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IBERIA SEISMIC RISK REVISITED
THE SACRED & PROFANE LESSONS ON LOSS ESTIMATION

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IBERIA SEISMIC RISK REVISITED
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CERTIFICAN QUE:

Luis Álvaro Fazendeiro de Sá, ha realizado bajo su supervisión el trabajo de investigación titulado:

SEISMIC RISK REVISITED, THE SACRED & PROFANE LESSONS ON LOSS ESTIMATION

Una vez revisado, autorizan la presentación del mismo como tesis doctoral en la Universidad de Sevilla y estiman oportuna su presentación al tribunal para su valoración. Dicha tesis ha sido realizada dentro del Programa de Doctorado en Arquitectura.

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I. ABSTRACT

The seismicity of the southwestern Iberian Peninsula is moderate but large events with long return periods can occur. This time span exceeds the life of several generations, creating a population unacquainted with seismic hazards. In fact, in the past, many Iberian cities have been severely damaged by earthquakes. Most earthquake-related losses are worsened by soil amplification phenomena. These mechanisms are frequently inferred from empirical formulas. These procedures are based on the average shear-wave velocity at 30 m depth - Vs30 - as a proxy for amplification phenomena. In this research, this relationship was further analysed. The 1531 Lisbon earthquake was revisited in this framework. Using the macroseismicity methodology, the 16th Century building stock has been characterised, by assigning the macro seismic vulnerability indexes and the buildings' vulnerability curves. This procedure can be used in present conditions as a real-time tool for different scenarios. For that purpose, an Earthquake Loss Estimation software called SIRCO was built using the aforementioned algorithm procedure. In this framework, and for the city of Seville, a scenario using the Maximum Credible Earthquake (MCE) was modelled in accordance with the potential seismogenic sources for Western Andalusia. The assessment, using a deterministic seismic hazard assessment approach, demonstrated that there is a credible scenario in which a large earthquake could seriously affect Seville causing outstanding damage in buildings with injured and dead people. Serious reasoning and analysis of these conclusions demand that Seville's local Authorities should thoroughly consider creating and enforcing a Local Emergency Plan to truly deal with this existing, but "hidden", risk.

II. ACKNOWLEDGMENTS

I would like to express my deep gratitude to Professor Antonio Morales-Esteban and Professor Percy Durand-Neyra, my research supervisors, for their patient guidance, encouragement and useful critiques of this research work. I would also like to thank *Autoridade Nacional de Proteção Civil* for offering me the resources to use the risk analysis software and its sub-routines. Finally, I wish to thank Mimi, Júlia and Ana Laura for their support and encouragement throughout my study.

III. PERSONAL MOTIVATIONS

My graduate coursework gave me some theoretical knowledge, including geology, earth physics and constructive processes in methods, theory and the application of tools. Working in Civil Protection has increased my ability to research, analyse and present key components of the decision-making process in a disaster context. This includes analysing, justifying and presenting risk analysis procedures. My research typically involves the qualitative and quantitative research of different hazard typologies and their relationship with the local vulnerability of populations and related assets, sometimes associated with climate change reporting. Later work in critical infrastructures with an analysis of the related assets and risks and their effect on business continuity improved the quality of my strategic and risk management scrutiny. The combination of my knowledge from graduate school along with work experience exemplifies the ideal PhD student who bridges the gap sometimes found in graduate students who choose to move directly to doctorate programmes after their graduate course.

I believe that I have contributed to the topic of seismic risk in urban environments by answering key questions regarding the *status quo* of transboundary seismic vulnerabilities, comparing mandatory versus voluntary disclosure schemes and their effect on potential losses in human lives and assets. The high quality of technical skills that I have received from Seville University refined my research skills in improving the quality of the analysis, thus helping to achieve our shared goal of minimising disaster-related losses. The merging of my abilities and an earnest passion for research complemented the University's impressive network of creative professionals and talented academicians.

