Seismic Risk Hierarchy Assessment of Portugal's Mainland Public Hospital Building Stock

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Abstract

The current work was requested by the ACSS, Administração Central do Sistema de Saúde, with the main purpose of assessing the seismic risk hierarchy of the public hospital building stock in Portugal's mainland. The HAZUS generalised risk assessment methodology was utilised for this purpose, applied to each of the 97 hospitals composed by a total of 602 buildings. The characterisation of the building stock was carried out through an online survey directed to each of the establishments, which together with specific parameters published by LNEC, Laboratório Nacional de Engenharia Civil, allowed to determine the seismic vulnerability of each building. By applying a generalised ground type classification methodology and providing this to the Portuguese Standard EN 1998-1 equations, as well as the location of each establishment, the seismic action for each building was characterised. After obtaining the seismic action and the vulnerability for each building, the performance point was calculated, which by interacting with the fragility curves proposed by Laboratório Nacional de Engenharia Civil, allowed for the computation of the probability of occurrence of different damage states. These probabilities of occurrence were then considered when calculating a single risk index per building. For each one of the establishments, the risk index of the buildings was weighted: i) by arithmetic average, and ii) by weighting of the net area. The result of this work is divided into three hierarchical lists: list of all buildings; list by establishment; list by establishment considering only the buildings that house emergency services.
Keywords: Seismic Risk; Generalised Assessment; Public Hospital Building Stock; Seismic Vulnerability; HAZUS

1. Introduction

This work is part of a series of three studies requested by the Administração Central do Sistema de Saúde (ACSS), the entity responsible for ensuring the management of financial and human resources of the Ministry of Health and the National Health Service, to Instituto Superior Técnico. The main purpose is the characterisation of the seismic risk hierarchy of the public hospital building stock in Portugal's mainland.

Since it is impossible to carry out a campaign of individual seismic studies for each of the buildings, ACSS intends to obtain a hierarchical list of seismic risk, in order to subsequently develop a more specific analysis of the group of buildings at higher risk.

In addition to the importance of this group of buildings in the daily service to society, the relevance of this study is further enhanced by its relevance in the first response after an earthquake. Furthermore, the public hospital building stock represents a high value asset, hardly replaceable in short to mid term, which determines the importance of carefully planning its maintenance.

Portugal's mainland is a territory in which earthquakes of great magnitude are spaced out in time, contributing to a reduced concern regarding this hazard in management and maintenance of public buildings. The cost associated with preventive strategies often distances decision makers from this perspective, regardless of the overwhelming costs of replacement and human lives at risk.

The deliverable of this study is composed by three distinct seismic risk hierarchy lists: (i) list by buildings; (ii) list by establishments; (iii) list by establishments only considering buildings that house emergency service.

Two major factors were considered in the seismic risk assessment of the buildings: i) the local seismic action, which is geographically and ground type dependent and ii) the vulnerability of each building.

2. Methods

In order to estimate the seismic risk of such a disperse building stock, a generalised methodology was used. From many methodologies available, HAZUS was considered to be the most adequate to the problem in hands. HAZUS was designed for risk assessment due to events of natural origin, authored by the National Institute of Building Sciences, Federal Emergency Management Agency, [1].

Among the various natural adverse events that the methodology considers, the direct seismic action in buildings stands out within the scope of this study. This methodology subdivides buildings into several categories: public, residential and first response services.

The methodology relates the seismic action with the response of each building, resulting in a state of probable damage. In order to generalise the methodology to enable its application to large samples where the exact structural characteristics of the entire building are not available, a division of categories that classify each building is applied. This division is performed using the following parameters:

- Seismic regulation applied in the execution of the project;
- Number of floors above ground;
- Structure typology.

Based on this information, it is possible to characterise the seismic behaviour and its probable damage state for a given seismic action.

2.1. Capacity Spectrum

In order to characterise the behaviour of the building, HAZUS provides a set of parameters that define the capacity spectrum through its yield and ultimate points, as illustrated in figure 1.

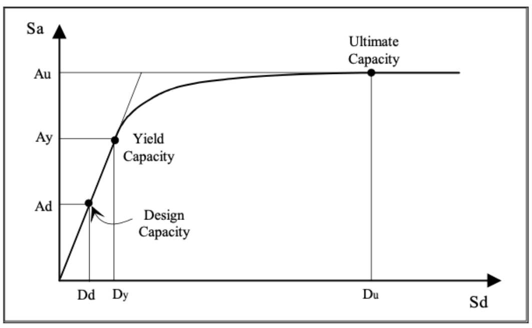

Figure 1: Capacity Spectrum. Reproduced from ref. [1].

