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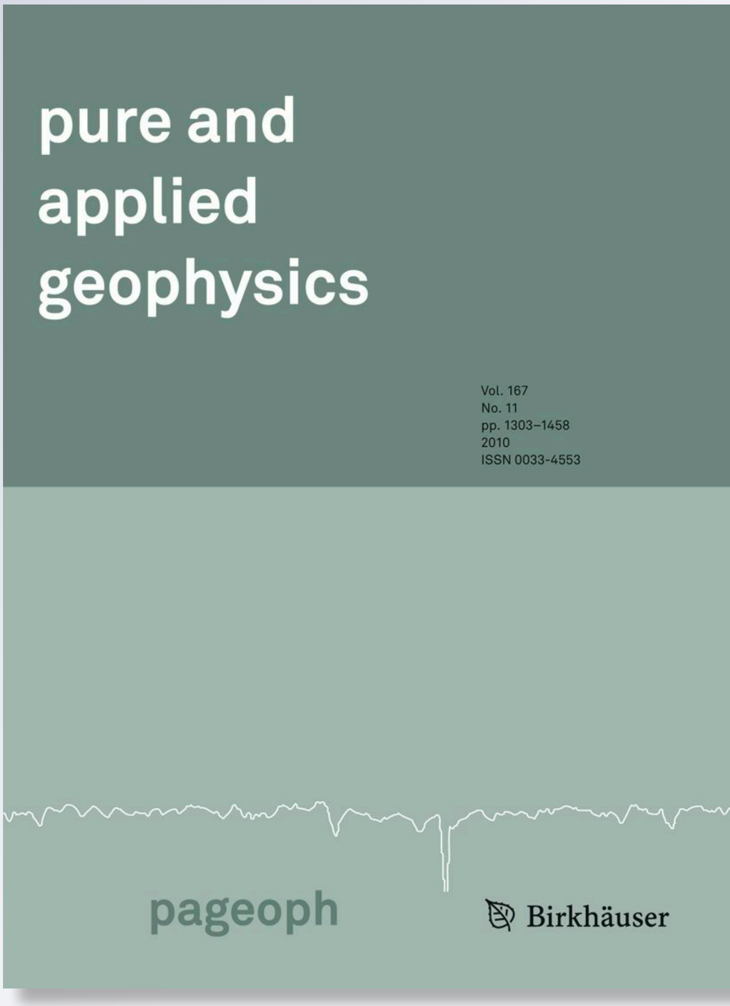

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Pure and Applied Geophysics

Ground-Motion Hazard Values for Northern Algeria

M. Hamdache,[1] J. A. Peláez,[2] A. Talbi,[1] M. Mobarki,[1] and C. López Casado[3]

Abstract—This study examines distinctive features of ground motion parameters in northern Algeria. An initial computation of seismic hazard in terms of horizontal peak ground acceleration (PGA) and spectral acceleration (SA) at different periods, damped at 5%, is carried out for three different types of soils (rock, stiff soils and soft soils) for return periods of 100 and 475 years. In addition, uniform hazard spectra (UHS) are computed for these two return periods at several locations in the region. Then, the UHS computed for different soil types are proposed as a starting point to define elastic design spectra for building-code purposes. We have used the well-known Newmark-Hall approach. As proposed in the most recent International Building Codes, the SA (0.2 s) value is used to establish the spectral region for lower periods (region controlled by acceleration), whereas the SA (1.0 s) value is used to establish the spectral region for intermediate periods (region controlled by velocity). We also obtained important relations, dependent on site condition, between SA (0.2 s), SA (1.0 s) or SA_{max} values, and the PGA, for both return periods of 100 and 475 years. Other relationships between PGA or SA_{max} values have also been derived for return periods of 100 and 475 years, in this case independent of site condition.

Key words: Seismic hazard, uniform hazard spectra, elastic design spectra, spectral acceleration, peak ground acceleration.

1. Introduction

Recent seismic activity in Northern Algeria, especially during the last 50 years, has included several damaging earthquakes. The El Asnam region suffered the most destructive earthquakes recorded in this region, 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 around 50 km northeast of Algiers (Hamdache *et al.*, 2004).

The interest of the scientific community regarding seismology and seismotectonics has greatly increased in Algeria in this context, especially in fields related to the seismic risk assessment of urban seismic areas and its possible reduction. It is well known that seismic hazard computation, whether deterministic or probabilistic, represents the most important tool to provide critical information on earthquake-prone areas to design engineers and planners.

In this study, we focus on the assessment of certain seismic hazard parameters for this region, i.e., horizontal peak ground acceleration (PGA) and spectral acceleration (SA) values, in order to improve the formulation of the seismic action aspect in earthquake-resistant building codes and to foster a better understanding of the correlation between seismic hazard values. The elastic design spectrum, as is well known, is typically the starting point for modern seismic codes, being more appropriate for design purposes than response spectra.

In this work, we present some new results of seismic hazard assessment, as well as typical relations between ground motion hazard parameters computed at 33 cities in northern Algeria with very different seismic hazard levels. Specifically, from the seismic hazard computed in terms of PGA and 5% damped uniform hazard spectra (UHS) at these cities, for return periods of 100 and 475 years, and for different soil types (rock, stiff soils and soft soils), we have derived characteristic relations between PGA, SA_{max}, SA (0.2 s), and SA (1.0 s) values. Moreover, from the UHS, and using the procedure by Malhotra (2005), we have obtained for each city (for both 100 and 475 year return periods) elastic design spectra based on the Newmark-Hall approach (Newmark and

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Hall, 1982), characterized only from SA (0.2 s) and SA (1.0 s) values. It is important to point out that the procedure is similar to the method proposed in recent versions of the International Building Code (ICC, 2009). In our study, it is observed that, independently of the return period, the SA (0.2 s) values are strongly related to PGA values both for rock and for stiff and soft soils. This dependence suggests that the [SA (0.2 s), SA (1.0 s)] pair or the [PGA, SA (1.0 s)] pair could be used in the proposed procedure to derive elastic design response spectra with practically the same reliability.

2. *Tectonic sketch and seismicity*

Northern Algeria, in the eastern part of the Ibero-Maghrebian region, is one of the most active seismogenic areas in the westernmost Mediterranean. Its seismicity is determined by compression between the Eurasian and African plates. The tectonic regime in this part of the Alpine chain has been mostly compressional since the early Cenozoic, with late Quaternary N–S to NW–SE convergence. This complex tectonic setting, inside an active deformation zone that absorbs 5–6 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). The main faults strike NE–SW and correspond to structures often organized in echelon systems of thrust faults dipping NW, such as the El Asnam, Tipaza, and Zemmouri faults (Meghraoui, 1986; Ayadi *et al.*, 2008).

