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Comparative Study Regarding the Choice of Structural System for Buildings with Regular Plan Configurations in Seismic Areas

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Summary

The introduction of Eurocodes regulations imposed on masonry structure buildings the use of a large number of reinforcing elements, especially in areas with intense seismic activity. Thus, in the Moldavia area of Romania choosing the structural system for buildings with regular plan configuration, aiming for optimal price-performance ratio, is a current issue.

The paper presents an analysis of the behaviour of concrete frame structure and active masonry structure, for a building with regular plan configuration, placed on areas with different peak ground acceleration. Structural and architectural conformation of the building follows the current regulations, 2013 version. The study is conducted by using numerical modelling program ETABS, information on the properties of the used materials is obtained by tracking the sites of producers.

Finally, some conclusions and recommendations are mentioned regarding the choice of the structural system for buildings with regular plan configuration, as well as regarding structural conformation of active confined masonry walls.

1. INTRODUCTION

In our country, Vrancea seismic zone is characterized by an intense seismic activity caused by the intersection of at least three tectonic units: Eastern - European plate and Intra - Alpina and Moesica microplates. The seismic activity is concentrated at depths of 60-200 km intermediate in an old subduction plate, almost vertical, which leads to the generation of 1-6 events of magnitude Mw > 7.0 on century, in a very small focal volume [1].

This intense seismic activity requires as essential priority the compliance of the strength and stability requirements. Earthquake design aims to satisfy, with an adequate degree of safety, the two fundamental requirements (performance levels), namely life safety requirement and the requirement to limit damages. To this purpose, the structural strength will be designed to meet the seismic action by the design value shown in P100 [2], with a sufficient margin of safety compared to the deformation level whereat local or general collapse occurred, so that people's lives to be protected. Also, the structural systems will be designed to respond to seismic actions with a higher probability of occurrence compared to the design value, without degradation of the building or taking of it out of service, whose costs are unreasonably high compared to the initial cost of the structure. In designing new buildings to meet the seismic action requirements, Romania is divided into seven seismic areas, characterized by the horizontal peak ground acceleration, "a_g" determined for a mean interval of recurrence of reference, value named hereinafter as „design ground acceleration". Considering this, the choice of the structural system is made by taking into consideration the design ground acceleration, aiming to obtain an optimal price-performance ratio.

The intention of both engineers and beneficiaries is to build as cheaply, as quickly and as less difficult as possible. Therefore, for buildings with regular plan configuration and reduced height regime (up to B + GF + 3F), placing them in different areas of Moldova, raised the issue of choosing the structural system, the most commonly used being reinforced concrete frames and confined masonry structural walls. According to the code governing the calculation of the strength structures with confined masonry walls CR6 - 2013 [3], in areas with $a_g \geq 0.30g$, the disposition of the tie-columns is thickened, their high number leading to a large volume of concrete and reinforcement.

This paper aims to examine the economic benefits of using confined masonry wall construction, in three different locations, $a_g \geq 0.30g$; $a_g = 0.20g - 0.25g$ and $a_g < 0.20g$. To this purpose, a building with regular plan configuration and height of B + GF + 2F was modelled in ETABS compute software, considering two structural systems - reinforced concrete frames and confined masonry structural walls. Next, were computed the materials quantities for the superstructure, namely for concrete, masonry and reinforcement, in order to obtain an estimate cost of the building, on the three locations and for the two different structural systems. Also, in the case of placing the building in areas where $a_g \geq 0.30g$, a number of solutions were analysed for the optimization of the structural strength with confined masonry walls in order to reduce the cost. Finally, there are noted a series of conclusions and recommendations.

2. STRUCTURAL AND ARCHITECTURAL CONFORMATION OF THE ANALYSED BUILDING

For the case study a condominium apartment building was analysed. The height regime of the building was B + GF + 2F. The research of the real estate market showed that lately these buildings are increasingly used, especially in suburban areas.

The analysed building has two apartments disposed on each floor with areas of 98.6 m^2 or 115.8 m^2 (Fig. 1).

