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Seismic Analysis

The Seismic Force Development Related to Romanian Designing Codes

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Summary

The seismic calculus researches in the past 50 years also based on experimental recordings are led to changes in the building design standards.

Major changes were made in estimating the dynamic amplification coefficient β which is established in relation to the spectral composition of the seismic movements generated by the Vrancea source and in relation with the reduction coefficient ψ, which accounts for the ductility of the structure.

This paper aims evolution of global seismic coefficient for 3 types of structures situated in Iasi and Bucharest.

By analyzing the results of the seismic force calculus according to the present standards one can notice the major increase of the seismic force value according to the P100-2006 Standard, in comparison with the former ones. Seismic force values representing 40-60% of the seismic force according to P100-2006 for various types of buildings designed in period 1963 - 1992 can be alarming if we think about the number of buildings are made in this time interval.

KEYWORDS: seismic force, global seismic coefficient, building design standards.

1. INTRODUCTION

After the earthquake in November 1940, the first norms of seismic design appeared in Romania in December 1941, and it was called *„Temporary Instructions Regarding the Prevention of Construction Damages Caused by Earthquakes and For Rehabilitation of the Damaged Ones"*. A new edition of these instructions appeared in 1945. In 1963 it was published the first *„Standards for Civil and Industrial Constructions Designing in Seismic Areas (P13-63)"*.

In 1970 was published the improved edition of these standards and it considered the specific characteristics of Romania.

The 1977 earthquake was led to the modification of the existent standards due to the registrations made during the earthquake. Thus, in 1978 *„The Seismic*

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Standards for Designing of Civil, Socio-Cultural, Agricultural and Industrial Constructions P100-78" and in 1981 a slightly improved edition P100-81 was published.

The years between 1980 and 1990 was a period of extended theoretical and experimental research which also used registrations of the seismic movements and these led to the improvement of the existent standards in order to assure a higher degree of seismic protection. Thus, in 1991 appears the P100-91 standard, modified and completed in 1992. In this latter version appears for the first time concepts such as *corner period, importance coefficient* and a detailed classification of the structures, in order to establish the *reducing factors* for the earthquake.

The Seismic Design Code P100-2006 is applied since 2006 and combines the Romanian and European regulations. In it appears some differences in seismic action representation, in establishing the requirements of performance and in specific regulations for structures of various materials.

2. THE ROMANIAN CODES - THE SEISMIC REPRESENTATIONS AND ITS INTERPRETATIONS

The seismic forces are conventionally considered to act according to the directions of the dynamic freedom degrees and represent the maximum values of the inertia forces. These depend on the dynamic characteristics of the structure and on the characteristics of the seismic action represented by the response spectrums.

For the nDOF systems, the seismic force corresponding to the *k* module of vibration can be determined by using the following:

2.1. P13-63, P13-70, P100-78 Standards

This standard computes seismic force with relation (1)

$$S_k = c_k G\,;\quad c_k = \alpha\, k_s\, \psi\, \beta_k \varepsilon_k\,;\quad \varepsilon_k = \frac{\left(\sum_{i=1}^{n} m_i u_{ik}\right)^2}{\sum_{i=1}^{n} m_i \sum_{i=1}^{n} m_i u_{ik}^2} = \frac{\left(\sum_{i=1}^{n} G_i u_{ik}\right)^2}{\sum_{i=1}^{n} G_i \sum_{i=1}^{n} G_i u_{ik}^2} \tag{1}$$

where: c_k is the global seismic coefficient corresponding to vibration *k* mode.

k_s is the seismic intensity coefficient corresponding to the seismic protection degree of the building (tab. 1 and fig. 1)

