Seismic Performance of Symmetric and Asymmetric Multi-Storeyed Buildings

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Abstract*: Multistoried buildings are very much common in the urban areas nowadays due to scarcity of land and increase in the cost of land. Many of these structures are not regular either in shape, stiffness or mass distribution. A structure with irregular configuration may be constructed so as to meet all the codal requirements, but the performance of such a structure will not be as good as a structure with regular configuration. It is even suggested to avoid such configuration but irregularity in structural components has been unavoidable due to various reasons. This paper aims to determine the differences in seismic performance of regular and irregular structures in plan and also to identify a suitable method that can be used in an asymmetric structure to reduce the effect of seismic load. Models of square-shaped, L-shaped and T-shaped G+4- and G+10-storied buildings are considered for analysis in Etabs software. From the static and dynamic analyses of these models, various parameters like storey shear, storey displacement and overturning moment have been calculated and compared. It is concluded that symmetrical structures are superior to asymmetric structures in view of resistance against seismic forces. Further, shear walls can be used in asymmetric structures to ensure safety against seismic forces.

***Index Terms*: Plan irregularity, Seismic coefficient method, Response spectrum method, Story shear, Overturning moment**

I. INTRODUCTION

Field observation confirms that asymmetric structures suffer more damage due to earthquake than their symmetric counterparts. Plan irregularity is one of the most common types of irregularity found nowadays. The shortage of land, lack of urban planning, varying functionality of structures, and aesthetic requirement of buildings leads designers to design asymmetric structures even in hilly regions of India which are falling in seismic zone IV and V. Seismic analysis must be performed before designing such structures which is not a common practice especially due to the financial constraints and lack of knowledge about seismic design in our country.

Seismic analysis can be broadly classified into static and dynamic methods. A static structural analysis method is such a method which determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed i.e. the loading and the response of the structure are assumed to vary slowly with respect to time. The seismic coefficient method and push over method are examples of static structural analysis. A dynamic structural analysis method is such a method which considers both the forces and structural response as a function of time. This type of analysis takes inertial forces into account. The structural responses are obtained in terms of displacement, acceleration and mode shape. The major examples of dynamic structural analysis are response spectrum method and time-history method. IS code suggests that static method of seismic analysis can be safely used for building up to 40m height in case of symmetric structure and up to 12m in case of an asymmetric structure[16]. All structures exceeding this limit must be analyzed using the dynamic methods of analysis.

Three specific fields were surveyed regarding the seismic response of the reinforced concrete structure i.e. plan irregularity, vertical irregularity and mitigation of torsional irregularity. The study concluded that the research then was more concentrated on the inelastic behaviour of the simplified one storey model. It was also concluded that the one storey model had shortcomings when compared to multistoried models and many building codes had to be reexamined to deal with the nonlinear model and most of the building codes could predict the effect of vertical irregularity to a satisfactory limit. [1]

3 RCC frames with asymmetric plans of 5, 7 and 10 stories were analysed. In each case, the area of the projected portion was taken greater than 33% of the total plan area. The difference between the centre of mass and centre of rigidity was less than 2.4% of the corresponding dimension of the building. The structures were analyzed by SAP2000 using the Iranian code of practice of seismic resistant building (BHRC 2005) Using pushover analysis and linear time history analysis building drift and base shear was calculated. It was obtained that the linear dynamic analysis is more reliable than nonlinear static analysis. [2]

Analysis of reinforced concrete structure walls and moment resisting frame using response spectrum analysis was performed. Indian standards (IS1893-2002), uniform building code and euro code 8 were used for the analysis. Elastic analysis was carried out in SAP2000. Three asymmetric plans were considered for analysis. It was found that IS code gave a comparatively higher value of base shear. The displacement was found to be the highest in the analysis using uniform building code while the Indian standard gave the least displacement. [3]

A study on six groups of typical multi-storey buildings composed of frames and walls, which were selected to carry out the parametric study was conducted. The typical

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structures were having asymmetric walls in a rectangular plan. The dimensions of the structural elements were determined using a preliminary design process. Torsional irregularity coefficient and maximum floor rotation were calculated for each structure. It was found that for all structures torsional irregularity coefficient increased as the storey number decreased and floor rotation was proportional to storey number. Also, floor rotations attained their maximum values for the structures where the walls were in farthest positions from the centre of mass. [4]

