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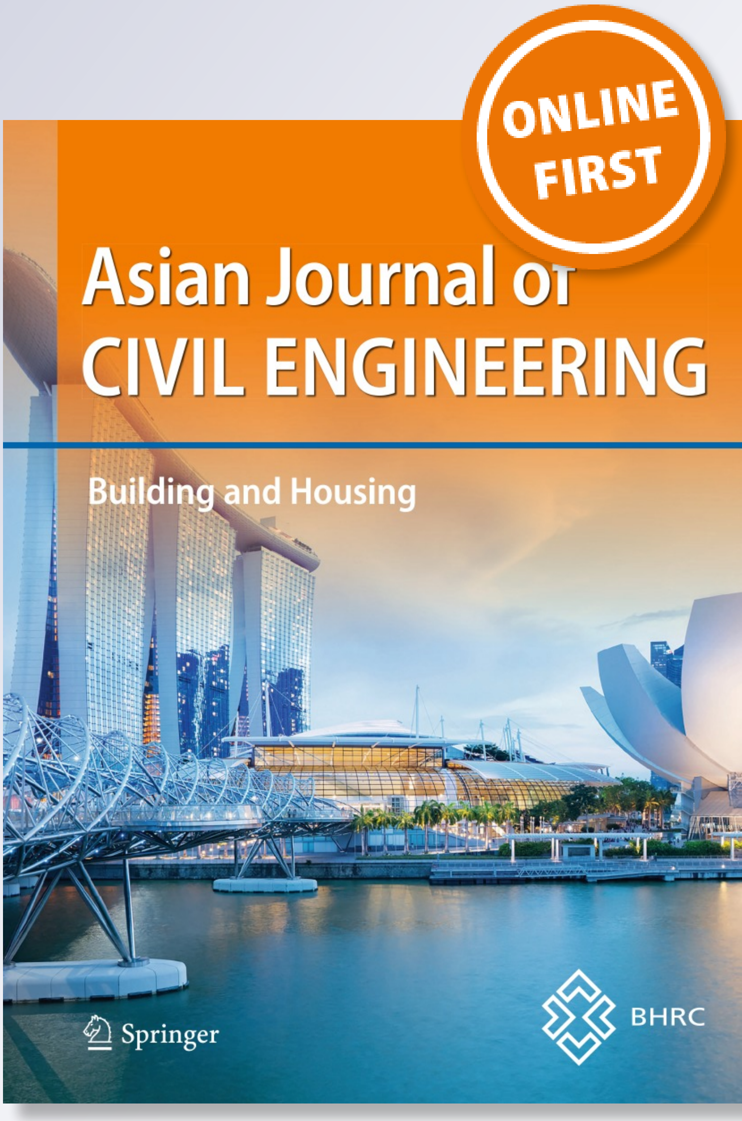

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ORIGINAL PAPER

Algerian seismic code improvement by proposition of a specific design spectrum for Algiers City

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Abstract
This paper is an involvement in the improvement of the Algerian seismic regulation (RPA) which presents many deficiencies. Investigations are focused on the so-called "spectral modal analysis" (SMA) method commonly used for seismic evaluation. The applications are made on reinforced concrete structures in both cases: self-steady frames and structures with shear walls (bearing walls). Furthermore, comparison is made with time history (TH) method based on a number of recent Algerian seismic records. This work led to the proposition of a more accurate design spectrum specific to Algiers City usable in the classical (force) method as well as in a simplified "performance-based" method.

Keywords Algerian seismic code · Behavior factor · Exact method · Improvement · Performance-based method · Spectral modal analysis

Introduction

To assure the public welfare, many countries have developed their own building codes, enforced in a uniform and legal standard so that they avoid wide divergence in design or construction and offer the building occupants protection against collapse.

At the beginning, these codes were only concerned about the resistance of buildings to large earthquake loading without structural collapse but this attitude evolved over time.

In the early twentieth century, building codes around the world began to introduce requirements that structures present sufficient strength to resist a specified lateral force. These requirements are retained in most building codes today as a basic design method and are frequently termed the equivalent lateral force (ELF) technique (Hamburger 2003).

In this technique, earthquake resistance was assured by providing lateral strength equal to 10% of the structure's supported weight as required by the Japanese Urban Building Law Enforcement Regulations following the great 1923 Tokyo earthquake, and adopted by the 1927 edition of the Uniform Building Code (UBC).

In the 1958 edition of the UBC, the concepts of dynamic spectral response were introduced and the total lateral force, now commonly known as the base shear, was given by the formula: $V = ZKCW$, where Z is a zone coefficient related to regional seismicity, K a structural system coefficient and C is an amplification factor related to the fundamental period. As a result of the 1971 Sylmar earthquake, the Structural Engineers Association of California (SEAOC) formed the Applied Technology Council (ATC). The ATC-3.06 report introduced response spectrum analysis methods as the more exact and preferred technique in comparison with the ELF procedure (Hamburger 2003).

