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An Approach for the Estimation of the Magnitude of Historical Earthquakes: a sensitivity study of the 1980 and 1998 Earthquakes in the Azores

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ABSTRACT

In regions with low-to-moderate seismicity, the return-period of seismic events with large magnitudes is relatively high. Nevertheless, historical seismic events are relevant for the evaluation of seismic hazard in those regions. Thus, seismologists study the records of the effects of historical earthquakes to map the distribution intensity points, using an Intensity Scale. Afterwards, the maximum intensity point is identified as well as the probable epicentral location and magnitude. Another method, introduced by earthquake engineers, incorporates the knowledge of the behaviour of structures into posterior distributions of magnitude using fragility functions and the damage reported in historical documents. The method uses the total probability theorem to combine the uncertainty in the structural behaviour, ground motion intensity, site-to-source distance. Then, the Bayes's theorem is employed to update a prior magnitude model into a posterior magnitude distribution. Thus, the reduction of the uncertainty in the final estimates requires the preliminary application of the method to instrumental events in order to validate the appropriate framework to address historical seismicity, namely ground motion and structural response. This paper investigates the earthquakes of January 1st 1980 with M_w=6.8-7.2 and of July 9th 1998 with M_w=5.9-6.2 in Azores Islands (Portugal) as study cases to test the sensitivity to different attenuation models Ambraseys *et al.* (2005) and Akkar *et al.* (2014). A single set of fragility functions, derived from a detailed vulnerability assessment in Faial, is assumed to model the structural response in both events. The results show that, for both events, the attenuation model from Akkar *et al.* (2014) and the fault source model presented results closer to those of detailed methods. Discrepancies can also be explained by differences in the prior distance model resulting from source models assumptions. The intervals Mw=5.96±0.53 and Mw=6.91±0.42 have been estimated for the 1998 and the 1980 earthquake, respectively.

Keywords: fragility functions; historical seismicity; 1998 earthquake; 1980 earthquake;

INTRODUCTION

In regions with low-to-moderate seismicities, such as the Azores Islands (Portugal), the return period of seismic events with large magnitude is relatively high. This fact drove seismologists to investigate the historical ground motion intensities that are described in historical documents through earthquakerelated phenomena, as shakes in objects, cracks in the ground and walls, and even structural failure. Each intensity point is mapped using an intensity scale, as the Mercalli Modified Scale (MMI), enabling the identification of the probable epicentral location and intensity. Afterwards, an empirical relationship is utilized to calculate the likely magnitude of the historical seismic event. Nevertheless, the traditional methodologies translate the damage of structures into a single intensity value, leaving their behaviour out of consideration (Eisinger *et al.*, 1992).

Another method, proposed by earthquake engineers (Ryu *et al.*, 2009), uses fragility functions of the type $P(\mathrm{DM} \geq ds_i|\mathrm{IM}=\mathrm{im})$, which describe the conditional probability of exceeding a certain damage state in structures ds_i given an intensity measure IM, with instances im. This is possible because the method defines the damaging seismic event E in terms of damage occurrences using probability theory. The calculation process is schematised in Figure 1.

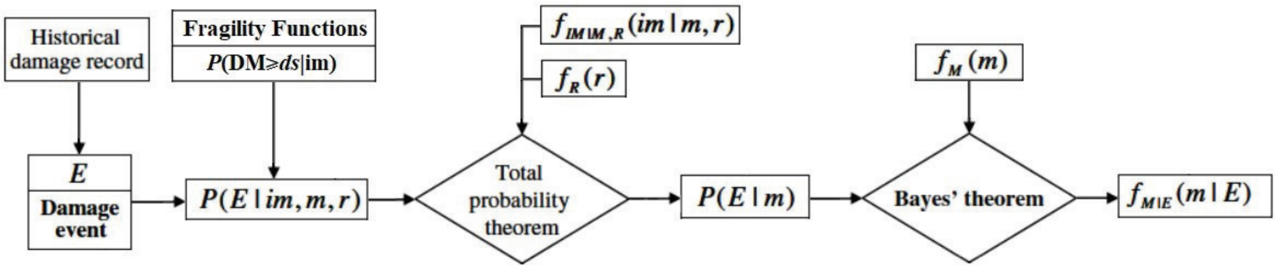

Figure 1. Flowchart of the magnitude estimation method (based on Ryu *et al.*, 2009).