An analysis of the distribution of earthquake epicenters over the last three centuries indicates that Algerian earthquakes occur mostly in certain Tell Atlas zones (see Fig. 1). However, a few earthquakes appear in the High Plateaus and in the Saharan Atlas. The seismicity analysis also shows that seismogenic areas lie in the vicinity of Quaternary basins. These tectonic zones (containing Neogene and Quaternary deposits) extend to the Messeta Basin (region of Oran) in the western Tell Atlas, in the centre to the Mitidja Basin (Tipaza-Algiers) close to the Blidean Atlas, to the Soummam, Constantine, and Guelma Basins in the eastern part, and to the Hodna Basin in the southeast, which is an integral part of the Tell Atlas. Although regional seismicity is characterized by the continuous activity of low to moderate ($5.5 < M_w < 6.5$) shallow earthquakes (Bezzeghoud and Buforn, 1999), the region has experienced several damaging earthquakes: those in the vicinity of Algiers on January 2, 1365 (I_{MM} = IX), February 3, 1716 (IX), March 17, 1756 (VIII), November 8, 1802 (VIII), and June 18, 1847 (VIII); those in the vicinity

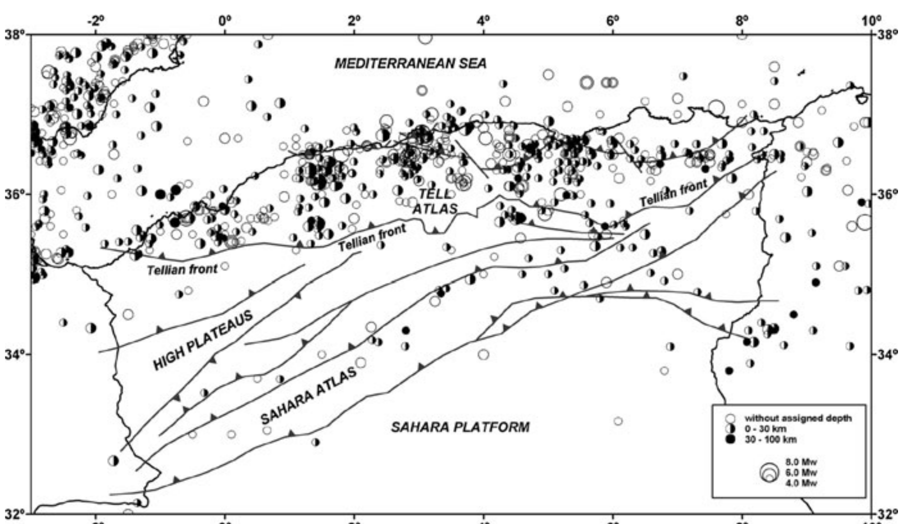

Figure 1
Seismicity and tectonic setting of northern Algeria (modified from Hamdache *et al.*, 2010)

of Oran, on October 9, 1790 (IX–X) and May 21, 1889 (VIII); the aforementioned ones in El Asnam, on September 9, 1954 (M_s 6.8) and October 10, 1980 (M_s 7.3); and the recent one in Zemmouri-Boumerdes, on May 21, 2003 (M_w 6.8, IX–X).

The earthquake catalog used in this study was compiled specifically for this area for seismic hazard purposes (Peláez *et al.* 2003), and later updated by Peláez *et al.* (2005). It consists mainly of the Ibero-Maghrebian catalog published by the Spanish Instituto Geográfico Nacional (IGN) (Mezcua and Martínez Solares, 1983), supplemented for the Algerian zone with data published by the CRAAG (CRAAG, 1994) and updated to 2002. The regional data published by the EMSC (European-Mediterranean Seismological Centre) and by the USGS (US Geological Survey) were also incorporated in the data file. All the magnitudes and intensities were converted to M_s magnitudes using the relationships suggested by López Casado *et al.* (2000). After testing other empirical relationships, such as the ones proposed by Benouar (1994) or CRAAG (1994), the relationships by López Casado *et al.* (2000) were found to be the most appropriate for the data file compiled. We used the methodology proposed by EPRI (1986) to identify and remove all the non-Poissonian earthquakes. Subsequently, the Poissonian character of the final catalog was analyzed by plotting the cumulative number of earthquakes, above different threshold magnitudes, versus time (Benjamin and Cornell, 1970). This check was a key step to establishing different complete and Poissonian seismic models to be used in the seismic hazard assessment (Peláez *et al.*, 2003, 2005; Hamdache *et al.*, 2007).

3. Methodology outline

For the seismic hazard assessment, as in the works by Peláez *et al.* (2003, 2005) and Hamdache *et al.* (2007), four complete and Poissonian seismic models were considered in the seismic hazard computation: (1) earthquakes above magnitude M_s 2.5 after 1960, (2) those of magnitude above 3.5 after 1920, (3) those above magnitude M_s 5.5 after 1850, and (4) those above magnitude M_s 6.5 after 1700.

The procedure was the standard one in the spatially smoothed seismicity methodology (i.e., Frankel, 1995; Peláez *et al.*, 2003). It combines zoned and non-zoned probabilistic methods. As in probabilistic zoned methods, seismogenic sources are delimited. In this study, seismogenic sources were defined as areas with seismic characteristics as homogeneous as possible, including a certain inference among seismicity and geological domains. Based on the work by Aoudia *et al*. (2000), some modifications were included in the seismogenic sources previously proposed (Hamdache, 1998; Hamdache *et al*., 1998; Hamdache and Retief, 2001) for northern Algeria. The geological description given in Aoudia *et al.* (2000) can be used to incorporate the geological knowledge in the seismogenic sources considered in this study.

Our assessment needs an appropriate attenuation relationship for spectral accelerations. Owing to the rate of great earthquakes in northern Algeria, as well as to the lack of an available strong motion regional database, we have adopted for the seismic hazard assessment the spectral acceleration attenuation relationship damped at 5% by Ambraseys *et al.* (1996).

In Peláez *et al.* (2005, 2006), seismic hazard values 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 and displayed. Figure 2 shows the results for PGA for a return period of 475 years. These results were examined and discussed in detail in Peláez *et al.* (2005).