The capacity spectrum is obtained from a push over analysis, the yield and ultimate points can be obtained considering formulas (1) to (4).

$$A_y = \frac{C_s \cdot \gamma}{\alpha_1} \tag{1}$$

$$D_y = \left(\frac{T_e}{2 \cdot \pi}\right)^2 \cdot A_y \tag{2}$$

$$A_u = \lambda \cdot A_y \tag{3}$$

$$D_u = \lambda \cdot \mu \cdot D_y \tag{4}$$

A_y - yielding spectral acceleration $[m/s^2]$

D_y - yielding spectral displacement $[m]$

A_u - ultimate spectral acceleration $[m/s^2]$

D_u - ultimate spectral displacement $[m]$

C_s - design strength coefficient

T_e - fundamental period of the building [s]

α_1 - fraction of effective building weight

α_2 - fraction of building height

γ - overstrength factor relating yielding and design capacity

λ - overstrength factor relating ultimate and yielding capacity

μ - ductility factor relating ultimate and yielding displacement, multiplied by $[\lambda]$

g - gravitational acceleration $[m/s^2]$

The capacity spectrum will later be intercepted with the response spectrum to determine the performance point of the building.

2.2. Fragility Curves

Similar to the capacity spectrum, the fragility curves are also described for each category of buildings based on the same parameters previously mentioned. Each of the fragility curves is a lognormal function that translates the probability of a certain damage state occurring or being overcome. For each category, 4 fragility curves are defined for the respective damage states, as exemplified in figure 2.

HAZUS defines 4 damage states for each building typology. In order to consider a general definition for every building typology the descriptions considered were:

- Slight Damage (ED1) - appearance of cracks in masonry elements and / or in the connection between structural and non structural elements;

- Moderate Damage (ED2) - appearance of considerable cracks in masonry elements and less evident in reinforced concrete elements, as well as the occurrence of occasional detachments;
- Extensive Damage (ED3) - collapse of some non structural elements or even structural elements that do not imply the total collapse of the structure;
- Collapse (ED4) - collapse or imminent collapse of a considerable area of the building.

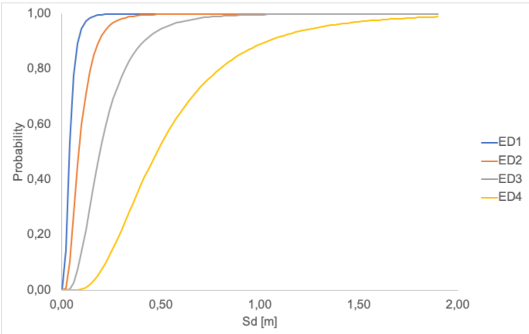

Figure 2: Fragility Curve Examples

For each of the damage states a median spectral displacement value (Sd_{ED}) is indicated, as well as the standard deviation (β_{ED}). The probability of the structural damage state (ed) being equal to or greater than a given damage state (ED) is obtained from the equation (5).

$$P(ed \geq EDi) = \Phi\Big(\frac{ln(Sd) - ln(Sd_{EDi})}{\beta_{EDi}}\Big) \quad (5)$$

ed - estimated damage state

EDi - damage state i

Sd - obtained spectral displacement

Sd_{EDi} - median spectral displacement of damage state i

β_{EDi} - standard deviation of damage state i

Φ - cumulative normal distribution

2.3. LNEC Parameters

In 2005, Laboratório Nacional de Engenharia Civil (LNEC) published a report on the seismic vulnerability of buildings in Lisbon, as part of a European project called LESSLOSS, [2]. The report contains an inventory of the construction typology and construction period of the different buildings present in the Lisbon Metropolitan Area. To this end, a division into different building categories was applied, similarly to the division made in HAZUS. After considering the division made in Census 2001, comparing with the categories defined in HAZUS, LNEC defined the following building categories, indicated in tables 1 and 2, regarding building type and number of floors above ground, respectively. The "traditional masonry" category includes also rammed earth and adobe buildings.

Category	Number of floors
1	1
2	2
3	3
4	4
5	5 to 7
6	8 to 15
7	More than 15

Table 1: Categorisation of buildings by number of floors.

