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The evolution of seismic provisions in codes P100-1/2006 and P100-1/2013 and the impact on the design of reinforced concrete structures

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***Abstract* – The paper aims to present the way in which reinforced concrete structures are addressed in the seismic design codes P100-1/2006 and P100-1/2013. Comparing the two editions requires a detailed analysis of their provisions, with a focus on identifying the main similarities and differences.**

The main objective is to highlight the evolution of the seismic design code, through the comparative evaluation of the two editions, using linear seismic analyses applied to the proposed reference structures. This approach allows capturing the conceptual and methodological changes introduced in the more recent version. The topic is relevant because it illustrates how the seismic performance criteria were formulated and developed over time within the codes P100-1/2006 and P100-1/2013.

Keywords – linear seismic assessment, reinforced concrete structures, seismic performance requirements, structural response.

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1. INTRODUCTION

In recent times, reinforced concrete structures have been increasingly used in the construction field, to the detriment of those made of other materials, such as wood or metal. Consequently, the study of their behaviour is an essential stage in the work of the structural engineer. Over time, the experience of earthquakes has highlighted the inadequacy of old design codes. For this reason, increasingly strict requirements have been imposed for the seismic calculation of structures. An important aspect is the fact that existing structures, designed prior to the appearance of P100-1/2013, are seismically evaluated according to the provisions of the P100-1/2006 code and must comply with the performance levels established by it.

The objective of the paper to highlight the evolution of the seismic design code will be achieved by completing the following stages:

-Analysis and study of the seismic design codes P100-1/2006 and P100-1/2013;

-Analysis of the seismic response for a symmetrical reinforced concrete frame structure from the perspective of the two design codes listed above. To achieve this stage, all the important aspects that appear in the behaviour of a structure will be compared. The differences between the relative level displacements of the structure for the two codes will be highlighted. Reference will also be made to the sectional efforts of the building as well as the differences between them.

-The influence of the design ground acceleration value in analysing the structural response from the perspective of P100/2006 and P100/2013. This stage of the study aims to address in detail the differences between the two codes regarding the influence of ag on the behaviour of a structure.

2. COMPARATIVE ANALYSIS OF CODES P100-1/2006 AND P100-1/2013: COMMON ASPECTS AND METHODOLOGICAL DIFFERENCES

To highlight the main differences and similarities between the two design codes, two comparative tables were developed, presenting the essential aspects of each edition.

DIFFERENCES BETWEEN THE CODES			
Nr.crt.	Difference	P100-1/2006	P100-1/2013
1	The peak ground acceleration value for design a_g	0,08g→	0,10g
		0,12g→	0,15g
		0,16g→	0,20g
		0,20g→	0,25g
		0,24g→	0,30g
		0,28g→	0,35g
		0,32g→	0,40g
2	Mean return period IMR	100 years	225 years
3	Control period T_B	0,07s; 0,1s; 0,16s	0,14s; 0,20s; 0,32s
4	Maximum dynamic amplification factor of horizontal ground acceleration β_0	2,75	2,5
5	Differentiated normalized elastic response spectrum for the Banat region	$\beta_0=3$	Disappears
6	Ductility classes	DCH, DCM	DCH, DCM, DCL

Fig. 1. The main differences between the two codes

SIMILARITIES BETWEEN THE CODES		
Nr.crt.	Similarity	Value
1	Control period T_C	0,7s; 1,0s; 1,6s
2	Control period T_D	3,0s; 3,0s; 2,0s
3	Classes of importance and importance factors	4 importance classes γ_I=1,4; 1,2; 1,0; 0,8
4	Geometric requirements	The minimum geometrical conditions for reinforced concrete beams, columns, and walls are maintained
5	Minimum concrete classes	The minimum concrete classes required are maintained: C20/25 for DCH and C16/20 for DCM.

Fig. 2. The main similarities between the two codes

As can be seen in the table above, the most important change brought by P100-1/2013 comes from the modification of the peak value of the ground acceleration for design. This value has the greatest influence on the behaviour of reinforced concrete structures.

3. CASE STUDY: EVALUATION OF REINFORCED CONCRETE STRUCTURES ACCORDING TO CODES P100-1/2006 AND P100-1/2013

In the first part of the case study, a symmetrical reinforced concrete frame structure was selected. The analysis of this structure aimed to highlight the differences between the two design codes in terms of structural behaviour, displacements, and internal forces. Initially, the structural calculation was performed using the P100-1/2006 design code, and subsequently, the same structure was analysed according to P100-1/2013.

