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GROUND MOTION PARAMETERS ESTIMATION IN NORTHERN ALGERIA

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ABSTRACT

This study focuses on ground motion parameters. Peak ground acceleration (PGA) and spectral acceleration (SA) for different periods of oscillation and damping at 5%, which are estimated in northern Algeria, using the spatially-smoothed methodology. First, seismic hazard maps in terms of ground motion parameters, as well as in terms of PGA and SA, with 10% probability of exceedance in 50 years, have been obtained, using the spatially-smoothed seismicity. The procedure used allows us to examine in details the contribution within the estimation of seismic hazard of the last major earthquake M6.8, which occurred near the Algiers city on 21 May 2003. A preliminary seismic hazard zonation in northern Algeria, in terms of PGA, has been carried out based on seismic hazard map for a return period of 475 years. All the results reported in this study are for rock soil and 5% damping.

In the second part, uniform hazard spectra (UHS) are computed and examined in detail for twelve of the most industrial and populated cities in northern Algeria. It deserves to be remarked that, in the seismic hazard maps as well as in the UHS plots, we observed maximum PGA and SA values in the central part of the Tellian Atlas. The higher values are in the Chleff region (previously El Asnam), specifically, in the vicinity of the Quaternary Basin, around the location of the destructive earthquake of September 9, 1954 (Ms6.8) and October 10, 1980 (Ms7.3). These maximum values are associated with period of 0.32s for a return period of 475 years.

Also, we have obtained in this part of the Tellian Atlas, seismic hazard values about 40% higher than previous one (Pelaez and *al.*, 2003), specifically in the Zemmouri-Boumerdes-Algiers area, corresponding to the contribution of the destructive earthquake of 21 May 2003, (Hamdache and *al.*, 2004b).

Keywords - Seismic hazard - Peak ground acceleration - Spectral acceleration - Spatially-smoothed seismicity method - Algeria.

ESTIMATION DES PARAMÈTRES DU MOUVEMENT DU SOL EN ALGÉRIE DU NORD

RÉSUMÉ.

On se propose dans cette étude d'estimer les paramètres du mouvement du sol, principalement l'accélération de pointe et l'accélération spectrale avec 5% d'amortissement pour différentes périodes. Nous utilisons une approche probabiliste d'évaluation de l'aléa sismique, particulièrement l'approche dite «spatially smoothed seismicity ». Les résultats obtenus tant en termes de PGA que de SA

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avec 10% de probabilités de dépassement en 50 ans, ce qui correspond aux valeurs ayant une période de retour de 475 ans, sont représentés sous forme de carte d'aléa sismique. Tous les résultats obtenus dans cette étude correspondent aux valeurs sur le rocher.

Dans une seconde partie, au niveau de douze des principales villes du nord de l'Algérie, le spectre uniforme (Uniform Hazard Spectra) est examiné en détail. Une première observation des résultats nous permet de déduire que les valeurs les plus élevées sont obtenues dans la partie centrale de l'Atlas Tellien, particulièrement aux environs de la localisation des événements majeurs, tel que celui du 09 septembre 1954, M_s 6.8 ou encore du 10 octobre 1980 (M_s 7.3). Ces valeurs maximales sont associées à la période de 0.32 s pour une période de retour de 475 ans. De plus, les valeurs obtenues dans cette partie de l'Atlas tellien sont supérieures de 40% par rapport à celles obtenues dans des études antérieures (Pelaez et *al.*, 2003), particulièrement dans la region de Zemouri-Boumerdes-Alger, ce qui correspond à la contribution du dernier séisme (21 Mai 2003) qui a eu lieu dans cette région (Hamdache et *al.*, 2004b).

Mots clés - Aléa sismique - Accélération de pointe - Accélération spectrale - Spatially-smoothed seismicity method - Algérie.

1 - INTRODUCTION

Northern Algeria has been the site of numerous historical earthquakes, and was therefore the subject to extensive damage and several thousands of casualties in the past. Earthquakes up to magnitude M_S 7.3 have been recorded in the Ibero-Maghrebian region during this last century (i.e. El Asnam earthquake of 10 October 1980). Other damaging earthquakes affecting northern Algeria have been recorded among them, those located in the vicinity of the Algiers city, which occurred in January 2, 1365 (I_0 = IX), February 3, 1716 (I_0 = XI), December 3, 1735 (I_0=VII), March 17, 1756 (I_0=VIII), November 8, 1802 (I_0=VIII), June 18, 1847 (I_0=VIII) and November 5, 1924 (I_{MM}=VIII), and those located in the vicinity of the city of Oran, in October 9, 1790 (I_0=IX-X) and May 21, 1889. During the last 50 years this region experienced other events as those of the Ain Temouchent earthquake of 22 December 1999 (m_{bLg} 5.7) and the one in Beni Ourtilane of 10 November 2000 (m_{bLg} 5.6). But, during a long time the El Asnam region was the one which experienced the two most destructives earthquake (i.e 1954 and 1980), but more recently, on 21 May 2003 M_w 6.8 struck the Algiers city (Hamdache and *al.*, 2004a). The epicentre was located near the coast at the eastern part of Algiers about 40 km. This event is the most destructive after that of October 1980, thereby indicating the importance of seismic hazard assessment for northern Algeria. The aim of this study is to evaluate the seismic hazard in northern Algeria in terms of ground motion parameters (PGA and SA) by using the new methodology proposed by Frankel (1995), Frankel and *al.*, (1996) and developed here with certain modifications (Pelaez, and *al.*, 2005a; 2005b). This methodology combines both parametric and non-parametric (non-zoning) probabilistic methods: seismic sources are used when considering zones where certain parameters may be considered homogeneous, as in parametric methods, while, on the other hand, earthquakes are considered wherever they have taken place, as in non-parametric methods. The Frankel (1995), Frankel and al., (1996) methodology is well adapted to model the seismicity that cannot be assigned to specific geological structures, which is usually known as background seismicity. Using this new methodology the seismic hazard for northern Algeria in terms of ground motion acceleration for a return period of 475 years have been computed. More attention is given to seismic hazard in terms of SA, in that Uniform hazard spectra (UHS) at twelve of the most industrial and populated cities of northern Algeria have been derived.

