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To cite this article: M F Botiš *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **399** 012005

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SUBMIT YOUR ABSTRACT

Study on the reduction of the general / overall torsion on multi – story, rectangular, reinforced concrete structures

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Abstract: This paper researches the reduction of the general / overall torsion of multi – story, rectangular, reinforced concrete structures. The general torsion is caused by the distance (eccentricity) between the centre of stiffness and the centre of mass of the structure. During the seismic shaking of the structural systems, the inertia force acts through the centre of mass, while the resistive force acts through the centre of stiffness. Under this coupled lateral - torsional motion, structural members located along the perimeter of the buildings develop increased deformations and stresses due to buildings' twisting, which results in a higher risk of collapse (brittle, non - ductile failure, damage). This leads to the torsional behaviour of buildings, which is one of the most frequent sources of structural damage and failure during strong ground motions. This paper investigates the influence of the cross sectional properties of the structural components / members, to reduce the above mentioned effect as much as possible. The reduction of the eccentricity can be obtained by modifying cross sectional properties of some rectangular reinforced concrete walls, such as the moment of inertia (length and width of the reinforced concrete walls), which are asymmetrically arranged relative to the central reinforced concrete core. The position of these rectangular reinforced concrete walls is known. Finding the optimal height and width of these walls can be done by using a MatLab function, which minimizes the distance between the centre of stiffness and the centre of mass. The obtained results are then verified in a structural software (ETABS 2016), using modal analysis, or the mode – superposition method, to determine the mode shapes of the structure.

1. Introduction

Buildings are mainly classified into regular and irregular. Asymmetric - plan buildings, namely buildings with in - plan asymmetric mass and strength distributions, are systems characterized by a coupled torsional - translational seismic response.

Asymmetric building structures are almost unavoidable in modern construction, due to various types of functional and architectural requirements. Even in symmetric structures, the asymmetric position of the structural components (non - symmetric distributions of mass and stiffness) tends to produce an effective asymmetric structure. Such an asymmetry, even if it is small, can produce a torsional response, coupled with a translational response.



The presence of structural irregularities has an adverse effect on the seismic response of the structure. Structural irregularities can be broadly classified as plan irregularities and vertical irregularities. In the present study, the effect of plan irregularity on the seismic response of a structure is studied [1].

1.1. Plan Irregularity

The condition of being non - uniform in the plan of a structure is called plan irregularity. These can be characterized by five different types such as torsional, reentrant corners, diaphragms discontinuity, out of plane offset and non – parallel system for plan irregularity [1].

1.2. Vertical Irregularity

Structures having significant physical discontinuities in a vertical configuration or in their lateral force resisting systems are termed as vertically irregular structure. The vertical irregularities in structures are Stiffness irregularity, Mass irregularity, Vertical geometric irregularity, Discontinuity in capacity [1].

1.3. Reinforced concrete (R.C.) cores

Reinforced concrete (R.C.) cores are used in many residential multi - story buildings as the primary seismic force resisting system. To minimize the effect of the structural system on the architectural layout, shear walls often act as stairway and elevator shafts in many R.C. buildings. Seismic damage surveys and analyses conducted on modes of failure of building structures during past severe earthquakes concluded that the most vulnerable building structures are those which are asymmetric in nature [2].

The lateral - torsional coupling due to the eccentricity between the centre of mass (C.M.) and the centre of stiffness (C.S.) in asymmetric building structures (in their floor plans or along their height) generates torsional vibration even under purely translational ground shaking, with significant swaying and twisting.

During the seismic shaking of the structural systems, the inertia force acts through the centre of mass, while the resistive force acts through the centre of stiffness, as shown in figure 1 [3].

