EPISTEMIC UNCERTAINTY IN HAZARD AND FRAGILITY MODELLING FOR EARTHQUAKE RISK ASSESSMENT

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ABSTRACT

The seismic risk assessment of building portfolios has benefitted from the continued improvement in the modelling and characterization of epistemic uncertainties in seismic hazard. Logic-trees have become a standard feature of probabilistic seismic hazard and risk assessments, reflecting model-to-model uncertainty through alternative models with different degrees of belief. However, the ability of fragility and loss models to adequately reflect these uncertainties in a consistent way has been subject of limited scrutiny. In this study, the subject of ‘hazard-dependency’ of fragility is addressed through a methodology that incorporates: probabilistic seismic hazard analysis, hazard-compatible record-selection, nonlinear response history analysis, and fragility assessment of three different building classes located at the sites of Lisbon and Faro (Portugal). A logic-tree with three distinct seismological models and twenty combinations of ground motion prediction equations (GMPEs) is used in order to evaluate if, when analytical methodologies are used to characterize both hazard and fragility components, fragility functions are in fact dependent on the hazard properties assumed for each branch. The impact of considering a single fragility model common to all the branches, as opposite to a distinct ‘hazard-specific’ fragility per branch, is investigated in the context of a probabilistic loss estimation exercise.

Keywords: Hazard analysis; epistemic uncertainty; hazard-consistent fragility; probabilistic seismic risk

1. INTRODUCTION

The evaluation of seismic risk of either single structures or building portfolios requires the consideration of various sources of uncertainty. The so-called aleatory uncertainty is due to randomness, while epistemic uncertainty is related to lack of knowledge of the process being observed (Bradley, 2009). In addition to the continuous improvement in the characterization of seismic hazard, recent years have seen a major swing in emphasis towards the explicit inclusion of uncertainties in the performance assessment of structural systems (Bradley, 2013). However, the main concerns have been mostly related with the treatment of record-to-record variability, and/or the random nature of geometric and structural parameters in the evaluation of the seismic response of buildings (e.g. Jalayer et al. 2010, Liel et al. 2009, Sousa et al. 2016). Epistemic uncertainty, on the other hand, has become a standard feature of probabilistic seismic hazard analysis (PSHA) (Bommer and Scherbaum, 2008). Logic-trees are commonly used to represent distinct hazard modelling possibilities, leading to a set of alternative views of a process that has only one true but unknown result (Der Kiureghian and Ditlevsen, 2008).

Recent developments such as the Conditional Spectrum (Baker, 2011) (CS) or the General Conditional Intensity Measure (GCIM) (Bradley, 2010) have allowed record-to-record variability to reflect ground motion properties determined by the local hazard, providing a direct link between seismic hazard and building response. Because structural response is dependent on the set of ground motions to which the

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building models are subjected (Bradley et al. 2009) and, in turn, ground motion selection is dependent on hazard, then an analytical fragility model shall not only be structure-specific but also “hazard-specific”. In practical terms, this would mean that when the epistemic uncertainty of the hazard model is quantified through a logic-tree approach, distinct record sets should be selected for each logic tree branch, leading to a distinct fragility model per branch. This issue has been subjected to recent yet limited scrutiny by the scientific community (Sousa et al. 2017, Kohrangi et al. 2017). In this research, the subject of “hazard-specific” fragility is addressed in order to demonstrate the impact of considering a set of fragility models consistent with the corresponding hazard branch, as opposed to a single fragility model for the entire logic tree. This methodology incorporates: a) PSHA for the sites of Lisbon and Faro (Portugal), using a logic-tree approach that reflects distinct seismological and ground motion prediction modelling options, b) hazard-compatible record selection and nonlinear response history analysis (NLRHA) for each logic-tree branch and each site, and c) fragility analysis and statistical comparison between fragility results obtained for each assessed hazard branch, at each site. Using this framework, the present study has the aim to assess whether the epistemic uncertainty of the hazard model should appropriately be propagated into the fragility analysis, when analytical methodologies are used to characterize both hazard and fragility components.

