability Index by the several typologies present in the region. Figure shows the average vulnerability map for Portugal taking into account the residential building exposure surveyed in the Portuguese Census 2001.

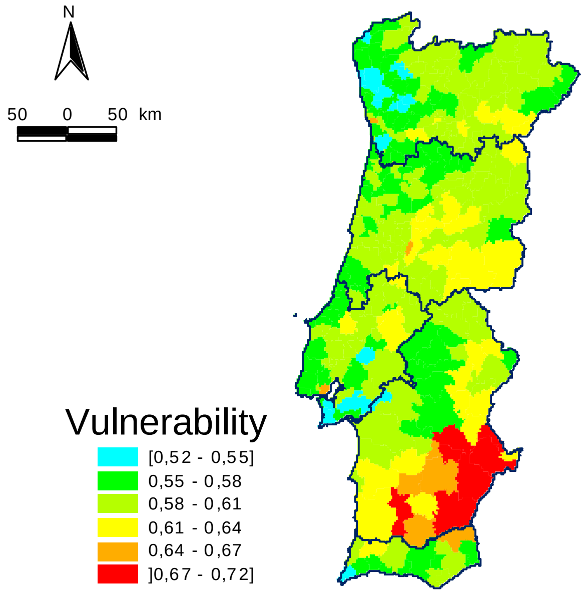


Figure 3. Average vulnerability map for Portugal (Sousa, 2008), exposure based on Census 2001

## LOSS ASSESSMENT

Figure 4 shows the geographic distribution at a county level of the different measures of economic losses considering the housing stock surveyed in the 2001 census. Notice that in the 2001 earthquake losses were valued at 2011 prices, taking into consideration the inflation rate in Portugal mainland for these ten years, according to information published by the Portuguese statistical institute.

Figure 5 (left) shows the expected loss of human life per year, the *AHL*, as a consequence of the Portuguese seismicity, and Figure 5 (right) shows this risk indicator normalised by the number of inhabitants in each county, the *AHLR*. The population was surveyed in the 2001 census.

