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Comparative study on the design of a condominium residential building with structural masonry walls located in Romania / Republic of Moldova

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Summary

For buildings with confined masonry structural walls, both European norms and Romanian codes that regulate their design require architectural-structural compliance and a mode of calculation which involves – in areas with high risk of earthquake – the use of high concrete and steel amounts. By taking into account the essential performance requirements of strength, stability, and economy of resources, the question of justifying these consumptions arises.

Thus, the authors propose to assess the need of excessive confinement of masonry walls in these seismic areas through a comparative study on designing a building with structural walls of solid brick confined masonry – placed simultaneously in Romania and in the Republic of Moldova – at such a distance that earthquake effect is similar, using the numerical program ETABS 2016.

Finally, in order to quantify the excess of material required, an estimated economic analysis regarding the cost of superstructures in the two cases analysed was performed.

Key words: confined masonry, strength and stability, economy of resources, buildings regulation, Etabs 2016

1. INTRODUCTION

Romania and the Republic of Moldova are two neighbouring countries that use different norms/standards for structural design, although certain areas of the two countries are similar concerning the effect of seismic action and that of wind or snow loads. Concerning the structural compliance of structural masonry walls, this is a topic of great actuality, taking into account that – on both banks of the Prut River – these buildings account for over 60% of the national built fund [4] and that the norms regulating this activity in the two countries impose different approaches [1, 2, 3]. The authors believe that the requirements of the Romanian Code – including the multiplication of tie-columns in areas with design ground acceleration a_g > 0,25g – lead to high consumption of concrete and steel, which is sometimes irrational. In order to highlight such forced consumption in Romania (a

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Member-State of the European Union) it was proposed a fictional placement of a building on both banks of the Prut River. It has been kept the same function, but with the change of the load-bearing frame compliance, pursuant to the technical regulations in effect in the two countries.

Hence, the purpose of this paper was to design a condominium residential building with structural masonry walls, located in the county of Vaslui and in the department of Ungheni, two border regions chosen because we want to meet the three essential requirements:

- Similar seismic area (Figure 1) and similar foundation base with identical stratification;
- Geographic area of the same nature that involves equal Load participations on the two banks of the Prut River.

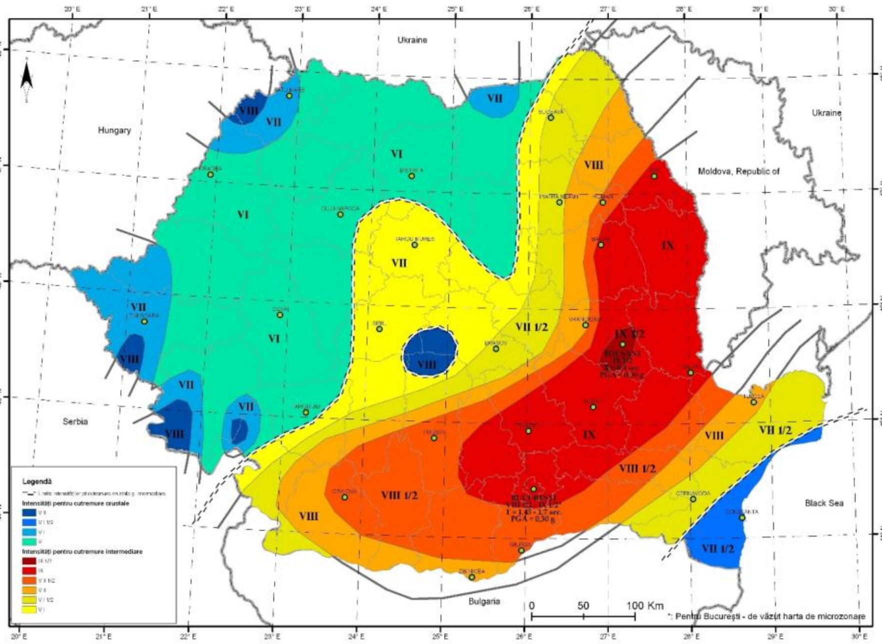

Figure 1. Map featuring earthquake intensities in Romania/The Republic of Moldova [10]

2. CALCULATION OF STRUCTURES

The preliminary compliance of the building was conducted in order to meet the rules imposed by both the CR6:2013 (Design Code for Structural Masonry Walls), P100-1:2013 (Seismic Deign Code), and by the NCM F.03.02-2005 (Moldovan Norms for the Design of Structural Masonry Walls). The height regime is GF (groundfloor) +2S (storeys), H_{storey} = 3 (m), S = 296 (m^2). The current floor plan for the two cases is represented by Figure 2 and Figure 4.

The calculation of section design internal forces was conducted in both cases by using the numerical program ETABS 2016 [9] and the design strengths were calculated manually. In order to conduct these calculations it was used in both cases the Romanian Design Norms [1],[2].