4. Uniform hazard spectra and design spectra

A standard probabilistic seismic hazard assessment (PSHA) output is the UHS, that is, a response spectrum having uniform (or constant) probability of exceedance for all periods at the site. UHS does not represent the effect of just one earthquake, but instead the joint effect of earthquakes of different magnitudes and source-to-site distances. It is standard to find that the low period part of the UHS is controlled by the contribution of small to moderate earthquakes from nearby seismic sources, whereas the biggest earthquakes from distant sources affect the large period

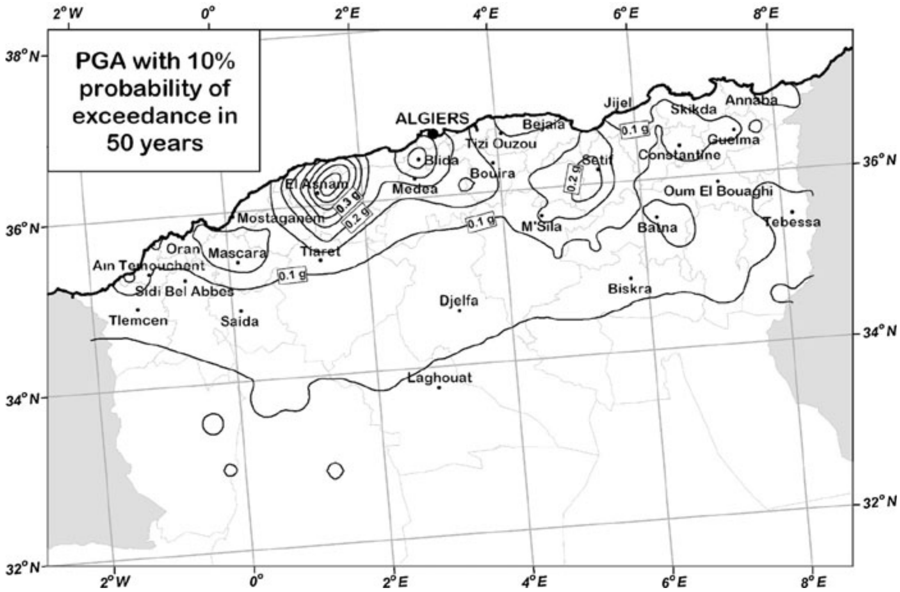

Figure 2
Seismic hazard values (PGA) for a 10% probability of exceedance in 50 years (475 year return period), for rock conditions, in northern Algeria (modified from Peláez *et al.*, 2005). Contour interval is 0.05 g

part of the spectrum (in the range of 0.5–2.0 s and beyond). It should be acknowledged that the UHS assumes that spectral ordinates at different periods are statistically independent of specific scenarios. It is established that, given a place and a certain soil type, spectral acceleration values increase when the return period increases, but they cannot be derived nor obtained from appropriate relationships; they must be computed for each return period and oscillation period. The UHS represents an appropriate probabilistic representation of the earthquake action, and it performs a key element in recent seismic design codes (Wen, 2004), such as the International Building Code (ICC, 2009), because it is a very efficient way of describing the seismic hazard and ground motion demand on a building or structure (Wen, 2004). It is considered the cornerstone of modern earthquake engineering and structural dynamics (Ebeling, 1992).

As proposed in the recent International Building Code (ICC, 2009), the SA (0.2 s) value is used to establish the spectral region controlled by acceleration, and the SA (1.0 s) value is used to establish the spectral region controlled by the velocity.

The current Algerian building codes do not propose an elastic design spectrum but a design spectrum depending on the following: (a) the seismic hazard level through a certain coefficient depending on the location (northern Algeria is divided into three areas, each one with a certain seismic hazard level) and on the importance of the building (buildings are catalogued in four different categories), (b) a “behavior coefficient” depending on the type of structure, and (c) a “quality factor” depending on certain characteristics of the building, including its redundancy, regularity and quality. The type of soil is included only in the selection of the spectrum characteristic period T_2, that is, the upper limit of the period of the constant spectral acceleration branch, not in the seismic hazard level of the location.

In this work, we have computed the UHS at 33 cities in northern Algeria with different seismic hazard levels, but in the estimated most seismic-prone area in Algeria (see Fig. 2). Calculations are carried out for three different soil types (rock, stiff soils and soft soils; classification by Ambraseys *et al.* (1996)) and for return periods of 100 and 475 years. Rock is characterized by v_S (30 m) values >750 m/s, corresponding to soil type A in the EC-8 (1998) classification and soil type S1 in the current Algerian Building Code (RPA, 2003). Stiff soil is characterized by v_S (30 m) values between 360 m/s and 750 m/s, corresponding to soil type B in the EC-8 classification and S2 in the Algerian building code. Finally, soft soil is characterized by v_S (30 m) values between 180 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 that previously proposed by Boore et al. (1994).

In order to obtain a high-definition spectrum and taking into account that the attenuation relationship by Ambraseys *et al.* (1996) allows it, 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 and 0.5 s, and a step size of 0.1 s between 0.5 and 2.0 s was used.

Figure 3 displays the results obtained at six places for the two return periods and for the three soil types considered.

From the computed UHS, different SA characteristic values for the chosen places are derived for the three soil types and for the two return periods. As well as PGA values, the maximum spectral acceleration value (SA_{max}), the period at which it is reached (T_{max}), and the SA values at 0.2 and 1.0 s are specifically computed. Table 1 displays all these computed values.

For return periods of both 100 and 475 years, the highest PGA and SA_{max} values are obtained in Ech-Chlef (formerly El Asnam). For a return period of 475 years, PGA values are 0.42, 0.44, and 0.45 g for rock, stiff soil and soft soil, respectively. At this location, maximum spectral acceleration SA_{max} values are equal to 1.32 g for rock and stiff soils, and 1.44 g for soft soils. In both cases, these values are reached at a period equal to 0.32 s. Considering a return period of 100 years, the PGA values are 0.19, 0.20, and 0.21 g, and the SA_{max} values are 0.41, 0.54, and 0.57 g for rock, stiff soil, and soft soil, reached at periods of 0.22, 0.30 and 0.26 s, respectively.

