Seismic Analysis of Asymmetrical Multi-storeyed R.C. Structures Using Shear Wall in Severe Seismic Zones as Per Is 1893:2016

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Abstract— Shear walls have very high in-plane stiffness and strength, which can be used to simultaneously resist large horizontal loads and support gravity loads, making them quite advantageous in many structural engineering applications. Structures must perform safely when subjected to numerous types of loading while still remaining aesthetic and fully functional. The nature of shear wall design in building structures is a difficult task, particularly if one wants to place the shear walls in such a way that the cost is minimal while still satisfying specific performance objectives when subjected to natural and human-induced loads. This study was conducted to study the effects of shear wall in the multi-storey buildings for different height, study on nodal displacement and storey drift of the building for different cases been carried out. Nodal displacement of stories and storey drift under consideration were evaluated using structural analysis software in accordance with IS 456:2000, IS 1893:2016 and IS 13920. Structures with asymmetric distribution of mass and stiffness undergoes torsional motions during earthquake. The performance of the structures is assessed as per the procedure prescribe in IS 1893:2016. To assess the seismic effect on the structures in the present study, different models with regular and plan irregularities were prepared and analyzed using Etabs 2018 software. For the purpose of study, regular and irregular buildings of G + 12 storeys with same columns sizes subjected to gravity loads and seismic loads are analysed using linear static analysis.

Keywords: Torsional Irregularity, Plan Irregularity, Base Shear, Drift, Displacement, IS 1893 – 2016, ETABS 2018

I. INTRODUCTION

Almost 80% of about 1 million deaths turn out to have been caused by just ten great earthquakes, together affecting a tiny proportion of the territory at risk from heavy ground shaking.

Is my building safe against earthquakes? This is a question that everybody should be concerned about. Many earthquakes have taken place recently in India and its neighborhood [e.g., Uttarkashi (1991), Latur (1993), Jabalpur (1997), Bhuj (2001), Sumatra and Andaman Islands (2004), Kashmir (2005)] (Fig.- 1.1 & 1.2) , and these have proved to be disastrous. A large number of buildings have collapsed and countless lives have been lost. There is usually a huge public outcry after every disaster. But public memory is short lived, and people tend to forget, until another major tremor occurs to wake them up. When and where will that quake happen? Nobody can predict this. But when it comes one day, unexpectedly, it destroys our buildings and takes our lives.

A. *Shear Walls*

One of the most popular methods of strengthening of seismically deficient structure is to provide shear walls. “Shear walls” are defined as vertically oriented wide beams that carry earthquake loads to the foundation. These are slender vertical cantilever RC walls resisting the lateral load with or without frames. RC walls are often introduced into multistory buildings at certain locations to resist lateral forces when frame systems alone are insufficient. The term “shear wall” covers elevator shafts, stairwells and central core units, in addition to plane walls. Shear walls acting with frames increase the rigidity for lateral load resistance. When walls are situated in advantageous position in a building, they can be very efficient in resisting lateral loads originating from wind or earthquake.

Analysis for lateral loads of buildings containing shear walls is generally carried out by assigning all lateral loads to the shear walls, since it is felt that the very big difference in stiffness between the shear walls and the frame would cause the shear walls to attract the total lateral loads. Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with sufficient amount of walls that were not specially detailed for seismic performance (but had enough well-distributed reinforcement) were saved from collapse. Shear walls are easy to construct because reinforcement detailing of walls (Shown in Fig.- 1.11) is relatively straight-forward and therefore easily implemented at site. The general method of providing a shear wall is to fill the gaps between columns of the moment resisting frame with partial or complete reinforced concrete wall is termed as Internal Shear Wall (Buttress Wall).

B. *Torsional Irregularity*

Torsion irregularity is one of the primary failure reasons in buildings during a strong dynamic excitation due to earthquakes or wind gusts. Such irregularity does not only have devastating effects in the torsional direction but also leads to excessive destructive effects in the lateral directions. Therefore, ignoring the torsional irregularity in the seismic design analysis can cause unexpected damages and losses. To enhance the safety and performance of the buildings, most of the current seismic provision deals with this irregularity with two main ways. The first is computing torsional moment at each floor by using equations provided in various current seismic code provisions. After they are applied on each floor, the seismic analysis will be performed. The second is shifting the center of mass (CM) or stiffness (CS) to eliminate the eccentricity by putting additional masses, adding structural components such as braced frame systems or applying control systems on the structures, which can be passive or active.

