

Determination of the optimal thickness of the floors of multi-storey concrete structures with modal analysis

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Abstract: For multi-storey concrete civil structures, the weight of the floors usually represents approximately 60% of the weight of the superstructure. For this reason, reducing the weight of the floors becomes important both for reducing the inertial mass of the structure and for reducing the reactive pressure of the ground on which the infrastructure rests. To optimize the thickness of the slabs, this article proposes a method based on modal analysis that allows establishing the thickness of the slabs by limiting the eigenvalue (period) in mode 1 at $T = 0.2$ s.

Keywords: reinforced concrete floors, multi-storey reinforced concrete structures, modal analysis.

1. Introduction

Plates are surface elements where two of the dimensions are larger than the third ($l_1, l_2 \gg hp$).

According to the bearing mode, loading, and geometry, they can be classified into: structural wall (vertical diaphragm), wall, beam, and floor plate (horizontal diaphragm) as shown in figure 1. The types of plates specified will have a specific behaviour. The type of dominant sectional stresses in the slabs can be determined according to the ratio l_{min}/hp ($l_{min} = \min(l_1, l_2)$):

- thin plates $l_{min}/hp > 40$, predominantly subjected to axial forces and are characteristic of coverings;
- plates with medium thickness $l_{min}/hp = 20-40$ which are predominantly required to bend in one or both directions and are used to make up the boards;
- thick plates $l_{min}/hp < 10$, mainly required for bending and shearing force and are used for the composition of foundations.

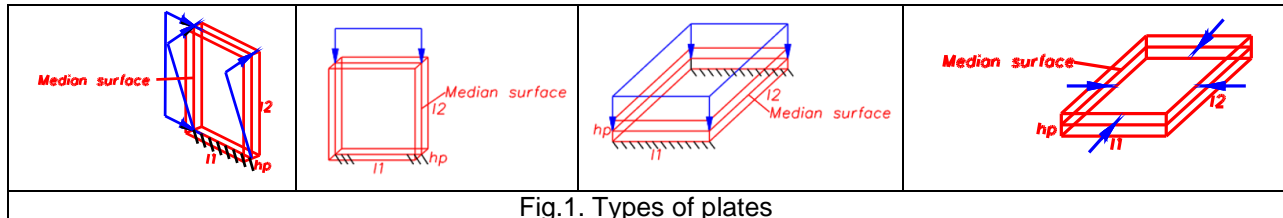


Fig.1. Types of plates

Floors are composed of slabs that can be loaded with transverse loads and loads in the plane of the slabs. They are structurally classified into three categories:

- Floors with slabs and main beams in both directions fig.2.a, with first-degree support on vertical structural elements. Boards can have one-way or two-way discharge. Payloads can reach up to 3kN/m^2 . In the case of two-way unloading, the area is limited to 50 m^2 . For larger surfaces, the weight of the concrete on the extended side is high, and the solution alone is economically justified;

- The slabs with thick ribs fig.2.b have unidirectional discharge and are used for useful loads greater than 3kN/m^2 . Second-order supported secondary beams rest on the main beams which can be dimensioned as frame beams for seismic incursions. The secondary beams allow the reinforcement to be concentrated at the bottom of the floor to take up the positive moments in the field. To take over the negative moments in the area of the supports, the rib can be thickened next to the supports or the spaces in the thickness of the slabs in the vicinity of the supports can be filled with concrete. This constructive solution also improves the shear force resistance capacity in the area of

the supports where the shear force is maximum. They are generally only used for gravity loads. For seismic incursions between rows of columns, frame beams with sufficient lateral rigidity are created;

-The boxed floors fig.2.c are made up of a plate resting on a network of beams arranged in two directions at distances of 1.5m-3m. The web of beams may rest on the main beams between rows of columns or walls. They are used for spans over 12m and loads over 3kN/m². This solution is economically justified by reducing the weight of the floor due to the concrete removed from the extended part of the simple floor and the concentration of reinforcements in the extended area of the beam network.

