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MODAL STABILITY OF HIGH-RISE BUILDING WITH IRREGULAR PLAN CONFIGURATION UNDER SEISMIC LOADS

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ABSTRACT

The aim of this paper is to determine the optimum solution for shear wall locations based on story drift, story displacement and torsion of an irregular building by varying location of shear walls. Earthquake load is calculated as per IS: 1893-2016, the various parameters like response reduction factor, importance factor, zone factor are taken from IS: 1893-2016. The building is modelled and analyzed using ETABS software. Providing adequate number of shear walls at appropriate locations, substantially reduces the displacements due to earthquake.

Keywords— *Shear wall, Irregular Building, Centre of Rigidity, Centre of Mass, ETABS, storey drift, storey displacement and torsion*

INTRODUCTION:

To ensure safety of building, designing the building properly and overcoming the effects of lateral loads, shear walls are provided from foundation level to the over-all height of building. It resists lateral loads in its own plane and provide large lateral stiffness to the building. The efficiency of shear wall is governed by its location in a building. For an irregular shaped building, defining optimum location becomes very difficult. This is because of the fact that, the irregular shaped buildings when subjected to lateral forces triggers torsion because of their geometry. In these cases provision of shear wall in danger zones can trigger more torsion in the building. Shear walls provide resistance against lateral forces. Thus, optimum location of shear wall can only be decided by considering the torsion generated in the building during the lateral forces. The major criteria now-a-days in designing RCC structures in seismic zones, is control of lateral displacement resulting from lateral forces. Main objective of this research work is to study about the behaviour of different configurations of shear walls in irregular high-rise building based on story drift, story displacement and torsion.

THEORETICAL BACKGROUND

A. Centre of Mass (CM)

It is an assumed point in a building which has equal distribution of mass around itself in all direction. In other words, the point where the whole mass of the building is assumed to be concentrated is called centre of mass (CM).

B. Centre of Stiffness/Rigidity (CR)

Like the centre of mass, centre of rigidity (CR) is also an assumed point in a building where the resultant stiffness of the building is assumed to be concentrated.

C. Cause of torsion in building

When the centre of mass and centre of stiffness in a building do not coincide, this produces torsion. The change in the location depends on the irregularity in structure. The more are the irregularities, the more is chance of eccentricity (gap between the centre of mass and centre of stiffness). This condition is very common in irregular shaped buildings. Thus, the location of shear wall should be such that, it should not ignite more torsion in the structure. Causes of dislocation of these points –

▪ When the stiffness in one part of the structure is dominant as compared to other areas in the structure, the centre of stiffness shift towards that area, causing an eccentricity in a structure.

▪ The stiffness can increase either through introduction of shear wall or in some of the cases; the building's irregular geometry causes self-triggering of torsion when subjected to seismic forces.

PROBLEM STATEMENT & ITS SIGNIFICANCE

For determining optimum solution for shear wall locations, an actual real-life plan is chosen as a problem statement. Thus, there are no equal spaced bays as assumed generally in ideal cases. The plan has irregularity about horizontal direction as shown in fig. no.1. The location of shear walls is decided such that it satisfies structural as well as architectural requirements.

A lateral force resisting wall system is to be designed for the following conditions:

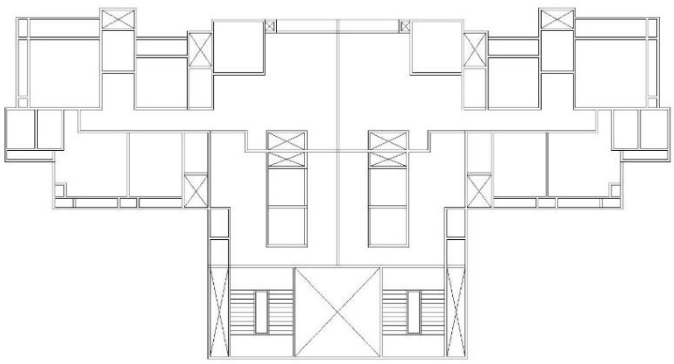

Figure 1. Plan for problem statement

- Type of structure – RCC Residential
- No. of Storey – G+15

- Floor to floor height – 3.2m
- Dead Load –
  - 1.5 kN/m^2 on all slabs
  - 3.0 kN/m^2 on sunk slabs
  - 2.5 kN/m on all beams (AAC Blockwork)
- Live Load –
  - 2 kN/m^2 on all slabs
- Earthquake Load – As per IS 1893-2016