2 - SEISMICITY AND SEISMOTECTONIC SKETCH

The area under study, northern Algeria, could be described in short by including four morphostructural domains: the Tell Atlas, the High Plateaus, the Sahara Atlas and the Sahara Platform (fig. 1). The tectonics of this region has been the subject of various studies, such as Meghraoui (1988), Meghraoui and *al.*, (1986). Briefly, the Tell Atlas consists of a succession of mountain ranges and valleys parallel to the coastline, and showing different morphological aspects, with juxtaposed platforms (alluvial basins) and high topography. Parallel ridges and valleys correspond to E-W to NE-SW trending alluvial basins and thrusts and folds systems with a transport direction to the south and southeast. The High Plateaus zone is situated in-between the Tell Atlas and the Sahara Atlas, in an elevated region of relatively tabular topography. The Sahara Atlas domain is a mountain range with a folded Mesozoic-Cenozoic cover. The Sahara Platform limits the whole region to the south.

The Tell Atlas is among the most important geological domain in the region, and lies within

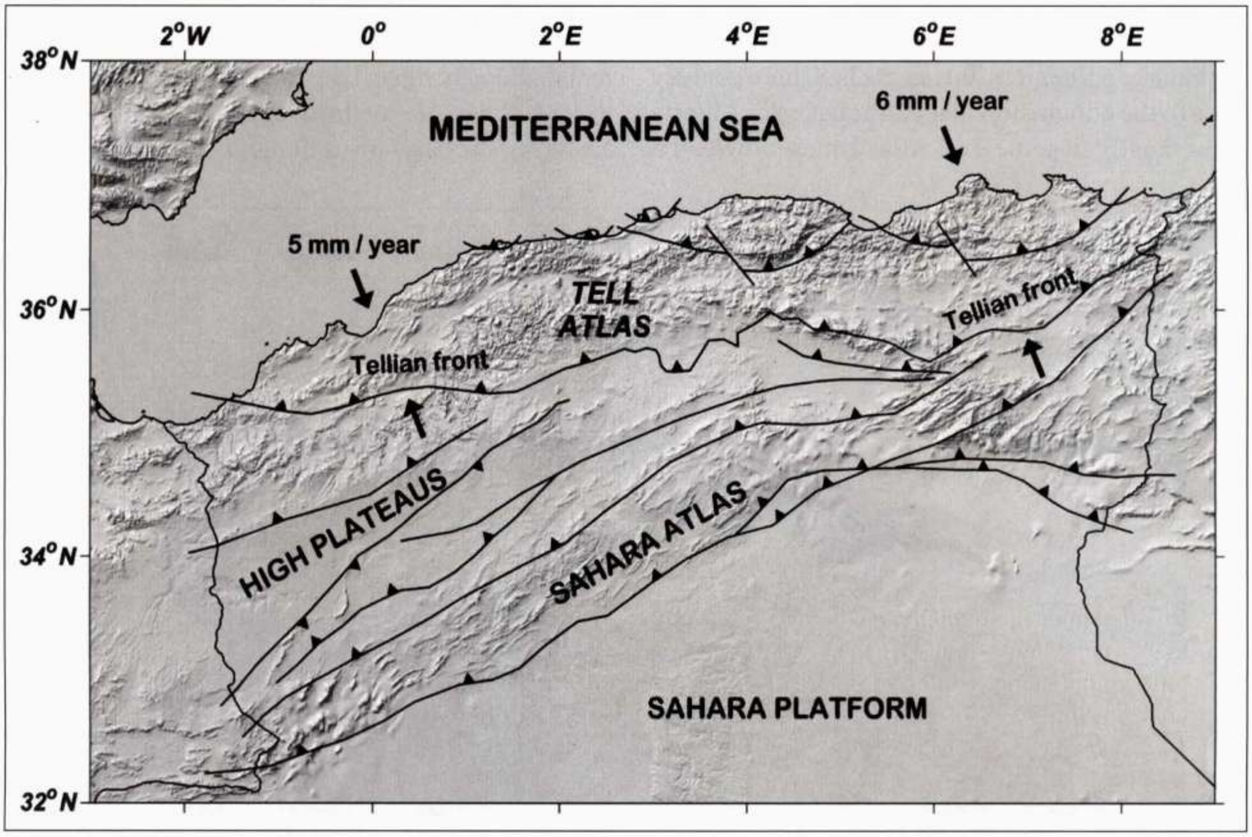

Fig. 1 - Schematic map showing the regional tectonic setting (modified from Bracene et *al.*, 2003).
Contexte tectonique régional (modifié à partir de Bracene et al., 2003).

the active collision zone between Eurasia and Africa plates. The tectonic regime in this part of the Alpine chain is mostly compressional since the early Cenozoic, with late Quaternary N-S to NW-SE convergence. 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., 2002), is responsible for the contemporary seismicity. The main faults with strike NE-SW correspond to structures often organized in echelon systems of thrust faults dipping to NW, such as the El Asnam and Tipaza faults.

Northern Algeria is known as the most active seismogenic area in the western Mediterranean region, in the eastern part of the Ibero-Maghrebian zone, therefore, during the last century, Algeria has experienced several strong earthquakes (CRAAG, 1994). The analysis of the distribution of earthquake epicenters during the last three century leads to the conclusion that earthquakes in Algeria occur mostly in some Tell Atlas zones, however a few earthquakes appear in the High Plateaus and in the Sahara Atlas.