For convenience, the response spectrum analysis proposed by codes uses a smooth and standard design spectrum. This latter is continually revised and its shape perfected.

In this context, one can cite, in a non-exhaustive manner, the works led by Calvi (2018) and Calvi et al. (2018).

Furthermore, attention is focused on sensible regions to develop their own design spectra. For example, Mexico City has its own design spectrum and site-specific response spectra are proposed for important districts or towns worldwide.

Concerning the Algerian seismic code (RPA) which is continually reviewed since its elaboration in 1981 by the Algerian organism of technical control (CTC) in collaboration with the Stanford University of California (USA), the most serious revision began after the terrible earthquake which struck the region of Algiers (Boumerdes) on May

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2003, leading to the last and present version of this regulation known as "RPA 2003" with fundamental modifications concerning many important fields such as the design rules and the seismic mapping. Nevertheless, many points remain to be reviewed, particularly those related to the seismic evaluation method.

In seismic evaluation, the base shear and the displacement are of great importance. In the classical method, the base shear is used to design the structure on the basis of strength criteria while the displacement is only verified at the end so as not to exceed a certain limit. Such a method permits to reach live safety goals, but is not economical. On the contrary, the new design concepts use the displacement as a key parameter in damage control on the basis of performance objectives which associate security with economy. These procedures are very effective for application to seismic rehabilitation of structures and are gradually extended to the design of new constructions. So, they are very relevant to the evaluation of the Algerian housing stock which consists mainly of reinforced concrete (RC) self-steady frames. A large part of this stock may not satisfy the limits imposed to such constructions by the "RPA 2003" code as they have been constructed before its advent (Algerian Ministry of Inhabitants 2003).

The RPA recommends only the classical method despite its limitations. This is one of many deficiencies that this work tries to fill to improve this code.

Investigations are focused here on the so-called "spectral modal analysis" (SMA) method commonly used for seismic evaluation. The applications are made on RC structures in both cases: self-steady frames and structures with shear walls (bearing walls) that it is to say frames with walls as lateral loading resisting system (LLRS). Furthermore, comparison is made with exact (time history) analysis based on a number of recent Algerian seismic records which concern in fact the region of Algiers, the capital of Algeria. This region is very particular as it groups most people and vital structures of the state in one hand and is often subjected to strong motions on the other hand. So, it requires a specific seismic regulation such as the "Mexico Federal Code, 1987" which applies to Mexico City. In this perspective, a design spectrum specific to Algiers City is proposed here.

Short description of the "SMA" method

In this method, the seismic responses are calculated for a suitable number of modes and then combined according to the well-known "square-root-of-sum-of-squares" (SRSS) rule.

The seismic response, in term of the base reaction (or base shear), for example, is proportionally related to the weight of the structure by the "normalized acceleration spectrum" S_a/g given by the following equations:

$$\frac{S_a}{g} = \begin{cases} 1.25 \cdot A \left[1 + \frac{T}{T_1}\left(2.5\eta\, \frac{Q}{R} - 1\right)\right] & \text{if} \quad 0 \le T \le T_1, & \text{(a)} \\ 3.125\, \eta\, A\, \frac{Q}{R} & \text{if} \quad T_1 \le T \le T_2, & \text{(b)} \\ 3.125\, \eta\, A \left(\frac{Q}{R}\right)\left(\frac{T_2}{T}\right)^{\frac{2}{3}} & \text{if} \quad T_2 \le T \le 3.0\ \text{s}, & \text{(c)} \\ 3.125\, \eta\, A \left(\frac{Q}{R}\right)\left(\frac{T_2}{3}\right)^{\frac{2}{3}}\left(\frac{3}{T}\right)^{\frac{5}{3}} & \text{if} \quad T \ge 3.0\ \text{s}. & (d) \end{cases} \tag{1}$$

In these formulas, A, T, T_1, T_2, Q, R and η represent, respectively, the acceleration coefficient of zone, the fundamental period, the characteristic periods, the quality factor, the behavior factor and the damping correction factor given in terms of the damping ratio ξ, by the following equation:

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

Criticism of the SMA method proposed by the RPA

The short description of this method in the previous chapter shows clearly that it is based essentially on the so-called "normalized acceleration spectrum" which depends on many factors of more or less importance. One can easily observe that all these factors are empiric and consequently questionable. Nevertheless, discussion will be focused only on two of these factors: the formulas used to determine the "normalized acceleration spectrum" and the values attributed to the behavior factor.

