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Full Length Research Paper

Review of the Algerian seismic design code spectrum

Abderrachid Boulaouad[1]* and Amar Hamitouche[2]

[1]University of Batna, Algeria.
[2]University of M'sila, Algeria.

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The specific "seismic design spectrum" proposed by the Algerian seismic design code, namely the "normalized acceleration spectrum", seems to present an anomaly in comparison with other seismic design spectra over the world and with computed spectra, especially in the first branch of the curve, corresponding to the range of short periods, where the spectrum is a decreasing line whereas it must be an increasing one. This anomaly is outlined and confirmed, in one hand, and treated by proposing an appropriate formula instead of the available one, in the other hand. Some numerical applications are made using both available and proposed formula. This work may be considered as a contribution to the revision of the Algerian seismic design code which is continually done in order to make it more realistic and more perfect.

Key words: Algerian seismic design code, response spectrum, seismic force.

INTRODUCTION

The North of Algeria is counted among the regions which are the most subjected to earthquakes over the world. According to the "RPA 88", the Algerian center of research in astronomy astrophysics and geophysics "CRAAG" has taken the census of 85 earthquakes, between 1716 and 1989, more than half of which were above a magnitude of 5. Between 1980 and 1989, about 26 earthquakes (of magnitude between 4 and 8) occurred. The 1980 Chlef earthquake (M 7.3), which caused a great disaster (big damage and loss of about 3500 lives), was a keystone in development of seismic regulation as, only one year after its occurrence, the first Algerian seismic code was born. Recently, other earthquakes have occurred in some regions of Algeria, particularly the 2003 Boumerdes earthquake (M 6.8) which killed more than 2000 persons and caused an immense economic loss (Cherait, 2006). This event egged on to serious review of the seismic design code. In fact, since its elaboration in 1981, the Algerian seismic design code known as Regles Parasismiques Algeriennes "RPA" is continually reviewed. Thus, "RPA 88", "RPA 99" and finally, "RPA 2003" appeared successively.

Historically after the 1954 Chlef earthquake (M 6.7), the French authorities which were occupying Algeria, edited a summary seismic code, entitled "Recommendations AS 55", which was used to rebuild the destructed part of the town. Later, the French code known as "PS 69" was applied even after independence. In 1976, the Algerian organism of technical control (CTC), in collaboration with the Stanford University of California (USA), began working on a project of a national code and a seismic map (Cherait, 2006). This work resulted in the elabo-ration of a specific Algerian seismic design code in 1981, officially approved in 1983, hence the name "R.P.A. 81 version 83". In the "RPA 88", the modifications were mainly of formal aspect (presentation, terminology…), but in the "RPA 99" there were fundamental modifica-tions concerning many fields (classification criteria, design rules, justification of security, seismic mapping …). Among the new most important concepts introduced by the "RPA 99", there were the formulae defining the response spectrum (S_a/g) and the behavior factor (R), both needed to calculate the seismic action. A last revision entitled "Addenda au RPA 99" led to the actually available version: the "RPA 2003".

The "equivalent static method" and "spectral modal analysis method" proposed by the Algerian seismic design code to calculate the seismic forces are based on

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*Corresponding author. E-mail: abd1_elwal@yahoo.fr. Tel: 00273773318487. Fax: 0021335555484.

the concept of "seismic design spectrum". So, it is desirable to take an interest in reviewing this design spectrum and treating any anomaly relevant to it.

DEFINITION OF SEISMIC DESIGN RESPONSE SPECTRA

In general, response spectra are prepared by calculating the response to a seismic excitation of single degree of freedom (SDOF) systems with various amounts of damping using a differential equation such as Equation (1):

$$\ddot{X} + 2.\xi.\omega.\dot{X} + \omega^2 X = -\ddot{X}_s(t) \qquad (1)$$

where: ξ, ω, $\dot{X}$ and $\ddot{X}$ are, respectively, the damping ratio, the angular velocity, the velocity and the acceleration of the mass. $\ddot{X}_s(t)$ is the input motion at the base specified by means of an acceleration function such as an earthquake accelerograph record. Earthquakes consist of a series of essentially random ground motions. Usually the North-South, East-West, and vertical components of the ground acceleration are measured. Figures (1a) and (b) show the N-S component of horizontal ground acceleration of, respectively, the November 8, 1980 Chlef aftershock recorded after the non recorded October 10, 1980 Chlef main event and the May 18, 1940 imperial valley earthquake recorded at the El Centro site, hence, the name "El Centro earthquake" commonly used for brevity.