The seismicity analysis also shows that the seismogenic areas are located in the vicinity of the Quaternary Basins. These tectonic zones contained in Neogene and Quaternary deposits extend to the Messeta Basin (region of Oran) in the western Tell Atlas, in the center to the Mitidja Basin (Tipaza-Algiers) close to the Atlas blideen, and extends to the Soummam, Constantine and Guelma Basins in the eastern part, to the Hodna Basin in the southeast, which is an integral part of the Tell Atlas.

3 - METHODOLOGY OUTLINE.

As in probabilistic zonified methods, we have used a delimitation in seismogenic source zones. Yet, without the standard general practice and methodologies employed, the delineation of the seismic sources remains mostly subjective. In this study, seismogenic source zones are defined as areas with seismic characteristics that are as homogenous as possible.

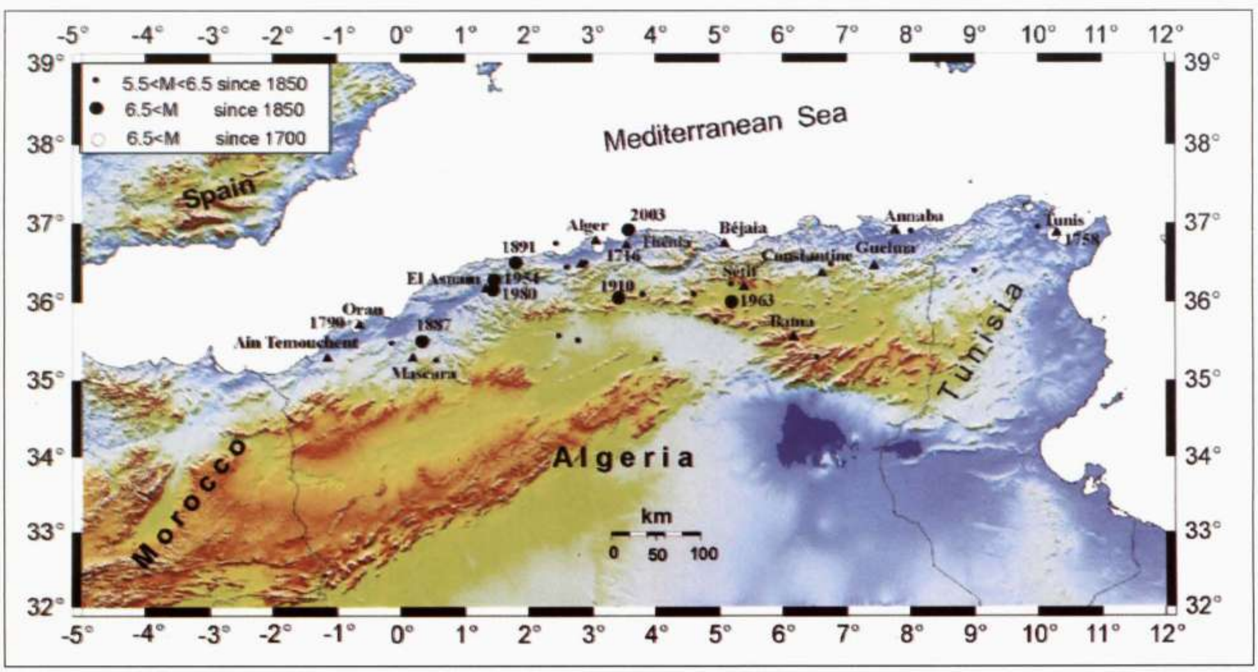

Fig. 2 - Major events in northern Algeria since 1700

Evénements majeurs au Nord de l'Algérie depuis 1700

Based on the work of Aoudia and *al*., (2000), some modifications have been introduced into the seismogenic source zones previously proposed (Hamdache, 1998a, Hamdache and *al*., 1998b; Hamdache and Retief, 2001) for northern Algeria.

The geological description given in Aoudia and *al*., (2000) has been used to incorporate the geological knowledge in the seismogenic sources considered in this study. Different geological structures have been included to identify ten seismogenic zone sources in northern Algeria. Each proposed source zone, which seems homogeneous in its seismic characteristics, is often related to active or potentially active geological structures. Some of them are included in the Quaternary basins previously mentioned. This seismogenic source model (fig. 3) is consistent with the distribution of the seismicity in the northern Algeria, as shown in figure 3. In northeastern Morocco and northern Tunisia, the sources have been defined without taking into account the geological context (seismicity sources), just to incorporate the contribution of the seismicity of these regions to the calculation of the seismic hazard in northern Algeria.

Four seismic models are used for the calculation of the seismic hazard in the studied area. All of them are obtained from the earthquake catalog compiled especially for this study and examined in details in the companion paper (Hamdache and *al*., 2007). Each model covers a different time period and being complete and poissonian. The shallow seismicity included in each model is shows on figure 4.

These four seismic models are summarised below.

Model I : It includes earthquakes with magnitude greater or equal than M_s 2.5 (H» m_b 3.6, I_0 = IV-V, according to the relationship by Lopez Casado and *al*., 2000) after 1960. This model is the

