Relationships between computed ground-motion values for Northern Algeria

M. Hamdache & A. Talbi
Dept. Études et Surveillance Sismique, CRAAG, Algiers, Algeria

J.A. Peláez & M.T. García Hernández
Department of Physics, University of Jaén, Spain
Andalusian Research Group on Seismic Risk and Active Tectonics

C. López Casado
Department of Theoretical Physics, University of Granada, Spain
Andalusian Research Group on Seismic Risk and Active Tectonics

SUMMARY:
The computation of seismic hazard in terms of both peak ground horizontal acceleration and spectral acceleration at different periods, damped at 5%, for three different types of soils, and for return periods of 100 and 475 years, has been carried out for northern Algeria. From these data, interesting relationships between *SA* (0.2-sec) and *PGA*, and *SA* (1.0-sec) and *PGA* values have been obtained, independently of the considered return period.
Moreover, detailed uniform hazard spectra have been computed for different return periods at several locations. Computed *UHS* for different types of soils and for return periods of 100 and 475 years have been the starting point to propose suitable design spectra. We have used the well-known Newman-Hall approach with certain modifications. The *SA* (0.2-sec) value is used to establish the spectral region for lower periods (region controlled by acceleration), while the *SA* (1.0-sec) value is used to establish the spectral region for intermediate periods (region controlled by the velocity). Finally, we have obtained a clear linear relationship between *SA* (0.2-sec) and *PGA* values for return periods of 100 and 475 years.

Keywords: Peak ground acceleration, spectral acceleration, uniform hazard spectra, design spectra, Algeria

1. INTRODUCTION

The recent seismic activity in northern Algeria, especially in the last 50 years, is characterized by the occurrence of several damaging earthquakes. The El Asnam region suffered the most destructive and damaging earthquakes recorded in northern Algeria, namely those of September 9, 1954 (M_s 6.8) and October 10, 1980 (M_w 7.3). The most significant recent event was the May 21, 2003 (M_w 6.9) Zemmouri earthquake, located at around 50 km northeast of Algiers (Hamdache *et al.*, 2004).

In this study we give a large summary of most recent results obtained for northern Algeria (Hamdache *et al*., 2012). These results are focused on the importance of the seismic hazard values obtained in previous studies (Peláez *et al*., 2003, 2005, 2006) in terms of *PGA* and *SA* values for this region. They are relevant for the design of buildings, and thus, they are a reliable tool for the improvement of the Algerian building code.

The relationships obtained recently between ground motion parameters computed at 33 cities with different seismic hazard level are presented (Hamdache *et al*., 2012). Specifically, from the computed uniform hazard spectra (*UHS*) at these cities, for return periods of 100 and 475 years and for different soil types (rock, soft and stiff), we have derived characteristic relations between *PGA*, SA_{max}, *SA* (0.2-sec) and *SA* (1.0-sec). Moreover, from the *UHS* and using the procedure by Malhotra (2005), we have obtained for each considered city for both 100 and 475 years return periods, elastic design spectra characterized only from *SA* (0.2-sec) and *SA* (1.0-sec) values. It is important to point out that the employed procedure is similar to the simplifications introduced on 2006 (ICC, 2006) to the procedure of the International Building Code (ICC, 2000). Among the most important results obtained in this study, it is observed that independently of the return period, *SA* (0.2-sec) values are on average twice of *PGA* values for rock soils, and of the order of 2.6 times for soft and stiff soil types. This dependency suggests that it can be used in the proposed procedure to derive design elastic response spectra the pair [*SA* (0.2-sec), *SA* (1.0-sec)] or the pair [*PGA*, *SA* (1.0-sec)] practically with the same reliability.

2. TECTONIC SKETCH AND SEISMICITY

Northern Algeria is located in the Eastern part of the Ibero-Maghrebian region, being one of the most active seismogenic regions in the westernmost Mediterranean area. The compressional movement between the Eurasian and the African plates control and conditions all the seismicity in this region. This complex tectonic setting, inside an active deforming zone that absorbs 5 to 6 mm/year (from Nuvel-1 model by Argus *et al.*, 1989) of crustal shortening and dextral shearing (Bezzeghoud and Buforn, 1999; Henares *et al.*, 2003), is responsible for the recent seismicity (Fig. 1).