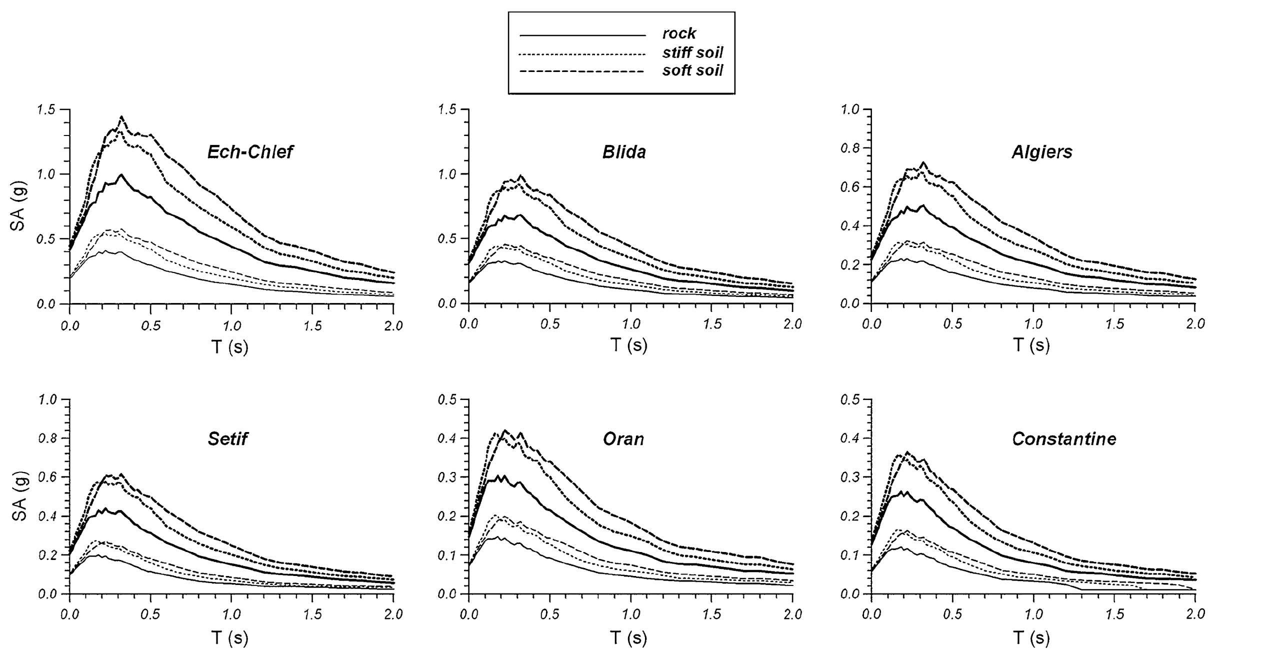

Figure 3
Uniform hazard spectra, damped at 5%, for different locations and soil conditions. *Thin lines*: return period of 100 years. *Bold lines*: return period of 475 years

Table 1

Seismic hazard values obtained at the northern Algerian locations

Location	Site condition	100 years					475 years				
		PGA (g)	SA_{max} (g)	T_{max} (s)	SA (0.2 s) (g)	SA (1.0 s) (g)	PGA (g)	SA_{max} (g)	T_{max} (s)	SA (0.2 s) (g)	SA (1.0 s) (g)
Algiers	Rock	0.111	0.232	0.18	0.220	0.080	0.228	0.503	0.32	0.466	0.206
	Stiff soil	0.118	0.313	0.16	0.301	0.108	0.242	0.674	0.30	0.636	0.760
	Soft soil	0.119	0.316	0.24/0.32	0.306	0.132	0.246	0.739	0.32	0.646	0.340
Oran	Rock	0.072	0.148	0.18	0.138	0.045	0.147	0.304	0.18	0.289	0.111
	Stiff soil	0.076	0.203	0.16	0.188	0.059	0.156	0.412	0.16	0.394	0.149
	Soft soil	0.077	0.200	0.18	0.191	0.074	0.158	0.421	0.22	0.400	0.161
Sidi Bel Abbes	Rock	0.049	0.102	0.22	0.096	0.038	0.086	0.196	0.32	0.178	0.087
	Stiff soil	0.052	0.136	0.16/0.18	0.131	0.051	0.092	0.261	0.32	0.244	0.116
	Soft soil	0.053	0.141	0.22	0.133	0.061	0.094	0.283	0.32	0.248	0.142
Mostaganem	Rock	0.075	0.158	0.22	0.149	0.057	0.132	0.291	0.32	0.270	0.126
	Stiff soil	0.079	0.212	0.16/0.18	0.203	0.075	0.139	0.388	0.30/0.32	0.368	0.169
	Soft soil	0.080	0.219	0.22	0.206	0.093	0.141	0.421	0.32	0.374	0.208
Medea	Rock	0.129	0.268	0.18	0.257	0.095	0.239	0.535	0.32	0.439	0.218
	Stiff soil	0.136	0.360	0.16/0.18	0.350	0.128	0.259	0.716	0.30	0.683	0.360
	Soft soil	0.138	0.376	0.22	0.356	0.157	0.255	0.775	0.32	0.672	0.293
Mascara	Rock	0.081	0.170	0.18	0.160	0.058	0.183	0.390	0.22	0.369	0.150
	Stiff soil	0.087	0.228	0.16/0.18	0.219	0.078	0.195	0.514	0.22	0.504	0.201
	Soft soil	0.088	0.235	0.22	0.222	0.096	0.198	0.555	0.22	0.512	0.248
El Asnam	Rock	0.193	0.408	0.22	0.387	0.149	0.416	0.995	0.32	0.865	0.441
	Stiff soil	0.205	0.539	0.30	0.529	0.199	0.443	1.327	0.32	1.180	0.593
	Soft soil	0.209	0.569	0.26	0.537	0.246	0.450	1.442	0.32	1.200	0.731
Tlemcen	Rock	0.038	0.077	0.22	0.073	0.028	0.070	0.149	0.32	0.141	0.060
	Stiff soil	0.039	0.103	0.16/0.18	0.097	0.036	0.074	0.200	0.22	0.193	0.081
	Soft soil	0.039	0.106	0.22	0.098	0.041	0.075	0.250	0.32	0.196	0.100
Tiaret	Rock	0.071	0.150	0.18	0.142	0.060	0.124	0.303	0.32	0.262	0.145
	Stiff soil	0.075	0.201	0.22	0.194	0.081	0.132	0.404	0.32	0.358	0.194
	Soft soil	0.076	0.215	0.32	0.179	0.100	0.134	0.439	0.32	0.364	0.239
Laghouat	Rock	0.022	0.049	0.18/0.22	0.045	0.010	0.038	0.087	0.32	0.077	0.040
	Stiff soil	0.025	0.063	0.18	0.059	0.025	0.039	0.116	0.32/0.40	0.107	0.057
	Soft soil	0.026	0.066	0.22	0.060	0.032	0.039	0.125	0.32/0.40	0.105	0.071
M'Sila	Rock	0.084	0.173	0.18	0.161	0.053	0.156	0.324	0.22	0.309	0.113
	Stiff soil	0.090	0.237	0.16	0.220	0.070	0.166	0.442	0.16	0.421	0.151
	Soft soil	0.091	0.234	0.22	0.224	0.085	0.169	0.450	0.22	0.428	0.186
Djelfa	Rock	0.039	0.085	0.22	0.078	0.037	0.063	0.148	0.30	0.134	0.075
	Stiff soil	0.040	0.112	0.22	0.106	0.048	0.069	0.202	0.32	0.181	0.098
	Soft soil	0.040	0.117	0.22	0.108	0.058	0.070	0.219	0.32	0.184	0.121
Tizi Ouzou	Rock	0.061	0.134	0.22	0.125	0.051	0.100	0.232	0.32	0.211	0.103
	Stiff soil	0.066	0.178	0.16/0.18	0.170	0.067	0.108	0.310	0.32	0.287	0.138
	Soft soil	0.068	0.185	0.22	0.173	0.081	0.109	0.336	0.32	0.291	0.170
Blida	Rock	0.159	0.329	0.22	0.315	0.108	0.314	0.685	0.32	0.638	0.264
	Stiff soil	0.170	0.442	0.16	0.429	0.145	0.334	0.920	0.30	0.871	0.355
	Soft soil	0.172	0.457	0.22	0.436	0.178	0.339	0.992	0.32	0.885	0.437
Batna	Rock	0.057	0.117	0.18	0.110	0.033	0.111	0.231	0.18	0.218	0.039
	Stiff soil	0.060	0.161	0.16	0.149	0.040	0.117	0.314	0.16	0.297	0.053
	Soft soil	0.060	0.158	0.22	0.152	0.051	0.119	0.318	0.22	0.302	0.063
Bejaia	Rock	0.070	0.145	0.18	0.135	0.039	0.114	0.240	0.18	0.226	0.800
	Stiff soil	0.074	0.200	0.16	0.183	0.053	0.119	0.331	0.16	0.308	0.109
	Soft soil	0.075	0.194	0.22	0.186	0.063	0.122	0.331	0.22	0.313	0.134
Biskra	Rock	0.037	0.074	0.18	0.069	0.023	0.059	0.132	0.22	0.120	0.052
	Stiff soil	0.038	0.099	0.16	0.093	0.032	0.062	0.173	0.18	0.165	0.058
	Soft soil	0.038	0.099	0.22	0.095	0.037	0.062	0.184	0.32	0.168	0.082