Thus, starting from two structural walls of solid brick masonry (Table 2) with different preliminary compliance (Table 1) we compared resistances and design efforts. We have also analyzed the work method of structures, the structural-spatial cooperation, and the optimal use of construction materials [1],[3].

Table 1. Differences in structural components

Main differences	RO	MDA
Number of tie-columns	93	43
Reinforcement of tie-columns	4 Ø 16 PC52	4Ø20 PC52
Reinforcement of tie-beams (long.)	4Ø16 PC52	4Ø14 PC52
Reinforcement of tie-beams (trans.)	Stirrups Ø8 OB37	Stirrups Ø6 OB37
Girdle sizes	25x30 cm	25x40 cm
Flooring thickness	13 cm	10 cm
Filling door and window spaces	Yes	No

Table 2. Load-bearing elements and materials used for the studied structures

Roof	roof framework
Structural walls	solid brick confined masonry walls 240x115x63 mm
Section of tie-columns	25x25 cm
Concrete	C 16/20

2.1. Assessment of active walls density on the two directions

This assessment was conducted according to CR6:2013 and P100-1:2013, and thus we obtained:

$p\% = \min (p\%_{(transv.)}; p\%_{(long.)}) = \min (6.66; 5.638)\ \% = 5.638\ \%$

Hence, $p\%_{min\ adm}$ = 5%, for a_g = 0.30g one can admit n_{niv} = 3 (GF+2S) [1],[2],[4].

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2.2. Load participation

Load participation and load combinations were conducted pursuant to SR EN 1991-1-1:2004/NA-2006, SR EN 1991-1-3:2005/NA-2006, P100-1:2013, and they are illustrated in Tables 3, 4, 5 [2],[6],[7].

Table 3. Permanent and variable load participation

Load type	Value
Superstructure weight	1.125 kN/m^2
Roof framework weight	1 kN/m^2
Roofing weight	0.7 kN/m^2
Live loads: -roof: -floorings:	 0.75 kN/m^2 2.5 kN/m^2
Snow	1.91 kN/m^2

Table 4. Seismic design parameters

γ_{Is}	1	Third importance class
a_g	0.30g	Design ground acceleration
T_C	0.7 s	Control period (corners)
T_D	3.0 s	Control period (corners)
T_B	0.14 s	Control period (corners)
q	2.8125	Structure behaviour factor

Table 5. Load combinations

1	Fundamental 1	1.35P + 1.5U + 1.05Z
2	Fundamental 2	1.35P + 1.05U + 1.5Z
3	Earthquake Sx	1P + 0,4U + 0.4Z + 1Sx + 0Sy
4	Earthquake Sy	1P + 0.4U + 0.4Z + 0Sx + 1Sy
5	Modal	1P + 0.4U + 0.4Z

2.3. Calculation of design internal forces and strengths

We defined the masonry embrasures:

- for the structure placed in the county of Vaslui (Romania) – Figure 2, 3 [4]
- for the structure placed in the department of Ungheni (The Republic of Moldova) – Figure 4, 5 [3]

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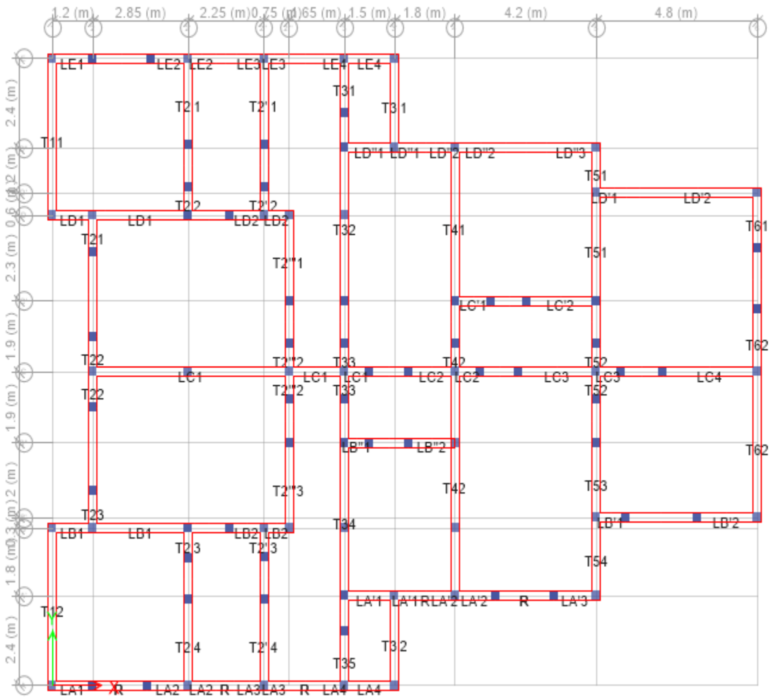