These categories were defined based on the seismic behaviour of the different structural typologies, as well as on the years of introduction of different design regulations in Portugal.

For each of the categories, the report provides the parameters that define the capacity and fragility curves, adjusted to the reality of the buildings in Lisbon. Although the sample of this study is within the Metropolitan Area of Lisbon, it is believed that it can be a more reliable information base to the Portuguese reality than the parameters of HAZUS.

2.4. Seismic Action

The seismic action can be defined according to the equations of Eurocode 8 (EC8), [3]. The horizontal elastic response spectrum is defined by equations (6).

$$T \leq T_b : S_e(T) = a_g \cdot g \cdot \Big(1 + \frac{T}{T_b} \cdot (\eta \cdot 2,5 - 1)\Big) \quad (6a)$$

$$T_b \leq T \leq T_c : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \quad (6b)$$

$$T_c \leq T \leq T_d : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \cdot \Big(\frac{T_c}{T}\Big) \quad (6c)$$

$$T_d \leq T \leq 4s : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \cdot \Big(\frac{T_c \cdot T_d}{T^2}\Big) \quad (6d)$$

S_e(T) - elastic response spectrum

T - vibration period of a single degree system

a_g - design surface acceleration for soil type A

T_b - minimum period of constant spectral acceleration level

T_c - maximum period of constant spectral acceleration level

Traditional Masonry		Any Time	
Masonry	Before 1961	Between 1961 and 1985	After 1985
Concrete	Before 1961	Between 1961 and 1985	After 1985

Table 2: Categorisation of buildings in typology and construction period.

T_d - minimum period of constant spectral displacement level

S - soil coefficient

η - damping correction factor

Considering the equations mentioned above, the response spectrum takes the form exemplified in figure 3. In order to represent the response in displacement-acceleration, which will be relevant in calculating the performance point, the EC8 indicates equation (7). This transformation in the abscissa axis gives rise to the response spectrum exemplified in figure 4.

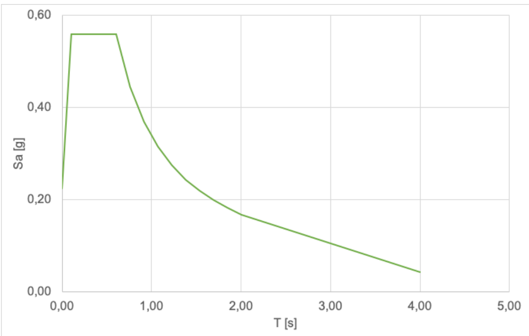

Figure 3: Response Spectrum.

$$S_{De}(T) = S_e(T)\left(\frac{T}{2\pi}\right)^2 \tag{7}$$

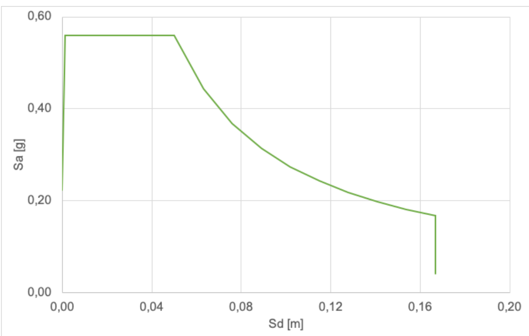

Figure 4: Response Spectrum (Acc-Disp).

It is relevant to emphasise the distinction between two types of seismic activity: Type 1 and Type 2. While Type 1 is characterised by a large magnitude with an epicentre in the Atlantic region, designated as "distant" earthquake, Type 2 is characterised by moderate magnitude with an epicentre in the mainland or in the Azores region, designated as a "near" earthquake. Each type of seismic action will interact with the building in a different manner, so it is necessary to analyse both response spectra. The Portuguese Standard (NP EN 1998-1 2010) establishes characteristic values for each type of seismic activity depending on the seismic zone and type of terrain, [4].

2.5. Performance Point

After obtaining the capacity and response spectra associated with the location of each building, it is necessary to find the performance point. This point results from the intersection of both spectra, capacity and response, and estimates the spectral displacement and acceleration to which the building will be subjected.

Among the various existing methodologies to determine the performance point, the one developed by ATC in 1996, called Capacity Spectrum Method, [5], stands out. This iterative methodology has the advantage of its easy application to automatic spreadsheets, as well as the ease and speed of application, important factors to consider when analysing a large sample.