Table 1 *continued*

Location	Site condition	100 years PGA (g)	100 years SA_{max} (g)	100 years T_{max} (s)	100 years SA (0.2 s) (g)	100 years SA (1.0 s) (g)	475 years PGA (g)	475 years SA_{max} (g)	475 years T_{max} (s)	475 years SA (0.2 s) (g)	475 years SA (1.0 s) (g)
Bouira	Rock	0.080	0.171	0.18	0.160	0.059	0.138	0.304	0.22	0.284	0.124
	Stiff soil	0.086	0.230	0.16	0.219	0.078	0.148	0.404	0.30	0.388	0.166
	Soft soil	0.088	0.236	0.22	0.223	0.097	0.150	0.438	0.32	0.394	0.204
Constantine	Rock	0.058	0.117	0.16/0.22	0.113	0.033	0.128	0.262	0.22	0.141	0.079
	Stiff soil	0.061	0.166	0.16	0.154	0.040	0.136	0.357	0.16	0.342	0.106
	Soft soil	0.063	0.162	0.22	0.156	0.050	0.138	0.364	0.22	0.348	0.131
Jijel	Rock	0.051	0.105	0.18	0.097	0.033	0.079	0.175	0.22	0.163	0.066
	Stiff soil	0.054	0.143	0.16	0.133	0.040	0.085	0.232	0.16/0.18	0.221	0.087
	Soft soil	0.055	0.142	0.22	0.135	0.051	0.086	0.244	0.32	0.225	0.107
Setif	Rock	0.097	0.199	0.18	0.188	0.053	0.207	0.438	0.22	0.416	0.151
	Stiff soil	0.103	0.273	0.16	0.256	0.069	0.220	0.577	0.22	0.567	0.202
	Soft soil	0.105	0.270	0.22	0.260	0.084	0.224	0.615	0.32	0.577	0.249
Skikda	Rock	0.042	0.090	0.18	0.082	0.024	0.075	0.158	0.18/0.24	0.149	0.053
	Stiff soil	0.046	0.112	0.16	0.112	0.033	0.078	0.215	0.16	0.202	0.070
	Soft soil	0.047	0.119	0.22	0.114	0.038	0.079	0.213	0.24/0.32	0.206	0.085
Oun Bouaghi	Rock	0.038	0.075	0.22	0.072	0.021	0.060	0.134	0.22	0.124	0.050
	Stiff soil	0.039	0.103	0.16	0.096	0.031	0.064	0.176	0.18	0.169	0.065
	Soft soil	0.039	0.103	0.22	0.097	0.037	0.066	0.185	0.22/0.32	0.171	0.079
Tebessa	Rock	0.031	0.058	0.18	0.054	0.010	0.040	0.092	0.18/0.22	0.084	0.035
	Stiff soil	0.033	0.078	0.16	0.072	0.010	0.045	0.121	0.16/0.18	0.114	0.043
	Soft soil	0.033	0.077	0.22	0.073	0.026	0.046	0.125	0.22	0.116	0.054
Boumerdes	Rock	0.086	0.181	0.22	0.171	0.065	0.172	0.378	0.32	0.352	0.157
	Stiff soil	0.093	0.243	0.16	0.233	0.087	0.183	0.507	0.30	0.480	0.210
	Soft soil	0.091	0.252	0.22	0.237	0.107	0.186	0.548	0.32	0.488	0.258
Ain Benian	Rock	0.119	0.259	0.22	0.244	0.099	0.217	0.516	0.32	0.455	0.228
	Stiff soil	0.128	0.342	0.22	0.333	0.133	0.231	0.688	0.32	0.621	0.306
	Soft soil	0.130	0.361	0.22	0.338	0.163	0.235	0.748	0.32	0.631	0.377
Ain Defla	Rock	0.151	0.324	0.22	0.306	0.123	0.296	0.718	0.32	0.622	0.325
	Stiff soil	0.160	0.428	0.22	0.417	0.164	0.315	0.958	0.32	0.863	0.436
	Soft soil	0.163	0.450	0.30	0.424	0.203	0.320	1.040	0.32	0.849	0.538
Kherrata	Rock	0.081	0.171	0.12	0.156	0.039	0.137	0.288	0.12	0.268	0.083
	Stiff soil	0.087	0.236	0.16	0.213	0.054	0.145	0.397	0.16	0.365	0.112
	Soft soil	0.089	0.216	0.18/0.20	0.216	0.065	0.148	0.387	0.32	0.371	0.137
Annaba	Rock	0.040	0.086	0.18	0.079	0.010	0.080	0.169	0.18	0.158	0.050
	Stiff soil	0.044	0.118	0.16	0.108	0.030	0.086	0.230	0.16	0.215	0.065
	Soft soil	0.045	0.114	0.22	0.109	0.035	0.088	0.229	0.22	0.219	0.079
Sidi Abdellah	Rock	0.134	0.277	0.22	0.264	0.094	0.260	0.196	0.32	0.531	0.229
	Stiff soil	0.141	0.373	0.16	0.360	0.125	0.277	0.829	0.30	0.725	0.307
	Soft soil	0.144	0.385	0.22	0.366	0.154	0.281	0.768	0.32	0.737	0.378
Tipaza	Rock	0.127	0.266	0.18	0.256	0.100	0.239	0.553	0.32	0.498	0.234
	Stiff soil	0.135	0.358	0.18/0.22	0.350	0.135	0.255	0.738	0.32	0.679	0.314
	Soft soil	0.137	0.380	0.32	0.355	0.166	0.259	0.801	0.32	0.690	0.234
Guelma	Rock	0.064	0.133	0.12	0.119	0.028	0.119	0.234	0.12	0.211	0.055
	Stiff soil	0.069	0.182	0.16	0.162	0.036	0.162	0.318	0.16	0.287	0.072
	Soft soil	0.070	0.169	0.22	0.165	0.041	0.165	0.300	0.22	0.291	0.088
Saida	Rock	0.034	0.092	0.22	0.085	0.038	0.075	0.178	0.32	0.156	0.085
	Stiff soil	0.045	0.118	0.30	0.115	0.051	0.078	0.238	0.32	0.213	0.114
	Soft soil	0.046	0.127	0.22/0.32	0.117	0.060	0.079	0.258	0.32	0.216	0.140