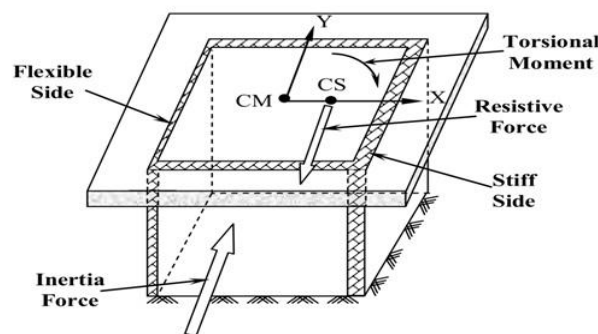


Figure 1. Generation of torsional moment in asymmetric structures during seismic excitation.

The natural eccentricity is generally defined as the distance between the centre of mass (C.M.) and the centre of stiffness (C.S.) for a considered floor, while accidental eccentricity generally accounts for factors such as the rotational component of ground motion about the vertical axis, the difference between computed and actual values of the mass and stiffness, and an unfavourable distribution of live load mass.

1.4. Types of eccentricities

The natural eccentricity is generally defined as the distance between the centre of mass (C.M.) and the centre of stiffness (C.S.) for a considered floor, while accidental eccentricity generally accounts for factors such as the rotational component of ground motion about the vertical axis, the

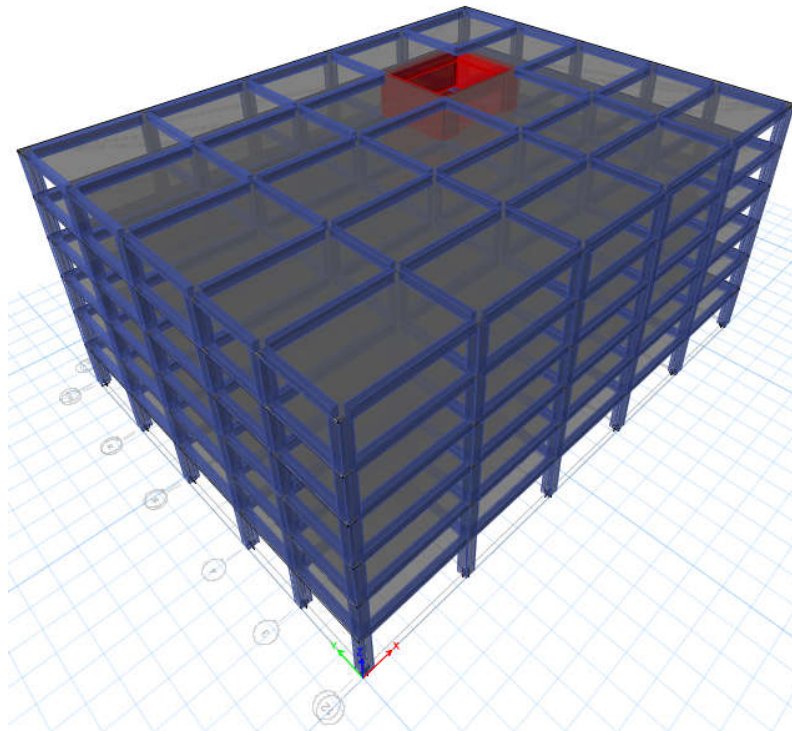


Figure 3. Isometric view of the structure “before”.

2.1. Structural data

Table 1. Structural data.

Number of stories	6
Ground story height	3.50 [m]
Intermediate story height	3.00 [m]
Total number of columns	32
Slab thickness	15 [cm]
Core wall thickness	35 [cm]
Outer wall thickness	$W_1 = 60$ [cm] $W_2 = 70$ [cm]
Beam size	$B_1 = 30 \times 65$ [cm] $B_2 = 25 \times 55$ [cm]
Column size	$C_1 = 70 \times 60$ [cm]
Grade of concrete	C 20/25
Grade of steel	BST 500S
Density of concrete	25 [kN/m ³]
Super dead load	1.3 [kN/m ²]
Live load	3.0 [kN/m ²]
Roof load	2.0 [kN/m ²]

Super dead loads are basically superimposed dead loads, which are applied on a structure; the load of any finished, partitioning, cladding, false ceiling are all super dead loads.

The live load is the load superimposed by the use or occupancy of the building, not including the environmental loads, such as wind load, rain load, earthquake load or dead load.

