A consistency test on probabilistic earthquake recurrence models and uncertainties

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Summary: Three recent Probabilistic Seismic Hazard Assessment Studies for Portugal mainland have shown very different results leading to concerns among the scientific community and doubts among decision makers and the public in general. As a response to these concerns, a group of researchers from the Portuguese scientific community started a study to evaluate the origin of such differences. The first results on the characterization of earthquake recurrence in terms of zoning and truncated Gutenberg-Richter law parameters showed very different values for the return period of the maximum expected magnitude, for two main seismogenic zones in the offshore southwest Portugal.

In the present work we evaluate each of the earthquake source models, expressed through the seismic deformation, converted into a relative velocity between blocks, for easier interpretation. For typical values of the length of the fault L, the seismogenic thickness H, the fault inclination α and slip angle λ, assuming a seismic coupling of 1, it was possible to verify that all 3 published studies present equivalent velocities of deformation of ~2 mm/year for the Lower Tagus Valley, much higher than expected. For the South and Southwest offshore zones, several models also exceed the expected convergence velocity between Africa and Eurasia, ~4 mm/year. Discussion on uncertainties associated to these estimations is also presented.

Introduction

Portugal mainland is located in the western part of Europe. Its seismicity is characterized by strong interplate earthquakes, originated offshore in the region of the Eurasian and African plates boundary, and moderate intraplate earthquakes originated inland. Several seismic hazard assessment were already performed, at regional, national and european level.

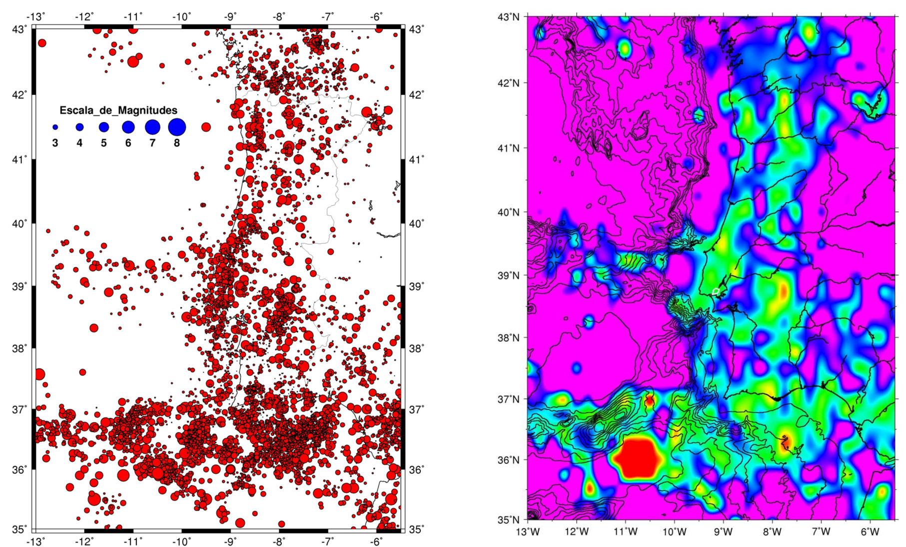


Figure 1 – Left: Portuguese seismic catalogue used on PSHA. Right: strain seismic energy released by instrumental earthquakes.

In 2013 the SHARE project published an European Seismic Hazard Map. For Portugal the most hazardous zone is the Lower Tagus Valley (LTV) region, close to Lisbon (Figure 2). However this map is not compatible with the Portuguese PSH maps produced for code implementation (EC8).