- Slab floors fig.2.d are made up of a plate that rests directly on the pillars. The local support leads to failure through penetration of the slab, therefore near the support on the column the slab is thickened using the capital. Slab floors are used up to 9m openings, and for seismic incursions, they are provided with perimeter beams that, together with perimeter pillars, form perimeter frames with sufficient lateral rigidity. These floors have the advantage that the space between two floors on the elevation increases.

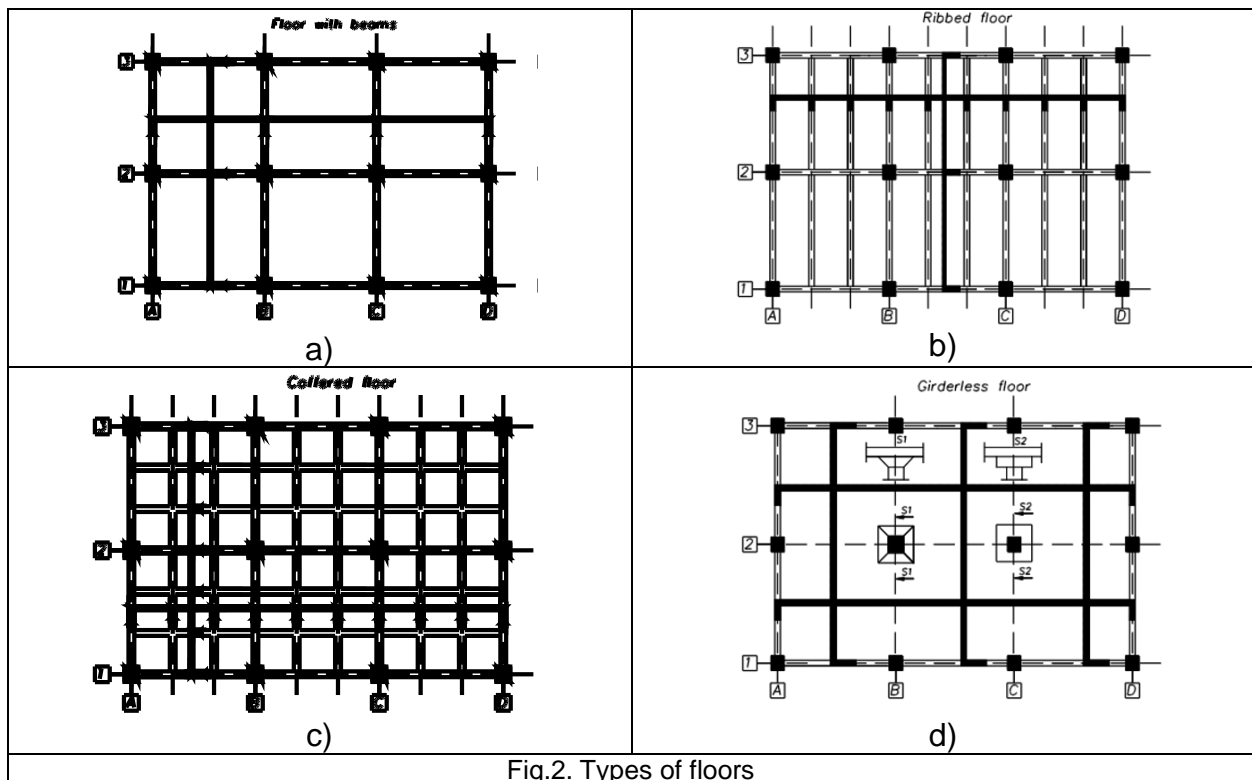


Fig.2. Types of floors

For the analysis in this work, the materials with the physical-mechanical characteristics from table 1 were used.

