UNIFORM HAZARD SPECTRA FOR CITIES IN ROMANIA

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ABSTRACT:
In this paper the issue of obtaining uniform hazard spectra through probabilistic seismic hazard analysis for various cities in Romania is addressed. The seismic hazard at the sites is mainly induced by Vrancea subcrustal seismic source. Nevertheless, the contribution to hazard of the crustal sources is also investigated. The seismicity parameters are determined using Vrancea earthquake catalogue recently revised by National Institute for Earth Physics of Romania and provided to the Technical University of Civil Engineering of Bucharest within *BIGSEES* Project financed by the Romanian National Authority for Scientific Research. Two ground motion prediction equations (GMPEs) are used in the seismic hazard analysis for subcrustal and crustal seismic sources respectively. The probabilistic seismic hazard analysis is performed for peak ground acceleration as well as for response spectral acceleration at different spectral periods of engineering interest. The obtained Uniform Hazard Spectra (UHS) are compared and discussed.

Keywords: Romania, probabilistic, seismic, hazard, analysis

1. INTRODUCTION

The seismic hazard analysis can be approached in a deterministic or a probabilistic manner. The probabilistic seismic hazard analysis has the advantage of fully integrating all the aleatory uncertainties arising from seismicity and ground motions parameters expected in a future earthquake on a particular site. In this paper the probabilistic seismic hazard assessment is performed for various cities in Romania. The hazard parameters are the peak ground acceleration and the response spectral accelerations at various periods of vibration of interest. The site-dependent Uniform Hazard Spectra (*UHS*) for selected cities in Romania is obtained. The sites are selected so that to be influenced by both, Vrancea intermediate depth source and shallow depth seismic sources. A complete probabilistic seismic hazard analysis framework, as described in (Kramer, 1995; Reiter, 1990; McGuire, 1999, 2004), requires information on the seismicity as well as on the ground motions prediction models appropriate for the seismo-tectonic context under investigation. The seismic hazard curve for a particular site under investigation is obtaining by integrating all the probabilistic information on the magnitude and location of the earthquakes and on the values of the ground motion parameter of interest expected to occur at a particular site, given all the possible combinations of magnitudes and locations of earthquakes. The combination of the probabilistic information previously mentioned is performed with total probability formula in a consistent manner given in (Kramer, 1996; Reiter, 1990; McGuire, 1999, 2004). All these aspects will be discussed in the followings given the Romanian seismo-tectonic context.

2. INPUT DATA FOR PROBABILISTIC SEISMIC HAZARD ANALYSIS

Romania is a seismic-prone country subjected to earthquakes occurring from both shallow and intermediate depths sources. Most of the seismic hazard of Romania is contributed by Vrancea intermediate depth (subcrustal) seismic source (Lungu et. al., 2000), (Marmureanu et. al., 2010), (Sokolov et. al., 2009). Complementary, thirteen shallow depth seismic sources from Romania, Bulgaria and Serbia are contributing at a smaller or a larger extent to the overall seismic hazard affecting Romanian territory, Figure 2.1. The contours of the seismic source's areas are refined starting from the definition given in (Radulian et al, 2000) to take into account the distribution of recent seismicity, keeping the same stress field characteristics. The contours of the seismic sources are provided by National Institute for Earth Physics, *INFP* as input data for the *BIGSEES* Project.

