Overview on current seismic hazard disaggregation studies for Western Iberia and consequences for ground shaking scenarios for Lisbon

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SUMMARY:

Probabilistic seismic hazard (PSHA) disaggregation is a tool that provides useful insights into the main sources contributing to the hazard at a specific site. The importance of the technique in assisting the selection of ground motion scenarios for seismic design and earthquake emergency planning has been established for more than a decade. Recently, a new exercise on the PSHA disaggregation for Portugal was published. In contrast to previous analysis, the study concludes that offshore seismic sources, located around 70km WSW of Cape St. Vincent, dominate the contributions to seismic hazard for southern and central Portugal sites, including Lisbon, for both 10% and 5% exceedence probability in 50 years. We challenge those results by attributing the obtained hazard pattern to biases in the input parameters used for the underlying PSHA assessment. In our opinion, PSHA desegregation analysis is only useful if supported by a robust and reliable PSHA assessment, following the best international practices regarding seismogenic sources, catalogue preparation, recurrence analysis, ground motion prediction models, and epistemic uncertainty.

Keywords: seismic hazard, disaggregation, ground shaking, SW Iberia

1. PROBABILISTIC SEISMIC HAZARD ASSESSMENT AND ITS DISAGGREGATION

1.1. Probabilistic Seismic Hazard Assessment

Probabilistic seismic hazard assessment (PSHA) is a time-honoured technique whereby the probability of exceedence of a specified level of ground motion over a certain period of exposure is estimated for a site, from the available information on the regional seismic sources, the characteristics of the attenuation of seismic waves, and local effects at the site (Cornell, 1968). Often, a probability of exceedence deemed socially acceptable is specified by a building code – typically 10%, 5% or 2% in a period of 50 years, depending on the type of structure – and for a particular site the PSHA must estimate the level of shaking associated with that probability. While in more traditional studies the ground motion was described via a macroseismic intensity scale, it became gradually more common to adopt peak ground acceleration (PGA), and ultimately spectral acceleration (SA) at specified periods, among other measures. The variable used is dictated by the ground motion prediction equation (GMPE) adopted for the hazard calculations.

The choice of GMPE is of paramount importance for the final PSHA result. It should be derived from instrumental strong motion data pertinent to the region under study, and used only within the range of distances of that data. However, this rule cannot always be followed, particularly in continental areas where strong motion data are very scarce. As the next best choice, limited data from the area of study may be used to test the applicability of GMPE's derived for regions of similar tectonic setting.

Alongside with the choice of GMPE, the characterization of seismic recurrence for the sources that are relevant to the site is also of key importance. Frequently, the seismic activity rate – the *a* value of the Gutenberg-Richter relation – can be well constrained from recent instrumental data, because it pertains to the minimum magnitude still considered relevant for the hazard. For example, *a* may correspond to the number of earthquakes in one year that have magnitude equal to or above M4, clearly dominated by seismicity in a range of magnitudes for which the instrumental catalogues are easily complete in the last decades. Moderate to high magnitude seismicity, on the other hand, is hard to estimate from seismicity catalogues in intraplate areas, because the catalogue completeness periods tend to fail short of the relevant return periods for PSHA. For a Poissonian model of seismic occurrence, the probabilities given above as examples correspond to 475, 975 and 2475 years, respectively. The rate of occurrence of moderate to large earthquakes is therefore inferred from low magnitude rates, through the *b* value adopted for the Gutenberg-Richter relation. Such inference is extremely sensitive to errors in *b*, given the logarithmic nature of the relation. If an error-free rate of occurrence of M4 earthquakes is used to extrapolate for the M8 rate, an error of 0.25 in the *b* value leads to a relative error of 100% in the M8 rate. Fortunately, it is widely confirmed by observation that *b* values tend to be in the vicinity of 1, and therefore large errors are unlikely. Because large sources of error may be present in any PSHA study, in particular in plate interiors, a great effort is put to quantify the uncertainties of the final result, both aleatory and epistemic.

1.2. Disaggregation

The Cornell (1968) approach to PSHA is based on an area summation, covering all the relevant sources. Restricting the summation to a given sub-area allows the estimation of the contribution of that sub-area to the total hazard. This notion is the basis of the technique known as hazard disagreggation (Bazurro and Cornell, 1999), which allows the identification of the seismic sources making dominant contributions to the hazard at a particular site. This information can in turn be used to define the ground shaking scenarios that are relevant for earthquake risk mitigation at the site. Gaining information on the location of the relevant sources may also focus the research onto other characteristics such as rupture mechanism and near-site effects (Bazurro and Cornell, 1999).

