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ANALYSIS AND DESIGN OF RC UNSYMMETRICAL MULTISTOREY BUILDING HAVING SOFT STOREY

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Abstract - Due to the tremendous destructions of buildings after earthquakes in past few decades, there is the need to evaluate and improve the seismic performance of multistoried reinforced concrete buildings. There are several numbers of factors affecting the behavior of building. Stiffness irregularity in vertical direction is one of them, as a result of which soft storey is formed. As per the latest seismic code IS 1893:2016, minimum 2% of plan density of shear walls should be available to resist earthquake force smoothly. In this paper, a parametric study is performed on unsymmetrical multi storey building with soft first storey, located in seismic zone III by considering different percentage of plan densities of shear walls at various locations. It is intended to describe the performance characteristics such as stiffness, displacement, drift etc. The study is carried out on a building with the help of different models considering various methods for improving the seismic performance of the building with soft first storey. The response spectrum analysis is carried out on all the 3D model using the software ETABS 2017 and the comparison of these models are presented. Also, the effect of torsion in the analysis of buildings is studied.

Key Words— soft storey; shear wall; response spectrum analysis; torsion

INTRODUCTION

Due to the increasing population since the past few decades, car parking space for residential apartments in populated cities is a major problem. So that the constructions of multistoried building with open first storey is a common practice in the world. Hence the trend has been to utilize the ground storey of the building itself for parking or reception lobbies in the first storey. These buildings have no infill masonry walls in the ground storey, but all the upper storeys have masonry infill walls are called “soft first storey or open ground storey building.

A. General Behavior of Soft Storey

The presence of infill walls in the upper storeys of the building makes them much stiffer than the open ground storey. Thus, all the upper storeys of the building move together as a single block, and most of the horizontal displacement of the building occurs in the open ground storey itself. In common, this type of buildings can be explained as a building on chopsticks. Thus, such type of buildings swing back-and-forth like inverted pendulums during earthquake shaking and the columns in the open ground storey are severely stressed. If the columns are weak i.e. do not have the required strength to resist these high stresses or if they do not have adequate ductility, they may be severely damaged which may even lead to collapse of the building. Therefore it is required that the ground storey columns have sufficient strength and adequate ductility. The vulnerability of this type of buildings is attributed to the sudden lowering of lateral stiffness and strength in ground storey, compared to upper storey with infill walls. A bare frame is much less stiffer than a fully infilled frame, it resists the applied lateral load through frame action and shows well-distributed plastic hinges at failure but when, frame is fully infilled, truss action is introduced. A fully infilled frame structure shows lesser inter storey drift, although it attracts higher base shear (due to increased stiffness).

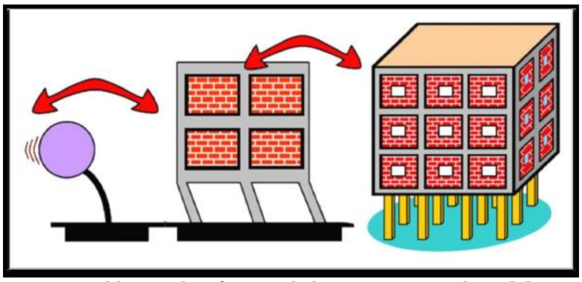

Fig.1. Building with soft storey behaving as inverted pendulum

B.Causes of Torsional Motion

The dynamic forces that act on structure during an earthquake are related to inertia and act through centre of mass. These inertia forces are resisted by elastic forces in the lateral load resisting elements whose resultants pass through centre of resistance. If the resisting element in the building are so distributed that the centre of resistance (CR) do not coincide with the centre of mass (CM), lateral seismic forces causes torsional motion in the structure. Structures with non coincident centre of mass and resistance are referred to as asymmetric structures and torsional motion induced in them is referred to as natural torsion.

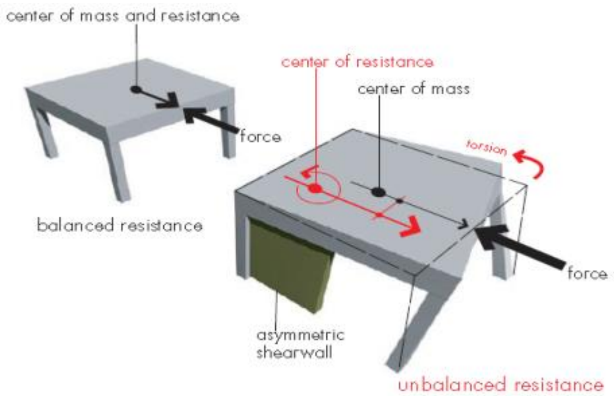

Fig.2. Generation of torsional moment in asymmetric structures during seismic excitation

C. Revisions in IS 1893 (Part I)-2016 for Design of Soft Storey

Clause 7.10.1-Open ground storey buildings shall be provided with

1-RC Structural walls, or

2-Braced Frames, in selected bays of the building.