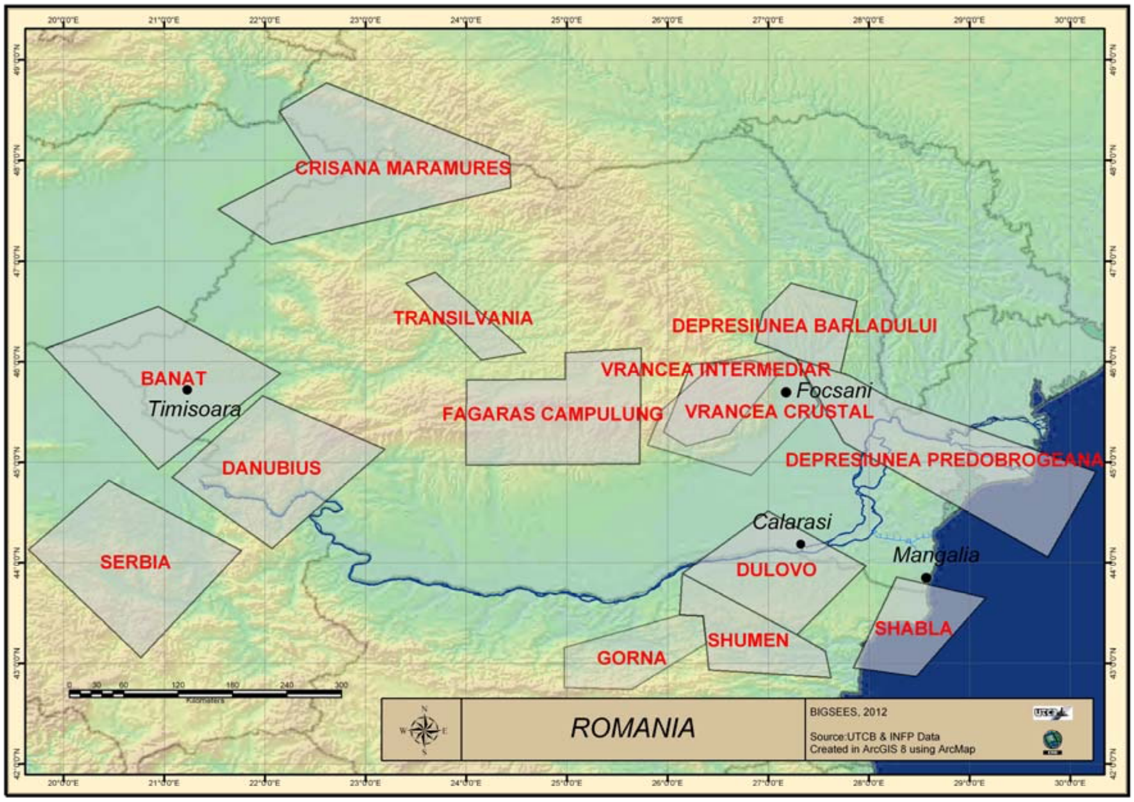


Figure 2.1. Sources contributing to the seismic hazard of Romania and the cities selected for PSHA

The seismicity parameters α and β (or a and b) are reported in Table 2.1 for the 20th century events exceeding moment magnitude 5.0.

Table 2.1. Seismicity parameters for Vrancea subcrustal source

20th century; $M_{\mathrm{w,min}} = 5.0$			
α	β	a	b
10.3164	1.9589	4.4803	0.8507

The empirical and analytic mean annual rates of earthquakes exceeding a certain value of moment magnitude are given in Figure 2.2 for the following seismic sources: Vrancea subcrustal (intermediate depth), Vrancea crustal (shallow depth), Shabla (shallow depth) and Banat (shallow depth). The hypocenters of earthquakes are considered to be equally probable distributed within the seismic sources. The uniform distributions of hypocenters does not translate in a uniform distribution of both epicentral and hypocentral distances. Consequently, the probability distributions of source to site distances are investigated within the seismic hazard analysis.

The ground motions prediction equations initially considered for the probabilistic seismic hazard analysis are the ones highlighted in (Delavaud et al., 2012), where four GMPEs selected within the

SHARE regional project of Global Earthquake Model (GEM) are recommended for Vrancea subcrustal seismic source. The selection of one of the four GMPEs (Zhao et. al., 2006), (Atkinson & Boore, 2003), (Youngs et. al., 1997) and (Lin & Lee, 2008) is performed according to the grading procedure given in (Scherbaum et al, 2004).