Table 2. Earthquake data [5].

Location, Country	Vrancea, Romania
a_g	3.924 [m/s ²]
T_c	1.0 [s]
T_B	0.20 [s]
T_D	3.00 [s]
Importance factor	1.00
Framing type	D.C.H.
Behaviour factor	6.75
Base shear coefficient, c	0.10
v	0.45
Damping	5 [%]

3. Analysis

The building is modelled in ETABS 2016; an infinite in-plane floor behaviour is assigned at every story level, as shown in figure 4. Supports are assigned as fixed supports, neglecting soil - structure interaction. A linear static analysis was performed for earthquake cases: X Dir.; X Dir. \pm Eccentricity; Y Dir.; Y Dir. \pm Eccentricity.

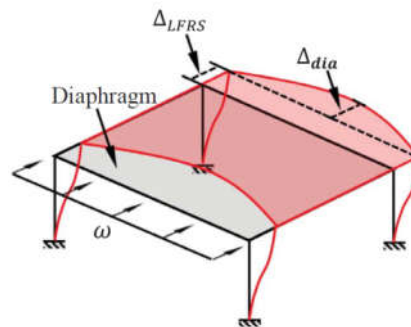


Figure 4. Prescribed diaphragm classification [6].

$$\Delta_{dia} \leq 0,50 \cdot \Delta_{L.F.R.S.} \rightarrow \text{Rigid diaphragm} \quad (1)$$

$$0,50 \cdot \Delta_{L.F.R.S.} < \Delta_{dia} \leq 2,0 \cdot \Delta_{L.F.R.S.} \rightarrow \text{Stiff diaphragm} \quad (2)$$

$$\Delta_{dia} > 2,0 \cdot \Delta_{L.F.R.S.} \rightarrow \text{Flexible diaphragm} \quad (3)$$

An infinite in - plane floor behaviour is considered for this study. In this case, its midpoint displacement, under lateral load, is less than half the average displacement of the lateral resisting system. The rigid diaphragm distributes the horizontal forces to the lateral resisting elements, in direct proportion to their relative stiffness. It is based on the assumption that the diaphragm does not deform itself and will cause each vertical element to deflect the same amount. Rigid diaphragms capable of transferring torsional and shear deflections and forces are also based on the assumption that the

diaphragm and shear walls undergo rigid body rotation, and this produces additional shear forces in the shear wall.

3.1. Analysis results

Table 3. Modal participating mass ratios “before”.

Case	Mode	Period [sec]	UX	UY	RZ	Sum UX	Sum UY	SumRZ
Modal	1	0.508	0.2387	0.2083	0.3861	0.2387	0.2083	0.3861
Modal	2	0.337	0.2822	0.4757	0.0089	0.5209	0.684	0.395
Modal	3	0.255	0.2546	0.074	0.4586	0.7755	0.758	0.8535
Modal	4	0.159	0.0535	0.0387	0.0242	0.829	0.7966	0.8777
Modal	5	0.095	0.0642	0.0959	0.0007	0.8932	0.8925	0.8784

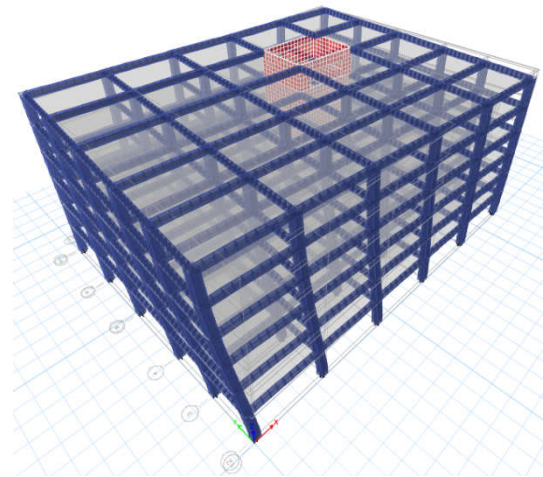
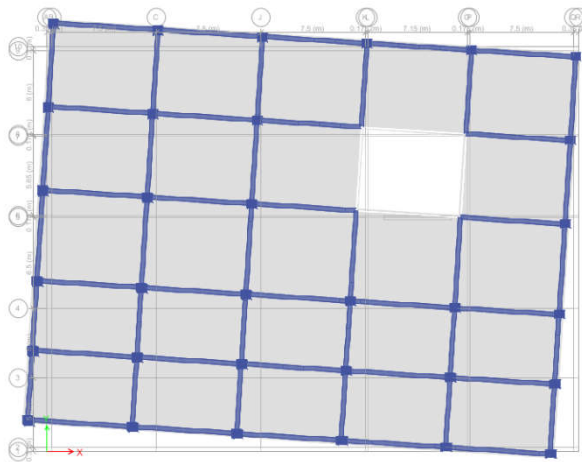


