Sensitivity Analysis of Probabilistic Seismic Hazard to Ground Motion Models: Case of Algiers Region and Conditional Mean Spectrum

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SUMMARY:
Algeria has suffered frequently from destructive moderate to strong earthquakes as it located between the African and Eurasian tectonic plates. Recent seismotectonics and seismic hazard studies show that the northern part is highly prone to seismic activity, while important facilities are located in Algiers the capital. This paper deals with the evaluation of the seismic hazard for Algiers region by using the probabilistic approach (PSHA).
Based on a recent developed sismotectonic model for the considered region, a seismic hazard analysis is performed and a deaggregation procedure is used to identify the distribution of scenarios (in term of magnitude M and distance R) that contribute to exceedance of a given spectral acceleration (*Sa*) level. Moreover, one extends the deaggregation in order to calculate the contribution of multiple GMPMs, and describe the epistemic uncertainties from multiple ground motion models. For this purpose, recent GMPMs developed in the world for similar sismotectonic context are selected.
An associated conditional mean spectrum (CMS) with a specific GMPM is calculated as it is considered as being the most appropriate target spectrum for selecting ground motions as input for dynamic analysis.

Keywords: PSHA, deaggregation, ground motion prediction models, UHS, CMS

1. GENERAL INSTRUCTIONS

Recent seismotectonics and seismic hazard studies show that the northern part is highly prone to seismic activity, while important facilities are located in Algiers the capital. Probabilistic hazard analysis is commonly used in earthquake engineering for the assessment of geotechnical and structural systems. PSHA incorporates uncertainty in ground motion predictions. The epistemic uncertainty, which is revealed by the differences in median values of ground motion parameters obtained from relations derived for different regions, is accounted for by the inclusion of two or more ground motion prediction relations in a logic-tree formalism.
Response spectrum is still remaining the meaningful tool to represent the earthquake hazard for the majority of engineers. The current seismic design codes use the Uniform Hazard Spectrum (UHS) as the design spectrum for different types of structures. The UHS is the envelope of the spectral acceleration values at all periods with identical exceedance probability computed from PSHA at the site.
For non-linear dynamic analysis, the Conditional Mean Spectrum (CMS) can be used instead of the UHS. CMS considers the spectral shape due to variations in causal magnitudes, distances and epsilons from period to period and for each ground motion prediction model. Through the deaggregation of multiples ground motion predictions, the computation of the target spectrum related to all the GMPMs specified in the logic tree can be computed.

2. SEISMOTECTONIC SETTING

Northern Algeria is a highly seismic area, as evidenced by the historical (1365–1992) seismicity (Bouhadad and Laouami 2002; CRAAG 1994; Benouar 1994). During the last three decades, northern Algeria experienced several destructive moderate-to-strong earthquakes.
The Quaternary tectonics, reverse faulting, and related north-northwest-south-southeast compression movements are consistent with thrust focal mechanisms of recent earthquakes that result from the 4–8 mm/yr of convergence of Africa toward Eurasia. It also reflects the characterization of potentially active seismic sources defined in the model (Meghraoui et al. 1988; Meghraoui 1992a 1992b, Boudiaf, 1996; Geomatrix Consultants, Inc. 2006; Maouche et al. 2011, Harbi et al., 2007).

3. HISTORICAL SEISMICITY.

The historical and instrumental seismicity recorded in Northern Algeria covers the period from 412 to 2005 (October 17). The primary source for the period 1900 to 1995 was the catalog compiled by Bennouar (1993) updated by the author until 1995. The primary source for the period prior to 1900 was the catalog of CRAAG (1994). For the period after 1995, the global catalog managed by the site of the ANSS (http://www.ncedc.org/anss) is used. For the period prior to 1996.
For the estimation of the earthquake occurrence parameters two different magnitude-frequency distributions were considered depending on the seismicity observed in each of the seismic sources as well as tectonic/mechanistic considerations. For the area sources an exponential magnitude distribution (Gutenberg & Richter, 1944) truncated at lower and upper magnitude limits was considered. For faults, a characteristic distribution (Youngs & Coppersmith, 1985) was considered.