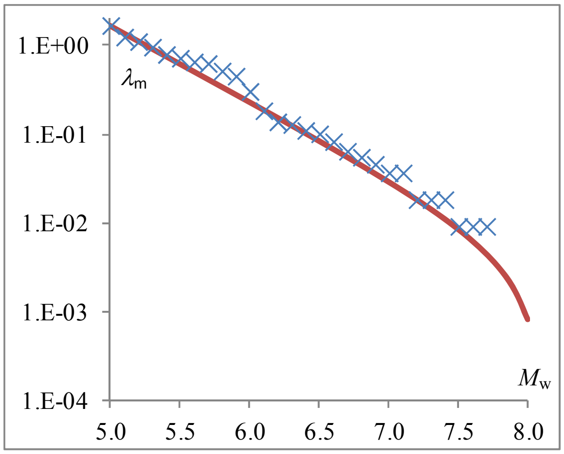


Figure 2.2.a. Vrancea subcrustal source. Mean annual rates of earthquakes, λ_m – empiric vs. analytic; $M_{w,min}$=5.0

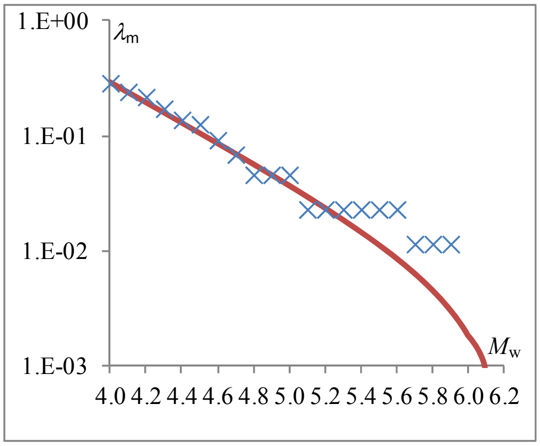


Figure 2.2.b. Vrancea crustal source. Mean annual rates of earthquakes, λ_m – empiric vs. analytic; $M_{w,min}$=4.0

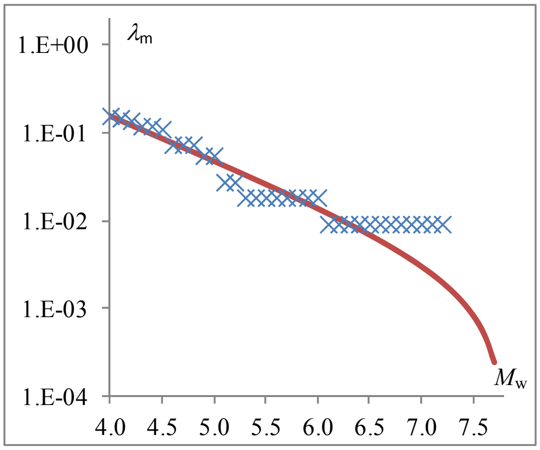


Figure 2.2.c. Shabla crustal source. Mean annual rates of earthquakes, λ_m – empiric vs. analytic; $M_{w,min}$=4.0

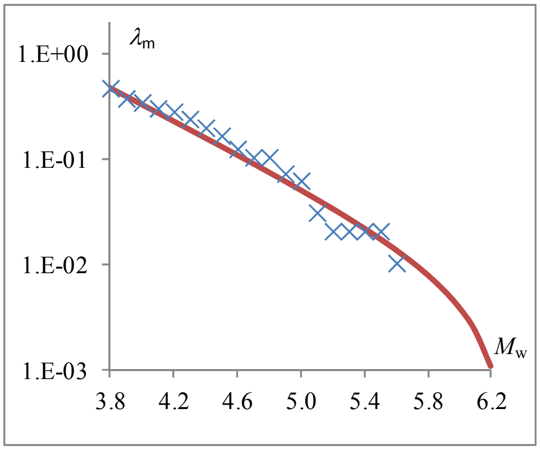


Figure 2.2.d. Banat crustal source. Mean annual rates of earthquakes, λ_m – empiric vs. analytic; $M_{w,min}$=3.8

A strong ground motion database of 217 horizontal components of strong ground motions recorded in Romania, Bulgaria, Republic of Moldova and Serbia during 7 intermediate-depth Vrancea seismic events is selected for the grading procedure. The characteristics of the 7 earthquakes (date, epicenter position, moment magnitude - M_W and focal depth - h are given in Table 2.2 (from www.infp.ro). The numerical distribution of the 217 horizontal components for each earthquake is also given in Table 2.2.