On the same token, it can be concluded that inadequate disaggregation of seismic hazard may be a distracting factor, allocating the research effort to sources that are not dominant and underestimating others that deserve attention. We contend that seismic hazard disaggregation proposed recently for SW Iberia is an example of this type of shortcoming, and discuss the subjective factors that may be at the origin of such bias. Finally, we discuss the implications for the hazard zonation adopted in the EC8 National Annex for Portugal.

2. ATTEMPTS OF DISAGGREGATION OF SEISMIC HAZARD IN SW IBERIA

To our knowledge, two attempts were conducted so far to disaggregate the seismic hazard in SW Iberia. The earlier study (Montilla et al., 2002) adopted macroseismic intensity as the measure of ground motion, and fitted empirical relations to the available intensity data to derive the GMPE's. More recently, Sousa and Costa (2009) use the same ground motion variable, and adopt the same procedure to derive the GMPE's. Surprisingly, the outcomes of the disaggregations are radically different. We will take the all-important result for Lisbon to illustrate the differences.

Montilla et al. (2002) conclude that, at a return period of 475 years, 52% of the hazard in Lisbon is due to sources located to the north of the city, within distances of 50 km. Sources within 60 km to the south of Lisbon account for another 35%, according to the same authors. Only the remaining 13% of the hazard are attributed to sources beyond 60 km.

Sousa and Costa (2009), on the other hand, conclude that the dominant rupture scenario for Lisbon at the same return period is located offshore, 70 km WSW of Cape St. Vincent. In the proposed disaggregation, the modal 10 km by 10 km bin contributes with 52.9‰ of the hazard in Lisbon, whereas the onshore bins that comes closer contributes with 14.3‰. This can be regarded as a mirror image to the conclusions of Montilla et al. (2002). The authors conclude that the modal scenario for 475 (and 975) years of return period is “dominated by the effect of the large magnitude Lisbon 1755 earthquake”.

In view of the disparate results of the two analyses, we are inclined to conclude that the available information does not warrant the disaggregation of the hazard in a robust and reliable way (Fonseca and Vilanova, 2011). Already for that reason, our own results for PGA-based PSHA (Vilanova and Fonseca, 2007), shown in Fig. 1, were not subject to disaggregation. That said, the pattern shown around Lisbon for a return period of 475 years – with high hazard “wavelengths” of the order of 50km to 100 km in the Lisbon region, depending on orientation – points to a dominant contribution of local sources, as opposed to dominant distant offshore sources that would result in a smoother pattern. The results of Vilanova and Fonseca (2007) are therefore more in line with the conclusions of Montilla et al. (2002). A similar conclusion may be derived from the analysis of other hazard maps such as the ESC-SESAME Euro-Mediterranean hazard map (e.g., Solomos et al, 2006, their Figures 6.2 and 6.3).