This simplified non-linear analysis methodology is based on the assumption of considering the viscous damping in the reduction of the response spectrum, instead of only considering the elastic damping. This methodology presents three procedures to obtain the performance point: A, B and C. After analysing all the procedures it was concluded that procedure A would suit this specific analysis better. The steps that lead to the development of procedure A are described below:

1. Calculation of the elastic response spectrum in acceleration-displacement form for a viscous damping coefficient of 5%;

2. Calculation of acceleration-displacement capacity spectrum;

3. Obtaining a test point to start the iterative process, which can be calculated by the characteristic displacement read in the elastic response spectrum for the elastic period of the building;

4. Development of bi-linear capacity spectrum representation;
5. Determination of response spectrum reduction factor and demand spectrum calculation;
6. Determination of the intersection point between the demand and capacity spectra;
7. Verification of the acceptable margin between the test point and the point determined in the previous step;
8. If the point previously determined is not within a 5% difference margin of the test point, perform a new iteration, returning to step 4, in which the point determined in step 6 becomes the new test point.

Once the test point has been determined, it is necessary to carry out the bi-linear approximation of the capacity spectrum. The basic principle of this transformation is that the integration of the capacity spectrum as of the respective bi-linear approximation, between the origin and the test point, are of equal value, as illustrated in figure 5.

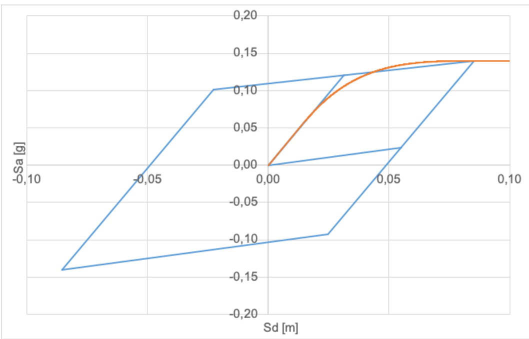

Figure 5: Hysteresis Cycle.

Once the test point (api,dpi) and the point limiting both linear sections (ai,di) have been determined, as illustrated in the figure, the hysteretic equivalent viscous damping is calculated. The energy dissipation along this plastic deformation of the structure, which can be quantified by the area comprised by the hysteresis cycle described in figure 6, additionally dampens the effects of the seismic action. This hysteresis damping can be taken into account as equivalent viscous damping, according to equations (8) to (11).

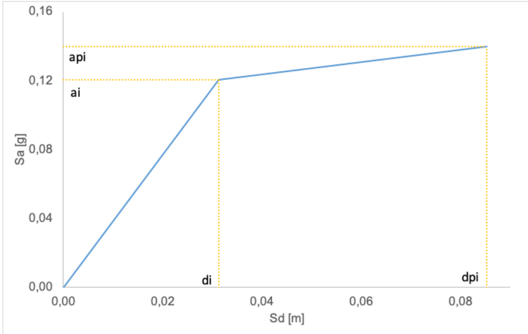

Figure 6: Bi-linear Approximation Points.

$$E_D = ai \cdot dpi - di \cdot api \tag{8}$$

$$E_{So} = \frac{api \cdot dpi}{2} \tag{9}$$

$$\beta_0 = \frac{1}{4\pi} \cdot \frac{E_D}{E_{So}} = \frac{2}{\pi} \cdot \frac{ai \cdot dpi - di \cdot api}{api \cdot dpi} \tag{10}$$

$$\beta_{eff} = \kappa\beta_0 + 5 \tag{11}$$

E_D - dissipated energy by damping

E_{So} - energy associated with peak of deformation

β_0 - hysteresis damping coefficient

β_{eff} - effective viscous damping coefficient

κ - correlation factor of idealised hysteresis cycle

The correlation factor is divided into three classes, from A to C, where class A is considered to have the real building hysteresis cycle closer to the idealised one, as opposed to class C where the real hysteresis cycle is considered to be less smoothed. The correlation factor decreases from A to C, and a reduction is also predicted from certain values of the damping coefficient, as illustrated in table 3.

