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BASIS FOR EARTHQUAKE INSURANCE POLICIES

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ABSTRACT

Earthquake insurance is analysed under three different perspectives: (i) determination of annual seismic risk premium, (ii) determination of probable maximum losses for a given seismic scenario and (iii) determination of probable maximum losses for various reference time intervals. To illustrate the method developed an application to some early-twenty-century parishes in the city of Lisbon is made .

KEYWORDS

Hazard analysis; seismic scenarios; vulnerability; building typology; risk analysis; seismic risk premium; Probable Maximum Loss.

METHODS

In insurance activity, seismic risk studies lead to the resolution of the following two problems: (a) evaluation of the annual seismic premium for different building typologies at various geographic locations, and (b) total losses that can occur in any given portfolio.

Presently there is no standard definition for the concept of Probable Maximum Loss (*PML*). In this paper a contribution for the clarification of this concept is addressed.

To obtain annual premium (seismic risk taxes) and probable maximum losses, hazard and vulnerability are analysed in first place.

Hazard Analysis

Hazard estimation was based on the standard Cornell/McGuire approach that involves the evaluation of: a seismic source model, the Gutenberg-Richter recurrence model (Oliveira *et al.*, 1994) and the attenuation of macroseismic intensities. The attenuation laws were refined with the inclusion of three types of soil conditions (Sousa *et al.*, 1996): hard, intermediate and soft soil.

The hazard is computed for each site and smoothed throughout geographic units, identified by the index z.

Vulnerability Analysis

Damage Ratio, DR, is defined as the cost of repair a building damaged during an earthquake, measured in percentage of the value of the building at the time of the earthquake. For a given site with a macroseismic intensity, I, there are buildings exhibiting different DR, leading to a probability distribution of DR given I. The expected value of DR, is the Mean Damage Ratio, $MDR(I) = \mathrm{E}\lfloor DR|I \rfloor$ or, in other words, is the mean percentage of the replacement value for a homogeneous group of elements at risk. This function is designated as the building vulnerability.

In this work, building vulnerability was modelled as a function of the seismic coefficient as used in the structural design. Data were adapted from world-wide earthquakes statistics compiled by Tiedmann (1992). According to Tiedmann, a dependence between vulnerability, translated into Mean Damage Ratio, and seismic intensity I can be obtained through the seismic coefficient $\beta(\%)$. The following expressions were estimated by regression for the values presented by Tiedmann:

$$MDR\% = e^{K_1} \cdot \beta^{K_2} \tag{1}$$

where K_1 and K_2 are given by:

$$\begin{cases} K_1 = 0.0188 \cdot I^3 - 0.5884 \cdot I^2 + 6.3515 \cdot I - 18.822 \\ K_2 = 0.0104 \cdot I^3 - 0.3047 \cdot I^2 + 3.1560 \cdot I - 11.938 \end{cases} \tag{2}$$

A seismic coefficient has to be assigned to each particular typology i and to each point of a grid covering the region under analysis. Hence $\beta \equiv \beta_{i,z}$.

This approach is particularly adequate to the analysis of modern buildings which were constructed under a given seismic code. However, for buildings constructed before recent seismic code practices, seismic coefficients are adopted based on empirical knowledge and expert opinion.

Annual Premiums

In insurance activity, technical annual premiums are defined as the annual expected loss of a given element at risk. In what concerns building structures and seismic action, the annual premiums $R_i(\%)$, for each typology i, located at a site with an seismic hazard defined by a probability density function $h(I)$, are given by

$$R_i = \mathrm{E}[MDR_i] = \int h(I) \cdot MDR_i(I) \cdot dI \tag{3}$$

where MDR_i (%) is the vulnerability associated to typology i.

