Deaggregation of the Regional Seismic Hazard: City of Patras, Greece.

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Abstract: The study describes an example of geographical deaggregation of probabilistic seismic hazard analysis (PSHA) for a region of high seismic hazard potential: the city of Patras, Greece. First, the PSHA is carried out for the site of interest, based on various ground motion parameters such as: peak ground acceleration PGA, Arias Intensity (Ia), Spectrum Intensity (SI) and Spectrum Acceleration (Sa) computed at two different periods: 0.2sec and 1sec. Next, the PSHA deaggregation is performed and the results are shown into so called 4D or geographically deaggregation plots. These plots allow a rapid visualization of the source(s) which contribute the most to the total seismic hazard.

Key-Words: PSHA, geographical deaggregation, 4D deaggregation, arias intensity, spectrum intensity, pga, Spectrum Acceleration, attenuation relationship, Patras, Greece

1 Introduction

For performance based design as well as for many earthquake and/or geotechnical engineering analyses, site-specific time histories are desired. The selection of these time histories it is desirable to be based on a probabilistic seismic hazard (PSH) consistent with the seismicity of the region. PSHA aggregates ground motion contributions from all earthquakes of all the possible magnitudes, at all the significant distances from the site of engineering interest, as a probability by taking into account their frequency of occurrence. Therefore, the PSHA results are not representative of a single – design earthquake, as the relative contribution to the total hazard of the selected event at a given magnitude and distance is difficult to be appreciated. For a given site of engineering interest, the deaggregation of the PSHA results provides a tool to understand the relative contribution to the overall seismic hazard of each source. Precisely, the deaggregation process extracts the combinations of magnitude (M), source-to-site distance (R) and ε-epsilon value of the ground motion that contribute to the total hazard at a given return period. The ε-epsilon value represents a measure of the standard deviation by which an observed ground motion parameter differs from the mean ground motion parameter predicted from an attenuation relationship.[1] The hazard deaggregation portrays the design or control earthquake from either the mean or modal values of M and R only or ε as well. The probabilistic deaggregation methodology it is explicated in great detail on the studies of McGuire [2], Chapman [3], and Bazzurro and Cornell [4].

The latest study gave an improved view and an additional insight to the probabilistic hazard deaggregation by introducing so called geographically deaggregation or 4D deaggregation. Harmsen and Frankel [5] implemented the 4D deaggregation to spatial illustrate the seismic hazard in the United States. The study was extended to assist the deaggregation analysis reported in the early of Harmsen et al.[6]. The major goal of these studies was the identification of the dominant hazard sources for major cities in the United States. The deaggregation results were exhibited as maps with vertical bars whose heights were proportional to the contribution that each geographical cell makes to the ground motion exceedance hazard.

The geographical deaggregation for the selected cities have been performed for 0.2 and 1 second pseudo spectral acceleration at 2% and 10% probability of exceedance in 50 years. Similar geographical deaggregation studies were conducted by Halchuck and Adams [7] for major Canadian cities; and by Montilla et al. [8] for important cities in Spain. Moreover, the hazard deaggregation became the standard output of PSHA analysis, such as the U.S. Geological Survey hazard maps.

Following the aforementioned studies and based on the geographically deaggregation methodology the present study presents the spatial deaggregation for Patras city. Greece. Patras city is located in Central Greece, and is bounded by most seismically active zones. The city of Patras experienced important damage although the earthquakes were small to moderate magnitude earthquakes, such as the earthquake of 14 July 1993. Although the earthquake was moderate, local magnitude 5.1 and maximum recorded peak ground acceleration was 0.2g, the damage consequences were significant. Due to the aforementioned statements, to perform a seismic hazard analysis for Patras city is timely. Moreover, the site-specific seismic hazard analysis would incorporate the recent developed new attenuation relationships developed for the territory of Greece, based on various engineering ground motion parameters.[9]

The ground motion parameters selected to reflect the hazard are peak ground acceleration (PGA), acceleration response spectra (S_a) computed for a fixed damping value of 5% and for two fixed periods (0.2 and 1 sec), Arias intensity (I_a) and Spectrum Intensity (SI). The acceleration parameters are well known parameters worldwide used in the hazard analysis. Lately, in the framework of PSHA both Arias intensity and Spectrum Intensity have become additional parameters to illustrate the seismic hazard. [10] [11] [12]. Therefore, the influence of these later parameters to the seismic hazard will be under the observation in this study, as a second aim. Herein, the seismic hazard is carried out for the selected city considering various ground motion parameters estimated for 10% probability of exceedance in 50 years (475-years mean return period).