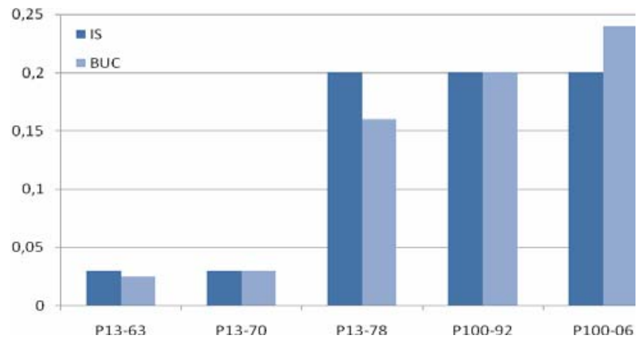

Figure 1. Seismic coefficient intensity variation

Table 1. Seismic intensity coefficient ks

Antiseismic protection degree		9 - A	8.5-B	8-C	7.5-D	7-E	6.5-F	6
P13-63		0,100		0,050		0,025		
P13-70	Very important buildings	0,12		0,08		0,05		0,03
	Buildings with a medium importance	0,08		0,05		0,03		
P100-78 (81)		0,32	0,26	0,20	0,16	0,12	0,09	0,07
P100-92		0,32	025	0,20	0,16	0,12	0,08	
P100-2006		**0,32**	**0,28**	**0,24**	**0,20**	**0,16**	**0,12**	**0,08**

where: β_k is the dynamic coefficient corresponding to vibration k mode (tab. 2)

ψ is the coefficient of the seismic loading effects reduction which takes into consideration the ductility of the structure, the capacity of stress redistribution and the cooperation between the structure and the nonstructural and damping elements. (tab. 3)

ε_k is the coefficient of equivalence between the real system nDOF and the system sDOF having a proper period of vibration T_k

u_{ik} is the ordinates of the eigenvector.

2.2. P100-92

The P100-92 norms determines the entire horizontal seismic loading depending on the coefficient of importance of the building, □ (eq. 2)

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$$S_k = c_k G \, ; c_k = \alpha \; k_s \; \psi \; \beta_k \varepsilon_k \, ; \; \varepsilon_k = \frac{\left(\sum_{i=1}^{n} m_i u_{ik}\right)^2}{\sum_{i=1}^{n} m_i \sum_{i=1}^{n} m_i u_{ik}^2} = \frac{\left(\sum_{i=1}^{n} G_i u_{ik}\right)^2}{\sum_{i=1}^{n} G_i \sum_{i=1}^{n} G_i u_{ik}^2} \qquad (2)$$

Table 2. Dynamic coefficient

		β_k	β_{min}	β_{max}
P13-63	ground: type *a (cliffs)*	$\beta_k = 0,90/T$	0,60	3,00
	type *b (normal)*	$\beta_k = 1,25*0,90/T$		
	type *c (clay)*	$\beta_k = 1,5*0,90/T$		
P13-70	ground: type a	$\beta_k = 0,8*0,80/T_k$	0,60	2,00
	type b	$\beta_k = 0,80/T_k$		
	type c	$\beta_k = 1,5*0,80/T_k$		
P100-78 (81)	ground: type a	$\beta_k = 0,8*3/T_k$	0,75	2,00
	type b	$\beta_k = 3/T_k$		
	type c	$\beta_k = 1,3*3/T_k$		
P100-92	$\beta_r = 2.5$	for $T_k < T_c$	1,00	2,50
	$\beta_r = 2.5 - (T_k - T_c)$	for $T_k > T_c$		
	Tc = 0,7s; 1,0s; 1,5s			
P100-06	$\beta(T) = 1 + \frac{(\beta_0 - 1)}{T_B} T$	$T \leq T_B$		2,75
	$\beta(T) = \beta$	$T_B < T \leq T_C$		
	$\beta(T) = \beta_0 \frac{T_C}{T}$	$T_C < T \leq T_D$		
	$\beta(T) = \beta_0 \frac{T_C T_D}{T^2}$	$T > T_D$		
	Tc = 0,7s; 1,0s; 1,6s			

