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ASPECTS REGARDING REDUCTION OF GENERAL TORSION IN THE STRUCTURES OF THE BRAŞOV CAMPUS

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Abstract: *In this paper there are presented three structures from a locative complex which will be built in the Transilvania University Campus Braşov. In order to reduce the general torsion, for each structure several successive modelling of the lateral stiffness has been performed, until the torsion effect introduced by the difference between the centre of mass and the centre of stiffness was minimal. The structural analysis was realized on structures modelled with stairs and elevator openings in the concrete floor, thereby the lateral stiffness and the effect of these elements were taken into consideration.*

Key words: *centre of mass, centre of stiffness, general torsion of a civil building.*

1. Introduction

The Campus is a residential complex consisted of three buildings. The buildings will accommodate postgraduate students seeking for master's degree, doctor degree, and between the two buildings there is an atrium (Figure 1).

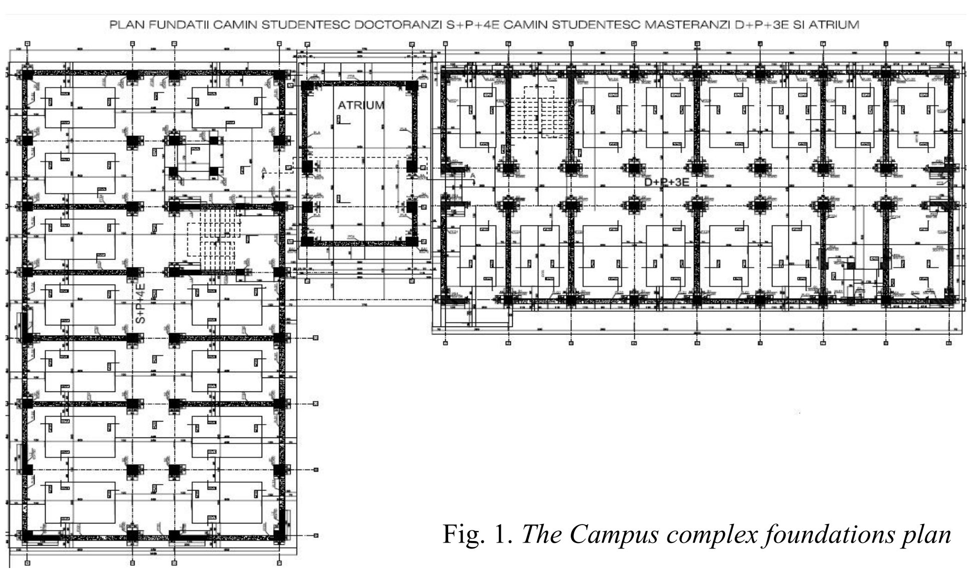

Fig. 1. *The Campus complex foundations plan*

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2. Material and Methods

2.1. General description

The structure for the master's students has the following layout. It has three spans, between axes A'-B'- 6 meters, between axes B'-C'- 2.4 meters, and between axes C'-D'- 6 m, as well as eight lateral spans, each one having 3.6 meters. The structure itself is consisted of a semi-basement embedded –3.35 meters below ground level, a ground floor and three storeys.

The foundation system is consisted of a slab foundation with gaps having 60 cm thickness. Under the foundation, a layer of 10 cm thickness levelling concrete is disposed. In the elevator well area, the foundation is embedded –5.75 m below ground level.

The stiffness structure of the semi-basement is a rigid-box type, consisted of perimetral walls 30 cm thick, and cross-cut these walls are coupled with transversal walls or ribs, also having 30 cm thickness.

The perimetral and transversal walls of the semi-basement are stiffened at the top by a 16 cm reinforced-concrete floor.

The superstructure is consisted of frames and shear walls. The staircase has two stringers and one stair landing, on each level. In the staircase area, two shear walls there have been designed, on which the stair landing unloads. In order to avoid the torsion effects and to provide sufficient lateral stiffness, there have been disposed eight perimetral shear walls. The elevator area is delimited by two shear walls. The reinforced-concrete floors are 16 cm thick, excepting the floor above level three, which is 18 cm thick.