In order to obtain a more meaningful comparison in the context of seismic risk, probabilistic loss estimation is further performed for 6 different building portfolios (located in Lisbon and Faro). In this exercise, risk metrics are evaluated for each group of assets and investigated hazard branch, using two distinct fragility assessment approaches: a) a distinct model for each logic-tree branch, consistent with each hazard model, and b) a state-of-the-art method in which only a single fragility model, common to all branches, is used.

2. FRAGILITY ASSESSMENT METHODOLOGY

The analytical methodology implemented in this research, presented further in detail, consists of: a) PSHA for Lisbon and Faro, Portugal, using a logic-tree approach in which distinct combinations of seismological and ground motion prediction models are considered in each of the branches, b) record selection and NLRHA for each branch defined in a), for each site and structural class, and c) analysis and comparison between fragility functions derived using the NLRHA results obtained in b).

2.1 Probabilistic Seismic Hazard

In order to perform PSHA for the sites of Lisbon and Faro (Portugal), the recent developments of the SHARE initiative (Woessner et al. 2015) have been considered. The epistemic uncertainty associated with the definition of seismicity at the two sites is characterized by three distinct seismological models. The first, designated herein as AS-model, is based on the definition of areal sources, the second relates to a kernel-smoothed zonation-free stochastic earthquake rate model (Hiemer et al. 2014) (SEIFA-model), and the last results from tectonic and geophysical evidence, incorporated into a fault source/background seismicity model (FSBG-model) (Haller and Basili, 2011). For the sake of synthesis, further details of these models are not presented herein.

For consistency, epistemic uncertainty in ground motion prediction has also been considered via the implementation of a logic-tree approach. According to the SHARE methodology, sets of possible GMPEs are defined for various tectonic regions (Stable Continental Crust (SCC) and Active Shallow Crust (ASC) exist in Portugal). ASC is relevant in Lisbon, whereas both SCC and ASC regions exist within 250km of Faro.

The final logic-tree structure is presented in Figure 1, where all the possible combinations of source model/GMPE are illustrated. In the case of Lisbon, a total of 15 branches (i.e. 3 source models * 5 SCC GMPEs) is applicable, whereas 60 combinations (i.e. 3 source models * 5 SCC GMPEs * 4 ASC GMPEs) exist for Faro. For clarity herein, a given branch is further denoted by an acronym that includes references to the corresponding source model, SCC GMPE and ASC GMPE, by this order (e.g. “AS-AB10-CF08” for AS-model source model and Akkar and Bommer (2010) and Cauzzi and Faccioli (2008) as the SCC and ASC GMPEs, respectively). In the case of Lisbon, where only SCC applies, acronyms include a single GMPE instance (e.g. “AS-AB10”).

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2.2 Record Selection Methodology and Hazard Disaggregation

The GCIM approach is adopted herein for the purpose of record selection, as it allows the predictability of all the intensity measures verified to influence the seismic response of the assessed structures. Readers are referred to the work of Bradley (2010) for a detailed description of the theoretical background of the methodology. In brief, upon definition of the GMPE of interest, the conditional probability density function a given intensity parameter (IMi) conditioned on a specific level of a selected intensity measure (IMj) is obtained via the total probability theorem as:

\[ f_{IMi|IMj=imj} = \sum_{i=1}^{I} f_{IMi|rup_i,IMj=imj} \cdot P_{rup_i|IMj=imj} \]  

(1)