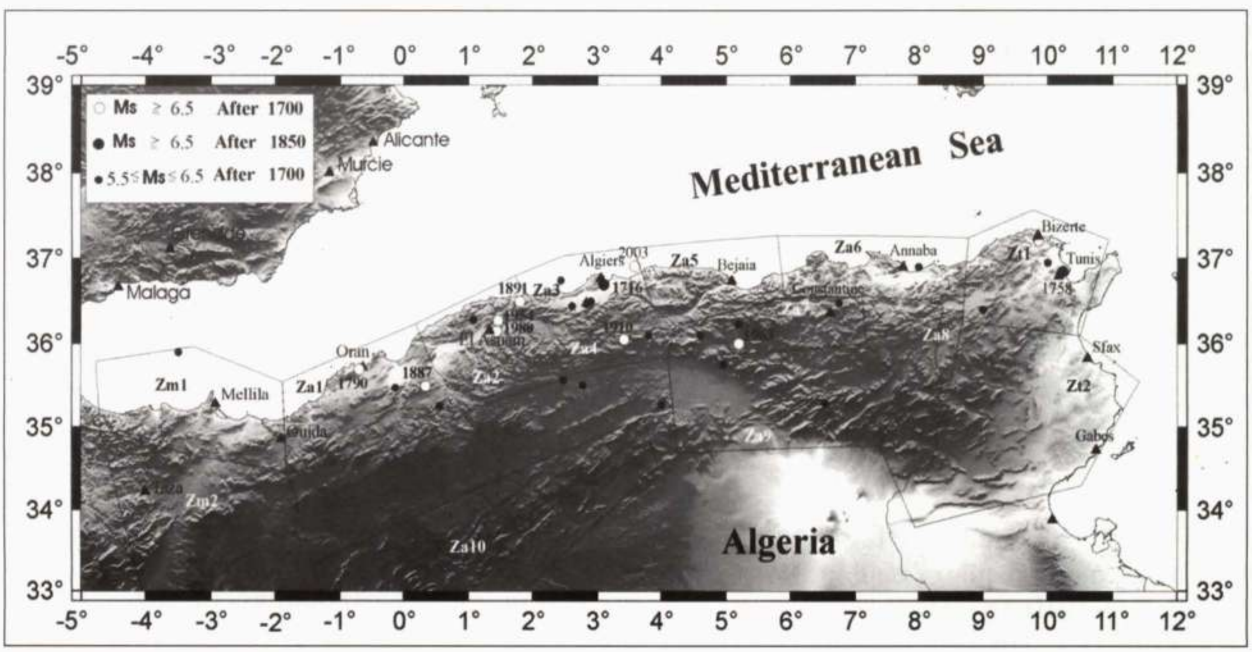

Fig. 3 - Seismicity map showing 5.5 ≤ M_s < 6.5 (small gilled circles) and M_s e» 6.5 (large gilled circles) earthquakes since 1850 and Ms ≥ 6.5 (large open circles) since 1700.

Représentation de la sismicité pour 5.5 ≤ M_s < 6.5 (petits cercles pleins), M_s e» 6.5 (larges cercles pleins) depuis 1850 et Ms ≥ 6.5 (larges cercles) depuis 1700.

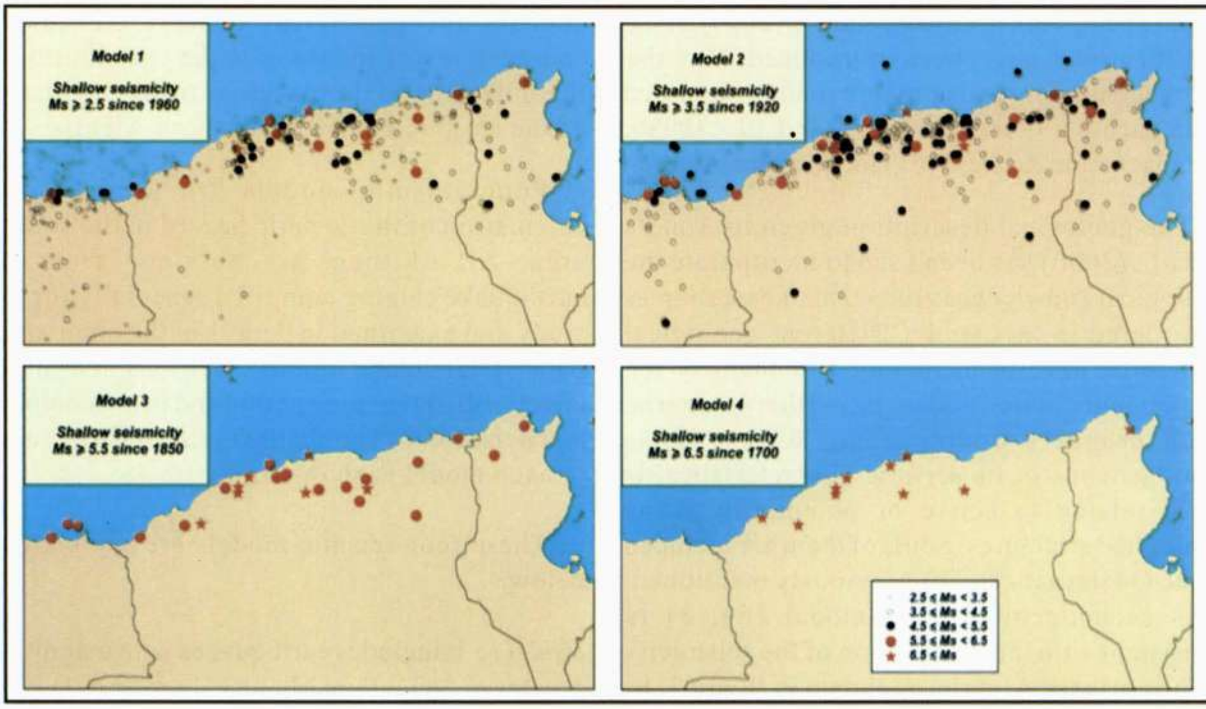

Fig. 4 - Shallow seismicity included in the different models.

Sismicité contenue dans chaque modèle

most complete from the spatial point of view (fig. 4). To include this model to seismic hazard analysis and taking into account the uncertainty in the location, the adopted value of the c parameter in the Gaussian filter (Frankel, 1995; Frankel and *al.*, 1996) is equal to 10 km.

Model II : It includes earthquakes with magnitude greater or equal than M_s 3.5 (H» m_b 4.2, I_0 = VI) after 1920. The c parameter in the Gaussian filter is equal to 15 km in this case.

Model III : This model includes earthquakes with magnitude greater or equal to M_s 5.5 (H» m_b 5.4, I_0 = VIII-IX) after 1850. A value of 20 km for the c parameter is adopted.