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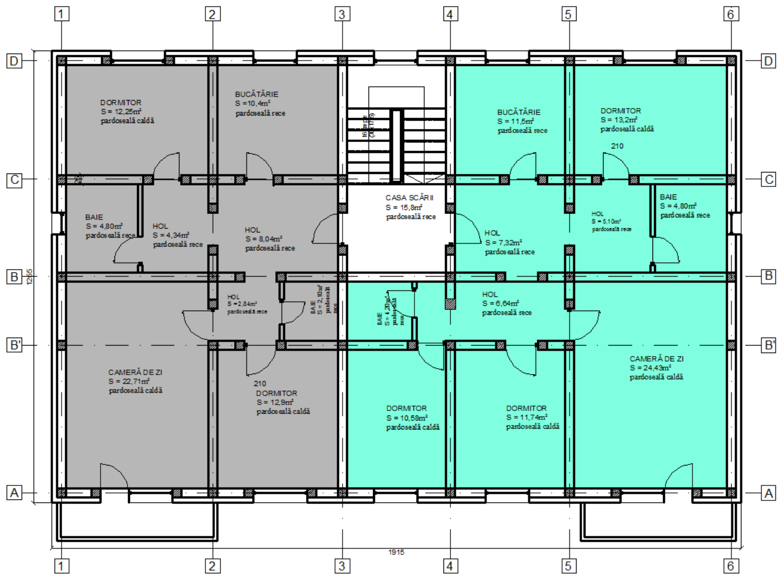

Figure 1. Architectural conformation of the analysed building - confine masonry walls placed in seismic areas with a_g = 0,35g

The building was structurally conformed in two different solutions, namely with reinforced concrete structural frames and with confined masonry structural walls.

In the case with confine masonry structural walls, Fig. 2, the wall thickness is of 25 cm, in the area with a_g> 0.25g being used bricks with dimensions of 240 x 115 x 63 mm, with a standardized compression strength of 30 N/mm^2, meanwhile in the areas with $a_g \leq$ 0.25g hollow ceramic blocks with dimensions of 240 x 290 x 138 mm, with a standard compressive strength of 15 N/mm^2 were used. Masonry mortar used an additive for increasing the plasticity which does not attack the seismic anchors placed in mortar joints, with the mean compressive strength of 5 N/mm^2. Confinement elements, as tie-beams (250 x 250 mm) and tie-columns (250 x 250 mm), are made of concrete of C16/20 class. The reinforcement of the tie-column is made with PC52 bar with a diameter of 16 mm, while the tie-beams reinforcing bars are made of Ø14 mm. Coupling girders are with low rigidity, made of reinforced concrete lintels with dimensions 250 x 150 mm, two bricks layers and the tie-beams. It is noted that in areas with a_g = 0.20 - 0.25g, which requires an active wall density of at least 5%, the walls on the axes B', compassed between the axes 2-3 and 4-5, and C axis, compassed between the axes 3-4 are replaced with non-structural walls. Also, in the case of placing the buildings in areas where a_g<0.20g, where the minimum required active wall density is 4% in the longitudinal direction, the walls on the axes C and B 'are replaced by non-structural walls.

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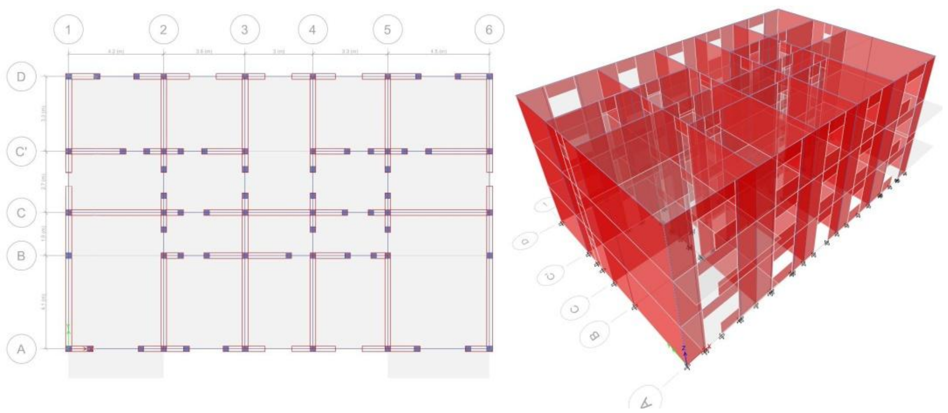