Clause 7.10.2-When RC Structural walls are provided, they shall be,

1-founded on properly designed foundations;

2-continuous preferably over the full height of the building; and

3- Connected preferably to the moment resisting frame of the building.

Clause 7.10.3-When the RC structural walls are provided, they shall be designed such that the building does NOT have;

1- Additional torsional irregularity in plan than that already present in the building. In assessing this, lateral stiffness shall be included of all elements that resist lateral actions at all levels of the buildings;

2- Lateral stiffness in open storey is less than 80% of that in the storey above;

3- Lateral strength in the open storey is less than 90% of that in the storey above.

Clause 7.10.4-When the RC structural walls are provided, the RC structural wall plan density ρ_{sw} of the building shall be at least 2% along each principal direction in seismic zones III, IV, and V. These walls shall be well distributed in the plan of the building along each plan direction RC structural wall.

D. IS Code Provisions for Torsion: IS 1893(Part-1):2016 (Clause 7.8)

Clause7.8.1-Provision shall be made in all buildings for increase in shear forces on the lateral force resisting elements resulting from twisting about the vertical axis of the building, arising due to eccentricity between the centre of mass and centre of resistance at the floor levels. The design forces calculated as, shall be applied at the displaced centre of mass so as to cause design eccentricity between the displaced centre of mass and centre of resistance.

Clause7.8.2-Design Eccentricity

While performing structural analysis by the seismic coefficient method or the response spectrum method the design eccentricity *(edi)* to be used at the floor *i* shall be taken as

$$edi = 1.5\ esi + 0.05\ bi$$

$$= esi - 0.05\ bi$$

Whichever gives the more severe effect on lateral force resisting elements;

where,

esi= static eccentricity at floor i

=distance between centre of mass and centre of resistance, and

bi=floor plan dimension of floor i, perpendicular to the dimension of force

The factor 1.5 represents dynamic amplification factor, and 0.05bi represents the extent of accidental eccentricity. The above amplification of 1.5 need not be used when performing structural analysis by Time History Method.

II. MODELING, DESIGN AND ANALYSIS

The study is carried out on unsymmetrical reinforced concrete frame buildings with open first storey and external brick infill walls in the upper storeys. The plan of the building is shown in figure.3. The building considered is G+9 storey residential building, of which first storey is kept open for parking. The building has non-uniform column spacing in both directions. The columns provided are square columns and plan dimension of the building is 15m x 9m. Height of each storey is kept 3.0m

In this paper, the unsymmetrical multi storey building of G+9 Storey is modeled in six different configurations.

Model 1: Bare frame Building without strut and shear wall.

Model 2: Building with equivalent strut and without shear wall.

Model 3: Building with equivalent strut and 0.88 % plan density of shear walls provided up to the top of soft storey only.

Model 4: Building with equivalent strut and 2 % plan density of shear walls provided up to the top of soft storey only.

Model 5: Building with equivalent strut and 0.88 % plan density of shear walls provided in full height of building.

Model 6: Building with equivalent strut and 2 % plan density of shear walls provided in full height of building.

TABLE1 BUILDING DESCRIPTION

Plane dimensions	15m x 9m
Total height of building	31.5 m
Height of parapet	1m
Depth of foundation	1.5m
Size of beams	230x450 mm
size of columns	450x450 mm
thickness of slab	150 mm
Thickness of external walls	230 mm
Seismic zone	III
Soil condition	Medium
Response reduction factor	5
Importance factor	1.2
Floor finishes	1.875 kN/m^2

Live load at all floors	3 kN/m^2
Grade of Concrete	M30
Grade of Steel	Fe500
Density of Concrete	25 kN/m^3
Density of brick masonry	20 kN/m^3