Model IV : It includes earthquakes with magnitudes greater or equal than M_s 6.5 (H» m_b 6.0, I_0 = IX-X) after 1700.

Using the empirical relation by Murphy and O'Brien (1977), the threshold magnitude for each seismic model is given in magnitude volume scale.

The procedure of the seismic hazard calculation is the usual one in the spatially smoothed seismicity methodology (i.e Frankel, 1995; Pelaez and *al.*, 2005a, 2005b). The area under study is first divided into square cells (10 km x 10 km), then we count the number of earthquake N_k recorded in the k-ieme cell. The Gaussian filter (Frankel, 1995; Frankel and *al.*, 1996) has been used to smooth the N values, thus, including the uncertainty in the earthquake location in the seismic hazard results. The fraction of q earthquakes in the interval magnitude m ± «m/2 is given by the expression (Pelaez and *al.*, 2003).

$$q(m,\Delta m) = N\frac{10^{-b(m-m_0)}}{1-10^{-b(m_{\max}-m_0)}}\left[10^{b\frac{\Delta m}{2}} - 10^{-b\frac{\Delta m}{2}}\right]$$

Where the truncated Gutenberg-Richter relationship has been used (Cosentino et al., 1977). The b, m_0 and m_{max} parameters characterize the adopted model recurrence, «m is the magnitude interval in the computation of the seismic hazard and N_k is the total number of earthquakes in the k-ieme cell. The calculation methodology to evaluate the seismic hazard is based on the well know total probability theorem, expressed in terms of rate of exceedance of a certain level of ground motion. The final results are obtained by weighting the output of each of the four models. For the calculation of the seismic hazard with 10% probability of exceedance in 50 years, which corresponds to a return period of 475 years, the respective weights are 0.2, 0.2, 0.3 and 0.3. In both cases, the weighted values are proposed according to the return period, always trying that the models for an interval comparable to the return period provide a higher contribution.

4 - PEAK GROUND ACCELERATION RESULTS

In this study we have used the attenuation relationship for ground motion parameters, PGA and SA, developed by Ambraseys and *al.*, (1996), especially to avoid the insufficient acceleration records database in northern Algeria to develop reliable regional attenuation model for the ground motion parameters. This attenuation model for peak ground acceleration is given by the following equation:

$$LnA = 3.408 + 0.612M - 0.922Ln(R^2 + 3.5^2) + \varepsilon$$

Where, M surface wave magnitude, R the epicentral distance and μ normal variable with standard deviation equal to 0.576.

The result obtained for each seismic model in terms of PGA with 10% probability of exceedance in 50 years is given on the following figure.

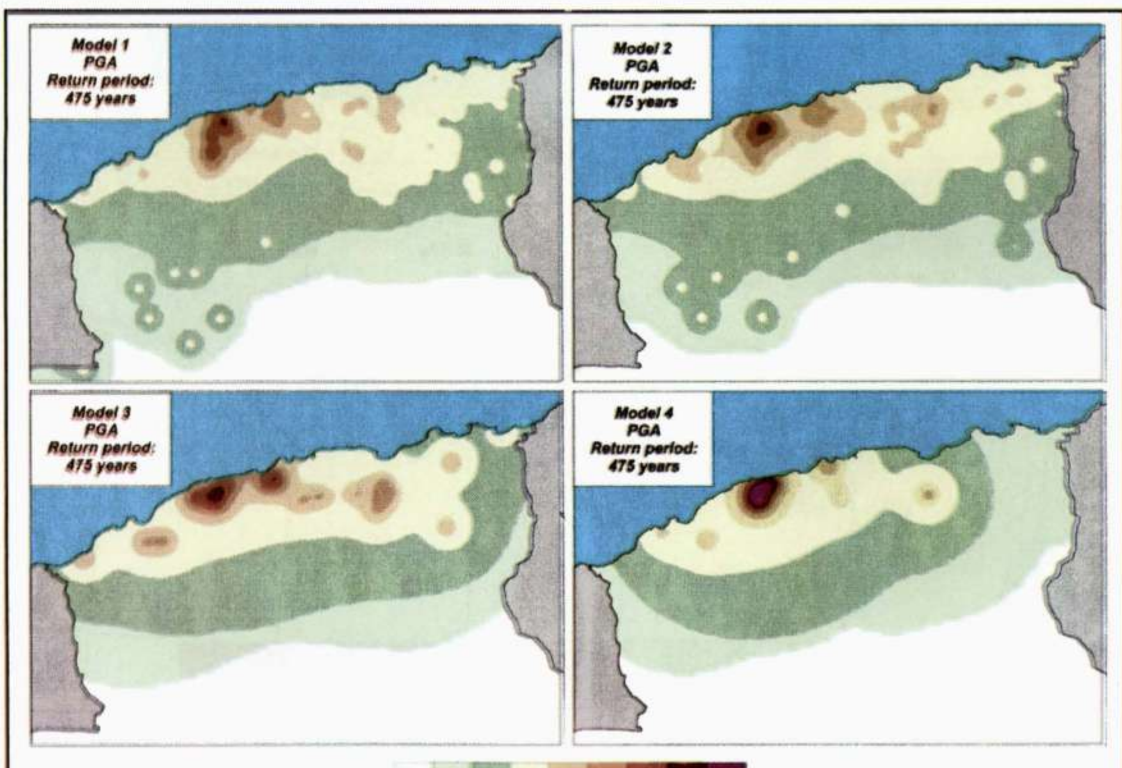

Fig. 5 - Seismic hazard maps in terms of PGA for a return period of 475 years, for the four seismic models.

Cartes d'Aléa sismique en termes de PGA pour une période de retour de 475 avis et pour chacun des quatres modèles

Using the weights explained previously, the figure 6 shows the seismic hazard map obtained for northern Algeria in terms of PGA for a return period of 475 years.

According to the obtained results in terms of PGA for a return period of 475 years, a preliminary seismic hazard zonification has been carried out (Pelaez and *al.*, 2005a, 2005b) using the guidelines by Giardini and *al.*, (1999).