Formulas of the "normalized acceleration spectrum"

First, one can note that they are of great complexity compared with formulas used in other codes as the American Uniform Building Code, 1994 (UBC 94) and the National Building of Canada, 1995 (NBCC 95), for example. The UBC 94 uses three simple equations (Eq. 3a–c) and the NBCC 95 uses only two (Eq. 4a, b), whereas the RPA uses four overloaded equations (Eq. 1a–d). This fact has been observed by Lam et al. (Lam et al. 1998), Hamdache et al. (Hamdache et al. 2010) and Chebihi and Laouami (Chebihi and Laouami 2014).

On top of that, the characteristic period T_1 is introduced in formulas of the RPA code as it was variable while it is fixed, in the specific tables, at a value of 0.15 s in all cases (Algerian Ministry of Inhabitants 2003).

The acceleration spectra A/g of UBC 94 (for soil profile S_1) and NBCC 95 (for zonal velocity ratio $\upsilon = 0.4$) are given, respectively, by the following equations:

$$\frac{A}{g} = \begin{cases} Z + T_n & \text{if} \quad 0 \le T_n \le 0.15 \text{ s}, \quad \text{(a)} \\ 1 & \text{if} \quad 0.15 \le T_n \le 0.39 \text{ s}, \quad \text{(b)} \\ \frac{0.39}{T_n} & \text{if} \quad T_n > 0.39 \text{ s}, \quad \text{(c)} \end{cases} \tag{3}$$

$$\frac{A}{g} = \begin{cases} 1.2 & \text{if} \quad 0.03 \le T_n \le 0.427 \text{ s}, \quad \text{(a)} \\ \frac{0.512}{T_n} = & \text{if} \quad T_n > 0.427 \text{ s}, \quad \text{(b)} \end{cases} \tag{4}$$

where Z is the seismic zone factor and T_n is the natural period of an SDF system (Chopra 1995).

Second, the present formulas of the RPA usually lead to two main defects:

- A negative slope of the first branch (i.e. range of short periods), whereas it must be a positive one as it is the case in either seismic design spectra or computed ones (Fig. 1). This anomaly has been already highlighted elsewhere.
- Very small values of base shear and displacement in comparison with both exact method and simplified one as it will be shown subsequently.

Values of the behavior factor

The behavior factor, noted R (or q in the Eurocode 8), is a parameter used to account for the inelastic behavior of the structure by reducing the earthquake load; hence, the name of reduction factor too. The values adopted in earthquake codes worldwide depend on parameters that affect its energy dissipation capacity such as ductility, overstrength, redundancy. Ductility is certainly the most important of these parameters, so that the associated ductility reduction factor R_μ has received considerable attention compared with the other components of the behavior factor. Even though it has been extensively discussed in literature, this important factor remains somehow empirical and subjected to the engineer judgment.

The behavior factor R emerges among the parameters defining the RPA design spectrum and the values attributed to it are subject to the following comments:

- They depend only on the LLRS type of the building.
- They are given arbitrarily without any scientific basis.
- They are, in many cases, higher than those given by other codes such as Eurocode 8 (EN 1998).
- The ductility itself, on which they depend fundamentally, is defined in a vague manner.
- They seem to be overestimated as it emerges from the results obtained by authors such as Edjtemai (1981) and Lam et al. (1998).
- This fact is confirmed here by comparison of the RPA method with the exact one (Figs. 2, 3) and with both exact and proposed ones (Fig. 6b) in evaluating both base shear and displacement.
- Last but not least, they do not take into account the particularity of some regions of high sensibility to earthquakes, such as Algiers, where the life-safety criterion takes precedence over the economical one. In such a case, the incursion in the plastic domain must be strictly limited and consequently R must be reduced.