Table 1. [1]			
Material	Concrete C25/30	Bst500	U.M.
Weight per unit	24,9926	76,9729	kN/m ³
Modulus of elasticity E	31000	210000	MPa

Poisson's ratio	0,2	0,3	
Coefficient of thermal expansion	0,00001	0,0000117	1/C ⁰
Shear modulus G	12916,67	80769,23	MPa
Strength of materials	fcd=16,67	fyd=435	MPa
	fck=25	fyk=500	MPa
	ftcd=1,2	fym=550	MPa

2. Modeling and simulation of slabs with main beams

Pre-dimensioning the thickness of the plates can be done with relationship 1, in which case only the geometric dimensions of the plates are taken into account, or with relationship 2, in which the thickness of the plate is determined under the condition that the reinforcement coefficient is optimal.

$$d = \frac{P}{180} + 1 \dots 2cm . \quad (1)$$

where,

P Is the perimeter of the plate.

$$d = \sqrt{\frac{M_{Ed}}{bf_{cd}\xi\left(1 - \frac{\xi}{2}\right)}}; \xi = \rho \frac{f_{yd}}{f_{cd}}; \rho = 0,008 . \quad (2)$$

where,

d-the effective thickness of the plate;

b-the width of the plate that is taken is 1m;

M_{Ed} -is the bending moment;

f_{yd}-design strength of steel;

f_{cd}-design compressive strength of concrete;

ξ - the relative height of the compressed area;

ρ - the optimal reinforcement coefficient;

In order to determine the optimal plate thickness in the case of floors with main beams, static and dynamic analyzes were performed with the Etabs program [2] in the case of a floor with the characteristics in table 2 and table 3.

Spacing between axes 1-2 / 2-3 / 3-4	9m/6m/9m
Spacing between axes A-B / B-C / C-D	9m/6m/9m
Height of the column above the floor	1,5m
Height of the column under the floor	1,5m

The dimensions of the cross section of the columns		0,8m x 0,8m
The dimensions of the cross section of the beams		0,3m x 0,9m
The thickness of the plates	Variant 1	22cm
	Variant 2	18cm
	Variant 3	18cm/corner-10cm/marginal-8cm/middle
Bending stiffness of the columns		EI _c
Bending stiffness of the beams		EI _b
Bending stiffness of the floor		EI _f
Real bending stiffness of the columns		0,5 EI _c
Real bending stiffness of the beams		0,5EI _b
Real bending stiffness of the floor		0,5EI _f

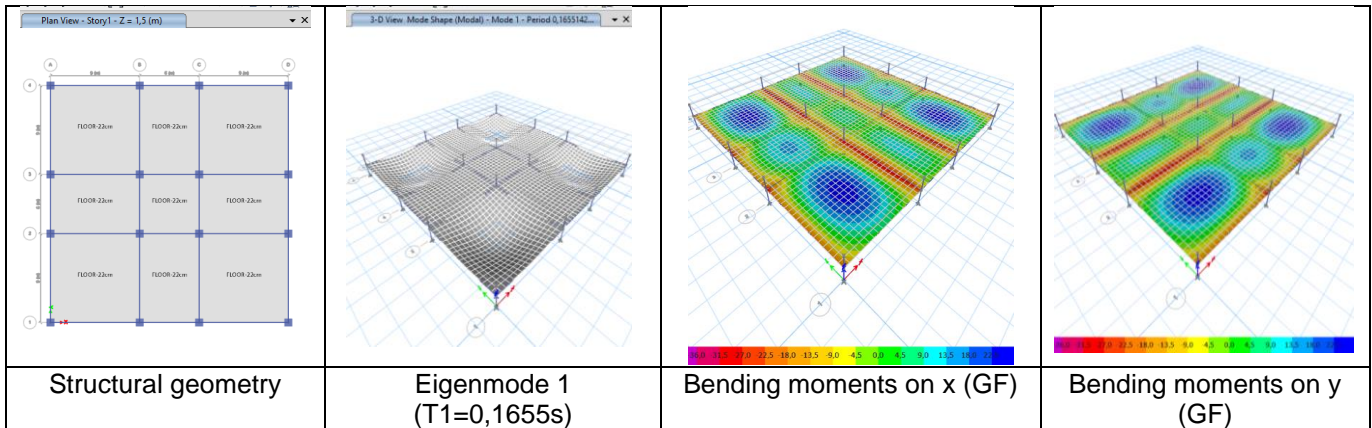


Fig.3.Variant 1- Plate with a thickness of 22 cm and a maximum transverse displacement of 9.15 mm.