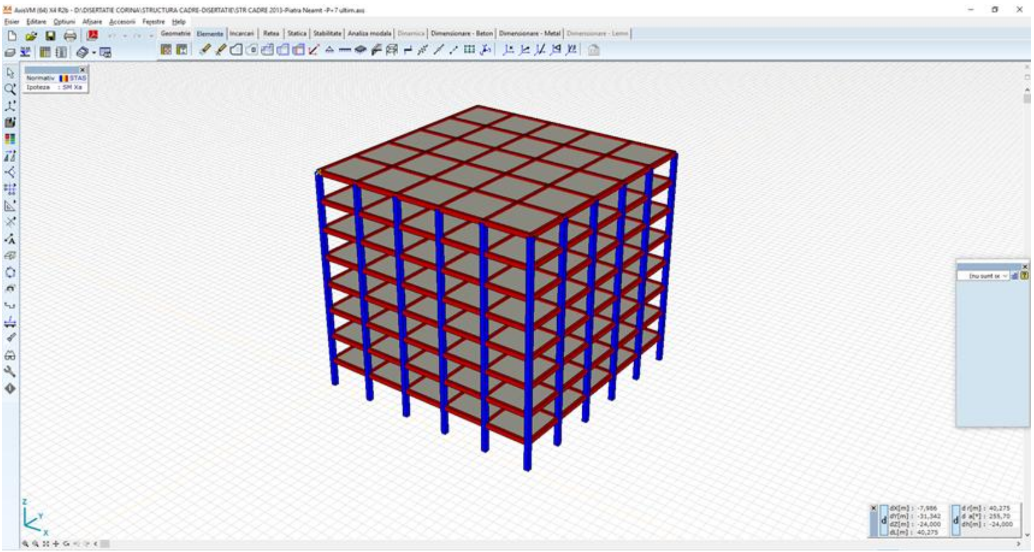

Fig. 3. Analysed symmetrical structure - reinforced concrete frames

The analysed structure has the following characteristics:
Geometric data:

Multi-storey structure with height regime P+7E; 5 spans of 5.00 m; 5 beams of 5.00 m; Square columns with a 50x50 cm cross-section; Longitudinal and transverse beams with 30x50 cm cross-section; Slab thickness 15 cm; Story height h=3.00m; The geometry of the structure was maintained for both structural analyses.

The location chosen for the calculation of the structure is the city of Piatra Neamț and has the following characteristics according to the design codes:

a) P100-1/2006:
- Design ground acceleration ag=0.20 g
- Control periods TC =0.7s; TB =0.07s; TD =3 s;
- Dynamic amplification factor β0 =2.75.

b) P100-1/2013:
- Design ground acceleration ag=0.25 g
- Control periods TC =0.7s; TB =0.14s; TD =3 s;
- Dynamic amplification factor β0 =2.50.

The finite element program Axis was used for the structural calculation.

P100-1/2006 Design Code					
Level	Z	SLS		ULS	
		d_r	$d_{r,a}$	d_r	$d_{r,a}$
	[m]	[mm]	[mm]	[mm]	[mm]
FLOOR 7	24	3,483	15	6,966	75
FLOOR 6	21	5,971		11,942	
FLOOR 5	18	8,305		16,611	
FLOOR 4	15	10,357		20,714	
FLOOR 3	12	12,091		24,182	
FLOOR 2	9	13,337		26,675	
FLOOR 1	6	13,581		27,161	
GROUND	3	8,781		17,562	

Fig. 4. Verification of lateral displacements at SLS and ULS according to P100-1/2006

P100-1/2013 Design Code					
Level	Z	SLS		ULS	
		d_r	$d_{r,a}$	d_r	$d_{r,a}$
	[m]	[mm]	[mm]	[mm]	[mm]
FLOOR 7	24	3,958	15	7,916	75
FLOOR 6	21	6,785		13,570	
FLOOR 5	18	9,438		18,876	
FLOOR 4	15	11,769		23,538	
FLOOR 3	12	13,740		27,479	
FLOOR 2	9	15,156		30,312	
FLOOR 1	6	15,433		30,865	
GROUND	3	9,979		19,957	

Fig. 5. Verification of lateral displacements at SLS and ULS according to P100-1/2013

Following the analysis of the results, it can be concluded that the new design code imposes stricter limits than the previous version, and for the analysed structure, the maximum SLS displacements increase by approximately 2 mm.