Torsional responses in structures arise from two sources mainly. Eccentricity in the mass and stiffness distributions, causing a torsion response coupled with translation response. Wherein the torsion arises from accidental causes, including uncertainties in the masses and stiffness, the differences in coupling of the structural foundation with the supporting earth or rock beneath and wave propagation effects in the earthquake motions that give a torsion input to the ground, as well as torsion motions in the earth itself during the earthquake.

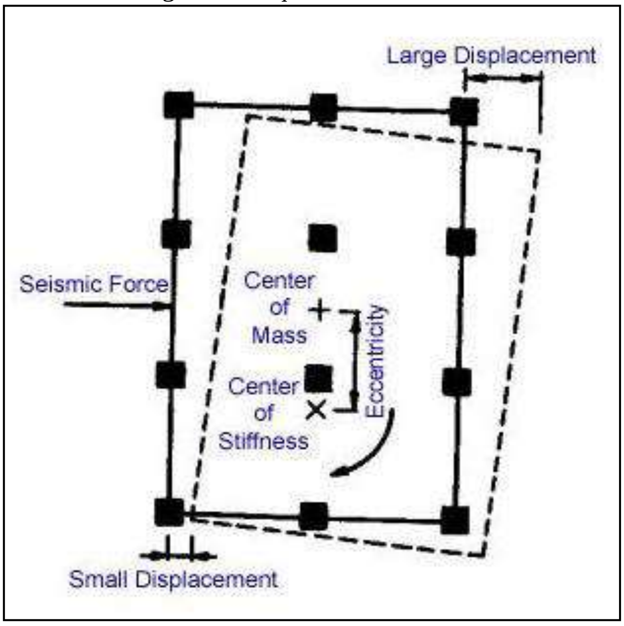


Fig. 1: Torsional Movement of Building

Eccentricity is another important criterion for the assessment of torsion. In order to design buildings in earthquake prone regions, seismic codes present different torsional provisions according to the seismicity of the region. Seismic provisions introduce design eccentricity to estimate the value of the torsion in buildings as accurately as possible. The dynamic eccentricity results from the irregular mass, resistance or stiffness distribution of the system, while the accidental eccentricity is expected to account for factors not explicitly considered, such as uncertain estimation of the mass, stiffness and rotational component, which is believed to play a highly important role. This accidental eccentricity, which is a fraction of the plan dimension, is considered in design to be on either side of the centre of stiffness. The design eccentricity e_{di} to be used at floor is prescribed as,

$$e_{di} = 1.5e_{si} + 0.05b_i$$

$$e_{di} = e_{si} - 0.05b_i$$

whichever of these gives the more severe effect in the shear of any of the frame where; esi = Static eccentricity at floor i defined as the distance between centre of mass and centre of rigidity, and bi = Floor plan dimension of floor i, perpendicular to the direction of force.

The torsional irregularity is an important parameter which measures the extend of torsion effect on the structures. It can be interpreted as the ratio of maximum drift to the average drift of the individual story. Torsional irregularity should be considered when maximum story drift at one end of the structure transverse to an axis is more than 1.5 times the minimum story drift (or inter-story drifts) at the two ends of the structure. Δmax and Δmin are the story drift (or inter-story drifts) at the two ends of the structure respectively, then θ is the parameter criterion for torsion.

$$\theta = \Delta max / \Delta min$$

θ is calculated considering not only actual eccentricity. It is not convenient for engineers to determine θ at the beginning of the design. θ must be calculated through the global analysis of structure. The relative eccentricity is usually considered as the important factor influencing torsion effects.

II. Objectives of the Study

With requirement of high infrastructure increasing day by day, more amounts of high rise structures have been designed and analyzed. The research works were undertaken with various issues related to seismic analysis of such structures in severe seismic zones. Regarding to such studies, following objectives have been taken in this study to overcome the problem -

- To understand the behaviour of irregular building subjected to lateral loading with the help of time period, frequency, modal mass participating ratio and the magnitudes of stress resultants.
- To study the structural response for torsion-al irregularities.
- To determine the structural response under seismic loading using shear walls with the same cross sectional area at different locations.
- To determine optimum position of shear walls by taking irregular building plan.
- To calculate the design lateral forces on irregular buildings using response spectrum analysis and to compare the results of different structures.
- To calculate the response of buildings subjected to various types of ground motions namely low, intermediate and high frequency ground motion using Response spectrum analysis and to compare the results.
- To accomplish a comparative knowledge on the various seismic parameters for the different forms of reinforced concrete moment resisting frames (MRF) with varying number of stories, configuration and types of irregularity.
- Now a day, complex shaped buildings are getting popular, but they carry a risk of sustaining damages during earthquakes. Therefore, such buildings should be designed properly taking care of their dynamic behaviour. As Response Spectrum Method, used for seismic analysis, it provides a better check to the safety of structures analyzed and designed by method specified by IS code.