Figure 2. Current floor plan (placed in Romania – county of Vaslui). ETABS Model

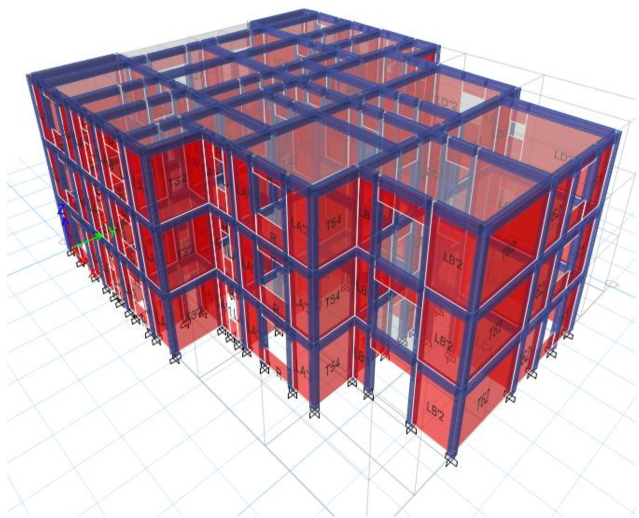

Figure 3. 3D structure representation (placed in Romania – county of Iași). Model ETABS

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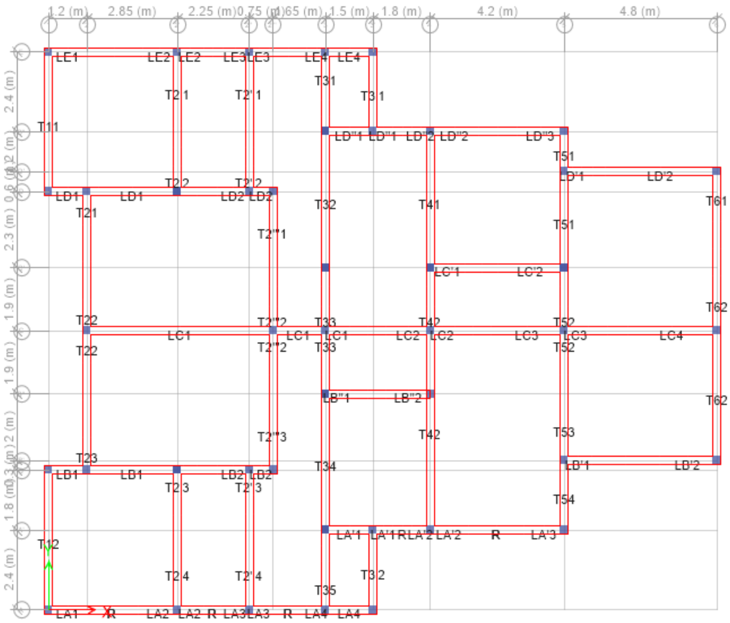

Figure 4. Current floor plan (placed in The Republic of Moldova – department of Ungheni). ETABS Model

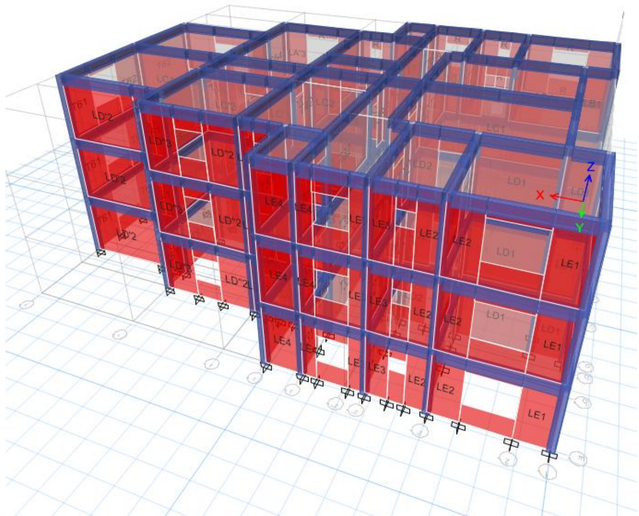

Figure 5. 3D structure representation (placed in The Republic of Moldova – department of Ungheni). ETABS Model

The dynamic characteristics of confined structural masonry walls were represented for each case in Tables 6 and 7 [5], [11].