Seismic response of five storied symmetric building with a different configuration of shear wall was studied. The building was assumed to be located at seismic zone V. Five different combination of four shear walls was considered. The lateral displacement of the building was found to be maximum when the shear wall was placed at the core and the displacement was found to be the least when the shear wall was placed mid-side away from the core. Also, the reduction in shear force in ground storey columns was found to be significant. [5]

A new displacement based method for design which can be applied to multistoried asymmetric reinforced concrete buildings was suggested. The proposed design method was tested for a large range of asymmetric plan reinforced concrete walled structures. It was concluded that the suggested design method which considered capacity design approach and dynamic higher mode effects has much wider applicability than the current design methods. [6]

II. OBJECTIVES OF THE STUDY

The objectives of this study are as follows:

1. To model a symmetric structure and its equivalent asymmetric structures in Etabs and perform seismic analysis by static and dynamic methods of analysis.
2. To compare the seismic response of symmetric and asymmetric structures.
3. To compare the structural response from the static and dynamic methods of seismic analysis.
4. To determine a suitable method to reduce the structural response parameters in the asymmetric building.

III. METHODOLOGY

1. G+4 and G+10 Reinforced concrete framed structures were modelled in Etabs. Keeping this model as a standard, T and L shaped structures were modelled.
2. The structures were loaded as per IS 875: 1987 and analyzed as per IS 1893:2002.
3. Seismic analysis was performed using Seismic coefficient method as well as the response spectrum method.
4. The maximum storey displacement, storey shear and overturning moments were determined and compared.
5. Shear walls were added to the T- and L-shaped G+10-buildings and analysed similarly as an attempt to reduce the seismic response parameters. The response parameters so obtained were compared to that of buildings without shear walls.

IV. MODELLING

A G+4 and a G+10 reinforced concrete structure symmetric in plan model were generated in Etabs. With the same floor area, L and T shaped models were also created. The size of the frame was determined by a preliminary design carried in the software. The details of the model are as follows:

Table I: Details of Model

Grade of concrete	M25
Grade of steel	Fe415
Height of each storey	3m
Area of plan	324 m^2
Size of columns for G+10 structure	450mmx450mm
Size of columns for G+4 structure	400mmx400mm
Size of beams	300mmx500mm
Thickness of staircase slab and landing	150mm
Depth of foundation for G+4 structure	1.5m
Depth of foundation for G+10 structure	2.5m

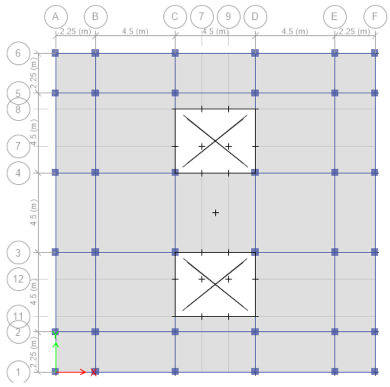

Fig. 1: Plan of symmetric structure

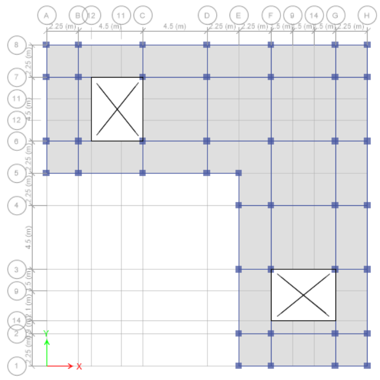

Fig. 2: Plan of L shaped structure

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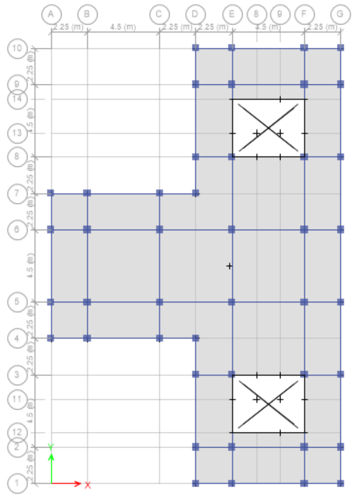

Fig 3: Plan of T shaped structure

On subsequent analysis, the L and T shaped structures were provided with shear walls. The position of shear walls was fixed based on the literature study. Four shear walls of 4.5m length and 150mm thickness were provided in each building.