2.3. P100-2006

Regulation determines the seismic force (the base shear force) with the expression:

$$F_{bk} = \gamma_I S_d(T_k) m_k \qquad (3)$$

$S_d(T_k)$ represent the ordinate of the response spectrum of design corresponding to the *k* mode;

$$S_d(T) = a_g \left[1 + \frac{\frac{\beta_0}{q} - 1}{T_B} T \right] \text{ or } S_d(T) = a_g \frac{\beta(T)}{q} \qquad (4)$$

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where: γ_I - the importance-exposure factor of the building;

T_k - vibration period corresponding to the k mode;

q - coefficient of behavior (tab. 4)

m_k - the modal mass associate to the proper mode of vibration k;

$$m_k = \frac{\left(\sum_{i=1}^{n} m_i s_{ik}\right)^2}{\sum_{i=1}^{n} m_i s_{ik}^2} \tag{5}$$

s_{ik} – the eigenvector component in the *k* mode which is corresponding to the dynamic free *i* degree (iDOF)

Table 3. Reduction coefficient ψ

Reinforced concrete structures	P13-63	P13-70	P100-78 (81)	P100-92
Rigid structure buildings (brickwork bearing walls or reinforced concrete diaphragm) or semirigid (semipermanent)	1,00	1,30 1,20	0,30 0,25	0,25 0,20
Storey framed buildings	1,20	1,00	0,25 0,20	0,20 0,15
Industrial buildings	1,00		0,20 0,15	0,20 0,15
Silo	1,00	-	0,25	0,25
Very flexible and high buildings (towers and chimneys)	1,50	1,80	0,35	
Water tower	1,50	2,00	0,35	0,35

Table 4. Coefficient of behaviour q - **P100-2006**

Reinforced concrete structures	Ductility class H	Ductility class M
Frames. Dual system. Coupling walls	5 α_u / α_1	3,5 α_u / α_1
Walls	4 α_u / α_1	3,0
Nucleus flexible at stress	3,0	2,0
Inverted pendulum structures	3,0	2,0

Table 5. Overstrength factor - **P100-2006**

		α_u / α_1
Frames or	Buildings with one storey and single aperture	1,15
Dual structures with main frames	Buildings with multiple stores and single aperture	1,25
	Buildings with multiple stores and multiple	1,35

	apertures	
Structural wall or	Structures with only two walls in each direction	1,0
Dual systems with main walls	Multiple walls structures	1,15
	Coupled walls structures and dual structures with preponderant walls	1,25
For structures having complete regularity and perfectly controlled execution conditions *q* can be increased with max.20%		

3. THE SEISMIC FORCE EVOLUTION RELATED TO THE ROMANIAN CODES

3.1. Reinforced concrete frame structure

Consider a reinforced concrete frame with P+7E. The structure was designed according to the ductility class *M*. The fundamental period of the structure is 0.6s.

In tab. 6 and fig. 2 is represented variation of global seismic coefficient for reinforced concrete frame structure localized in Iasi and Bucharest.

Table 6. Variation of global seismic coefficient

P+7E Reinforced concrete frame structure	P13 - 63	P13 - 70	P100 - 78 (81)	P100 - 92	P100 - 06	P13 - 63	P13 - 70	P100 - 78 (81)	P100 - 92	P100 - 06
	IASI					BUCURESTI				
α ; γ_1	-	-	-	1.00	1.00	-	-	-	1.00	1.00
κ_s	0.03	0.03	0.20	0.20	0.20	0.025	0.03	0,16	0.20	0.24
β_κ	1.875	1.33	2.00	2.50	2.75	1.875	1.33	2.00	2.50	2.75
ψ	1.20	1.00	0.20	0.20	-	1.20	1.00	0.20	0.20	-
$3^*\alpha_u/\alpha_1$	-	-	-	-	4.725	-	-	-	-	4.725
α_u/α_1	-	-	-	-	1.35	-	-	-	-	1.35
ε_k ; λ	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
c_k	0.0574	0.034	0.068	0.085	0.0989	0.0478	0.034	0.054	0.085	0.1187
	58%	34%	69%	86%	100%	40%	29%	45%	72%	100%