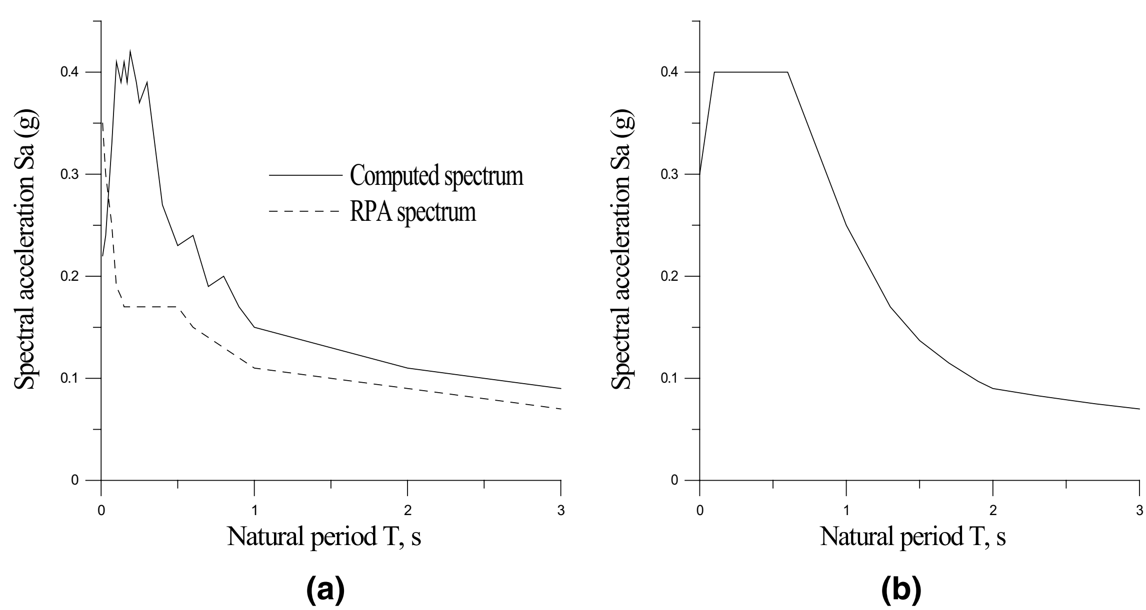

Fig. 1 **a** RPA spectrum and computed one and **b** EC8 Type I spectrum

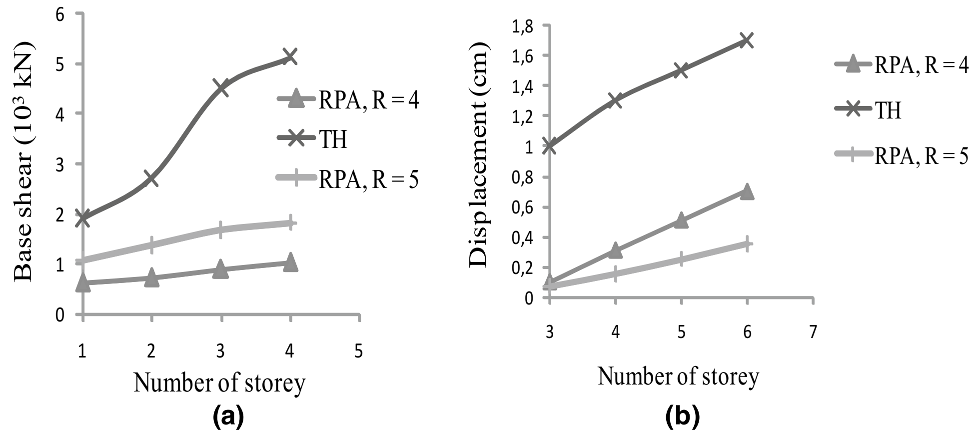

Fig. 2 Exact method and RPA one: **a** base shear vs. number of storey and **b** displacement vs. number of storey

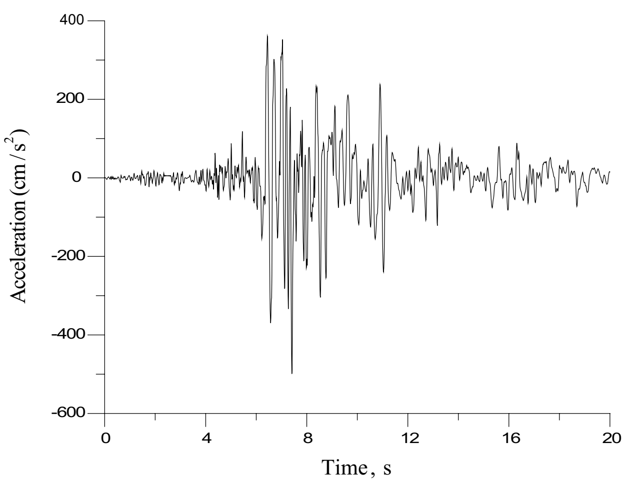

Fig. 3 Dar El Beida 2003 seismic record

RPA method versus "simplified performance-based procedures"