The transversal beams have 30 cm in thickness and 55 cm in height, and the longitudinal ones have 30 cm in thickness and 50 cm in height, on each floor.

The beams from the stair landings and the lintel-type beam form the elevator area are 25 cm by 50 cm. The structure's columns which ensure the lateral stiffness, except for the shear walls, are 50cm by 50 cm.

The vertical building traffic is done trough a stairway disposed between axes D'-C' and 2'-3', and trough an elevator disposed between axes 7'-8' and A'-B' (Figure 2).

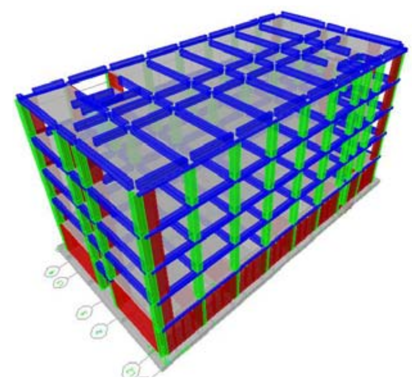

Fig. 2. *The master's degree structure*

The structure for the doctoral students has the following layout. It has three spans, between axes 1-2 - 6 meters, between axes 2-3 - 2.4 meters, and between axes 3-4 - 6 m, as well as seven lateral spans, each one having 4.2 meters.

The structure itself is consisted of a basement embedded –3.35 meters below ground level, a ground floor and four storeys.

The foundation system is consisted of a slab foundation with gaps having 60 cm thickness. Under the foundation, a layer of 10 cm thickness levelling concrete is disposed. In the elevator well area, the foundation is embedded –5.25 m below ground level.

The stiffness structure of the basement is a rigid-box type, consisted of perimetral walls 30 cm thick, and cross-cut these walls are coupled with transversal walls or ribs, also having 30 cm thickness.

The perimetral and transversal walls of the basement are stiffened at the top by a 16 cm reinforced-concrete floor.

The superstructure is consisted of frames and shear walls. The staircase has two stringers and one stair landing, on each level. In the staircase area, two shear walls there have been designed, on which the stair landing unloads. In order to avoid the torsion effects and to provide sufficient lateral stiffness, there have been disposed four more perimetral shear walls. The elevator area is delimited by two shear walls. All reinforced-concrete floors are 16 cm thick.

The transversal beams have 30 cm in thickness and 60 cm in height, and the longitudinal ones have 30 cm in thickness and 50 cm in height, on each floor.

The beams from the stair landings and the lintel-type beam form the elevator area are 25 cm by 50 cm. The structure's columns which ensure the lateral stiffness, except for the shear walls, are 60cm by 60 cm.

The vertical building traffic is done trough a stairway disposed between axes E-F and 1-2, and trough an elevator disposed between axes F-G and 1-2 (Figure 3).

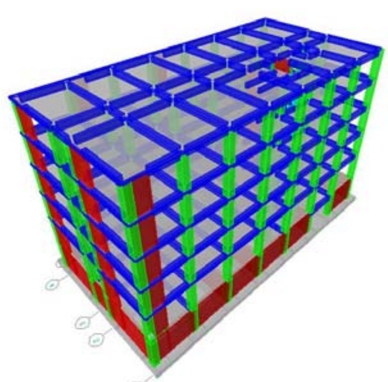

Fig. 3. *The doctoral degree structure*

The atrium building is a mixed concrete-steel building.

The structure itself is consisted of a rigid-box type basement, embedded –3.55 meters below ground level, a ground floor and one storey. The ground level and the storey have a steel stiffness structure.

The foundation system is consisted of a slab foundation with gaps having 60 cm thickness. Under the foundation, a layer of 20 cm thickness levelling concrete is disposed.

The stiffness structure of the basement is a rigid-box type, consisted of perimetral walls 30 cm thick.