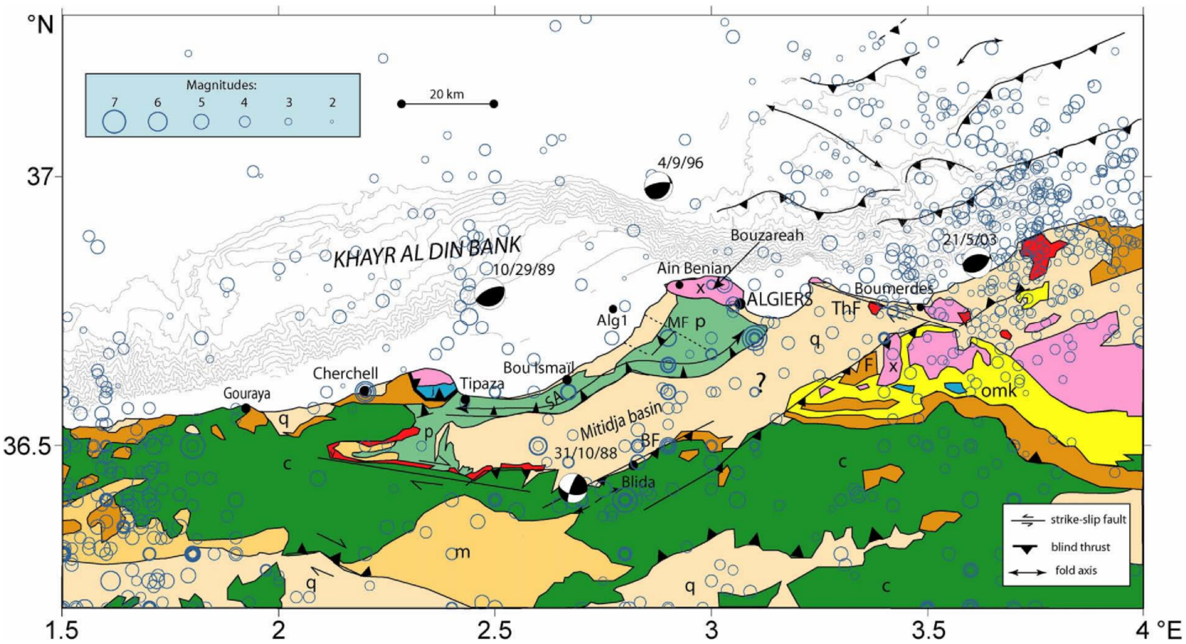


Figure 1. Tectonicframework of the Algiers region ; BF: Blida fault, ThF: Thenia fault, MF: Mahelma fault, SA: Sahel anticline, X: Kabylian Internal metamorphic rocks, F: Flyschs, omk: Kabylian Oligo-Miocene, c: Cretaceous, m: Miocene, q: Quaternary, p: Pliocene, v: volcanism. The cluster of events located near the shoreline east of ThF corresponds to the westernmost part of aftershocks triggered by the 2003 Mw 6.8 Boumerdès earthquake. (Yelles et al 2009)

4. GROUND-MOTION PREDICTION MODELS (GMPMs)

The seismotectonic map of the north of Algeria developed in previous studies shows that Algiers falls within an area of active shallow crustal seismicity. Therefore, the GMPEs of: Akkar & Bommer (2010), Boore & Atkinson (2008), Ambraseys et al. (2005) and Berge-Thierry (2003) for active shallow crustal seismicity are used. All these models predict PGA and PSA (or spectral acceleration, which is assumed equivalent here). Because of the lack of a large expert group for the definition of weights to apply to each of the selected models within the logic trees we have decided to equally weight each model in the analysis.