Where \( I \) is the total number of ruptures (rup) in the earthquake rupture forecast (ERF) (Silva et al. 2014a), \( f_{IMi|IMj=imj} \) is the probability density function (pdf) of IMi given IMj=imj, \( f_{IMi|rup_i,IMj=imj} \) is the pdf of IMi given IMj=imj and Rup=rup, and \( P_{rup_i|IMj=imj} \) is the contribution of rup to the assessed level of seismic intensity (imj), obtained from hazard disaggregation. PSHA and disaggregation were computed in the OpenQuake engine (Silva et al. 2014a). Given the large number of earthquake ruptures generated by the ERF for each source model, OpenQuake does not provide the contributions on a rupture-by-rupture basis. Instead, these are classified and grouped into magnitude (M)/distance (R) bins. However, given the open-source nature of the platform, it was possible to produce the necessary intermediate results for the computation of the contribution of a particular rupture (rup) to the occurrence of a given ground motion intensity level (IMj=imj) - \( P_{rup_i|IMj=imj} \). Readers are referred to Sousa et al. (2016) for additional details on its computation.

3. NUMERICAL MODELS AND RECORD SELECTION

Reinforced concrete construction accounts for approximately 50% of the Portuguese building stock and hosts 60% of the national population. Within this building class, at the time of the 2011 Census Survey, 49% of the buildings had not been designed to the most recent seismic code (Silva et al. 2014b). In this context, the numerical models considered in this study represent typical “pre-code” reinforced concrete (RC) buildings with masonry infills, constructed in Portugal before the introduction of seismic design regulations, in 1958.
In agreement with the work Silva et al. (2014b), statistical distributions of material and geometrical properties have been used to create synthetic portfolios of structures for different building typologies. Sets of 100 structures have been generated for classes of two, five and eight story buildings, in order to guarantee the statistical significance of the generated distribution of structural capacity. The resulting dynamic properties can be characterized by the mean fundamental periods of vibration extracted from the sets of 100 assets, which have been found to be 0.26, 0.45 and 0.70 seconds, for the two, five and eight story buildings, respectively.

To maintain the computational effort at a reasonable level, each structure is modelled as a single infilled moment frame with three bays. As schematically presented in Figure 2 for the case of 5 story buildings, each frame was modelled in a 2D environment using the open-source software OpenSees (McKenna et al. 2010), with force-based distributed plasticity beam-column elements.

![Figure 2. Schematic view of the five-story RC frame model: front (left), side (centre) and isometric view (right) without infills, adapted from Silva et al. (2014b).](image)

For the sake of synthesis herein, readers are referred to the work by Silva et al. (2014b) for details on section reinforcement, cross-section discretization and integration points, material constitutive relationships, P-delta effects, and the infill panel modelling.

### 3.1 Targets for Record Selection

The vector of intensity measures considered in the definition of ‘targets’ for ground motion selection (denoted herein as IM) includes intensity parameters (i.e. IMi) of peak ground acceleration (PGA), Housner intensity (HI) and spectral ordinates within the range of 0.05 to 3.0 seconds, conditioned on IMj being the spectral acceleration at the mean fundamental period of vibration of each class - Sa(Ti). This approach builds on the work of Sousa et al. (2016), where the issues of predictability, efficiency, sufficiency and scaling robustness have been verified when analysing similar structural models. As a result, 60 ground motion records have been selected and scaled per level of Sa(T) (from 0.1g to 1.0g), for each site, logic tree branch and structural typology.

The probabilistic distribution of the selected IM vector conditioned on a given level of Sa(Ti) is determined according to the conditional probabilistic distribution of each IMi, as established in Equation 1, and the correlation models selected by Sousa et al. (2016). For details regarding the database of ground motion records used, readers are also referred to study by Sousa et al. (2016).

In order to illustrate the differences between ‘targets’ computed for different branches of the logic-tree, Figure 3 presents the comparison between the mean and variance of ‘target’ distributions of spectral ordinates between periods of 0.05 and 3.0 seconds for different logic-tree branches. The colour distinction is made only for the source model used in each logic-tree branch, for visual clarity. The discrepancies between target distributions of spectral ordinates across different logic-tree branches are evident in the results of Figure 3. However, the seismic response of structures is influenced by ground motion properties other than spectral ordinates. Therefore, as further presented, NLRHHA was additionally performed to evaluate the impact of these differences on fragility and loss.