Figure 5. Mode shape 1 – $T_1 = 0.508$ s.

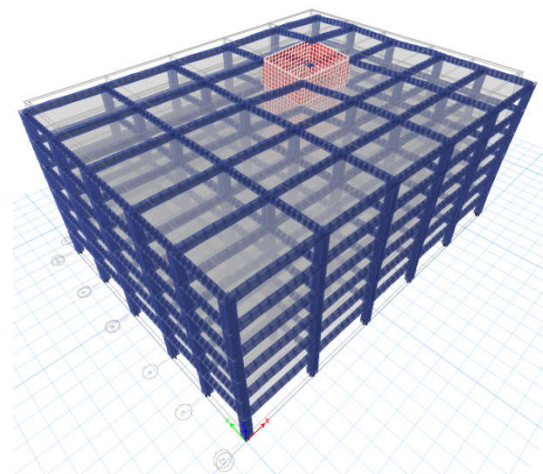
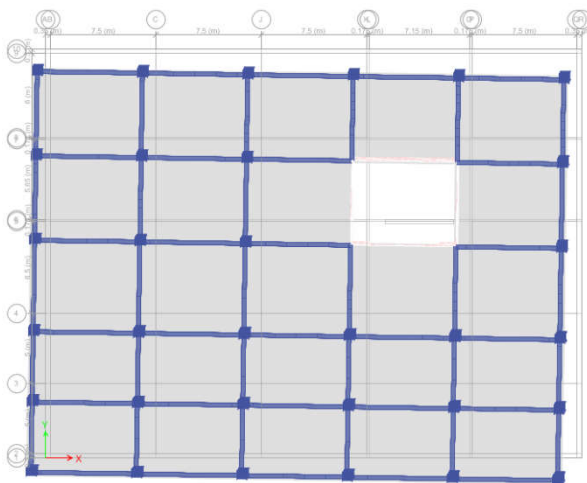


Figure 6. Mode shape 2 – $T_2 = 0.337$ s.

During this preliminary phase, the additional accidental eccentricity, according to P100 / 1 – 2013 [5], was not taken into account:

$$e_{a_i} = \pm 0.05 \cdot L_i \quad (7)$$

where:

e_{a_i} is the accidental eccentricity of the mass, at level i , relative to the calculated position of the centre of the masses, applied to the same direction at all levels.

L_i is the dimension of the floor, perpendicular to the direction of the seismic action.

$$\begin{cases} \frac{\sum_{i=1}^n A_i \cdot x_i}{\sum_{i=1}^n A_i} - \frac{\sum_{i=1}^n I_{x_i} \cdot x_i}{\sum_{i=1}^n I_{x_i}} = 0 \\ \frac{\sum_{i=1}^n A_i \cdot y_i}{\sum_{i=1}^n A_i} - \frac{\sum_{i=1}^n I_{y_i} \cdot y_i}{\sum_{i=1}^n I_{y_i}} = 0 \end{cases} \quad (8)$$