IV. OBJECTIVES

Within the scope of this thesis the objectives proposed were to:

- ✓ Contribute to the knowledge of the seismic hazard and risk assessment in South Iberia;
- ✓ Analysis of temporal and spatial heterogeneities assessed through the variations of the frequency and magnitude distribution in the upper crustal seismicity of the Iberia region;
- ✓ Appraise seismic hazard assessment employing deterministic and macroseismicity approaches;
- ✓ Demonstrate the importance of seismic hazard and assets vulnerability in the seismic risk analysis;
- ✓ Assess the population and building seismic risk in likely future earthquakes in SW Iberia;

All these objectives were successfully attained as depicted by the papers published and submitted.

V. JUSTIFICATION FOR THE RESEARCH

The development of risk-based applications for disaster management can be described as one of the single most important aspects lacking in the assessment of potential risks. Although highlighting key research needs towards risk assessment and management in Europe, similar issues are evident in other countries, including Australia, indicating that research conducted towards addressing these needs are of international significance. This research project was aimed at contributing to the knowledge base related to the risk-based decision making associated with seismic events. In particular, the development of a risk assessment and management framework that is both universally acceptable and scientifically robust to reduce uncertainty in establishing the structural and non-structural risks would be beneficial in the assessment of scenarios and in minimizing the inherent risks associated with poor performance. This is particularly important for regions such as Iberia due to the current rate of urban development, sometimes coinciding with numerous seismic sensitive areas for which the region is famous. The outcomes of this research, including the integrated risk assessment framework developed and subsequent risk maps will be a part of the development assessment process that is expected in the near future for the Algarve and the Andalusia Region. This will allow an adequate assessment of the numerous seismic hazards within their regulatory directives, and permit the management and mitigation of the risks identified.

VI. RESEARCH METHODOLOGY

The implementation of an appropriate methodology which effectively encompasses the specific research aims and objectives set out for this project was crucial. The process of going from the initial problem design to the final integrated risk framework involved several iterations prior to achieving the quantified purposes and the development of the risk maps. Fundamentally, the methodology involved several stages to allow both the individual and final integrated risk frameworks to be developed via an iterative approach, which was developed with the collection of significant data and the progressive analysis undertaken. This process endorsed the improvement of the risk frameworks to move from a qualitative approach based on empirical and qualitative relationships to a quantitative process integrating the appropriate scientific data and information. The enactment of the research methodology developed was communicated through four scientific research papers. Each of these studies was focused on a specific stage of the research with the particular outcomes employed in the development of the risk framework.

VII. STRUCTURE OF THE THESIS AND RESULTING PUBLICATIONS

This thesis is divided into chapters with a relationship between them except for the introduction and conclusion sections. It is based on four research papers that were published in indexed Journals. A top to bottom approach[1]was used, essentially by breaking down the methodologies and related algorithms that are the compositional sub-systems of an Earthquake Loss Estimation (ELE) software package.

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[1] In a top-down approach an overview of the system is formulated, specifying, but not detailing, any first-level subsystems. Each subsystem is then refined in greater detail, sometimes in many additional subsystem levels, until the entire specification is reduced to base elements.

In this framework, seismic losses have been analysed and assessed using the SIRCO engine. This is a regional seismic risk computer simulator developed for the Portuguese Civil Protection that employs worldwide accepted methodologies which are carefully described in an assessment made at a national/regional level in Sá *et al., (*2016), the first published paper included in this dissertation. The assessment is also analysed at a local level in Sá *et al.,* (2018), introducing significant changes in the structural vulnerability variable by using 16th Century building typologies, ascertaining a proficient usage of the macroseismicity as a time independent methodology.
Characteristically, seismic assessment refers to the following issues:

- the site-dependent seismic hazard;
- the expected seismic response of buildings;
- the seismic vulnerability of structures;
- seismic damage and human losses;
- the analysis of the spatial distribution of the existing building stock;

The first issue mentioned, perhaps the most relevant, is the site-dependent seismic hazard. As the name well describes, in seismic risk, the hazard is strongly conditional on its location. Therefore, the study of local site effects is an important part of the assessment of strong ground motions, seismic hazard and engineering seismology in general. The 1985 Mexico City earthquake is still a poignant proof of this. In this line of thought, Sá *et al., (*2020a) analysed the potential site amplifications for SW Iberia and compared their different estimation methodologies this region. Finally, with the procedures for vulnerability and hazard refined and revised to SW Iberia, an assessment was made in Sá *et al.,* (2020b) by means of an analysis for the city of Seville, assessing its need for a seismic emergency planning. This was done by using a deterministic hazard assessment (DHSA), a methodological choice conventionally recommended for "worst-case" approaches. These extreme scenarios are used by Civil Protection for relief operations planning in a disaster context.