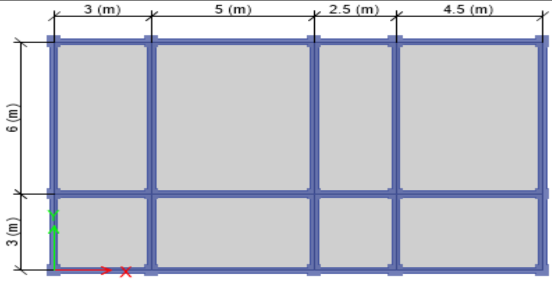

Fig.3. Plan of the building

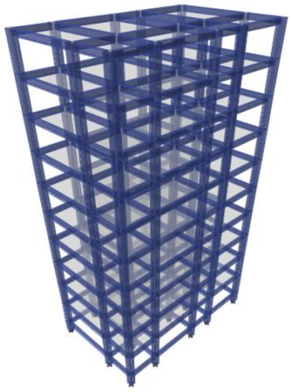

Fig.4. Three Dimensional view of the building

A. Calculation of Design Eccentricity

The values of centre of mass and centre of rigidity for various floors are collected from ETABS. The static eccentricity is calculated from difference between centre of mass and centre of rigidity. The design eccentricity is calculated from equations given in IS 1893: 2016 (part 1) clause 7.8.2. Calculated design eccentricity is override to the rigid diaphragm in ETABS for respective lateral loading cases.

III. RESULTS AND DISCUSSION

Analysis of the different building models is carried out for earthquake zone III. Comparison of different performance characteristics is made to check the performance of soft storey buildings and building having various plan densities of shear walls as an improving measure. Response Spectrum Analysis is carried out on all the six models using the software ETABS 2017 and results are discussed.

A. RESULTS AND DISCUSSION WITHOUT CONSIDERATION OF TORSION

1) Lateral Displacement

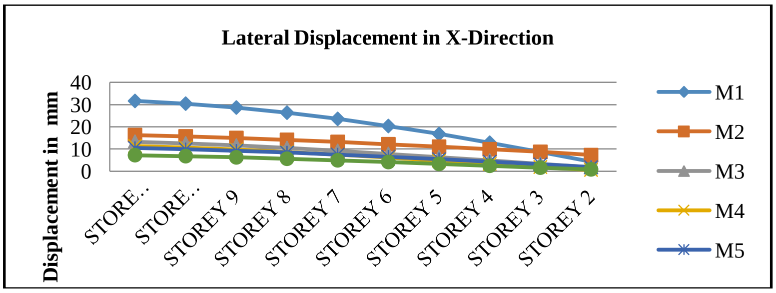

Fig.5. Displacement profile in longitudinal direction

From the displacement profile, it is observed that large displacement occurs in case of the bare frame (model 1). In the case of model 2 i.e. when the infill walls are modeled as an equivalent strut approach, there is a significant reduction in the top storey displacement as compared to model 1 by 48 %. Introduction of different percentage of plan densities of reinforced concrete shear walls at certain locations reduces the displacement to much extent. In the case of 0.88% plan density of shear wall up to soft storey (Model 3), there is a reduction in the top storey displacement up to 58%. In the case of 2% plan density of shear wall up to soft storey (Model 4), there is a reduction in the top storey displacement up to 64%**.** In case of 0.88% plan density of shear wall in full height of the building (Model 5), there is a reduction in the top storey displacement up to 67%. In the case of 2% plan density of shear wall in full height of the building (Model 6), there is a reduction in the top storey displacement up to 77%,. Maximum reduction in top storey displacement is achieved in the case of 2% plan density of shear wall in full height of the building. Storey displacement of all the models are within the permissible limits. Nearly the same percentage of reduction in displacement is observed in the transverse direction also.