The fragility functions are then utilized to compute the probability of observing single damage states $P(\mathrm{DM}=ds_k|\mathrm{im})$ using Eq. (1).

$$P(\mathrm{DM} = \mathrm{dm}_k | \mathrm{im}) = P(\mathrm{DM} \geq \mathrm{dm}_k | \mathrm{im}) - P(\mathrm{DM} \geq \mathrm{dm}_{k+1} | \mathrm{im}) \quad (1)$$

Using Eq. (2), these probabilities are then combined with the number of damage occurrences $n_{ds,k}$ to find the probability $P(E|\mathrm{im},m,r)$ of a damaging event given an intensity measure im, magnitude m and distance r.

$$P(E | \mathrm{im}, m, r) = \frac{n_t!}{\prod_{k=0}^{n_d} n_k!} \times \prod_{k=0}^{n_d} P(\mathrm{DM}=\mathrm{dm}_k | \mathrm{im}, m, r)^{n_k} \quad (2)$$

This step is possible due to the assumption that the observed damage is also caused by magnitude and distance. Afterwards, the total probability theorem employed together with an attenuation equation $f_{IM|M,R}(im,m,r)$ and a prior distance distribution $f_R(r)$ to estimate the probability of the damage event given magnitude $P(E|m)$, as in Eq. (3).

$$P(E | M = m) = \int\int P(E | \mathrm{im}, m, r) \times f_{IM|M,R}(\mathrm{im} | m, r) \times f_R(r) \, d\mathrm{im} \, dr \quad (3)$$

Finally, the Bayes' theorem is employed as in Eq. (4) to update a prior magnitude distribution f_M into the posterior distribution of magnitude $f_{M|E}$.

$$f_{M|E}(m | E) = \frac{P(E | M = m) \times f_M(m)}{\quad} \quad (4)$$

$$\int P(E\mid M=m)\times f_M(m)\,dm$$

In order to apply this method to historical contexts, it is first necessary to validate the framework. One option is to utilize data from recent instrumental earthquakes. The present study cases are the January 1st 1980 with M_w=6.8-7.2 (Borges et al., 2007; Carvalho *et al.*, 2001) and of the July 9th 1998 with M_w=6.0-6.2 (Borges *et al.*, 2007; Matias *et al.*, 2007) in Azores Islands (Portugal). More specifically, the method (Ryu *et al.*, 2009) is here employed to study the sensitivity of the magnitude estimates to different attenuation models, namely Ambraseys *et al.* (2005) and Akkar *et al.* (2014), and soil types A, B and C. The fragility functions are derived from a detailed study of the structural vulnerability distribution of typical buildings from Faial damaged by the 1998 earthquake (Ferreira *et al.*, 2017). The same set of fragilities is extrapolated for the case of the 1980 earthquake, despite the different damage datasets ("Soeiro" and "GAR", from Lucas *et al.*, 1992).

MAIN RESULTS

The framework of assumptions for the presented approach, consistently with Figure 1, is endorsed by earlier studies on ground motion, building typologies and damage. The fragility functions – assumed as lognormally distributed with moments μ_{ds}={0.037 0.078 0.153 0.328 0.907} and σ_{ds}={0.126 0.132 0.210 0.212 0.212} –, attenuation equation for different Joyner-Boore distances R_{JB}, assuming a strike-slip fault type, M_w=6.1, and soil of type C (V_{s30}=270 m/s), as well as prior distance densities in the form of histograms are presented in Figure 2.

