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SEISMIC PROTECTION OF REINFORCED CONCRETE WALL BUILDINGS IN ROMANIA

BY

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Abstract. In this article it is highlighted the evolution of the romanian seismic standards concerning reinforced concrete (RC) wall buildings. For the same type of building the values of the seismic forces against the seismic romanian standards are analysed.

The first particular seismic design code in Romania was based mainly on the Soviet regulations at the time. It referred to a seismic zoning of Romania, that has been continously improving ever since and it layed out the formula to calculate the seismic forces for a specific building.

The c global coefficient for reinforced concrete wall buildings has been evolving ever since towards its ultimate goal, that is to attain the real behaviour characteristics of the studied buildings. In present time this coefficient shows a significantly higher value than it did in the regulations before 1977 earthquake.

At the end of the paper there will be drawn some conclusions about the tendency of seismic design codes to show the real behaviour of reinforced concrete wall buildings.

Key words: normalized response spectra; global coefficient.

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1. Introduction

The theory behind the seismic protection of buildings states that the inertia force in a building is the product between its mass and ground acceleration

$$F = m\,a. \tag{1}$$

The evolution of design codes in this paper is referring to a ten-storey RC wall building located in Bucharest, city whose seismic features are presented in Table 1.

Table 1
Seismic Feature Evolution for the City of Bucharest, Romania

Seismic design code	Feature	National range	Bucharest
P 13-63	Seismic protection ranking	VI – IX	VII
P 13-70	Seismic protection ranking	VI – IX	VII
P 100-78(81)	Seismic protection ranking	VI – IX	VIII
P 100-90(92)	Multiplication factor (seismic regions)	0.08 – 0.32 (A – F regions)	0.20 (C region)
P 100-2006	Ground acceleration a_g	0.08 g – 0.32 g	0.24 g
P 100-2013	Ground acceleration a_g	0.10 g – 0.40 g	0.30 g

The values of the corner periods in the latest 3 design codes for the city of Bucharest are shown in Table 2.

Table 2
Corner Periods for Bucharest

Seismic design code	Corner period, T_c
P 100-92	1.5
P 100-2006	1.6
P 100-2013	1.6

Following earthquake surveys taking place in Romania and around the world and studying building behaviours during and post earthquake, the seismic standards have met an evolution that brings a contribution to the actual level of safety of new designed buildings. A key role in understanding the mechanism of earthquake behaviour of buildings is their capacity to disipate earthquake induced energy. Reinforced concrete wall buildings show a good behaviour in this process. They have a satisfying load bearing route and absorb a large amount of energy produced by horizontal earthquake forces.

The 1977 Vrancea earthquake (7.2 M_w magnitude) has had a surprising aftermath in Bucharest (the capital of Romania), meaning that a large number of buildings have been damaged, therefore requiring a significant change in design regulations in our country.

2. Evolution of Romanian Seismic Design Codes

The first glimpse of design regulations in Romania were not to be found any sooner than P13-1963, unless we take a look at the book translated from russian language called "*Bazele proiectarii cladirilor in regiuni seismice"(Basic design for buildings in seismic regions)* which was printed barely in the following year of 1964 (Korcinski *et al*., 1964). Korchinscki and authors have put toghether a volume that comes in handy to the design engineers of the era. The book reffered to seismic design regulations from Russia and thus, to russian teritory seismic characteristics, which differed from the romanian ones.

The first design regulations have emerged from the need to design buidlings in order to withstand the disturbing consequences of earthquakes in our country. It was based on the Soviet Standard SN8-1957.

The horizontal seismic force was defined as follows:

$$S = c\,Q, \tag{2}$$

where: Q stands for the total gravitational loads of the building (constant) and $c \geq 2$ represents the seismic coefficient and is defined as a multiplication of factors

$$c = K_s \beta \varepsilon \psi, \tag{3}$$

K_s – a multiplication factor, showing the proportion between ground acceleration and gravitational acceleration; β – the dynamic coefficient determined for a SDOF (single degree of freedom) system and depends on the oscillation period of the building T

$$0.6 \leq \beta - \frac{0.9}{T} \leq 3, \tag{4}$$

ε – a coefficient that links the SDOF systems to the MDOF (multiple degree of freedom) systems and is constant in value; ψ – a coefficient regarding the type of structure and the materials of the structure and is shown in Table 3.

Table 3
Evolution of ψ

Type of structure	ψ
a. All except b. and c.	1.0
b. Reinforced concrete frames	1.2
c. High-rise flexible buildings: radio and tv antennas, water towers, smoke towers	1.5

The third Romanian Standard came along the following year of the 1977 earthquake (death toll of over 1500 casualties), by the name of P 13-78 and revised in 1981 (P100-81).