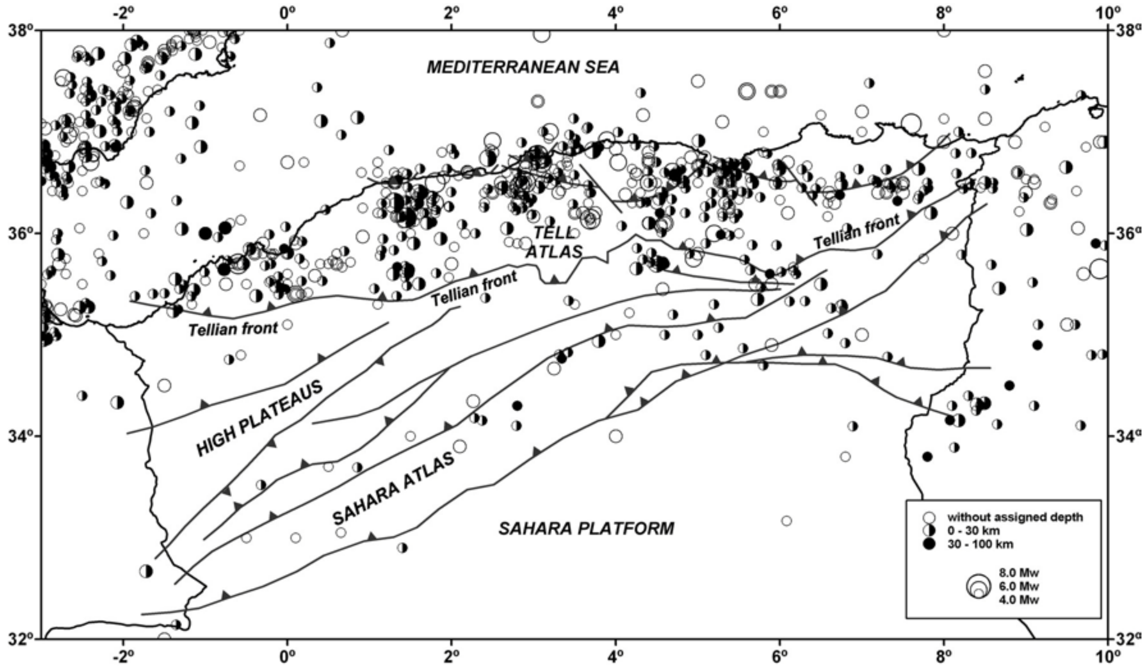


Figure 1. Seismicity and tectonic setting of northern Algeria (modified from Hamdache *et al*., 2010).

The earthquake data file used in this study has been initially compiled for this area for seismic hazard purposes (Peláez *et al.*, 2003), and updated afterwards by Peláez *et al.* (2005, 2006). All the magnitudes and intensities were converted to M_S magnitudes using the relationships by López Casado *et al.* (2000). The non-Poissonian events have been identified and removed. The analysis of the final earthquake data file obtained is presented in Hamdache *et al.* (2007). This check is a key step to establish different complete and Poissonian seismic models to be used in the seismic hazard assessment (Pelaez *et al.*, 2003, 2005, 2006; Hamdache *et al.*, 2007). Fig. 1 displays the more recent seismicity including low to moderate events occurred in the region. Although in the last 50 years the El Asnam region has suffered the most destructive and damaging earthquake in northern Algeria, the most significant and recent event was the May 21, 2003 (M_W 6.8) Zemmouri earthquake. It caused extensive damage in the north-central part of Algeria, reaching an intensity of IX-X in Zemmouri and Boumerdes, two towns near the epicenter (Hamdache *et al.*, 2004).

3. METHODOLOGY OUTLINE

The used methodology was the usual one in the spatialy smoothed seismicity approach, proposed by Frankel (1995). As used in the works by Peláez *et al.* (2003, 2005) and Hamdache *et al.* (2007), four complete and Poissonian seismic models have been considered in the seismic hazard computation, summarized as follow: 1) earthquakes with magnitude above M_s 2.5 after 1960, 2) those with magnitude above 3.5 after 1920, 3) those with magnitude above M_s 5.5 after 1850, and 4) those with magnitude above M_s 6.5 after 1700. The procedure combines zonified and non zonified probabilistic methods. As in probabilistic zonified methods, seismogenic sources are delimitated. In this study, seismogenic sources were defined as areas with seismic characteristics as homogenous as possible, including a certain inference among seismicity and geological domains. Based on the work by Aoudia *et al*. (2000), some modifications were included into the seismogenic sources previously proposed (Hamdache, 1998; Hamdache *et al*., 1998; Hamdache and Retief, 2001).

In Peláez *et al.* (2005, 2006), seismic hazard maps in terms of *PGA* and *SA* at different periods for rock, damped at 5%, and for return periods of 100 and 475 years, were computed using attenuation relationships by Ambraseys *et al.* (1996). Figs. 2a, 2b and 2c show results for *PGA* and *SA* for rock, damped at 5%, for periods of 0.2 and 1.0 s, and for a return period of 475 years. These results were examined and discussed in detail in Peláez *et al.* (2005, 2006).