In this study, the procedure developed by Malhotra (2005) based on the Newmark-Hall approach (Newmark and Hall, 1982) to establish a design spectrum is used. As explained by the author, the procedure is as follows.

(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

$$T_S = \frac{\mathrm{SA}\ (1.0\ \mathrm{s})}{\mathrm{SA}\ (0.2\ \mathrm{s})}\ 1\ \mathrm{s}$$

(b) Then, design spectra values are calculated by

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

The design response spectra obtained using the above equation (Malhotra, 2005) have been analyzed in detail, comparing them to the computed UHS and other estimated design spectra. Figure 4 displays in a single graph the plot of the EC-8 type-I spectra, our computed UHS, and the design response spectra obtained from the above method. This figure displays spectra computed at certain characteristics locations for the three soil types and for the two return periods considered.

Figure 4 shows the good agreement, regardless of the return period and soil type, between our computed UHS and the design spectra proposed in this study. The reason is that seismic hazard values for oscillation periods of 0.2 and 1.0 s are clearly representative of the UHS overall shape. In contrast, it is clear that EC-8 design spectra values, defined only from PGA values, are greater (well above in certain cases) than the UHS values and design spectra values proposed in this study, also regardless of the return period and soil type. It appears clear 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 with only two values, the computed spectral acceleration values for 0.2 and 1.0 s.

One parameter that causes significant differences between the shapes of the EC-8 design spectra and the design spectra proposed in this paper is the period from which we define the constant spectral acceleration branch in the spectrum, T_B in the EC-8, and $0.2{\cdot}T_S$ in the design spectrum. For EC-8 type-I spectra, T_B values are independent of seismic hazard level, depending only on soil conditions: 0.15 s for A and B soil types, and 0.2 s for C soil type. In the proposed design spectra, this period is dependent on the seismic hazard level, that is, on UHS values, being in all cases below T_B values. For example, 0.10 s for Ech-Chlef, 0.09 s for Algiers, or 0.08 s for Oran, for rock and for a return period of 475 years. For the same cities and for the same return period, these values are 0.12, 0.10, and 0.08 s for soft soils, respectively.

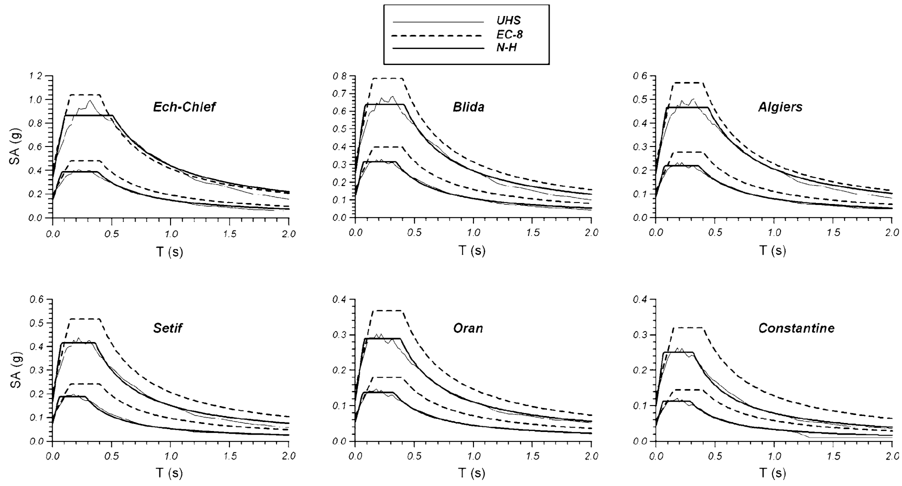

Figure 4

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

5. *Ground motion parameter relationships*

In this section, we focus on some relationships between ground motion parameters obtained in the previous seismic hazard assessment, in particular, PGA, SA_{max}, SA (0.2 s), and SA (1.0 s), for return periods of 100 and 475 years. Although more complex relationships were tested and could be employed, we have used in all cases the simplest one with a physical meaning, that is, a straight line passing through the origin. This relationship has proven to be accurate, as shown below.