The grading scheme of ground motion prediction equations developed in (Scherbaum et al., 2004) is grounded on the values of several goodness-of-fit measures related to the normalized residuals: (i) the mean (MEANNR), median (MEDNR) and standard deviation (STDNR) of the normalized residuals and (ii) the median of likelihood LH (MEDLH). The estimators of standard deviation σ of the previous statistical measures are obtained with the “delete-1” jackknife resampling procedure (Wu, 1986).

Table 2.2. Characteristics of the considered earthquakes (www.infp.ro)

Earthquake date	Lat. N	Long. E	M_W	*h* (km)	No. of components
04.03.1977	45.34	26.30	7.4	109	6
30.08.1986	45.52	26.49	7.1	131	72
30.05.1990	45.83	26.89	6.9	91	87
31.05.1990	45.85	26.91	6.4	87	32
27.04.2004	45.84	26.63	6.0	105	12
14.05.2005	45.64	26.53	5.5	149	4
25.04.2009	45.68	26.62	5.4	110	4

The grading of GMPEs is made on a scale from A to D, where D which means an unacceptable model up to A that corresponds to the best fitted model. The overall analyses grade the (Youngs et. al., 1997) attenuation model developed for soil conditions as a grade B model for Vrancea subcrustal source, the highest grade of all four GMPEs. The overall values of grading parameters for (Youngs et. al., 1997) GMPE are given in Table 2.3. The (Youngs et. al., 1997) GMPE developed for soil condition is assumed in the study based on the results of (Trendafiloski et. al., 2009) that classify the soil conditions in classes C and D (NEHRP, 1994) for the sites where seismic records highlighted in Table 2.2 are obtained.

Table 2.3. Overall grading parameters for Youngs et. al., 1997 GMPE

MEANNR	*σ*	*MEDNR*	*σ*	*STDNR*	*σ*	*MEDLH*	*σ*	*Grade*
0.228	0.024	0.313	0.011	0.843	0.021	0.561	0.005	B

A comprehensive image of the fit between the predicted data and the observed data is the normalized representation of data, shown in the Fig. 2.3. The procedure given in (Zhao et. al., 2006) requires the normalization of recorded data for a generic seismic event. The generic earthquake considered is a M_W = 7 event, produced at 100 km depth.

For all the crustal sources analyzed in the study the GMPE of (Ambraseys et. al., 2005) is considered. This attenuation relationship is developed for crustal seismic events using a database of strong ground motions recorded in Europe and Middle East. The model takes into account the source mechanism and it is developed for both, soft soil conditions and stiff soil conditions.

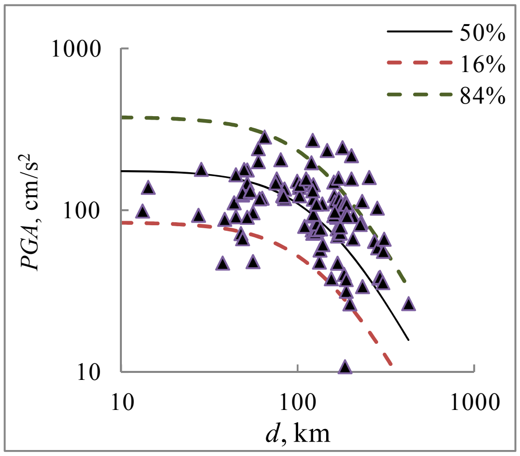


Figure 2.3.a. Comparison of predicted *PGA*'s with the recorded *PGA*'s normalized to a M_W =7 earthquake at 100 km focal depth; *d* is the epicentral distance