Generally, the calculation of technical premiums does not follow strictly the above equation due to difficulties in numerical processing. A simplification of equation 3 has been proposed by Munich Re (1991) as:

$$R_i = \mathrm{E}[MDR_i] \approx \sum_{I=VI}^{IX} \frac{MDR_i(I)}{T(I)} \tag{4}$$

where $T(I)$ represents the return period for macroseismic intensity I. Alternatively, Swiss Re (Tiedmann, 1992) suggests:

$$R_i = \max_I \left(\frac{MDR_i \cdot f \cdot v \cdot P \cdot 100}{SI \cdot T(I)} \right) \tag{5}$$

where f is a factor covering overheads, profits, etc.; v is a factor covering uncertainties; P is a period of exposure to hazard (or reference time interval) and SI is a percentage of sum insured. Expression 5, is a particular parcel of sum in equation 4, and states that the premium should be associated only with the scenario that contributes the most, in probabilistic terms, to the expected value given by equation 3. Naturally, the above definitions give rise to different figures of premium being the one by equation 5 (disregarding the considered additional factors) the lowest estimate.

Probable Maximum Losses for a Given Seismic Scenario

According to EERI (1989) the Probable Maximum Loss, *PML*, for a given seismic scenario is defined as "a probable upper limit of the losses that are expected to occur as a result of an earthquake, normally defined as the largest monetary loss associated with one or more earthquakes proposed to occur on a specific fault or within specific source zones".

Although the above definition is related to the economic impact of earthquake scenarios, meaning that the stock of buildings must be represented in monetary units, the Probable Maximum Loss can also be assessed in terms of distribution of the stock building by different typologies. In this way, the economic value assigned to the building property is, implicitly, considered uniform. On the other hand, the value of *PML* depends, first of all, on the chosen economical measuring unit, then on the object of analysis such as a given typology or the entire stock of buildings, and, finally, on the geographical unit under consideration. For instance, the *PML* can be applied to any particular insurance portfolio.

To evaluate the losses, l, in a given geographic unit z, with a known number of buildings of typology i, $N_{i,z}$ (normalised to the total number of buildings considered), that suffered damages corresponding to a macroseismic intensity $I_{s,z}$ of a scenario s, one compute:

$$l = \sum_i \sum_z DR_i(I_{s,z}) \cdot N_{i,z} \tag{6}$$

For the cases in which the conditional distribution of $p(DR_i|I)$ is available, reflecting the dispersion of Damage Ratios for a given intensity, the distribution of losses $f(l)_s$ for a given scenario s, is:

$$f(l)_s = \sum_i \sum_z p(DR_i|I_{s,z}) \cdot N_{i,z} \tag{7}$$

Once this distribution has been obtained, its expected value or any other fractile can be analysed. For instance, if one considers that the PML_s is the expected value of that distribution, it can be mathematically defined as:

$$PML_s = \int l \cdot f(l)_s dl \approx \sum_i \sum_z MDR_i(I_{s,z}) \cdot N_{i,z} \tag{8}$$

where the approximation in the rightmost term is valid under certain conditions. In some cases the 90% fractile has been considered as the PML_s.

In seismotectonic zones characterised by rare but strong seismic scenarios, the concept of *PML* can not be analysed without considering the low probability of occurrence of those scenarios. On the other hand, there may occur other moderate events with much higher probability causing total losses of significance. Consequently, the *PML* should be evaluated taking into account not only the dispersion on Damage Ratio but also on the seismic environment.

Probable Maximum Losses for Various Reference Time Intervals

To overcome the limitation of using a single scenario, several seismic scenarios s should be considered, each one with its own probability of occurrence. The resulting distribution of losses $f(l)$ is given by

$$f(l) = \sum_s \sum_z \sum_i p(DR_i|I_{s,z}) \cdot h(I_{s,z}) \cdot N_{i,z} \tag{9}$$

where $h(I_{s,z})$ is the probability density associated with scenario s.

To compute $f(l)$, first one determines the losses corresponding to different return periods T, $L(T)$, which, disregarding Damage Ratio uncertainty (DR replaced by MDR), are given by:

$$L(T) = \sum_{i}\sum_{z} MDR_i(I_z(T)) \cdot N_{i,z} \tag{10}$$

where $MDR_i(I_z(T))$ is obtained for each intensity associated with the hazard for the return period T, in each geographic unit. Inhere, $h(I_{s,z})$ is associated with the hazard function. The method used to compute the final probability distribution function of losses $F(l,\mathbf{q})$, where the vector $\mathbf{q}$ is a set of parameters, consists in finding the parameters $\mathbf{q}$ of a given analytical distribution that best fits the losses corresponding to the several return periods T. Another way to proceed was to obtain an analytical form of the hazard and then to evaluate the other distribution.

