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Evaluation of the behavior factor of portal structures according to Moroccan seismic code RPS2000

Said Louhibi[1], Elbachir El Kihel[2], Mimoun Chourak[3]
[1]Mohammed Premier University, Ecole Nationale des Sciences Appliquées, E.N.S.A - BP 669 Quartier Alquods complexe universitaire, Oujda – Morocco
[2]Mohammed Premier University, Ecole Nationale des Sciences Appliquées, E.N.S.A - BP 669 Quartier Alquods complexe universitaire, Oujda – Morocco
[3]Département de Bioologie, Chimie, Géologie, Faculté Pluridisciplinaire Nador – Morocco

Abstract:- The behavior factor K recommended by the Moroccan seismic code (RPS2000) is the main subject of this work to evaluate the elastic force and its use in the procedure for seismic design of portal structures. In fact, the current formulation of the behavior factor k under RPS2000 totally neglects the resistance, the redundancy as well as the second-order dynamic P-Δ effect of the portal structures; this led us to proceed to the comparison of the behavior factor K with other universal formulations. This work has therefore for goal to improve the security reserve of portal systems for different cases of sites. The results clearly show that the behavior factor as presented in RPS2000 is far to be able to guarantee the required security. Our suggestion is to introduce the behavior factor K in a new format ($K = R_\mu C.R_S.R_R$) to provide a better estimation of the shear force and therefore a better earthquake-resistant protection.

Keywords:- behavior factor, ductility, portal structure, relative displacement, resistance, RPS2000, seismic performance.

I. INTRODUCTION

The first seismic regulations in Morocco are AGADIR standards appeared in 1960 after the earthquake of Agadir (Decree No. 2-60-893 of 21-12-1960).

In April 2000, a new regulation "RPS2000" [1] presented and approved by Decree No. 177 (22 February 2002), establishing the National Committee for Earthquake Engineering (CNGP).

This Regulation lays down the rules for the calculation and design of structures to enhance the holding of buildings to earthquakes. It also lays down the technical requirements of civil engineering and architectural design necessary to ensure buildings optimal resistance to shock intensities.

II. THE MOROCCAN SEISMIC CODE RPS2000-VERSION 2011 [2]

Objectives of the review:

After seven years of application of the RPS2000, the Ministry of Habitat and Spatial Planning has initiated a partnership framework with the Moroccan University Mohammed V, the updating of this regulation. This updating has the main objective of:

- Accompany the dynamic evolution of the earthquake engineering;
- Exceed the problems of application detected on the application of RPS2000 with the professionals of the Building and Public Works;
- Update the technical content of the RPS2000: new seismic maps of Morocco and new seismic parameters .
- Redefine a new classification of buildings according to their importance and their functions.

The main changes introduced by the new RPS 2011 have been defined following an approach of extended consultation with institutional and professionals partners of the Ministry and this, among other things, by the launching of a survey in 2008 among professionals in the housing and Construction (Architects, Consultants, Property Developers and Contractors …). This survey was primarily designed to assess the opinion of professionals concerning the RPS2000 and to detect the difficulties encountered in its application.

III. PRESENTATION OF THE BEHAVIOR FACTOR ACCORDING TO THE CODE RPS2000 AND RPS2000-VERSION 2011

In Morocco, the procedure of elastic analysis of structures is the main practice of seismic design. It takes into account the nonlinear response of a Paraseismic system through the response modification factors, also called behavior factor K. This factor is used to reduce the shearing force (V_e) calculated from the elastic analysis using a response spectrum with 5% damping.

The equivalent lateral seismic force representing elastic response of V_e according to RPS2000 [1] is calculated using the following formula:

$V_e = A.S.D.I.W/K$ (RPS2000) and $V_e = v.S.D.I.W/K$ (RPS2000-VERSION 2011) (1)

A: the acceleration coefficient of seismic zones in Morocco
v : speed coefficient
S : the site coefficient based on soil properties
D: the dynamic amplification factor given by the dynamic spectrum of amplification
I : the coefficient of importance or priority based on Building Class
K: the behavior factor
W: the load taken by weight of the structure

The behavior factor K has not changed in the two versions of the RPS2000 and the RPS2000-version 2011, the values of K according to the RPS2000 (Table I) includes only the desired level of ductility and selected type of bracing regardless of the period of the site and also neglects the resistance, the redundancy of the structure and the second-order dynamic P-Δ effect.