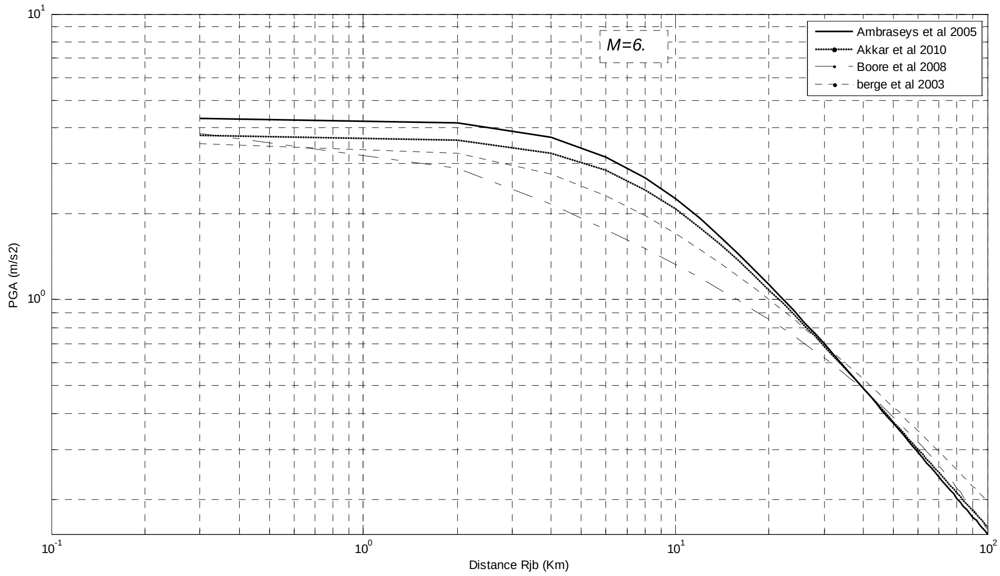
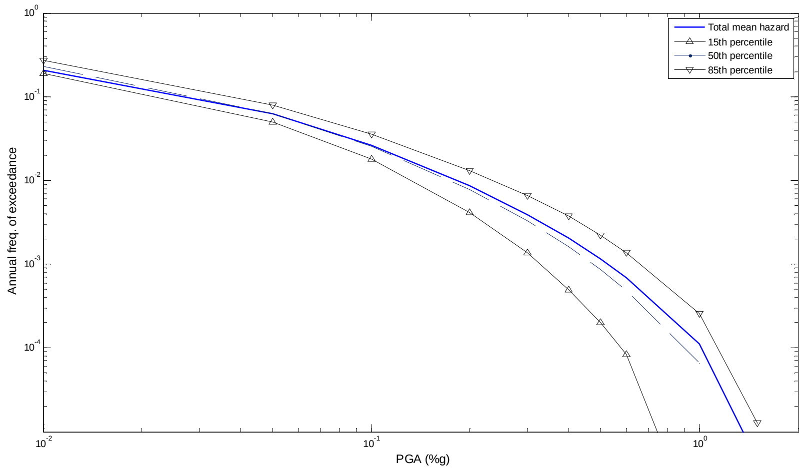


Figure 2. Ground motion prediction models used in the PSHA calculation

5. RESULTS

5.1. Hazard curves

Using the inputs described previously and HAZARD FORTRAN code derived from EZrisk standard PSHA was conducted for rock site conditions on site in Algiers region. The possible local site amplifications are not considered here.
Figure 3 shows the computed mean hazard curves for the considered ground-motion parameters for site at 36.780N-3.050E.: PGA, PSA (0.1s), PSA (0.2s), PSA (0.5s), PSA (1.0s) and PSA (2.0s). These curves reflect the high seismicity in the region and indicate that for the commonly-used return period of 475years the expected mean ground motions are: PGA=4 m/s2, PSA(0.1s)= 8.35m/s2, PSA(0.2s)=10.28 m/s2, PSA(0.5s)=6.80 m/s2, PSA(1.0s)=3.24 m/s2, PSA(2.0s)= 1.3m/s2. Which are high values compared to another region.