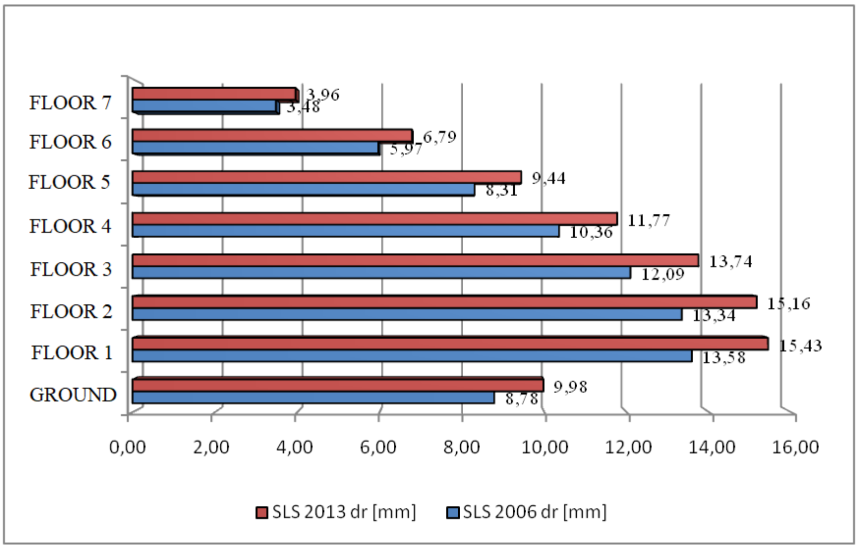

Fig. 6. Story relative displacements for the Serviceability Limit State according to the two codes

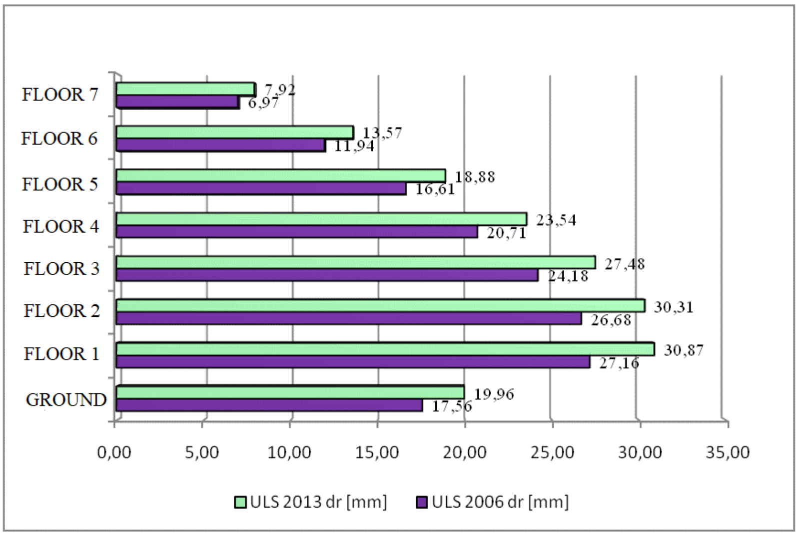

Fig. 7. Story relative displacements for the Ultimate Limit State according to the two codes

In the figures above, two graphs are presented that clearly illustrate the comparison of story displacements of the structure according to the two design codes, for the serviceability limit state (Fig. 6) and the ultimate limit state (Fig. 7).

Comparison between P100-1/2006 and P100-1/2013 regarding the modification of the ground acceleration value for design (ag)

In this subsection, the analysis of a reinforced concrete frame structure is proposed from the perspective of the two design codes across all seismic hazard zones in Romania. Specifically, the same structure is calculated according to all ag zonings provided by P100-1/2006 and compared with the analysis performed according to P100-1/2013.