On the other hand, the major aim of this study was the deaggregation of the seismic hazard for the city of Patras. The geographically deaggregation is presented herein, for five different ground motion parameters for the selected city.

2 Seismic Hazard Model

The probabilistic seismic hazard analysis (PSHA) is site specific through definition. At the site of engineering interest the PSHA is expressed in terms of exceedance probability per unit time period, of a given measure of ground motion intensity by integrating the contributions of available geological, seismological and statistical information. The annual hazard curves are the result of the probabilistic hazard analysis for a site; for a given region the hazard maps can be obtained by simultaneously hazard analysis for many sites in the selected region and constructing iso-maps for specified ground motion levels corresponding to given return periods.

First, the PSHA methodology [13] was applied to the region of interest - Patras City following the next assumptions.

The selected shallow seismic source zones were used and the geographical distribution of these zones is presented on Fig.1.For the seismic zones considered, the slope (b-value) and the intercept (a-value) were reported in Table1 of Papaioannou and Papazachos [14].

The set of predictive equations developed for engineering ground motion parameters and proposed by Danciu and Tselentis [9] was selected herein. The selected predictive equations are based on strong motion data primary from Greek shallow earthquakes. The predictive equation model adopted to represent the attenuation of the ground motion has the following form:

$$\log_{10}(Y_{ij}) = a + bM_i - c\log_{10}\sqrt{R_{ij}^2 + h^2} + eS + fF + \varepsilon_{ij} \qquad (1)$$

where Y_{ij} is the response variable (the arithmetic average of the two horizontal components) from the j^{th} record of the i^{th} event, M_i is the moment magnitude of the i^{th} event, R_{ij} is the epicentral distance from the i^{th} event to the location, h is the "fictitious" focal depth obtained from the regression analysis, and ε_{ij} is the error term for the j^{th} records from the i^{th} earthquake.

The error term in equation (1) is normally distributed with zero mean and standard deviation σ^2. The error term, accounts the ground motion variability and has an important contribution to the final results of the probabilistic seismic hazard analysis. Neglecting the ground motion variability would produce lower values on the PSHA results [15, 16]. The coefficients of the predictive equations are presented on the Table 1.

The dummy variables *S, F* refer to the site classification and fault mechanism, respectively. The proposed attenuation function are valid for earthquakes of moment magnitude (in the present study, referred as M_w) M_w = 4.5 to 7 and epicentral distance (in the present study, referred as *R*) up to 136 km.

The Cornel-McGuire methodology incorporated in SEISRISK III [17] computer code was adopted in the present analysis. The software allows for earthquake location uncertainty by considering location normally distributed with standard deviation; and ground motion variability is incorporated assuming a log-normal distribution about the mean, with a constant standard deviation σ^2.

	$\log_{10}(Y_{ij}) = a + bM_i + c\log_{10}\sqrt{R_{ij}^2 + h^2} + eS_o + fF_o + \varepsilon_{ij}$								
	a	b	c	h	ϵ	f	τ	σ	ε_{total}
PGA	0.883	0.458	-1.278	11.515	0.038	0.116	0.109	0.270	0.291
S_a(0.2 sec)	1.339	0.477	-1.368	14.302	0.024	0.103	0.103	0.287	0.304
S_a(1 sec)	-1.517	0.799	-1.113	9.128	0.016	0.050	0.156	0.314	0.351
I_a	-2.663	1.125	-2.332	13.092	0.028	0.200	0.205	0.482	0.524
SI	-1.577	0.651	-1.029	9.157	0.031	0.069	0.116	0.294	0.316

Table 1: Coefficients of the predictive equations (attenuation laws) selected for the present study.