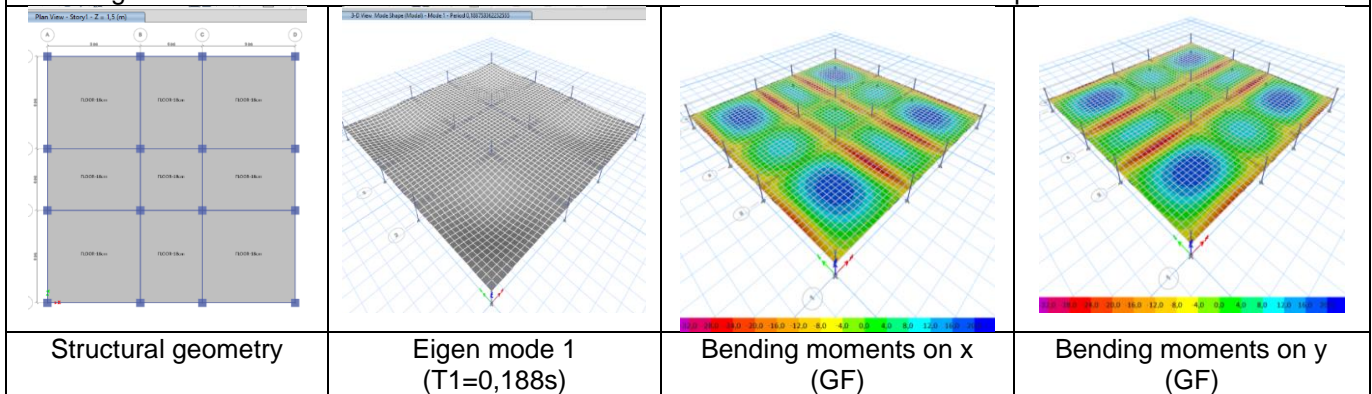
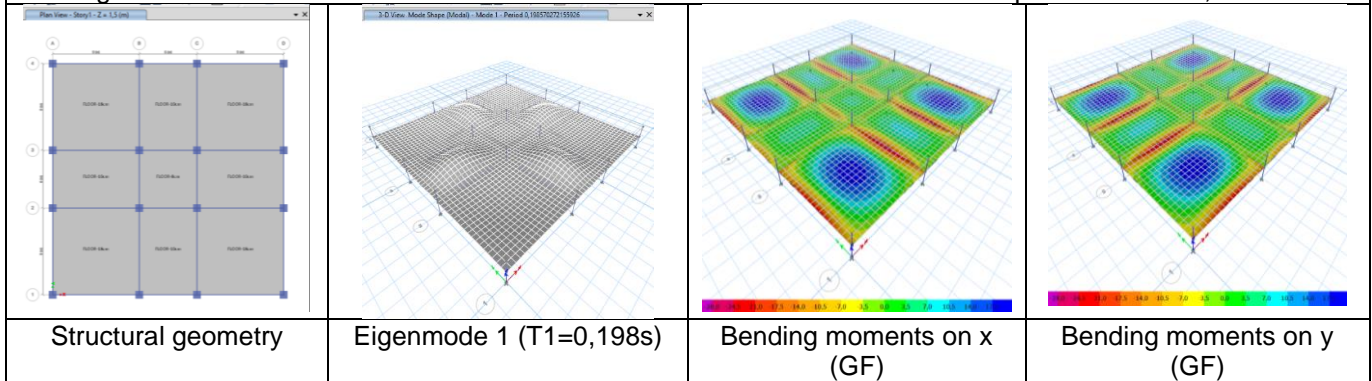


Fig.4.Varianta 2- Plate with a thickness of 18 cm and a maximum transverse displacement of 12,15 mm.



After performing the modal analyzes on the three plate variants, it also found that by imposing a proper vibration period of 0.2s in vibration mode 1, variants 2 and 3 become more economical compared to variant 1 from the material used point of view. The useful load was considered $3kN/m^2$, and the driven mass was transverse to the floor. The field of sectional stresses in the two directions was determined in the fundamental group (GF).