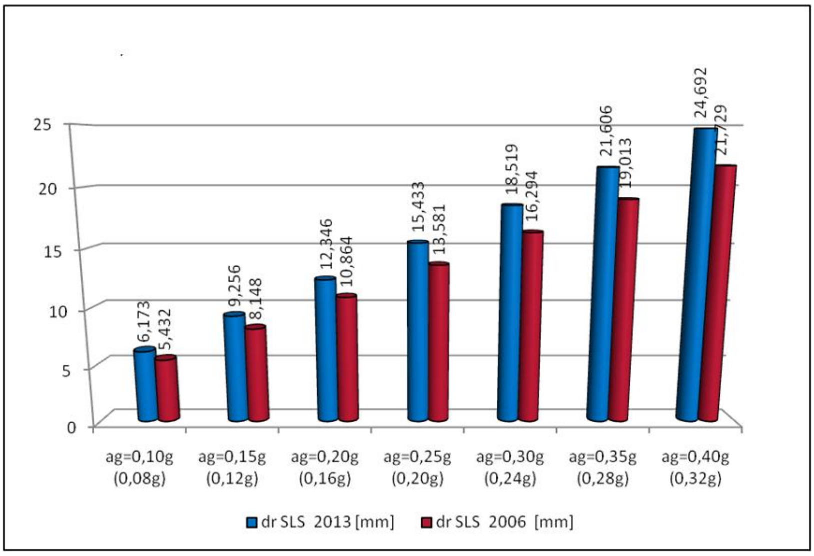

Fig. 8. Variation of displacements depending on the intensity of the design ground acceleration - serviceability limit state

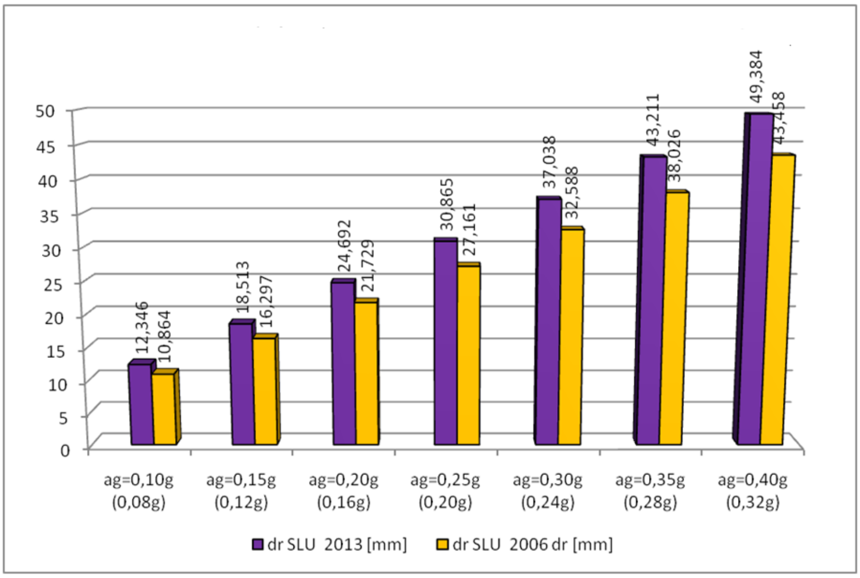

Fig. 9. Variation of displacements depending on the intensity of the design ground acceleration - ultimate limit state

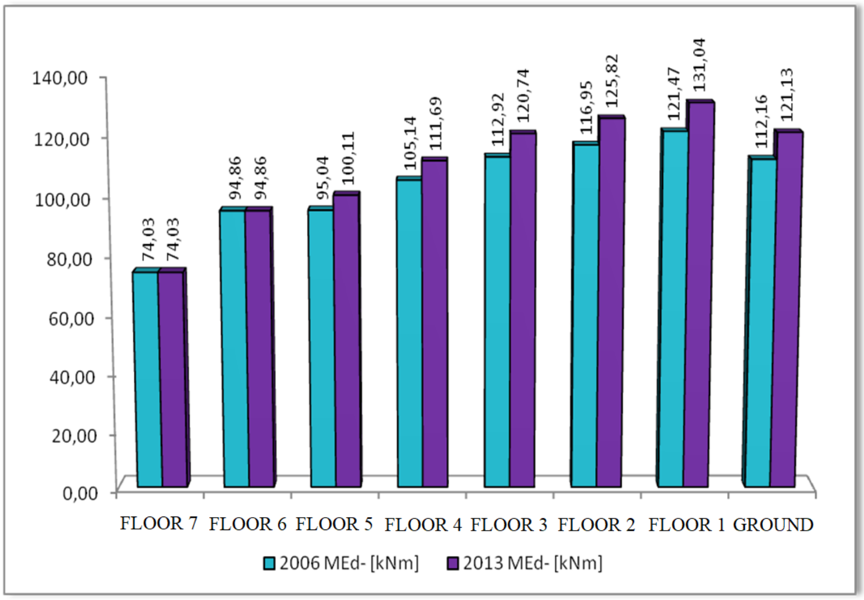

Fig. 10. Bending moments axis 2

The differences between the two design codes regarding the sectional forces, in this case bending moments, are very small. The largest difference was recorded on the 1st floor of the building and has a value of 9.57 kNm. On the upper floors there are no differences between the two codes, as can be seen in the figure above.