Figure 2.Building with confined masonry structural walls
Horizontal section. ETABS 3D model

In the second version of structural conformation, figure 3, the structure is a three-dimensional reinforced concrete frame, consisting of 3 longitudinal plane frames and 6 transverse plane frames. Structural elements are made of reinforced concrete, class C 20/25. The columns sections are 35 x 35 cm, for areas with ground acceleration $a_g \geq 0.30g$ and 30 x 30 cm for areas with $a_g < 0.30g$. The beams sections are 30 x 50 cm. Reinforcement of columns and beams is made according to current regulations. The framed masonry walls are made of hollow ceramic light blocks, with low standard compression resistance, of around 5 N/mm^2. The mortar used is lime and cement mortar, M5. Characteristic compressive strength of the panels was 2 N/mm^2.

The slabs are similar in both structure variants, with 13 cm thickness and made of concrete class C16/20.

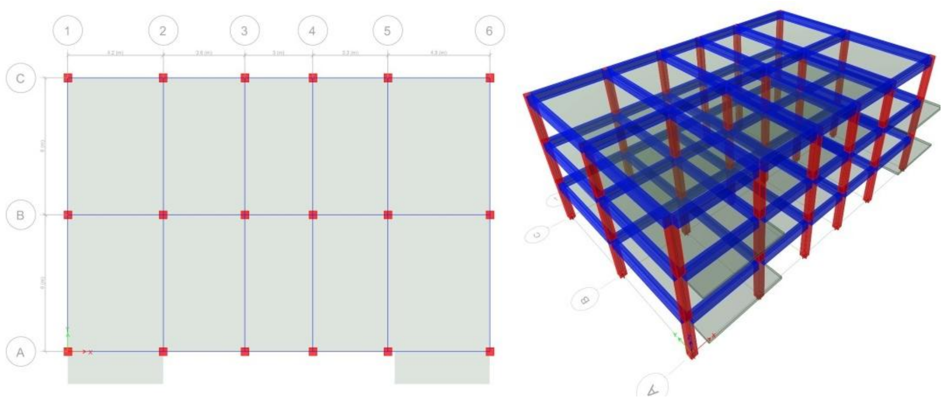

Figure 3. Building with reinforced concrete structural frames
Horizontal section. ETABS model

3. NUMERICAL ANALYSIS OF THE BUILDING ON VERTICAL AND SEISMIC ACTION

Numerical analysis was performed in ETABS software. Load combinations are modelled according to in force regulation [4]. With the intention of pointing out that analyzed resistance structures successfully takes and transmits to the foundation ground both vertical loads and seismic loads, in tables 1 and 2 are presented the values of their periods of vibration and maximal drift and the borderline values. It is noted that all six buildings have their vibration periods beyond the limits and the maximum drift below the value imposed by the regulations.

Table1. Dynamic characteristics of the building with confined masonry structural walls, obtained from modelling

Nr. Crt.	Building's emplacement	Modes of vibration	Period of vibration	Borderline values	Maximal drift (ETABS)	Maximum allowable values P100 (SLS)
1	$a_g = 0{,}35g$	Mode 1	0,0711	<0,7 >1,2	0,52 mm	42 mm
		Mode 2	0,0621			
		Mode 3	0,0558			
2	$a_g = 0{,}25g$	Mode 1	0,0919	<0,7 >1,2	0,56 mm	42 mm
		Mode 2	0,0717			
		Mode 3	0,0651			
3	$a_g = 0{,}15g$	Mode 1	0,0978	<0,7 >1,2	0,53 mm	42 mm
		Mode 2	0,0706			
		Mode 3	0,0646			

Table 2. Dynamic characteristics of the building with reinforced concrete frames, obtained from modelling

Nr. Crt.	Building's emplacement	Modes of vibration	Period of vibration	Borderline values	Maximal drift (ETABS)	Maximum allowable values P100 (SLS)
1	$a_g = 0{,}35g$	Mode 1	0,4397	<0,7 >1,2	8,61 mm	42 mm
		Mode 2	0,3661			
		Mode 3	0,3513			
2	$a_g = 0{,}25g$	Mode 1	0,4397	<0,7 >1,2	8,79 mm	42 mm
		Mode 2	0,3661			
		Mode 3	0,3513			
3	$a_g = 0{,}15g$	Mode 1	0,5144	<0,7 >1,2	7,98 mm	42 mm
		Mode 2	0,4472			
		Mode 3	0,4194			

