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Comparative study between the push-over analysis and the method proposed by the RPA for the evaluation of seismic reduction coefficient

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ABSTRACT

A good understanding of the seismic behavior of structures through nonlinear models based on simplified laws linking deformation to its effort associates on the one hand with the development of new nonlinear methods has allowed the formulation of Factor of behavior, factor responsible for the reduction of the seismic effort. In the seismic regulations, in particular the RPA99, the non-linear behavior of a structure is taken into account in a simplified way by standard values of this coefficient. But in reality, this factor is a complex function of a number of parameters whose expression cannot be summarized to a simple constant. The aim of this work is to evaluate the behavior factor of a reinforced concrete gantry using a non-linear method described by the Push-Over analysis, this method makes it possible to evaluate this factor in a more precise.

1. Introduction

The dimensioning of structures takes into account very roughly the non-linear behavior of the structure by means of a coefficient called "behavior factor". Most codes or regulations take into account a single flat value of this factor which is not applicable to the same type of bracing, regardless of the seismic zone, the intensity of the vertical loads, etc.

The determination of this behavior factor presents a certain difficulty because it depends on several parameters (type of materials used, type of bracing, ...). However, an overall behavior factor is retained in conventional calculations.

Various recent methods have been used in order to establish the value of this coefficient characteristic of various types of framework and allowing an overall flat-rate consideration of their capacity for dissipating energy by plastic deformations. Push-over analysis consists in evaluating over time changes in the dynamic characteristics of the structure (eigen frequencies and eigen modes) as

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a function of parameters characterizing the damage suffered, thus the precise evaluation of the behavior Non-linear expected on each structural element.

2. Definition of Behavior Factor

The seismic stresses are deduced by affinity of a ratio 1 / R of those applied to its resistant structure. The latter is supposed endowed with an ideal behavior that is to say infinitely elastic and linear. The coefficient 'R' is called the behavior factor. A more restrictive definition is to say that the behavioral factor is essentially there to reflect the fact that the reinforced concrete structure behaves differently from the ideal behavior assumed at the beginning [1].

3. Analyse Push-Over

Push-over analysis is a non-linear static analysis [2] conducted under constant gravity loads and horizontal loads that grow monotonically. It is therefore a step-by-step study for which the material data (behavior laws of materials, sections) are similar to those of elasto-plastic dynamic analysis, but where the difficulties of time-step calculation are avoided. It makes it possible to evaluate the expected plastic mechanisms and the distribution of damage in complex structures.

4. Behavior Factor According to Certain Seismic Regulations

4.1 Behavior Factor According to European Regulation

The behavior factor used in the European regulation ″ Eurocode 8″ [3], designated "q" and representing the ratio between the elastic spectrum and the inelastic spectrum, has values between 1 and 5. The choice of these values holds taking into account the type of structure, the bracing method, the materials used and the constructive arrangements adopted to promote the ductility of the elements of this structure. This makes it possible to improve the ability of these elements to withstand deformations that are greater than the elastic limit. Moreover, the Eurocode 8 defines a force reduction factor "q" depending on the period T and the behavior factor q according to the following expression [4]:

$$q' = \frac{1+\frac{T}{T_C}(\eta\ \beta_1 - 1)}{1+\frac{T}{T_C}\left(\eta\ \frac{\beta_1}{q} - 1\right)} \text{ Si} \qquad \text{if} \qquad T < T_c \tag{1}$$

$$q' = q \qquad \text{if} \qquad T > T_c \tag{2}$$

where
T_c : Characteristic period of the soil;
η : Damping correction factor of the taken structure equal to 1 when the depreciation is 5%;
β_1 : Dynamic Amplification Factor.

4.2 Behavior Factor According to RPA99 (2003 Version)

The Algerian seismic regulation RPA 99 (version 2003) designates the behavior factor by R, its value is given according to the bracing system classified into four categories [5]:

The new recommendations (of year 2010) of our regulations (2003 version) contain some modifications concerning the coefficient of behavior affecting the type of reinforced concrete bracing presented by a decrease in certain values [6]; The purpose of this decrease is to increase the safety margin of buildings during seismic excitation.

4.3 Behavior Factor According to US Regulations

The behavior factor in US regulations is marked "R". Its values range from 1 to 8. In 1980, experimental research made it possible to establish curves expressing the shear force at the base as a function of the displacement at the top of the structure. These curves make it possible to express the behavior factor as the product of three coefficients

$$R = R_\mu . R_s . R_\zeta \tag{3}$$

where
R_s : force or over-resistance factor (ratio between elastic force and computational force);
R_μ: reduction factor (ratio between elastic force and inelastic force);
R_ζ: damping factor.