5 - SPECTRAL ACCELERATION AND UNIFORM HAZARD SPECTRA.

From the smoothed earthquake, as explained in the previous section we compute the seismic hazard using the well know total probability theorem expressed in terms of rate of exceedance of a certain level of ground motion parameter. In this section we use the spectral acceleration for rock soil and 5 % damping. We use the Ambraseys and *al.*, (1996) attenuation model which could be written as follow:

$$\log y = C_1 + C_2 M + C_3 \log r + \varepsilon, \quad r = \sqrt{d^2 + h_0^2}$$

In this relationship C_1, C_2, C_3 *and* h_0 are coefficient depending on the periods, log y is dependent variable (log of spectral acceleration), M is the Ms magnitude, and d is the Joyner-Boore distance (Joyner and Boore, 1981) usually denoted r_{jb}, and μ standard deviation which depends on the periods.

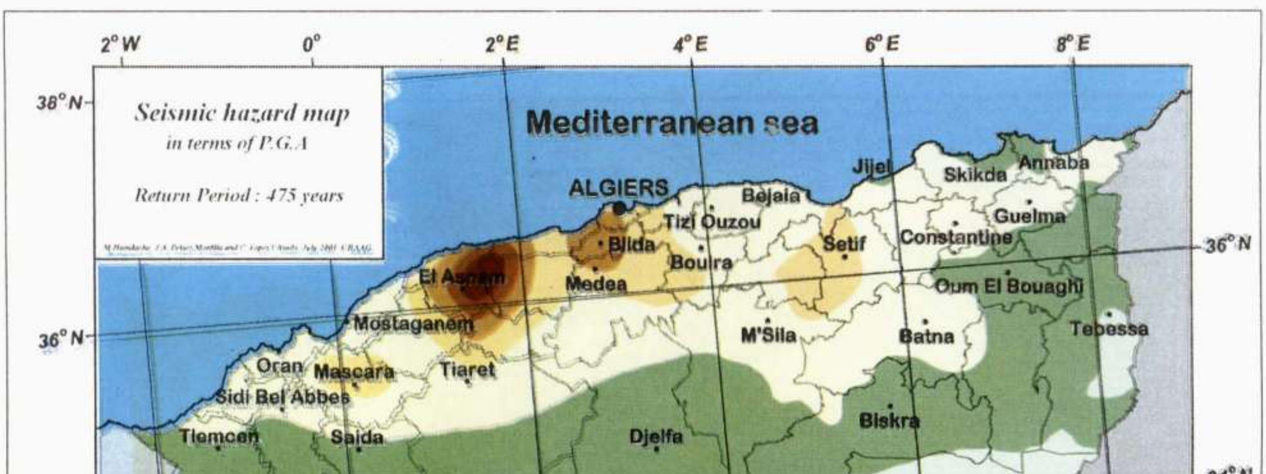

Fig. 6 - Seismic hazard map for northern Algeria in terms of PGA acceleration with 10 % probability of exceedance in 50 years.

Cartes d'Aléa sismique en termes de PGA avec 10% de probabilité de dépassement en 50 ans

We are deriving SA values for rock ($V_s >$ 750 m/s), corresponding to soil type A in Eurocode 8 (EC 8, 1998) and S1 in the Algerian building code (RPA, 1999 revised 2003), damped at 5%, at periods of 0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 1.5 and 2.0 s. the results obtained could be adjusted to other level of damping by using the procedure developed in 2000 by the International building code (ICC, 2000) for adjusting 5 % damping spectra to other level of damping.

These adjustments are given by the equation

$$SA\mu = SA_{5\%} / C(\mu)$$

Where $C(\mu)$ is the corresponding damping adjustment factor. Newmark and Hall (1982) proposed C values or more recently Naeim and Kircher (2001) give more reliable values, for example $c(10\%) = 1.239$ $\sigma = 0.133$. The results obtained in northern Algeria are shown in figure 8.

The Uniform Hazard Spectra (UHS) computed at the selected cities among the most important and populated city in northern Algeria is shown in figure 9.

6 - CONCLUSIONS.

In this study we summarised the most important recent results in seismic hazard estimation in northern Algeria by Pelaez and *al.*, (2005a and 2005b). The spatially smoothed seismicity has been used to derive probabilistic