METHODOLOGY

A. Preliminary Modelling

Considering all given data, the assumed preliminary dimensions of the structural elements are as follows:

- Plinth Beams – 230mm x 450mm
- Floor Beams – 230mm x 600mm
- Slab thickness – 125mm
- Staircase slab – 125mm
- Shear wall – 300mm x 1200mm
- Grade of Concrete – M30
- Grade of Steel – Fe500

B. Assigning Loads & Boundary Conditions

- Loads
  - Dead Load
  - Live Load
  - Earthquake Load
- Boundary Conditions
  - Pinned Base

C. Defining Mass Source

As per IS 1893-2016

- Dead Load 100%
- Live Load 25%

D. Defining Lateral Load Case

As per IS 1893-2016

- Static – Equivalent Static Method
- Dynamic – Response Spectrum Method

E. Performing Analysis

Checking model for errors if any and performing analysis.

F. Result Interpretation

Checking load transfer, understanding modal behaviour, checking storey displacements and drift. Comparing positions of centre of mass and centre of rigidity.

Notations used:

CM – Centre of Mass

CR – Centre of Rigidity

Ux – Translation in X direction

Uy – Translation in Y direction

Rz – Rotation in Z direction

G. Performing Trials

For the given plan, trials of different configuration of shear walls are performed in order to minimize eccentricity between centre of mass (CM) and centre of rigidity (CR).

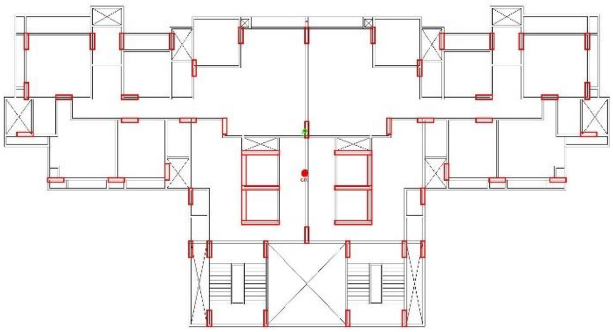

Figure 2. 1st Trial

In the 1st trial, preliminary location and sizes of shear walls required for load transfer are placed as shown in red in fig. no. 2. In this case after analysing, it is found that CR is 3.13m away from CM, downwards towards the lift core. And the modal participating mass ratios for this trial are as tabulated in table 1.

Table 1. Modal participating mass ratios for 1st Trial

Mode	**Time period (seconds)**	**Ux (%)**	**Uy (%)**	**Rz (%)**
1	1.775	17.83	0	57.66
2	1.512	57.83	0	17.54
3	1.266	0	71.88	0

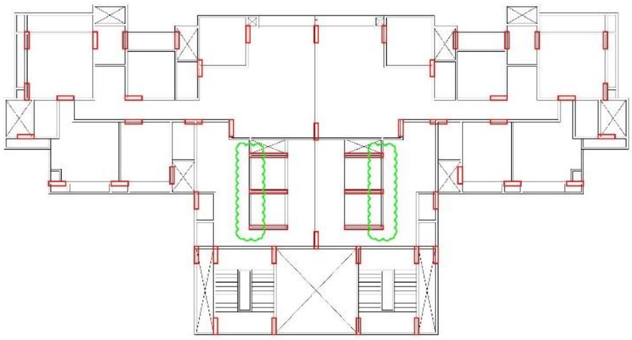

Figure 3. 2nd Trial

In the 2nd trial, in order to minimize eccentricity, the four vertical walls of lift core marked in green as shown in fig. no. 3 are removed. Removing these walls, shifts the CR towards CM. But yet there is eccentricity of 1.54m. And the modal participating mass ratios for this trial are as tabulated in table 2.

Table 2. Modal participating mass ratios for 2nd Trial

Mode	**Time period (seconds)**	**Ux (%)**	**Uy (%)**	**Rz (%)**
1	1.914	0.52	0	68.67
2	1.652	0	77.63	0
3	1.599	68.47	0	8.6

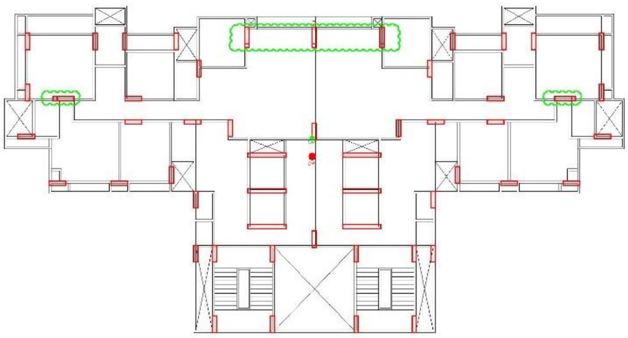

Figure 4. 3rd Trial

In the 3rd trial, the length of highlighted walls shown in fig. no.4 is changed from 1200mm to 1500mm. It is found that there is shift of CR towards CM at an eccentricity of 1.37m. And the Modal participating mass ratios for this trial are as tabulated in table 3.