Class	β_0[%]	κ
A	$\leq$ 16,25	1,0
	$>$ 16,25	$1,130 - \frac{0,51 \cdot (ai \cdot dpi - di \cdot api)}{api \cdot dpi}$
B	$\leq$ 25,00	0,67
	$>$ 25,00	$0,845 - \frac{0,446 \cdot (ai \cdot dpi - di \cdot api)}{api \cdot dpi}$
C	Any value	0,33

Table 3: Correlation Factor.

Calculating the effective viscous damping allows to calculate the demand spectrum, which results from the reduction of the response spectrum. By superimposing the demand spectrum and the capacity spectrum, it is possible to determine the performance point of the building.

2.6. Soil Classification

The type of foundation soil (also known as "ground type") of a building is an essential parameter for calculating the seismic action. EC8 defines the foundation soil types through several parameters, one of which is $V_{s,30}$, which by definition describes the average value of the S-wave propagation velocity in the upper 30 meters of the profile soil for shear deformations equal to or less than 10^{-5}. In EC8, propagation speed intervals are established for each ground type, from A to E and additional special soil types S1 and S2. In order to classify the type of soil in all establishments' locations, a generalist methodology that could indicate an approximate type of soil was searched, as there was no verified information available. In 2018, a model for determining the $V_{s,30}$ for mainland Portugal was published, [6]. This model was developed around a sample of known points through tests, and addressed the relationship between propagation velocity and types of geological formations, based on the physical characteristics of different types of geological formations. The classification of geological formations was mostly done in geological maps at a 1:50000 scale provided by the National Laboratory for Energy and Geology (LNEG). In some cases where 1:50000 scale geological charts were not available, smaller scale charts were used.

The study ended up differentiating 6 soil classifications, later reduced to 3 through statistical analysis of significance, as illustrated in table 4. The propagation velocity values showed are the median values with a confidence interval of 68%.

Thus, the result for the distribution of propagation velocity values in Portugal's mainland is illustrated in figure 7. The propagation velocity values obtained by the proposed methodology, corresponding to the intervals provided in EC8, allow for the classification of the type of terrain for all establishments, subsequently allowing the calculation of the response spectrum.

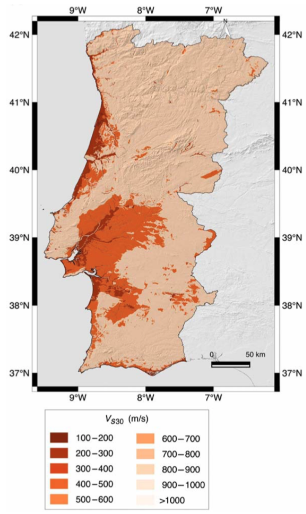

Figure 7: $V_{s,30}$ Mean Values. Reproduced from ref. [6]

3. Implementation

3.1. Database

The public hospital building stock in Portugal's mainland has 97 establishments, most of which have more than one building and some of them have more than ten buildings.

With regard to information on hospitals and the buildings that constitute them, ACSS has a database available online. Initially, some information was sent by ACSS, as described:

- Location (county and coordinates);
- Construction / opening date;
- Population served by establishment;
- Seismic zone according to EC8;
- Type of emergency service;
- Medical specialities available;
- Number and characteristics of buildings in each establishment.

Some of this information proved to be of little use, either because it was incomplete, or because it did not match the necessary requirements for the analysis. The population allocated to each of the establishments was defined by municipality, which means assuming that citizens will use their own municipality's hospital and not necessarily the nearest one, with quicker access to or even more reliable. From the data provided, it is also not possible to determine the affluence to each establishment when there is more than one in the same municipality, in the same way that the existence of private hospital establishments is not considered. As for the number

Soil Class.	Geologic Formations	$V_{s,30}[m/s]$
F1	Igneous, Metamorphic and Old Sedimentary Formations	829
F2	Neogene and Pleistocene Formations	470
F3	Holocene Formations	237

Table 4: Soil Classification Types.

and characteristics of the buildings in each establishment, buildings were considered in administrative and medical terms, not reflecting the division into physically distinct buildings, nor so much into structurally independent bodies. It was also found that not all establishments were listed because this database relating to the building was already outdated. Obtaining this type of specific information about buildings proved to be a difficulty due to its decentralisation, an effort that is now being developed by ACSS.

Knowing the available information was not suitable to pursue the seismic risk assessment, a questionnaire was created and sent to every establishment in order to gather the required information to apply the methodology. The questionnaire had two types of questions: i) regarding the establishments campus; and ii) regarding the buildings. It was properly noted that the building division to be considered should be defined as a structural block independent from other. One of the optional questions asked referred to the soil type regarding EC8.