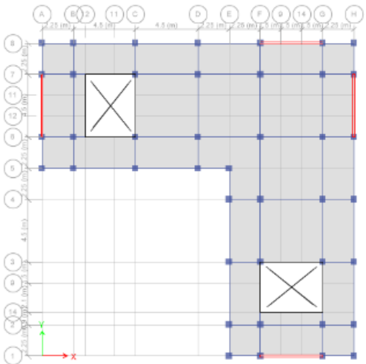

Figure 4: Position of shear wall in L shaped structure

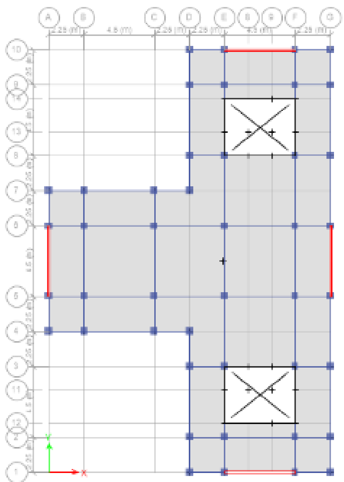

Figure 5: Position of shear wall in T shaped structure

The following parameters were used for the seismic analysis.

Table II: Seismic loading parameters

Type of frame	Special moment resisting frame
Response reduction factor	5
Importance factor	1
Seismic zone	Zone V (very severe)
Zone factor	0.36
Soil type	Medium (Type-2)
Damping	5%
Modal Combination	Complete quadratic combination

V. RESULTS AND DISCUSSION

A. G+4 Structure

The variation of overturning moment throughout the height of symmetric, L and T shaped G+4 building while using seismic coefficient and response spectrum method is shown in Figures 6 and 7 respectively. The overturning moment is found to be 11.80% and 12.70% higher in the case of L shaped building than that in the symmetric building when analyzed by static and dynamic method respectively. Similarly, the increment is found to be 15.50% and 17.05% in T shaped building when analysed using static and dynamic method respectively. Also, the overturning moment obtained by dynamic method is about 13% lower than the static method.

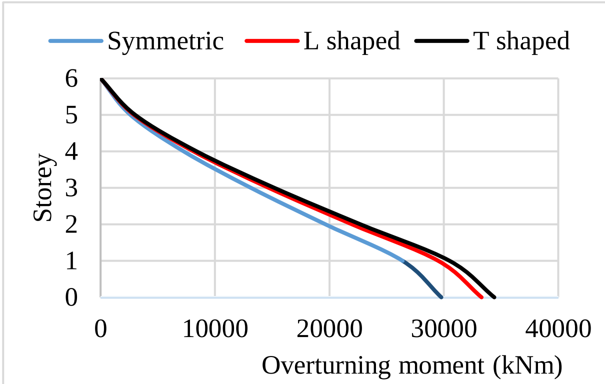

Fig. 6: Overturning moment of G+4 structure using seismic coefficient method

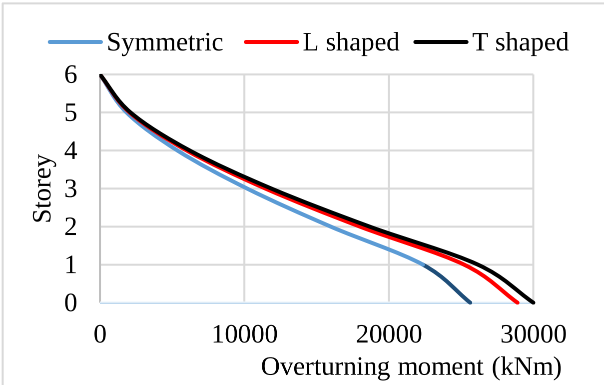

Fig. 7: Overturning moment of G+4 structure using Response spectrum analysis

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The variation in storey displacement for the G+4 models is shown in Figures 8 and 9. The maximum storey displacement of T shaped building is found to be almost similar to that of symmetric structure but the storey displacement of L shaped structure is found to be 2.5% and 11.17% higher than that of symmetric structure when analysed using static and dynamic method respectively. Also, the maximum storey displacement by dynamic method is found to be around 15% lower than that obtained by static method.