The comparison between results obtained for the same ground parameter for return periods of 100 and 475 years gives typical relations (see Fig. 5 for the PGA, and Fig. 6 for the SA_{max}). In both cases, an evident linear relationship can be observed. These two relationships were inferred, using less data and only results for rock, in Peláez *et al*. (2006). Table 2 shows estimates for the slope and its standard error for the two fits. It must be noted that this relationship is practically independent of soil conditions.

These relationships imply 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 the 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). That is, from these results, we demonstrate 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.

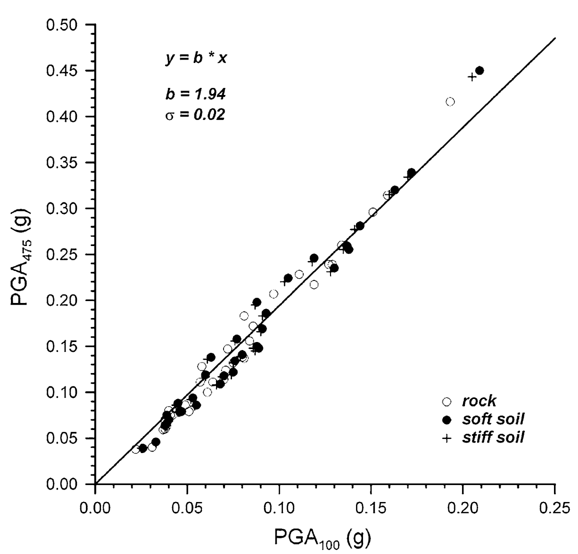

Figure 5
Plot of fitted model that describes the relationship between PGA_{475} and PGA_{100}

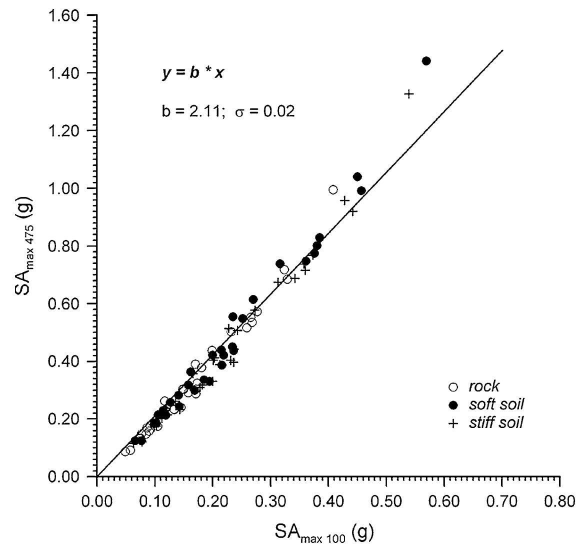

Figure 6
Plot of fitted model that describes the relationship between $SA_{max\text{-}475}$ and $SA_{max\text{-}100}$

Table 2

Estimate for the fit parameters and the standard error for fits in Figs. 5 and 6

Relationship	Site condition	b	σ_b
PGA_{475} vs. PGA_{100}	All	1.94	0.02
$SA_{max\ 475}$ vs. $SA_{max\ 100}$	All	2.11	0.02
PGA_{rock} vs. $PGA_{stiff\ soil}$	–	1.065	0.001
PGA_{rock} vs. $PGA_{soft\ soil}$	–	1.080	0.001

We have depicted the relationship between PGA values computed for stiff and soft soils versus PGA values computed for rock conditions (Fig. 7). As can be seen in this figure and in Table 2, we can also establish firm linear relationships between these parameters. Both plots are independent of the return period, which increases their meaning and significance. The effect of soil type on PGA values, when compared to rock, is an increase on the order of 6.5% for stiff soil, and on the order of 8.0% for soft soil.

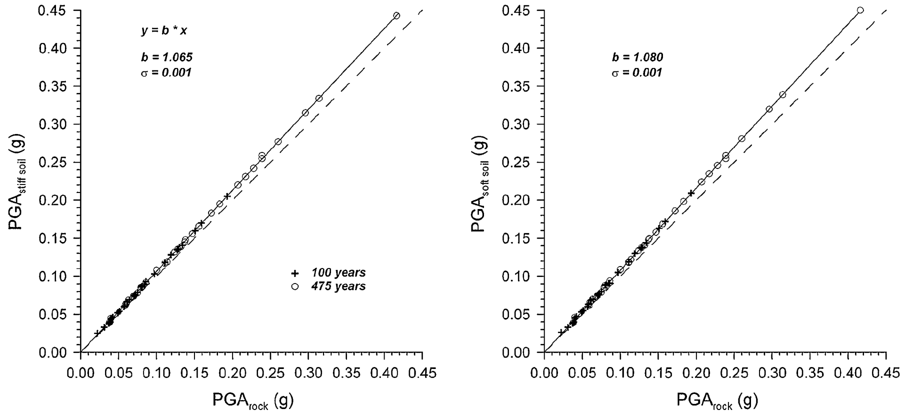

Figure 7
Plot of fitted models that describes the relationships between $PGA_{stiff\ soil}$ or $PGA_{soft\ soil}$, and PGA_{rock}. As a comparison, the *dashed line* is a straight line with a slope equal to 1.0

Evidently, these values are mainly induced for the attenuation relationship used.

From these relationships, inferring PGA values for stiff or soft soils from PGA values for rock in our study region is immediate and reliable. It can be confidently used for design purposes.

Other interesting relationships can be inferred from Fig. 8. We have studied the correlation between the SA_{max}, SA (0.2 s), and SA (1.0 s) parameters, and PGA, in this case, soil type and return period dependency. Table 3 shows estimates for the slope and its standard error for the different fits.

A very interesting result is the fact that SA (0.2 s) is also strongly related to PGA. For rock, SA (0.2 s) values are twice the PGA values. For stiff and soft soils, SA (0.2 s) values are 2.5–2.6 times PGA values. In both cases, fits are practically independent of return periods. This linear tendency between these parameters is one of the main results of the present study, and deserves more attention.