The above methodology has been applied to the city of Patras, and the estimated ground motion parameters computed for 10% probability of exceedance in 50 years exhibit the following values: PGA = 280 cm/sec^2; Sa(0.2sec) = 25 cm/sec^2; Sa(1sec) = 65 cm/sec^2; I_a = 115 cm/sec; SI = 65 cm. It is worth to mention here, that the estimated values of the selected ground motion parameters are taking into account the uncertainty in the ground motion prediction. We have investigated the sensitivity of accounting the standard deviation of the predictive equations for the selected parameters and these results have shown that the estimated values are increased of almost 15%. In addition, these ground motion parameters were estimated for rock site conditions, and considering three types of fault mechanism: normal, thrust and strike-slip.

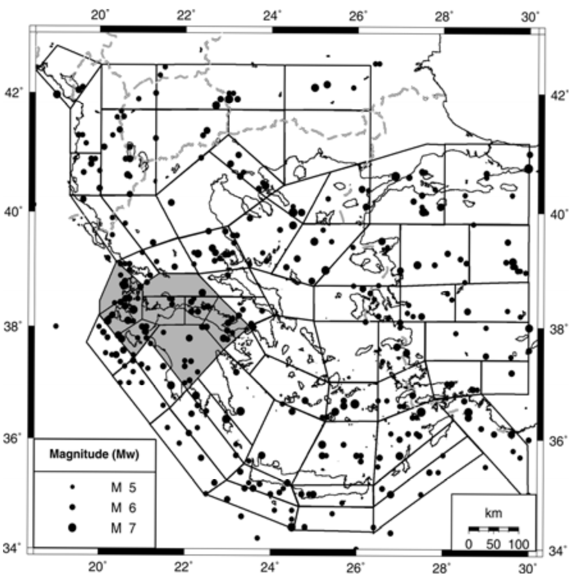

Fig.1.Geographical distribution of the major Shallow earthquakes (M_w>5) and the selected seismogenic sources

Next, the PSHA results were deaggregated in different types of bins to determine and understand the relative contribution of sources to the overall hazard results at the given site- Patras city. The integration of the PSHA is carried out and the final results are presented often in terms of 2D M-R bins or 3D M-R-ε bins. Herein the geographical deaggregation or 4D deaggregation methodology described in great details in the study of Bazzurro and Cornell [4] and implemented in the computer package rms [18] was employed in the present study. Additional, the 3D deaggregation or the joint probability mass function (PMF) of M–R–ε is computed and reported for both mean and modal values. The results of the deaggregation analysis are presented as a typical maps of the region and they permit to rapid identify and understand the sources dominating the hazard.

3 Deaggregation Results

The PSHA deaggregation analysis was carried out for Patras city, for five different ground motion parameters and the exceedance probability of 10% in 50 years. The obtained deaggregation results are plotted in terms of latitude/longitude on the Fig. 2 to 6.

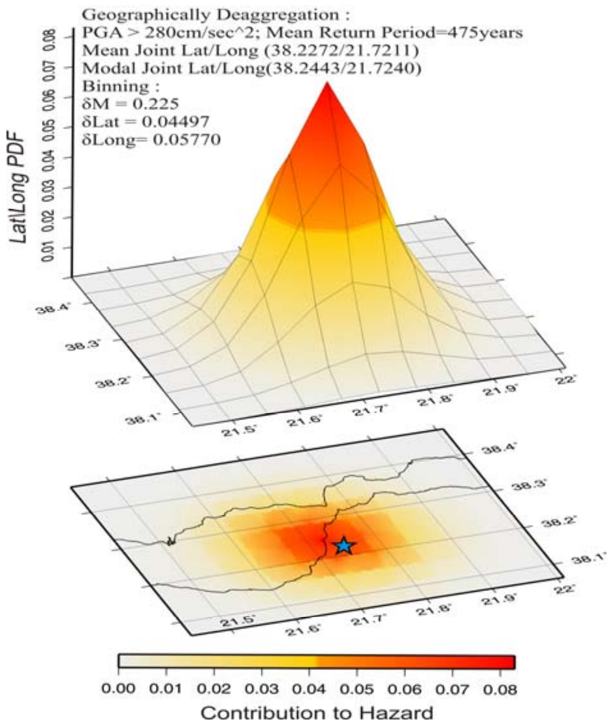

Fig.2.Geographically deaggregated seismic hazard for a site in Patras for 10%in 50years probability of exceedance for PGA