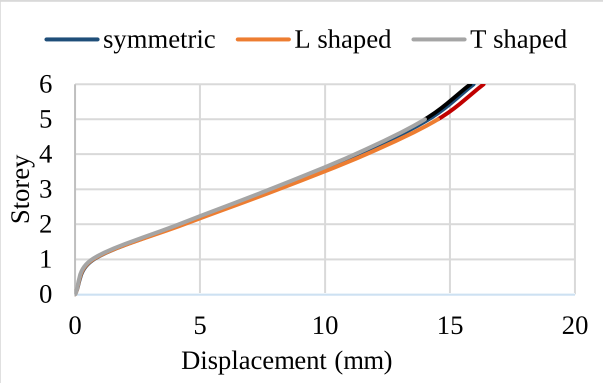

Fig. 8: Storey displacement of G+4 structure by seismic coefficient method

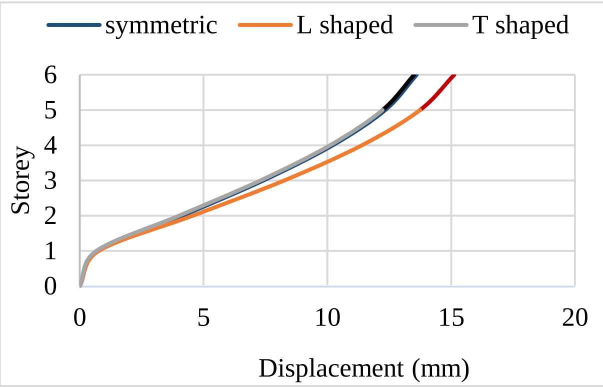

Fig. 9: Storey displacement of G+4 structure by Response spectrum method

The storey shear values for G+4 models is shown in Figure 10. Base shear in L and T shaped buildings is found to be 13% higher than the symmetric building.

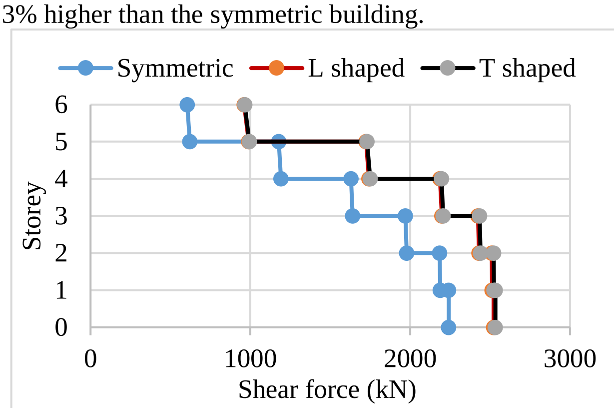

Fig. 10: Storey shear of G+4 structure

B. G+10 Structure

The variation of overturning moment throughout the height of symmetric, L and T shaped G+10 buildings while using seismic coefficient and response spectrum method is shown in Figures 11 and 12 respectively. The overturning moment is found to be 11.06% and 28.42% higher in the case of L shaped building than that in the symmetric building when analyzed by static and dynamic method respectively. Similarly, the increment is found to be 17.38% and 28.63% in T shaped building when analysed using static and dynamic method respectively. Also, the overturning moment obtained by dynamic method is 20%, 8% and 16% lower than that obtained by the static method in symmetric, L and T shaped structures respectively.