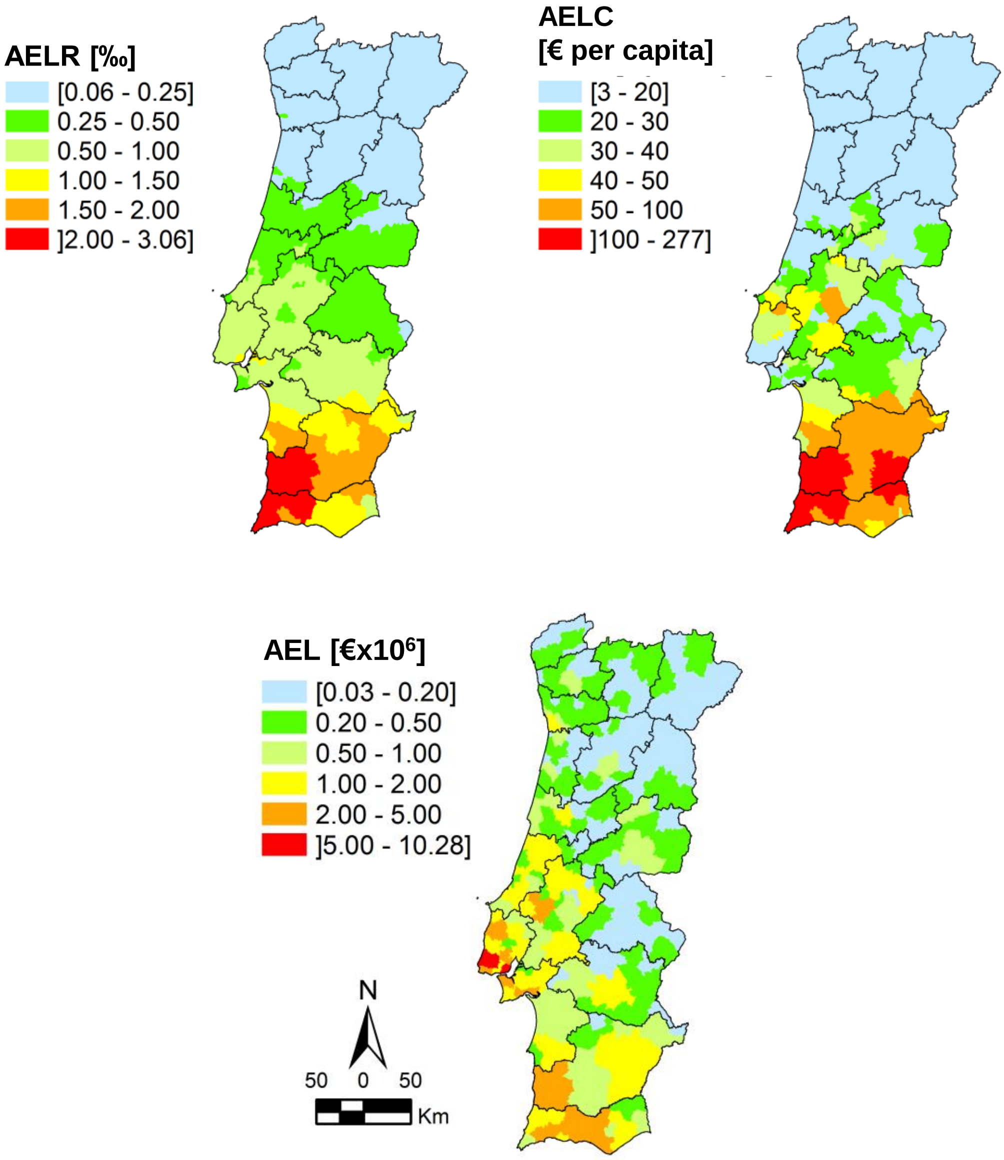


Figure 4. Expected Annualised Economic earthquake Losses by county, based on the census of 2001 (adapted from Sousa, 2008).

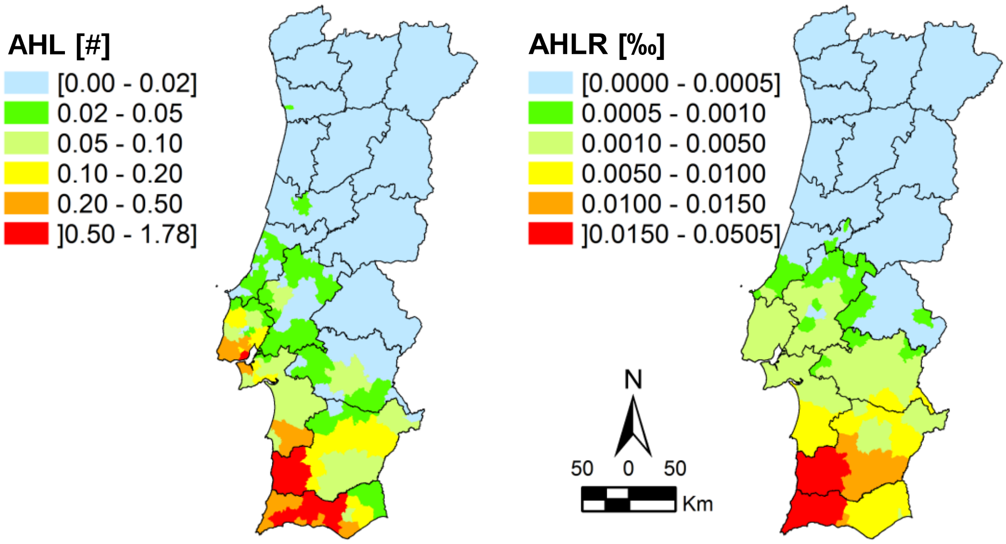


Figure 5. Expected Annualised Human earthquake Losses by county, based on the census of 2001 (adapted from Sousa, 2008)

Figure 6 and Figure 7 show the geographic distributions, at a county level, of the same measures of risk, but considering the housing stock and population surveyed in the census of 2011.