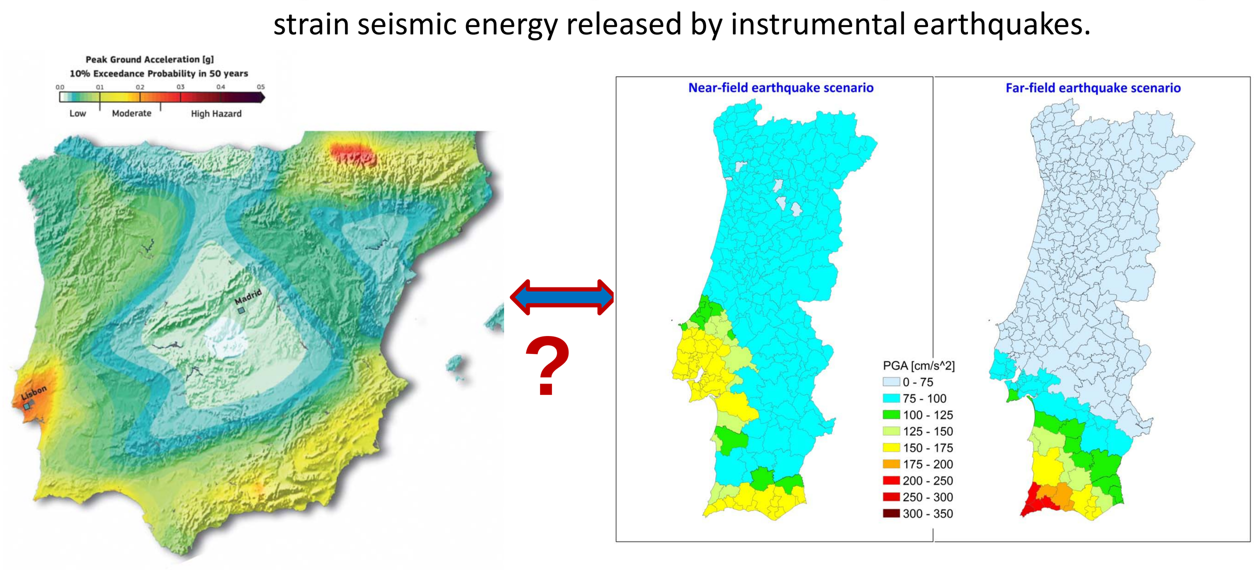


Figure 2 – Left: SHARE map (Giardini et al. 2013). Right: Portuguese PSHA produced for EC8 basis (Campos Costa et al. 2008)

The difference must be investigated and can be due to the several options that we have to assume during the steps necessary to develop a PSHA. And the fist step is the seismic zoning, identifying and characterizing the main seismogenic zones.

Seismic zoning

Three different seismic zoning were used for recent PSHA performed for Portugal (Figure 3). Carvalho & Malfeito (2016) tested the influence of these zonings on the recurrence periods for largest expected earthquakes. They found small differences for the LTV region, but great differences on the south and SW regions of Portugal.