2) Storey Drift

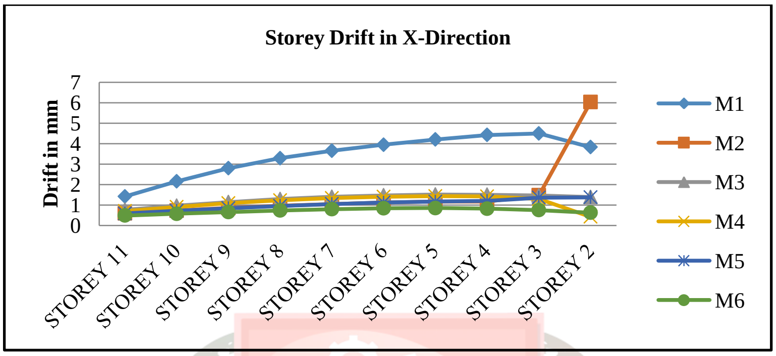

Fig.6. Drift profile in longitudinal direction

From the graph, it is found that storey drift is maximum for model 1. In case of model 2 i.e. when infill walls are modeled as an equivalent strut approach there is an increment in the drift at the soft storey as compared to model 1 by 57% in longitudinal directions .By this, we can comment that we must consider the stiffness of infill walls while doing analysis. Introduction of different percentage of plan densities of reinforced concrete shear walls at certain locations reduces storey drift about 67-90%. Maximum reduction in storey drift is observed in the case of 2% plan density of shear wall up to the top of soft storey (Model 4) i.e. about 90%. Storey drift of all the models are within the permissible limits.

3) Area of Reinforcement

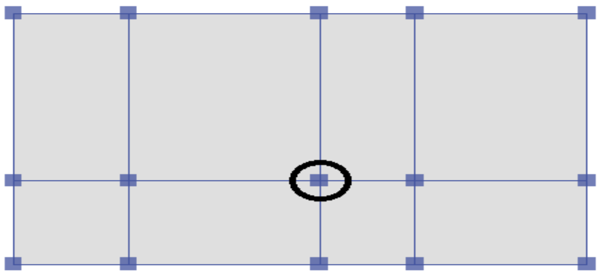

Fig.7. Internal column considered for comparison

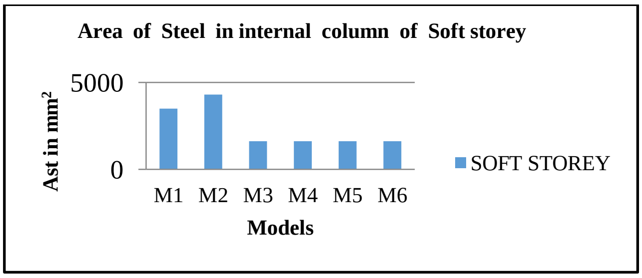

Fig.8: Comparison of maximum area of reinforcement in internal column

The area of reinforcement of the internal column increases when infill walls are modeled as an equivalent strut approach i.e. model 2. The use of the different percentage of plan densities of reinforced concrete shear walls at certain locations reduces the area of reinforcement of the internal column. In the case of 0.88% plan density of shear wall up to the top of the soft storey, area of reinforcement is reduced to the minimum percentage i.e. 0.8% as compared to model 1 and model 2.