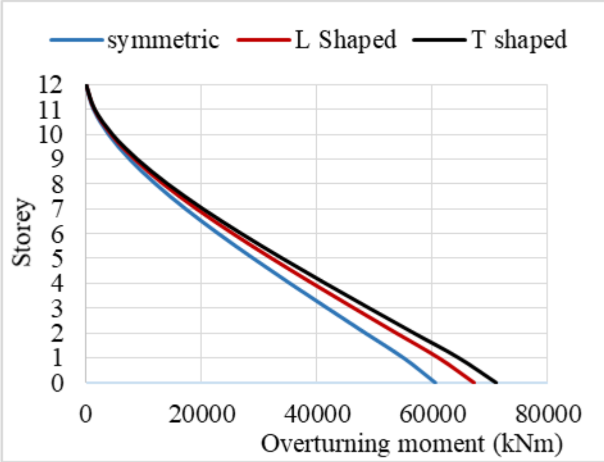

Figure 11: Overturning moment of G+10 using seismic coefficient method

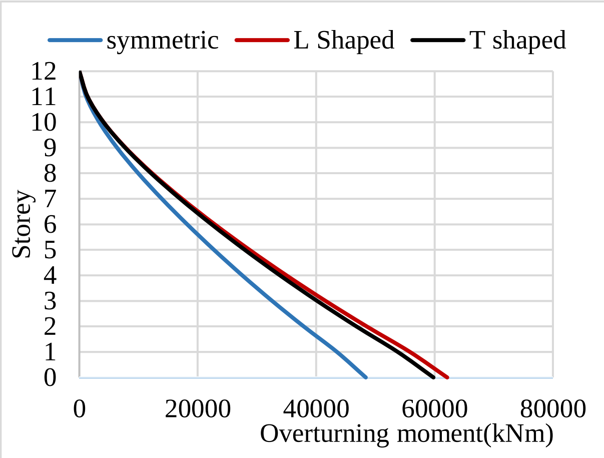

Fig. 12: Overturning moment of G+10 by Response spectrum method

The variation in storey displacement for the G+10 models is shown in Figures 13 and 14 respectively. The maximum storey displacements of L and T shaped buildings are found to be almost similar to that of symmetric structure when static method of analysis is used but the same is found to be 12.58% and 7.58% higher in L and T shaped building than the symmetric structure when analysed using dynamic method. Also, the maximum storey displacement by dynamic method is found to be around 21.3%, 10.5% and 15.4% lower than that obtained by static method in symmetric, L and T shaped structure respectively.

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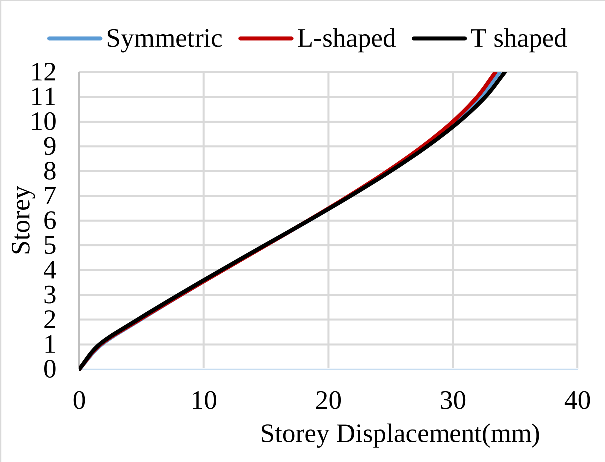

Figure 13: Storey displacement of G+10 structure by seismic coefficient method

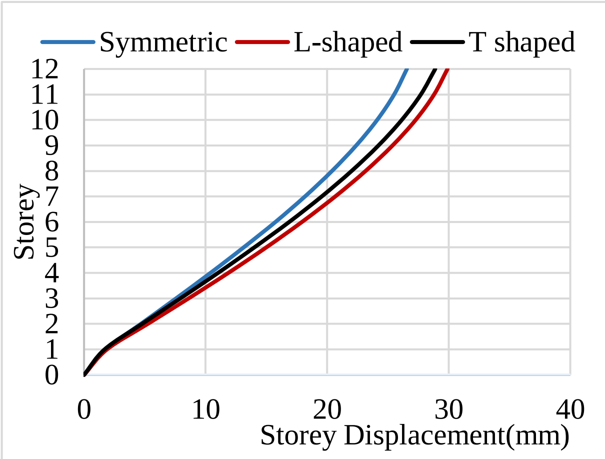

Figure 14: Storey displacement of G+10 structure by Response spectrum method

The storey shear values for G+10 models are shown in Figure 15. Base shear in L and T shaped building is found to be 11% and 17% higher than the symmetric building respectively.