Due to the randomness of the underlying physical phenomena, the probability distribution of losses should be evaluated for low probability of being exceeded, or with a high safety margin. The expected value of that distribution can be analysed for different reference time intervals of n years. Assuming that the losses occurring in each year are independent, the annual distribution $F(l,\mathbf{q})$ can be transformed in $G(l,\mathbf{q},n)$, which is the distribution for a reference time interval of n years:

$$G(l,\mathbf{q},n) = F(l,\mathbf{q})^n \tag{11}$$

Finally, the Probable Maximum Losses will be a chosen fractile of the distribution $G(l,\mathbf{q},n)$, depending on the safety margin selected in the decision process.

APPLICATION TO LISBON

As it was referred, the methodology developed above is particularly suitable for the analysis of the buildings which were constructed under a given seismic code; however, there are no reliable surveys for this type of buildings in Portugal.

To illustrate the methodology, an application was made to an old area of the city of Lisbon for which the housing stock is known (Oliveira *et al.*, 1994). The results presented are preliminary, essentially due to the difficulties in assigning seismic coefficients to the typologies identified in the study area.

Hazard Analysis

Figure 1 presents the hazard curve for the region of Lisbon. To obtain this curve an intermediate soil condition was considered for the town of Lisbon. Macroseismic intensity was evaluated in EMS-92 scale leading to lower hazard estimates than if MMI scale was used.

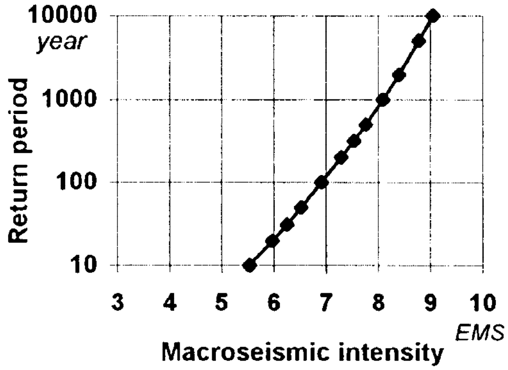

Fig. 1. Seismic hazard at Lisbon region.

Housing Stock and Vulnerability Analysis

The behaviour of buildings during earthquakes is very difficult to predict and depends upon a great number of parameters. In order to allow a more correct understanding of their seismic behaviour and according to their main structural properties, Lisbon's buildings of the "early twenty century" parishes under study have been classified into five different typologies, adapted from Oliveira, *et al.* (1993), according to two simple parameters: epoch and type of construction.

A - Masonry stone buildings prior to 1755, low rise, most in bad shape (Freq. > 3Hz);
B - Masonry stone buildings constructed during the period 1755-1880 with horizontal ties and in good shape (Freq. > 2.5 Hz);
C - Brick masonry tall buildings constructed during the period 1880-1940. Wooden floors. (Freq. > 2 Hz);
D - Dual structures with masonry resistant walls and RC slabs or RC moment resistant frames heavily infilled with brick walls constructed during the period of 1940-1960 (Freq. > 2 Hz);
E - RC buildings constructed in the period 1960 - 1983, designed according to the seismic resistant code for lateral load requirements (RSCCS, 1958 and RSEP,1978).

The mean number of stories per typology was also considered in the analysis leading to two categories: greater than 4 stories and less than 4 stories.

The structural characterisation of Lisbon's building stock was made, up to now, using several types of questionnaire surveys covering different areas (Oliveira, *et al.*, 1994). The survey covering the area of Campolide-Beato (Fig. 2), composed of nine parishes, was made under LNEC's (National Laboratory of Civil Engineering) supervision and was specially designed for future seismic impact studies. Table 1 presents the number of buildings per typology and parish. The mean number of stories above ground level is also shown.

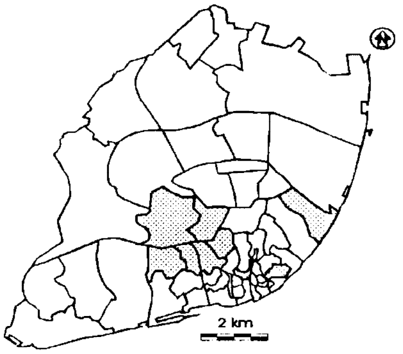

Fig. 2. Lisbon town and area of Campolide-Beato where the survey was made.