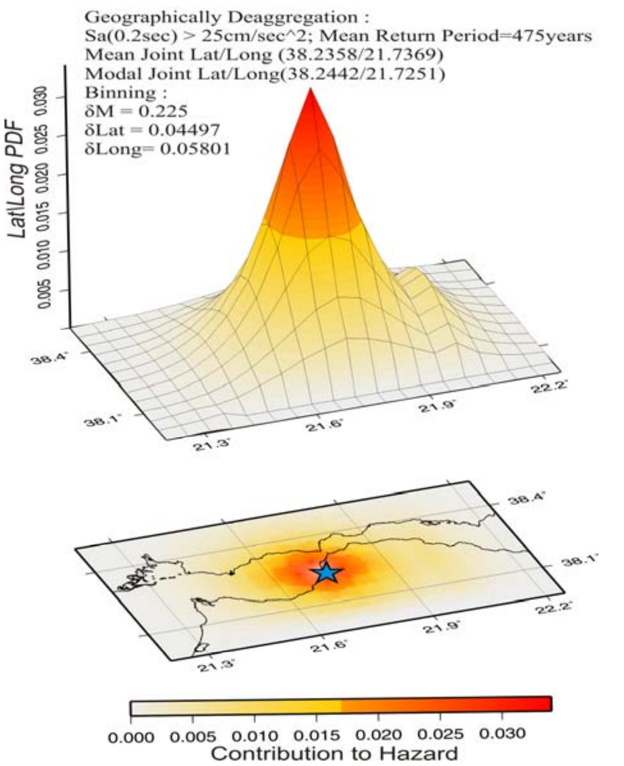

Fig.3. Geographically deaggregated seismic hazard for a site in Patras for 10%in 50years probability of exceedance for S_a(0.2sec)

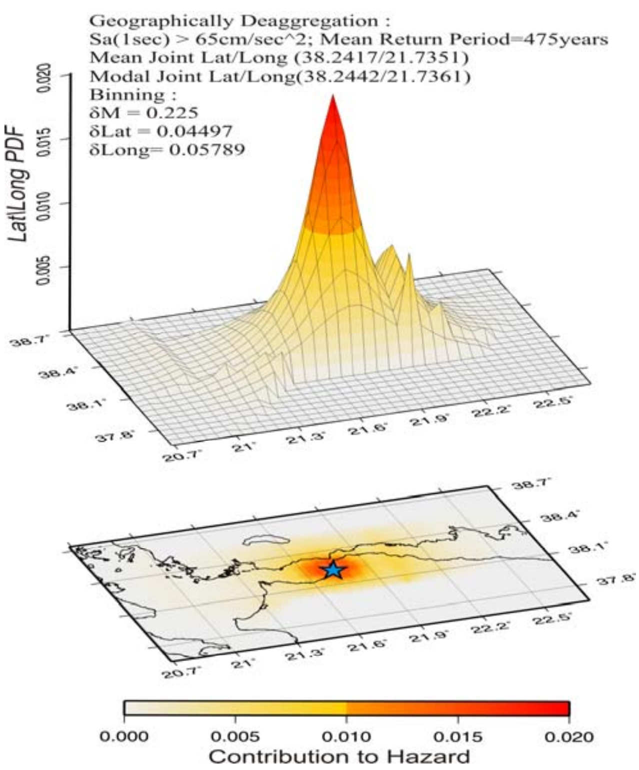

Fig.4. Geographically deaggregated seismic hazard for a site in Patras for 10%in 50years probability of exceedance for S_a(1sec)