With resort of ACSS communication channels, the questionnaire was sent to every establishment, achieving 78 responses out of 97. The establishments that did not respond within the limit date were contacted directly by ACSS, gathering the necessary information for the analysis.

3.2. Information Processing

From all the responses received, the fundamental information regarding the methodology application was narrowed to three questions:

- Structural typology;
- Number of floors above ground;
- Time of construction.

The number of floors above ground was labelled according to LNEC categories. The structural typology and time of construction were also labelled according to LNEC with the notation illustrated in table 5. In this sense, all the buildings were categorised in one of 49 categories, 7 regarding type and time of construction, 7 regarding the number of floors.

The total number of buildings declared through out the questionnaire was 602. Four of this buildings were temporary prefab steel, which were not

	Prior 1961	1961-85	After 1985
Traditional		1	
Masonry	2	3	4
RC	5	6	7

Table 5: Building Categories.

included in the analysis. The distribution of building through categories is illustrated in figure 8.

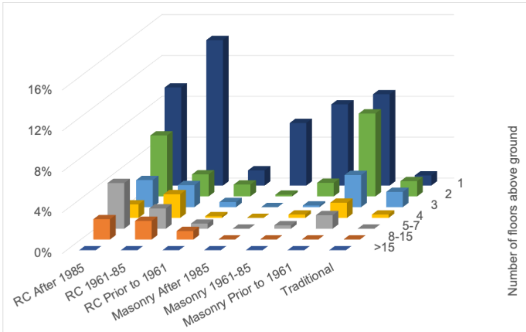

Figure 8: Building Distribution by Categories.

3.3. Foundation Soil

After classifying the geological formations using LNEG geological maps on all establishments' locations in a scale from F1 to F3, the correlation to the EC8 soil type classification was performed. In the majority of cases, the mean value of the methodology corresponding to the interval of V_{s30} indicated in EC8 was adopted. For those situations where the classification considered in the questionnaires did not correspond to the classification of the methodology, it was verified if there was an accordance considering the interval given by the methodology for each classification. After this correction, few cases remained unmatched and in this situations the classifications of the methodology was prioritised. The intervals of both the methodology and EC8 are illustrated in table 6.

3.4. Response Spectrum

Regarding Portuguese Standard EN 2998-1, when considering buildings of first response, such as hospitals, the importance coefficient $[\gamma_I]$ of class IV takes the values of 1,95 and 1,50 for seismic type 1 and 2, respectively. The soil type influence and the design ground acceleration were calculated us-

Class	Median	Interval 68% NC	Class EC8	Interval EC8
F1	829	523-1315	A	≥ 800
F2	470	329-672	B	360-800
F3	237	144-392	C	180-360

Table 6: Soil Classification Intervals in m/s.

ing formulas (12) and (13).

$$a_g = a_{gr} \cdot \gamma_I \quad (12)$$

$$a_g \leq 1m/s^2 : \qquad S = S_{max} \quad (13a)$$

$$Other : \qquad S = S_{max} - \frac{S_{max} - 1}{3} \cdot (a_g - 1) \quad (13b)$$

$$a_g \geq 4m/s^2 : \qquad S = 1 \quad (13c)$$

Having defined this variables, the response spectrum was fully defined for all the establishments.

3.5. Capacity Spectrum

In order to obtain a continuous capacity spectrum from the yield and ultimate points, three branches needed to be defined:

- 1st Branch - linear between the origin and the yield point;
- 2nd branch - approximation by a polynomial equation of fifth degree between the yield point and the ultimate point;
- 3rd Branch - linear constant acceleration for displacements greater than the ultimate point.

Defining the second branch, the following parameters are used to determine the expression: i) yield point and ultimate point; ii) slopes identical to the end branches; iii) inflection point coincident with the ultimate point. It was noted that the fifth-degree equation suited the definition of the capacity spectrum better than the fourth-degree equation, which commonly placed a maximum of the function between the yield point and ultimate point. Still, using the fifth degree polynomial, the same problem occurred in some cases. In these situations, a slight discontinuity was introduced in the slope of the 2nd branch of the function at the point of yielding, reducing it. This decrease in slope was as small as possible so that the maximum of the function in the range was the ultimate point. In cases where the iterative process converged at the yield point, continuity was returned to the function to not affect convergence up to the performance point. This analysis was carried out on a case-by-case basis, for all buildings.