Table I: Behavior factor K (RPS 2000) according to the level of ductility [ND1: level 1 of ductility (low); ND 2: level 2 of ductility (average); ND3: level 3 of ductility (large)]

Type of bracing	ND1	ND2	ND 3
Concrete frames	2	3.5	5

This formulation thus adopted is far from being perfect, contrary to the different formulations of this factor in the international seismic codes, despite its empirical character.

To take into account of the period of the site, we expressed the values of behavior factor in portal bracing system for different levels of ductility for periods ranging from 0 to 2 seconds (Fig. 1).

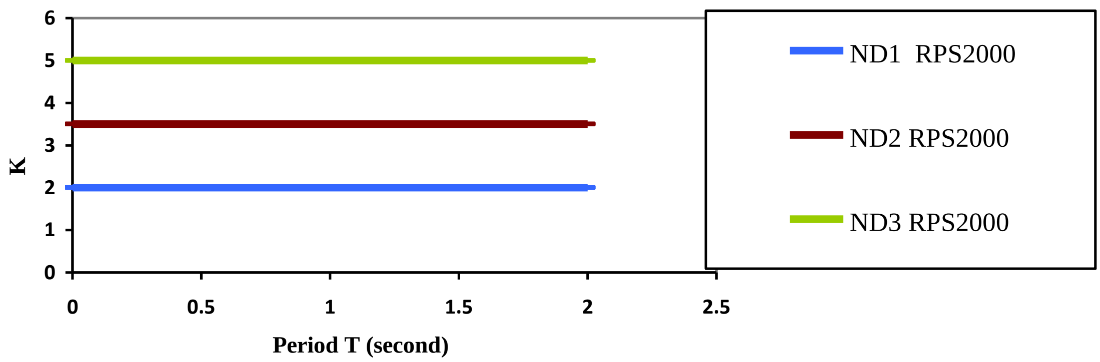

Fig.1: Distribution of the behavior coefficient K according to RPS2000 for the portal bracing system

Fig.1 shows that there is no influence of the period of the site on the values of the behavior factor for a portal system that takes constant values and only the level of ductility influences the values of the behavior factor.

IV. METHODS AND BIBLIOGRAPHIC SYNTHESIS OF THE REDUCTION FACTOR R IN THE UNIVERSAL SEISMIC CODES

The structural behavior factor, the equivalent of the behavior coefficient K of the seismic code RPS2000, represents the minimum reduction coefficient of the corresponding calculation strength to a specific level of ductility in order to ensure an inelastic behavior.

R= Velastic/Vcalcul (2)

The behavior factor K under the RPS2000 takes exact values depending on the level of ductility and the selected type of bracing. While in its universal formulation, the behavior factor R depends on the ductility factor

R_μ that has been the subject of several formulations based on statistical studies that were able to give more accurate values of this factor.

A. Ductility factor Rµ

R_μ is a measure of the overall nonlinear response of a bracing system according to the characteristics of the structure (ductility, damping and vibration period of ground motion).

The formulation of ductility coefficient is very complex. It must take into account the soil-structure interaction, imperfection related to the geometry of the structure and its degradation over time.

All these shortcomings have led the majority of seismic codes to adopt empiric formulations of the behavior factor. The seismic codes NEHRP [3] "National Earthquake Hazards Reduction Program" (1997), ATC [4] "Applied Technology Council" (1995), SEAOC [5] "Structural Engineers Association of California" (1999) as well as UBC code [6] "Uniform Building Code" (1982) also obeyed to empirical formulation of the behavior factor; this makes their reliability on the performance of the seismic response unknown.