3. Modeling and simulation of boxed floors

To optimize the floors with an opening greater than 9m, the variants presented in tables 4 and 5 were analyzed. After the modal analysis of the variants and limiting the period of the floor's vibration in vibration mode 1 at $T=0.2s$, variant 5 results (the floor cast) as being the most economical from the point of view of concrete consumption. The live load it was considered $3kN/m^2$ and the driven mass was transverse to the floor. The field of sectional stresses in the two directions was determined in the fundamental group (GF).

Spacing between axes 1-2 / 2-3 / 3-4	12m/12m/12m
Spacing between axes A-B / B-C / C-D	12m/12m/12m
Height of the column above the floor	1,5m
Height of the column under the floor	1,5m

The dimensions of the cross section of the columns		1mx1m
The dimensions of the cross section of the beams		0,3mx0,9m
The dimensions of the cross section of the ribs		0,25mx0,5m
The thickness of the plates	Variant 4-simple floor	30cm
	Variant 5-ribbed floor	6cm
Bending stiffness of the columns		EI_c
Bending stiffness of the beams		EI_b
Bending stiffness of the floor		EI_f
Real bending stiffness of the columns		$0,5 EI_c$
Real bending stiffness of the beams		$0,5EI_b$
Real bending stiffness of the floor		$0,5EI_f$

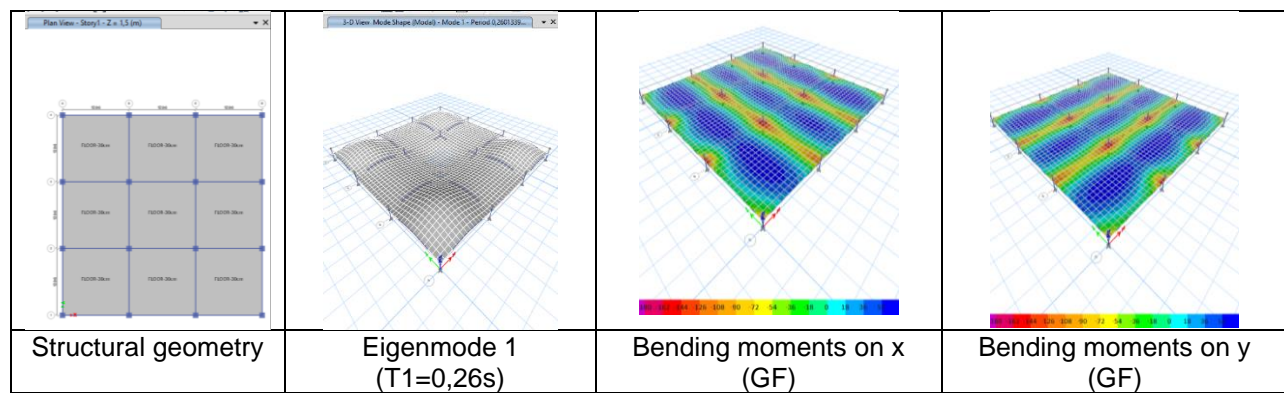


Fig.6.Variant 4- Plate with a thickness of 30 cm and a maximum transverse displacement of 21.96 mm