Numerical integration is applied in order to calculate the response of the system and the process is continued until the earthquake record has been completed. The largest value is recorded and becomes the response of the system to that excitation. Changing the parameters of the system to change the natural frequency, the process is repeated and a new maximum response is recorded. This response is repeated until all frequencies of interest have been covered and the results plotted. Since two earthquakes are not alike, this process must be repeated for all earthquakes of interest. Thus, the "design response spectrum" incorporates the spectra for several earthquakes and represents a kind of "average" response spectrum for design. More the number of recorded earthquakes are great, more the spectrum is representative and more the design is accurate. Simulated earthquakes are sometimes used, in addition to the real ones, to obtain the "average" response spectrum (Paz, 1985). This type of spectrum covers only the elastic range and is, consequently, known as "elastic response spectrum".

Nevertheless, for certain types of extreme events such as strong motion earthquakes, it is sometimes necessary to design structures to withstand strains beyond the elastic limit and the generation of inelastic response spectra is, thus, necessary. This operation can be achieved by two main methods:

(1) The calculation of the inelastic displacements by integration of the non linear equation of motion. A specified ductility factor is also assumed. Then, as done for the elastic response spectrum, the maximum values are plotted versus the period (or frequency) to give the inelastic spectrum.
(2) The derivation of the inelastic response spectrum from the elastic one by displacing this latter downward by an amount which is related to the ductility factor and commonly called reduction factor. This derivation is based either on the equal displacement concept or on the equal energy one (Paz, 1985).

REVIEW OF THE RPA DESIGN SPECTRUM

Algerian seismic design spectrum according to the RPA 2003

The normalized acceleration spectrum (S_a/g) is given by the following equations:

$$\frac{S_a}{g} = \begin{cases} 1.25A\left[1 + \frac{T}{T_1}\left(2.5\eta\frac{Q}{R} - 1\right)\right] & if \quad 0 \le T \le T_1 \qquad (2a) \\ 2.5\eta(1.25A)\frac{Q}{R} & if \quad T_1 \le T \le T_2 \qquad (2b) \\ 2.5\eta \cdot (1.25A) \cdot \left(\frac{Q}{R}\right) \cdot \left(\frac{T_2}{T}\right)^{\frac{2}{3}} & if \quad T_2 \le T \le 3.0\,s \qquad (2c) \\ 2.5\eta \cdot (1.25A) \cdot \left(\frac{Q}{R}\right) \cdot \left(\frac{T_2}{3}\right)^{\frac{2}{3}}\left(\frac{3}{T}\right)^{\frac{5}{3}} & if \quad T \succ 3.0\,s \qquad (2d) \end{cases}$$

where: T is the fundamental period of the structure given by the empirical equation:

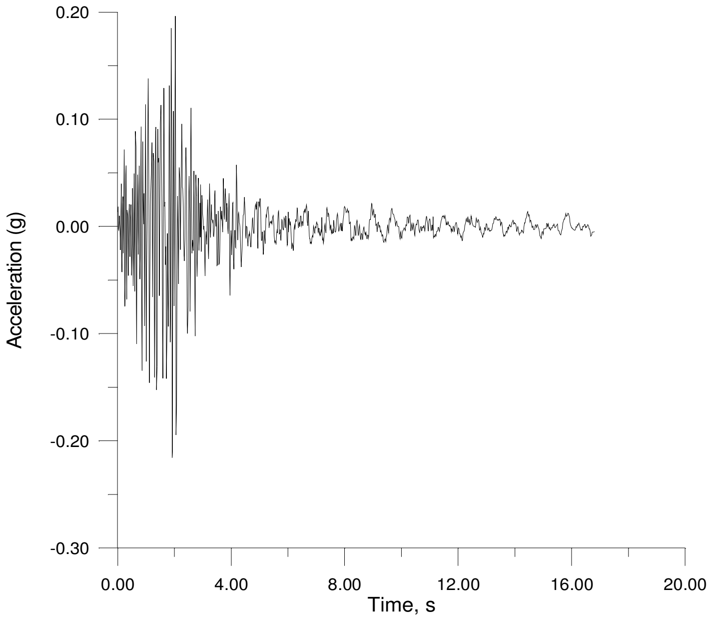
$$T = C_t.(H_n)^{3/4} \qquad (3)$$

T_1 = 0.15 s in all cases, while T_2 depends on site type (e.g. T_2 = 0.4 s for firm soil) C_t depends on type of LLRS (e.g. C_t= 0.075 for R.C. frame with masonry infill) and H_n is the total height, η is a correction factor of the damping ζ, given by Equation (4):