B. RESULTS AND DISCUSSION WITH CONSIDERATION OF TORSION

Model I: - Bare Frame Building without Strut and Shear Wall

1) Lateral Displacement

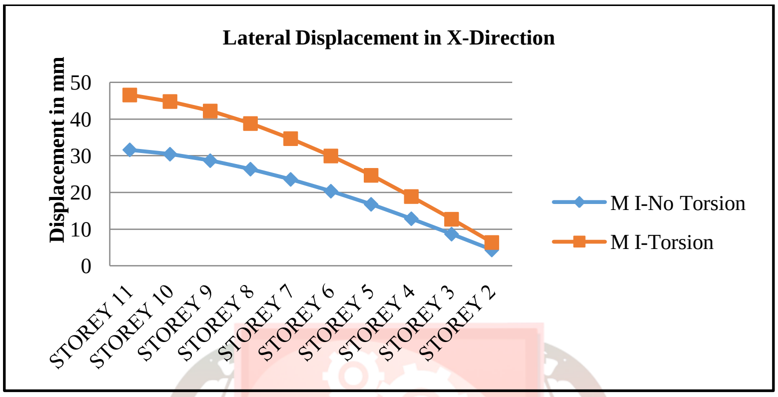

Fig.9. Displacement profile in longitudinal direction

2) Storey Drift

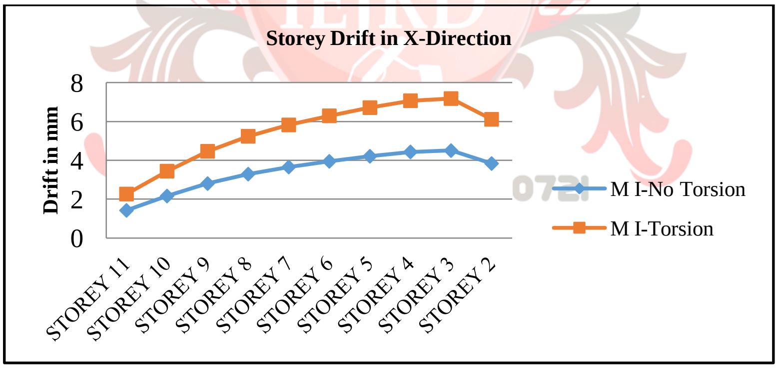

Fig.10. Drift profile in longitudinal direction

3) Area of Reinforcement

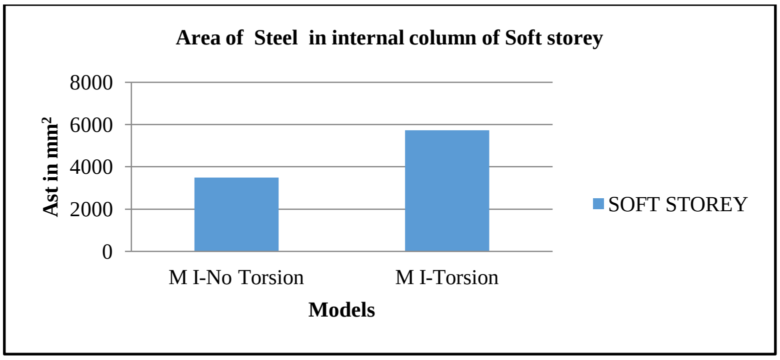

Fig.11. Comparison of maximum area of reinforcement in internal column

Model II: - Building with Equivalent Strut and without Shear wall.

1) Lateral Displacement

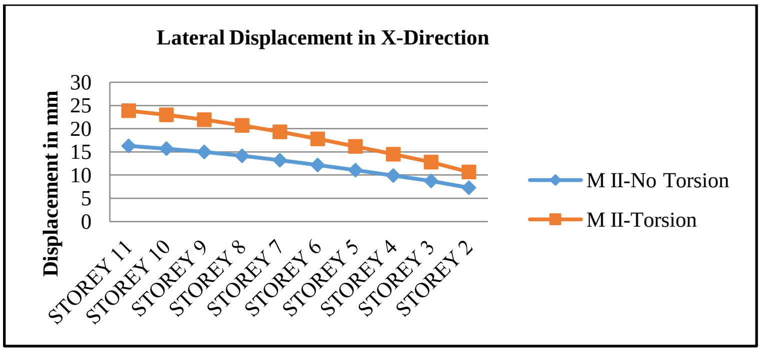

Fig.12. Displacement profile in longitudinal direction

2) Storey Drift

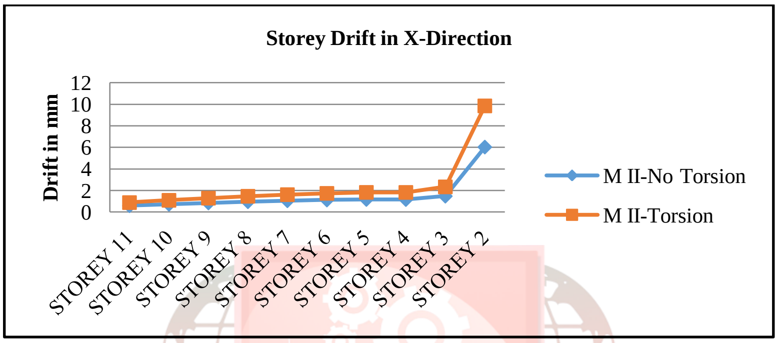

Fig.13. Drift profile in longitudinal direction

3) Area of Reinforcement

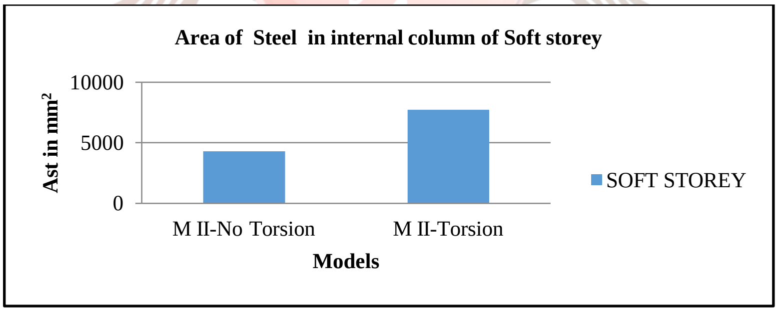

Fig.14. Comparison of maximum area of reinforcement in internal column

Model III: - Building with Equivalent Strut and 0.88 % plan density of Shear Walls provided up to soft storey only.