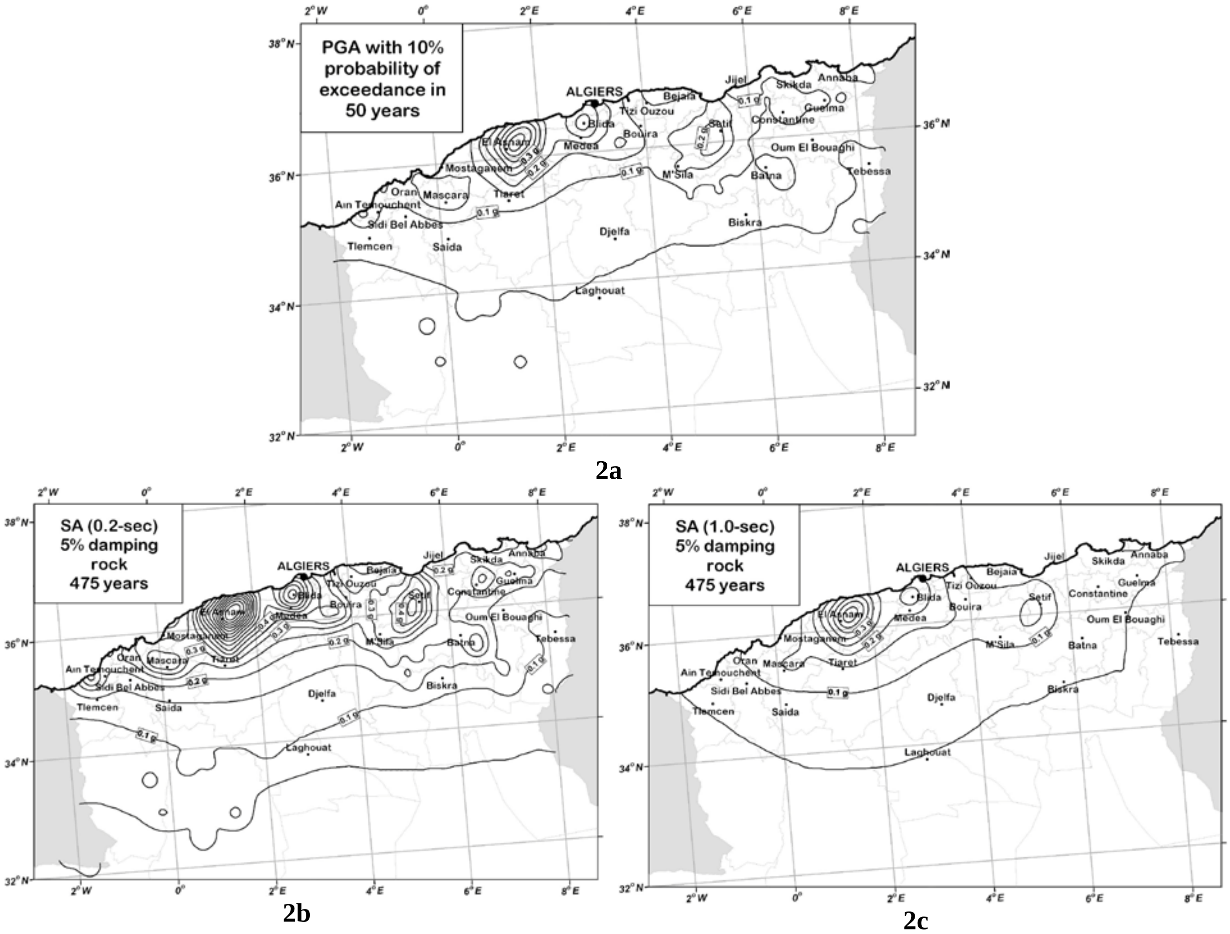


Figure 2. Seismic hazard values with a 10% probability of exceedance in 50 years (475 years of return period), for rock conditions. Contour interval is 0.05 g. 2a) In terms of *PGA*. 2b) In terms of *SA* (0.2-sec) damped at 5%. 2c) in terms of *SA* (1.0-sec) damped at 5%.

4. UNIFORM HAZARD SPECTRA AND DESIGN SPECTRA

In this section, the uniform hazard spectra computed at the 33 cities located in northern Algeria are discussed. These cities have different seismic hazard level, but all are located in the highest seismic prone area in Algeria, as shown in Fig. 2a. The calculation has been carried out for three different soil types, *i.e.*, rock, stiff and soft soils, and for return periods of 100 and 475 years. The soil type is characterized using v_S (30 m). The soil classification used is the one by Ambraseys *et al.* (1996). Rock type is characterized by v_S (30 m) greater than 750 m/s, corresponding to the soil type A in the EC-8 (1988) classification and soil type S1 in the Algerian building code in its 2003 version (RPA, 2003). Stiff soil is characterized by v_S (30 m) between 360 m/s and 750 m/s, corresponding to soil type B in the EC-8 classification and soil type S2 in the Algerian code. Finally, soft soil type is characterized by v_S (30 m) between 180 m/s and 360 m/s, corresponding to soil type C in the EC-8 and S3 soil in the Algerian code. This classification is very similar to the one previously proposed by Boore *et al.* (1994). The ground motion attenuation equations by Ambraseys *et al.* (1996) allow to obtain high definition spectra. As in Peláez *et al.* (2006), we compute *UHS* values at 0.0 s (*PGA* value) and at 36 different period values ranging from 0.1 to 2.0 s. A step size of 0.02 s between 0.1 s and 0.5 s, and a step size of 0.1 s between 0.5 and 2.0 s were used.