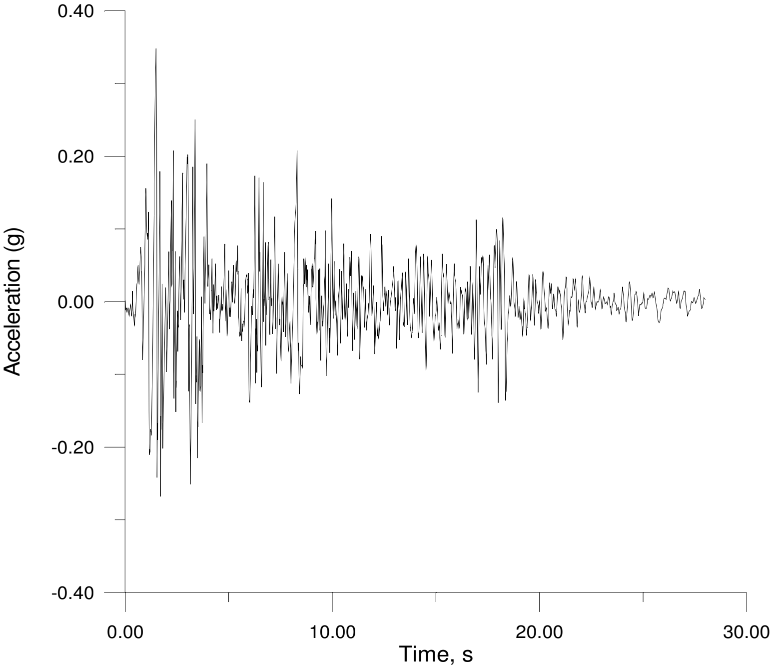
$$\eta = \sqrt{7/(2+\xi)} \ge 0.7 \qquad (4)$$

where ζ is the damping ratio, A is the acceleration coefficient of zone, given by Table (1):

Q is the quality factor depending on geometry and checking quality of the construction. The values of Q are included in the interval (1, 1.35); so the mean value is1.175, R is the global behavior factor of the structure,



(a) Chlef record, N-S component



(b) El Centro record, N-S component

Figure 1. Ground acceleration records for Chlef, Algeria and El Centro, California earthquakes.

Table 1. Values of the acceleration coefficient of zone, A.

	Zone			
Group of use	**I**	**IIa**	**IIb**	**III**
1A	0.12	0.25	0.30	0.40
1B	0.10	0.20	0.25	0.30
2	0.08	0.15	0.20	0.25
3	0.05	0.10	0.14	0.18

Table 2. Values of global behavior factor, R.

Type of LLRS	Self-steady frames without masonry rigid infill	Frames with walls as LLRS	Self-steady frames with masonry rigid infill	Vertical cantilever with distributed mass
R	5	4	3.5	2

given by Table (2), for RC structures.

Anomaly of the Algerian seismic design spectrum

For application, Two cases are considered, with T_2 = 0.4s (firm soil), Q = 1.175 (mean value) and ζ = 5%. First case: A = 0.08 and R = 4. Second case: A = 0.2 and R = 3.5

A plot of the corresponding acceleration spectra is shown in Figure 2, in the range of period (0 - 4 s).

A comparison between the Algerian seismic design spectrum and other seismic design spectra over the world has shown an anomaly in the Algerian spectrum, especially in the first branch of the curve corresponding to Equation (2a). The curve is a decreasing line in the Algerian spectrum (Figure 2) whereas it is an increasing one in the other spectra (Figures 3a, b, c and d). These four figures represent, respectively, a subsoil class B of EC8 spectrum (Type I), a UBC 97, a NEHRP 97 and a Chinese spectrum, for 5% damping.

