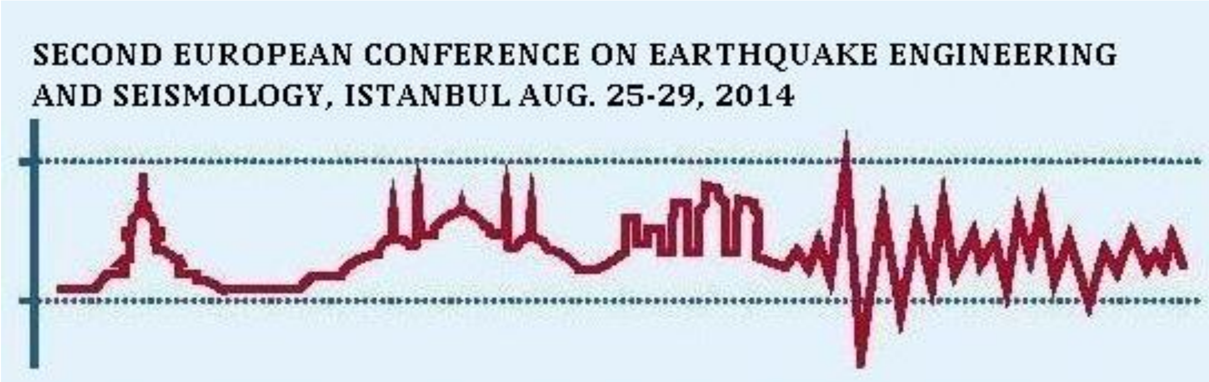

DERIVATION OF DESIGN SPECTRA BASED ON ALGERIAN STRONG MOTION DATABASE

Nasser LAOUAMI[1]

ABSTRACT

The present work has been exclusively based on recorded data provided by the Algerian strong ground-motion database. Emphasis is given on the proposal of appropriate design spectra and comparisons with Eurocod-8 and RPA-99 design spectra. The Algerian strong motion database contains 82 seismic events since the El Asnam earthquake 10.10.1980 (M = 7.3) up to the Oran earthquake 06.6.2008 (M = 4.5), 633 horizontal records and covers a 3.0 to 6.8 surface wave magnitude range and a 5 to 150 km hypocentral distance.

This work proposes a new site characterization approach to better classify the Algerian accelerograph network sites by considering the criteria required by the seismic codes. It aims to define a design HVSR amplification functions based on both the wave propagation theory and the building code soil classification. The obtained results show that the proposed spectrum has best fits with the experimental Algerian data and agrees with recent published spectrum.

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. Northern part is a highly seismic area, as evidenced by the historical seismicity and tectonic setting shown in fig. 1. During the last 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, 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), Beni Ourtilane November 10, 2000 (Ms 5.5) earthquakes and the 2003 (Ms 6.8), Boumerdes May 21 which caused considerable damages and claimed over 2300 lives.

Our contribution tries firstly to propose a new soil classification to better classify the Algerian accelerograph network sites by considering the criteria required by the Eurocode-8 and the HVSR functions derived from seismic motions measures. In the EC-8, four sites categories (A, B, C and D) are considered: Rock site, Stiff site, Soft site and very soft site. As it is well known, the shear wave velocity profile is rarely available in civil engineering or geotechnical engineering applications. In the recent years, it has been shown that HVSR can supply useful information about the resonance properties of the shallow subsoil and represent a cost-effective tool for microzoning studies and site classification. In the absence of reliable shear wave velocity profile, it should be noted that the actual design code are devoid of any design tools allowing to take advantage of the HVSR functions obtained from microtremor or seismic motions to classify the accelerograph stations.