In our work we focused on the evaluation of behavior factor for the different formulations compared to most currently used, of which we cite as follow:

Newmark and Hall [7] proposed for the behavior factor the following expressions:

$R_\mu = 1$ for $T < 0.03s$ (Equal accelerations) (3)

$R_\mu = \sqrt{2\mu - 1}$ $0.12s < T < 0.5s$ (Equal energy) (4)

$R_\mu = \mu$ $T > 1s$ (Equal displacement) (5)

Krawinkler and Nassar [8] evaluated relationships of based on the natural period, and the second slope of the bilinear system by considering a damping of 5%.

$$R_\mu = [c(\mu - 1) + 1]^{1/c} \tag{6}$$

$$c(\mathrm{T},\alpha) = \frac{\mathrm{T^a}}{1+\mathrm{T^a}} + \frac{b}{T} \qquad a = 1; b = 0.42 \text{ for } \alpha = 0$$

Where the parameters a and b were obtained from the regression analysis, and α is the hardening parameter.

Miranda and Bertero [9] have established expressions of a unified shape and easy to use, obtained from recordings of ground motion as follows:

$$R_\mu = \frac{\mu - 1}{\phi} + 1 \tag{7}$$

$$\phi = 1 + \frac{1}{10\mathrm{T} - \mu\mathrm{T}} - \frac{1}{2T}\exp\left[-1.5(1n(T) - 0.6)^2\right] \quad \text{Rock site}$$

ϕ: Coefficient characterizing the nature of soil and its characteristic period

Factor R_μ proposed by Priestley [10], takes in account the specific characteristic period in the site and is expressed by the relation:

$$R_\mu = 1 + (\mu - 1)\frac{T}{1.5T_g} \leq \mu \tag{8}$$

Which assumes equal displacement $R_\mu = \mu$ when $T > 1.5Tg$ and equal accelerations $R_\mu = 1$ when $T \to 0$.

Borzi and Elnashai [11] found that the behavior coefficient is the same for the whole structure. It allows the limitation of constraints and their transformation in movements. For this it must not reduce the demand for resistance and thus have a behavior factor equal to 1 to remain in the elastic spectra.

The Algerian seismic code RPA99 [12] introduced a quality factor Q to consider the effect of irregular geometric structures, where the seismic force calculation is quantified as follows:

$$V = \frac{\mathrm{A.D.Q}}{\mathrm{R}}. \quad W = .\frac{V_e}{R}.Q \tag{10}$$

The ratio 'R/Q' refers to the coefficient characterizing the structural behavior.

Recent studies conducted by Mouzzoun et al. [13] based on the examination of eight reinforced concrete structures dimensioned according to the seismic code RPS2000 by push over analysis using the software “Structural Analysis Program” (SAP2000), showed the influence of several parameters on the value of the behavior factor K, i.e., the number of Portal Frames, type of soil and fundamental period of the structure.

The regulation ATC [4] proposes a new formulation based on experimental research in three independent coefficients of the behavior factor. It is given as:

$$R = R_{\mu}.R_S.R_R \quad (9)$$

Where R_R is the factor of structural redundancy, R_{μ} is the ductility factor and R_S is the resistance factor.

B. Strength reduction factors R_S

The seismic effort Vcalcul provided by the majority of the earthquake-resistant codes generally exceeds the demand of the structure resistance V_R which allows the structure to support a large capacity of resultant efforts.

The report $\left(\frac{V_R}{V_{CALCUL}}\right)$ for a structural system depends on the seismic zone and the fundamental period.

Several studies for different portal structures have been made to calculate the coefficient R_S. Some different R_S values obtained by some authors and seismic codes are as follow: 1.5 [14], 1.67 (N.E.H.R.P Code [3]), 1.5 (N.Z.S Code [15]), 2.7 for T = 0.11 and 1.7 for T ≥ 0.31 [16].

The significant differences between R_S values (ranging from 1.5 to 2.7) may have unfortunate consequences for its professional use, therefore a need for further studies to better control and have rational values that can be adopted by seismic codes.

C. Redundancy Coefficient R_R

It is known that when an element of the structure suffers damage, the entire 3D structure is mobilized to redistribute and resist efforts; and this is related to the effect of hyperstatic system and alternative paths of load redistribution.