III. Modelling

In this present section, the 3 D model of reinforced cement concrete structure building of G+12 storied building have been modelled. The linear dynamic analysis as response spectrum analysis been performed for RCC building model using IS 456:2000 and IS 1893:2016 with the help of ETABS Software. The following models are analyzed in this work.

Model 1 – Regular Frame
Model 2 - C Shaped Frame
Model 3 – L Shaped Frame
Model 4 – T shaped Frame
Model 5 – H shaped Frame
Model 6 – Regular Frame with shear wall at corner
Model 7 - C Shaped Frame with shear wall at corner
Model 8 – L Shaped Frame with shear wall at corner

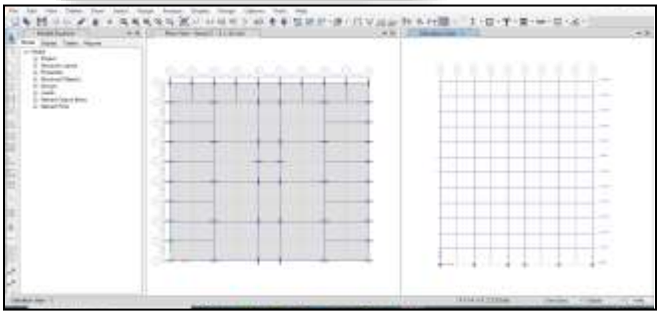
Model 9 – T shaped Frame with shear wall at corner
Model 10 – H shaped Frame with shear wall at corner
Model 11 – Regular Frame with shear wall at c
Model 12 - C Shaped Frame with shear wall at centre
Model 13 – L Shaped Frame with shear wall at centre
Model 14 – T shaped Frame with shear wall at centre
Model 15 – H shaped Frame with shear wall at centre

A. Detail Specification of Building

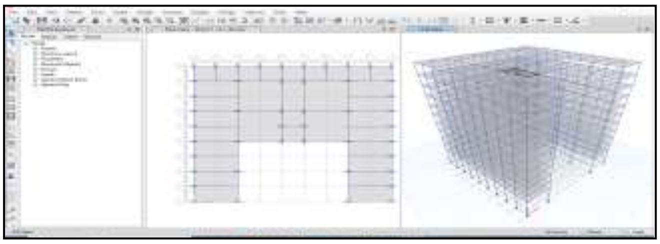
The dimensions of beams, columns and slab are mentioned below and other data used for the purpose of analysis have been taken from IS 1893:2016. The general specification used in building for analysis shown in table 3.1.

General Properties	
No. of storeys	G+12
Typical Storey Height	3.5 m.
Size of Column	400 mm x 1000 mm
Size of Beam	400 mm x 500 mm
Thickness of Slab	150 mm.
Thickness of Wall	230 mm.
Material Properties	
Grade of Concrete	M 30
Grade of Steel Rebar	Fe 500
Type of Loading	
Wall Load	13.5 KN/m
Live Load	3 KN/m^2
Floor Finishing	1.2 KN/m^2
Seismic Details (IS 1893:2016)	
Seismic Zone	V
Zone Factor	0.36
Importance Factor	1
Type of Soil	II - Medium
Building Type (R)	5 (SMRF)