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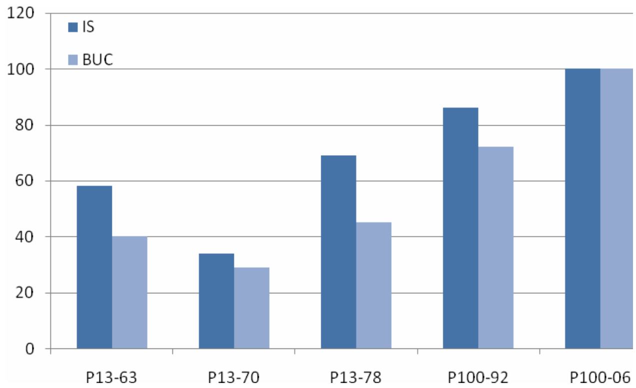

Figure 2. Global seismic coefficient variation

3.2. Structural Walls - Structure of Reinforced Concrete

Consider a structure of reinforced concrete structural walls with P+7E. The structure was designed according to the ductility class *M*. The proper fundamental period of the structure is 0.4s. In tab. 7 and fig. 3 is represented variation of global seismic coefficient for buildings with reinforced concrete structural walls localized in Iasi and Bucharest.

Tab. 7. Variation of global seismic coefficient

P+7E Structure of reinforced concrete structural walls	P13-63	P13-70	P100-78 (81)	P100-92	P100-06	P13-63	P13-70	P100-78 (81)	P100-92	P100-06
	IASI					BUCURESTI				
α ; γ_1	-	-	-	1.00	1.00	-	-	-	1.00	1.00
κ_s	0.03	0.03	0.20	0.20	0.20	0.025	0.03	0,16	0.20	0.24
β_κ	2.00	2.00	2.00	2.50	2.75	2.00	2.00	2.00	2.50	2.75
ψ	1.00	1.20	0.25	0.25	-	1.00	1.20	0.25	0.25	-
q	-	-	-	-	3.00	-	-	-	-	3.00
α_u/α_1	-	-	-	-		-	-	-	-	
ε_k ; λ	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
c_k	0.045	0.054	0.075	0.09375	0.1375	0.0375	0.054	0.06	0.09375	0.165
	33%	39%	55%	68%	100%	23%	33%	36%	57%	100%

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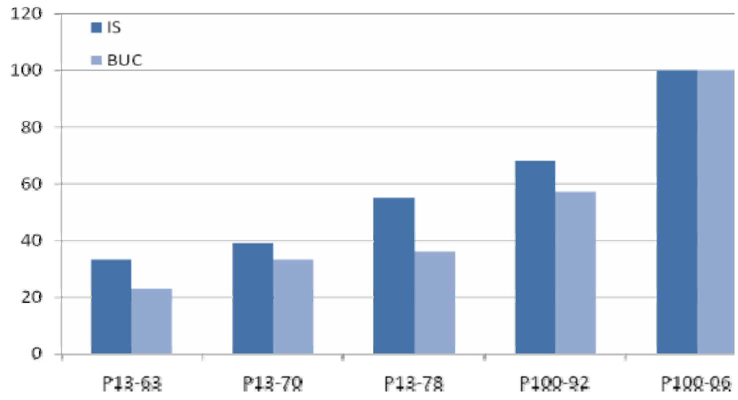

Figure 3. Global seismic coefficient variation

3.3. Structural Walls - Structure of Brick Masonry

Consider a structure of brick masonry structural walls with P+4E. The fundamental period of the structure is 0.4s. In tab. 8 and fig. 4 is represented variation of global seismic coefficient for buildings with structure of brick masonry structural walls situated in Iasi and Bucharest.