1. INTRODUCTION

In several world regions, there are ruins of ancient constructions where it is possible to appreciate the trace of past earthquakes. In particular, structures which survived over time can testify the effectiveness of local building construction traditions. An example of this are historical locations prone to recurring earthquakes in the Mediterranean basin, like the Italian Peninsula, Greece and Asia Minor. This experience played, at some extent, an educational role, highlighting effective constructive solutions and signalizing misconceptions; that is, the builder's intuition was stimulated to understand the laws of the building response to the ground motion. However, as in the past, this circumstance is still currently a problematic challenge.

The case of Iberia is paramount. Here the regional seismicity is a product of the earthquake activity that is produced by the contact region of Euro-Asian and African plates and from the activity in the continental margin crossed by diverse local faults. This geological framework generates medium to large events with long return periods. This event typology also occurs in SW Iberia, particularly in locations like the Low Tagus Valley, the Cordillera Bética, or the Guadalquivir depression. These are locations where somewhat every 100-200 years a Mw>6 earthquake occurs (Bonachea *et al.,* 2014). This is a return period that exceeds a generation´s lifespan. This is one of the reasons why some authors advocate that there is little awareness of the potential seismic risk in this region of the world (Garrido and Gutiérrez, 2015). Indeed, seismic risk has a lot to do with awareness and perception. Scholars tend to agree that only in places where an event occurred within one or two generations is there memory and it is easier to find high building code enforcement, good design and construction practices. This is a situation seldom described in books, but empirically applied in both construction and restoration works (Salgado-Gálvez *et al.,* 2015). That was not the case of Lisbon or Seville, the largest cities in the area of interest. Although the February 1969, Mw=7.3 event was felt in both cities, it did not cause major losses in terms of buildings or human lives in the two metropolitan areas[2]. In fact, the last large earthquake felt in these metropolitan areas with an Intensity (MMI) ≥VI – assuming that damage to buildings and human live occurs with intensities (MMI) equal or superior to VI – happened in 1858 – the Setúbal earthquake, November 1858, Mw 7.1 (Martínez Solares and Mezcua, 2002). This results in that present generations not having any memory of an event of this magnitude, thus they are not prepared for its occurrence. This has led attention to the necessity of taking urgent measures to reduce casualties, and social and economic losses. Emergency planning is one of these measures. Its main objective is to reduce injuries, protect the

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[2] In this same event, although the western Algarve area suffered relevant losses, these were not disclosed in the media due to the censorship policy enforced by the undemocratic Portuguese government of that time.

community and maintain social and economic continuity. An emergency plan usually includes procedures necessary during a crisis, a clear set of roles and responsibilities and established procedures for a local emergency response, search and recover actions. These are a crucial part of keeping the loss of human lives as low as possible. The emergency procedures consist fundamentally in the planning of an organisation, operating in conjunction with the entities and bodies involved in the actions of civil protection in order to ensure effective management of relief if the earthquake happens, as well as a scaling and efficient organisation of the means and resources necessary to cope with the consequences produced by the event.

The definition of scenarios and the identification of critical areas constitute the basic pillars for the development of instruments and measures for minimising seismic risk, as well as the phenomenon's potential effects. The actions to minimise this risk include, but are not limited to, preventive initiatives, such as, for example, intervention in and the strengthening of the vulnerable built structures, the implementation of corrective measures on the location of critical infrastructures, and the organisation of urban space and increasing the population's self-awareness and preparation .