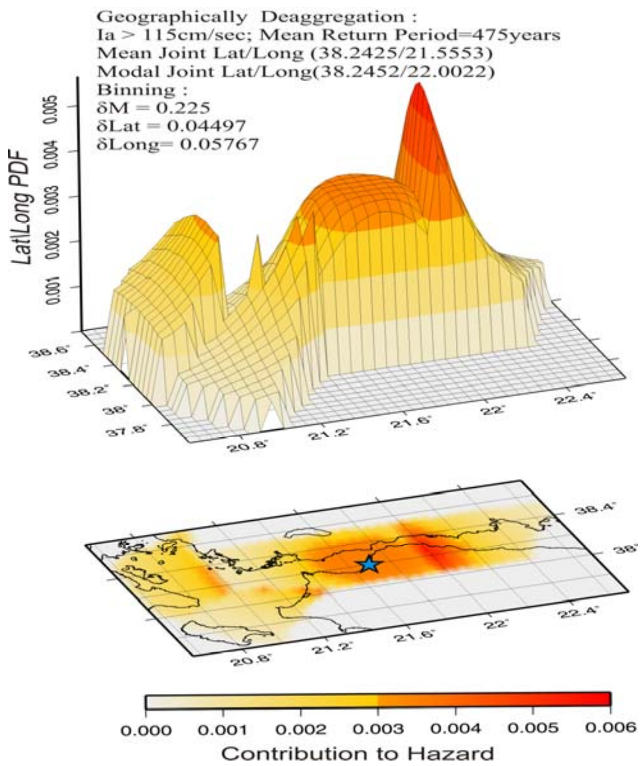

Fig.5. Geographically deaggregated seismic hazard for a site in Patras for 10%in 50years probability of exceedance for I_a

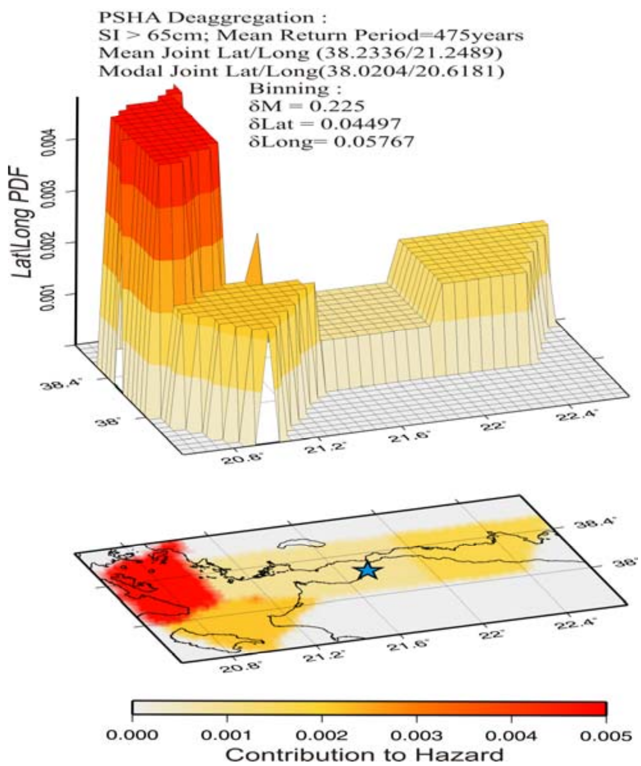

Fig.6. Geographically deaggregated seismic hazard for a site in Patras for 10%in 50years probability of exceedance for SI

Additional the 3D deaggregation or the joint probability mass function (PMF) of M–R–ε results are reported for both mean and modal values in Fig.7 (a-e). With the aim of 3D deaggregation results and the geographical deaggregation plots, the identification of the relative contribution to the hazard might be efficient.

Fig. 2 shows the geographically deaggregated seismic hazard for a site in Patras city, for PGA having 10% probability of exceedance in 50 years (corresponding to a mean return period equal to 475years). In this figure it can be observed that the hazard is dominated by the local sources surrounding the selected site. The identified sources with the higher contribution are described by moderate magnitude at very near distance. These results combined with those presented in the Fig.7.a identify the contribution of moderate to high magnitude events at small distances. The mean and modal magnitude values are comparable (about 6.6-6.9); similar for the modal mean and modal distance values (about 10km).

Fig. 3 and 4 illustrate the relative contribution for S_a (0.2 sec) and S_a (1sec) corresponding to 10%50years for the selected site. Similar with the PGA based deaggregation map, the geographical deaggregation emphasize the relative contribution of local sources to the overall hazard. Moreover, from these maps can be detected that the relatively high frequency ground motions are likely to emphasize the closest local sources. The area describing the local sources is decreasing from the intermediate frequency (1sec) toward the PGA. These local sources are most likely dominated by more frequent (b=0.96), high magnitude, closer earthquakes. Although, the long period structures is thought that are more susceptible to the large and far earthquakes, comparing the results for S_a (0.2 sec) and S_a (1sec) herein this statement is not evident. The plots presented in the Fig.7b and 7c show the same distance (25km) and decreased magnitude with the increased period.