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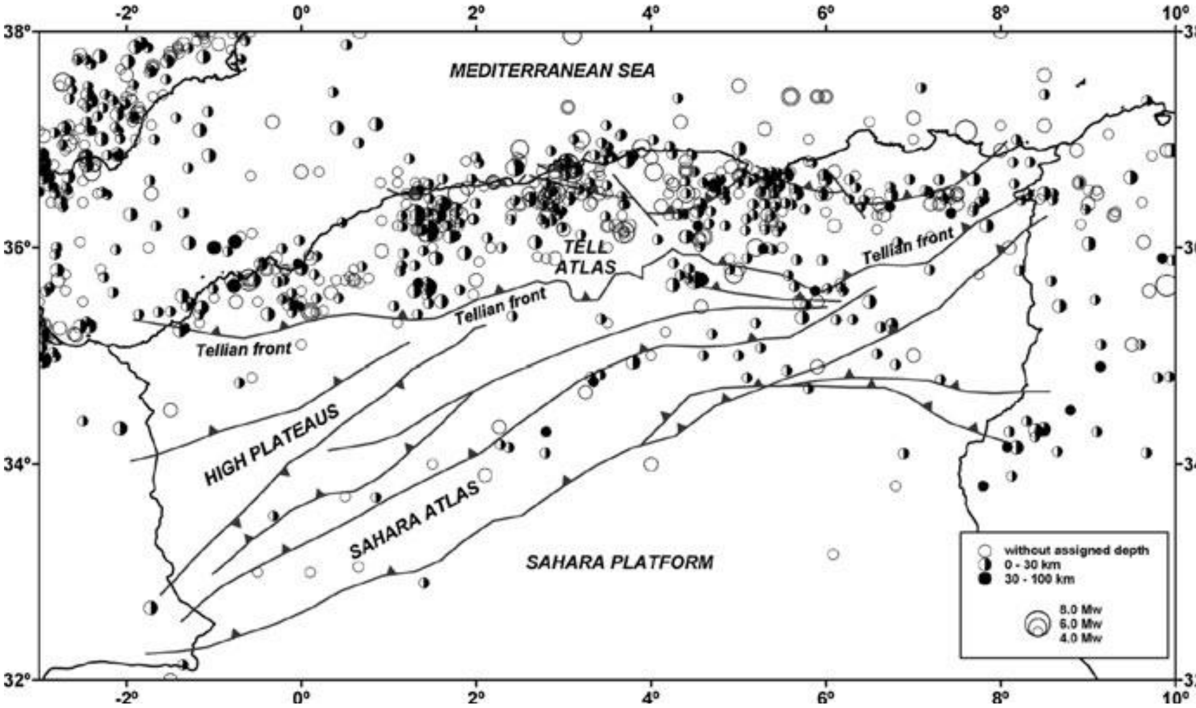


Figure 1. Seismicity and tectonic setting of northern Algeria (Redrawn from Hamdache et al., 2011)

THE ALGERIAN ACCELEROGRAPH NETWORK

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, 218 of which are already installed in the free field, and 30 in structures (buildings, dams …etc.) (Fig. 2). The network was acquired in three stages: (i) following the 1980 El Asnam earthquake, 90 analog SMA-1 accelerographs were installed mainly in the free field, (ii) in 1990, 80 SMA-1 analog and 40 SSA-1 digital accelerographs were acquired in order to densify the existing network, with more emphasis on structures (buildings, dams), and (iii) 125 Etna digital accelerographs, acquired in 2002-2003.