Furthermore, this anomaly is confirmed by a plot of acceleration spectra using numerical methods and real ground acceleration records (Figure 4). On the plotted spectra (Figure 5), one can note easily that the first part of the curve corresponding to the range of period (0 - T_1), which is approximately a straight line, is increasing and that when T → 0, S_a tends to the maximum ground acceleration $\left|\ddot{X}_s \max\right|$ or PGA. This latter statement is due to the fact that for an infinitely stiff oscillator, the relative displacement equals zero which makes the total displacement and therefore the total acceleration equal to those of the ground (Gupta, 2010). This fact may be illustrated by considering the limits of response spectra (Figure 4) as follows:

$$\ddot{X}_a + 2.\xi.\omega.\dot{X} + \omega^2 X = 0 \quad \ddot{X}_a + 2.\xi.\omega.\dot{X} + \omega^2 X = 0$$

$$X = 0 \Rightarrow \ddot{X}_a = \ddot{X}(t) + .\ddot{X}_s(t) = \ddot{X}_s(t)$$

$$\ddot{X}(t) = -\ddot{X}_s(t) \Rightarrow X(t) = -X_s(t)$$

where: X , $\dot{X}$, $\ddot{X}$, $\ddot{X}_a$, X_s and $\ddot{X}_s$ are the relative displacement, velocity, acceleration, the absolute acceleration, the soil displacement and the soil acceleration, respectively:.

If the structure is very stiff (that is T is very low) the mass M follows practically the ground motion so that the relative acceleration of the mass equals zero. If the structure is very soft (that is, T is very high) that is the base of the structure which follows the soil motion and the mass M does not displace, so that the relative acceleration equals the soil acceleration. Thus, in all cases, the relative acceleration does not exceed the maximum soil acceleration and consequently: $\frac{S_a}{g} \leq \left|\ddot{X}_s \max\right|$ for all values of the period T (Gupta, 2010).

Analysis of the anomaly

In order to have an increasing line in the first branch of the spectrum, the slope obtained by deriving Equation (2a) as a function of the period T, must be positive, leading to:

$$\text{Rmax} = 2.937\ \eta.\text{Q} \qquad (5)$$

For a mean value of Q = 1.175 and ζ = 5% (that is, η = 1), Rmax = 2.937. This means that the anomaly (negative slope in the range 0 ≤ T ≤ T1) occurs for all cases given in Table 2, except that corresponding to R = 2. This fact is confirmed by the examples given previously (Figure 2).

Proposed formula

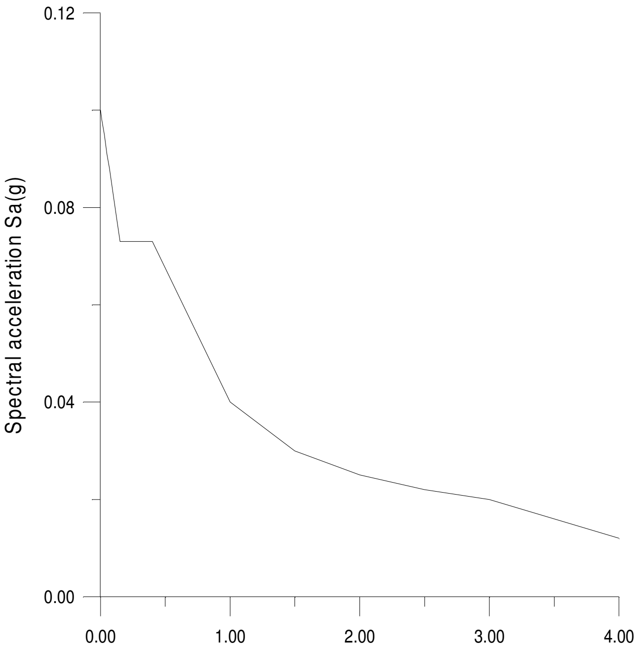
The proposed formula is based on the following considerations:

(1) The part of spectrum corresponding to this formula should be an increasing straight line.
(2) On this branch, when T → 0, Sa tends to the PGA, as mentioned before.
(3) The mean largest PGA recorded to date in Algeria is about 0.48 g (Pelaez, 2005).
(4) Because of the continuity of the spectrum curve, the value of Sa obtained from Equation (2a) should be the same with that obtained from Equation (2b) for T=T1.