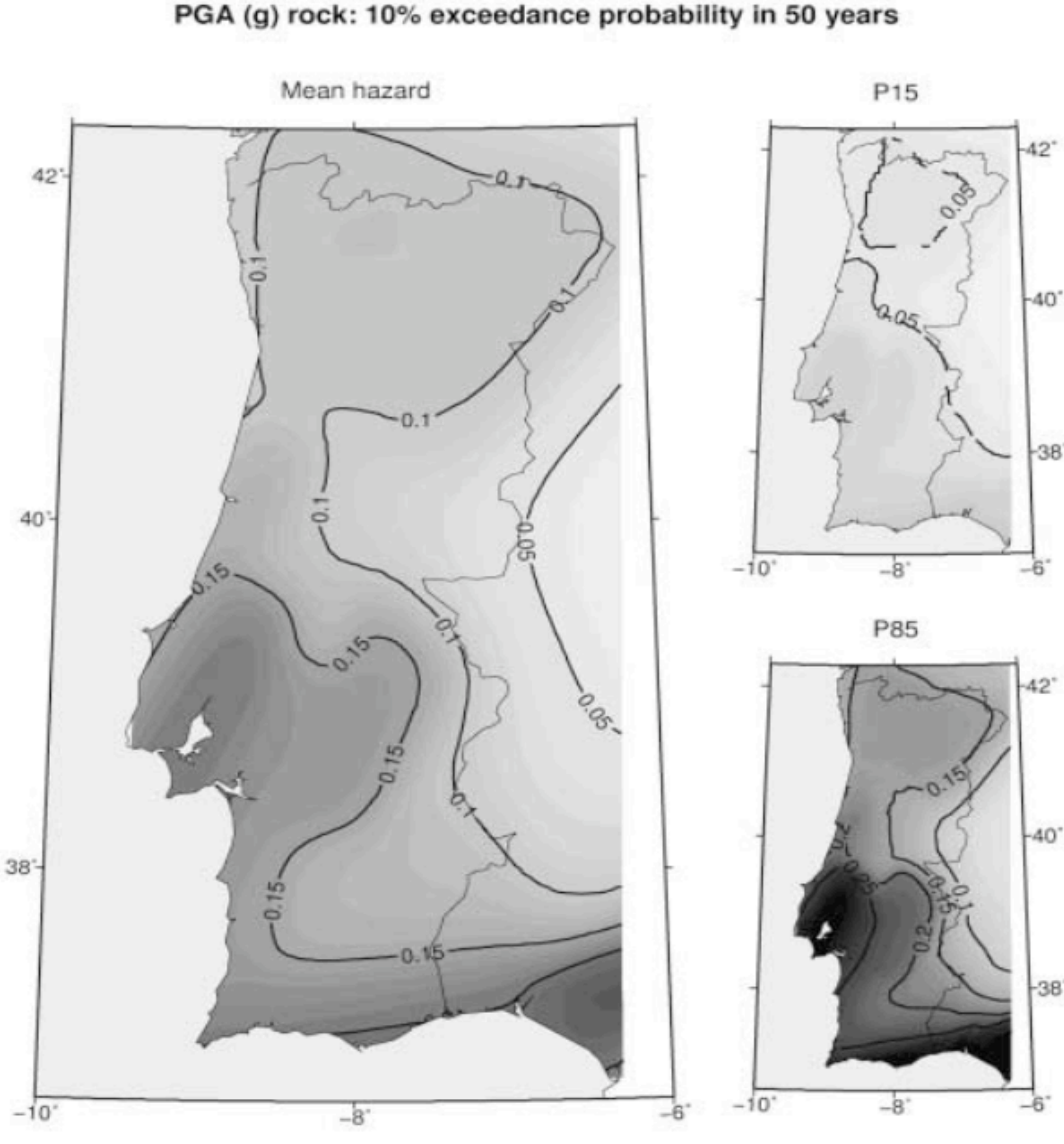

Figure 1. Mean peak ground acceleration in rock with a probability of 10% of being exceeded in 50 years, in units of g. Also shown are the 15th and the 85th percentiles. Increment between different shades of gray is 0.01g. After Vilanova and Fonseca (2007).

3. DISCUSSION

The conflicting results presented above highlight the difficulty inherent to the disaggregation of seismic hazard when the starting point is an analysis already affected by large uncertainties. Fonseca and Vilanova (2011) identified and discussed in detail several causes of bias in Sousa and Costa (2009). In particular, we showed that the proposed source 70 Km WSW of Cape St. Vincent is an artefact due to strong contrast in GMPEs and *b* values across the converging borders of three source zones. We refer the reader to Fonseca and Vilanova (2011) for a detailed discussion of the inadequacy of GMPE's (intensity differences of up to 2.5 for the same distance and magnitude, depending on source zone) and b values (ranging from 5.9 to 1.22, lowest value associated with the proposed source) used in Sousa and Costa (2009). Here we will highlight two aspects: 1) the danger that a large historical disaster such as the Lisbon earthquake may subjectively "force its way" into hazard assessment; 2) the effect of this "traditional"view on the zonation associated with the EC8 National Annex.

3.1. The "invisible" role of the 1755 earthquake.

Whereas PSHA is desired objective, despite more than 250 years elapsed since its occurrence the 1755 earthquake still carries a strong weight in Portuguese cultural references. Somehow this may have influenced also the seismic hazard assessment. As an example of this, we examine two aspects of the input data used in Sousa and Costa (2009). Arguing in favour of the *ad hoc* empirical GMPE's that would be adopted in the paper, Sousa (2006) states that no relation published in the literature could predict the high intensities of the 1755 earthquake, while the adopted relations had the advantage of being derived from (mainly) those high intensities. It is therefore not surprising that the resulting analysis should point to a remarkable contribution from very distant (~200 km) sources, since the GMPE's were designed so that they would reproduce that unusual effect. However, alternative explanations have been put forward for the extreme intensities reported for Lisbon in 1755, including a secondary rupture in the vicinity of the city (Vilanova et al., 2003).