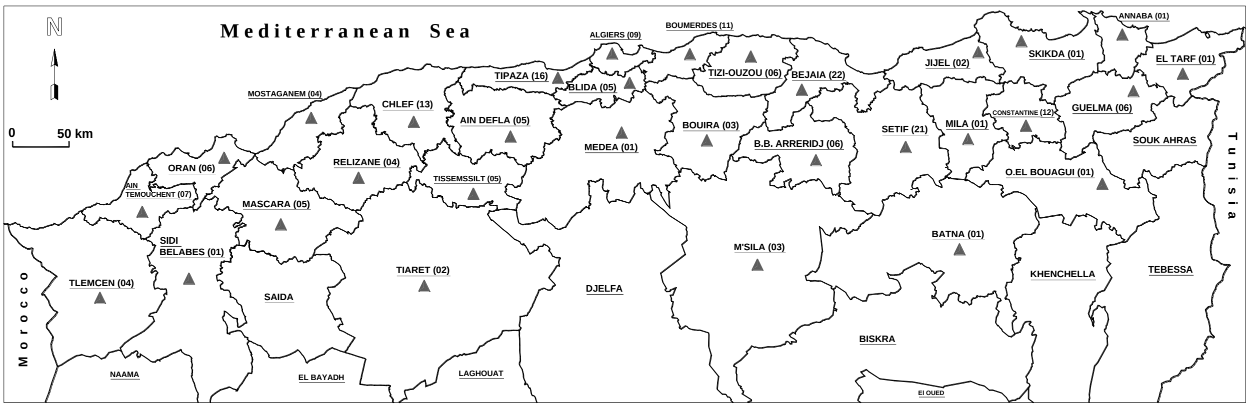


Figure 2: The national accelerograph network, with the regional administrative limits. The numbers in parentheses next to the filled triangles stand for the number of stations installed in the region.

STRONG MOTION DATABASE

The strong motion database is a fundamental step for any application in the fields of earthquake engineering and specially for developing seismic code design spectra. Each record is characterized by several parameters such as: magnitude, hypocentral distance, main or aftershock, soil …etc. The Algerian strong motion database contains 86 seismic events (main shock and aftershocks) since the El Asnam earthquake 1980 (M = 7.3) up to the Chlef earthquake 2010 (M = 4.5).

Data has been processed with the Kinemetrics SWS [8] and SMA [9] softwares. Analog records were digitized using a 600 dpi scanner [10] and processed with the Kinemetrics scanview software [11]. The sampling frequency for both digital and digitized analog data has been set to 200 sps. The Trifunac method (Trifunac et al. 1973) used for data processing is based on three steps: (i) instrument correction, (ii) baseline correction of the acceleration data, and (iii) high-pass filtering of velocity and displacement, using an Ormsby filter. For instrument correction the low-pass cut-off frequency of the Ormsby filter was set to 25 Hz for the SMA-1, SSA-1, and ETNA, with a 3 Hz roll-off width. The corner frequency for both long-period baseline correction filtering and high-pass filtering of velocity and displacement, depends mainly on the spectral signal-to-noise ratio of each component, and has been estimated in the 0.12-0.2 Hz range with a roll-off width of 0.06 Hz and in the 0.2-0.3 Hz range with a roll-off width of 0.1 Hz for digital and analog data respectively.

Finally, a set of 633 data is considered for the horizontal motion (the two horizontal components assumed independent).

SOIL CLASSIFICATION

The objective of site classification is to classify a group of strong-motion station sites into several classes so that the conditions within the same site class are similar (Rock, firm, soft, very soft). This makes it possible then the development of tools for engineers such as design spectra and attenuation models taking into account the specificity of each site. The difficulty to dispose of the average shear wave velocity over 30 m firstly, and secondly the fact that Vs30 does not always capture the predominant period of the site, since it represents only the shallowest portion of the geological profile (Fukushima et al., 2007) has encouraged the development of other site classification schemes. The best known is proposed by Kanai and Tanaka (1961) and based on the site's predominant period. This is used in Japan for the seismic design code of highway bridges (Japan Road Association 1980, 1990). Using this method, Zhao et al. (2006) proposed four site categories and classified K-net sites.