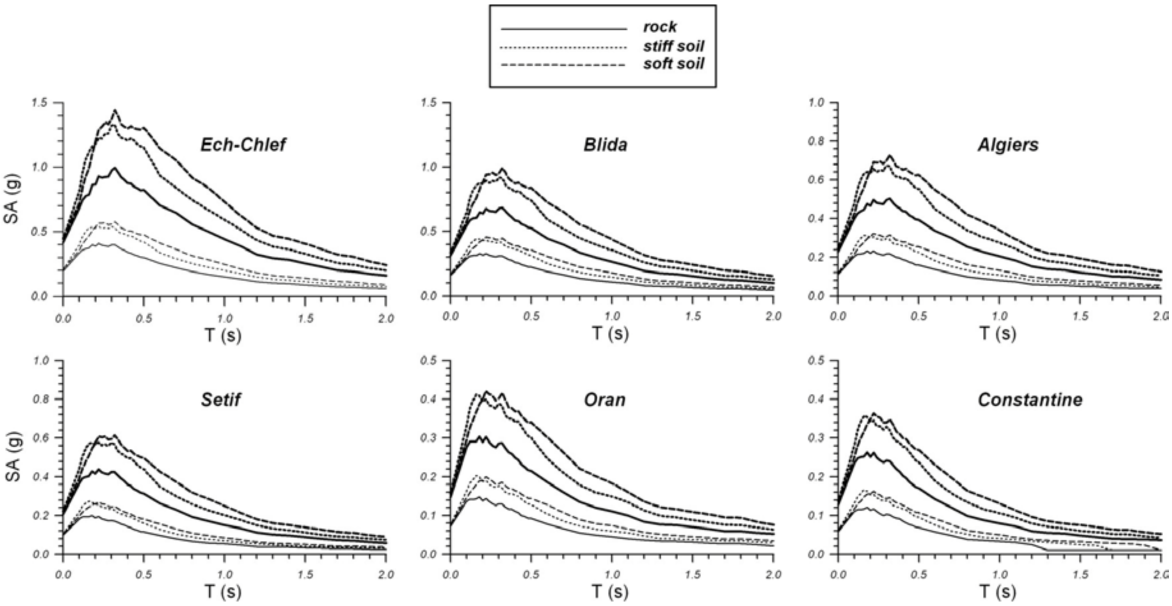


Figure 3. Uniform hazard spectra, damped at 5%, for different locations and considered soil conditions. Thin lines: return period of 100 years. Bold lines: return period of 475 years.

Fig. 3 displays results obtained at some places for the two considered return periods and for the three considered soil types. From the computed *UHS*, different *SA* characteristic values for the chosen places have been obtained for the three concerned soil types and for the two considered return periods (Hamdache *et al.*, 2012). For example, as well as *PGA* values, *i.e.*, *SA* (0.0-sec), the maximum spectral acceleration value (SA_{max}), the period at which it is reached (T_{max}), and the *SA* values at 0.2 s and 1.0 s are specifically computed. The procedure developed by Malhotra (*2005*) based in the Newmark-Hall approach (Newmark and Hall, 1982) in order to establish a design spectrum has been used in Hamdache *et al.* (2012). In the same work the different stages of the procedure are summarized as follow.

a) Specifically computed, or from the computed *UHS*, *SA* (0.2 s) and *SA* (1.0 s) values are used to compute the so-called control period (T_S) from

$$T_S = \frac{SA\,(1.0\ s)}{SA\,(0.2\ s)}\,1\ s \tag{4.1}$$

b) Then, design spectra values are calculated by

$$SA(T) = \begin{cases} 0.4 \cdot SA(0.2\,s) + 3 \cdot SA(0.2\,s)\,\dfrac{T}{T_S} & T \le 0.2 \cdot T_S \\ SA\ (0.2\,s) & 0.2 \cdot T_S < T \le T_S \\ SA(1.0\,s)\,\dfrac{1\,s}{T} & T > T_S \end{cases} \tag{4.2}$$

The design response spectra obtained using the previous equation (Malhotra, 2005), have been analyzed in detail, comparing it with the computed *UHS* and other estimated design spectra. Fig. 4 displays in the same graph the plot of the EC-8 type-I spectra, the computed *UHS*, and the design response spectra obtained from the previous method.