4. CONCLUSIONS

From all the analyses performed, it is observed that the main factor that determines the change in the behaviour of a structure analysed with the new design code, compared to the old one, is the change in the peak value of the design ground acceleration (ag).

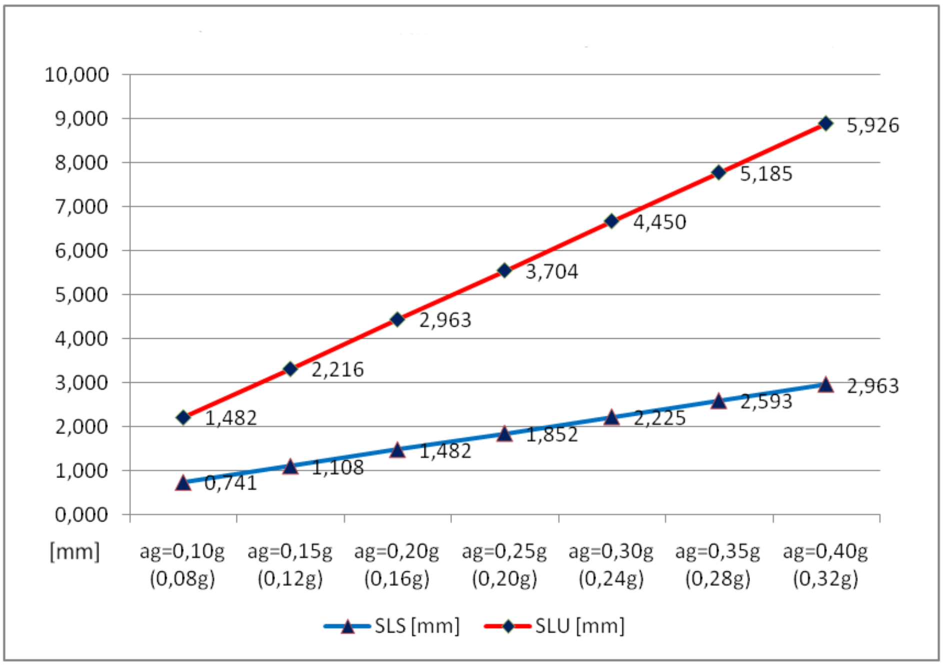

Fig. 11. Graph of the difference between the maximum displacements of the two design codes

The graph above shows the differences in the maximum displacements of the structure, both in the ultimate limit state (red) and in the serviceability limit state (blue).

To prepare this graph, 14 seismic analyses were performed in the structural calculation program. The most interesting thing about this graph is that with the increase in the value of the design ground acceleration (ag), the difference in displacements between the two design codes also increases. Therefore, the stronger the location is in a seismic zone, the stronger the criteria of the new design code are felt.

Also, another change is that the new design code includes the low ductility class, which did not exist until then. However, it is recommended to design with this ductility class only buildings located in areas with design acceleration values ag≤0.10 g.

Analysing the relative level displacements, it was found that a structure calculated with the new design code has these displacements greater than in the case of the old code. The sectional forces, on the other hand, do not show a significant variation. They do not change on the upper floors, but only on the intermediate floors, where the seismic action has a much greater influence.

In conclusion, all the results of the analyses performed show that a structure designed according to P100/2013 has a better behaviour in the code earthquake than P100/2006.

Thus, all the changes brought by the new seismic design code for reinforced concrete structures led to the improvement of their resistance capacity.

A particularly relevant aspect, which may constitute an important direction for further research, is the examination of the evolution of design norms over time, with a focus on the imminent publication of the new edition P100-1/2025. The realization of a dedicated case study would allow to rigorously capture the successive modifications of these regulations and their impact on the structural design process.

5. REFERENCES

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