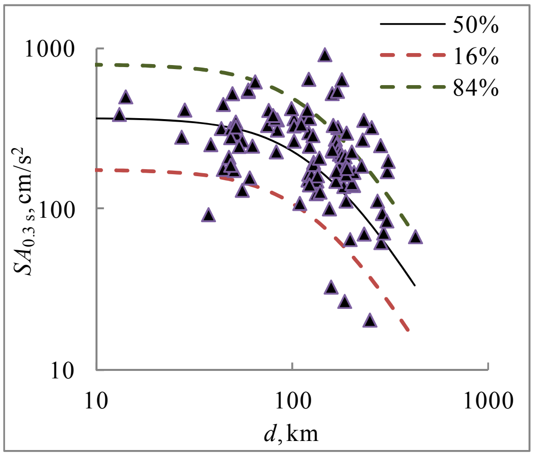


Figure 2.3.b. Comparison of predicted pseudo spectral acceleration at *T* = 0.3 s with the recorded pseudo-spectral accelerations normalized to a M_W =7 earthquake at 100 km focal depth; *d* is the epicentral distance

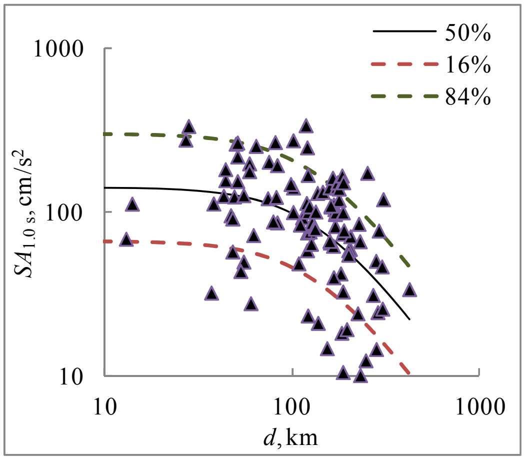


Figure 2.3.c. Comparison of predicted pseudo spectral acceleration at $T = 1.0$ s with the recorded pseudo-spectral accelerations normalized to a $M_W = 7$ earthquake at 100 km focal depth; d is the epicentral distance

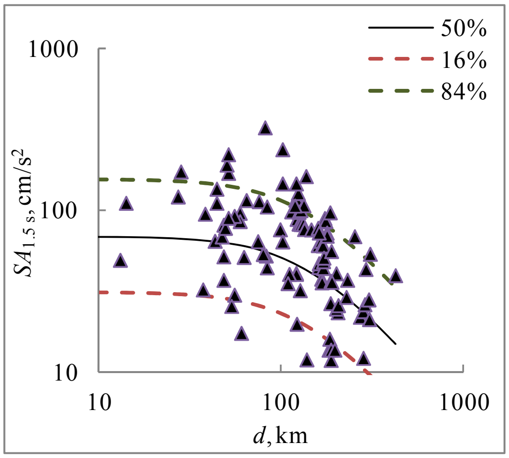


Figure 2.3.d. Comparison of predicted pseudo spectral acceleration at $T = 1.5$ s with the recorded pseudo-spectral accelerations normalized to a $M_W = 7$ earthquake at 100 km focal depth; d is the epicentral distance

3. PROBABILISTIC SEISMIC HAZARD ANALYSIS RESULTS

The Probabilistic Seismic Hazard Analysis (*PSHA*) is a consistent approach that integrates over all seismic events likely to occur and ground motions likely to affect a given site in order to estimate the mean frequency of exceedance of any given ground motion parameter at that site (Bazzurro & Cornell, 1999). The frequency γ of exceedance of a given ground motion parameter y is obtained by summing the products of the probabilities of all possible combinations of magnitudes and source-to-site distances and the associated exceedance probabilities of ground motion parameter y, through the total probability formula (Cornell, 1968).