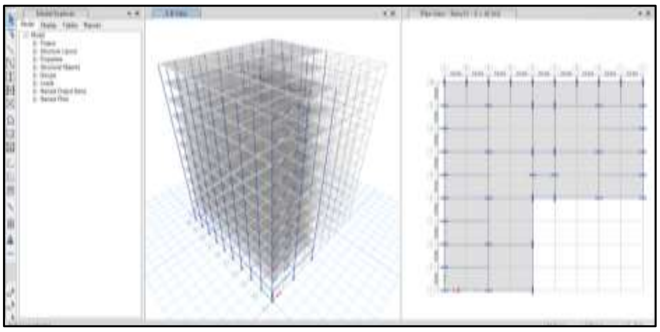
IV. PLAN OF THE BUILDING



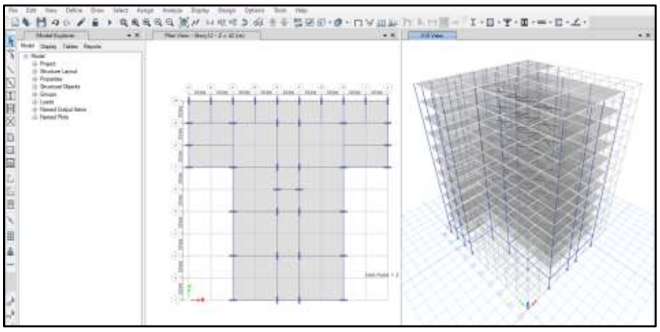
MODEL 1: REGULAR BARE FRAME



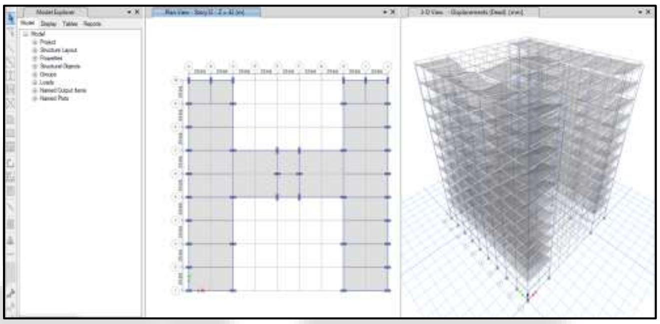
MODEL 2: C SHAPE BUILDING



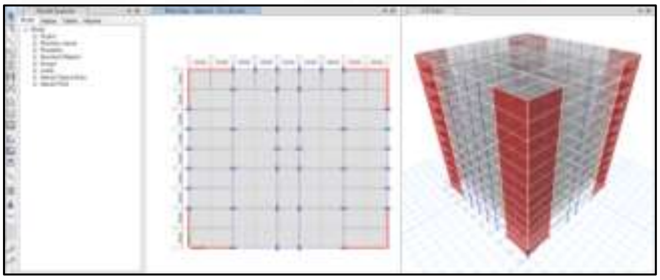
MODEL 3: L SHAPE BUILDING



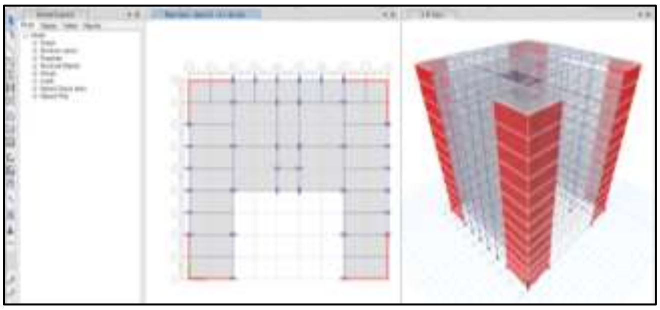
MODEL 4: T SHAPE BUILDING



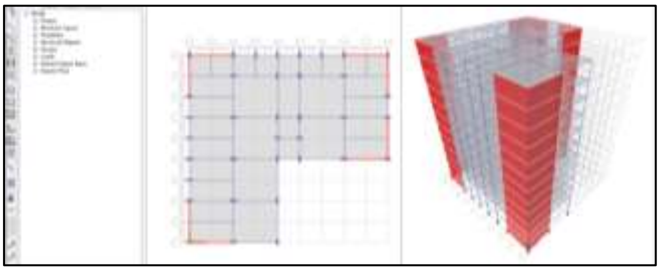
MODEL 5: H-SHAPE BUILDING



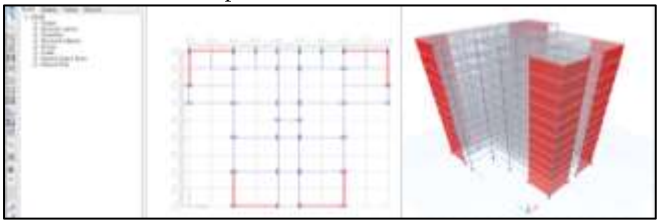
MODEL 6: Bare Frame with shear wall at corners