2. SEISMIC RISK CONCEPTUAL FRAMEWORK

The foremost calculations for determining seismic risk were formulated by C. Cornell in 1968 and, depending on their level of importance and use, can be challenging. The regional geology and seismology setting are first examined for sources and patterns of earthquake occurrence, both in depth and at the surface, from seismometer records. Secondly, the impacts from these sources are assessed relative to local geologic rock and soil types, and construction typologies. Zones of similar potential risk are thus determined and drawn on maps.

Lantada *et al.,* (2010) defined "*urban seismic risk*" as the convolution of hazard and vulnerability, describing the potential expected loss which can be represented in maps showing the expected damage of the urban area due to a specified earthquake. In a broader definition, UNISDR (2015) defined "disaster risk" as the combination of the severity and frequency of a hazard, the numbers of people and assets exposed to the hazard, and their vulnerability to damage. In this context, back in the 90s the Pan American Health Organization (PAHO, 1993) described the following definitions for a risk analysis framework, that even today are quite relevant:

Hazard (H): the probability that a potentially disastrous event might occur during a certain period of time in a given site.

Vulnerability (V): the degree of loss of an element or group of elements at risk as a result of the probable occurrence of a disastrous event, expressed on a scale from 0 or no damage, to 1, total loss.

- ✓ Specific Risk (Rs): the degree of loss expected due to the occurrence of a specific event, as a function of the hazard and vulnerability.
- ✓ Elements at Risk (E): the population, buildings and public works, economic activities, public services, utilities, and infrastructure exposed in a given area.
- ✓ Total Risk (Rt): the number of people killed or injured, damage to property, and the impact on economic activity due to the occurrence of a disastrous event, in other words the product of the specific risk (Rs) and the elements at risk (E).

Hence, risk can be estimated using the following general formula:

$$Rt = E\,.Rs = E(H.V) \qquad (1)$$

Taking the elements at risk (E) implicit in vulnerability (V), without modifying our original approach, it could be said that:

Once the hazard (Hi) is known to be the probability that an event will ensue with an intensity larger or equal to (i) during exposure period (t), and once vulnerability (Ve) is known to be the intrinsic predisposition of an exposed element (e) to be affected should a disaster occur with an intensity (i), risk (Rie) can be the probability of a loss in element (e) as a consequence of the occurrence of a disaster with an intensity greater than or equal to (i).

$$Rie = (Hi.Ve) \tag{2}$$

that is, the probability of exceeding a certain level of social and economic consequences during a given period of time (t).

Thus, a distinction can be made between concepts that have seldom been incorrectly considered identical, but which are undeniably different from a qualitative and a quantitative feature:

- The hazard, represented by a latent danger associated with a physical phenomenon of natural or technological origin that may occur in a specific place and at a given time producing adverse effects on people, assets or the environment, scientifically expressed as the probability of a disaster larger than a certain intensity happening in a specific place and over a definite period of time.
- The risk, damage, or probable loss resulting from a permutation of the probability of dangerous events occurring and the vulnerability of the elements exposed to such hazards.

In general terms, vulnerability can be understood, then, as the inherent susceptibility of an element to suffer damage due to possible external events. As a result, its evaluation is a key part of assessing the risk derived from interactions of a susceptible element with a hazardous environment.

The fundamental difference between hazard and risk is that hazard is related to the probability of a natural or an induced event occurring, while risk is related to the probability of certain consequences occurring that are related not only to the level at which those elements are exposed but also to the vulnerability of those elements to the effect of such an event.

In conceptual terms the model used in the overall research for determining the risk, that is, the losses that can occur following a certain earthquake, were based on the macroseismic method. This method was used with intensity hazard maps, commissioned with hazard scenarios provided in terms of peak ground accelerations. The macroseismic method was developed by Giovinazzi and Lagomarsino (2004) from the definition provided by the European Macroseismic scale EMS-98 (Grunthal 1998).