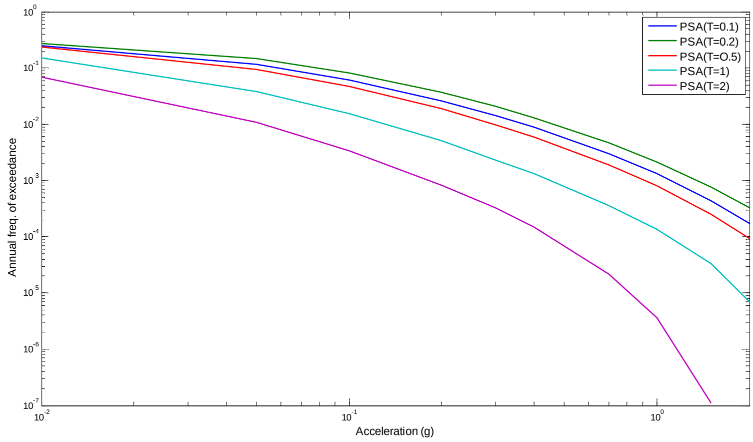


Figure3. Hazard curves for PGA and SA for response periods of 0.1 , 0.2, 0.5, 1 and 2 sec

5.2. Uniform hazard spectrum

Response spectrum is still remaining the meaningful tool to represent the earthquake hazard for the majority of engineers. A sample response spectrum for a 475 years return period (10% probability of exceedance in 50 years) is shown in Figure 4. Response spectra can also be computed for 100 years shown in Figure 5

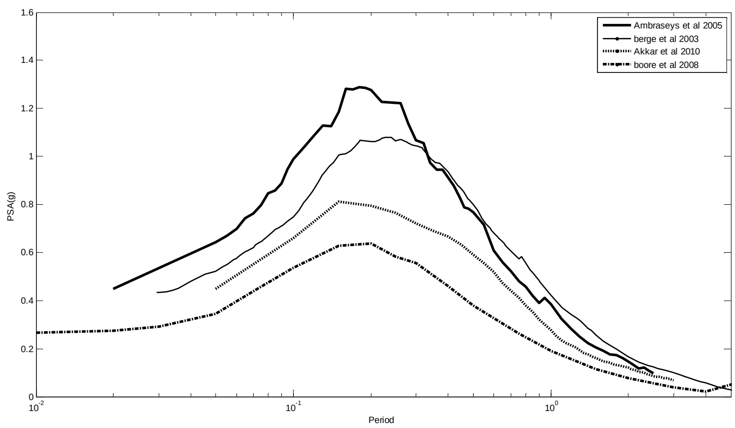


Figure 4. Uniform hazard spectra for 475-years return period.

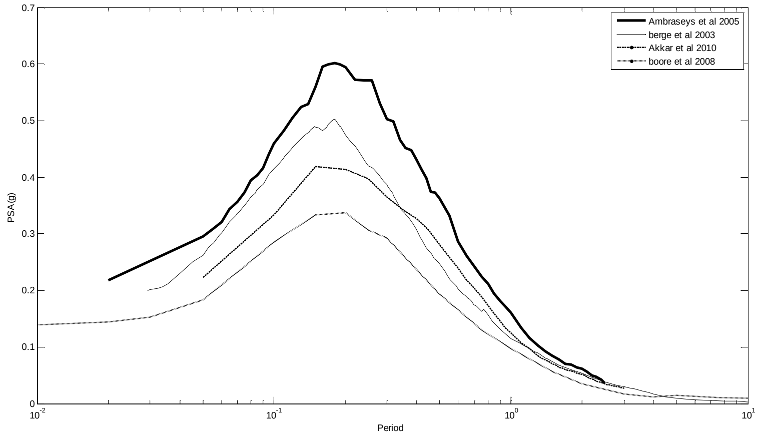


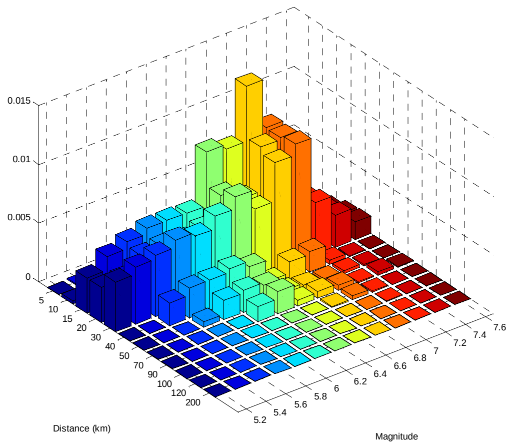
Figure 5. Uniform hazard spectra for 100-years return period.