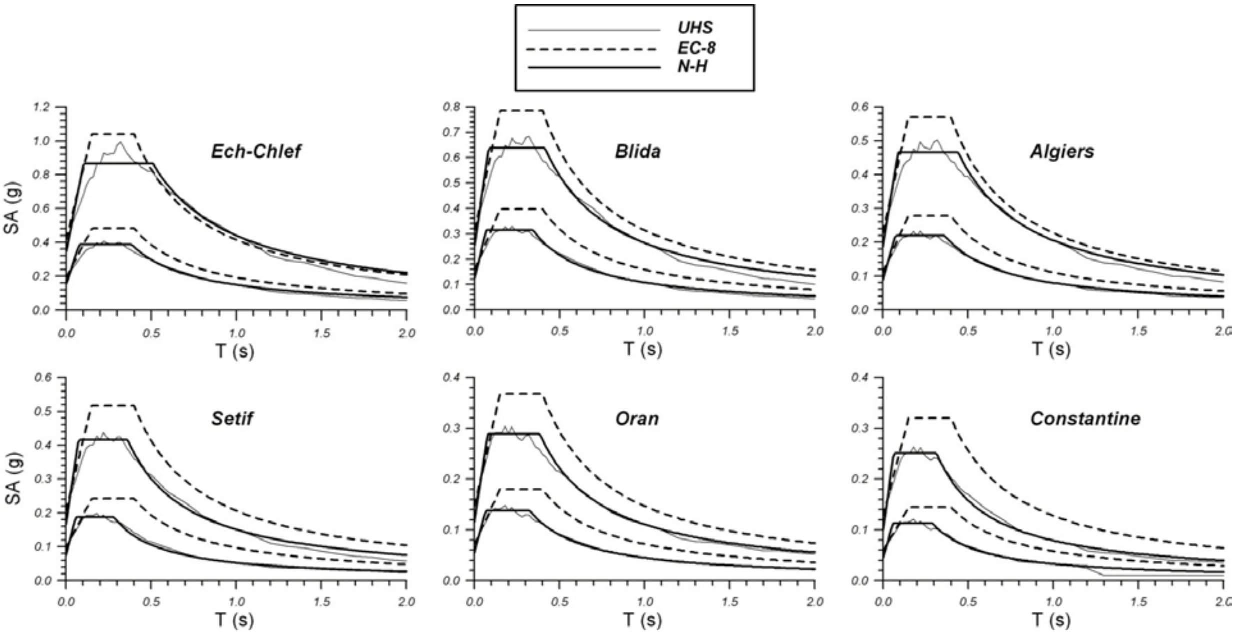
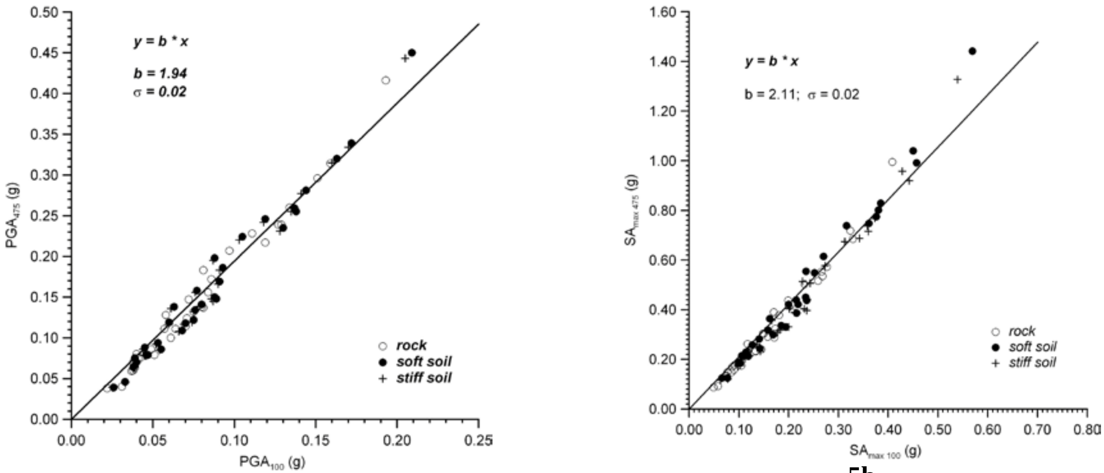


Figure 4: Uniform hazard spectra, EC-8 (type I) spectra and design spectra (Newmark-Hall spectra), damped at 5%, for different locations and rock conditions.
Upper lines: return period of 475 years. Bottom lines: return period of 100 years.

It is important to stand out that the Algerian building code, in its more recent version, do not propose any standard design spectra. Fig. 4 shows the good agreement, irrespective of the return period and soil type, between the computed *UHS* and the design spectra proposed in this study. It appears clearly that for a given location, it is a better approach to include in a building code, considering that it is not a good option to give the entire *UHS*, a design spectra defined only with two values, the spectral acceleration values for 0.2 and 1.0 s. These results are analyzed and discussed in depth in Hamdache *et al.* (2012).