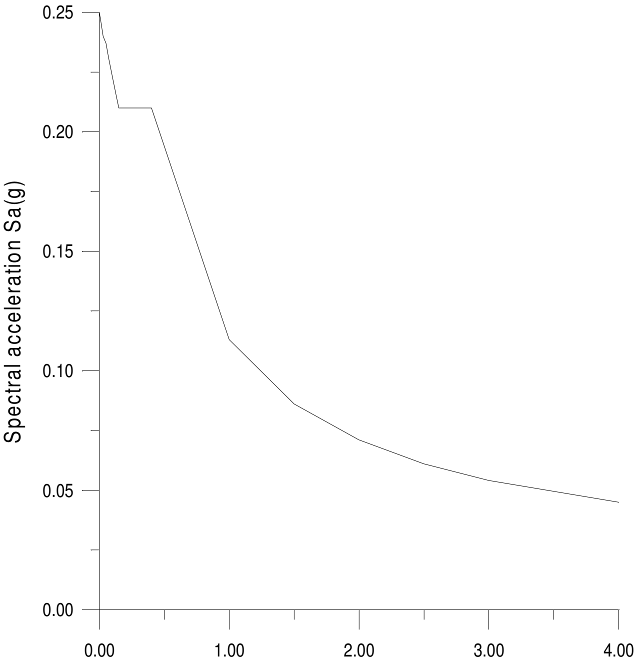
Thus, instead of equation (2a), the proposed formula corresponding to the first branch is as follows:

$$\frac{S_a}{g} = 1.25\,A \cdot \left[1 + \frac{T}{T_1}\left(2.5\eta\frac{Q}{R} - 1\right)\right] + \alpha \cdot (T_1 - T) \qquad if \quad 0 \leq T \leq T_1 \qquad (6)$$

Where α is a parameter taking into account the fact that



(a) First case

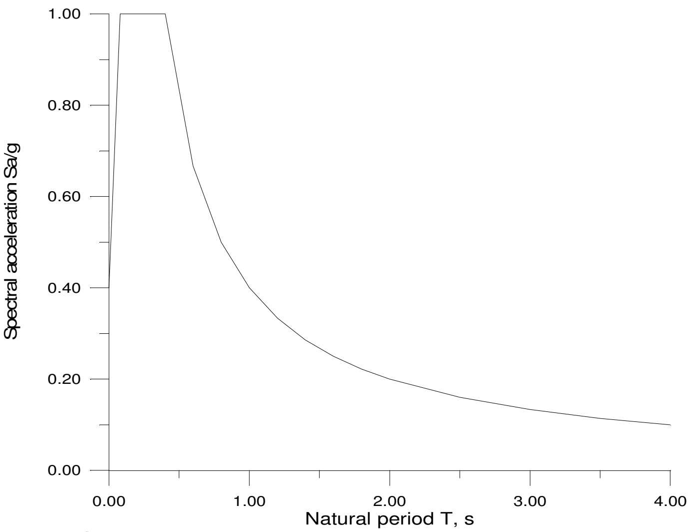


(b) Second case

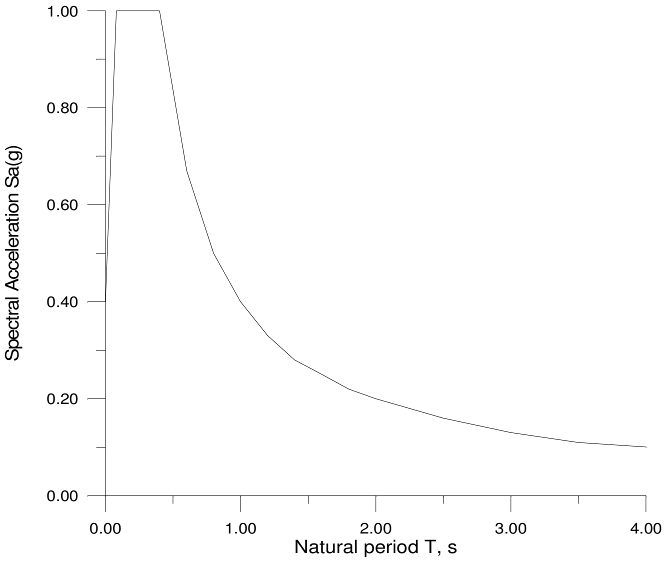
Figure 2. RPA spectra for 5% critical damping.