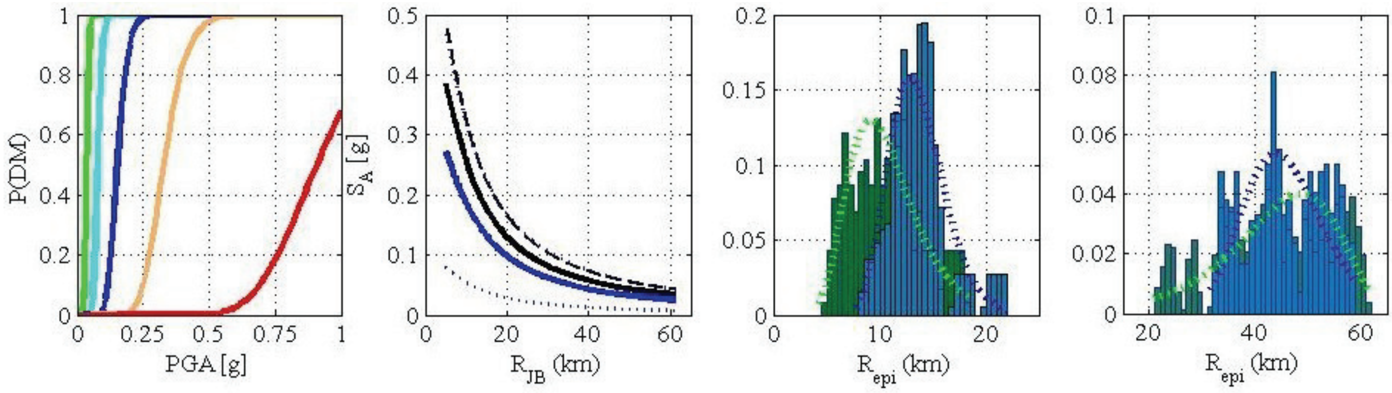

Figure 2. Sequence of fragility functions, on the left; attenuation models Ambraseys *et al.* (black) and Akkar *et al.* (blue), on the centre-left; histograms for the densities of the epicentral distances for Faial earthquake, considering epicentral locations Epi1 (blue) and Epi2 (green), on the centre-right, and for the densities of the epicentral distances in Terceira for "Soeiro" (blue) and "GAR" (green), on the right.

The epicentre of the 1980 earthquake was considered in 38.810ºN, 27.780ºW, and the epicentre of the 1998 earthquake in locations "Epi1" with 38.634ºN, 28.523ºW, and "Epi2" with 38.640ºN, 28.590ºW (Borges *et al.*, 2007). Additionally, the fault systems are also studied, considering Joyner and Boore distances R_{JB} to the edges of a 30 km fault, in the case of the 1980 earthquake (Estevão & Oliveira, 2012), of a 16.5 km fault, in the case of the 1998 earthquake (Estevão & Carvalho, 2014). The expected values of magnitude μ_M and respective standard deviations σ_M are presented in Table 1 and Table 2, respectively, for the 1998 and 1980 earthquakes. The distance model has a uniform uncertainty of ± 1.0 km on the site and point sources, while the fault sources are assumed as deterministic. The prior magnitude distribution is considered here as uniform in the strong magnitude range ($5.0 \leq M_w \leq 8.0$).

Table 1. Magnitude distribution moments $\mu_M(\sigma_M)$ for the 1998 "Faial" earthquake.

	Ambraseys *et al.*, 2005			Akkar *et al.*, 2014								
	Fault						Epi1			Epi2		
f_M	A	B	C	A	B	C	A	B	C	A	B	C
1	**5.43** (0.59)	**5.38** (0.59)	**5.30** (0.60)	**6.02** (0.86)	**5.96** (0.85)	**5.99** (0.88)	**6.05** (0.78)	**5.97** (0.78)	**5.98** (0.81)	**5.91** (0.78)	**5.85** (0.77)	**5.89** (0.81)

Table 2. Magnitude distribution moments $\mu_M(\sigma_M)$ for the 1980 "Terceira" earthquake.

	Soeiro			GAR			Soeiro			GAR			Soeiro			GAR		
	Ambraseys *et al.*, 2005						Akkar *et al.*, 2014											
	R_{JB} (Fault)												R_{epi}					
f_M	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	**7.06** (0.39)	**6.92** (0.40)	**6.69** (0.43)	**6.78** (0.52)	**6.66** (0.51)	**6.44** (0.51)	**7.10** (0.72)	**7.05** (0.72)	**6.94** (0.75)	**6.96** (0.77)	**6.90** (0.77)	**6.79** (0.79)	**7.01** (0.69)	**6.95** (0.70)	**6.83** (0.73)	**6.87** (0.73)	**6.80** (0.74)	**6.68** (0.76)