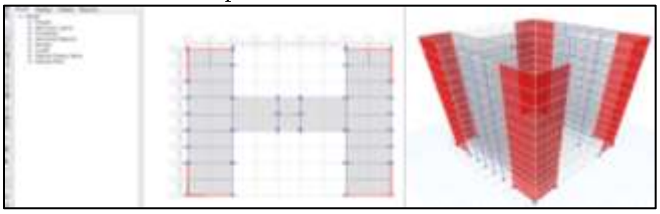
MODEL 7: C Shaped Frame with shear wall at corners



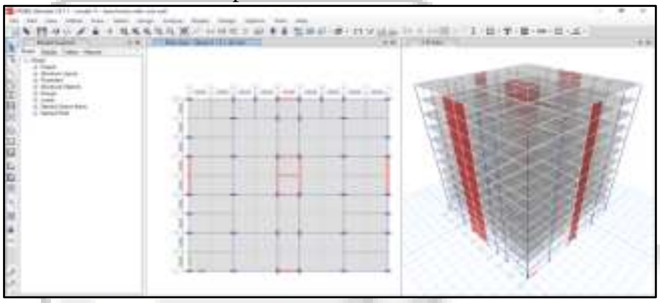
MODEL 8: L Shaped Frame with shear wall at corners



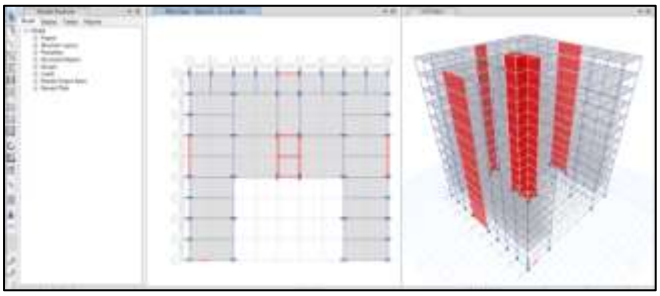
MODEL 9: T Shaped Frame with shear wall at corners



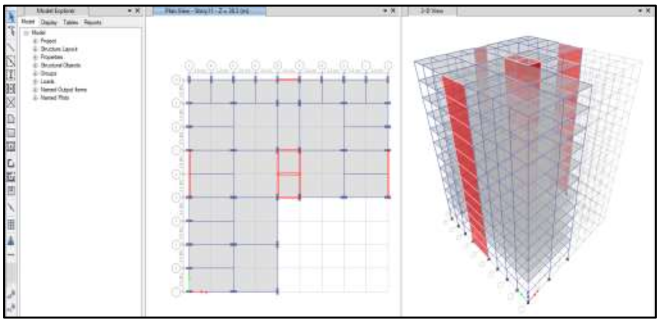
MODEL 10: H Shaped Frame with shear wall at corners



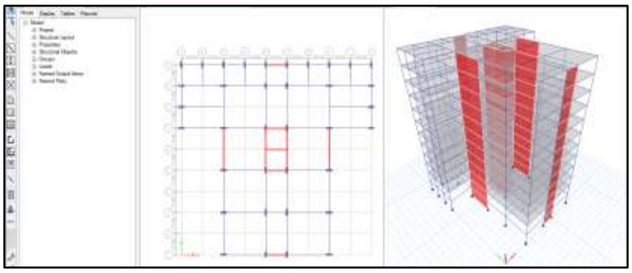
MODEL 11: Bare Frame with core wall and shear wall at centre



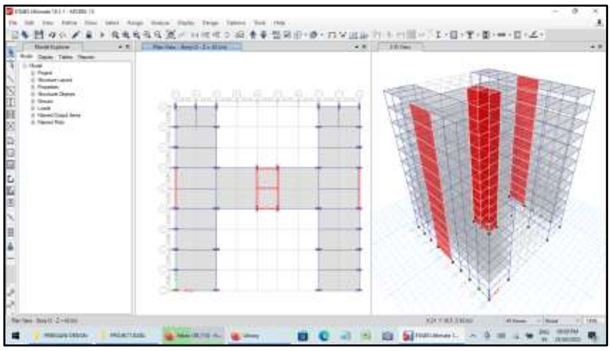
MODEL 12: C Shaped Frame with core wall and shear wall at centre