5. GROUND MOTION PARAMETER RELATIONSHIPS

This section is devoted to the obtained relationships between some ground motion parameters computed in the previous seismic hazard assessment, in particular, *PGA*, SA_{max}, *SA* (0.2-sec) and *SA* (1.0-sec), for return periods of 100 and 475 years. Although more complex relationships were tested and could be employed, we have finally used in all cases the most simple one with physical meaning, that is, a straight line passing through origin. Fig. 5 displays the relations between obtained results for the same ground motion parameter for return periods of 100 and 475 years. Fig. 5a displays the PGA and Fig. 5b the SA_{max}. In both cases, an evident linear relationship can be observed.



5a **5b**

Figure 5. Plot of fitted model that describes the relationship
5a) between PGA_{475} and PGA_{100}, and 5b) between $SA_{max-475}$ and $SA_{max-100}$.

The most interesting consequence we can deduce from these linear fits is that *PGA* values and maximum values of the *UHS* damped at 5% in a certain location for a return period of 475 years (10% probability of exceedance in 50 years) are approximately twice than values for a return period of 100 years (39.3% probability of exceedance in 50 years, or approximately, 10% probability of exceedance in 10 years). From these results, we evince that an increase of four times in the probability of exceedance, or a decrease of five times in the exposure time, implies that these ground motion parameters increase twofold. In the same way, in Fig. 6 we have depicted the relationship between *PGA* values computed for stiff and soft soils versus *PGA* values computed for rock conditions.

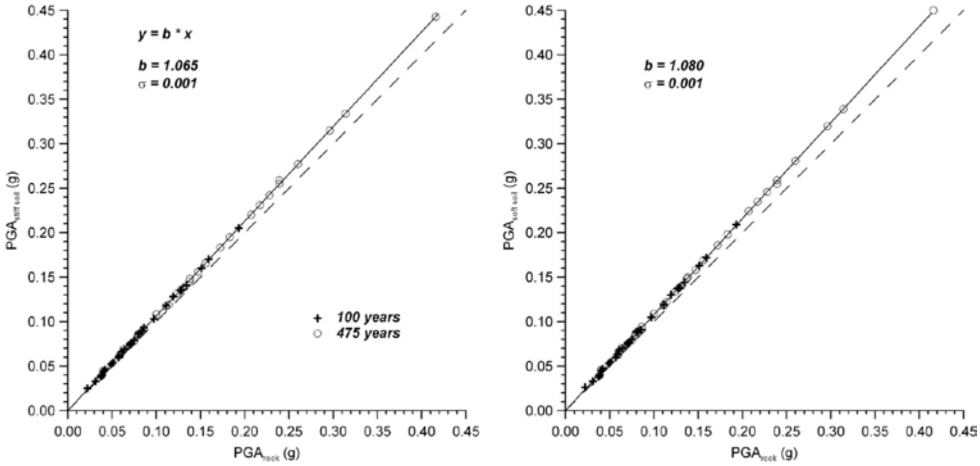


Figure 6. Plot of fitted models that describes the relationships between $PGA_{stiff\ soil}$ or $PGA_{soft\ soil}$, and PGA_{rock}. As a comparison, dashed line is a straight line with slope equal to unity.

Another interesting and important result has been established (Hamdache *et al*., 2012), showing that both plots are independent on return period, which increase its meaning and significance. In the same time the effect of soil type on *PGA* values has been analyzed. It is clearly shown that when comparing with rock, the *PGA* increases of the order of 6.5%, for stiff soil, and of the order of 8.0% for soft soil. It is well known that these values are mainly induced for the used attenuation relationship. This aspect allow to infer *PGA* values for stiff or soft soils from *PGA* values for rock. Fig. 7 displays the correlation between SA_{max}, *SA* (0.2-sec) and *SA* (1.0-sec) parameters, and *PGA*, for the three soil types. The estimate for the slope and its standard error for the different fits are displayed on the graph. It is important to point out the interesting result derived in Hamdache *et al.* (2012), showing that *SA* (0.2-sec) is also strongly related with *PGA*. For example, for rock, *SA* (0.2-sec) values are twice *PGA* values, and for stiff and soft soils, *SA* (0.2-sec) values are 2.5-2.6 times *PGA* values. In both cases, fits are practically independent of return period. This linear tendency between these parameters is one of the main results obtained in Hamdache *et al*. (2012). This dependency implies that we can use to derive the proposed design spectra the pair [*SA* (0.2-sec), *SA* (1.0-sec)] or the pair [*PGA*, *SA* (1.0-sec)] practically with equal reliability.