$$\begin{cases} f_1(L_1, L_2) = 21.2491 - \left(\frac{\left(\frac{0.6^3 \cdot L_1}{12} \cdot 15.35 \right) + \left(\frac{0.7 \cdot L_2^3}{12} \cdot 0.35 \right) + (41.39219 \cdot 26.60) + 7.12530}{\left(\frac{0.6^3 \cdot L_1}{12} \right) + \left(\frac{0.7 \cdot L_2^3}{12} \right) + 41.39219 + 0.37800} \right) = 0 \\ f_2(L_1, L_2) = 15.9379 - \left(\frac{\left(\frac{0.6 \cdot L_1^3}{12} \cdot 0.30 \right) + \left(\frac{0.7^3 \cdot L_2}{12} \cdot 5.30 \right) + (80.54802 \cdot 20.4569) + 7.22015}{\left(\frac{0.6 \cdot L_1^3}{12} \right) + \left(\frac{0.7^3 \cdot L_2}{12} \right) + 80.54802 + 0.51450} \right) = 0 \end{cases} \quad (9)$$

where:

L_1, L_2 are the optimal length of the reinforced concrete (R.C.) walls.

$$M(L_1, L_2) = \sum_{i=1}^2 f_i^2(L_1, L_2) = f_1^2(L_1, L_2) + f_2^2(L_1, L_2) \quad (10)$$

Using the MatLab [3] function `fminsearch('func',[1 1])`, with the initial solution vector $X_0 = [1 \ 1]$ the following solutions are obtained:

$$L_1 = 7.731 \text{ m} \cong 7.75 \text{ m}; \quad L_2 = 5.649 \text{ m} \cong 5.65 \text{ m} \quad (11)$$

To verify the results, another numerical method was used (genetic algorithm). The genetic algorithm (G.A.) is a metaheuristic method inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (E.A.). Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection.

The obtained results are:

$$L_1 = 7.736 \text{ m} \cong 7.75 \text{ m}; \quad L_2 = 5.647 \text{ m} \cong 5.65 \text{ m} \quad (12)$$

After finding the optimal length of the reinforced concrete walls, a linear static analysis was performed again to see the differences between the two models (with and without reinforced concrete walls).



Figure 8. Building plan “after”.

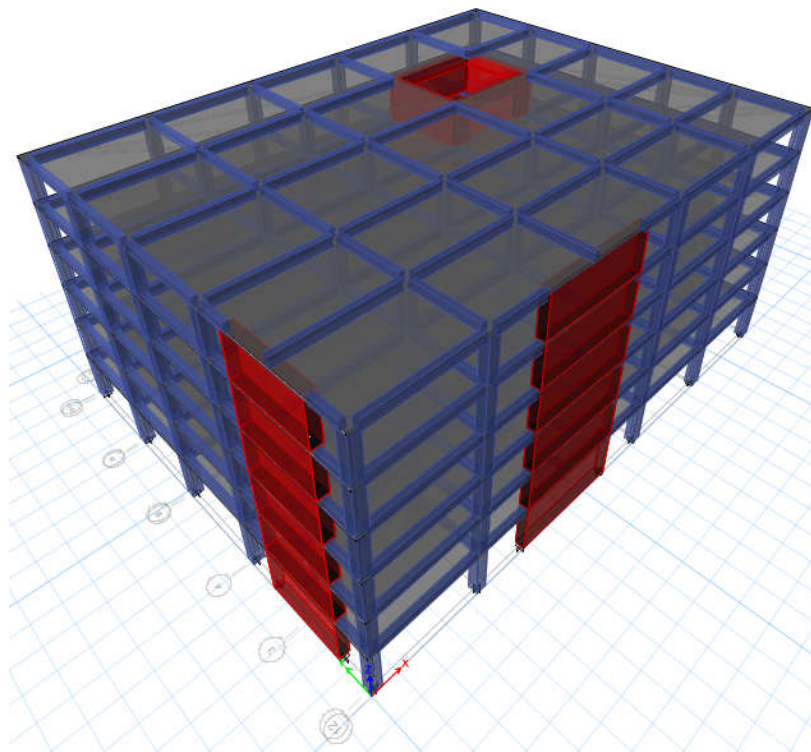


Figure 9. Isometric view of the structure “after”.