After the terrible Northridge 1994 earthquake and similar further earthquakes, the classical approach implemented in design codes proved to be unsuccessful in the prevention of earthquake consequences. The use of more perfect approaches that clearly takes into account the nonlinearities of structures became necessary (Pinho 2007). In this perspective, we have to choose among two analysis tools that differ in complexity, accuracy and time consuming: nonlinear time history procedure and nonlinear static (pushover) one. As mentioned in the introduction, the first procedure is complex but relatively more accurate. So, it is used here only for comparison. It consists of calculating the seismic response of a structure by a numerical method considering that the seismic loading is known only from experimental data. For this purpose, the Duhamel's integral can be evaluated numerically, based on its approximation by a summation utilizing a numerical integration technique such as the trapezoidal rule or the Simpson's rule. Nevertheless, the Duhamel's integral is used only for linear systems where the superposition principle is applicable. For nonlinear systems, in which the properties (mass, damping and particularly stiffness) change during the earthquake, step-by-step numerical integration schemes are most suitable as they permit to approximate the nonlinear behavior by a sequence of successively changing systems. The most popular time integration methods are those of the Newmark family. Between them, the linear acceleration method has been found to yield excellent results with relatively little computational effort as mentioned by Mario Paz in "Structural Dynamics, theory and computation" (Paz 1985) where one can find this method presented in detail.

The second procedure consists of comparing the capacity of a structure with a target displacement derived from a pushover analysis. This target displacement corresponds actually to the maximal displacement predicted in the structure during an earthquake. The nonlinearities of materials are taken into account by a combination of the nonlinear static (pushover) analysis and the response spectrum approach (Fajfar and Eeri 2000). The applications of such an approach are: the capacity spectrum method of ATC 40 (Applied Technology Council (ATC) 1996), the nonlinear static procedure of FEMA 356 (American Society of Civil Engineers 2000), the N2 method (Fajfar 1999) implemented in the Eurocode8 (EN 1998) and the modal pushover analysis (Chopra 1995). In these methods, the pushover analysis of a multi-degree-of-freedom (MDF) model is combined with the response spectrum analysis of an equivalent single-degree-of-freedom (SDF) system.

The most important steps of a simplified method are given in the following:

Main steps of a typical simplified method

- A planar MDF structural model is used vibrating predominantly in the first mode.
- Seismic demand is defined by an elastic acceleration spectrum S_{ae}.
- A nonlinear force–displacement relationship of the MDF system is determined using a pushover analysis. For this purpose, force and displacement are usually represented by base shear and top displacement, respectively, for different types of lateral load distribution.
- Structure is modeled as an equivalent SDF system.
- A simplified bilinear acceleration–displacement relationship is determined by the idealization of the pushover curve on the basis of some criteria as the equal energy rule.
- Target displacement of the SDF model is determined by two different approaches. The first one (ATC 40) uses equivalent elastic systems with an iterative procedure, whereas the second one (FEMA 356 and N2) is based on inelastic spectra derived from a nonlinear time history analysis, or a typical elastic design spectrum reduced by appropriate behavior factors.
- The target displacement for the MDF system is obtained from the SDF displacement demand using the inverse MDF to SDF equivalence procedure.
- Finally, comparison between the seismic demands and the capacities gives the expected performance.

Main application features

Applications were made on a regular RC frame structure with a number of stories varying from one to six using the 13 Algerian ground motions provided by the National Center of Applied Research in Seismic Engineering (CGS) and mentioned in Table 1.

Static and dynamic nonlinear analyses were performed with the well-known SAP (Structural Analysis Program) developed by Computers and Structures Inc. (SAP 2000). This computing program permits easily the use of the ATC and FEMA procedures.

Note that all the stations are situated in the neighborhood of Algiers.

Comparison of RPA, ATC and FEMA methods with exact method

Figure 4a, b shows that the values given by the RPA method are very small in comparison with both exact method and simplified ones.

Table 1 Recorded PGA, velocity and displacement of the Boumerdes earthquake

Station/hypo-central distance in km/distance from Algiers in km	East–west		
	A (g)	*V* (cm/s)	*D* (cm)
Keddara/1/20/25, east	0.34	18.9	4.6
Keddara/2/20/25, east	0.58	19.7	6.0
Dar El Beida//29/10, east	0.52	27.5	9.1
Hussein Dey/36/0	0.27	16.5	3.9
Kouba/41/0	0.31	10.5	1.9
Tizi Ouzou/49/40 east	0.20	9.0	2.0
Blida/72/35 west	0.05	3.4	1.0
Azazga/75/60 east	0.12	14.1	4.0
El Afroun/86/50 west	0.16	5.0	0.4
Tipaza city/100/30 west	0.03	2.5	0.7
Ham. Righa/110/50 west	0.10	10.2	1.3
Miliana/130/50 west	0.03	2.3	1.4
Ain Defla/151/60 West	0.03	1.6	0.9

Propositions to improve the RPA

Behavior factor R

The discussion developed in Sect. 3.2 has led to the following proposed R values given against the RPA ones in Table 2.