Without precise additional data, the values of the factors Rs and R are taken to be unity.
Recent studies [ATC 1995a)] adopt a similar formulation [7]:

$$R = R_\mu . R_s . R_R \tag{4}$$

where
R_R: structural redundancy factor.

5. Comparative Study of Reinforced Concrete Portico

In this study, we will determine this behavior coefficient by using a more exact formulation based on the actual behavior of the structure and compared with the value proposed by the Algerian regulation RPA 99 (2003 version).

5.1 Structure

It is to study a reinforced concrete portico of a multi-storey hospital (R + 6) as shown in Figure (1), located in Bejaia, classified in zone IIa according to RPA 99 (2003 version), The structural elements are posts and beams of dimensions shown in the table below, with a floor height equal to *4.08m.*

According to the RPA 99 (2003 version), we have

$$\left.\begin{array}{l}\text{Zone } \mathbf{IIa} \\ \text{Usage Group } \mathbf{1A}\end{array}\right\} \Rightarrow (\xi = 6\%)$$

$$\left.\begin{array}{l}\text{Reinforced concrete gantry} \\ \text{Light filling}\end{array}\right\} \Rightarrow (A = 0,25)$$

$$\eta = \sqrt{7/(2+6)} = 0,9354 \geq 0,7 \tag{5}$$

Self-stable gantry without filling in rigid masonry: *R = 5*

The value of Q is determined by the following formula

$$Q = 1 + \sum_{1}^{5} P_q = 1{,}20 \tag{6}$$

For a movable site (S3)

$$T_1 = 0{,}15 \text{ s} \tag{7}$$

$$T_2 = 0{,}50 \text{ s} \tag{8}$$

The fundamental period is determined by the following formula:

$$T = C_T . h_n^{3/4} = 0{,}618 \text{ sec} \tag{9}$$

where
h_n: Height measured in meters from the base of the structure to the last level (h_n = 28.56 m);
C_T: Coefficient, function of the bracing system, type of filling (Self-supporting gantry cranes with masonry filling: C_T =0.050)

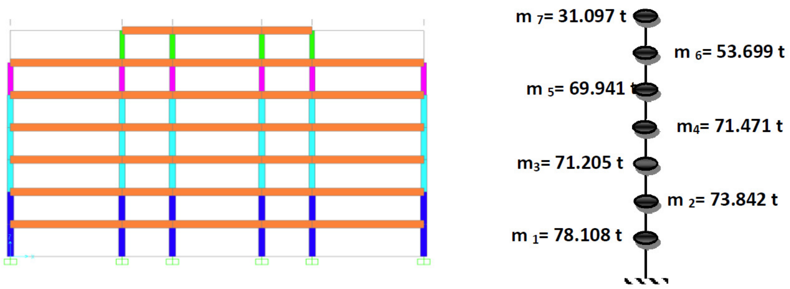

Fig. 1. Overview of the gantry

Table 1
Dimensions of the gantry components

	Levels	Dimensions (cm^2)
Column	RDC+1er	45x70
	2th+3th+4th	40x65
	5^{éme} floor	35x60
	6th floor	30x55
Beams	35x100	

5.2 Elastic Spectrum

The determination of the elastic response spectrum is obtained from the formulation of the inelastic spectrum by performing some operations which have led to the unconventional expressions of the acceleration. The elastic spectra are represented in Fig. 2 for different types of soil.

5.3 Push-Over Analysis
5.3.1 The push-over curve

The Push-over curve of the building is obtained by using the SAP2000 software which contains the different seismic calculation methods (Response Spectrum Function, Time History Function ...), this software was developed by the CSI (Computers and Structures Incorporation). The Push-over curve is a non-linear curve connecting the shear force to the base V and the displacement of the top of the structure as shown in Fig. 3.