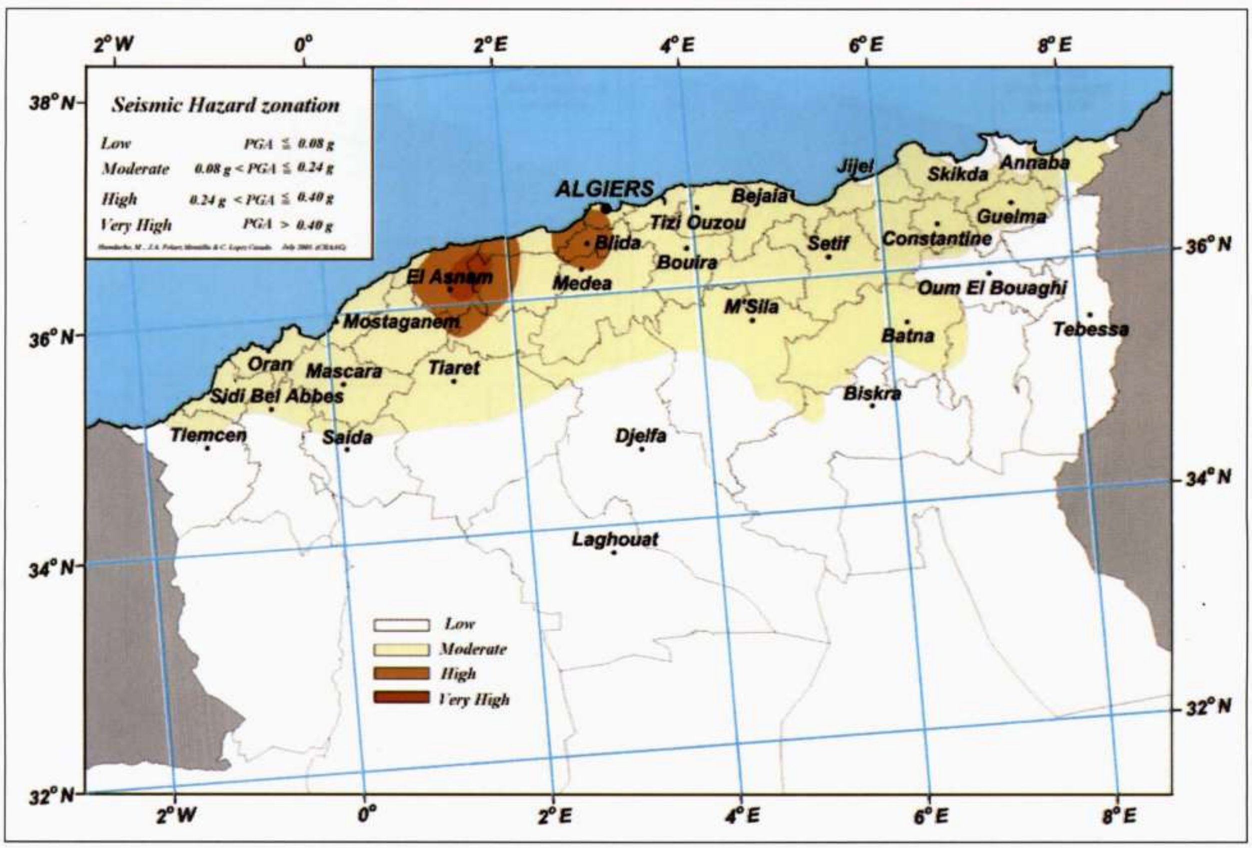

Fig. 7 - Seismic hazard zoning in northern Algeria.

Zonage de l'Aléa sismique en quatre niveaux faible, modéré, fort et très fort

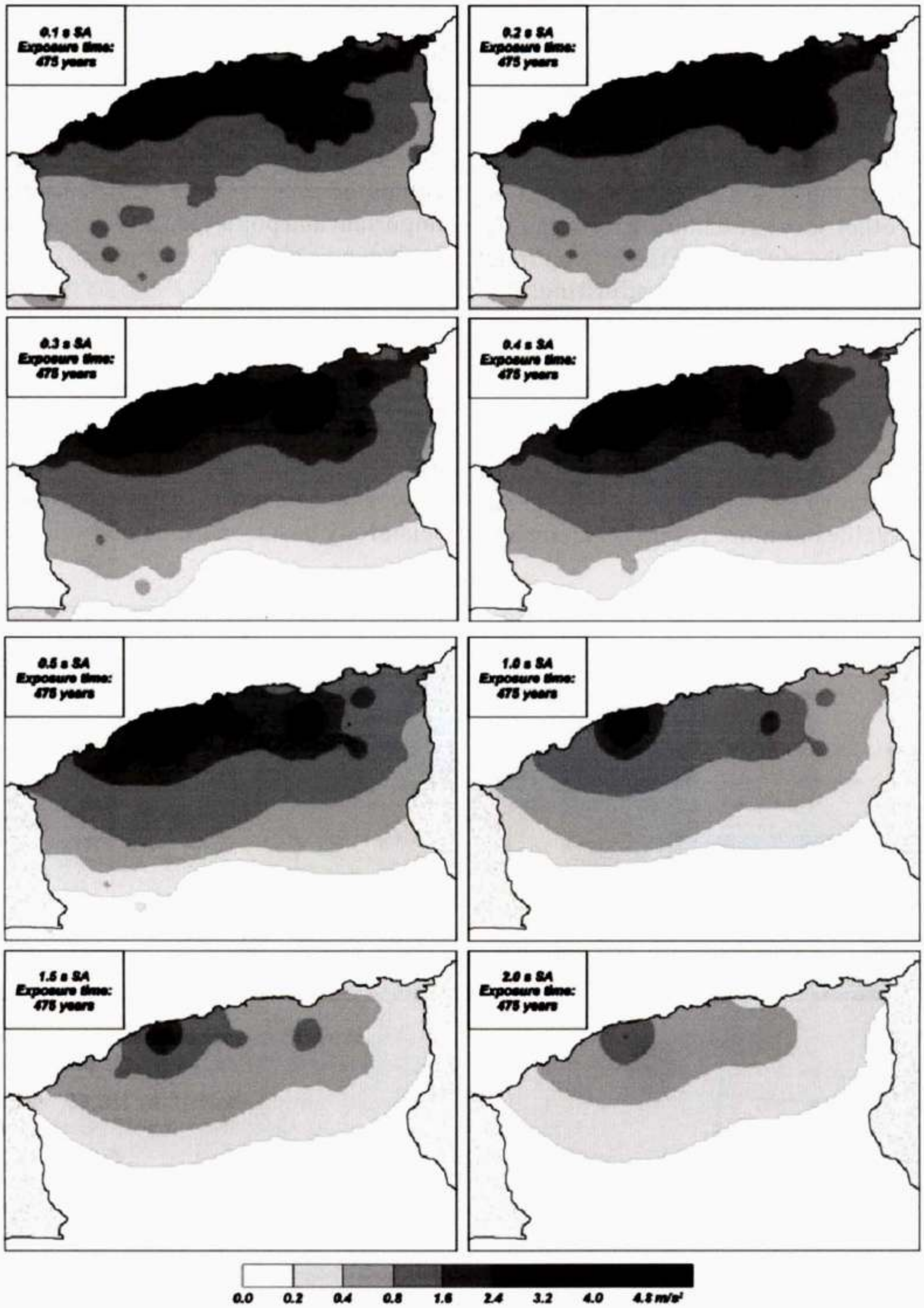

Fig. 8 - Seismic hazard in terms of SA for rock and 5 % damping at different period 0.1 to 2.0s for a return period of 475 years.