Proposed design spectrum

Elastic response spectra are obtained by calculating the response of SDF systems by linear integration and plotting the maximum response versus the period (or frequency) for a given amount of damping and different types of structures. This process is repeated for several earthquakes to obtain the "average" response spectrum. The inelastic response spectrum is obtained either by the same process done for the elastic response spectrum but with a nonlinear integration and the assumption of a specified ductility factor, or by the derivation of the inelastic response spectrum from the elastic one by reducing this latter with the commonly called reduction factor (Paz 1985).

As mentioned before, codes use smooth and standard design spectra for convenience.

As regards the RPA code, the "normalized acceleration spectrum" S_a/g given by Eq. 1 has been revised here because of the deficiencies pointed out in Sect. 3. The main revisions can be summarized in the following: In addition to the characteristic period T_1 which has been replaced with 0.15 s in the first equation, the equations have been not only reduced but also corrected by appropriate coefficients. These coefficients have been adjusted

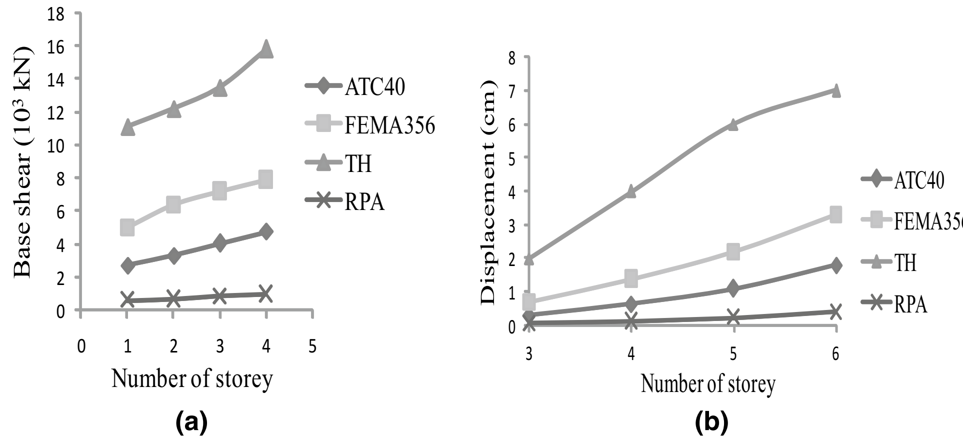

Fig. 4 RPA, ATC, FEMA and exact methods: **a** base shear and **b** displacement

Table 2 RPA values of R and proposed ones

Class	Type of LLRS	RPA value	Proposed value
1a	Self-steady frames without masonry rigid infill	5	4
1b	Self-steady frames with masonry rigid infill	3.5	3
2	Shear walls	3.5	3
3	Central shear wall	3.5	3
4a	Frames and walls with interaction	5	4
4b	Bearing wall system	4	3
5	Cantilever system with distributed mass	2	2
6	Inverse pendulum	2	2

little by little until they gave shapes similar and close to computed spectra (Fig. 5a) generated using numerical integration and with real seismic records collected in the vicinity of Algiers taking into account the particularity of this region. The authors insist on the fact that this work has been deeply inspired by the guidelines given in "Chapter 1, Sect. 1.6.15: General Response Spectrum" of FEMA 356 (American Society of Civil Engineers 2000), in particular the equations from (1–8) to (1–12) and Fig. 1-1 of this prestandard (Fig. 5b).

The authors think that the validity of the renovated equations has been verified in a way but it still needs to be enhanced.

Definition

The proposed "normalized acceleration spectrum" is defined by the following equations:

$$\frac{S_a}{g} = \begin{cases} 3.125\ \eta\ \frac{A \cdot Q}{R}\left(1 + \frac{T}{0.15}\right) & \text{if} \quad 0 \le T \le 0.15\ \text{s}, \quad \text{(a)} \\ 6.25\ \eta\ \frac{A \cdot Q}{R} & \text{if} \quad 0.15 \le T \le T_2, \quad \text{(b)} \\ 6.25\ \eta\ \frac{A \cdot Q}{R} \cdot \frac{T_2}{T} & \text{if} \quad T \ge T_2, \quad \text{(c)} \end{cases} \tag{5}$$

where the different parameters have the same definitions given above.

Comparative study

Equation 5a–c and Fig. 6 permit the following observations:

- The equations giving the proposed spectrum are simpler.
- The first part of the proposed spectrum is an increasing line as well as in other codes.
- Values of displacement given by the proposed spectrum seem to be more accurate.
- The proposed spectrum looks a lot like design spectra of many countries not only in the shape but also in the values as it may be ascertained from the comparison with different design spectra worldwide.