The building vulnerability was measured in terms of a vulnerability index "*V*" and a ductility value "*Q*", both evaluated taking into account the building typologies and their constructive qualities. The index variables for vulnerability and ductility allow the construction of fragility curves using a Beta distribution, continuous probability distributions parameterised by two shape parameters. Both appear as exponents of the random variable and control the shape of the distribution. The probability density function of the beta distribution, for $0 \leq x \leq 1$, and shape parameters α, $\beta > 0$, is a power function of the variable x and of its reflection $(1 - x)$ as follows (Giovinazzi and Lagomarsino, 2004):

$$f(x, \alpha, \beta) = constant \,.\, x^{\alpha-1}(1-x)^{\beta-1} \qquad (3)$$

$$= \frac{x^{\alpha-1}\,(1-x)^{\beta-1}}{\int_0^1 u^{\alpha-1}(1-u)^{\beta-1}\,du}$$

$$= \frac{\Gamma\,(\alpha+\beta)}{\Gamma\,(\alpha)+\Gamma\,(\beta)} \,.\, x^{\alpha-1}(1-z)^{\beta-1}$$

$$= \frac{1}{\mathrm{B}(\alpha,\beta)} \,.\, x^{\alpha-1}(1-z)^{\beta-1}$$

Where: $\Gamma(z)$ is the gamma function. The beta function, $\mathrm{B}(\alpha,\beta)$ is a normalisation constant to guarantee that the total probability is 1. In the above equations x is an observation — an observed value that actually occurred — of an arbitrary process X.

The cumulative distribution function is:

$$f(x, \alpha, \beta) = \frac{\mathrm{B}(x,\alpha,\beta)}{\mathrm{B}(\alpha,\beta)} = \mathrm{I}_z\,(x, \alpha, \beta) \qquad (4)$$

where $\mathrm{B}(x;\alpha,\beta)$ is the incomplete beta function and $\mathrm{I}_z(\alpha,\beta)$ is the regularized beta function.

To use the beta distribution, it is necessary to make the link to the damage level D, which is a discrete variable for this purpose. So it is desirable to allocate a value 0 to the parameter α and a value 6 to the parameter β. Generating this assumption, it is possible to calculate the probability associated with damage level k (k=0, 1, 2, 3, 4, 5) as follows:

$$p(k) = p\,\beta(k+1) - p\,\beta(k) \qquad (5)$$

Subsequent to this definition, the mean damage level, mean value of the discrete distribution, and the mean value of the beta distribution can be correlated through a third-degree polynomial.

$$\mu D = \sum p.k$$

$$\mu x = 0.042\mu^3 - 0.315\mu^2 + 1.725\mu D \qquad (6)$$

Thus, it is possible to correlate the two parameters of the beta distribution with the mean damage grade:

$$r = t(0.007\mu^3 - 0.0525\mu^2 + 0.2875\mu D) \qquad (7)$$

In sequence, it is assumed that the usage of a beta distribution enables the construction of fragilities curves relating ground motion with damage. Furthermore, fragility curves are a statistical tool representing the probability of exceeding a given damage state as a function of an engineering demand parameter that represents the ground motion.

Fragility analysis is a crucial component in seismic risk assessment and specifically in regional seismic risk assessment (Coburn and Spence 2002). Implemented in a universe of structures with similar characteristics, such as material and design code level, it reveals the estimation of damage for a number of structures present within a specific geographical area.

The hazard is described in terms of the macroseismic intensity, according to the European macroseismic scale EMS-98, which is considered, in the framework of the macroseismic approach, as a continuous parameter. The hazard calculation was based on:

- Attenuation laws best suited considering the research area, using as variables the distance to the epicentre and the moment magnitude;
- Site-effects, related to the amplification of seismic waves in superficial geological layers. Several calculation methodologies were tested and compared, finalising at the final steps of this research on the usage of V_{s30} as proxy to amplifications.

Then, the risk is modelled using a computer programme that integrated the hazard variables and produced a most probable value, per census track, for the key ground motion parameter (PGA) and integrates them with the fragility curves for each building typology present in the same census tract.

The software routines were constructed in Visual Basic, fundamentally based on Coburn *et al.* 's (1992) and Spence *et al.* 's (1998) approaches, both essentially supported on the analysis and modelling of past cases of casualties in relevant urban earthquakes. The risk was expressed in terms of human losses (deaths, injured or homeless persons) and building damage (in damage levels from D1 to D5 as proposed by the EMS-98).