The analysis of Figure 4 to Figure 7 shows that the geographic distribution pattern of the annualised losses remained almost the same, between the 2001 census and the 2011 census. The specific risk parameters, *AELR* and *AELC*, (top of Figure 4 and of Figure 6) have high values in the south of the country, due to the influence of high hazard and vulnerability values, whereas the geographic distribution of *AEL* (bottom of Figure 4 and of Figure 6) shows higher losses in Lisbon Metropolitan Area, due to the important exposure in this region and to the moderate hazard level.

The geographic distribution of human losses (Figure 5 and Figure 7) is similar to the pattern observed in Figure 4 and in Figure 6, that refers to economic losses, more precisely, absolute risk is concentrated in Lisbon Metropolitan Area due to high exposure and moderate hazard, whereas the normalized risk is significant in the south of the country, due to the influence of severe seismic hazard.

Nevertheless, some differences may be pointed out between the two sets of maps: (i) the absolute Economic Annualised Losses (*AEL*) decreased in general, between the census of 2001 and the census of 2011, except for a few counties in the northeast of Portugal; and the expected Annualised Human earthquake Losses decreased both in absolute and in relative terms mainly in the southern region of Portugal.

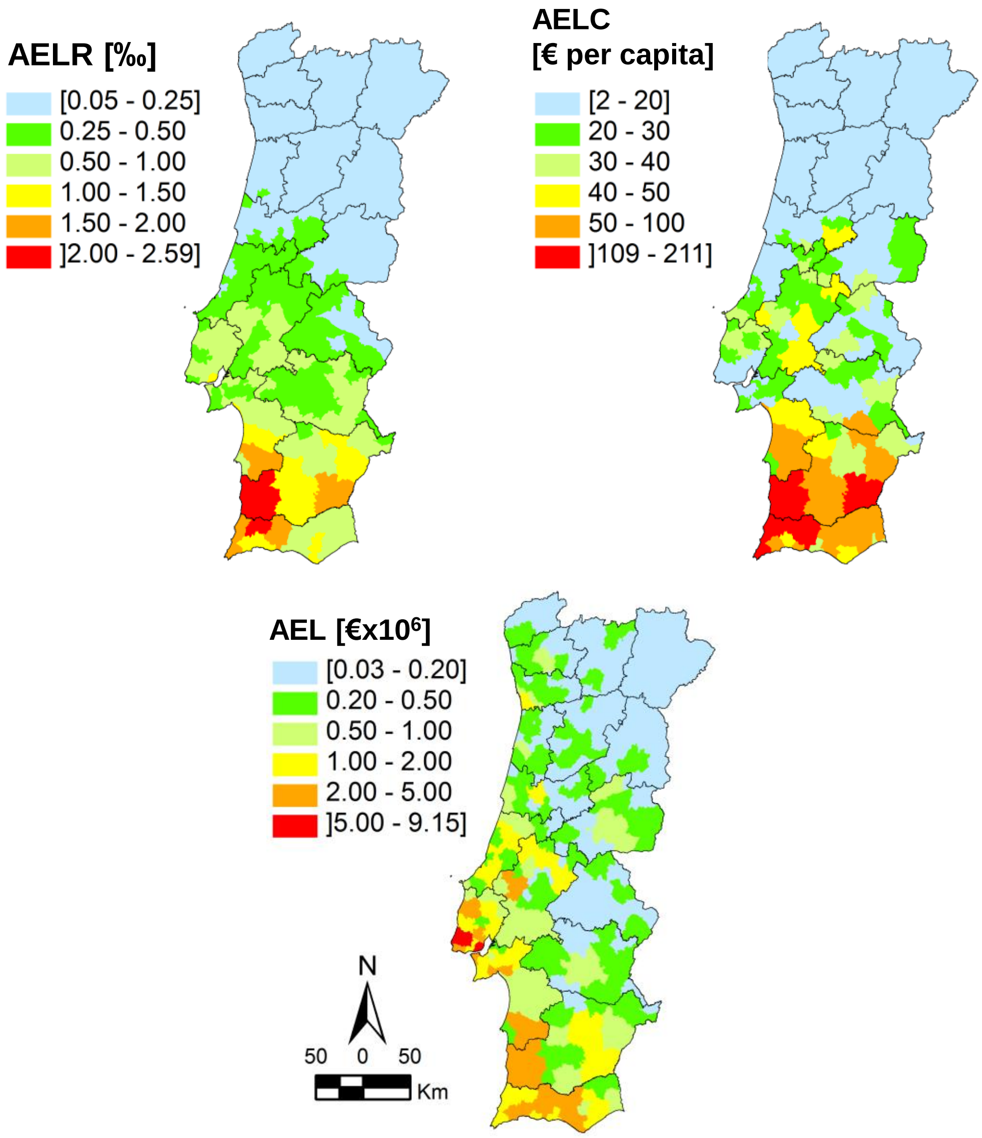


Figure 6. Expected Annualised Economic earthquake Losses by county based on the census of 2011.

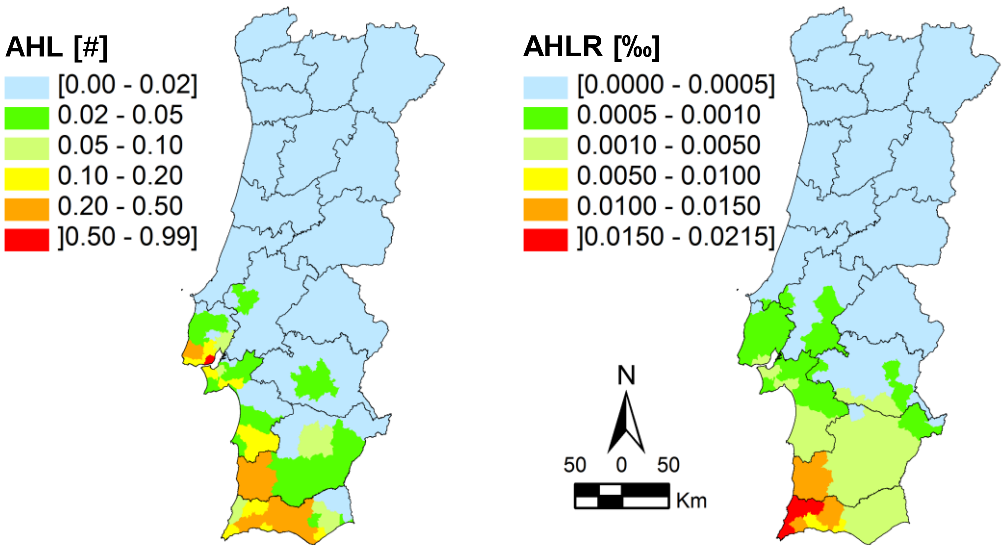


Figure 7. Expected Annualised Human earthquake Losses by county based on the census of 2011.

When the elements at risk are spatially distributed in a region, the individual losses are not statistically independent, and their variance cannot be added without considering the spatial correlation of losses (EERI, 2000). However, although spatial correlation is essential to describe the global loss distribution, the expected individual losses can be accumulated to obtain the global expected annualised earthquake losses of the region (FEMA, 2001).

In Table 1, the expected annualised economic and human earthquake losses were accumulated for regions larger than counties, and in particular, for the Algarve region. Table 1 also shows the inventory of the elements at risk and the corresponding exposure values.