This dependency implies that we can derive the proposed design spectra using the pair [SA (0.2 s), SA (1.0 s)] or the pair [PGA, *SA* (1.0 s)] practically with equal reliability. It must be taken into account that the standard error of the slope of the SA (0.2 s) versus the PGA relationship, in all cases, is 0.01. Although there is also a clear linear relationship between SA (1.0 s) and PGA (see Fig. 8), the data are more scattered, with standard errors in the range of 0.02–0.04 (see Fig. 8 and Table 3). The reliability of these relations, although significant, is not as accurate as the relationship between SA (0.2 s) and PGA.

6. Conclusions

In this work, we propose Newmark-Hall type design spectra for northern Algeria from computed UHS, and investigate certain empirical relationships between computed ground-motion hazard parameters for different type of soils and return periods.

Concerning design spectra, and as has been proven in this work, a Newmark-Hall type spectra defined from SA (0.2 s) and SA (1.0 s) values agrees much better with computed UHS than required, for example, in the EC-8 code. Furthermore, proposed design spectra in this study, unlike current Algerian code, are dependent on soil conditions, not only through the characteristic periods but in the hazard level, i.e., the level of the constant spectral acceleration branch.

Moreover, several interesting relationships have been obtained between different ground-motion hazard parameters computed for several northern Algerian cities. Particularly deserving of attention are the return period-independent relationships between PGA values for stiff and soft soil types versus the PGA values for rock, as well as the return period-virtually independent relationships between SA

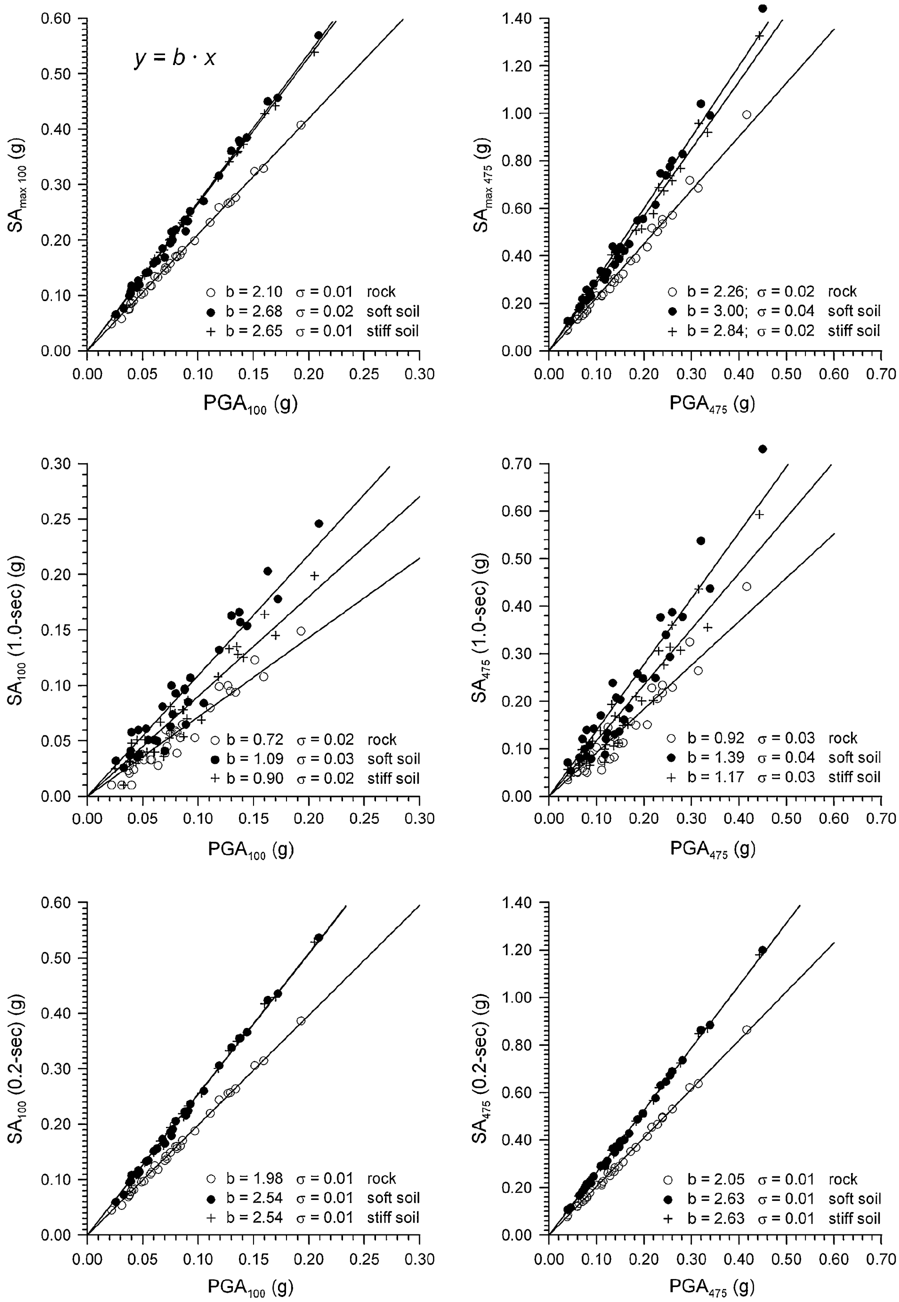

Figure 8
Plots of fitted models that describe the relationships between SA_{max}, SA(1.0 s) or SA(0.2 s), and *PGA*. Fits are conducted for return periods of 100 and 475 years and for the different soil conditions considered

(0.2 s) versus PGA values. The latter allow the equal use of either SA (0.2 s) values or PGA values in order to define proposed design spectra.

Less significant, although substantial, empirical relationships have been obtained from other computed parameters. For instance, relations independent of soil conditions 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.

Table 3

Estimate for the fit parameters and the standard error for fits in Fig. 7

Relationship	Site condition	100 years		475 years	
		b	σ_b	b	σ_b
SA_{max} vs. PGA	Rock	2.10	0.01	2.26	0.02
	Stiff soil	2.65	0.01	2.84	0.02
	Soft soil	2.68	0.02	3.00	0.04
$SA_{0.2\ s}$ vs. PGA	Rock	1.98	0.01	2.05	0.01
	Stiff soil	2.54	0.01	2.63	0.01
	Soft soil	2.54	0.01	2.63	0.01
$SA_{1.0\ s}$ vs. PGA	Rock	0.72	0.02	0.92	0.03
	Stiff soil	0.90	0.02	1.17	0.03
	Soft soil	1.09	0.03	1.39	0.04

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