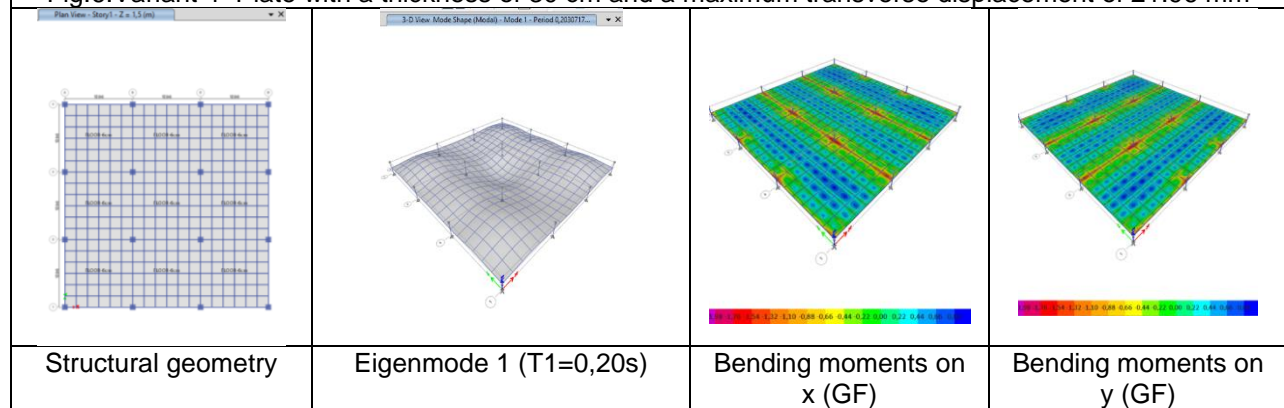


Fig.7.Variant 5- Plate with a thickness of 6 cm and a maximum transverse displacement of 21,37 mm

To determine the reinforcement area, the percentage of reinforcement and the relative height of the compressed area, equations (3) according to EC2 [3] were used:

$$A_a = \frac{M_{Ed}}{f_{yd}z}; K = \frac{M_{Ed}}{bd^2 f_{cd}}; z = \frac{d(1 + (1 - 3,529K)^{0,5})}{2} < 0,95d;$$

$$f_{yd} = 435MPa; f_{cd} = 16,67MPa$$

$$\xi = \frac{\lambda x}{d} 100 \in [2,6\% - 20\%]; p = \frac{A_a}{bd} 100 \in [0,1\% - 0,8\%]$$
(3)

Unde,

- d-the effective thickness of the plate;
- b-the width of the plate that is taken is 1m;
- M_{Ed} -is the bending moment;
- ξ - the relative height of the compressed area;

4. Results and conclusions

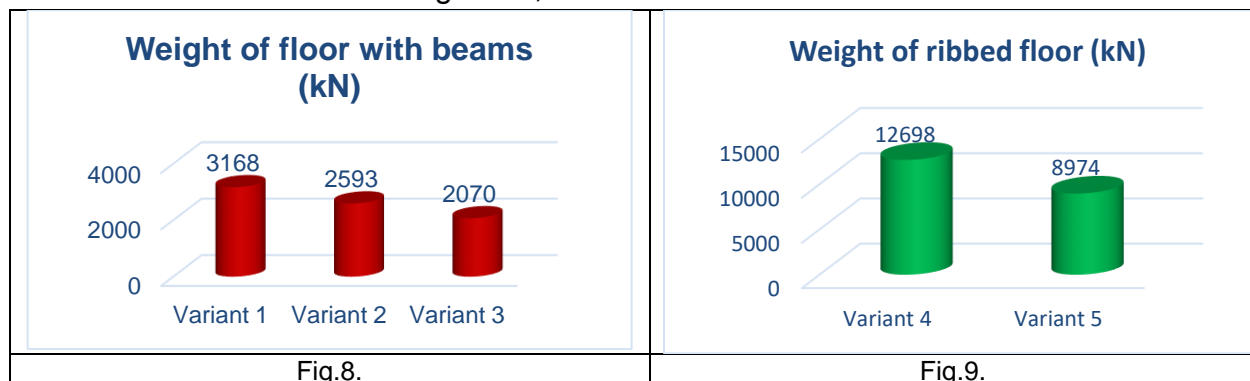
Following the dynamic analysis on plates with main beams and coffered plates, it results:

-The method of modal analysis allows the determination of the thickness of the floors taking into account the rigidities as well as the way of supporting the plates. The classic method of determining the thickness of the floor refers only to the geometric dimensions of the floor and leads to an oversizing of the thickness of the floor;

- Fig. 8 shows a reduction in the weight of the floors with main beams of 35% and Fig. 9 shows a reduction in the weight of the coffered floors by 29%;