Table 3. Modal participating mass ratios for 3rd Trial

Mode	**Time period (seconds)**	**Ux (%)**	**Uy (%)**	**Rz (%)**
1	1.904	7.8	0	69.45
2	1.642	0	77.53	0
3	1.588	69.17	0	7.85

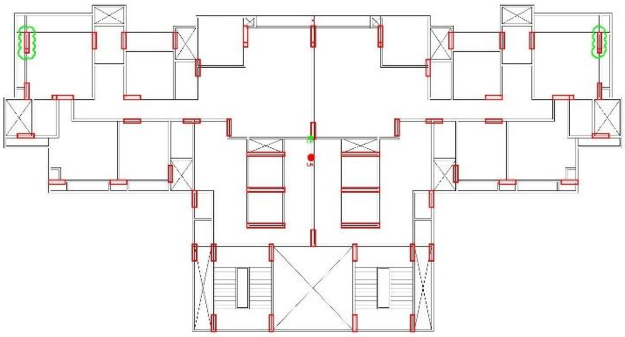

Figure 5. 4th Trial

In the 4th trial, the highlighted walls shown in fig. no.5 of 1200mm are made 1500mm. But the CR does not move towards CM and is same as in 3rd trial, so this trial failed. Thus, this change in length is discarded in the next trial. And the Modal participating mass ratios for this trial are as tabulated in table 4.

Table 4. Modal participating mass ratios for 4th Trial

Mode	Time period (seconds)	Ux (%)	Uy (%)	Rz (%)
1	1.872	10.25	0	66.54
2	1.63	0	77.34	0
3	1.58	66.84	0	10.19

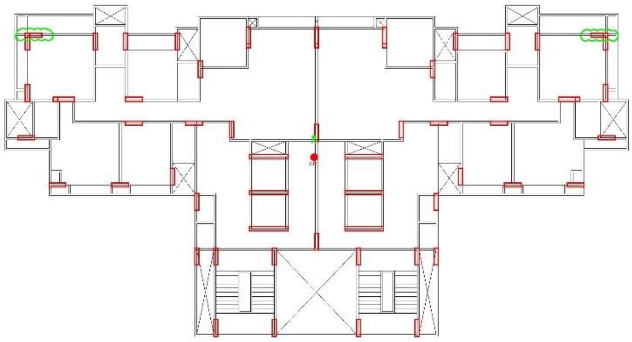

Figure 6. 5th Trial

As the 4th trial failed, next trial is continued taking the 3rd trial into consideration. In the 5th trial, the change in shape is done by introducing L-shaped sections at highlighted locations as shown in fig. no. 6 to resist torsion. It is found that there is significant change in the modal participating mass ratios which are tabulated in table 5.

Table 5. Modal participating mass ratios for 5th Trial

Mode	Time period (seconds)	Ux (%)	Uy (%)	Rz (%)
1	1.775	0	77.53	16.83
2	1.616	56.66	0	10.5
3	1.57	10.19	0	66.64

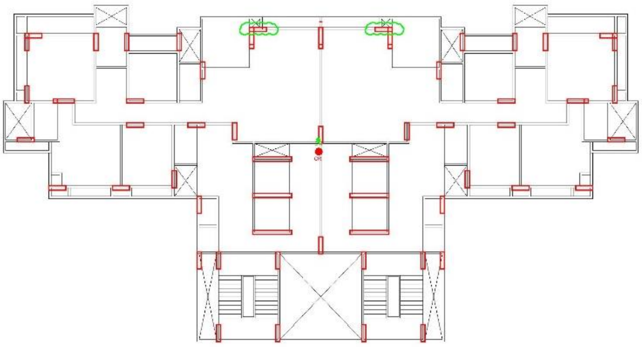

Figure 7. 6th Trial

Introduction of L-shaped sections seems to be better option hence, in the 6th Trial, two more L-shaped sections are introduced as shown in fig. no. 7 and it is found that there is shifting of CR, now at an eccentricity of 0.84m. And the modal participating mass ratios for this trial are as tabulated in table 6.