$\frac{S_a}{g} = PGA$ for T = 0. So, it is given by Equation (7):

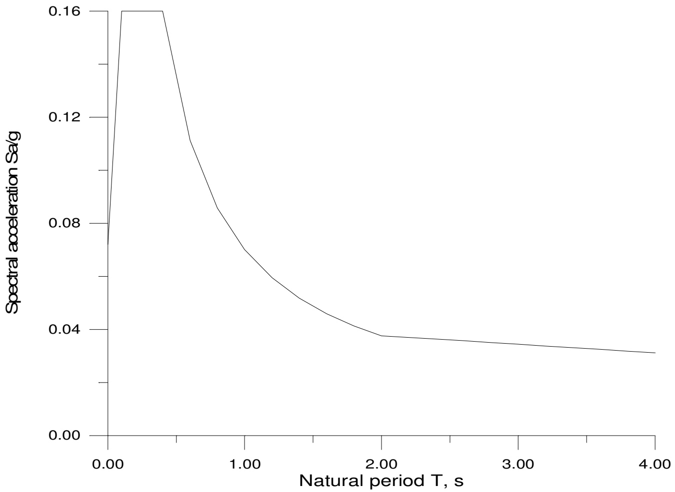
$$\alpha = \frac{PGA - 1.25A}{T_1} \qquad (7)$$



(b) UBC spectrum

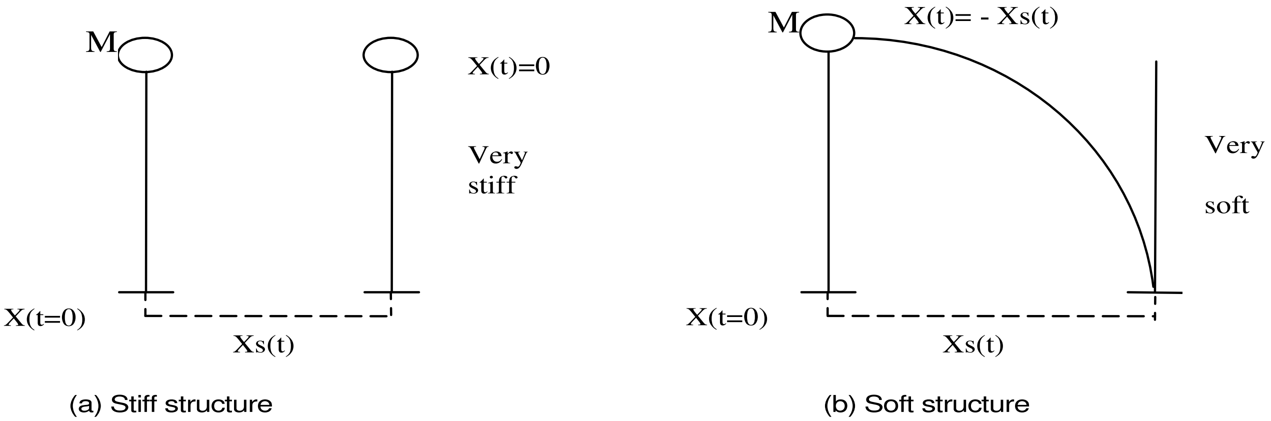


(c) NEHRP spectrum



(d) Chinese spectrum

Figure 3. EC8 Type I, UBC 97, NEHRP 97 and Chinese design spectra for 5% critical damping



(a) Stiff structure (b) Soft structure

Figure 4. Limits of response spectra.

In order to have an increasing line, the slope obtained by deriving Equation (6) as a function of the period T, must be positive, leading to:

$$\frac{1.25A}{T_1}\left(2.5\eta\frac{Q}{R}-1\right)-\alpha\succ 0 \qquad (8)$$

Using Equation (7) for T1 = 0.15 s and taking Q = 1.17, Inequality (8) becomes:

$$R_{max}=3.67\cdot\eta\cdot\frac{A}{PGA} \qquad (9a)$$

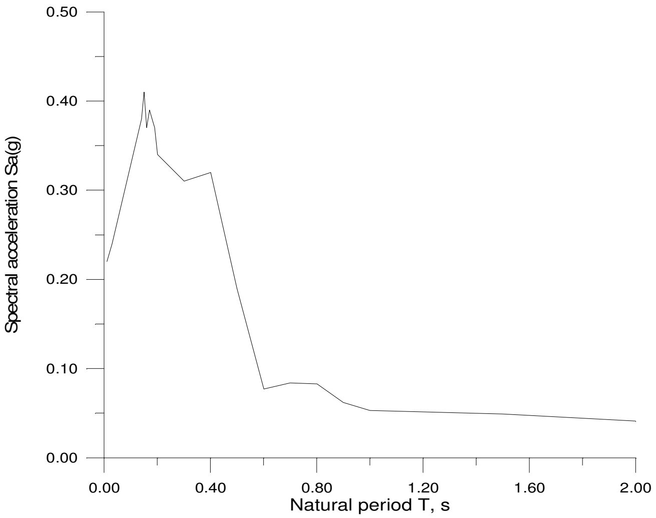
Taking PGA = 0.8 A (that is α = -3.A), leads to:

$$R_{max} = 4.59\eta \qquad (9b)$$

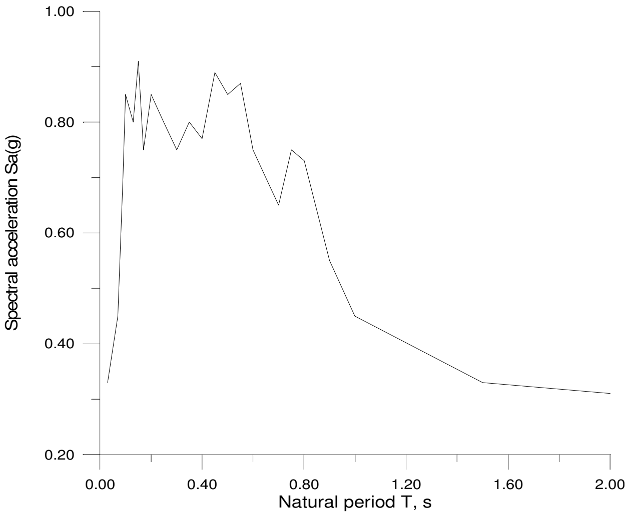
The values of Rmax corresponding to ζ = 5% and ζ = 7% are, respectively, Rmax = 4.59 and Rmax = 4.03.

Then, the condition of Inequality (8) is satisfied for all the values given in Table 2, except for R = 5. However, this value seem to be excessive as mentioned by Djebbar et al. (2009) in a recent study of the reduction factor showing that the value suggested by the RPA in the short period range, corresponding to high ductility structures (μ ≥ 4, R = 5), is not appropriate and must be reduced. This fact may be confirmed by the affirmation of Lam et al. (1998) that "an overall strength reduction factor of about 2.25 in the short period zone could result in a controllable ductility demand imposed on the structure under earthquake excitation". Furthermore, according to Edjtemai (1998), ductility for RC structures cannot exceed the value of 2.

Finally, if the value of R = 5 is not considered in the first branch of the spectrum, corresponding to the short period seismic code is R = 4. Thus, the condition of Inequality(8) is satisfied in all possible cases, even for ζ = 7% (that