In the present study we adopted the 4 site classes defined in the EC-8 along with the corresponding average shear-wave velocity of the top 30 m (Tab. 1). Each soil type is bounded by two extreme shear wave velocity values $V_{\min}^{30}$ and $V_{\max}^{30}$. The simulation of shear wave velocity bounded random field for each soil category (Fenton and Griffiths, 2000) is performed to derive average horizontal and vertical transfer functions for each soil type (Eq. 1).

$$V_j = V_{\min}^j + \frac{1}{2}\left(V_{\max}^j - V_{\min}^j\right)\left[1 + \mathrm{th}\left(s\frac{\Delta V_j}{2\pi}\right)\right] \quad (1)$$

where $V_{\min}^j$ and $V_{\max}^j$ are minimum and maximum shear wave velocity expressing the bounds for the jth soil type. ΔV_i (Eq. 2) is a random field with zero mean and a unit variance, and s is a factor governing the mean shear wave velocity variability between its two bounds.

$$\Delta V_i = \left(\frac{2}{N}\sum_i^N \cos(2\pi\phi_i)\right)^{\frac{1}{2}} \quad (2)$$

With ϕ_i is a random phase.

Then, average HVSR curve is derived based on the Kawase et al. (2011) equation (Eq. 3).

$$\frac{H(\omega,0)}{V(\omega,0)} = \sqrt{\frac{2\alpha}{\beta}} \frac{TF_H(\omega,H)}{TF_V(\omega,H)} \tag{3}$$

with H and V are respectively the horizontal and vertical surface motions, α and β are respectively the P and S wave velocities. TF_H and TF_V are respectively the S-horizontal and P-vertical transfer functions, and ω is the pulsation.

Table 1. Ground types (according to Table 3.1 from EC8).

Ground type	Description of stratigrafic profile
A	Rock or rock-like geological formation including, at most, 5 m of weaker material at the surface, $Vs_{,30} > 800$ m/s
B	Deposits of very dense sand, gravel or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth, $Vs_{,30}$ = 360–800 m/s, $NSPT_{,30} > 50$ in granular materials, $cu_{,30} > 250$ kN/m^2 in cohesive materials
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters, $Vs_{,30}$ = 180–360 m/s, $15 < NSPT_{,30} < 50$ in granular materials and $70 < cu_{,30} < 250$ kN/m^2 in cohesive materials
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers) or of predominantly soft-to-firm cohesive soil. $Vs_{,30} < 180$, $NSPT_{,30} < 15$ in granular materials, $cu_{,30} < 70$ kN/m^2 in cohesive materials

Four site classes (A, B, C and D) are defined by the proposed HVSR classification function named hereunder $\frac{H}{V}(T)_{\mathrm{Re}\,f}$. Fig. 3 shows the proposed HVSR amplification functions based on both the wave propagation theory and the building code soil classification.

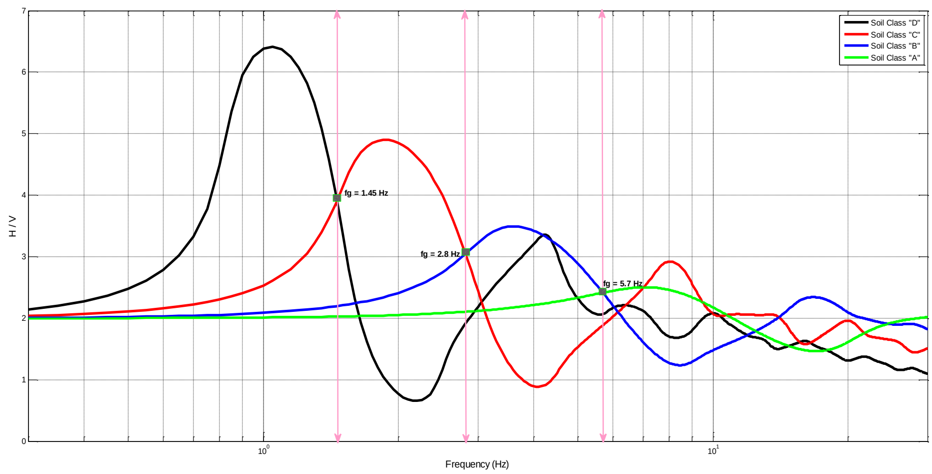


Figure 3. Proposed HVSR reference curves for EC-8 Site Class.