The topic of uniform hazard spectra in Romania is firstly approached and discussed in (Lungu et. al., 1994). In this paper, four cities - Focsani, Timisoara, Mangalia and Calarasi, affected by earthquakes originating from Vrancea intermediate-depth source are selected for performing the probabilistic seismic hazard analysis (Figure 2.1). In addition, the selected cities are affected as well by seismic hazard from shallow depth sources, as follows: Focsani by Vrancea source, Timisoara by Banat source, Mangalia by Shabla source and Calarasi by both Dulovo and Shabla sources. The probabilistic analysis is discriminating the seismic hazard against sources and is aggregating the seismic hazard for all the sources considered to affect a particular site. The results of the *PSHA* in terms of hazard curves for peak ground acceleration and pseudo-spectral accelerations at spectral period $T = 0.5$s and uniform hazard spectra UHS are given in the following, for the selected cities. The computations are performed according to the PSHA methodology given in (Kramer, 1996; Reiter, 1990; McGuire, 1999, 2004) using MATLAB-based developed routines. The map of Romania and the seismic sources are covered with a grid of points spaced at 0.1 degrees of latitude and longitude, respectively. The input data on seismicity and on GMPEs are according to the details given in Chapter 2. The computations are performed using $-2 \leq \varepsilon \leq 2$, where ε is the number of logarithmic standard deviations by which the logarithm of the ground motion amplitude deviates from the mean value of the logarithm of the ground motion amplitude.

The hazard curves for the selected cities for peak ground acceleration and for a spectral period of $T = 0.5$ s are shown in Fig. 3.1 and Fig. 3.2, respectively. The graphs show the hazard curves obtained from crustal sources and from the Vrancea subcrustal source, as well as the overall hazard curve.

The Uniform Hazard Spectra (*UHS*) for the four selected cities for two Mean Return Intervals (*MRI*)

MRI = 225 years (respectively, 20% exceedance probability in 50 years) and *MRI* = 475 years (respectively, 10% exceedance probability in 50 years) are shown in Figure 3.3.