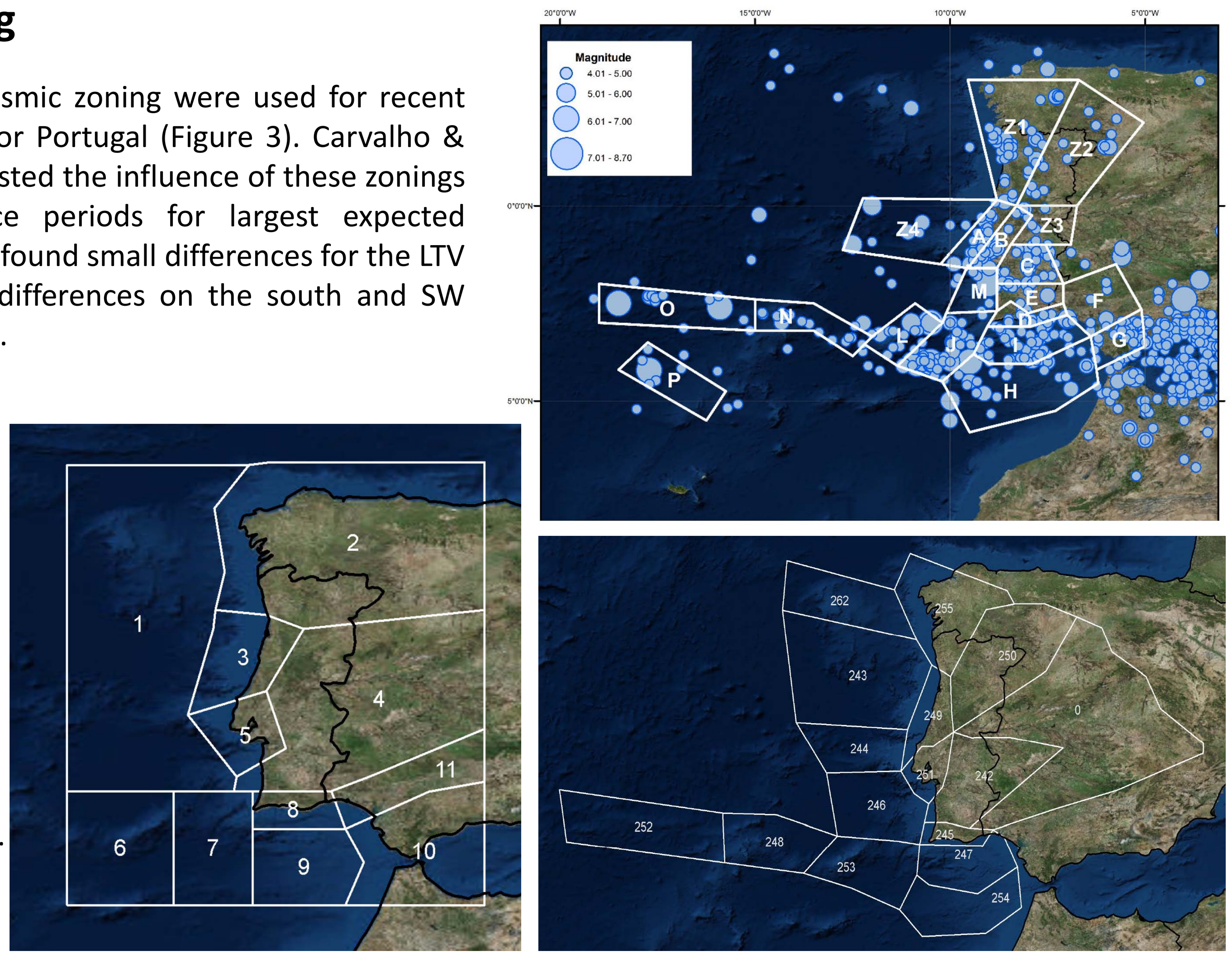


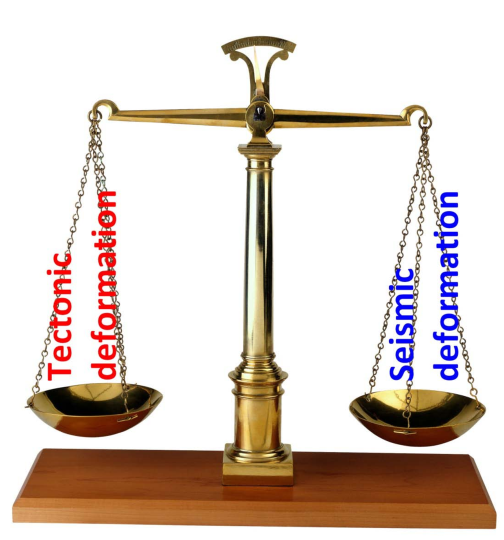
Figure 3 – Different recent seismic zoning for Portugal. Upper: ERSTA project (Carrilho et al. 2010); Bottom: SHARE project (Woessner et al. 2015); Left: EC8 (Campos Costa et al. 2008)

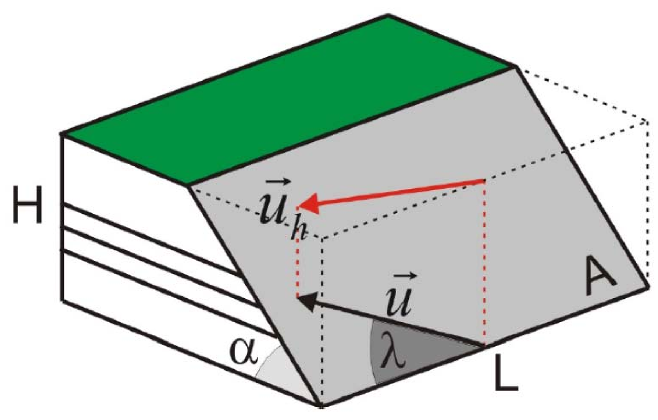
Seismic deformation vs. Tectonic deformation

The seismic deformation cannot exceeds, or be very smaller, when compared with the tectonic deformation.

The convergence rate between the Africa (Nubia) the Eurasia plates, at S – SW Iberia, is about 4 mm/year. So, the average slip rate of each fault cannot exceeds this value.

Matias et al. (2017) proposed a simple fault model (Figure 4) to compute the average slip rate on the faults. They made the computations for different offshore faults in the S and SW of Portugal and they found slip rates between 0.2 and 1.4 mm/year, depending on the selected zoning, verifying that none exceeds the tectonic deformation.





Fault Model

- Fault dimensions: Length (L) and Width (W)
- Seismic coupling = 1 (underestimated)
- Geometrical factors (F1, F2)

Figure 4 – Single fault model used to compare the earthquake recurrence models with plate kinematics constrains.