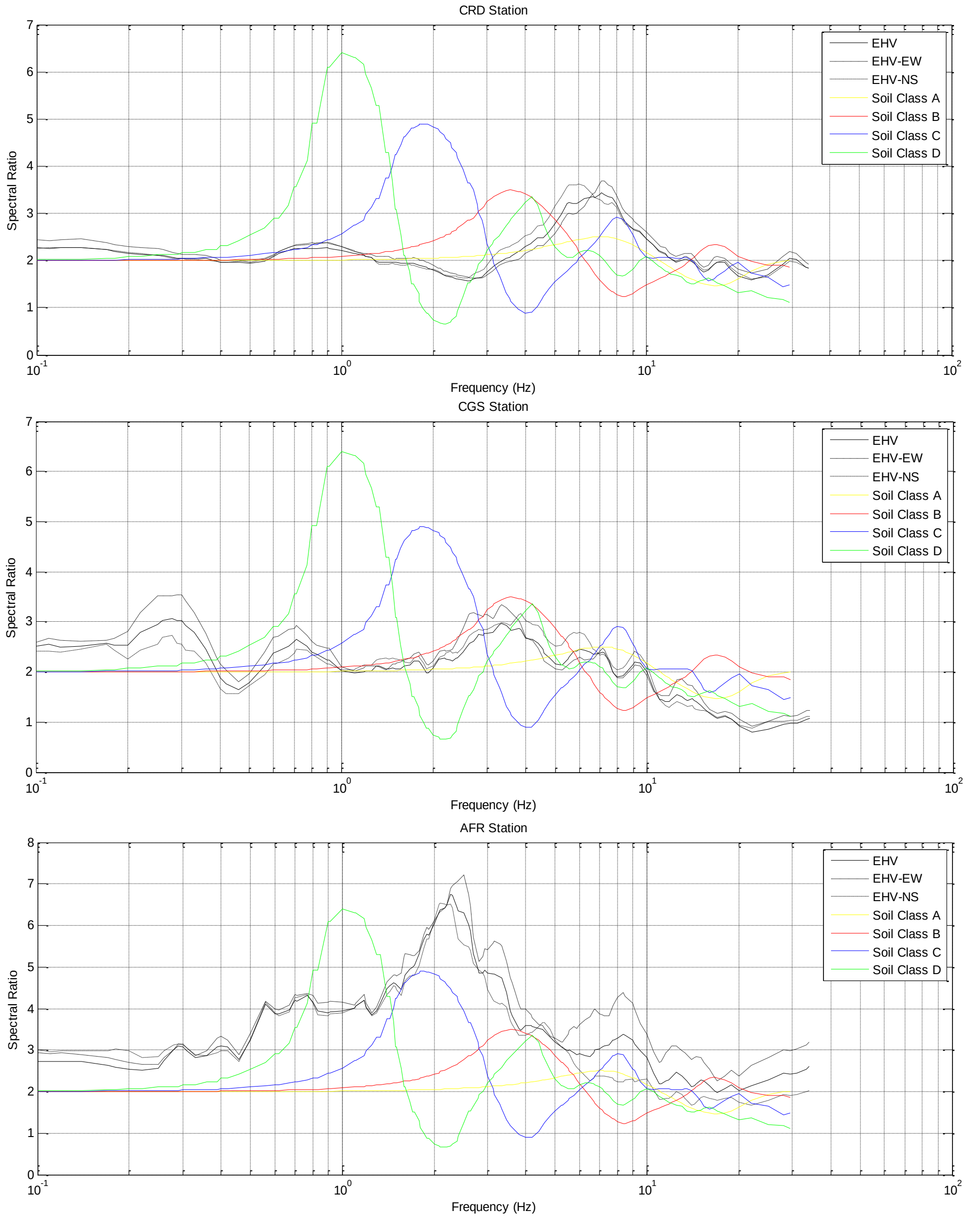
APPLICATION TO ALGERIAN STRONG MOTION ACCELEROGRAPH