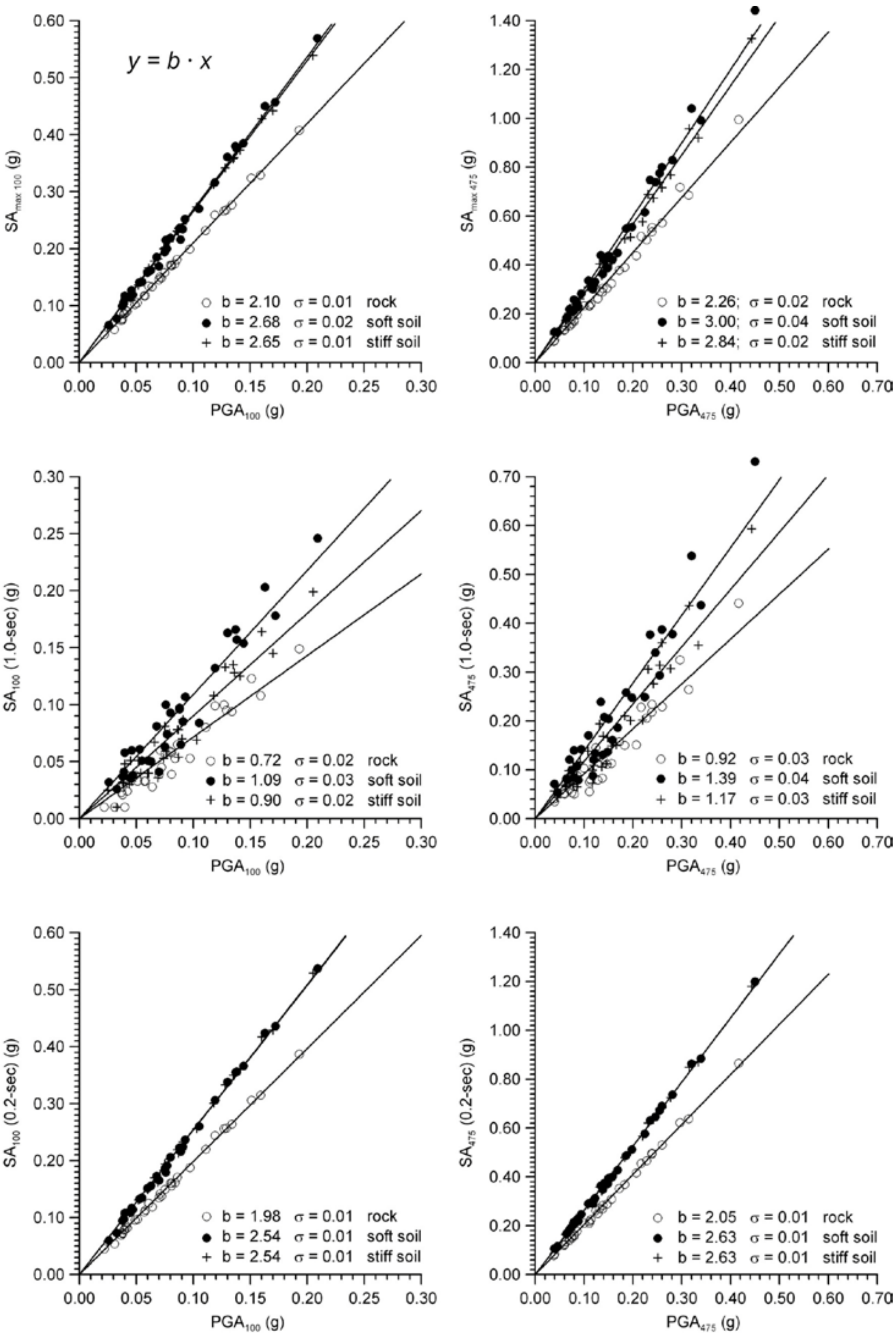


Figure 7. Plots of fitted models that describe the relationships between SA_{max}, *SA* (1.0-sec) or *SA* (0.2-sec), and *PGA*. Fits are conducted for return periods of 100 and 475 years and for the different considered soil conditions.

6. CONCLUSIONS

In this work we present a large overview of some results recently established (Hamdache *et al.*, 2012). Some of these results propose a Newmark-Hall type design spectra for northern Algeria from computed *UHS*, others one investigate some empirical relationships between computed ground-motion hazard parameters for different type of soils and return periods. Concerning design spectra, and as it has been shown, a Newmark-Hall type spectra defined from *SA* (0.2-sec) and *SA* (1.0-sec) values, agrees much more with computed *UHS* than proposed in EC-8. Moreover, we have highlighted the different relationships obtained between different ground-motion hazard parameters computed for several northern Algerian cities. The results also include, independently of the return period, relationships between *PGA* values for stiff and soil types versus *PGA* values for rock, as well as relationships between *SA* (0.2-sec) versus *PGA* values. The last ones allow to use indistinctly *SA* (0.2-sec) values or *PGA* values in order, for example, to define proposed design spectra. Other less significant, although substantial, empirical relationships have been obtained from other computed parameters. For example, soil conditions independent relationships between *PGA* and SA_{max} parameters, computed for a return period of 475 years, and the same parameter computed for a return period of 100 years.

AKCNOWLEDGEMENT

This research was supported by the Spanish Seismic Hazard and Active Tectonics research group, the Algerian C.R.A.A.G., and the grant CGL2011-30153-C02-02 of the Spanish Ministerio de Ciencia e Innovación.