The superstructure is consisted of steel frames, with steel columns HEA and steel beams IPE (Figure 4).

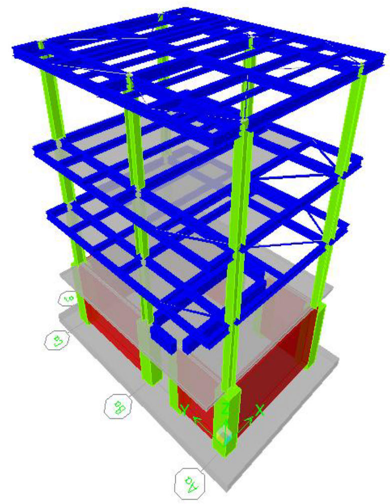

Fig. 4. *The atrium structure*

The levelling concrete grade is C8/10, and the structures concrete grade is C25/30. The reinforcing grade is PC 52.

2.2. Analytical determination of the centre of stiffness on each level of a civil multi storey building

Centre of stiffness, centre of torsion or centre of rotation is defined as being the point in which by applying a lateral force F, the upper story only has a translation movement relative to the lower story. This movement can be decomposed in two components in respect to a triorthogonal system (Figure 5).

If a unitary displacement is induced to the structure on the x direction and for each

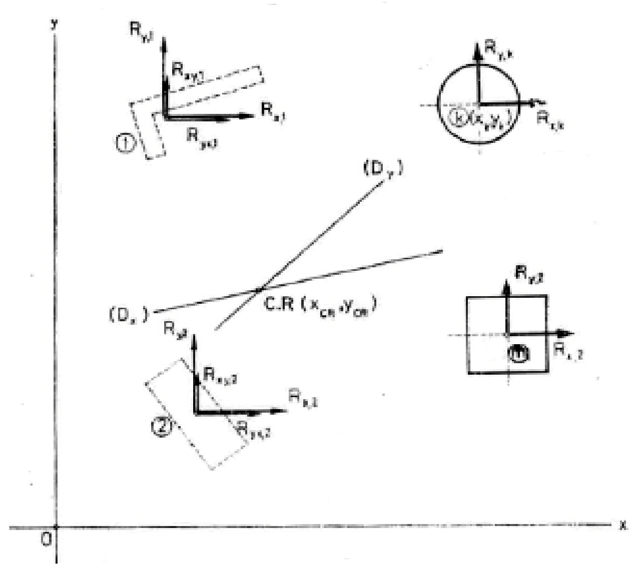

Fig. 5. *The triorthogonal system*

vertical element $K_{x,i}$ and $K_{xy,i}$ stiffnesses are determined, then the resultant of these stiffnesses which compose a system of coplanar forces is reduced to a resultant on the D_x direction.

Analogue, by applying a unitary displacement on the y direction, the system of coplanar forces generated by the $K_{y,i}$ and $K_{yx,i}$ stiffnesses, is reduced to a resultant on the D_y direction.

After reducing the system of forces, the equations of the two lines D_x and D_y can be determined, as following [2]:

$$\begin{aligned} (D_x) \quad & K_{xy}\,x - K_x y + M_{ox} = 0, \\ (D_y) \quad & K_y\,x - K_{xy} y + M_{oy} = 0. \end{aligned} \tag{1}$$

At the intersection of the two lines D_x and D_y the centre of stiffness is positioned, which has the following coordinates:

$$\begin{aligned} X_{CR} &= \frac{M_{ox}K_{xy} - M_{oy}K_y}{K_x K_y - K_{xy}^2}, \\ Y_{CR} &= \frac{M_{ox}K_y - M_{oy}K_{xy}}{K_x K_y - K_{xy}^2}. \end{aligned} \tag{2}$$

In the case in which the principal directions of inertia of the vertical elements transverse sections are parallel with the axes of the reference system, the coordinates of the centre of stiffness are:

$$\begin{aligned} X_{CR} &= -\frac{M_{oy}}{K_y} = -\frac{\sum_{i=1}^{n} K_{y,i} X_i}{\sum_{i=1}^{n} K_{y,i}}, \\ Y_{CR} &= \frac{M_{ox}}{K_x} = -\frac{\sum_{i=1}^{n} K_{x,i} Y_i}{\sum_{i=1}^{n} K_{x,i}}. \end{aligned} \tag{3}$$

The centre of stiffness of an ensemble of vertical elements is an elastic characteristic of a structure.

