SPECTRAL GROUND-MOTION PREDICTIVE MODEL FOR ALGERIA CONSIDERING SITE EFFECT BASED HVSR

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Abstract

A local site condition profoundly affects the ground motion record characteristics, and has an important impact on the accurate of the empirical ground motion prediction relations. Based on a large database containing 1555 records homogeneously processed with more than 600 recorded in Algeria and the rest from essentially Mediterranean region, this study aims to develop a spectral ground motion predictive model for Algeria which has experienced several destructive earthquakes in the past. As for Algerian tectonic environment, only shallow earthquakes were included. The data ranges are 5 to 150 Km for distance, and 3.0 to 7.8 for magnitude. The considered spectral attenuation model accounts for geometrical spreading, anelastic attenuation, and geological site conditions. The regression method, introduced by [1], is a two-step inversion [2, 3]. The attenuation model describes the evolution of spectral acceleration according to magnitude, hypocentrale distance, and category of the site.

The site classification is based on the predominant period computed using average horizontal to vertical response spectral ratio. Four site categories are defined according to [4] classification scheme. Because of the reduced number of records for very soft soil, we consider three soil types for the calculation of the empirical ground motion prediction relations: rock, firm and soft. Spectral attenuation laws were derived from 1555 horizontal components. The introduction of a more accuracy site classification leads to significantly lower prediction of average spectral acceleration at rock site. Moreover, in Algeria, unlike the seismic zones 3 and 2b, which are characterized by moderate to high seismic activity, for areas with low seismicity as it is the case for seismic zones 1 and 2a who represent a broad range of Algerian territory, considering a low magnitude equal to 5.0, leads to significantly higher prediction of average spectral acceleration.

Keywords: Algeria; GMPE; HVSR; Site effect

1. Introduction

Algeria is located on the northern edge of the African plate, which is converging with the European plate since the Mesozoic, with a shortening rate of about 4-8 mm/yr [5, 6, 7]. Northern Algeria is a highly seismic area, as evidenced by the historical (1365 to 1992) seismicity [8, 9, 10]. During the last three decades, northern Algeria experienced several destructive moderate-to-strong earthquakes.

In order to perform probabilistic seismic hazard analysis (PSHA) it is necessary to have GMPE which relate, in probabilistic terms, magnitude and source-to-site distance with the intensity measure of interest, usually peak ground or spectral accelerations. The lack, until recently, of strong motion data in Algeria, and the pressing need for studies of seismic hazard in different potentially seismic regions, motivated the use of American and European attenuation laws [11, 12] as considered most appropriate to the Algerian context. In this study, it has been intended to derive the attenuation relationships for PGA and PSA parameters using the earthquake records database which includes more than 1,000 records obtained since 1980. Local site conditions profoundly affect the ground motion record characteristics, and have an important impact on the accurate of the empirical ground motion prediction relations. The site classification is based on the predominant period computed using average horizontal to vertical response spectral ratio.

Recently [4] proposed a site classification based on random field simulation and considering the criteria required by the Algerian seismic code [13]. Mean transfer functions are derived for each class of soil. Comparison with Kik Net data shows good correlation between the classification based on geophysical data and the proposed approach. In this work, this classification scheme is used to classify the recorded data provided by Algerian and European strong ground-motion database. Based on a large database containing 1555 records homogeneously processed with more than 600 recorded in Algeria and the rest from essentially Mediterranean region, emphasis is given on the proposal of appropriate spectral GMPE taking into account site effect.