### 4. HAZARD-CONSISTENCY OF FRAGILITY FUNCTIONS
Structural response is evaluated in terms of maximum inter-story drift (ISD) and global drift (GD), considering four damage states: Slight Damage (SD), Moderate Damage (MD), Extensive Damage (ED) and Collapse (Col). For the purpose of fragility assessment, the selected limit state criteria are consistent with the work of and Silva et al. (2014b), where similar structural models have been analysed. GD criteria are determined according to the evaluation of capacity of each frame through a displacement-based adaptive pushover. Displacement thresholds at each limit state are thus defined for each sampled frame without masonry infills (bare frame):

- Slight damage: global drift at 50% of maximum base shear capacity;
- Moderate damage: global drift when 75% of maximum base shear capacity is achieved;
- Extensive damage: global drift at maximum base shear capacity;
- Collapse: global drift when 20% decrease of the maximum base shear capacity is verified, or 75% of the ultimate global drift attained, whichever is achieved first.

In terms of ISD, a fixed set of values per limit state are defined based on the evaluation of global damage with increasing inter-story drift from 25 dynamic tests performed in real reinforced concrete moment resisting frames by Rossetto and Elnashai (2003):

- Slight damage: 0.08% maximum inter-story drift;
- Moderate damage: 0.30% maximum inter-story drift;
- Extensive damage: 1.15% maximum inter-story drift;
- Collapse: 2.80% or higher maximum inter-story drift.

4.1 Fragility Assessment

For the purpose of fragility assessment, the methodology proposed by Sousa et al. (2016) when analysing the fragility of similar structural models is adopted. For a given limit state and structural class, instead of computing a single damage exceedance probability per level of $\text{Sa}(T_1)$, one is interested in determining 60 ‘record-specific’ damage exceedance probabilities for each of the assessed levels of $\text{Sa}(T_1)$. Because 100 numerical models are analysed for each ground-motion record, the ‘record-specific’ probability of exceedance of any limit state can be inferred from the 100 engineering demand parameters (EDPs) obtained for each record.

As illustrated in Figure 4 for the case of ISD, ‘record-specific’ probabilities of exceeding a given limit

![Figure 3](image-url)
state correspond to the areas in grey. Unlike ISD criteria, where damage state thresholds are similar for all the structures (horizontal line in Figure 4), GD criteria are specific to each sampled frame. Thus, probabilities of exceeding a given limit state are perceived as the number of ‘successes’ (i.e. number of exceedances) in a sequence of 100 independent experiments that result in ‘success’ with identical probability (see Sousa et al. (2016) for additional details).

Figure 4. Record-specific distributions of EDP and corresponding probabilities of exceedance of Extensive Damage, determined according to ISD limit state criteria for 8 story frames. Records selected and scaled for $Sa(T_1)=1.0g$ (adapted from Sousa et al. 2016)

For illustration, Figure 5 shows sets of 60 record-specific exceedance probabilities of SD, MD, ED and Col., given $Sa(T_1)=0.1g$ to 1.0g, as a function of GD and ISD (site of Lisbon and 5-story frames).

Figure 5. Record-specific probabilities of exceedance of SD, MD, ED and Col, as a function of GD (upper) and ISD criteria (lower). Site of Lisbon and 5-story buildings.