From the analysis of results presented in Table 1, it can be noted that between 2001 and 2011:

i) the values of the building exposure increased in absolute terms in the Algarve and Portugal mainland, and show almost no variation in Lisbon. The value of building exposure increased by 28% in the Algarve and by 13 % in Portugal mainland.
ii) the exposed population increased in absolute terms in the Algarve (14%) and in Portugal (1%), but showed a slight decrease in Lisbon (-3%);
iii) the expected Annualised Economic earthquake Losses (*AEL*) decreased in Lisbon (11%), in the Algarve (10%) and in mainland Portugal (14%);
iv) the expected Annualised Economic earthquake Losses Ratio (*AELR*) decreased in Lisbon (10%), in the Algarve (27%) and in mainland Portugal (24%);
v) the expected Annualised Economic earthquake Losses per capita (*AELC*) decreased in Lisbon (8%), in the Algarve (21%) and in Portugal mainland (16%);
vi) and the expected annualised human losses, in both absolute (*AHL*) and relative terms (*AHLR*), were reduced by almost one half.

Table 1. Evolution of the expected losses in the residential building stock surveyed in 2001 and 2011 in Lisbon and the Algarve, and on the Portugal mainland.

| | 2001 | | | 2011 | | |
|---|---|---|---|---|---|---|
| Exposure/ Losses | Lisbon | Algarve | PT | Lisbon | Algarve | PT |
| *Build. Expos.* [Euro x $10^9$] | 8.5 (2%) | 19 (5%) | 392 (100%) | 8.4 (2%) | 24 (6%) | 442 (100%) |
| Population [x $10^3$] | 553 (6%) | 390 (4%) | 9 789 (100%) | 537 (5%) | 444 (4%) | 9 906 (100%) |
| *AEL* [Euro x $10^6$] | 10 (6%) | 30 (18%) | 171 (100%) | 9.2 (6%) | 27 (19%) | 147 (100%) |
| *AELR* [‰] | 1.22 | 1.54 | 0.44 | 1.09 | 1.12 | 0.34 |
| *AELC* [Euro per capita] | 19 | 77 | 18 | 17 | 61 | 15 |
| *AHL* [#] | 1.8 (12%) | 5.2 (37%) | 14.1 (100%) | 0.99 (14%) | 2.7 (38%) | 7.2 (100%) |
| *AHLR* [‰] | 0.003 | 0.0133 | 0.0014 | 0.0018 | 0.0062 | 0.0007 |

PT, Portugal mainland

## CONCLUSIONS

The synthesis of expected losses based on the census of 2001 and 2011 shows that the exposure increased in the analysed regions, except for the population in Lisbon.

Comparing losses relative to two different instants in time, with a time interval of ten years, it was observed a mitigation of seismic risk, as measured in terms of expected economic and human losses, even if there is a significant increase in the exposure. Notice that earthquake losses obtained with the 2001 survey were valued at 2011 prices, taking into consideration the inflation rate in Portugal Mainland for these 10 years.

According to the assumptions of this study it can be concluded that the natural regeneration of the residential housing stock contributes to the reduction of the expected seismic economic losses in Portugal, at a rate of 14% per ten years, and to the reduction the expected annualised human losses to almost one half after ten years.

In future, the studied period of evolution will be enlarged taking into considerations other census, namely the 1991 Portuguese census.

## ACKNOWLEDGMENTS

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## REFERENCES

Coburn, AW and Spence, R (2002) Earthquake protection John Wiley & Sons, LTD, 2002, UK

EERI (2000) Financial management of earthquake risk, EERI, Oakland, California, U.S.A.

FEMA (2001) HAZUS99 Estimated annualized earthquake losses for the United States. FEMA 366, Federal Emergency Management Agency Mitigation Directorate, Washington DC., U.S.A.

Giovinazzi S and Lagomarsino S (2003) “Seismic risk analysis: a method for the vulnerability assessment of built-up areas”, *Proceedings of the European Safety & Reliability Conference*, Maastricht.

Giovinazzi S and Lagomarsino, S (2004) “A macroseismic method for the vulnerability assessment of buildings”, *Proceedings of 13th World Conference on Earthquake Engineering*, Vancouver, B.C., Canada.

Sousa, ML (2006) Risco Sísmico em Portugal Continental, PhD Thesis, IST, UTL, Lisbon, Portugal.

Sousa, M.L. (2008) "Annualized Economic and Human Earthquake Losses for Mainland Portugal”. *14th World Conference on Earthquake Engineering*, Pequim, China.