Using this model, the average slip rate on the fault can be computed by summing the moment released by all possible earthquakes as

$$\Delta\dot{u} = F_1 \sum \frac{M_0}{\mu A T} = F_1 \sum \frac{M_0}{\mu LW T} = F_2 \sum \frac{M_0}{\mu LH T}$$

T is the total time-span considered while F_1 and F_2 are scaling factors that depend on the geometry of the fault and the slip angle. To simplify the computation we will assume that the representative fault in each zone will be a pure reverse fault, a pure normal fault or a pure strike-slip fault. For a pure dip-slip fault the scaling factor is given by $F_2 = \sin\alpha \cos\alpha$. For a strike-slip fault the scaling factor is unity.

Probabilistic Seismic Hazard Validation

A PSHA consists on several steps: (1) seismic zoning; (2) seismic potential of each zone (Gutenberg & Richter parameters and Mmax); (3) attenuation law; (4) probability to exceed a certain level of ground motion during the exposure time (seismic hazard curves).

Each step is characterizes by a probability distribution but their parameters depending on individual assumptions and choices.

Epistemic incertitude !

To account on this epistemic incertitude it is usual to perform several PSHA using Monte Carlo simulations and/or logic trees.

But when using, for instance, Monte Carlo simulations are all results consistent with the seismotectonic constraints?

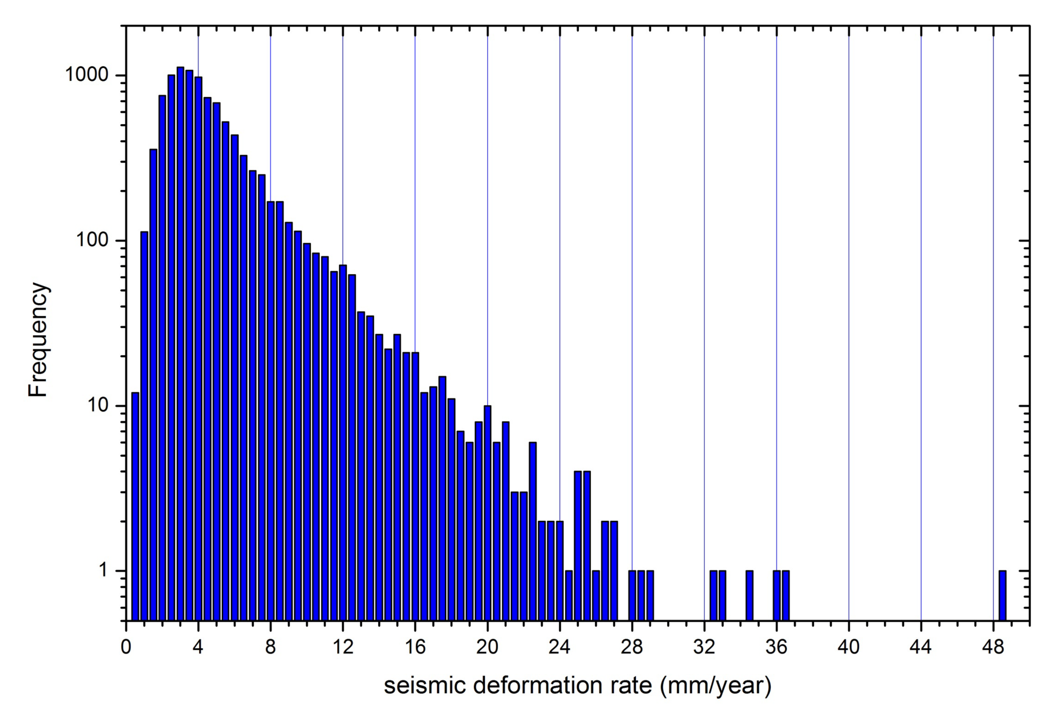
Gulf of Cadiz seismogenic zone

m_{min} = 4.5
β = 2.01 ± 0.05
λ = 78.3 ± 10.7
m_{max} = 8.8 ± 0.3
L = 300 km
W = 52 km
u = 4 mm/year

$$F_M(m|m_{min}, m_{max}) = \begin{cases} 0 & m < m_{min} \\ \dfrac{1 - exp[-\beta\,(m - m_{min}]}{1 - exp[-\beta\,(m_{max} - m_{min}]} & m_{min} \le m \le m_{max} \\ 1 & m > m_{max} \end{cases}$$

$$\dot{N}(m) = \lambda\,[1 - F_M\,(m\,|m_{min}, m_{max})]$$

10 000 Monte Carlo simulations for the G-R bounded recurrence law



Mean = 4.95
Standard deviation = 3.32
Interval/range = [0.55 ; 48.5]
Median = 4.03
Q1 = 2.88
Q3 = 5.90