Table 6. Modal participating mass ratios for 6th Trial

Mode	**Time period (seconds)**	**Ux (%)**	**Uy (%)**	**Rz (%)**
1	1.73	0	67.47	8.8
2	1.608	62.68	0	5.64
3	1.555	4.3	0	72.83

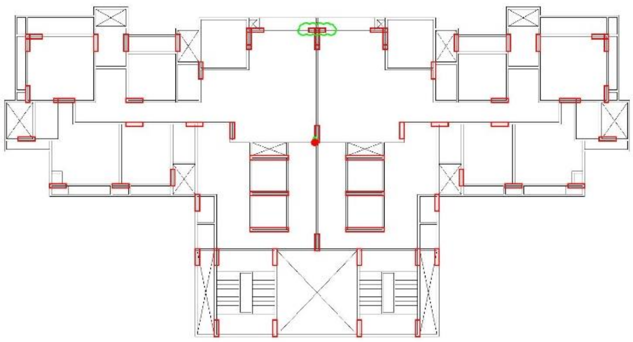

Figure 8. 7th Trial

In the 7th Trial, a T-shaped section is introduced as shown in fig. no. 8. It is found that CM and CR almost coincides. Thereby, achieving zero eccentricity. The modal participating mass ratios for this trial are as tabulated in table 7.

Table 7. Modal participating mass ratios for 7th Trial

Mode	**Time period (seconds)**	**Ux (%)**	**Uy (%)**	**Rz (%)**
1	1.689	0	77.42	0
2	1.605	77.01	0	0
3	1.515	0	0	77.04

RESULTS AND DISCUSSION

The results of storey displacement at roof level under seismic loads acting in both directions are tabulated as follows:

Table 8. Storey Displacement in X Direction due to RSX (mm)

Model no.	1	2	3	4	5	6	7
Roof level	905	1008	994	985	929	876	765

Table 9. Storey Displacement in Y Direction due to RSX (mm)

Model no.	1	2	3	4	5	6	7
Roof level	832	705	670	726	598	367	16

Table 10. Storey Displacement in X Direction due to RSY (mm)

Model no.	1	2	3	4	5	6	7
Roof level	0.01	0.05	0.04	0.04	0.04	0.04	0.2

Table 11. Storey Displacement in Y Direction due to RSY (mm)

Model no.	1	2	3	4	5	6	7
Roof level	567	914	903	892	875	866	863

Table 12. Modal participating mass ratios for the Final Trial

Mode	**Time period (seconds)**	**Ux (%)**	**Uy (%)**	**Rz (%)**
1	1.689	0	77.42	0
2	1.605	77.01	0	0
3	1.515	0	0	77.04

As per IS 1893-2016, for achieving modal stability, the first two modes shall be translational and the third shall be rotational, which is achieved in the 7th trial.

Since actual real-life plan is chosen for the research, achieving true behaviour is possible. Generally, cut outs are not considered in ideal cases. But cut outs in the plan have a considerable effect in torsion.

The location of the shear wall which results in reduction of torsional forces as well as the storey displacements is termed as the optimum location. If the location only exhibits reduction in displacement but produces huge torsion, that will not be considered as an optimum location. From the comparative analysis, it is found that trial model no. 7 is best in resisting both lateral displacement and torsion effects in the building. It is observed that number of shear walls required were less if they are correctly positioned and located. Thus, reducing amount of concrete, dead load and cost of construction.

CONCLUSION

It can be concluded that shear walls are very important in high rise buildings in resisting lateral forces. But placing of shear wall at adequate locations is more significant in case of base shear and displacement. If the location of shear wall is such that it causes an increase in torsional forces, it becomes the biggest enemy of the structure. Thus, one has to place the shear walls such that centre of mass and centre of stiffness of the structure should be as close as possible. It is possible that, some configuration of shear walls can cause huge reduction in lateral displacements but it can also trigger huge amount of eccentricity which in turn cause torsional forces in the structure. Thus, a balance has to be set up in the configuration of shear such that both the lateral forces along with torsion are eliminated at a greater extent. Also, simply increasing dimensions and no. of shear walls does not work every time. Optimality is achieved by correctly positioning and locating the shear walls and sometimes by decreasing no. of unwanted shear walls.

SCOPE OF WORK

During this research the plan selected was irregular only about horizontal axis. Same process can be done for plans showing irregularity about both axes. The behaviour of the proposed systems in seismic areas can be investigated in depth using advanced nonlinear analysis.

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