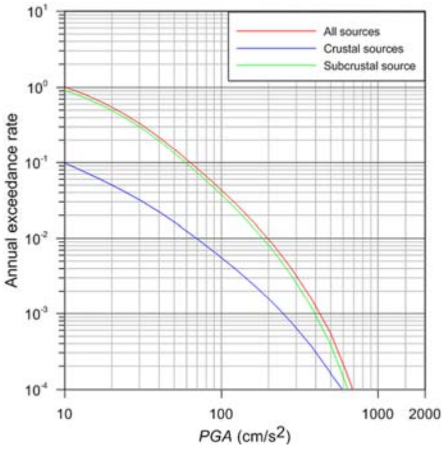


Figure 3.1.a. Calarasi - Hazard curve for *PGA*

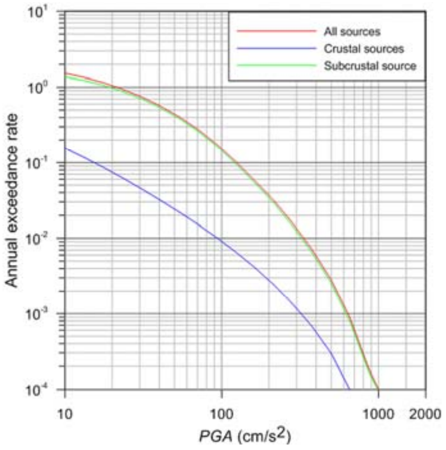


Figure 3.1.b. Focsani - Hazard curve for *PGA*

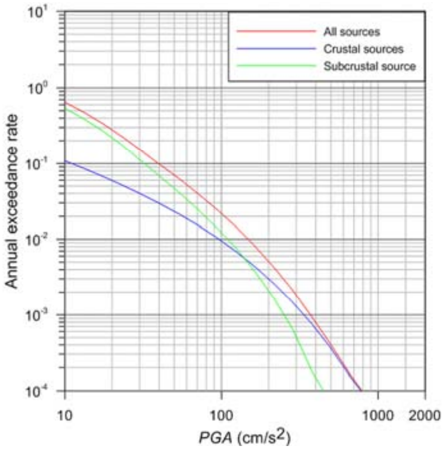


Figure 3.1.c. Mangalia - Hazard curve for *PGA*

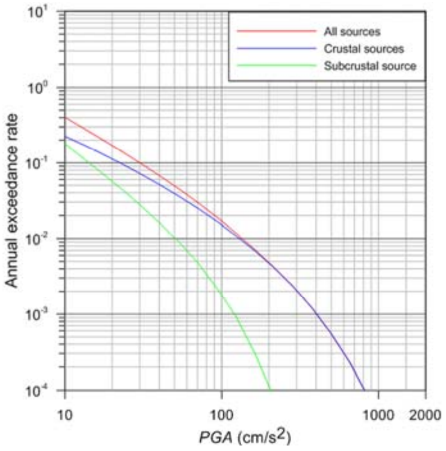
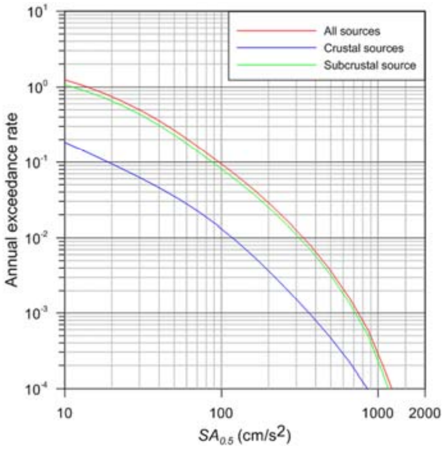


Figure 3.1.d. Timisoara - Hazard curve for *PGA*



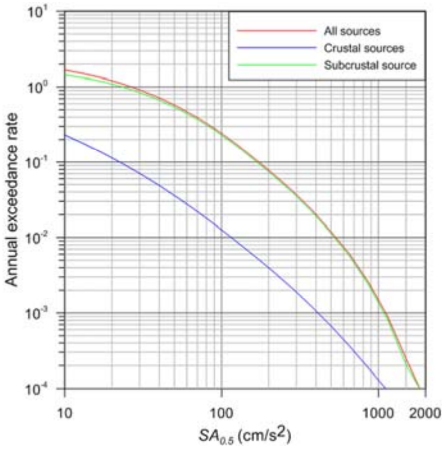


Figure 3.2.a. Calarasi - Hazard curve for *SA* at *T* = 0.5s **Figure 3.2.b.** Focsani-Hazard curve for *SA* at *T* = 0.5s