4.2 Fragility Comparison

For a given level of $Sa(T_1)$ and limit state, the 60 corresponding ‘record-specific’ probabilities follow a certain probabilistic distribution that can be determined empirically (Sousa et al. 2016). As a result, one can easily recognize that, in order to compare the fragility results obtained for two different logictree branches, one can assess the null hypothesis that intensity-specific distributions arising from branch i are identical to those corresponding to branch j, at a given significance level. For this purpose, the two-sample Kolmogorov-Smirnov (KS) methodology (Ang and Tang, 2007) is used, since it allows also a helpful visual representation of the performed test.
Loosely speaking, the null hypothesis that two data samples are drawn from the same parent distribution is tested by checking the largest discrepancy between the two empirical cumulative distributions (CDFs). Based on the significance level of interest (10% in the present case), a maximum allowed difference (Dm) is computed. If the largest discrepancy between CDFs is lower than Dm, one cannot reject the null hypothesis that the two samples share the same parent distribution. On the other hand, the samples are assumed statistically different if the largest discrepancy is higher than Dm. According to Figure 6, where the black squares correspond to the rejection of the hypothesis of two samples of 60 damage exceedance probabilities sharing the same parent distribution, discrepancies amongst branches tend to increase from SD to Collapse (for 5 and 8-story buildings). Evidently, this trend is related with the increase of non-linear excursions as the damage severity increases. For more severe limit states, a higher degree of uncertainty in structural response and consequent disparities between any two particular branches are verified.

Figure 6. p-values obtained with the KS test when comparing empirical distributions of damage exceedance probability for each of the logic-tree branches at the site of Lisbon. Structural typologies of 2 (left), 5 (middle) and 8-floors (right). Conditional Sa(T1)=0.5g and GD criteria. P-values lower than 0.1 are plotted in black.

In the case of 2-story frames, however, a distinct trend is exhibited. In this case, the number of discrepancies amongst branches is similar for limit states of SD, MD and ED, due to the higher influence of infill panel behaviour (in comparison with 5 and 8-story buildings). In the case of collapse, discrepancies across branches are much smaller than for prior limit states (for 2-story frames), because, unlike 5 and 8-story frames, the infill panels are still effective at high levels of deformation, resulting in values of collapse probability that tend to zero for virtually all the 60 records, irrespectively of the hazard branch. Moreover, it is also possible to conclude that, irrespective of the
limit state, the differences in ‘branch-specific’ samples of damage exceedance probability increase with the number of floors of the assessed structural class.

It is interesting to note that the discrepancies described above seem to be influenced equally by the differences between seismic source and ground motion prediction models. There is no evidence that discrepancies amongst branches are more pronounced when changing the GMPE for a given source model, when compared with the differences registered between source models for a given GMPE.

For the sake of synthesis, only the results corresponding to GD criteria and one location (Lisbon) are presented here. For the same reason, only $Sa(T_1)=0.5g$ has been addressed in Figure 6. However, results similar to those presented in this section have been verified for all the assessed levels of $Sa(T_1)$ and damage criteria (for locations of Lisbon and Faro). These results demonstrate that, when the epistemic uncertainty of the hazard model is quantified through a logic-tree approach, fragility results are in fact “hazard-specific” (or “branch-specific”, for simplicity).

One might argue that this is the direct result of the selected primary intensity measure - $Sa(T_1)$ – not being sufficient. On the other hand, because such a sufficient intensity measure arguably does not exist and intensity measures other than $Sa(T_1)$ do in fact influence structural response, the different probabilistic distributions of these intensity measures across logic-tree branches have led to distinct (‘branch-specific”) fragility results.

5. EPISTEMIC UNCERTAINTY AND PROBABILISTIC LOSS ESTIMATION

This section addresses the impact of considering a set of hazard-specific fragilities on the evaluation of seismic losses, when the epistemic uncertainty of the hazard model is accounted for in a logic-tree.

Using the data from the Portuguese Building Census survey of 2011 (INE, 2011), three building portfolios referring to two, five, and eight-story reinforced concrete pre-code buildings in the districts of Lisbon and Faro have been considered (resulting in a total of 6 portfolios). Since the referred survey provides building counts at the parish-level resolution, the aggregation of assets at a single location (e.g. the parish centroid) can introduce significant errors. As a result, the GEOSTAT population distribution dataset (GEOSTAT, 2011), which provides the population count in a grid of 1 km$^2$ resolution, has been used to distribute the number of buildings in each parish proportionally to the amount of population estimated at each grid cell, as illustrated in Figure 7.