5.3. Disaggregation

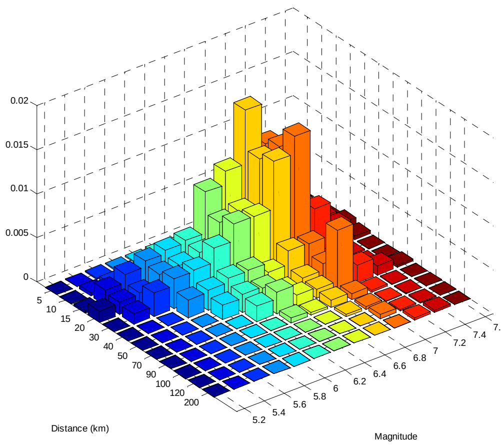
A disaggregation analysis has been done to identify scenarios in term of magnitude and distance to be used for the selection of ground motion record that could be used after to derive the dynamic analysis of structures.

Disaggregation plots with respect to magnitude-distance scenarios for the city considered showing the variation of the contribution for PGA and SA for response periods of 0.5 and 2.0 s and for 475 yaers return periods are shown from Figure 6.

PGA, (M mean=6.30 and R mean=16km)



SA(T=0.5sec), (M mean=6.65 and R mean=18km)



SA(T=2sec), (M mean=6.8and R mean=22km)

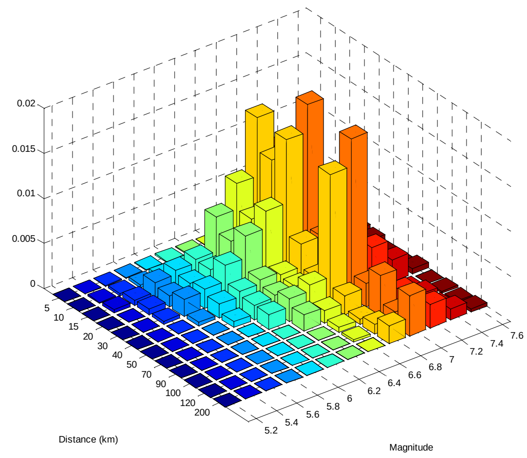


Figure 6. Disaggregation for the city of Algiers for PGA and for 475-yr return period).

6. CONDITIONAL MEAN SPECTRUM AND GROUND MOTION MODELS DEAGGREGATION

The CMS is shown to be the appropriate target for selecting ground motions to process a dynamic analysis of structures instead of UHS that does not correspond to a real event of an earthquake. (Baker 2008).
The CMS can estimate the expected *Sa* values at all periods of vibration (T_i) conditional on the target Sa value at the period of interest (T^*) and for each $\mu_{lnSa(Ti)|lnSa(T^*),GMPK_k}$ using the correlation coefficient between pairs of spectral values at two periods ($\rho(T_i, T^*)$*)* Eqn.6.1 and Eqn.6.2

$$\mu_{\mathrm{lnSa(Ti)|lnSa(T^*),GMPK_k}} = \mu_{\mathrm{lnSa,k}}\left(\widehat{M}_k, \widehat{R}_k, T_i\right) + \rho(T_i, T^*)\sigma_{\mathrm{lnSa,k}}\left(\widehat{M}_k, T^*\right)\hat{\varepsilon}_k(T^*) \quad (6.1)$$

$$\mu_{\mathrm{lnSa(Ti)|lnSa(T^*)}} = \sum_k \mu_{\mathrm{lnSa(Ti)|lnSa(T^*),GMPK_k}} \ \mathrm{P(GMPM_k|Sa} > y) \quad (6.2)$$

Where $\widehat{M}_k$, $\widehat{R}_k$ and $\hat{\varepsilon}_k$ are the mean values of magnitude distance and epsilon derived from deaggregation analysis, $\mu_{lnSa,k}$ and $\sigma_{lnSa,k}$ are the mean logarithmic spectral acceleration value and its standard deviation for the ground motion model $\mathrm{GMPM_k}$
In this section, the CMS is calculated for a range of fundamental periods that could represent the majority of reinforced concrete building in Algiers city and for different attenuation lows.
Figure 7 show a comparison between the UHS and the CMS for the fundamental period of 0.5 s.
A comparison between spectrums derived from different attenuation lows is shown in figures 8, 9, and 10.