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4. ESTIMATED ECONOMICAL ANALYSIS FOR THE SUPERSTRUCTURE COST

The purpose of the paper is to analyse the economic advantages of choosing confined masonry wall structures for buildings with regular plan configuration. Therefore, they have been calculated for the 6 fictitious buildings material consumption necessary to construct the superstructure namely those of concrete, masonry and reinforcement. To determine the estimated costs, the materials prices were obtained from researching building materials market in Iasi area.

In Tables 3 and 4 are presented the material consumptions for buildings located in the area with a_g = 0.35g. For building with structural masonry walls (table 4) were used bricks in order to achieve greater resistance and to avoid using horizontal reinforcement in the mortar joints. In this case it is noted that the estimated cost is higher than for building with reinforced concrete frames. This is mainly due to the high cost of bricks. Consumption of reinforcement and concrete for tie-columns are higher than the one necessary for the columns of the frame, but surpluses are balanced by consumption of material needed for the beams, much higher than those needed for the tie-beams. When using hollow ceramic blocks for structural walls, the estimated cost is 31366.27 Euros still higher than the frame structure.

Table 3. Estimated consume for the reinforced concrete frames building placed in areas with ag=0.35g

Element name	Material	Quantity/ Volume	Units of measurement	Cost [Lei]
Beams	Concrete C20/25	57.51	mc	280
Columns	Concrete C20/25	15.21		
Slabs	Concrete C16/20	81.55		240
Masonry walls	Hollow bricks	231.2		226.84
Beams reinforcement	PC 52	5607.37	kg	2.97
	OB 37	3649.8		
Columns reinforcement	PC 52	1687.38		
	OB 37	1382		
	Total weight of concrete C20/25	72.72	mc	20361.6
	Total weight of concrete C16/20	81.55	mc	19572
	Total weight of masonry	231.2	mc	52445.4
	Total weight of reinforcement	12326.55	kg	36609.9
	TOTAL COST [RON]	128988.86		
	TOTAL COST [EURO]	29997.41		

Table 4. Estimated consume for the building with confined masonry structural walls placed in areas with a_g=0.35g

Element name	Material	Quantity/ Volume	Units of measurement	Cost [Lei]
Tie-beams	Concrete C16/20	29.82	mc	240
Tie-columns	Concrete C16/20	32.51		
Slabs	Concrete C16/20	81		
Masonry wall	Bricks	242.76		735.6
Tie-beams reinforcement	PC 52	3014	kg	2.97
	OB 37	1808		
Tie-columns reinforcement	PC 52	3610		
	OB 37	1857		
	Total volume of concrete	143.33	mc	34399.2
	Total volume of masonry	242.76	mc	178574.3
	Total weight of reinforcement	10289	kg	30558.33
	TOTAL COST [RON]		243531.79	
	TOTAL COST [EURO]		57968.60	

In tables 5 and 6 are presented consumption of material for buildings located in the area with a_g = 0.25g. It is noted that estimated cost of reinforced concrete frames building is higher than the one for masonry building due to the reducing of tie-columns number required for confinement of masonry walls. Also, for this areas can be used hollow ceramic blocks for the structural masonry wall, without the need for reinforcement in the horizontal joints.

Table 5. Estimated consume for the building with confined masonry structural walls placed in areas with ag=0.25g

Element name	Material	Quantity / Volume	Units of measurement	Cost [Lei]
Tie-beams	Concrete C16/20	27.22	mc	240
Tie-columns	Concrete C16/20	16.25		
Slabs	Concrete C16/20	83.16		
Masonry wall	Bricks	232.62		236.67
Tie-beams reinforcement	PC 52	2135	kg	2.97
	OB 37	1478		
Tie-columns reinforcement	PC 52	1382.3		
	OB 37	928.28		
	Total volume of concrete	126.63	mc	30391.2
	Total volume of masonry	232.62	mc	55054.18
	Total weight of reinforcement	5923.58	kg	17593.03
	TOTAL COST [RON]		103038.41	
	TOTAL COST [EURO]		23962.42	