3. RESEARCH PUBLICATIONS

I. FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2016). ***A SEISMIC RISK SIMULATOR FOR IBERIA***. BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA, 106(3), 1198-1209.

IMPACT FACTOR (JCR) 2.146, Q2; IMPACT FACTOR (SJR) 1.865, Q1

II. FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2018). ***THE 1531EARTHQUAKE REVISITED: LOSS ESTIMATION IN A HISTORICAL PERSPECTIVE***. BULLETIN OF EARTHQUAKE ENGINEERING, 16(10), 4533-4559.

IMPACT FACTOR (JCR) 2.406, Q2; IMPACT FACTOR (SJR) 1.457, Q1

III. FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2020). ***REGIONAL CORRELATIONS FOR ESTIMATING SEISMIC AMPLIFICATION. IMPLICATIONS FOR LOSS ASSESSMENT IN SW IBERIA***. SOIL DYNAMICS AND EARTHQUAKE ENGINEERING, 130, 105993.

IMPACT FACTOR (JCR) 2.637, Q2; IMPACT FACTOR (SJR) 1.194, Q1

IV. FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2021). ***A DETERMINISTIC SEISMIC RISK MACROZONATION OF SEVILLE.*** *ARAB J GEOSCI* **14,** 2392 (2021).

IMPACT FACTOR (JCR) 1.827, Q2; IMPACT FACTOR (SJR) 0.415, Q2

FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2016). ***A SEISMIC RISK SIMULATOR FOR IBERIA***. BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA, 106(3), 1198-1209.

IMPACT FACTOR (JCR) 2.146, Q2; IMPACT FACTOR (SJR) 1.865, Q1

FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2018). ***THE 1531 EARTHQUAKE REVISITED: LOSS ESTIMATION IN A HISTORICAL PERSPECTIVE***. BULLETIN OF EARTHQUAKE ENGINEERING, 16(10), 4533-4559.

IMPACT FACTOR (JCR) 2.406, Q2; IMPACT FACTOR (SJR) 1.457, Q1

FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2020). ***REGIONAL CORRELATIONS FOR ESTIMATING SEISMIC AMPLIFICATION. IMPLICATIONS FOR LOSS ASSESSMENT IN SW IBERIA***. SOIL DYNAMICS AND EARTHQUAKE ENGINEERING, 130, 105993.

IMPACT FACTOR (JCR) 2.637, Q2; IMPACT FACTOR (SJR) 1.194, Q1

FAZENDEIRO SÁ, L., MORALES-ESTEBAN, A., & DURAND NEYRA, P. (2021). ***A DETERMINISTIC SEISMIC RISK MACROZONATION OF SEVILLE.*** *ARAB J GEOSCI* **14,** 2392 (2021).

IMPACT FACTOR (JCR) 1.827, Q2; IMPACT FACTOR (SJR) 0.415, Q2

4. CONCLUSIONS AND RECOMMENDATIONS FOR POLICY

Three papers were published during this research (Sá *et al.*, 2016, Sá *et al.*, 2018, Sá *et al.*, 2020a) and another was submitted (Sá *et al.*, submitted) that support the improving of the seismic hazard knowledge in the SW Iberia region. This contribution is divided into four different groups:

- ✓ Analysis of the regional seismicity;
- ✓ The identification and analysis of the events that in the past had relevant ground motion;
- ✓ The establishment of a model to analyse physical vulnerability in the area of interest, including potential site-effects;
- ✓ A forecast projection of human losses plus damage assets in likely future earthquakes.

The last group is novel since (to the author's knowledge) this is the first time that it has been applied for the city of Seville. This thesis, therefore, reveals a comprehensive study of the seismicity and seismic hazard assessment. It starts with the analysis of the different seismic patterns observed then, based on this knowledge, we identify and characterise the seismogenic behaviour responsible for most of the recorded seismicity. With the seismicity from the historical and instrumental period we assessed the regions that in the past underwent strong ground shaking, and we made the transition from the seismic hazard to the seismic risk estimating human losses in future earthquakes. Using a DHSA approach, an MCE event was modelled for the Gulf of Cadiz. The aforementioned damage effects assessment has clearly demonstrated the presence of a risk that must be dealt with through organised actions, such as operational preparedness and emergency planning. With a hazard thus estimated, risk can be assessed and included in such areas as building codes for standard buildings, designing infrastructure projects, land use planning and determining insurance values. The seismic hazard studies may also generate two standard measures of anticipated ground motion, both confusingly abbreviated MCE: the simpler probabilistic Maximum Considered Earthquake, used in standard building codes, and the more detailed and deterministic Maximum Credible Earthquake incorporated in the design of larger buildings and civil infrastructure like dams, bridges or nuclear power plants.