The geographically deaggregation presented in the Fig.5 reflects the deaggregation results for Arias Intensity. A closer examination of the geographically deaggregation results indicated that the seismic hazard based on I_a is predominated by both local and regional sources. The probability mass function presented in the Fig.7d exhibit a bimodal distribution, one spike for short-distances earthquakes and the other for moderate-distance earthquakes. The regional sources are dominated by the source located near to the Aegion fault. The modal joint latitude-longitude (lat = 38.2452 / Long= 22.0022) is comparable with the location of the earthquake of 15 June 1995 (lat = 38.27 / Long= 22.15). A local magnitude of 6.5 was reported for Aegion earthquake and the assigned earthquake intensity in Patras was I=VMM. The regional source identified is described by frequent (b=0.93), high magnitude and moderate distance to the considered site.

Fig.6 presents the geographically deaggregation plots for SI. In this case the hazard is described by regional sources, characterized by moderate magnitude earthquakes occurred at large distances.

The zone with the most contribution to the hazard is described by frequent (b=0.99), high magnitude, large distance to the considered site. This statement is evident in the Fig.7.e, as can be observed the probability density function seems to be unimodal and highlights the contribution of distant earthquakes.

Comparison of the geographical deaggregation results for the selected ground motion parameters, shown that these parameters are appropriate to describe the selected scenarios, for example, Arias intensity emphasize both high magnitude at small or large distance event(s), while Spectrum Intensity highlights the contribution of large and distant event(s).

This illustrates that multiple scenarios earthquakes, with different hazard parameters need to be considered in PSHA.[19]

4 Conclusion

In the present study, the geographically deaggregation of the seismic hazard is performed in order to identify the sources with specific faults that have major contribution to the most important contribute to ground motion exceedance at the selected site:-Patras city. The implication for the seismic hazard is that additional to the conservative PGA and S_a, some alternative ground motion parameters, such as Arias Intensity or Spectrum Intensity should be considered. The use of such parameters would better describe the hazard scenarios, by identifying either the local and distant sources, or large magnitude events.

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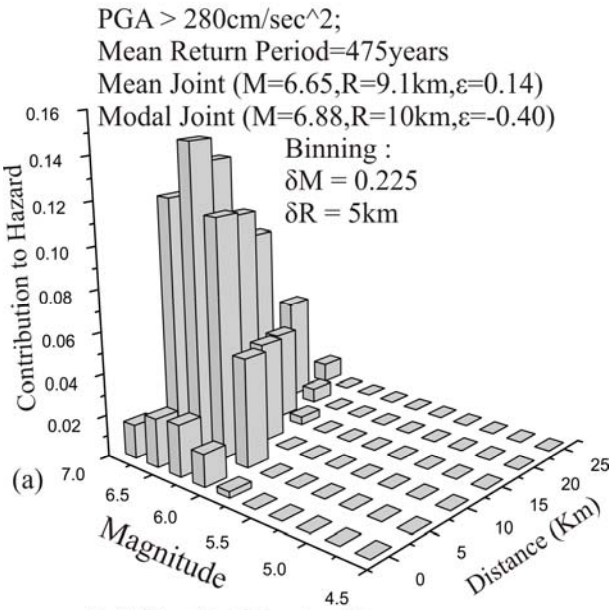