The information provided by Silva et al. (2013) was used to determine the economic value of each building class as the product of: a) average number of dwellings per class, b) the average area per dwelling, in m$^2$, and c) the average unit cost of replacement in EUR/m$^2$.

Figure 7. Total value of 2 (left), 5 (middle) and 8-story (right) RC pre-code buildings in the districts of Lisbon (top) and Faro (Bottom) (spatial resolution of 1km$^2$). For visual clarity, only part of the Faro district is shown.
5.2 Fragility and Vulnerability Models

In order to assess the impact of propagating the uncertainty of the hazard model into the corresponding “branch-specific” fragilities, one is interested in determining what are the differences in risk estimates when considering:

- A distinct ‘branch-specific’ fragility for each logic-tree branch; and
- A single model common to all branches, as in the state-of-practice.

For the sake of consistency, it is important that approaches a) and b) are common in terms of the methodology used in their analytical derivation. Therefore, model b) is herein selected as the ‘branch-specific’ model that corresponds to the median hazard branch. It shall be highlighted that, in this context, the median branch is that associated with the median hazard curve.

The fragility results (such as those illustrated in Figure 5) are used to fit a lognormal fragility function and associated uncertainty to each of the logic-tree branches. In brief, the estimate of uncertainty is obtained by means of bootstrap sampling with replacement. In this framework, 200 synthetic datasets are randomly generated from the original damage exceedance probabilities, resulting in 200 bootstrapped fragility curves per logic-tree branch (one set of 200 curves per building class). For additional details on the fragility regression methodology, readers are referred to the work of Sousa et al. (2016).

In order to combine the fragility curves into vulnerability function, the damage-to-loss model proposed by Silva et al. (2014b) in the study of similar structural models is used herein. Deterministic damage ratios (i.e. ratio between attained loss and replacement value of an asset) of 0.10, 0.30, 0.60 and 1.0 are assumed for limit states of SD, MD, ED and Col., respectively. Consequently, 200 vulnerability curves are obtained for logic-tree branch, for each structural class (as a function of $S_a(T_1)$).

5.2 Loss Estimation Methodology

Several studies have demonstrated the importance of accounting for spatial cross-correlation of ground motion residuals in the evaluation of portfolio losses (e.g. Weatherill et al. 2015). Therefore, the so-called OpenQuake probabilistic event-based risk tool (Silva et al. 2014a) has been used in this study. This calculator uses stochastic event sets and spatially correlated ground-motion fields to compute loss exceedance curves for each asset contained in the exposure model, using the correlation model proposed by Jayaram and Baker (2009).

When the correlation of uncertainty of the vulnerability model is incorporated in loss estimation, it is typically done such that when sampling the vulnerability of two assets with the same building class, the residuals are assumed to be either uncorrelated or perfectly correlated (Taylor, 2015). This is evidently done in order to provide boundary conditions to the problem. However, in the opinion of the authors, there is no evident physical meaning behind the assumption of any degree of spatial correlation between damage ratio residuals in cases (such as the present one) where their variability arises from the uncertainty in fragility regression. For this reason, damage ratio residuals are assumed to be perfectly uncorrelated.

5.2 Loss Estimation Results

The risk to earthquake action of a given building portfolio is commonly described through a loss exceedance curve that specifies the annual frequency of exceedance of a range of possible loss values. Unquestionably, loss exceedance curves (and associated uncertainty) are extremely relevant to the comparison presented in this study. However, comparing these curves may not be a straightforward matter, as doing so would require evaluating the differences in exceedance rates obtained for each of the possible loss values. Average Annual Loss values (AALs), on the other hand, while still encapsulating the information of the entire loss curve, are more concise and easily understandable outputs.