3.6. Performance Point

After calculating the function that describes the capacity spectra and estimating the first test point, an assumption had to be done regarding the correlation factor. Since it was not possible to understand the relation between the idealised hysteresis loop and the real one, the class B correlation factor was used for all the buildings.

After calculating the bi-linear approximations and the effective viscous damping, EC8 equations for the response spectra include a reduction factor to take additional damping into account, as described in formula 14.

$$\eta = \sqrt{\frac{10}{5 + \xi_{eff}}} \geq 0,55 \quad (14)$$

η - damping correction coefficient

ξ_{eff} - effective viscous damping $[B_{eff}]$

After the reduction of response spectra, the point of intersection with the capacity spectrum is verified to be within less than 5% of the relative difference to the test point. This step determines if the analysis will proceed to another iteration or not. Reaching the final iteration, the intersection point refers to the so called performance point, which represents the expected behaviour of the building to the conditions considered, as illustrated in figure 9 for seismic action type 1 and 2.

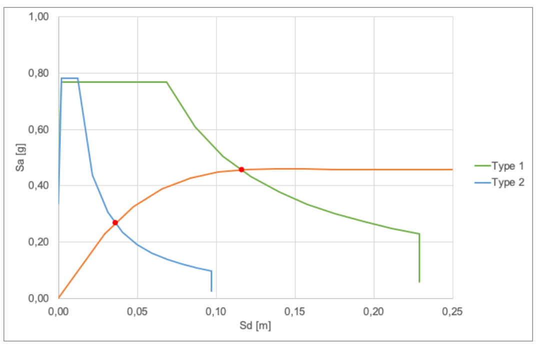

Figure 9: Performance Point.

3.7. Damage State

The function that describes the damage state probability is defined through a median value of spectral displacement and a standard deviation. Although the HAZUS suggests different values of standard deviation for each typology and damage state, those values were not published for the LNEC fragility curves. Therefore, considering the lack of reliable data to distinguish the variability of each case, a constant value of 0,6 was adopted, similarly to what had been adopted in a 2005 seismic risk study in Portugal, [7].

In order to calculate the isolated probability for each damage state formulas (15) were used.

$$P(ed = ED0) = 1 - P(ed \geq ED1) \qquad (15a)$$

$$P(EDi \leq ed < ED(i+1)) = \\ = P(ed \geq EDi) - P(ed \geq ED(i+1)) \qquad (15b)$$

With the purpose of creating a marker that could be comparable between every building, a seismic risk index was calculated using formula 16. This index varies from 0 to 4, being 4 the highest level of risk.

$$I_{ed} = \sum_{i=0}^{4} i \times P(ed = EDi) \qquad (16)$$

I_{ed} - risk index

4. Results

The results were presented in 3 groups of information:

1. Results by Establishment - where an arithmetic average of the risk index of all the buildings composing them was made, through formula (17), and the risk index was weighted through the net area of each building, using formula (18);
2. Results by Emergency Establishment - where the application methodology is identical to the previous point but only addresses the buildings that include emergency services;
3. Results by Buildings - which illustrates the isolated analysis of all buildings separately.

$$I_{ed,estab.arith.} = \frac{\sum_{i=1}^{n} I_{ed,i}}{n} \qquad (17)$$

$$I_{ed,estab.area} = \frac{\sum_{i=1}^{n} I_{ed,i} \cdot A_i}{\sum_{i=1}^{n} A_i} \qquad (18)$$

$I_{ed,i}$ - building risk index

n - establishment's number of buildings

A_i - building net area

In figure 10 is displayed the building distribution per risk index intervals.

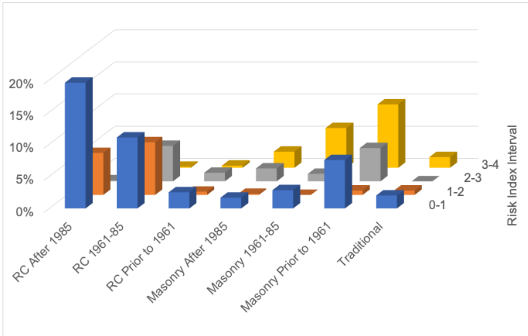

Figure 10: Building Distribution Per Risk Index.