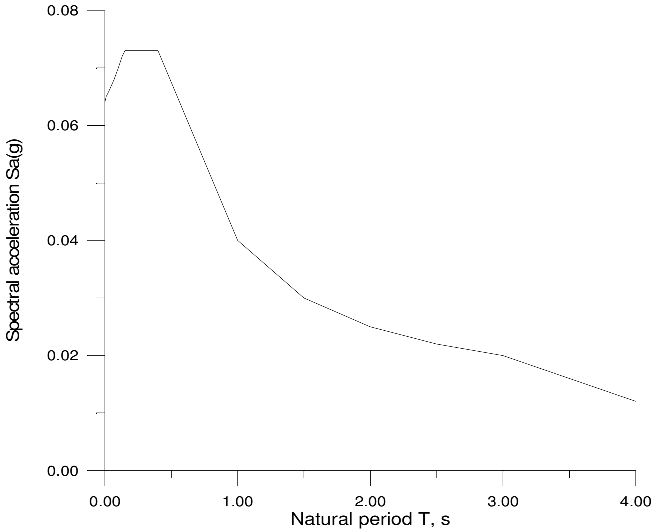


(a) Spectrum for Chlef earthquake

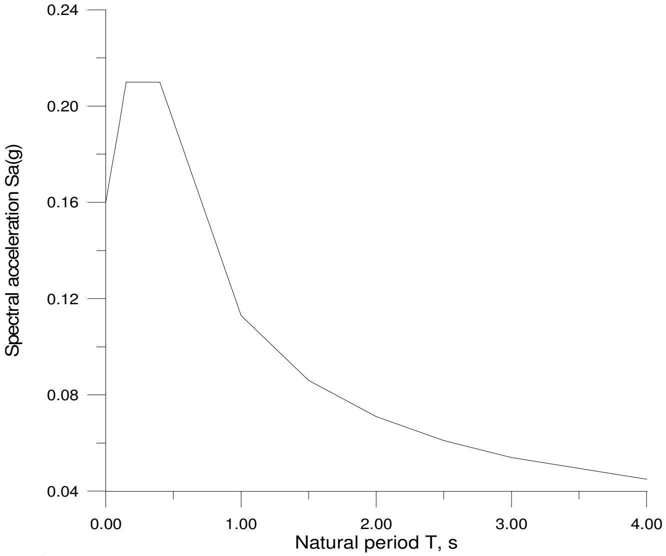


(b) Spectrum for El Centro earthquake

Figure 5. Elastic response spectra for the Chlef and El Centro earthquakes with 5% damping.

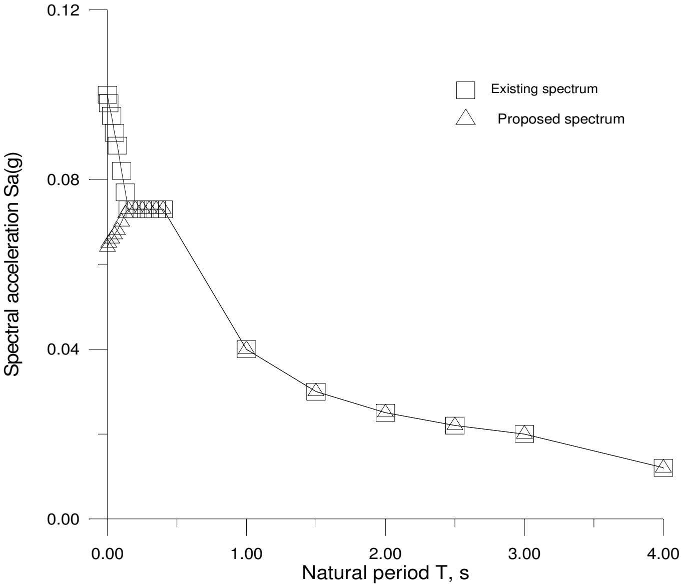


(a) First case

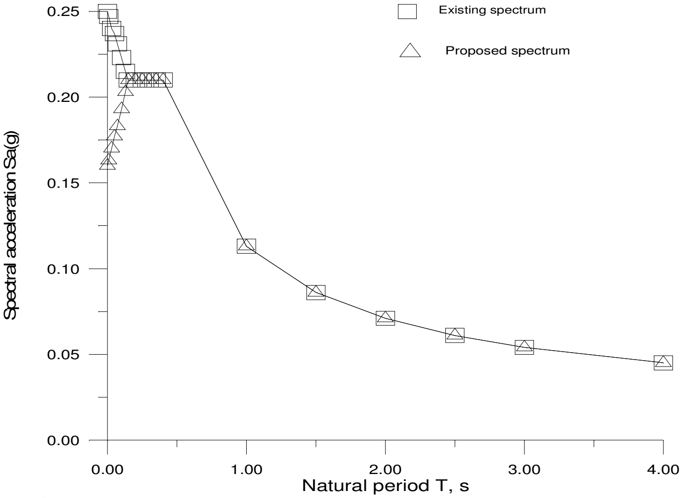


(b) Second case

Figure 6. Proposed design spectrum for 5% critical damping.



(a) First case



(b) Second case

Figure 7. Comparison between the proposed spectrum and the existing one.

is η = 0.88) which is the largest value given by the Algerian seismic code in case of RC frames.

However, the study gives, as examples, the corrected spectra (Figure 6) of the actual ones previously shown in Figure 2.

Comparison between the proposed spectrum and the existing one is made by plotting both spectra on the same chart (Figure 7) which shows clearly that the difference between the two spectra is concentrated in the first branch corresponding to the range of period (0-T1) where the existing spectrum is decreasing while the proposed one is increasing.

CONCLUSION AND FURTHER WORK

Thus, it is clear now that the first branch of the design spectrum is an increasing line as well as in the other design spectra over the world, and the correct corresponding formula is the proposed one, providing that the values of the behavior factor do not exceed R = 4 and for an appropriate ratio A / PGA.

Further work is still necessary to complete the review of the RPA, particularly on defining the behavior factor R and the relation between the PGA and the acceleration coefficient of zone.

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