Use of the proposed spectrum in a simplified nonlinear method

Since the available simplified methods are approximate and fairly equivalent, the criterion of choice among them is the ease of use. The ATC and FEMA procedures seem to be convenient in this sense as they are available in the so-called SAP computing program which is largely used by Algerian engineers and scholars.

Main tools

The main tools needed in a simplified nonlinear procedure are the capacity curve and the seismic demand. The

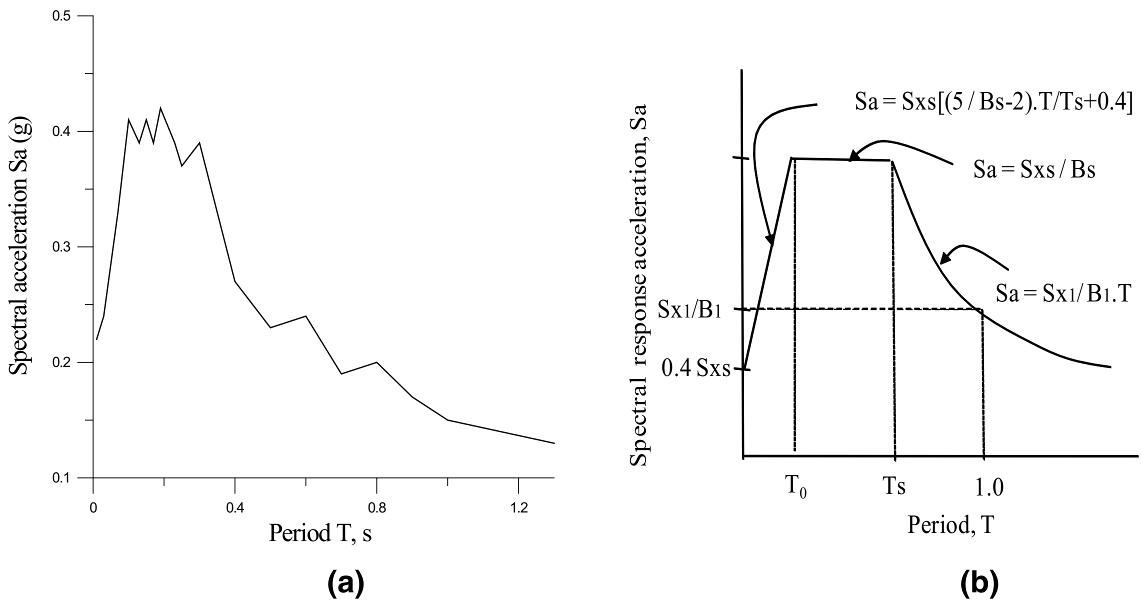

Fig. 5 **a** Boumerdes computed spectrum and **b** FEMA response spectrum

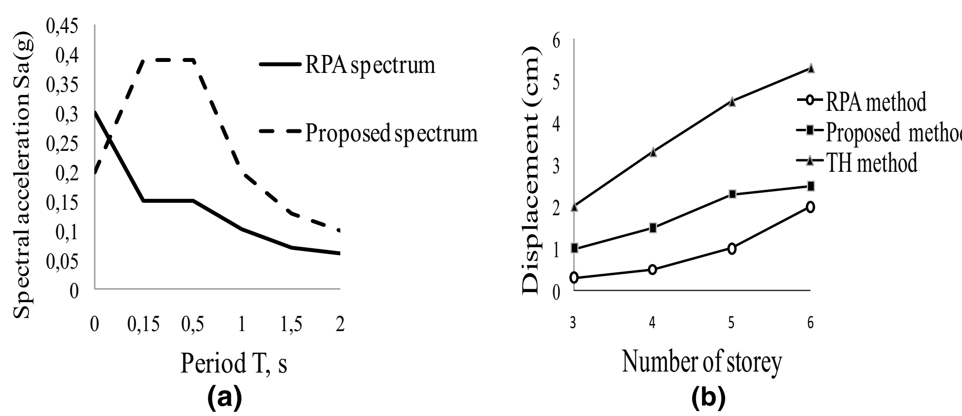

Fig. 6 Comparison between: **a** RPA and proposed spectra, **b** TH, RPA and proposed methods

pushover curve is obtained by submitting the structure to the sub-described earthquakes and then idealized according to the FEMA method to give the capacity curve. This latter is compared to the seismic demand derived from the proposed design spectrum to assess the expected performance.

Illustrative example

Application is made to a simple two-bay five-storey building. The data used are given in Table 3.

An example is given in Fig. 7.

From this example, the performance point coordinates (Sa, Sd) for RPA method and proposed one are (0.70, 0.015) and (0.77, 0.017), respectively.