2. Strong motion database

The lack of strong ground motion data was significantly experienced when elaborating the first Algerian aseismic building code in 1976. It was therefore decided to implement a countrywide accelerometer network. The installation of 335 3-component accelerographs started in 1980, 270 of which are already installed in the free field and 30 in structures (buildings, dams …etc.). During the last three decades, northern Algeria experienced several destructive moderate-to-strong earthquakes. Since the 1980 El Asnam earthquake (Ms 7.3), which claimed over 2700 lives and destroyed about 60 000 housings, many moderate, but destructive, earthquakes occurred with magnitude larger than 5.0, such as the Constantine October 27, 1985 (Ms 5.7), Chenoua October 29, 1989 (Ms 6.0), Mascara August 18, 1994 (Ms 5.6), Algiers September 4, 1996 (Ms 5.6), Ain Temouchent December 22, 1999 (Ms 5.6), the Beni Ourtilane November 10, 2000 (Ms 5.5), the Boumerdes May 5, 2003 (Mw 6.8), the Laalam March 20, 2006 (Ms 5.0), the Chlef December 12, 2006 (Ms 5.2) and the Oran June 06, 2008 (Ms 5.5).

The Algerian strong motion database contains 86 seismic events (main shock and aftershocks) and about 633 horizontal motions. The strongest one is the destructive 05.21.2003 Boumerdes earthquake (Mw = 6.8). About 922 ESM Database and few American records collected from USGS and the California Division of Mines and Geology (CDMG) strong motion database are also used in this study (see distribution M-D on Fig. 1).

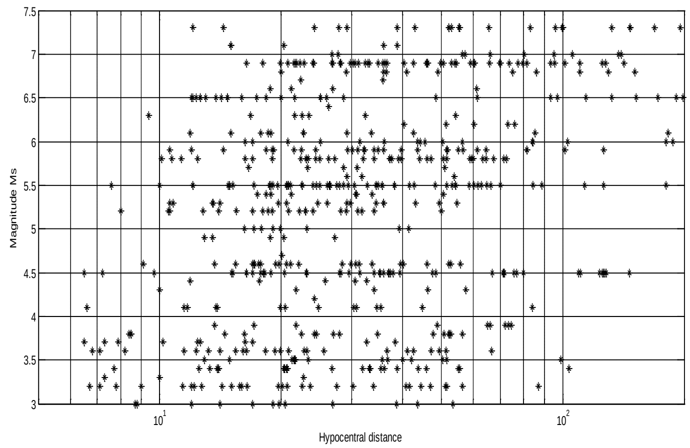


Fig. 1 : Magnitude and distance distribution of the recorded database.

3. Strong motion records site classification

In the recent years, it has been shown that NHV for noise and EHV for seismic motions can supply useful information about the resonance properties of the shallow subsoil and represent a cost-effective tool for microzoning studies and site classifications and characterization of accelerometric networks which represent an important field of potential application of HVSR measurements. On the other hand, when the number of accelerometric sites is of the order of hundreds as is, the case of the Algerian accelerograph network, the application of intensive seismic surveys (e.g., cross-hole or down-hole) requires funds well beyond those commonly allocated on purpose. Actually, microtremor measurements providing direct information on the resonance soil frequencies allow the application of classification schemes alternative to those based on the single $V_{S,30}$. In this way, several alternative classification schemes have been proposed [4, 14, 15, 16, 17] that are based on the use of fundamental/predominant resonance frequency by alone or in parallel to the $V_{S,30}$.

In the scheme proposed by [4], average transfer function for each design site classified in the RPA99 (Table 1) are computed based on shear velocity random field simulation associated with intensive seismic response analysis. The proposed criteria based on the fundamental frequency of each station are shown in Table 2. A classification based on the predominant period of each record and each station identified through the average H/V spectral ratio of the 5%-damped response spectra is done for the entire strong motion database.

Table 1. Site classification (accord ing to Table 3.2 from RPA99).

Soil Class	Mean value of Vs (m/s)
S1 Rock	$V_s \geq 800$
S2 Firm	$V_s \geq 400$
S3 Soft	$V_s \geq 200$
S4 Very soft	$V_s < 200$

Table 2 Criteria defined by Beneldjouzi and Laouami (2015).

Site Class	Fundamental frequency (Hz)
S1	$f_0 \succ 7.0$
S2	$3.76 \prec f_0 \leq 7.0$
S3	$1.53 \prec f_0 \leq 3.76$

S4	$f_0 \leq 1.53$

Fig. 2 shows as example the obtained classification for the Bouzareah, Hadjret Ennous, Mohamadia and Isser stations classified respectively as rock (S1 class according to RPA99 Algerian seismic code), firm, soft and very soft soils. Based on this methodology, 1555 records from Algeria and the Mediterranean region are classified with the following proportion (Table 3).