However, the RPS2000 code does not consider the redundancy factor while the structural redundancy is strongly recommended in earthquake-resistant codes.

To endow structures with adequate redundancy, Whittaker et al. [17] recommend for an auto-stable structure four portal lines in each direction as minimum requested (R_R=1).

D. Factor taking into account the dynamic P-Δ effect

The second-order dynamic P-Δ effect is determined by the stability index θ in the RPS2000.

Han et al (2001) considered the dynamic P-Δ effect into seismic design procedures:

$R\mu$ = Ao{1-EXP(-BoT) with Ao = 0,99u + 0,15 and Bo = $23{,}9u^{-0{,}83}$ (11)

Regression analysis encompassing 40 earthquake records (rock or stiff soil condition), 37 natural periods (0.2 sec to 2 sec with 0.05 sec interval), 9 stability coefficients (0 to 0.2 with 0.025 interval), and 6 ductility ratios (1 to 6) allowed the introduction of The modification factor C with the following expression:

$$C = F(\mu,\theta) = [1-(1.591\mu - 2.8749)\theta].(1-\theta) \quad \text{where} \quad \mu \leq 0.4/\theta \quad (12)$$

$$R'_{\mu} = R_{\mu}.C(\mu,\theta,T) \quad (13)$$

E. Introduction of the behavior factor in Performance Based Seismic Design

In order to properly estimate the seismic effort in Performance Based Seismic Design of RPS2000, the Introduction of the behavior factor (K) in its overall shape becomes a necessity [18]:

$$K = R_{\mu}C.R_S.R_R \quad (14)$$

This formulation will allow us to better assess the seismic effort and therefore would be suitable for incorporation into seismic design procedures.

In this case, for a preliminary design, the limits of ductility ratio demand and its relative displacement vary with the structural system and the level of selected performance (life safety, near collapse, collapse); in addition, their tolerable maximum requests must necessarily be specified.

V. RESULTS AND DISCUSSIONS

We wanted as illustration for rocky site ($R_{\mu} < 5$) in figure 2 to compare the values of factor K according to the RPS 2000 with different level of ductility (ND1, ND 2, and ND3), Algerian seismic code RPA99 [12], and the aforementioned authors (Newmark and Hall [7]; Krawinkler and Nassar [8]; Miranda and Bertero [9]; Priestley [10]).

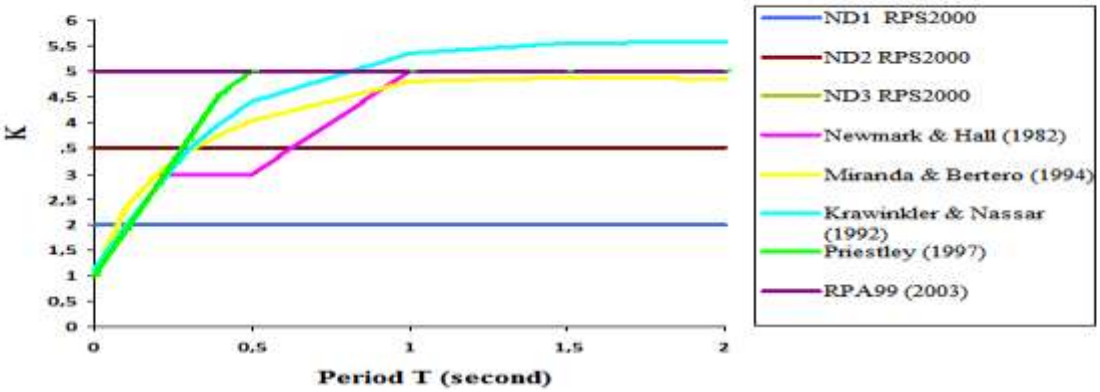

Fig 2 Variation of K according to the period T for μ = 5 (rocky site).
K: Behavior factor

Figure 2 show that RPS2000 does not join different universal codes in the formulation of behavior factor. The value taken for levels of ductility ND1 and ND2 is significantly underestimated and therefore the seismic effort will in turn underestimated.