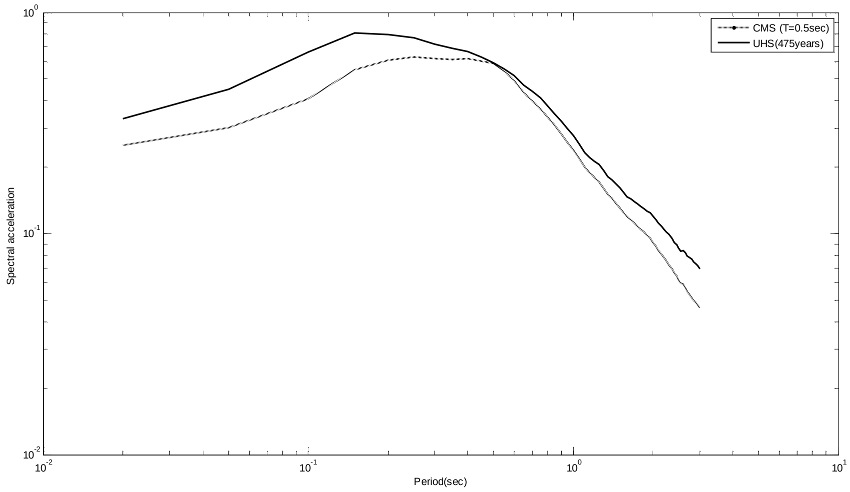


Figure7. Comparison of the UHS, and the conditional mean spectrum (expected shape) scaled to match the UHS at 0.5s.

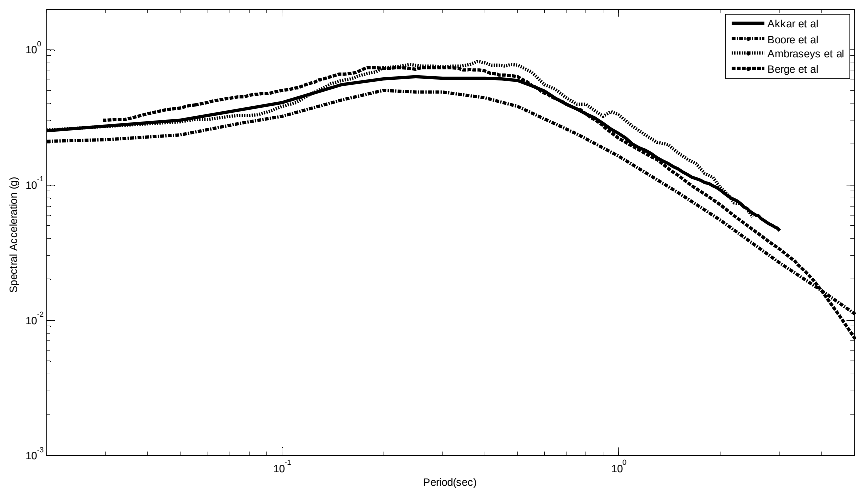


Figure 8. CMS for different ground motion prediction models for Sa(T=0.5s) at 475 yr