If the lateral force which acts in the plane of each reinforced-concrete floor passes through the centre of stiffness, it will only generate a translation movement, but if this lateral force will not pass through the centre of stiffness, it will generate a translation movement as well as a rotational movement [1].

In the general case in which even if the centre of stiffness coincides with the centre of mass in the case of a reinforced-concrete floor of a structure, an accidental eccentricity must be considered, this can differ form a floor to another (Figure 6).

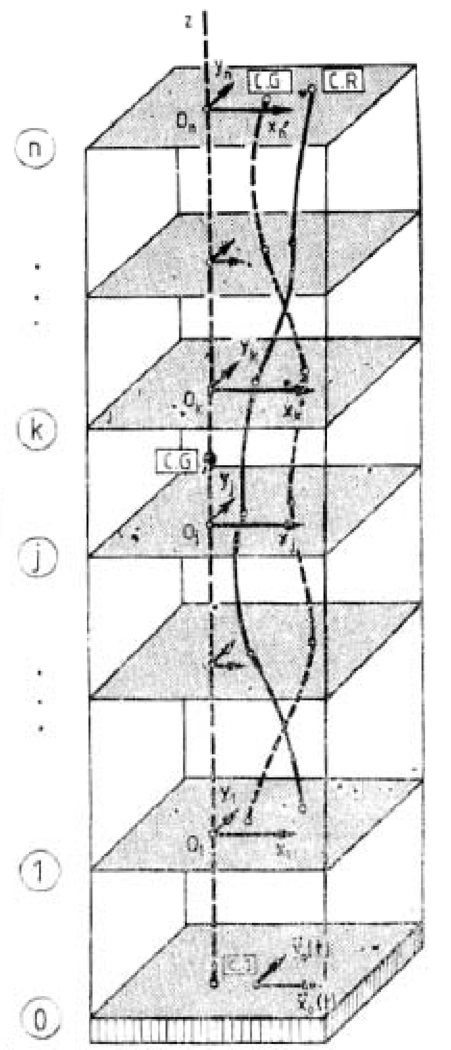

Fig. 6. *The accidental eccentricity*

The accidental eccentricity is generally determined because the masses on a floor are usually not evenly distributed.

In the performed analysis, distance alteration between the centre of mass and the centre of stiffness due to the different cracking of the structural elements was not taken into consideration.

3. Conclusions

In tall buildings where the difference between the centre of stiffness and centre of mass is relatively significant, vertical elements like shear walls must be disposed on the structures perimeter, or vertical closed elements (tube-type: exterior framing and internal core) [3].

In order to limit the distance between the centre of stiffness and centre of mass in the case of the analyzed structures in this paper, the process was done adaptive, by modifying the geometric dimensions of the vertical elements that provide lateral stiffness.

In order to diminish the number of steps needed to make the centre of stiffness and centre of mass to coincide, the vertical elements that have the largest stiffness were diagonally disposed in the structures (Figures 7-9).

Reducing the distance between the centre of stiffness and centre of mass has a major importance in the case of the analyzed structures, because by reducing the general torsion effect, fragile ruptures induced by shear or torsion are avoided, increasing the beams ductility which are going to be subjected to bending and not to traction.

The qualitative effect of reducing the general torsion effect is determined in the case of the analyzed structures by the deformed shape of the first vibration mode in the modal analysis (Figures 10-12).

The quantitative effect of approaching the centre of stiffness to the centre of mass, is quantified by the displacement difference between the building ends in the first vibration mode, mode in which the percent of the modal participating masses is the largest.