MODEL 13: L Shaped Frame with core wall and shear wall at centre



MODEL 14: T Shaped Frame with core wall and shear wall at centre

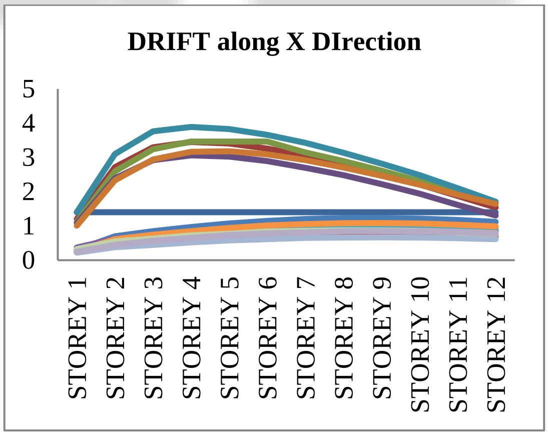


MODEL 15: H Shaped Frame with core wall and shear wall at centre

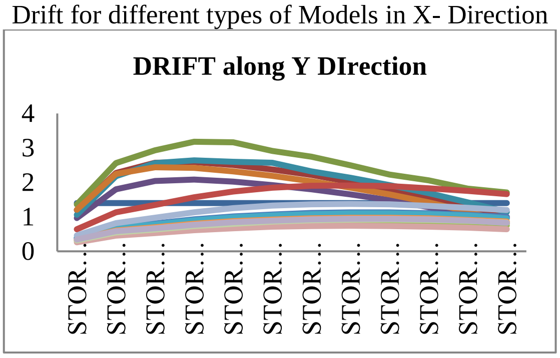
V. RESULTS

A. Drift

Below figures compares the drift of all the four models along both X and Y directions. The drift values exceed the permitted drift range which is suggested by IS 1893:2016 Cl 7.11.1[3]. The code recommends a maximum permitted drift value of 0.004H where H is the storey height (H=3.5m) and the permissible drift value is 0.014.



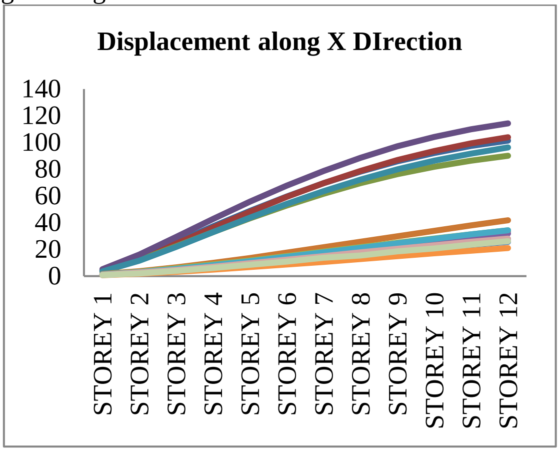
Drift for different types of Models in X- Direction



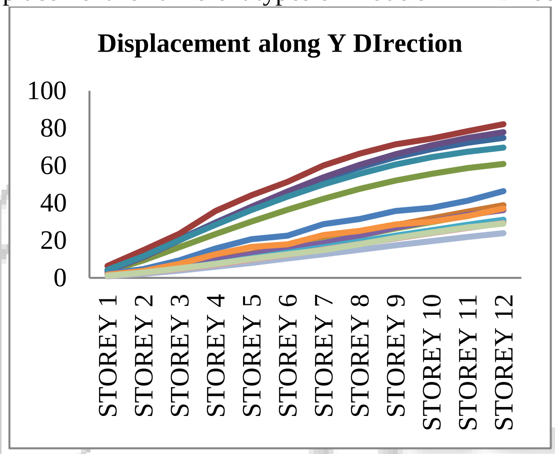
Drift for different types of Models in Y- Direction

B. Displacement

The storey displacements of all the four models are depicted in Figure below. It shows an increase in storey displacement along the height of the structure.



Displacement for different types of Models in X- Direction

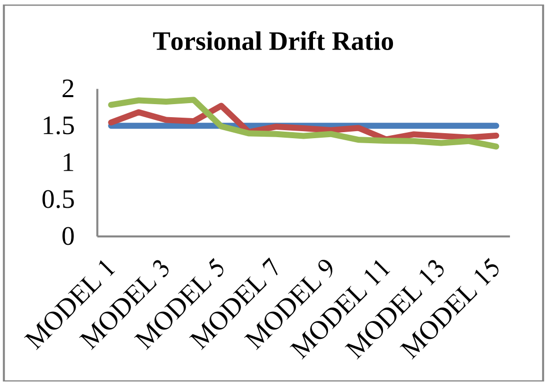


Displacement for different types of Models in Y- Direction

Storey displacement is the predicted movement of a structure under lateral loads, in medium rise structures, the higher the axial forces and deformations in the column and the accumulation of their effects over a greater height, all these causes the flexural component to become dominant. Apart from translational motion there is also floor rotation for displacement.