The seismic protection of buidings designed after the latest two regulations, P 100-2006 and P 100-2013, requires the meeting of 2 fundamental performance demands: life safety criterion and degradation restriction criterion. The other requirements are: avoiding general building collapse, equipments and machineries, avoiding disruptions on important functions that take place inside buildings, avoiding wrecking of important goods and material damaging restriction.

The P 100-2006 introduces, for the first time, the vertical constituent of the seismic forces through the vertical component of the elastic spectra, vertical corner periods and vertical ground acceleration.

The average recurrence interval (ARI) is considered as follows:

ARI = 100 years for life safety 2006 (P 100-2006) and ARI = 30 years degradation restriction 2006 (P 100-2006);

ARI = 225 years for life safety 2013 (P100-2013) and ARI = 40 years degradation restriction 2013 (P100-2013).

As specialists have gained experience in earthquake engineering, we have come to understand the post elastic behaviour of buildings, unaproached in the regulations before 1977. Thus the capacity of buildings to dissipate earthquake induced energy has introduced the notion of ductility classes:

a. as shown in P 100-2006: *H* (high) ductility class: $a_g > 0.16$ g; *M* (medium) ductility class: $a_g \leq 0.16$ g;

b. as shown in P 100-2013: *H* (high) ductility class: $a_g > 0.30$ g; *M* (medium) ductility class: $0.10 \text{ g} < a_g \leq 0.30$ g; *L* (low) ductility class: $a_g =$ $= 0.10$ g.

3. Evolution of Normalized Response Spectra

The way the normalized response spectra β was calculated among the various design codes in Romania is comprised in Table 4.

Table 4
Evolution of β

Seismic design code	β
P13-63	$0.6 \le \beta - \frac{0.9}{T} \le 3.0$ (5)
P13-70	$0.6 \le \beta - \frac{0.8}{T} \le 2.0$ (6)
P100-78(81)	$0.75 \le \beta - \frac{3}{T} \le 2.0$ (7)
P100-90(92)	$1.0 \le \beta = 2 - (T - T_C) \le 2.5$ (8)
P100-2006	$0 < T \le T_B \rightarrow \beta = 1 + \frac{1+\beta_0}{T_B} T$ $T_B < T \le T_C \rightarrow \beta = \beta_0$ $T_C < T < T_D \rightarrow \beta = \beta_0 \frac{T_C}{T}$ $T_D < T \le 5s \rightarrow \beta = \beta_0 \frac{T_C T_D}{T^2}$ (9)
P100-2013	

where

$$T_B = 0.1T_C \text{ according to P100-2006,} \tag{10}$$

$$T_B = 0.2T_C \text{ according to P100-2013,} \tag{11}$$

β_0 is the dynamic magnifying factor of the soil horizontal acceleration. It has the value of 2.75 in P100-2006 and decreases down to 2.50 in the P100-2013 design code.

Table 5
Corner periods for the seismic response spectra in P 100-2006 and P 100-2013

Corner period	Values according to seismic zonation		
T_C, [s]	0.70	1.00	1.60
T_D, [s]	3.00	3.00	2.00
T_B, [s], (P100-2006)	0.07	0.10	0.16
T_B, [s], (P100-2013)	0.14	0.20	0.32

The teritory of Romania has been each time divided into 3 regions, from the corner period point of view: 0.7 s, 1.0 s and 1.6 s in P 100-2013 and P 100-2006 and 0.7 s, 1.0 s and 1.5 s in P 100-90(92).

The evolution of the normalized response spectra β along all romanian standards is presented in the Figs. 1,...,3.