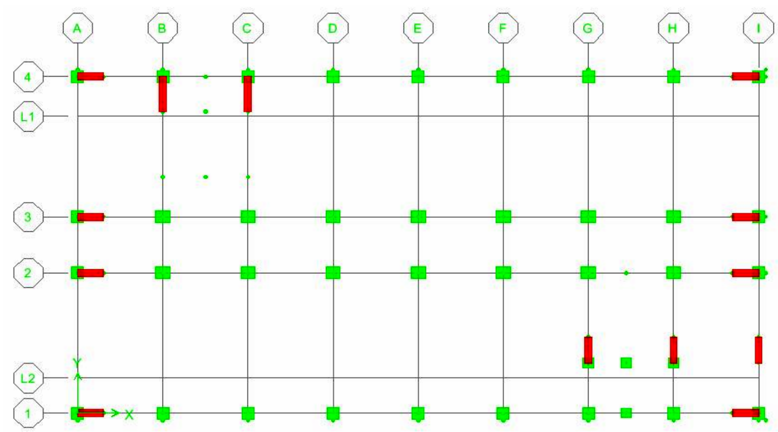

Fig. 7. *Structural walls and columns - master's degree building*

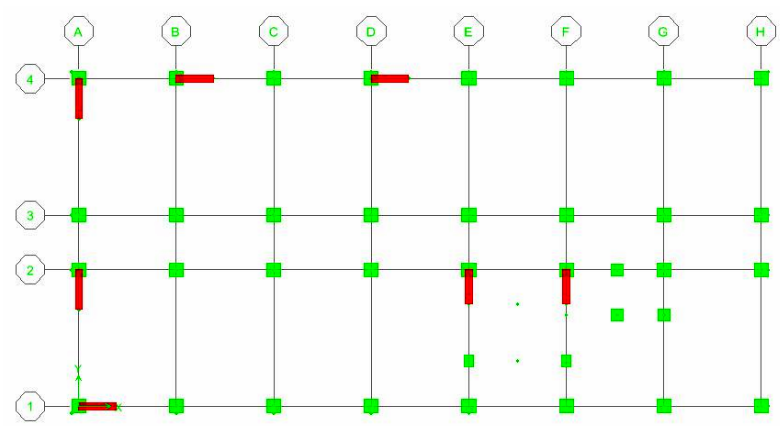

Fig. 8. *Structural walls and columns* - *doctor's degree building*

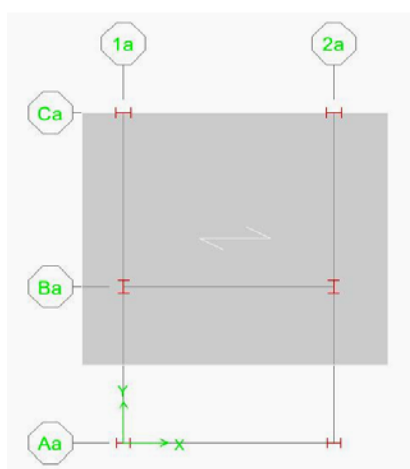

Fig. 9. *Columns - atrium building*

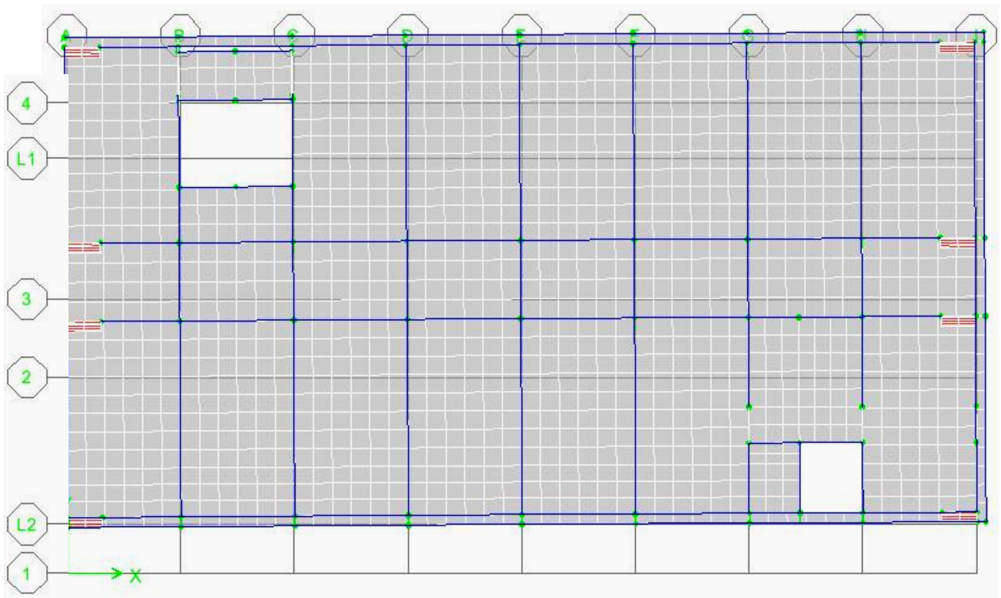