To face the seismic risk in SW Iberia, both Portugal and Spain have building codes that mitigate this risk. In fact in both countries, since the 1960s, in all projects for new building structures, it has been mandatory to carry out a set of measures and calculation checks based on the notion of the need for structures to be ductile; that is, that they have the capacity to deform, withstanding pressures and loads, without breaking or losing stability.

However, the similarities between both codes ends here. The analysis of the provisions established in each seismic code has revealed considerable differences regarding the seismic action level designation (Requena-García-Cruz *et al.*, 2019). This is mainly due to the seismic hazard assessment that each code is based on, especially the calculus of the probability of occurrence of an event in a time or spatial framework. The NCSE-02 is based on a Poisson distribution, tending to use more average values. On the contrary, the Portuguese Decree-Law n. 235/83 – "Regulamento de Segurança e Acções para Estruturas de Edificios e Pontes" is based on a seismic hazard assessment that uses the Gumbel distribution, also known as the extreme value distribution. The latter is commonly used to describe the largest value of a response over a period of time. Contrary to the Poisson distribution, Gumbel represents a scattering of largest values of events. This results in upper values for ground acceleration in the case of Portugal since only uppermost values are considered in its hazard assessment. This different statistical approach makes the Decree-Law n. 235/83 more demanding than the NCSE-02 in terms of provisions established, since it defines a more demanding seismic action for a building to withstand. (Requena-García-Cruz *et al.,* 2019) observed that in a transborder comparison, nonlinear static analyses have shown that the poorest seismic performance is obtained when considering the Portuguese seismic action. Moreover, upper values of damage have been obtained when considering the NCSE-02 response spectrum. This difference was augmented due to the decrease of the Ayamonte ground acceleration value established in the 2012 Spanish update. Requena-García-Cruz *et al.,* (2019) analysis led to the conclusion that safety provisions may not be fulfilled if a less restrictive seismic code is taken into account. Therefore, as pointed out in several works, an arrangement between codes should be made, at least for border regions.

In a parallel dimension, Portugal and Spain have also directives of civil protection planning against seismic risk.

Portugal has a specific plan for seismic risk in the Lisbon Metropolitan Area and for the Algarve region, with specific actions for each local authority, using the 1755 event (distant source) as base scenario and 1722 event (near source) as secondary one, both using a deterministic approach of a worst-case-scenario. This *status quo* disregards the Alentejo region, which is also an area with a considerable seismic hazard that should be included.

Spain has a specific plan for Andalusia, without defining local guidelines or a base scenario. The local emergency planning in Spain is assured by the DBPPCRS, the Spanish norm that sets up the general conditions under which emergency response plans for earthquake disasters must be carried out. The DBPPCRS is based on a probabilistic hazard analysis, which was founded on the Spanish building code NSCE-2. This building code uses a Poisson approach for seismic events distribution, increasing the recurrence periods for a specific seismic event. Notwithstanding, the

DBPPCRS has another problematic characteristic. It dispenses with emergency planning, areas with a probable intensity MSK ≤ VI for a 500-year return period. This unbalanced situation results in the existence of an ambiguous outcome in terms of the edge line criterion for the necessity of local seismic emergency plans - municipalities where the predicted intensities are larger than IMSK VI. This is the case of Seville where a seismic event can produce IMSK VII-VIII, generating human losses when site effects are considered.

In conclusion, both the Spanish building code and the Spanish directive of civil protection planning are less demanding than their Portuguese counterpart. The DBPPCRS is constrained by the usage of a Poisson distribution, by the related NSCE-02 and to make matters worse, they define the use of a probabilistic approach in emergency planning by absentia. As there is no scenario base defined, the NSCE-02 seismic hazard maps – 500-year return period are to be used.