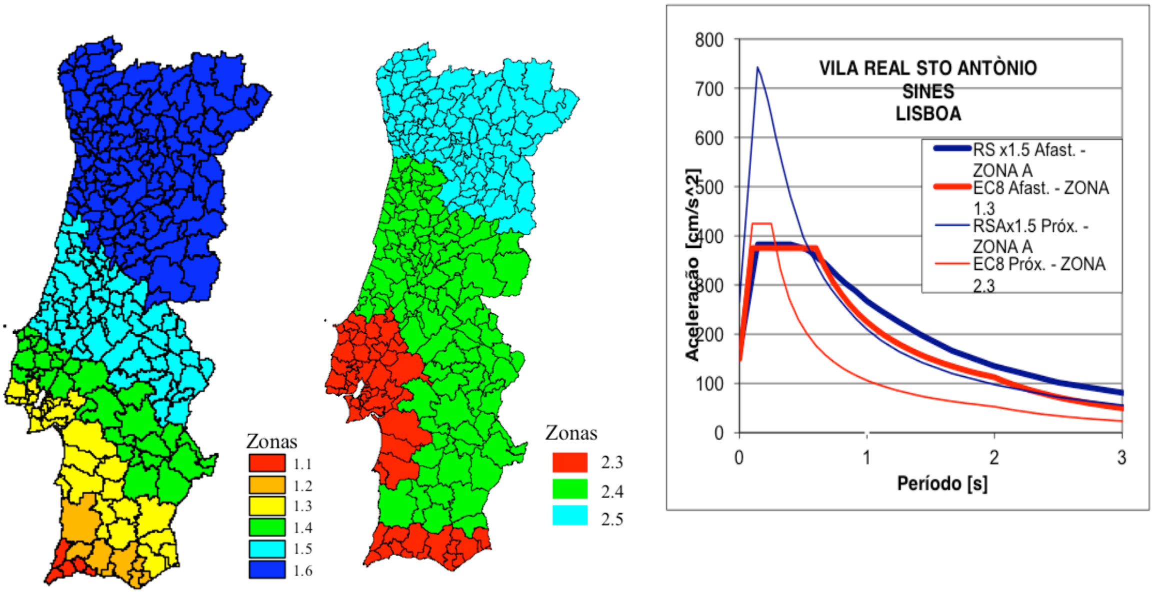
(A.1) (A.2) (B)

Figure 2. Seismic zonation for a distant scenario (A1) and for a nearby scenario (A2), in the EC8 National Annex. Colours correspond to different PGA values, and at each site the highest of the two values is adopted. For Lisbon, PGA is 1.5 ms^{-2} in the distant scenario and 1.7 ms^{-2} in the nearby scenario. However, in combination with the different shapes of elastic response spectrum to be used with each scenario, for all sites to the south of, and including, Lisbon the distant scenario (B, thick red line) dominates with respect to the nearby scenario (B, thin red line) except at very low periods of marginal engineering interest. This effect is stronger than with LNEC (1983), the building code previously in force (B, blue lines, same convention). After Carvalho (2011).

Also “boosting” the effect of the 1755 earthquake scenario in the hazard assessment of Sousa and Costa (2009) is the low *b* value of 0.59 adopted for the area encompassing its offshore epicentral region (Vilanova and Fonseca (2007) found 0.94 and 1.09, with a more robust analysis).

3.2. The dual zonation of the Eurocode 8 National Annex

Contrary to general practice, the Portuguese National Annex of the Eurocode 8 adopts two zonations, one for the near-source scenario and the other for a distant-source scenario. This is in line with the approach taken in the previous building code (LNEC, 1983). It can be seen in Fig. 2A.1 that the distant scenario zonation is strongly dominated by the 1755-type earthquake scenario, as should be expected. At each site, the higher value given by the two zonations is adopted. However, taken in conjunction with the regulatory elastic response spectra, the nearby scenario for Lisbon and all sites to its south exceeds the distant scenario only at periods below 0.3 s, of marginal engineering relevance (Fig. 2B).

4. CONCLUSION

The identification of rupture scenarios through hazard disaggregation as proposed by Sousa and Campos (2009) for SW Iberia should only be performed starting with robust hazard results. Otherwise, it may lead to biased ranking of seismic sources, as we contend was the case in the cited study. This bias may have contaminated the seismic zonation adopted in the National Annex of Eurocode 8, and may distract research from relevant seismogenic sources at short distances. The EC8 zonations should therefore be revised taking into account the best practices recommended at international level. In particular, the recommendations of FP7 project SHARE (Seismic Hazard Harmonization for Europe) should be taken on board for the revision of the National Annex.

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