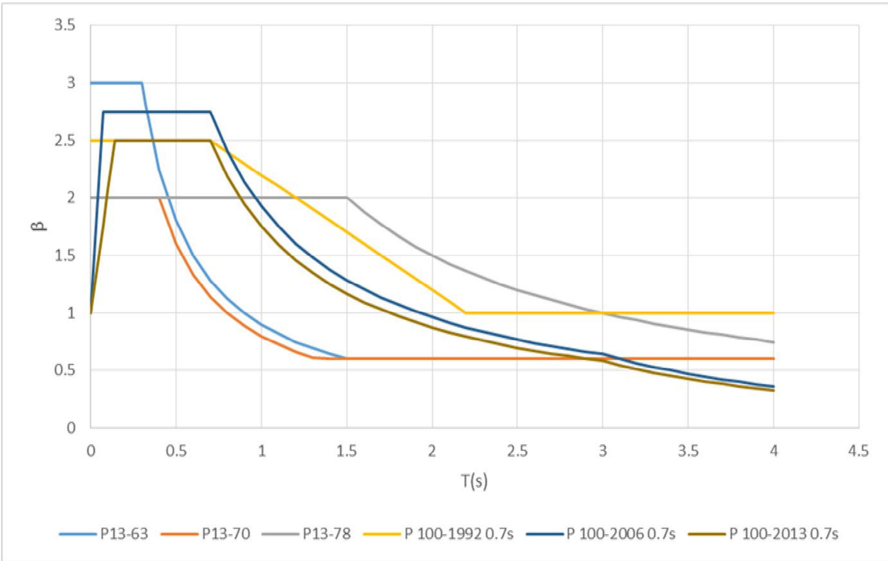

Fig. 1 – Evolution of β in the range of lowest corner period.

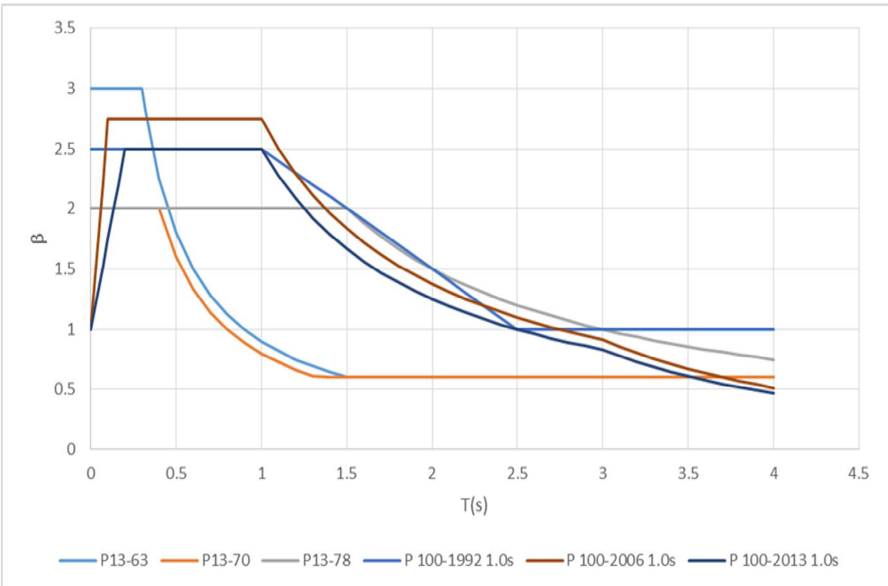

Fig. 2 – Evolution of β in the range of middle corner period.

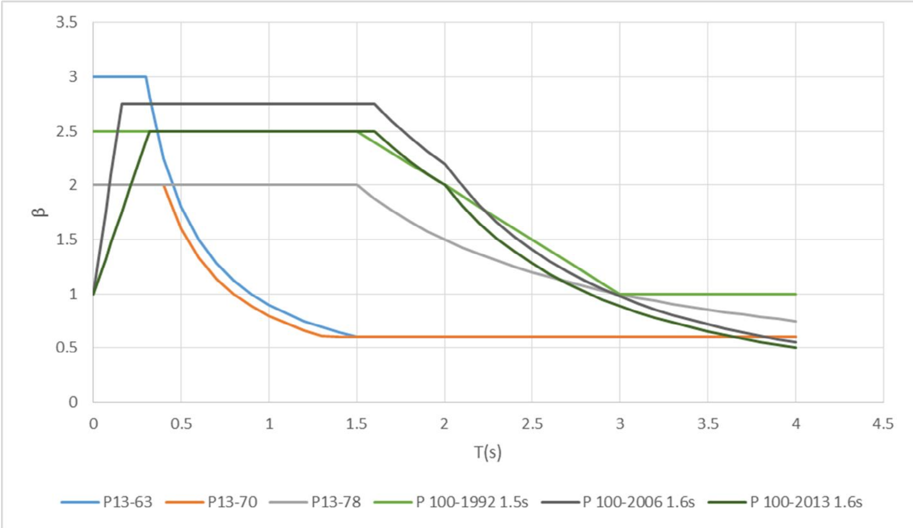

Fig. 3 – Evolution of β in the range of highest corner period (Bucharest included).