1) Lateral Displacement

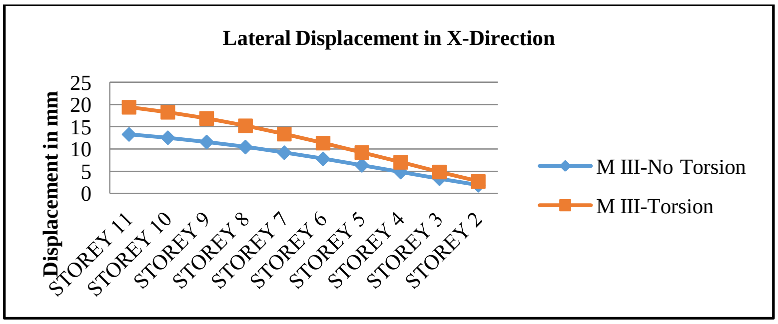

Fig.15. Displacement profile in longitudinal direction

2) Storey Drift

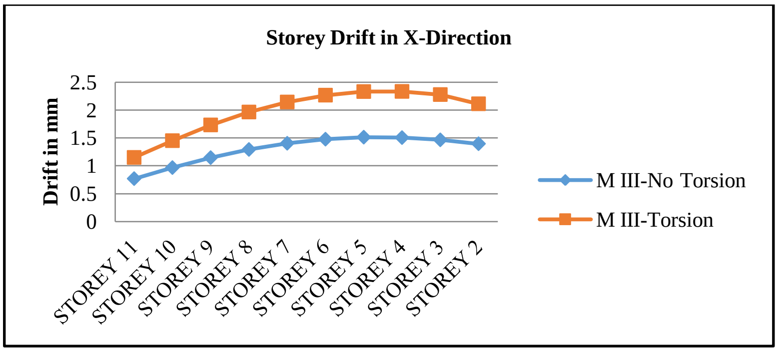

Fig.16. Drift profile in longitudinal direction

3) Area of Reinforcement

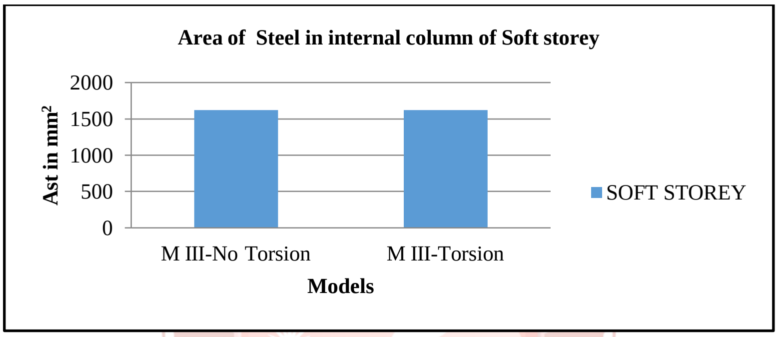

Fig.17. Comparison of maximum area of reinforcement in internal column

From the above graphs, it is observed that if the effect of torsion is considered in the analysis, the lateral displacement, storey drift increases in all the three models. The area of reinforcement increases in model I and model II but the area of reinforcement does not changes in model III, in which the building has outer diagonal struts and 0.88% plan density of shear wall up to the top of soft storey.

IV. CONCLUSIONS

Based on the analysis results, the following conclusions are drawn:

- As per IS 1893(part I)-2016, 2% plan density of shear wall up to full height of the building is preferred, but from study it is observed that building with less than 2% plan density of shear wall and up to the top of the soft storey is also sufficient.
- Lateral displacement, Storey drift and Area of reinforcement in the columns are also get reduced in the building with the addition of shear walls.
- The use of masonry infill walls as an equivalent struts approach is also found effective in reducing lateral displacement and drift of the building.
- There is increase in lateral displacement and Storey drift of the building while considering torsion effect.
- Buildings with no shear walls, required more area of reinforcement in the columns as compared to the buildings with shear walls, while considering torsion effect.
- From the study, it is concluded that effect of torsion must be considered while designing the buildings.

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