REFERENCES

Ambraseys, N.N., Simpson, K.A., and Bommer, J.J. (1996). Prediction of horizontal response spectra in Europe. *Earthquake Eng. Struct. Dyn.* **25**, 371-400.

Aoudia, A., Vaccari, F., Suhadolc, P., and Meghraoui, M. (2000). Seismogenic potential and earthquake hazard assessment in the Tell Atlas of Algeria. *J. Seismol.* **4**, 79-98.

Argus, D.F., Gordon, R.G., de Mets, C., and Stein, S. (1989). Closure of the Africa-Eurasia-North America plate motions circuit and tectonics of the Gloria fault. J. Geophys. Res. 94, 5585-5602.

Bezzeghoud, M., and Buforn, E. (1999). Source parameters of the 1992 Melilla (Spain, Mw = 4.8), 1994 Alhoceima (Morocco, Mw = 5.8), and 1994 Mascara (Algeria, Mw = 5.7) earthquakes and seismotectonic implications. *Bull. Seism. Soc. Am.* **89**, 359-372.

Boore, D.M., Joyner, W.B., and Fumal, T.E. (1994). Estimation of response spectra and peak accelerations from northern North American earthquakes; an interim report; Part 2. USGS Open-File report 94-127, Denver, Colorado.

EC-8 (1998). Design provisions for earthquake resistance of structures - Part 1-1: General rules. Seismic actions and general requirements for structures. European Prestandard ENV 1998-1-1. Comité Européen de Normalisation, Brussels.

Frankel, A. (1995). Mapping seismic hazard in the central and eastern United States. *Seismol. Res. Lett.* **66**, 8-21.

Hamdache, M. (1998). Seismic hazard assessment for the main seismogenic zones in north Algeria. *Pure Appl. Geophys.* **152**, 281-314.

Hamdache, M., Bezzeghoud, M., and Mokrane, A. (1998). Estimation of seismic hazard parameters in the northern part of Algeria. *Pure Appl. Geophys.* **151**, 101-117.

Hamdache, M., and Retief, S.J.P. (2001). Site-specific seismic hazard estimation in the main seismogenic zones of north Algeria. *Pure Appl. Geophys.* **158**, 1677-1690.

Hamdache, M., Peláez, J.A., and Yelles Chauche, A.K. (2004). The Algiers, Algeria earthquake (M_W 6.8) of 21 May 2003: preliminary report. *Seismol. Res. Lett.* **75**, 360-367.

Hamdache, M., Peláez, J.A., M. Mobarki., F. Bellalem and C. Lopez Casado. (2007). Seismic parameters estimation in Northern Algeria**.** *Bulletin du Service Géologique National*. Vol.**18**, n 2.

Hamdache, M., Pelaéz J.A., Talbi, A., and López Casado, C. (2010). A unified catalog of main earthquakes for Northern Algeria from A.D. 856 to 2008. *Seism. Res. Lett.* **81**, 732-739.

Hamdache, M., Pelaéz J.A., Talbi, A., M. Mobarki., and López Casado, C. (2012). Ground-motion hazard values for Northern Algerie. *Pure and Applied Geophysics* **169**, 711-723.

Henares, J., López Casado, C., Sanz de Galdeano, C., Delgado, J., and Peláez, J.A. (2003). Stress fields in the Iberian-Maghrebi region. *J. Seismol.* **7**, 65-78.

ICC - International Code Council (2000). International Building Code 2000. International Code Council, USA.
ICC - International Code Council (2006). International Building Code 2006. International Code Council, USA.
López Casado, C., Molina, S., Giner, J.J., and Delgado, J. (2000). Magnitude-intensity relationships in the Ibero-Magrebhian region. *Nat. Hazards* **22**, 269-294.
Malhotra, P.K. (2005). Return period of design ground motions. *Seismol. Res. Lett.* **76**, 693-699.
Newmark, N.M., and Hall, W.J. (1982). Earthquake spectra and design. Earthquake Engineering Research Institute Monograph Series **no. 3**, Berkeley, California, USA.
Peláez, J.A., Hamdache, M., and López Casado, C. (2003). Seismic hazard in northern Algeria using spatially smoothed seismicity. *Tectonophysics* **372**, 105-119.
Peláez, J.A., Hamdache, M., and López Casado, C. (2005). Updating the probabilistic seismic hazard values of northern Algeria with the 21 May 2003 M 6.8 Algiers earthquake included. *Pure Appl. Geophys.* **162**, 2163-2177.
Peláez, J.A., Hamdache, M., and López Casado, C. (2006). Seismic hazard in terms of spectral accelerations and uniform hazard spectra in northern Algeria. *Pure Appl. Geophys.* **163**, 119-135.
RPA (2003). Règles Parasismiques Algériennes 2003. Centre National de Recherche Apliquée en Génie Parasismique, Algiers, Algeria.