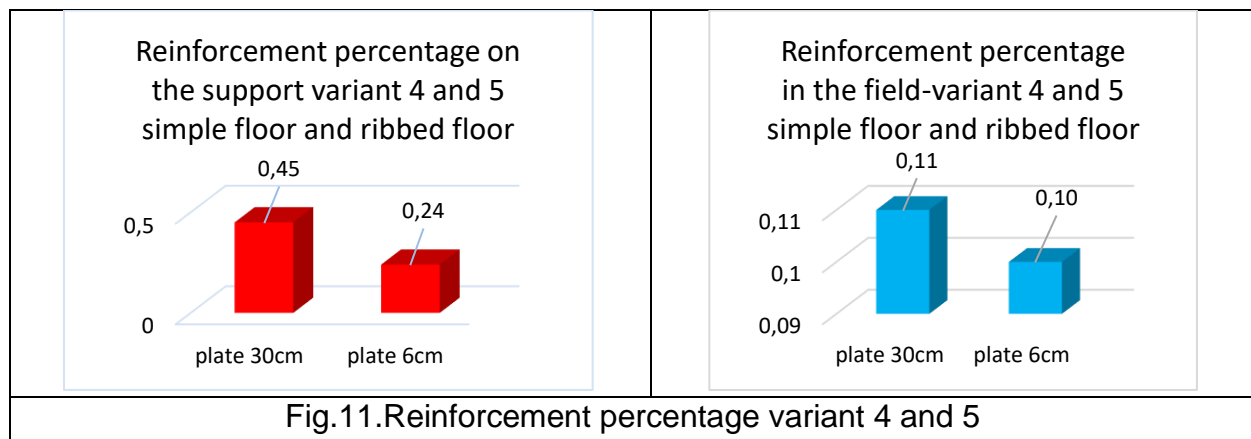
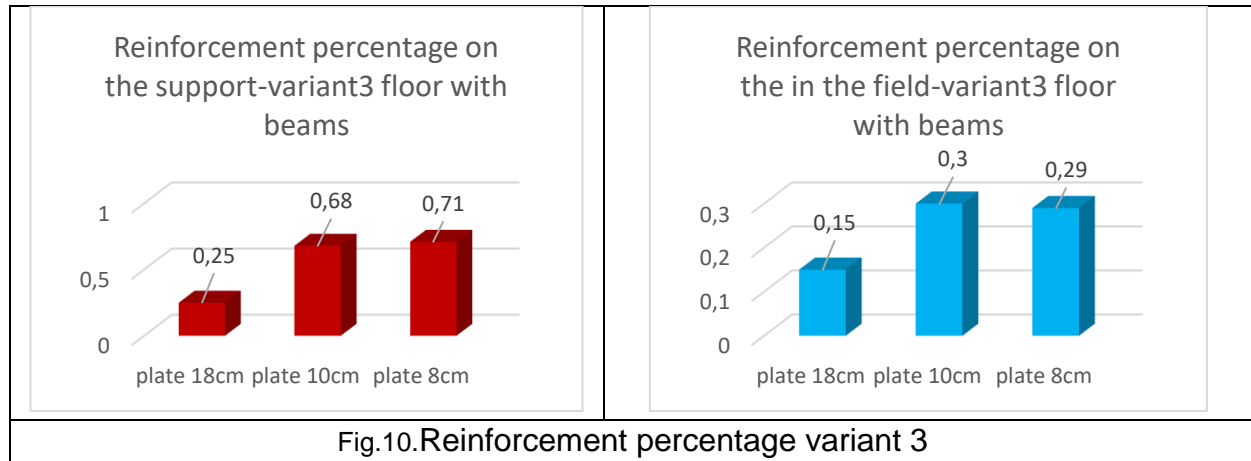
-The reduction of the floor mass leads to the reduction of the construction mass and implicitly of the inertial forces that develop at the seismic incursions of the structure.

-Reduction of the mass of the floors in the case of high structures leads to a lower load on the foundation ground;



-From the analyses performed, it is found that limiting the own period of a floor in a transverse direction to $T = 0.2$ s, is sufficient to ensure the rigidity conditions of the floors fig. 10 and fig. 11 show that the reinforcement percentages required for field and support reinforcement for the analysed cases are below 0.62%. For the analysed floor variants, the relative height of the compressed area is between 2.7% and 17.07%, so the behaviour of the plates is ductile.

- The transverse displacements of the floors in all variants are less than 1/600 of the opening.



5. Bibliography

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