Using the fragility and vulnerability results presented in section 5.2, it is possible to obtain 200 loss exceedance curves for each logic tree branch, for each building class (one per fragility/vulnerability curve). Loss curves can further be used to compute the corresponding sets of 200 AALs. Using the branch-specific sets of AALs, it is possible to evaluate the median, 16% and 84% percentile (absolute)
differences between AALs computed using method a) and b) for each branch, for each structural class. According to Figure 8 and Figure 9, it is evident that approach b) (i.e., considering a single fragility model for all the logic-tree branches) is not capable of reflecting the ‘hazard-dependency’ of building fragility and associated epistemic uncertainty. As illustrated, absolute errors with respect to the ‘branch-specific’ model a) can reach values of 1000% for portfolios of 5 and 8-story buildings located in the districts of Lisbon and Faro, irrespectively of damage criteria. It shall be noted that, for the sake of synthesis, only the results of the 5-story portfolio are presented in the case of Faro. However, the errors obtained for 8-story structures are similar to those illustrated for the 5-story buildings. In the case of 2-story portfolios, on the other hand, errors tend to be one order of magnitude lower than those of 5 and 8-story buildings (Figure 8). This is consistent with the smaller discrepancies between ‘branch-specific’ fragilities exhibited in the case of the 2-story building class (section 4.2). More specifically, because differences between ‘branch-specific’ fragilities are generally lower in the case of 2-story buildings (especially for damage state of Col.), the discrepancies between fragility models a) and b) are also smaller than in the cases of 5 and 8-story buildings. Nonetheless, the errors attained are still in excess of 100% for most branches, which is clearly not satisfactory.

![Figure 8](image1.png)

Figure 8. Median, 84% and 16% percentile absolute differences between EALs computed using models a) and b), for all the branches. 2 (left), 5 (middle) and 8-story (right) building portfolios located in Lisbon.

![Figure 9](image2.png)

Figure 9. Median, 84% and 16% percentile absolute differences between EAL computed using models a) and b), for all the branches. 5-story building portfolio located in Faro.

6. CONCLUSIONS

In this research, the subject of ‘hazard-dependency’ of building fragility has been addressed, through a methodology that incorporates: a) probabilistic seismic hazard analysis (PSHA) for the sites of Lisbon and Faro (Portugal), using a logic-tree approach that reflects 3 distinct seismological models and 20 combinations of ground motion prediction equations, b) hazard-compatible record selection and nonlinear response history analysis for each logic-tree branch and each site, and c) fragility analysis and comparison between fragility functions obtained for each assessed hazard branch, at each site. According to the appraised results, it has been demonstrated that, when analytical methodologies are used to characterize hazard and fragility components, the epistemic uncertainty of the hazard model
shall be propagated into the fragility analysis. More specifically, it has been verified that, in such analytical exercises, fragility results are statistically different amongst logic-tree branches. In order to further evaluate the impact of the above findings in the context of seismic risk, the probabilistic loss estimation of 6 different building portfolios located in the districts of Lisbon and Faro has been performed. In this exercise, loss exceedance curves and corresponding Average Annual Losses were computed for each hazard branch (and each portfolio), using two distinct fragility assessment approaches: a) a distinct fragility per logic-tree branch, consistent with each distinct hazard model, and b) a single fragility model common to all the branches, as commonly used in practice. It was demonstrated that the errors associated with using a single fragility model (approach b)), can be as high as 1000%, when compared with the hazard-consistent approach a).

In light of the significance of the above results, it is clear that, in order to appropriately propagate the epistemic uncertainty of the hazard model into the corresponding loss estimation results, one shall use a distinct fragility model per hazard branch.

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7. REFERENCES


Cauzzi, C., & Faccioli, E. (2008). Broadband (0.05 to 20 s) prediction of displacement response spectra based on worldwide digital records. J. Seismol., 453–475.