Table 3: Classification of the used strong motion database.

Class of soil	S1	S2	S3	S4
Record number	675	594	244	42

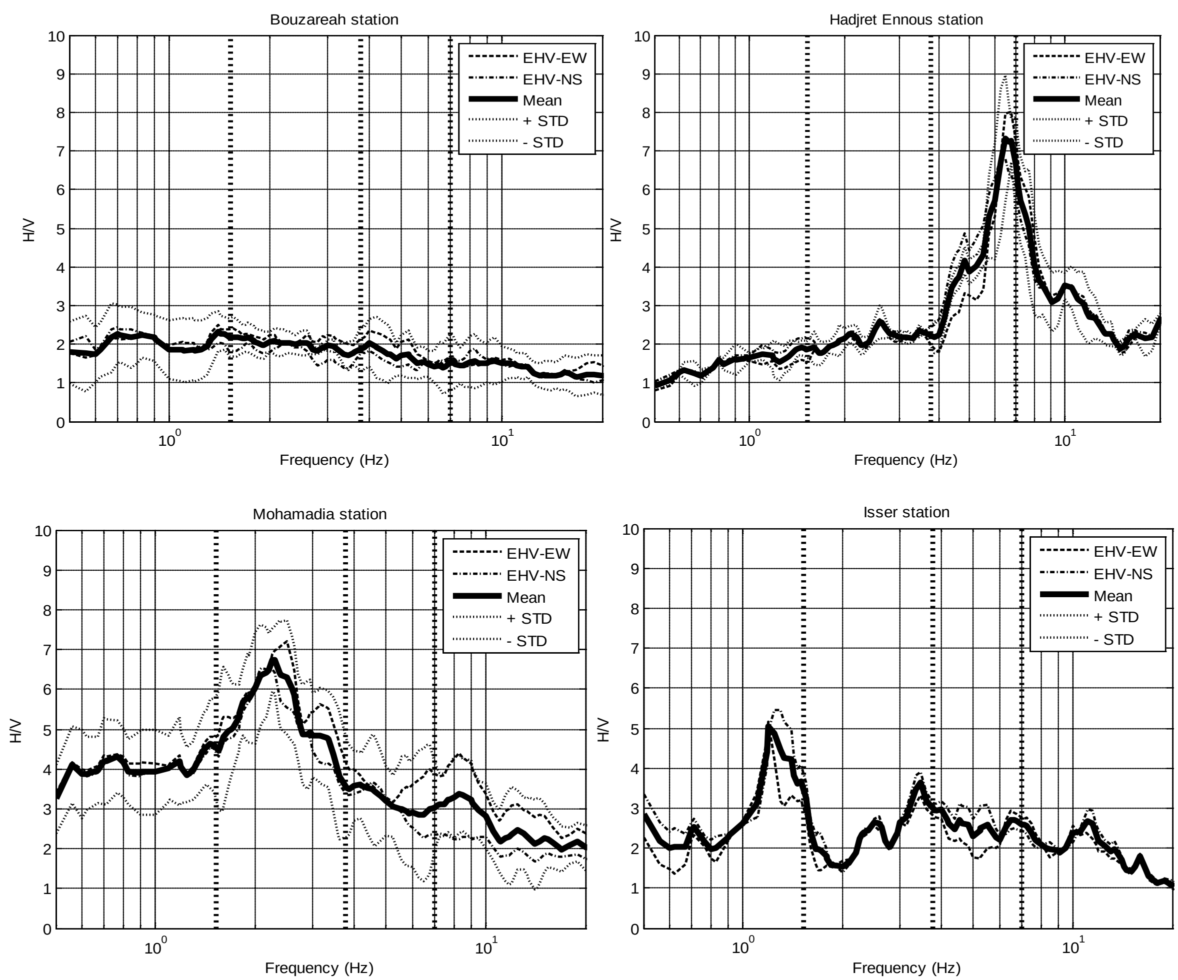


Fig. 2. Shows examples of stations that were classified according to [4] classification scheme respectively as S1 (top left), S2 (top right) S3(bottom left) and S4 (bottom right).