Aléa sismique en termes de spectrale accélération (SA) sur le rocher et pour 5% d'amortissement pour les périodes 0.1s à 2.0s et pour une période de retour de 475 ans

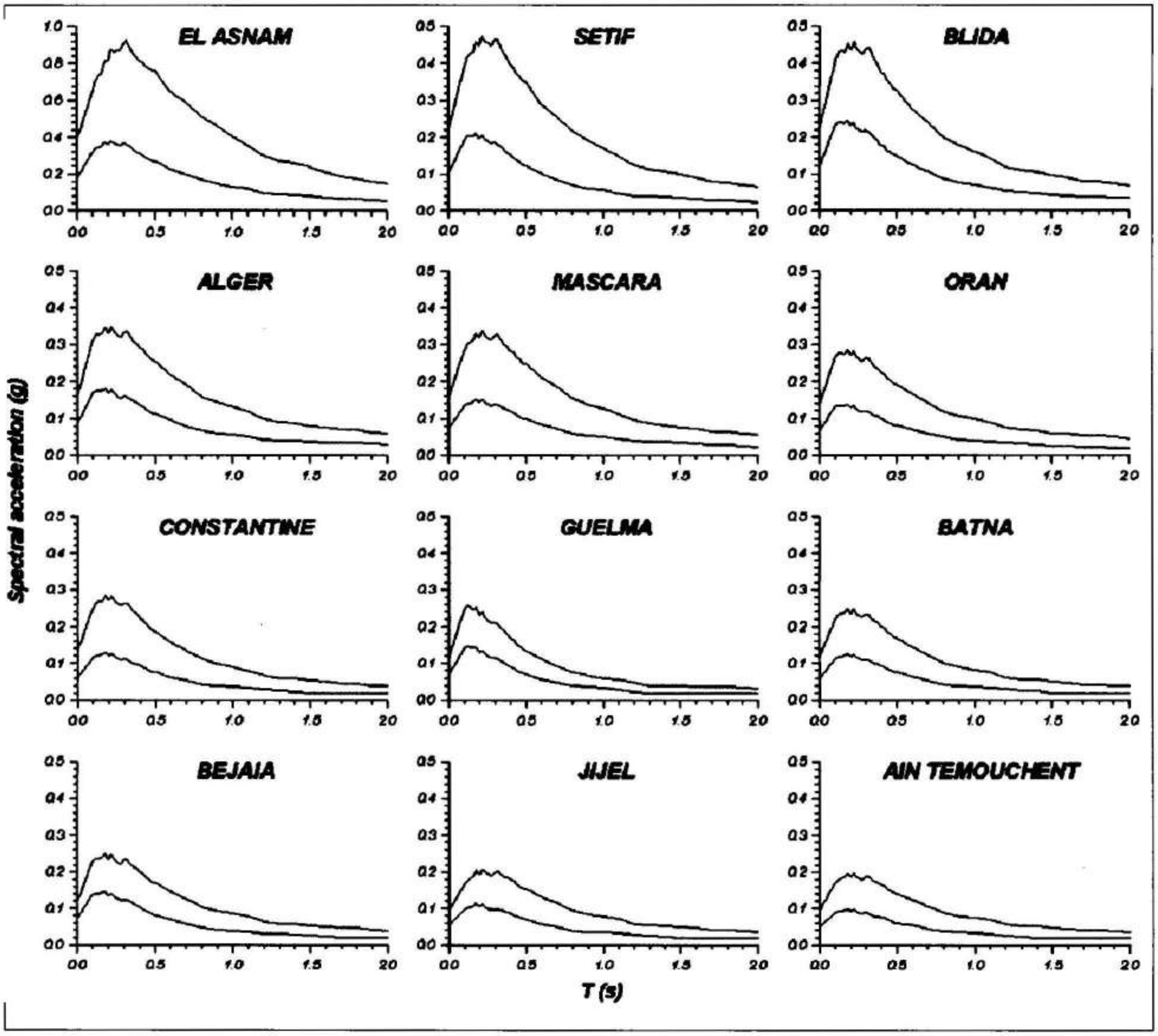

Fig. 9 - UHS (for rock and 5% damping) with 39.3% and 10% probability of exceedance in 50 years for 12 selected cities in northern Algeria. The unit of the y-axis is in g ($g \approx 10m/s^2$)

Spectre uniforme (sur le rocher et à 5% d'amortissement) avec 39.3% et 10% de probabilité de dépassement en 50 ans pour 12 grands sites urbains en Algérie du Nord. L'unité de l'axe des ordonnées est en pourcent du gal ($g \sim 10m/s^2$)

seismic hazard in northern Algeria in terms of PGA and SA for rock soil damped at 5%.

We have presented the obtained results as SA maps at different periods with 10% probability of exceedance in 50 years, which correspond to a return period of 475 years. Besides, the UHS have been derived at twelve of the most important cities of northern Algeria. Some characterics of the obtained results have been explored in Pelaez and *al.*, (2005a and 2005b). Especially from the seismic hazard maps, it has been noticed that high values are observed in the central part of the Tell, with some very well defined areas and slow decay also toward the east and west respectively. Such areas appear to be related to the regional geological context, with known geological structures being potentially active. It is also important to note that the morphology of the distribution of the seismic hazard level bands is clearly affected by the distribution of the seismicity, i.e, higher spatial density of moderate and large earthquakes implies a higher seismic hazard. Great attention has been devoted to the last major earthquake which occurred near the Algiers city (Hamdache and *al.*, 2004a), to evaluate clearly the contribution of this new event in the seismic hazard evaluation (Hamdache and *al.*, 2004b; Pelaez and *al.*, 2005a)

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