Table 1. Number of buildings as a function of the typology at the area of Campolide-Beato. Mean number of stories above ground level (Oliveira *et al.*, 1994).

Typology	**Parishes**								
	Beato	Campolide	Sta Isabel	Sto Condest.	S. Vic. Fora	S. Mamede	Sta Justa	S.S. Pedreira	C. de Jesus
A	3	2	32	58	204	2	32	1	42
B	137	587	329	265	162	245	133	41	176
C	569	513	191	268	29	144	60	347	182
D	539	339	109	61	12	69	3	116	29
E	480	790	114	49	14	124	1	92	43
Total	1728	2231	775	701	421	584	229	597	472
Stories	2.39	2.07	3.38	2.15	3.44	4.13	4.31	5.28	4.41

In Portugal the seismic coefficient varies spatially from zone to zone in the country reflecting both the geological conditions, the number of stories of the building and the seismicity included in the seismic code (or its absence) at the epoch of construction (RSA, 1983, RSEP, 1978 and RSCCS, 1958). It is assumed that, for the selected five typologies, the majority of which are prior to the modern seismic code (RSA, 1983), the seismic coefficient varies between the extreme values of 0.01 and 0.10. Figure 3 presents the curves of vulnerability for the five identified typologies and for the two categories of number of stories.

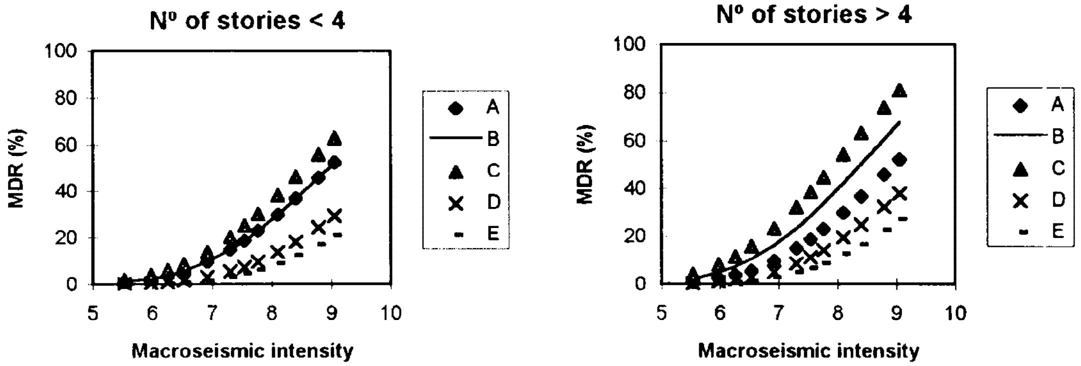

Fig. 3. Vulnerability functions for the five typologies considered in this paper. Left: mean number of stories less than 4; Right: mean number of stories greater than 4.

Annual Premiums

The annual seismic premiums for the various seismic coefficients representative of the typologies that can be found in the area of Campolide-Beato in Lisbon were computed using equations 1, 2 for the Mean Damage Ratio, and equations 3, 4 and 5 for the premiums, Fig. 4.

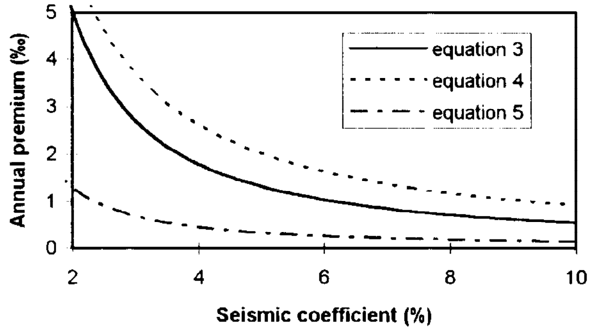

Fig. 4. Annual premiums as a function of the seismic coefficient according to equations 3 to 5.