4. Developed GMPE for Algeria considering site effect

4.1. Model

The attenuation model considered in this study to predict the seismic motion in terms of response spectrum accounts for geometrical spreading, anelastic attenuation and geological site condition. This model needs three parameters: magnitude, distance and site condition. The regression introduced by [1], follows the two-step method [2, 3], which considers independently the magnitude and the distance. The GMPE describes the evolution of the spectral acceleration, PSA(f), with respect to the Ms magnitude, the hypocentral distance and the soil category, following Eq. 1,

$$\log10\ PSA(f) = a(f).M + b(f).d - \log10.d + c_{1,2,3}(f) \quad (1)$$

d being the hypocentral distance, and Ms the surface wave magnitude.

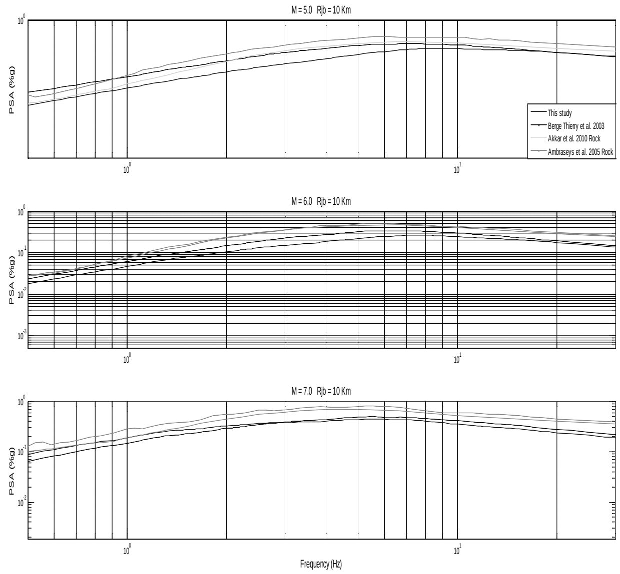
The b(f) coefficient is determined in the first step, and in the second step, a(f) and c1,2 coefficients are computed. Coefficients c_1, c_2 and c_3 are respectively for rock, firm and soft soil.

4.2. Results and discussions

Fig. 3 compares, for rock condition, and for magnitude Ms=5.0, 6.0 and 7.0, the spectral acceleration GMPE obtained for Algeria in the present study with worldwide used models, as [18, 19, 20]. Because each model has its distance definition, the conversion between distance scales developed by [21] was used. It result from the plotted curves, that the developed model gives relatively lowest PSA, compared to the published ones. This difference is probably due to the fact that the considered lowest magnitude is 3.0 for the present study, and 5.0 for the published models. This result shows that the minimum magnitude influences the prediction of the attenuation model particularly in low seismic activity regions. Also, we have introduced a strong motion record site classification based on the HVSR fundamental frequency. A good classification of the strong motion database leads to a best prediction of the GMPE for rock condition characterized by relatively lower PSA.

Fig. 4 shows comparison between the predicted PSA obtained for Rock, Firm and soft soil. As expected, the model lead to amplification in the case of soft soil and firm soil compared to the rock soil condition. This amplification which is related to site factors is more pronounced in low frequencies, which is in agreement with the site effect phenomenon.

Fig. 5 presents the computed residual values, the difference between the observed and the predicted values of the spectral acceleration at 0.5 Hz, 1 Hz, 10 Hz and PGA, with respect to the hypocentral distance. In the distance range of the data distribution, residual values are nearly symmetrical with respect to zero. On the figures the standard deviation of the attenuation law at the associated frequency is also plotted. The figures show the relative scarcity of data at low frequencies (f=0.5 Hz), but do not exhibit any systematic bias (large residual values) associated to a specific distance range.