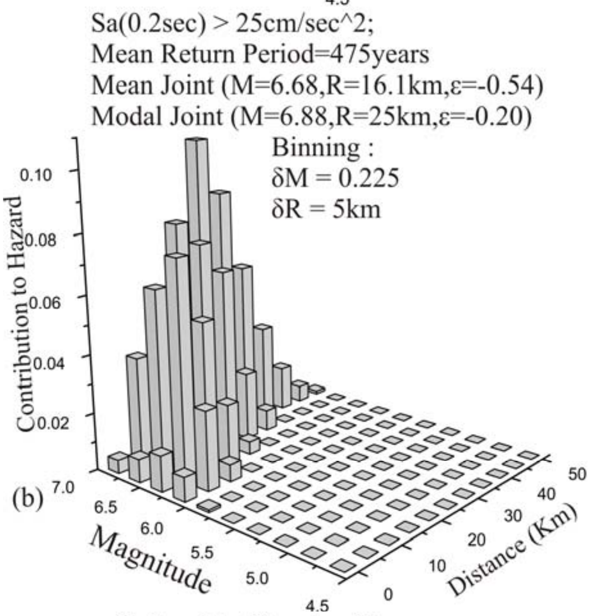

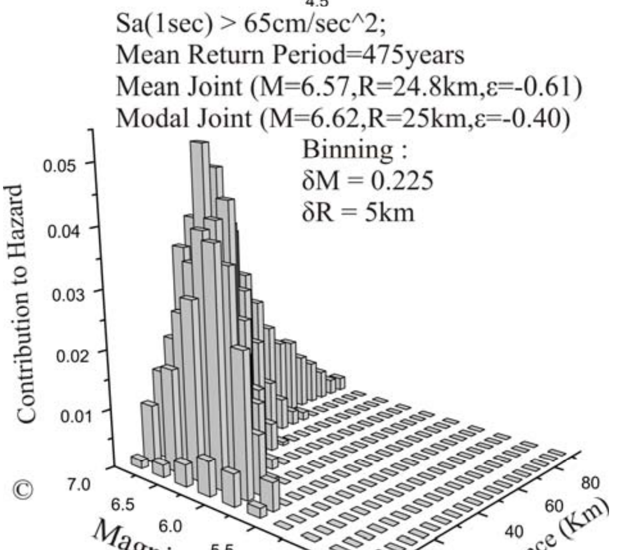

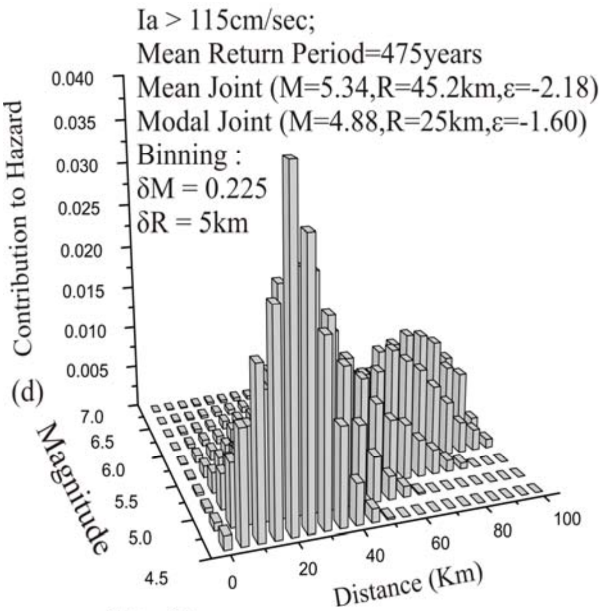

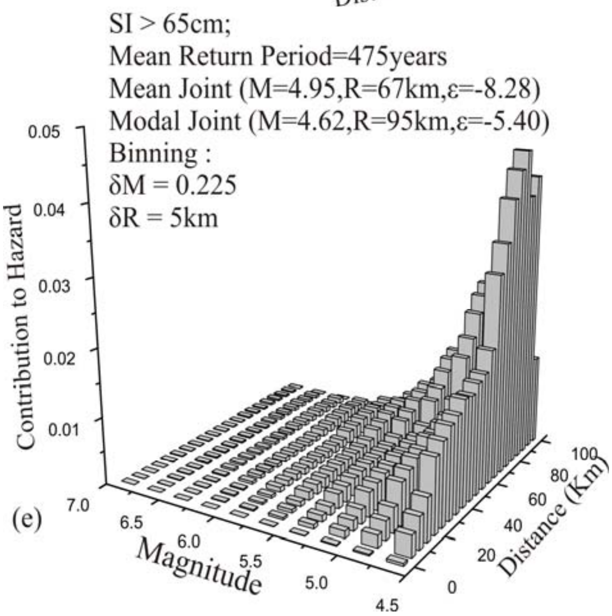

Fig.7 Deaggregated seismic hazard for a site in Patras for 10%in 50years probability of exceedance for: (a) PGA; (b) Sa (0.2sec); (c) Sa (1sec); (d) I_a; (e) SI.

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