Table 6. Modal periods, frequencies, and drift

	Case	Mode	Period sec	Frequency cyc/sec	UX mm	UY mm
RO	Modal	1	0.094	10.587	0.7415	0.0505
RO	Modal	2	0.091	10.958	0.0814	0.6238
RO	Modal	3	0.081	12,295	0.0066	0.1476
MDA	Modal	1	0.097	10.261	0.4873	0.1996
MDA	Modal	2	0.095	10.573	0.3207	0.4263
MDA	Modal	3	0.084	11,882	0.0172	0.1911

Table 7. Modal load participation ratios

	Case	Item type	Item	Static %	Dynamic %
RO	Modal	Acceleration	UX	99.85	93.66
RO	Modal	Acceleration	UY	99.86	93.8
MDA	Modal	Acceleration	UX	99.83	93.19
MDA	Modal	Acceleration	UY	99.86	93.61

The final results of section design internal forces and of design strengths on the two directions (longitudinal, transverse) for both researched structures stand to show that both structures successfully bear both gravitational and horizontal loads from the seismic action.

3. ECONOMIC ANALYSIS ESTIMATED FOR SUPERSTRUCTURE COST

In order to highlight the additional consumption of resources, we calculated for the two buildings the consumption of materials (concrete, masonry, steel) necessary for the superstructure.

- In order to determine the prices of materials necessary for the studied buildings, we analyzed the building material market in Vaslui.
- The Tables below feature the consumption of materials in the usual order [13].

Table 8. Estimate of material consumption for the confined masonry structure (placed in Romania – county of Vaslui)

Element name	Material	Quantity/ Volume	Units of measurement	Cost (RON)
Tie-columns	Concrete C16/20	52.31	m^3	260
Tie-beams	Concrete C16/20	47.52		
Slabs	Concrete C16/20	115.44		
Masonry wall	Brick	265.985		803.64
Tie-columns reinforcement	PC52	5936.37	kg	2.3
	OB37	2512.67		
Tie-beams reinforcement	PC52	4671.27		
	OB37	1649.52		
Slabs reinforcement	PC52	8081.07		
Total volume of concrete C16/20		**215.27**	m^3	55970.2
Total weight of reinforcement PC52		**18688.71**	kg	42984.03
Total weight of reinforcement OB37		**4162.19**		9573.04
Total volume of masonry		**265.985**	m^3	213756.19
TOTAL COST (RON)				**322283.46**
TOTAL COST (EURO)				**70902.36**

Table 9. Estimate of material consumption for the confined masonry structure (placed in The Republic of Moldova – department of Ungheni)

Element name	Material	Quantity/ Volume	Units of measurement	Cost (RON)
Tie-columns	Concrete C16/20	24.18	m^3	260
Tie-beams	Concrete C16/20	58.83		
Slabs	Concrete C16/20	88.8		
Masonry wall	Brick	282.8		803.64
Tie-columns reinforcement	PC52	4282.19	kg	2.3
	OB37	1161.77		
Tie-beams reinforcement	PC52	3577.36		
	OB37	1112.48		
Slabs reinforcement	PC52	5328.18		
Total volume of concrete C16/20		**171.81**	m^3	44670.6
Total weight of reinforcement PC52		**13187.73**	kg	30331.779
Total weight of reinforcement OB37		**2274.25**		5230.775
Total volume of masonry		**282.8**	m^3	227269.39
TOTAL COST (RON)				**307502.55**
TOTAL COST (EURO)				**67650.56**

	RON	EURO
DIFFERENCE	**-14780.91**	**-3251.8**

Figure 6. Difference in total cost for the superstructure of buildings following the economic analysis

4. CONCLUSIONS AND RECOMMENDATIONS

The proposed study led to the following conclusions:

- In both cases, certain short walls stressed by shear force have not been verified, but the building as a whole can successfully bear loads of the seismic action;
- The minimum strengths causing the $V_{Ed} > V_{Rd(0-1)}$ phenomenon is the design strengths to failure mechanism per inclined section for walls;
- Because the density of active walls was preserved, in both cases (RO, RofM) the values of $V_{Rdi(0-1)}$ (design strengths to failure mechanism per inclined section) are the same;
- Due to the rigid structure loads more from the horizontal action (earthquake), without consuming the energy of the earthquake by deforming, it results that for the Vaslui-based building the shearing forces are higher than those for the other region. Therefore, the number of walls non-resistant to shearing force is higher;
- In both cases, the structure is more loaded in the transverse direction with horizontal action because of the structural geometry (the short side is more loaded).
- From the perspective of structure behaviour in a seismic area with a_g=0.30g and of spatial-structural compliance, the building designed pursuant to the NCMF.03.02 – 2005 regulations has a better response;
- In addition, following an economic analysis, we concluded that such building is more budget-friendly because of the reduced number of tie-columns, of less thick flooring, of proper reinforcement according to design sections etc. Thus, the overall price difference is 3,250 Euros in favour of the building designed in The Republic of Moldova.

Recommendations:

- In order to solve the issue related to the design strengths per inclined section for slabs, one can use walls reinforcing in horizontal joints, at a height difference of three bricks;
- The use of seismic shock absorbers for certain walls.

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