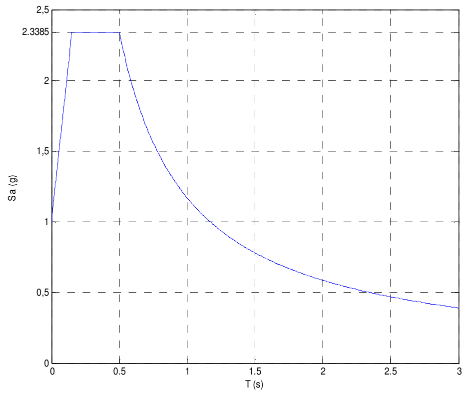

Fig. 2. Elastic Spectrum of RPA99 for Mobile Site

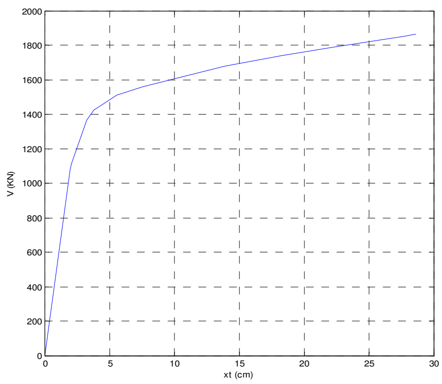

Fig. 3. Push-over curve

5.3.2 Idealized push-over curve

An iterative procedure based on the principle of equality of areas is used to transform the Push-Over curve into a bilinear curve. The results of the iterations gave the curve represented in Fig. 4.

5.4 Curve Transformation

5.4.1 Transformation of the elastic spectrum to the acceleration-displacement format

The elastic response spectrum is transformed from the traditional acceleration-period (Sa-T) to the acceleration-displacement (Sa-Sd) format using the following relation

$$S_{de} = \frac{T_n^2}{4\pi^2} S_{ae} \tag{10}$$

where: S_{ae} and S_{de} de are respectively the spectral acceleration and the spectral displacement corresponding to the periods T, with a viscous damping constant set at 6% (FIG. 5).

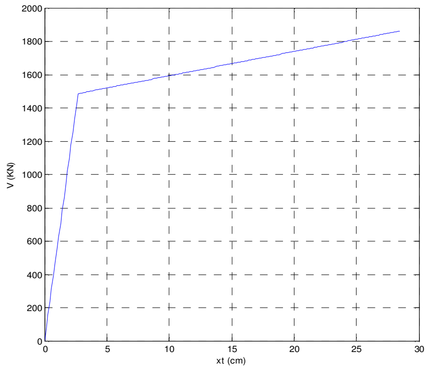

Fig. 4. Idealized Push-over Curve

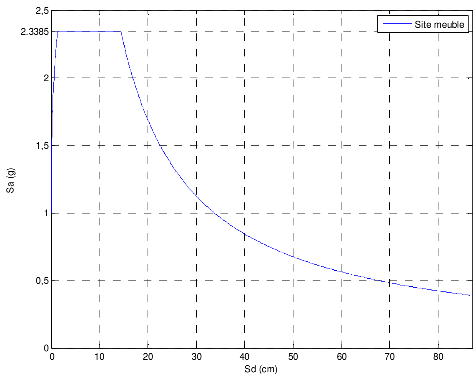

Fig. 5. Spectrum elastic format Acceleration-Displacement for a movable site

5.4.2 The push-over curve for a single degree of freedom system

The push-over curve for a multi-degree system is transformed to a curve for a single degree of freedom system by dividing the shear force and displacement by the modal participation factor Γ_1 given by the expression), One obtains Γ_1 = 1.2516, which makes it possible to trace the curve illustrated in Fig. 6 herein after.

$$\Gamma_1 = \frac{\sum_{j=1}^{n} m_j \phi_{t,1}}{\sum_{j=1}^{n} m_j {\phi^2}_{t,1}} \tag{11}$$

5.4.3 Capacity Curve

The capacitance curve describes the relationship between the acceleration at the base and the displacement of a single oscillator, this curve can be easily determined by dividing the force by the effective mass of the construction related to the amplitude of the first vibration mode M1 * given by equation (11), the application of this expression gives a value of 390.705 t Thus we obtain the curve represented by Fig.7.

$$M_1^* = \frac{\left(\sum_{j=1}^{n} m_j \phi_{t,1}\right)^2}{\sum_{j=1}^{n} m_j {\phi^2}_{t,1}} 390.705\ t \tag{12}$$