Table 8. Variation of global seismic coefficient

P+4E Structure of brick masonry structural walls	P13-63	P13-70	P100-78 81)	P100-92	P100-06	P13-63	P13-70	P100-78 (81)	P100-92	P100-06
	IASI					BUCUREŞTI				
α ; γ_1				1.00	1.00				1.00	1.00
κ_s	0.03	0.03	0.20	0.20	0.20	0.025	0.03	0,16	0.20	0.24
β_κ	2.00	2.00	2.00	2.50	2.75	2.00	2.00	2.00	2.50	2.75
ψ	1.30	1.00	0.30	0.25		1.30	1.00	0.30	0.25	
$q = 3\times\alpha_u/\alpha_1$	-				3.75	-				3.75
α_u/α_1	-				1.25	-				1.25
ε_k ; λ	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
c_k	0.059	0.045	0.09	0.094	0.11	0.0487	0.045	0.072	0.094	0.132
	54%	41%	82%	85%	100%	37%	34%	55%	71%	100%

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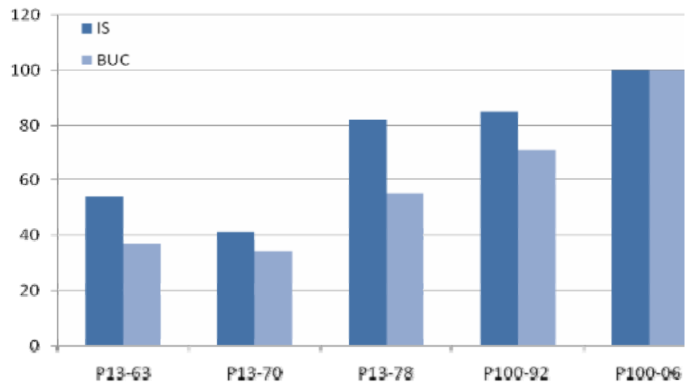

Figure 4. Global seismic coefficient variation

4. FINAL CONCLUSIONS

The seismic calculus researches in the past 50 years also based on experimental recordings are led to changes in the building design standards.

Were made major changes in estimating the dynamic amplification coefficient β (which is established in relation to the spectral composition of the seismic movements generated by the Vrancea source) and in relation with the reduction coefficient ψ (which accounts for the ductility of the structure).

Analyzing the results of the seismic force calculus according to the present standards one can notice the major increase of the seismic force value according to the P100-2006 Standard, in comparison with the former ones. Seismic force values representing 40-60% of the seismic force according to P100-2006 for various types of buildings designed in period 1963 - 1992 can be alarming if we think about the number of buildings are made in this time interval. This fact can become even more arming if we take into account the effects of the earthquakes produced in 1977, 1986 and 1990. The structures of the buildings have been more or less affected by those earthquakes.

This can be proved with the results obtained after the evaluations on various types of buildings made before 1992. Thus:

- structures made of bearing brick masonry - the bearing capacity being reduced with 22%.

- structures with reinforced concrete prefabricated diaphragms - real medium reduction of 25 to 28% (major problems with joints);

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- reinforced concrete framed structures - real reduction of almost 6% (constant degradation mainly present in beams).

By corroborating the effects of the designing standards changes with the degradations caused by the earthquakes it could draw the alarming conclusion for the heritage witch was built before 1992 – the most of the buildings do not meet the terms of seismic insurance.

REFERENCES

1. P13-63 - *Conditioned Standards for Civil and Industrial Constructions Design in Seismic Regions*
2. P13-70 - *Standards for Civil and Industrial Constructions Design in Seismic Regions*
3. P100-78 - *The Seismic Standards for Design of Civil, Socio-Cultural, Agricultural and Industrial Constructions*
4. P100-92 - *The Seismic Standards for Design of Civil, Socio-Cultural, Agricultural and Industrial Constructions*
5. P100-1/2006 - *Seismic Design Code - part I – Building Design Provisions*

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