As an application to the Algerian accelerograph stations, the geometrical average $H/V(T)$ spectral ratio of all periods curve computed for each station is compared with $H/V(T)_{\mathrm{Re}\,f}$. We propose a new site classification criteria based on the cross correlation coefficient between the four $H/V(T)_{\mathrm{Re}\,f}$ curves and the computed geometrical average $H/V(T)$ spectral ratio for each station (Eq. 4). This approach allows consideration of other peaks other than the fundamental peak as well as the shape of the spectral ratio with respect to spectral periods.

$$\rho = \frac{\operatorname{cov}\left[\frac{H}{V}(T_i)x\frac{H}{V}(T_i)_{\operatorname{Re}f}\right]}{\sqrt{Var\left(\frac{H}{V}(T_i)\right)Var\left(\frac{H}{V}(T_i)_{\operatorname{Re}f}\right)}} \tag{4}$$

Where T_i is the i^{th} period and $H/V(T_i)$ is the geometrical mean HVSR for a given station and $H/V(T_i)_{\operatorname{Re}f}$ is the proposed HVSR functions. The site class with the highest ρ was assigned to this site.

For a particular site ρ is calculated for each site class (A, B, C and D), and the site class with the highest ρ was assigned to this site. Fig. 4 shows examples of stations that were classified according to our proposed classification scheme respectively as A (fig 24a), B (fig. 4b), C (fig. 4c) and D (fig. 4d).



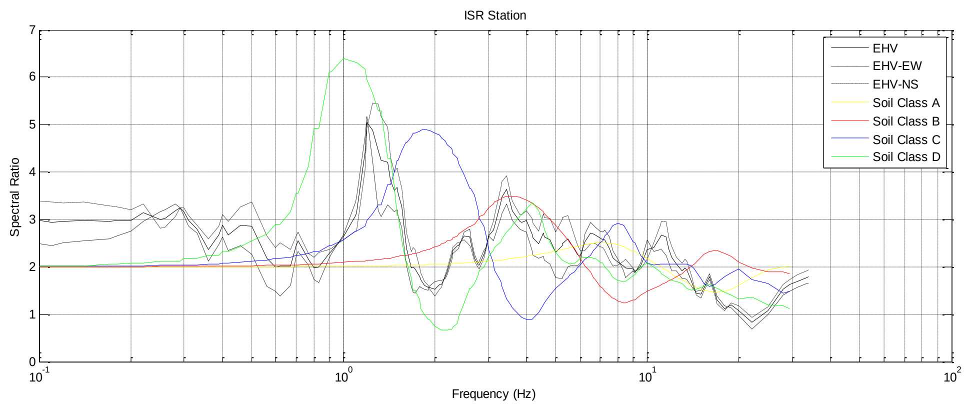


Figure 4. Comparison between Mean, East-West and North-South geometrical HVSR_Staion with the $H/V(T)_{\mathrm{Re}\,f}$ developed for the four site class (A in yellow, B in red, C in bleu, D in green). From top to bottom, according to the proposed site classification criteria, CRD station is classified in class A, CGS in class B, Afroun in class C and Isser in class D.

PROPOSED ACCELERATION RESPONSE SPECTRA AND CONCLUSION

Based on the new classification scheme, a new acceleration response spectra is developed and compared with "Eurocode8" and recent studies on improving Eurocodes8 (Pousse et al . 2005; Pitilakis et al. 2011). The Eurocode8 proposes two types of spectra (1 and 2) according to seismic activity (type 1 for an important activity with Magnitude> 5.5, and type 2 for low to medium activity with magnitude ≤ 5.5).