The distribution of buildings per typology per risk index intervals is displayed in figures 11 and 12. Analysing these two figures, it is clear that the traditional and masonry buildings have a bigger percentage of high risk index cases compared with the Reinforced Concrete ones.

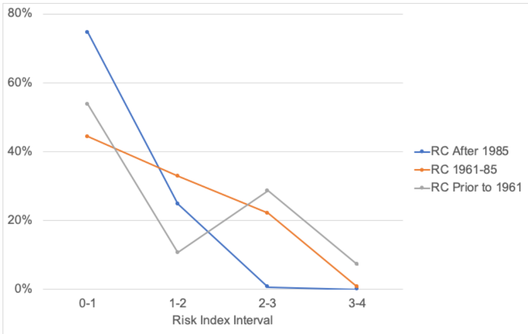

Figure 11: Building Distribution Per Typology Per Risk Index (1/2).

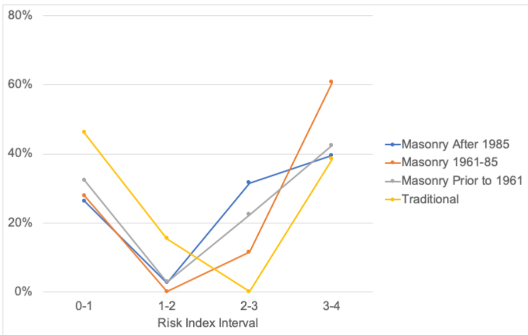

Figure 12: Building Distribution Per Typology Per Risk Index (2/2).

There is also a correlation between the number of floors classification and the risk index interval, as shown in figure 13. The fact that some of the classes of fewer floors have a higher percentage in

3-4 interval than 1-2 and 2-3 can be correlated with the fact that masonry and traditional buildings are mostly concentrated in these classes.

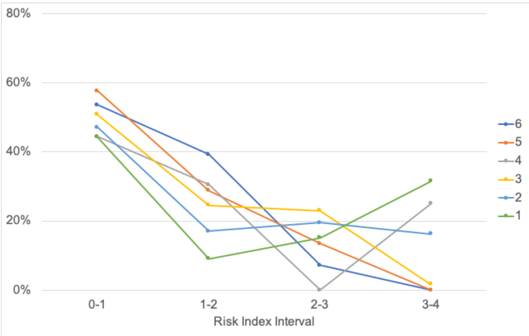

Figure 13: Building Distribution Per Number of Floors Per Risk Index.

5. Conclusions

The public hospital building stock in Portugal's mainland is an asset of great importance to the population, especially in a catastrophic event of any nature in which the emergency services need to act promptly. As it happens, these buildings are also susceptible to seismic events and can suffer damage that endangers people who utilise them, besides disabling the relief services for the population. Therefore, it is natural that the seismic risk of these infrastructures has to be considered in their design, construction and maintenance, along with other first-response ones.

The methodology applied in order to understand the relative result of this risk is quite generalist. Only doing so would it be possible to gather all the information and analyse it within the scope of a Master's Dissertation project. To the same extent, various forms and methods were applied to estimate the characteristic conditions of each establishment and each location, from the soil type classification, to the characteristic values related to each building category and to all the information received through the questionnaire. Regarding the latter, it must be stated that the filling out of the questionnaire may have led to some errors due to misinterpretation or insufficient technical knowledge from some of those charged with that task, further adding some uncertainty and variability to the results.

It is also relevant to point that LNEC parameters were not specially designed for hospital buildings, which usually have higher design criteria to fulfil than others. On the other side, part of the buildings considered were not initially designed to be hospitals and did not have a special regulation to satisfy.

The results achieved in this work are not intended to suggest which interventions or strategic decisions should be carried out in the management of the hospital building stock, but rather to guide the responsible decision-makers in prioritising the specialised and localised survey efforts. This generalist analysis of a sizeable sample aims to direct more specialised studies, but also more onerous ones, which would hardly be applied to all the buildings in question and at the same time, hence the relevance of better understanding where to start from.

The analysis carried out results in a clear priority list, even if the risk index applied has a comparative essence rather than an effective one. This analysis correlated the location of buildings and seismic action, foundation soil type, construction typology and number of floors in each building. Although the relationship of seismic risk with any of these isolated factors is already known in a relative way, the results raised correlate them all, which is the real result of this project.

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