Table 4. Modal participating mass ratios “after”.

Case	Mode	Period [sec]	UX	UY	RZ	Sum UX	Sum UY	Sum RZ
Modal	1	0.304	0.0001	0.7422	0.0003	0.0001	0.7422	0.0003
Modal	2	0.270	0.7419	0.00003687	0.0109	0.742	0.7423	0.0112
Modal	3	0.228	0.0171	0.00003025	0.751	0.7591	0.7423	0.7622
Modal	4	0.079	0.0042	0.1755	0.0039	0.7633	0.9177	0.7661
Modal	5	0.075	0.1536	0.0076	0.0053	0.9168	0.9254	0.7714

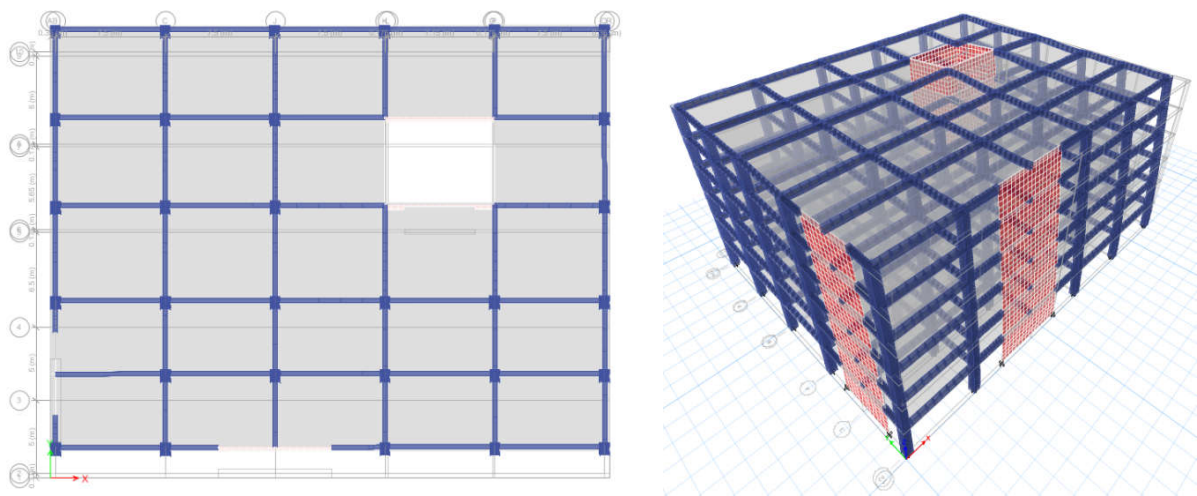


Figure 10. Mode shape 1 – $T_1 = 0.304$ s.