These values, in addition to others, may be used to assess the structure in terms of performance level

Table 3 Used data

Seismic parameters		
Acceleration coefficient of zone, *A*	0.35	
Quality factor, *Q*	1.35	
Behavior factor, *R*	4	
Characteristic period, T_2 (s)	0.7	
Damping ratio, ξ (%)	5	
Damping correction factor, η	0.88	
	Column	Beam
Characteristics of the structure		
Length (m)	3	4
Section (cm × cm)	30 × 30	30 × 40

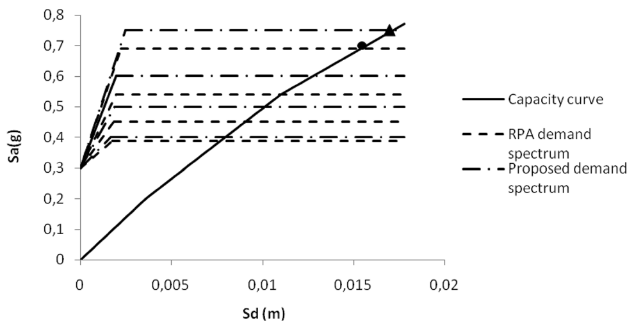

Fig. 7 Performance point according to both RPA method (filled circle) and proposed one (filled triangle)

Conclusion and further work

To improve the Algerian seismic code (RPA) which presents many deficiencies, a simple and more accurate design spectrum is proposed for the district of Algiers based on many considerations and parameters such as local seismic records. This new spectrum is usable to determine the base shear in the classical method and the seismic demand in any simplified method. This work may be considered as a basis of a big project which must be completed by similar further work to validate and perform the proposed spectrum, particularly using more real or simulated earthquakes, and may be extended to specific design spectra for other important regions such as the regions of Oran and Constantine, the two most important towns after Algiers, the capital.

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Compliance with ethical standards

Conflict of interest On the behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Algerian Ministry of Inhabitants. Règles Parasismiques Algériennes, C.G.S (2003), Algeria.

American Society of Civil Engineers. (2000). Prestandard and commentary for the seismic rehabilitation of buildings. FEMA-356. Federal Emergency Management Agency, Washington D.C., p. 519.

Applied Technology Council (ATC). (1996). Seismic evaluation and retrofit of concrete buildings, ATC 40, Report No. SSC 96-01, prepared for the Seismic Safety Commission, State of California, Redwood City, CA.

Calvi, G. M. (2018). Revisiting design earthquake spectra. *Earthquake Engineering and Structural Dynamics, 47*(13), 2627–2643.

Calvi, G. M., Rodrigues, D., & Silva, V. (2018). Introducing new design spectra derived from Italian recorded ground motions 1927 to 2017. *Earthquake Engineering and Structural Dynamics, 47*(13), 2644–2660.

Chebihi A., & Laouami N. (2014). Comparative seismic study between Algerian code (RPA99), European code (EC8) and American code (UBC97). 2nd European Conference on Earthquake Engineering and Seismology, Istanbul, Turkey.

Chopra, A. K. (1995). *Dynamics of structures theory and applications to earthquake engineering*. Englewood: Prentice Hall.

Edjtemai, N. (1981). Modèles de calcul de la réponse élasto-plastique d'une structure à une action sismique. E.N.P.C. de Paris.

EN 1998-1. (2004). Eurocode 8: design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings, European Committee for Standardization (CEN), Brussels, Belgium.

Fajfar, P. (1999). Capacity spectrum method based on inelastic demand spectra. *Earthquake Engine Structural Dynamics, 28,* 979–993.

Fajfar, P., & Eeri, M. (2000). A nonlinear analysis method for performance-based seismic design. *Earthquake Spectra, 16*(3), 573–592.

Hamburger, R. O. (2003). *Building code provisions for seismic resistance, earthquake engineering handbook 11*. Boca Raton: CRC Press LLC.

Hamdache M., Peláez J. A., Talbi A., & Mobarki M. (2010). Evaluation of probabilistic seismic hazard in Northern Algeria. A contribution to the Algerian building code, "SICZS_2010", Université Hassiba Benbouali de Chlef, Algeria.

Lam, N., Wilson, J., & Hutchinson, G. (1998). The ductility reduction factor in the seismic design of buildings. *Earthquake Engineering and Structural Dynamics, 27,* 749–769.

Paz, M. (1985). *Structural dynamics, theory and computation*. New York: Van Nostrand Reinhold Company.

Pinho, R. (2007). Nonlinear dynamic analysis of structures subjected to seismic action. *Advanced Earthquake Engineering Analysis, CISM Courses and lectures, 494,* 63.

SAP2000. (1999). Web tutorial1-quick pushover analysis tutorial.computer and structures, Inc.Berkeley, California.