Figure 5 – Histogram of the computed seismic strain and statistical values

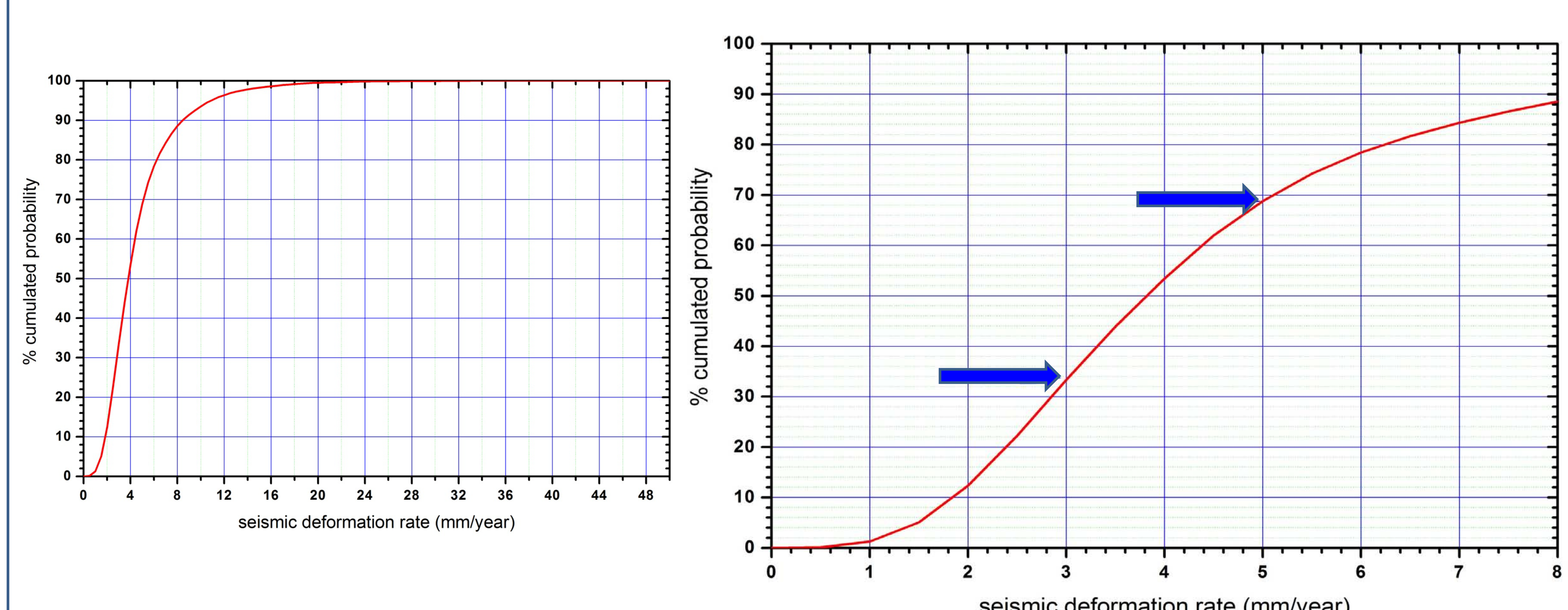


Figure 6 – Left: cumulative frequency; Right: zoom for seismic strain lower than 8 mm/year

If we consider an incertitude of ± 25% on the tectonic constraint (± 1 mm/year on the tectonic strain rate), only 34% of the simulations are consistent with the geologic strain!

Conclusions

PSHA includes incertitudes (random and epistemic) difficult to quantify. An attempt to overcome this difficulty is to perform a large number of simulations, using mathematical algorithms, and presenting the statistical analysis of the results. These statistical parameters (for instance, mean and standard deviation) intend to represent the accuracy, or the quantified incertitude of the results. However, the validation of the results with geologic and tectonic constraints is never done.

So, on the PSHA it is necessary to take into account the lithospheric deformation of the crust on the target region, in order to reduce the "error" on the estimation of our results incertitude.
Similar tests must be performed for the PSHA using logic trees.

Acknowledgements
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