4. Evolution of Seismic Forces

Table 6
Evolution of Seismic Forces

Seismic design code	Seismic force	
P 13-63	$S = cQ$ $c = K_s \beta \varepsilon \psi \geq 0.02$	(12)
P 100-90(92)	$S = \alpha K_s \beta \varepsilon \psi G$	(13)
P 100-2006	$F_b = \gamma_I S_d(T) m \lambda$	(14)
P 100-2013	$F_b = \gamma_{I,e} S_d(T) m \lambda$	(15)

Where G is the total value of gravitational loads of the building, γ_I and $\gamma_{I,e}$ – importance factors (that depend on the purpose of the buiding), λ – an adjustment factor depending on corner period and number of storeys of the building, $S_d(T)$ – the building's response spectrum and represents a fraction of the gravitational acceleration

$$0 < T \leq T_B \rightarrow S_d(T) = \left[1 + \frac{(\beta_0/q) - 1}{T_B} T\right] a_g ,$$
$$T_B < T \rightarrow S_d(T) = a_g \frac{\beta}{q}. \qquad (16)$$

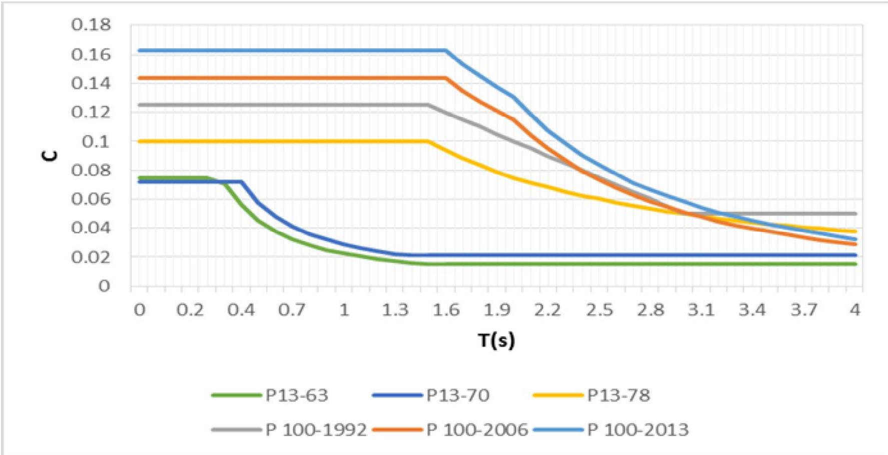

Fig. 4 – Evolution of global coefficient *c* in Romanian Standards for a 10 storey RC wall structure in Bucharest.

Table 7
Values for c for two oscillation periods

Seismic design code	Global coefficient *c*	
	T = 0.3 s	*T* = 1.5 s
P13-63	0.075	0.015
P13-70	0.072	0.022
P100-78(81)	0.1	0.1
P100-90(92)	0.125	0.125
P100-2006	0.143	0.143
P100-2013	0.163	0.163

Pop *et al*., (2008), have set ratios between the global coefficients of the romanian design codes.

5. Conclusions

Considering the global coefficient, there has been a continuous evolution of the seismic force value, that shows an increasing closeness to real behaviour of buildings. The value of the global coefficient has increased significantly from the first design code to the latest (as seen in Table 7), due to current performance demands. One can conclude that old and very old RC wall buildings remain very vulnerable to seismic actions.

As continuous data has been collected, it is noticeable that current seismic standard expect a value of the average recurrence interval (ARI) up to

225 years for life safety and up to 40 years for degradation restriction in 2013 (P100-2013, 2013).

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PROTECȚIA SEISMICĂ A CLĂDIRILOR CU STRUCTURĂ DE REZISTENȚĂ DIN PEREȚI DE BETON ARMAT

(Rezumat)

Se conturează evoluția normelor seismice în calculul clădirilor cu structură de rezistență din pereți de beton armat. Se analizează o clădire în toate codurile de proiectare seismică. Primul cod de proiectare seismică s-a bazat în principal pe normele sovietice de la acea vreme. Făcea referire la o zonare seismică a României, care s-a îmbunătățit în mod continuu şi prezenta formula forței seismice. Coeficientul global *c* pentru clădirile cu structură de rezistență din pereți de beton armat a continuat să evolueze spre scopul de a obține o comportare cât mai reală a structurii. În prezent acest coeficient prezintă o valoare semnificativ superioară celei din normativele premergătoare cutremurului de la 4 martie 1977. La sfârşitul lucrării se trag nişte concluzii despre tendința normativelor de a urmări comportarea reală a clădirilor cu structura de rezistență din pereți de beton armat.