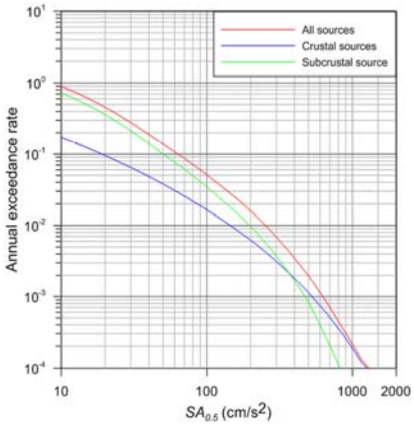


Figure 3.2.c. Mangalia-Hazard curve for *SA* at *T* = 0.5

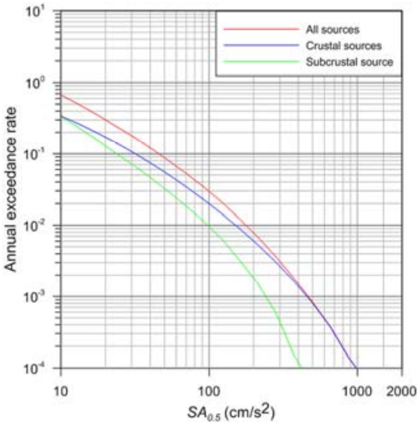


Figure 3.2.d. Timisoara-Hazard curve for *SA* at *T* = 0.5s

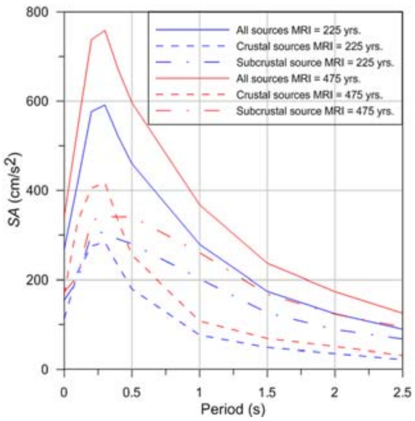


Figure 3.3.a. *UHS*s for Calarasi

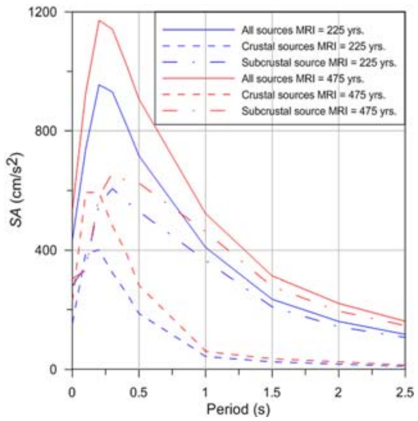


Figure 3.3.b. *UHS*s for Focsani

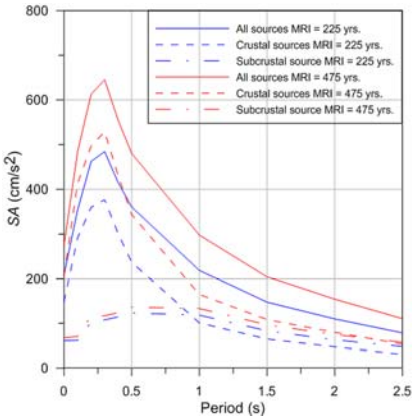


Figure 3.3.c. *UHS*s for Mangalia

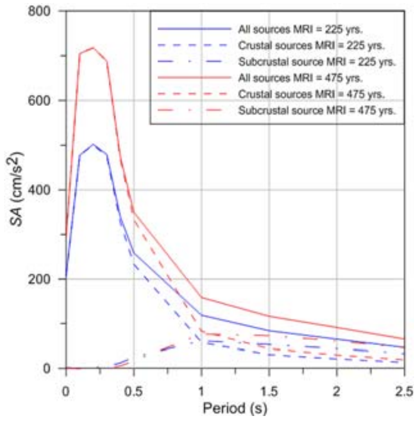


Figure 3.3.d. *UHS*s for Timisoara

4. CONCLUSIONS

The 20% exceedance probability in 50 years values of *PGA*s in the selected cities (Figure 3.2) are in line with the values provided in the revision of the Romanian Seismic Design Code P100-1. The *UHS*s corresponding to 20% exceedance probability in 50 years are consistent with the Romanian code-based elastic response spectra. Nevertheless, any comparison between UHS and code-based elastic response spectrum is futile since they are conceptually different. From Figure 3.3 one can notice that for Calarasi and Focsani the subcrustal source is controlling the *UHS*s, while for Timisoara and Mangalia the crustal sources are controlling the *UHS*s up to a spectral period T = 1.0 s; at longer spectral periods the contribution of the subcrustal source to the seismic hazard becomes prevalent. This previous remarks are explained by the different source-to-site distances and seismicity of the sources.

ACKNOWLEDGEMENT

Funding for this research was provided by the Romanian National Authority for Scientific Research (ANCS) under the Grant Number 72/2012. This support is gratefully acknowledged.

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