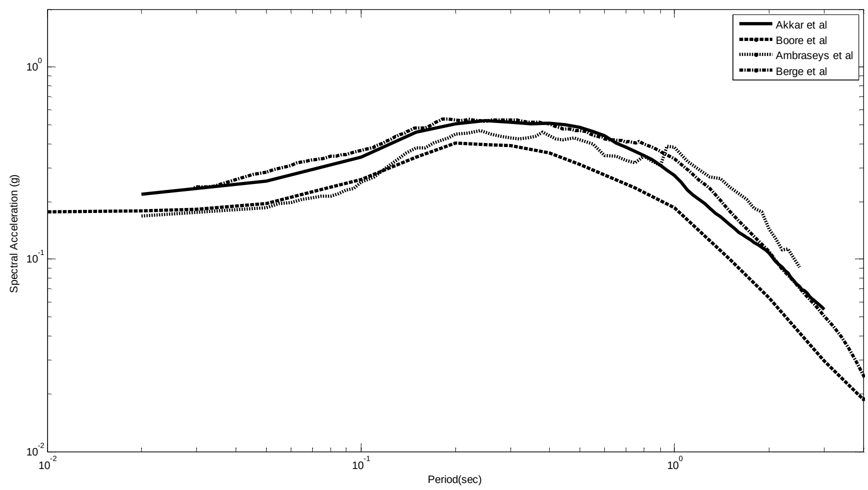


Figure9. CMS for different ground motion prediction models for Sa(T=1s) at 475 yr

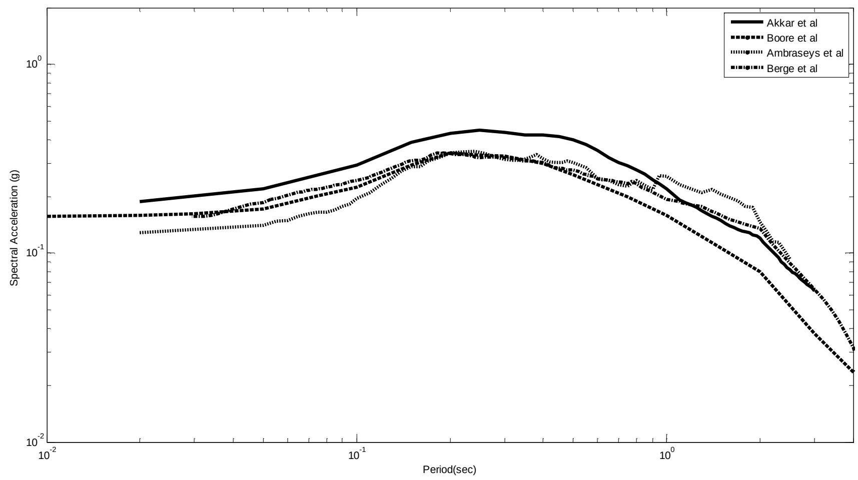


Figure10. CMS for different ground motion prediction models for Sa(T=2 s) at 475 yr

The deaggregation of GMPMs is similar in concept to the deaggregation of magnitude and distanceit and can be done by computing the probability that the exceedance of a given *Sa* level is predicted by a specific GMPMs, (LIN,T. and BAKER,B. 2011).

$$P(\mathrm{GMPM_k}|\mathrm{Sa} > y) = \frac{1}{\mathrm{v(Sa}>y)} \sum_j \iiint f_{M,R,E}(m, r, \varepsilon) P(\mathrm{Sa} > y|m, r, \varepsilon, \mathrm{GMPM_k}\ dm\ dr\ d\varepsilon\ P(\mathrm{GMPM_k}) \quad (6.3)$$

Figure 11 shows that the conditional probability of each GMPM is different of the weights given in the logic-tree.

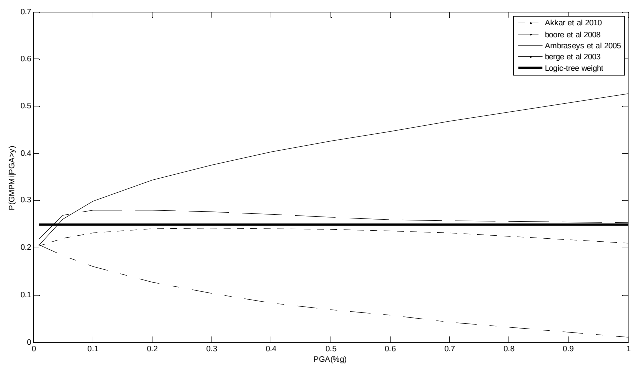


Figure 11. Deagregation of GMPMs given SA(0.5 s) > y for the site considered.