Table 6. Estimated consume for the reinforced concrete frames building placed in areas with ag = 0.25g

Element name	Material	Quantity/ Volume	Units of measurement	Cost [Lei]
Beams	Concrete C20/25	57.51	mc	280
Columns	Concrete C20/25	15.21		
Slabs	Concrete C16/20	81.55		240
Masonry walls	Hollow bricks	231.2		226.84
Beams reinforcement	PC 52	4582.89	kg	2.97
	OB 37	3649.8		
Columns reinforcement	PC 52	1492.64		
	OB 37	1382		
	Total weight of concrete C20/25	72.72	mc	20361.6
	Total weight of concrete C16/20	81.55	mc	19572
	Total weight of masonry	231.2	mc	52445.41
	Total weight of reinforcement	11107.33	kg	32988.77
	TOTAL COST [RON]	125367.78		
	TOTAL COST [EURO]	29155.30		

In the tables 7 and 8 are shown consumption of material for buildings located in the area with a_g = 0.15g. It is noted that the difference between the estimated costs is maintained, with decreasing intensity seismic action, structural elements of the concrete frame are more slender and less reinforced.

Table 7. Estimated consume for the building with confined masonry structural walls placed in areas with ag=0.15g

Element name	Material	Quantity/ Volume	Units of measurement	Cost [Lei]
Tie-beams	Concrete C16/20	25.02	mc	240
Tie-columns	Concrete C16/20	16.25		
Slabs	Concrete C16/20	84.21		
Masonry wall	Bricks	210.25		236.67
Tie-beams reinforcement	PC 52	1855.6	kg	2.97
	OB 37	1365		
Tie-columns reinforcement	PC 52	1014.4		
	OB 37	928.28		
	Total volume of concrete	125.48	mc	30115.2
	Total volume of masonry	210.25	mc	49759.87
	Total weight of reinforcement	5163.28	kg	15334.94
	TOTAL COST [RON]	95210.01		
	TOTAL COST [EURO]	22141.86		

Table 8. Estimated consume for the reinforced concrete frames building placed in areas with ag=0.15g

Element name	Material	Quantity/ Volume	Units of measurement	Cost [Lei]
Beams	Concrete C20/25	57.65	mc	280
Columns	Concrete C20/25	12.15		
Slabs	Concrete C16/20	81.55		240
Masonry walls	Hollow bricks	231,8		226.84
Beams reinforcement	PC 52	3685.04	kg	2.97
	OB 37	3649.8		
Columns reinforcement	PC 52	1268.86		
	OB 37	1382		
	Total weight of concrete C20/25	69,8	mc	19544
	Total weight of concrete C16/20	81,55	mc	19572
	Total weight of masonry	231.8	mc	52581.51
	Total weight of reinforcement	9985.7	kg	29657.53
	TOTAL COST [RON]	121355.04		
	TOTAL COST [EURO]	28222.10		

4. CONCLUSION AND RECOMANDATION

The above analysis argues that in areas with low and medium seismicity, peak ground acceleration $a_g \leq 0.35g$, it is economically advantageous to use confined masonry structural walls. In addition to lower material consumption, another argument is the more accessible implementing technology. It was noted that in these areas the estimated cost is lower for buildings with masonry walls, 22141.86 euro to 28222.10 euro in areas with $a_g = 0.15g$ and 23962.42 euro to 29150.30 euro in areas with $a_g = 0.25g$.

In areas with $a_g > 0.25g$, by thickening the tie-columns, the material consumption increased. If masonry walls are made of bricks, the estimated cost is much higher than the cost for reinforced concrete frames, 57968.60 euro to 29997.41 euro. If ceramic hollow blocks are used, estimated cost decreases but still remains higher than the reinforced concrete frame structure, due to the need to use reinforcement in horizontal mortar joints.

In the future, the authors intend to continue the research and to use numerical analysis to optimize confined masonry structural walls for buildings located in areas with $a_g = 0.35g$, in terms of material consumption.

The authors noted that the numerical modelling of the specific structural strength was one specific to current design.

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