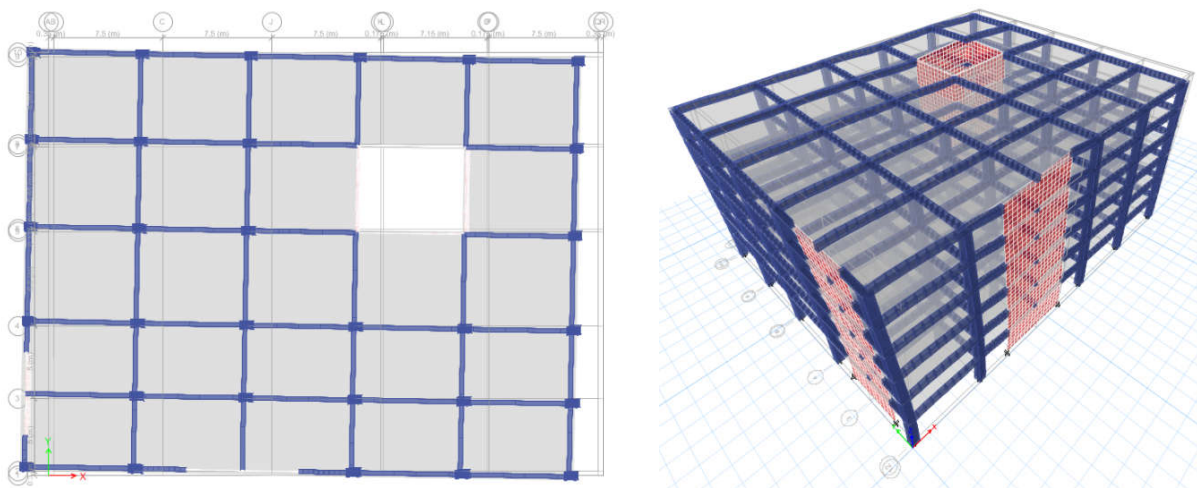


Figure 11. Mode shape 2 – $T_2 = 0.270$ s.

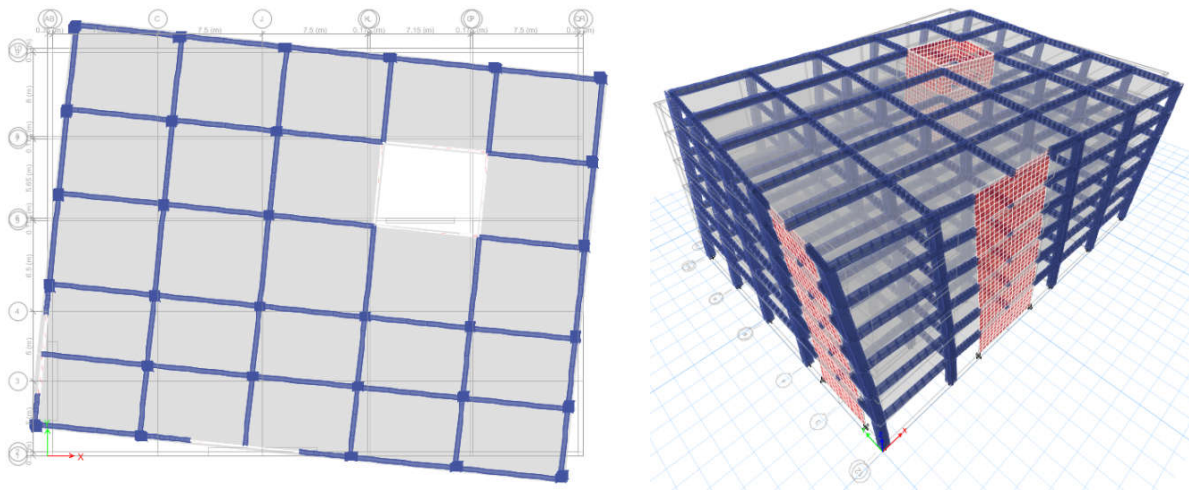


Figure 12. Mode shape 3 – $T_3 = 0.228$ s.

It is clearly visible now that, after optimizing the R.C. walls, the structure has a smooth orthogonal motion in the first two mode shapes (figure 10, figure 11) and the coupled lateral - torsional motion has been reduced to the minimum (table 5). The torsional motion appears only in the third mode shape (figure 12).

5. Conclusions

From the above mentioned results it can be seen that now the structure has a proper mode shape in the first three modes, thus preventing the coupled lateral - torsional motion, increased deformations and stresses due to buildings' twisting.

Asymmetric buildings are no longer a problem to create / design, due to this method, applied with numerical methods, as the distance between the centre of mass (C.M.) and the centre of stiffness (C.S.) can be reduced to 0.

For the structure, a much more favourable behaviour can be obtained, such as post-yield behaviour and energy dissipation when subjected to actual earthquake ground motions, but with the following important observation:

Such a building / structure must have only an elastic structural behaviour, because, in a postelastic response, if the structural walls are damaged, the whole building will get a strong torsion behaviour (and a possible structural collapse) is expected, due to the additional mass of these R.C. walls, which will not work as structural members. Hence, supplementary safety measures for the seismic structural behaviour must be applied if a post-elastic design is considered.

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