The Graphs in Figure 3 (a, b, c, and d) show the evolution of behavior factor K according to the RPS2000 based on the periods related to different sites and compared the different universal formulations of the reduction coefficient.

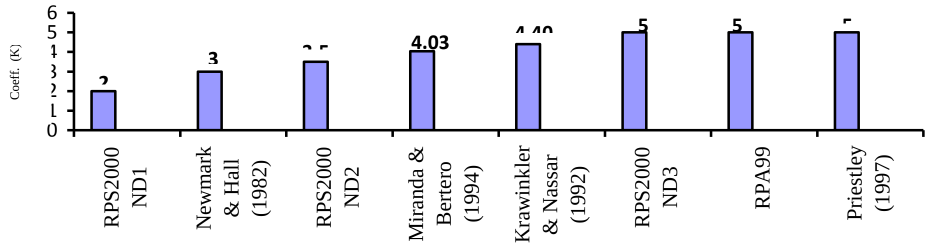

Fig 3a Variation in behavior factor for T = 0.5 s

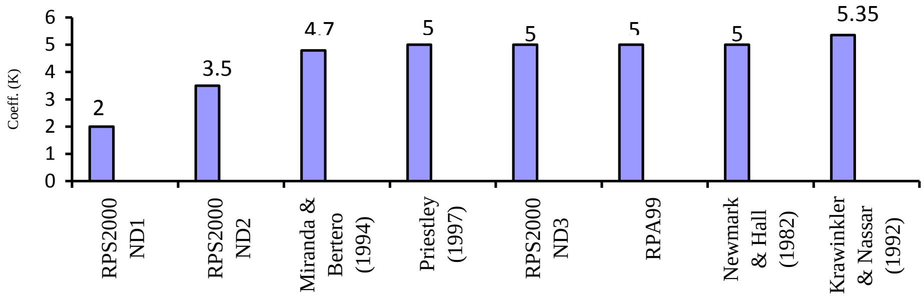

Fig 3b Variation in behavior factor for T = 1s

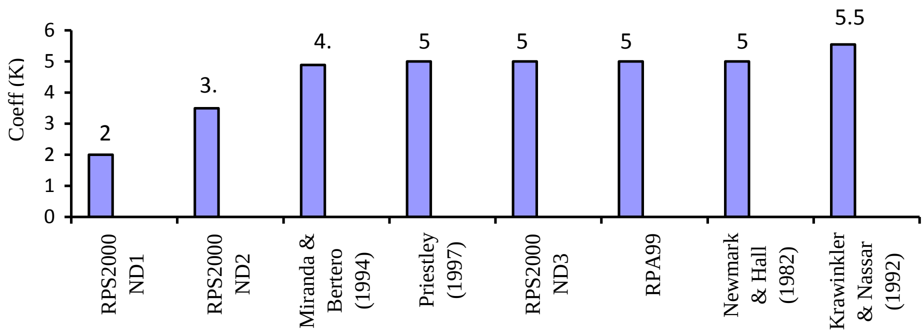

Fig 3c Variation in behavior factor for T = 1.5s

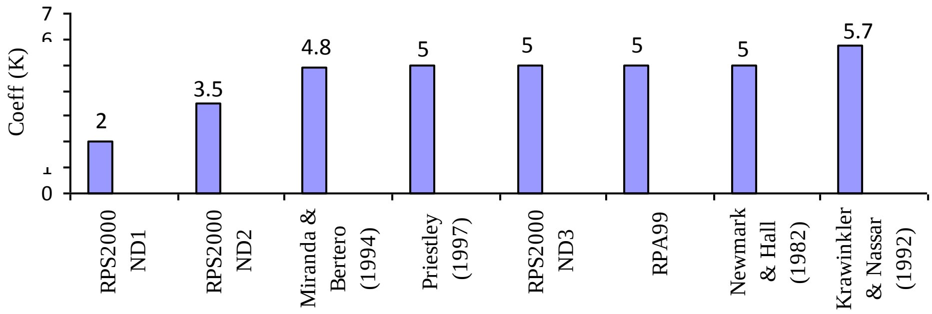

Fig 3d Variation in behavior factor for T = 2s
Fig 3 Variation in behavior factor for different periods (0 to 2s).