Fig. 5 shows the comparison between the design spectra type 1 proposed by Pitilakis et al. (2011) in green, Pousse et al. (2005) in blue, Eurocode8 in yellow, the experimental mean and mean plus sigma elastic spectra in red, and the proposed design spectra (by this study) in black. It appears that the proposed spectrum has best fits with the experimental Algerian data. It agrees with the Pitilakis spectrum for high periods, and it is between the Pitilakis and Pousse spectra for low periods.

Fig. 6 shows the comparison between the design spectra type 2 proposed by Pitilakis et al. (2011) in green, Pousse et al. (2005) in blue, Eurocode8 in yellow, the experimental mean and mean plus sigma elastic spectra in red, and the proposed design spectra (by this study) in black. It appears that the proposed spectrum has best fits with the experimental Algerian data. It agrees with Pousse spectrum for high periods, and it is between the Pitilakis and Pousse spectra for low periods.

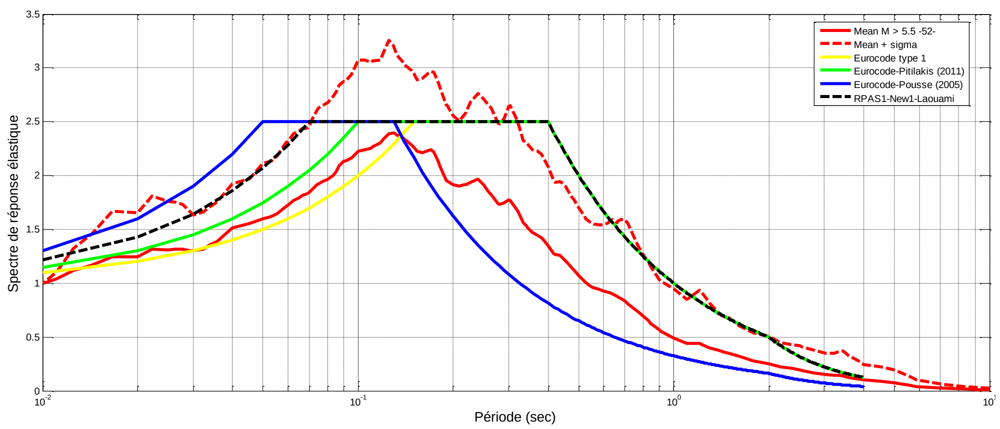


Figure 5. Proposed design spectra type 1 for rock soil class.

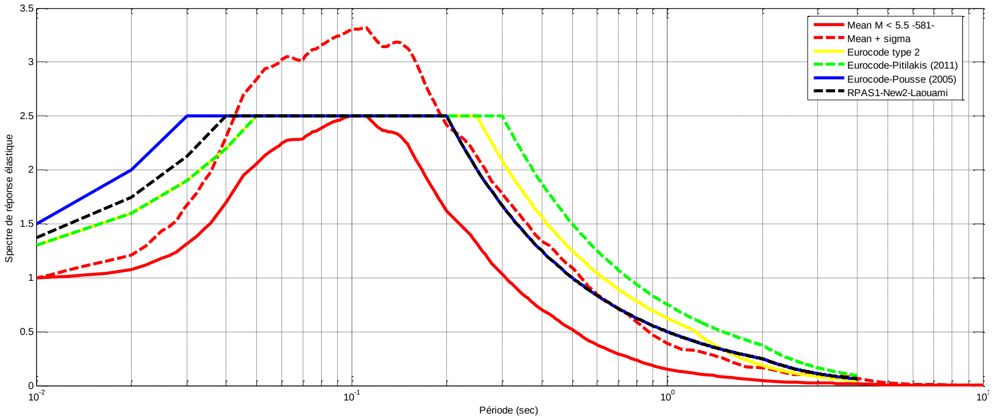


Figure 6. Proposed design spectra type 2 for rock soil class.

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