Fig. 10. *First vibration mode - master's degree building*

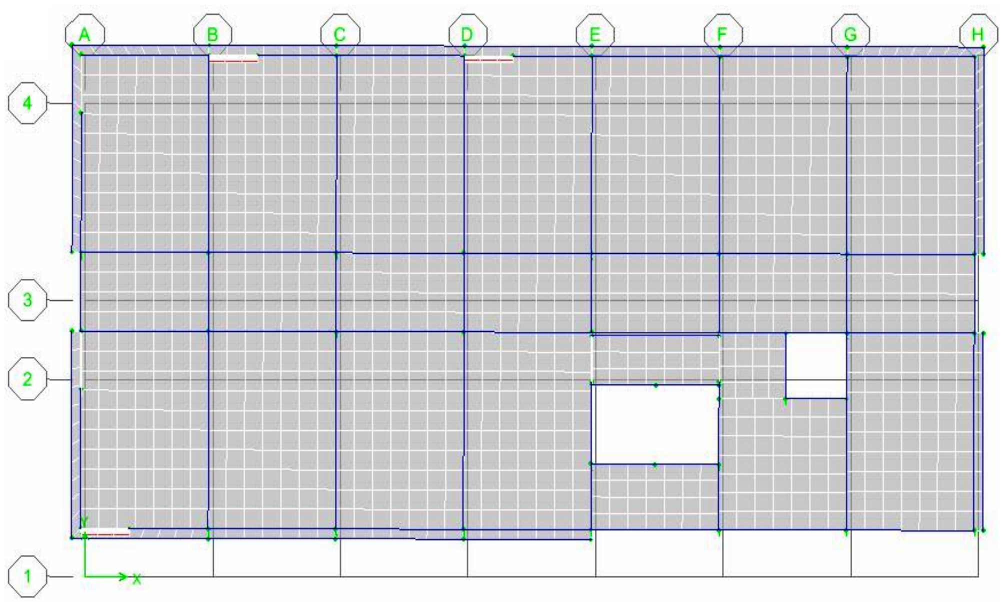

Fig. 11. *First vibration mode - doctor's degree building*

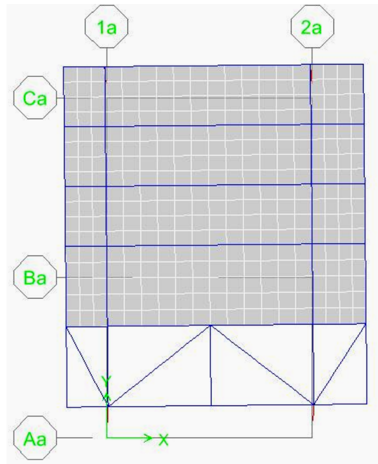

Fig. 12. *First vibration mode - Atrium building*

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