The behavior factor K according to the RPS2000 is in good agreement with the values of the majority of universal seismic codes and the aforementioned authors for a ductility level ND3, while it is for a ductility level ND3, while it is significantly lower for the ductility levels ND1 and ND2.

We apply this correction for ductility demand $\mu = 4$, and if the second-order dynamic P-Δ effect are neglected ($\theta \leq 0.1$) following RPS2000 then C takes the value of 0.58, which results in an increase of almost 70% over the base shear buildings. Hence the important influence of the dynamic P-Δ effect into seismic design procedures.

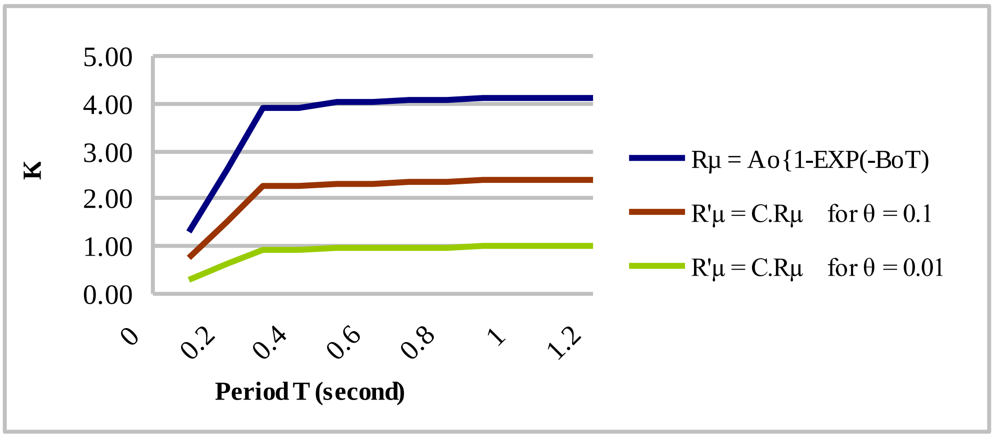

Fig 4 Effect of Stability Coefficient (θ) on the behavior Factor (K) for (μ = 4)

In our example (fig. 4) we take μ = 4 portal structure Auto stable highly ductile for two stability coefficients θ = 0.1 and θ = 0.01.

For short and intermediate periods (fig 4), there is a significant regression of behavior factor/ coefficient for different stability coefficients; these lead us to the conclusion as follows:

- There is a strong relationship between the variables θ and μ with the factor C, which affects its role in reduction factor.
- As long as the stability coefficient increases, the modification factor becomes smaller, which leads to an underestimation of the lateral forces.

VI. CONCLUSIONS AND PERSPECTIVES

The formulation of the behavior factor including ductility demand, the strength reduction and second-order dynamic P-Δ effect, allows a better estimation of the modifying factor of the seismic effort. This study highlights the following points:

- The behavior factor K in RPS2000 does not take into account the soil type and the fundamental period of the structure [13].
- The behavior factor K of the RPS2000 takes constant values depending on the level of ductility and bracing system chosen regardless of the period that led to an underestimation of lateral seismic force V_e especially for short and intermediate periods.

- The behavior factor K according to the RPS2000 is in good agreement with the values of the majority of universal seismic codes and aforementioned authors for a ductility level ND3, while it is significantly lower for the ductility levels ND1 and ND2.
- The RPS2000 neglects the resistance, structural redundancy and the second-order dynamic P-Δ effect, this leads to an underestimation of about 70% of the shear force at the base.
- Introducing the behavior factor K in its overall shape will allow better estimating the seismic effort and ensuring an additional reserve of resistance to the structures studied.
- The main purpose of this work is to review the design procedure established by RPS2000 to the freestanding concrete portal.

However, this work is far from being sufficient to improve the reliability of the values attributed to the behavior factor K for different structural systems, by characterizing the interdependence of factors of ductility, strength and redundancy.

Ductility and resistance factors should be evaluated for each type of structural system and for each seismic zone using the standard definitions of ductility and resistance.

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