The scientific community acknowledges that the seismic risk in SW Iberia exists, aggravated by the existence of large events with longer return periods. This fact increases the unpreparedness of the populations for the possible occurrence of such an event. This situation is shared by both the Spanish and Portuguese inhabitants who live in this region. Therefore, we can assume a similar vulnerability between the two populations. The problem starts with the definition of the hazard and finishes with the civil protection provisions to face the risk.

Some policy proposals are to be made:

1. Regarding the Hazard

The NSCE-02 should consider a revision of the calculus method. The introduction of a Gumbel statistic, related in some form with actual Poisson usage, could improve the range values of the seismic action by reducing the recurrence periods for each event magnitude. As an example of the need for this adjustment, we select the 2011 Lorca event, where the recorded seismic acceleration of 0.37g was three times greater than that estimated in NCSE-0.2 of 0.12g.

If saving lives is the most important goal, the reintroduction, in the same way or approach, of the deterministic philosophy of the former MV-101 1962 / PGS-1 1968 / PDS-1 1974 building codes could be advantageous.

The case of Huelva province is a landmark in comparison. An update made to the hazard maps in 2012 reduced the seismic action for this region, thus minimising the risk, and broadening the difference between the hazard levels considered for the Algarve and Huelva transborder regions.

The introduction of a two-scenario approach, as used in Decree-Law n. 235/83 for events in Lisbon and onshore Algarve could be advantageous in the provinces of Huelva and Cadiz, with a near source for a moderate magnitude and an ocean source for a larger event. This same approach should be used in Portugal in all the municipalities to the south of Mondego River, enforcing the modelling of a near- and a far-source event, with the consequential emergency planning

2. Enlightening the Risk

As a proposal, the DBPPCRS should follow a deterministic approach as recommended by the emergency planning best practices. It ought to avoid using the probabilistic approach of the NSCE-02, which was created considering structural engineering standards and goals. This awkward situation can be explained by the existent "urban myth" that building codes, like the NSCE-02, are made to save buildings. They are not: they are made to save lives. This is a misconception that exists among the population and even among emergency planners today. So, if the NSCE-02 is made to save lives, the post event usability of the buildings is disregarded. In fact, if building codes were to consider a post-event usage factor, the level of project safety and physical construction cost would become socially intolerable.

A revision of the local seismic emergency planning criterion expressed in the DBPPCRS must be endorsed by the Spanish Administration, with the inclusion of regions of Spain where the occurrence of an event with intensity IMSK = VI for a 500-year return period is probable. This criterion should be altered by also considering the presence of potential amplifications.

As stated before, in Portugal the seismic emergency planning ought to be enforced in all the municipalities to the south of the river Mondego. Circumscribing the planning to the Lisbon or Algarve regions is a negligent policy at the very least.

We saved a special analysis of Seville to the last. Using a deterministic approach as advisable in emergency planning policy, Sá *et al.,* 2020b concluded that an MCE event can induce extensive loss of lives and assets to the city. However, as Seville is located in an area that NSCE-02 defines as IMSK = VI (for a 500-year return period), it is not mandatory to have a local specific emergency plan for this risk. For now, and considering the delays and extended time frame associated with the change of national codes, only a policy decision made by the Seville City Council could correct the *status quo*. In fact, as a local civil protection authority, the City Council is not legally obliged to make a local emergency plan for seismic risk, but considering the expected losses that are caused by a simulated scenario, this is a natural decision which any local decision maker should take. In fact, this state of affairs is a conundrum that only an audacious local policy change can resolve in the near future. Taking that option by the path of a Municipal Acting Plan on Seismic Risk, as foreseen by Spanish Law, is paramount. This plan ought to focus on four axial lines: 1) population risk awareness and training; 2) information technologies; 3) technical assessment; and 4) the identification and enrolment of human and material resources. Thus, a future Seville Municipal Action Plan could represent an important and innovative effort in the seismic risk framework.

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