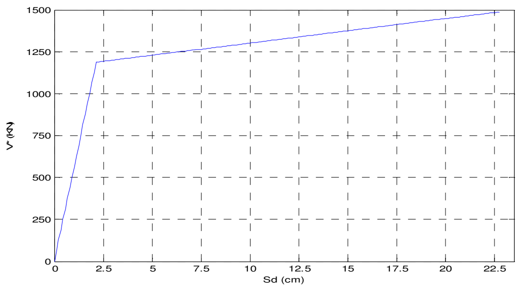

Fig. 6. The Push Over curve for a system

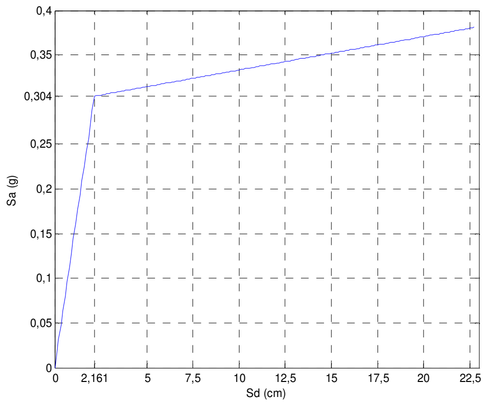

Fig. 7. Capacity curve

5.4.4 From the elastic spectrum to the inelastic spectrum

The inelastic spectrum is deduced from the elastic spectrum by reducing the latter by the reduction factor R_μ defined by the following relation

$$R_\mu = \frac{S_{ae}}{S_{ay}} = \frac{0.781}{0.304} = 2.5689 \tag{12}$$

S_{ae}: Elastic acceleration;
S_{ay} : Elastic acceleration;

The curve shown in Fig. 8 is obtained as shown

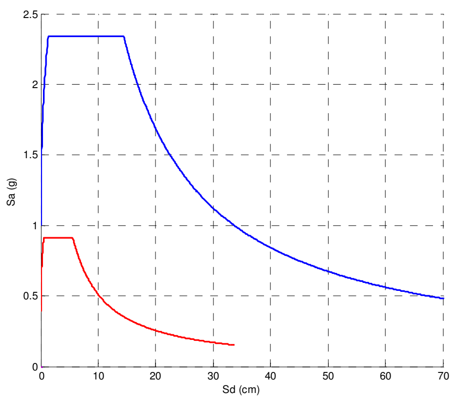

Fig. 8. Elastic and inelastic spectrum

5.5 Determination of Performance Point

The seismic performance of the system equivalent to a single degree of freedom is graphically represented by the intersection between the capacity curve and the reduced response spectrum.

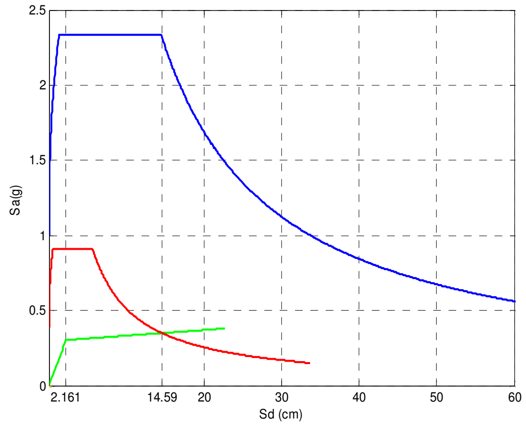

Fig. 9. Performance Point Determination

At first reading, the values S_{dmax} = 14.59 cm and S_{dy} = 2.161 cm are directly read from the graph in the figure above. Here
S_{dmax}: Maximum displacement of the system with a single degree of freedom;
S_{dy}: Displacement at elastic limit;
One can therefore calculate the ductility, it is the ratio between the two values of these displacements

$$\mu = \frac{S_{dmax}}{S_{dy}} = 6.75 \tag{13}$$

The maximum displacement of the system with several degrees of freedom is obtained by multiplying the maximum displacement of the system to a single degree of freedom by the modal participation coefficient

$$x_t = S_{dmax} \,.\, \Gamma_1 = 18.2\ cm \tag{14}$$

5.6. Evaluation of Reduction Factors
5.6.1. Ductility factor R_μ

Since
***T_{eq}**= 1.4972 > **T_c**= 0.5 s* therefore $\boldsymbol{R_\mu = \mu = 6.75}$

5.6.2 Resistance factor R_s

Without precise additional data, the factor value Rs is taken equal to the unit

5.6.3 Redundancy factor R_R

In the Algerian earthquake regulation 99 (version 2003), the redundancy factor is represented by the following relationship: R_R = 1 / Q = 0.83.

5.6.4 R Seismic behavior factor R

The seismic reduction factor is the multiplication of the three factors R_μ, R_s and R_R previously determined as indicated in the following relation

$$R = R_\mu \, x \, R_s \, x \, R_R = 5.40 \tag{15}$$

6. Conclusion

The comparative study in this chapter determined the value of the behavior factor using a more accurate method compared to that proposed by the RPA 99 (2003 version), which gives unjustified values of this Factor, by contrast the method currently used based on the notion of performance, makes it possible to calculate this factor and give values more accurate. The results obtained resulted in a justified value comparable to the standard value proposed by the RPP.

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