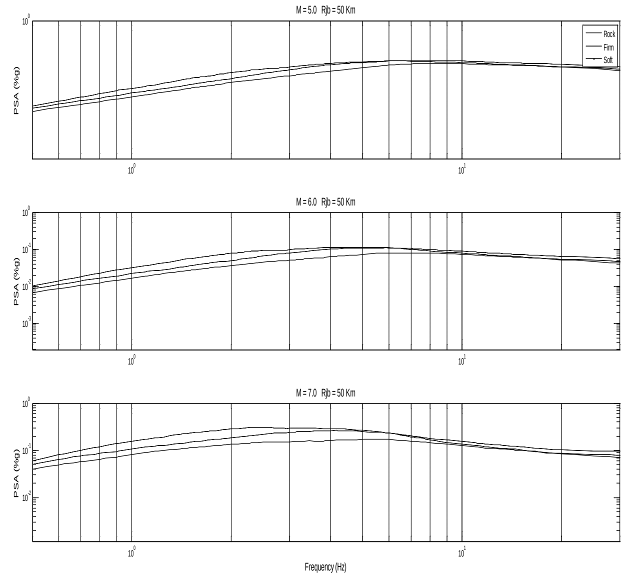


Fig. 3. Predicted PSA compared to Worldwide GMPE's

Fig. 4. Predicted PSA for rock, firm and soft soil.

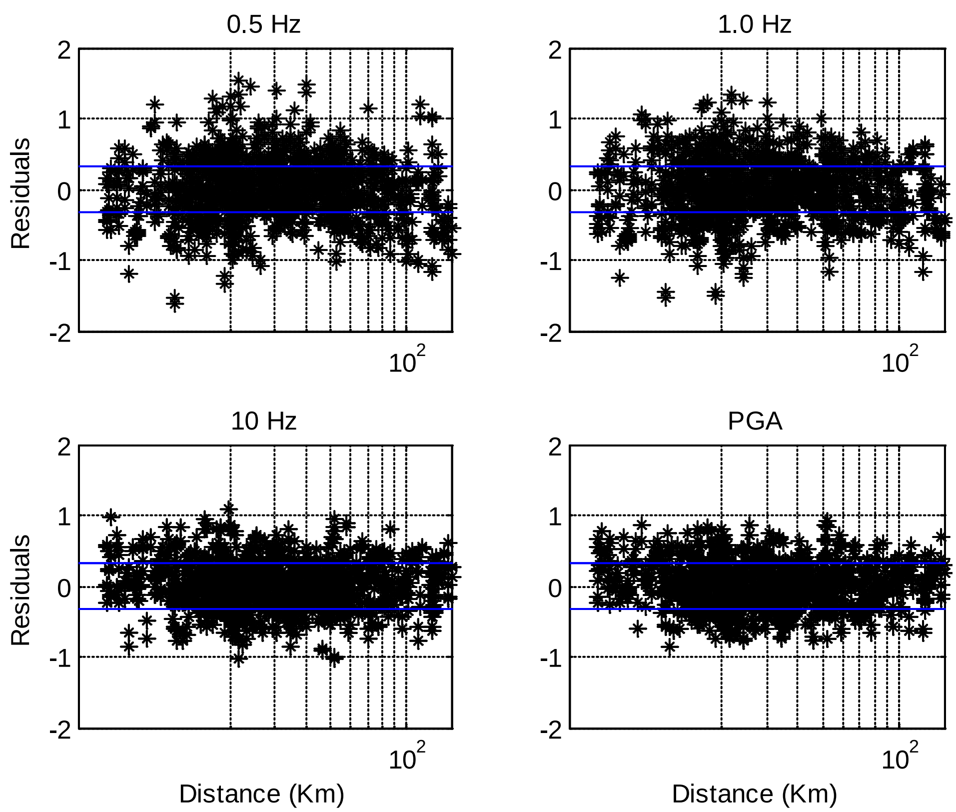


Fig. 5 : Residuals between predisted and recorded acceleration versus distances for frequencis 0.5, 1.0, 10 Hz and PGA.

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