7. CONCLUSION

Algiers as an economical and historical city in Algeria has been faced several destructive earthquakes and disastrous damages. In this study due to presence of several active faults in close distance of urban area, probabilistic seismic hazard analysis was carried out to evaluate the ground motion levels for design of structures considering multiple ground motion predictions.

When assessment of structures is based on non-linear dynamic analysis, selection of record ground motions is an important consideration, the CMS is an alternative target spectrum which can be used instead of the UHS in seismic design codes. In this study we are considered both aleatory uncertainties from the earthquake scenarios and the epistemic uncertainties in ground motion selection by using the GMPMs deaggregation technique.

REFERENCES

Akkar, S. & Bommer, J. J. (2010), Empirical equations for the Prediction of PGA, PGV, and Spectral Accelerations in Europe, the Mediterranean Region, and the Middle East, *Seismological Research Letters*, **81,** 195–206.

Ambraseys, N. N., Douglas, J., Sarma, S. K. & 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, Bulletin of Earthquake Engineering, 3(1), 1-53. *European Conference on Structural Control.* **Vol II**: S6-92-S6-95.

Baker, J. W. & Jayaram, N. (2008), Correlation of spectral acceleration values from NGA ground motion models, *Earthquake Spectra*, **24(1),** 299-317.

Benouar,D The seismicity of Algeria and adjacent regions during the twentieth century, PhD thesis, Imperial College of Science, Technology and Medicine, University of London, 1993, 712 p.

Berge-Thierry, F C.. Cotton, O. Scotti, D.A. Griot-Pommera, Y.Fukushima, « New empirical response spectral attenuation laws moderate European earthquakes» *Journal of Earthquake Engineering*, 2003. **7(2)** : 193-222.

Boore, D. M. and G. M. Atkinson (2008). Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s, *Earthquake Spectra* **24**

Boudiaf, A., 1996. Etude sismotectonique de la région d'Alger et de la Kabylie (Algérie), PhD thesis, University of Montpellier, p. 274.

Bouhaded, Y., and Laouami, N. (2002), Earthquake hazard assessment in the Oran region (Northwest Algeria), *Natural Hazards*, **26**, 227-243.

CRAAG (1994), Les séismes de l'Algérie de 1365 à 1992, Publication du CRAAG, Alger, 227 p.

Geomatrix Consultants, Inc. and Centre National De Recherche Appliquee en Génie parasismique (CGS) (1998), Probabilistic hazard assessment of the the Algiers region: » UNCH project No. ALG/92/003, Technical Rapport submitted to United Nation Centre for Human Settlements, Nairobi, Kenya, 53 pp., plus Tables, figures and plates. doi:10.1029/2004GL021646.

Harbi A., Maouche S., Vaccari F., Aoudia A., Oussadou F., Panza G.F. & Benouar, D. (2007), Seismicity, seismic input and site effects in the Sahel—Algiers region (North Algeria), *Soil Dynamics and Earthquake Engineering*, **27,** 427–447

Maouche, S., Meghraoui, M., Morhange, C., Belabbes, S., Bouhadad, Y. & Haddoum, H. (2011), Active coastal thrusting and folding, and uplift rate of the Sahel Anticline and Zemmouri earthquake area (Tell Atlas, Algeria), *Tectonophysics*. doi: 10.1016/j.tecto.2011.06..003.

Meghraoui, M., 1988. Géologie des zones sismiques du Nord de l'Algérie. Thèse d'Etat, Université Paris Sud, Orsay, 356 p.

Philip, H., Meghraoui, M., 1983. Structural analysis and interpretation of the surface deformations of the El Asnam earthquake of October 10, 1980. *Tectonics* 2, 17–49.

Lin,T. Baker,J. : Probabilistic seismic hazard deaggregation of ground motion prediction models, *5th International conference on earthquake geotechnical engineering.*

Yelles A. a , Domzig A., Déverchère J., Bracène R., Mercier B, Strzerzynski P., Bertrand G. Boudiaf A., Winter T , Kherroubi A., Roy P., Djellit H.: Plio-Quaternary reactivation of the Neogene margin off NW Algiers, Algeria: The Khayr al Din Bank ; *Tectonophysics* (2009), doi: 10.1016/j.tecto.2008.1 1.030