Probable Maximum Losses for 1755 Scenario

Regarding Portuguese seismicity, the worst event causing large losses is the well known 1755 Lisbon with magnitude 8.5, producing an intensity varying between VIII and X (MM) in Lisbon (Table 2).

Table 2. Macroseismic intensities (MM) of 1755 earthquake in Campolide-Beato (Pereira de Sousa, 1928).

	Parishes								
	Beato	Campolide	Sta Isabel	Sto Condest.	S. Vic. Fora	S. Mamede	Sta Justa	S.S. Pedreira	C. de Jesus
Intensity (MM)	IX	VIII	VIII	IX-X	VIII	VIII	X	VIII	VIII

Using equation 6, the global value of *PML* for the area of Campolide-Beato under the 1755 seismic scenario was 38.1%. This value is quite large due to the low seismic coefficient assigned to the building typologies represented in the parishes analysed.

Probable Maximum Losses for Various Reference Time Intervals

Among the current distributions it was verified that the one that best fits the observed annual distribution of losses in the analysed parishes, is the Weibull distribution:

$$F(l,\mathbf{q}) \equiv F(l,\alpha,\beta,\gamma) = 1-\exp\left[\left(\frac{l-\alpha}{\beta}\right)^{\gamma}\right] \tag{12}$$

The fitted values of the parameters α, β, and γ, for each parish, are presented in Table 3.

Table 3. Parameters of the annual distribution of losses for each parish.

Parish	α	β	γ
Beato	-0.098	0.056	0.318
Campolide	-0.086	0.054	0.317
Sta Isabel	-0.090	0.074	0.322
Sto Condest.	-0.063	0.089	0.323
S. Vic. Fora	-0.068	0.077	0.319
S. Mamede	-0.257	0.272	0.390
Sta Justa	-0.030	0.275	0.371
S.S. Pedreira	0.116	0.281	0.377
C. de Jesus	0.040	0.272	0.372
Total	0.0262	0.0916	0.3286

The expected value of the distribution of losses for a reference time interval of n years was obtain according to the following expression:

$$\mathrm{E}(l,n) = \int_{0}^{100} l \cdot g(l,\alpha,\beta,\gamma,n)\,\mathrm{d}l \tag{13}$$

Table 4 presents the expected values of *PML* for each parish, for various reference time intervals and for the global area under study.

Table 4. Expected values of probable maximum losses (%) for various reference time intervals and for several parishes.

Parishes	**Reference time interval (year)**			
	25	50	75	100
Beato	5.24	8.05	10.13	11.81
Campolide	5.15	7.91	9.95	11.61
Sta Isabel	6.48	9.89	12.38	14.39
Sto Condest.	7.65	11.60	14.48	16.78
S. Vic. Fora	7.06	10.76	13.47	15.65
S. Mamede	10.01	14.50	17.63	20.06
Sta Justa	12.45	18.01	21.85	24.82
S.S. Pedreira	12.12	17.43	21.10	23.95
C. de Jesus	12.27	17.73	21.50	24.42
total *PML*	7.36	11.08	13.79	15.96

Note that the last 4 parishes for which the *PML* is larger, are the ones with mean number of stories greater than 4 (see Table 1).

CONCLUSIONS

The present paper defines a methodology to compute the technical insurance premiums and the *PML*. This methodology, which is illustrated with the results for a selected set of parishes, is a good basis for setting an insurance policy.

While the determination of premiums depends essentially on the values of the probability distributions, the determination of the *PML* is influenced by its definition. The contribution of this paper is to describe the concept of *PML* introducing several seismic scenarios each one with its own probability of occurrence. In this context, the *PML* is determined by the decision on the fractiles to be considered.

The results obtained in this analysis are subjected to several uncertainties which deserve further research, especially in what concerns the typologies not included in modern seismic codes, and the assignment of their seismic coefficients. Other uncertainties, not so critical, are related to the hazard, to the *MDR* and to the stock of building.

Another form to reduce the uncertainty in the process is to consider the hazard in terms of strong ground motion spectral ordinates and the *MDR* as a function of the spectral response. It is also of great importance the consideration of a more detailed typology classification where, for instance, the structural irregularities are taken into consideration aggravating the premiums and losses.

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