The attenuation model Akkar et al. (2014) provided higher estimates with relatively higher standard deviations for both case studies. This trend is consistent with the spectral accelerations and standard deviations presented for the two attenuation models in the second plot of Figure 2. Within attenuation, the model from Akkar et al. (2014), provided magnitudes in between **6.05**(0.78) and **5.85**(0.77) for the 1998 earthquake, and **7.10**(0.72) and **6.68**(0.76) for the 1980 earthquake. The use of epicentral distances or the attenuation model Ambraseys *et al.* (2005) resulted in relatively smaller standard deviations.

CONCLUSION

This study aimed at understanding the impact of different attenuation and source models in the final magnitude estimates. The expected values of magnitude were found in ranges consistent with magnitude estimates obtained with instrumental data, namely in the case of the attenuation model Akkar *et al.* (2014), with M_w=**5.96** ± 0.53 for the 1998 earthquake, and M_w=**6.91** ± 0.42 for the 1980 earthquake (confidence level of 95%). The epicentre source model presents relatively lower standard deviations for both earthquakes, while the source models presented relatively more accurate values of magnitude. The resulting distance distributions can partially explain the discrepancies found between the results obtained from assuming the "Epi1" and "Epi2" models, in the case of the 1998 earthquake, and between "Soeiro" and "GAR" damage datasets.

REFERENCES:

Ambraseys N.N., Douglas J., Sarma S.K. and Smit P.M. (2005) "Equations for the estimation of strong ground motions from shallow crustal earthquakes using data from Europe and the Middle East: horizontal peak ground acceleration and spectral acceleration", *Bull Earthquake Eng*, 3(1), 1-53.

Akkar S., Sandıkkaya M.A., Ay B.O. (2014) "Compatible ground-motion prediction equations for damping scaling factors and vertical-to-horizontal spectral amplitude ratios for the broader Europe region", *Bull Earthquake Eng*, 12(1), 517-47.

Borges J.F., Bezzeghouda M., Buforn E., Proc C., Fitasa A. (2007) "The 1980, 1997 and 1998 Azores earthquakes and some seismo-tectonic implications", *Tectonoph*, 435(1-4), 37-54.

Carvalho A.M., Sousa L., Oliveira C.S., Campos-Costa A., Nunes J.C., Forjaz V.H. (2001) "Seismic hazard for the central group of the Azores islands", *Boll Geof Teor App*, 42(1-2), 89-105.

Eisinger U., Gutdeutsche R., Hammerl C. (1992) "Historical earthquake research – an example of interdisciplinary cooperation between geophysicists and historians", *Abh Geol B-A*, 48(1), 33-50.

Estevão J.M.C., Oliveria C.S. (2012) Point and fault rupture stochastic methods for generating simulated accelerograms considering soil effects for structural analysis, *Soil Dyn and Earthq Eng*, 43(1), 329–341.

Estevão J.M.C., Carvalho A. (2014) Uncertainties in the stochastic simulation of earthquakes: the case of Azores. 5th JPEE; 2014 Nov 26-28; Lisbon, Portugal.

Ferreira T.M., Maio R., Vicente R. (2017) "Seismic vulnerability assessment of the old city centre of Horta, Azores: calibration and application of a seismic vulnerability index method", *Bull Earthquake Eng*, 15(7), 2879-99.

Matias L., Dias N.A., Morais I., Vales D., Carrilho F., Madeira J., et al. (2007) "The 9th of July 1998 Faial Island (Azores, North Atlantic) seismic sequence", *J Seismology*, 11(3), 275-98.

Ryu H., Kim J., Baker J. (2009) A Probabilistic method for the magnitude estimation of a historical damaging earthquake using structural fragility functions", *Bull Seismol Soc Am*, 99(2), 520-37.

Lucas A., Oliveira C.S., Guedes J.H.C. (1991) "Quantificação dos danos observados no parque habitacional e do processo de reconstrução", In: Oliveira CS, *et al.* (eds), *10 Anos após o sismo dos Açores de 1 de Janeiro de 1980*, GRA, LNEC, Lisbon, 667-742. (in Portuguese