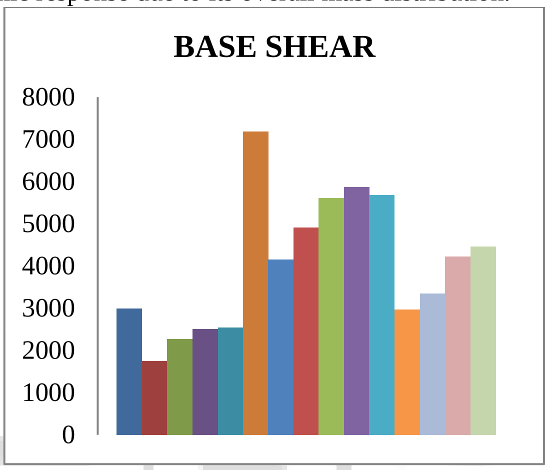
C. Torsional Constant or Drift Ratio

The torsion-al irregularity or drift ratios of models I to XV are shown in below figure. From the graph it is evident that symmetric structure has got least percentage of variation of maximum to average drift ratio and similar maximum to average drift ratios are exhibited in all stories. Asymmetric structure of L shape exhibited maximum drift ratios and indicates it has got higher degree of irregularity. Models II, III IV & V exhibited almost same range of irregularity, which implies that the structural elements that are being introduced also promote to the torsion effects.



D. Base Shear

The value of base shear mainly depends on the stiffness factor of the structure indicating that structure is much stiffer for seismic response due to its overall mass distribution.



Base shear for different types of Models

VI. CONCLUSIONS

The results obtained for the building carried out through response spectrum analysis approach will be near to realistic response of the structure to the actual. Following conclusions are made on the basis of the study -

1) The plan irregularities in structures have significant impact on the seismic response of the structure especially in terms of displacement and drift. The value of displacement and drift has been varied for x and y direction due to different symmetries in the respective direction. The use of shear wall reduces the value of drift and displacement for irregular models.
2) Building with irregular plan configuration causes severe damage than the regular building during earthquake in high seismic zones caused due to increase in drift and displacement. The value of displacement and drift are found less in model XI to XV with reference to other models as of the use of shear wall in core location. It is found to be the displacement and drift of building with core walls are 20% & 12% respectively lower than the conventional column building.
3) The building with core wall and shear wall at centre produces low torsional values as well as less drift as compare to other buildings. Hence for asymmetric buildings, shear wall at core and at centre position are desirable.

4) From the analysed models, the estimated time period for first modes indicated that the model with base isolation shown less vulnerability to seismic actions as compare to other irregular models. Also, it can be concluded that flexible longer period design may be expected to experience proportionately lesser accelerations than a stiffer building.
5) The permissible limit of $\Delta Max / \Delta Min < 1.5$ as per IS 1893(part-1):2016. The maximum torsional irregularity ratio was found for models without shear wall which concludes that the correct orientation of columns and use of lateral load resisting elements is also a key point to remember while design such structures in severe seismic zones. The value of torsion-al drift for building without shear wall is 25% higher than the values for building with core walls.
6) Proper use and positioning of bracing elements like shear wall, core wall etc will reduce the torsional irregularity. Also due to torsional irregularity, the shear forces in columns are high.
7) From the study it is also been observed that though the outside perimeter of the buildings are almost similar, a significant variation in values of torsional related parameters is observed due to plan asymmetry with and without lateral load resisting elements.
8) The value of base shear is found more in models without shear wall than other models indicating that structure is much stiffer for seismic response. It is found that the value of base shear for such building without shear wall is 2.4 times higher than the value of base shear for other buildings with shear wall.
9) Special moment resisting frame is more suitable in severe seismic zones than ordinary moment resisting frame.
10) In case of irregular shape structure the centre of mass do not coincide with the centre of rigidity due to asymmetrical positioning of stiff elements with respect to stiffness. Since torsion is the most critical factor leading to major damage or collapse of building therefore, it is very essential that irregular buildings should be carefully analyzed for torsion and designer should try avoid excess irregularities especially in the multi storied building.

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