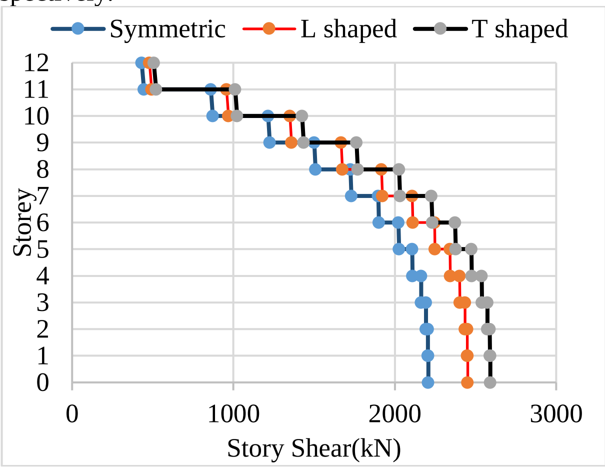

Figure 15: Storey Shear of G+10 structure

C. Comparison with shear wall provided structure

The maximum storey displacement for L and T shaped building with and without shear wall is shown in Figure 16. The percentage decrease in the maximum storey displacement due to shear wall in L and T shaped building is found to be about 19% and 18% when analysed by static method and 26% and 22% when analysed by dynamic method.

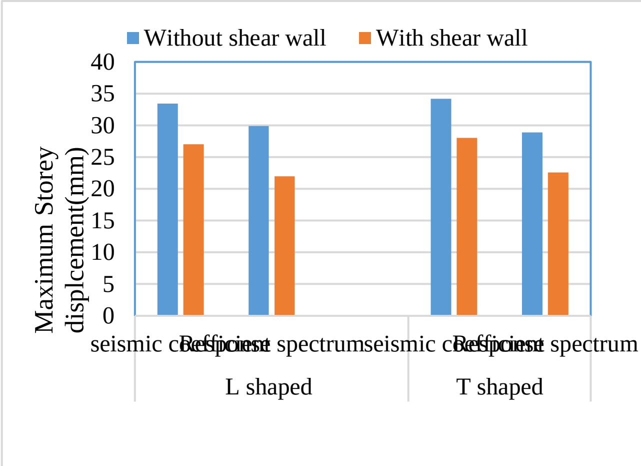

Fig. 16: Displacement comparison with shear wall provided building

The change in shear force, maximum moment and axial load in columns when shear wall is provided is shown in figure 17, 18 and 19 respectively. A 50% reduction in maximum shear force and 54% reduction in the maximum moment in columns is obtained when shear wall is provided. But the reduction in maximum axial load in columns is found to be about 3-5%.

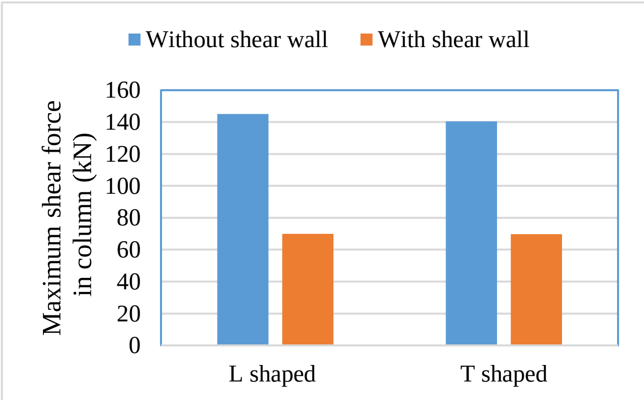

Fig. 17: Shear force comparison with shear wall provided building

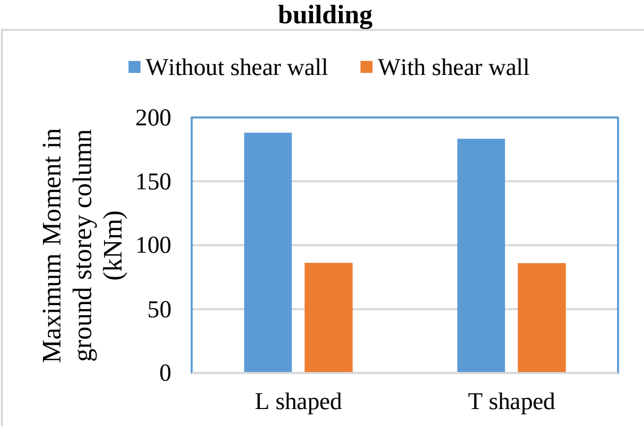

Fig. 18: Column moment comparison with shear wall provided building

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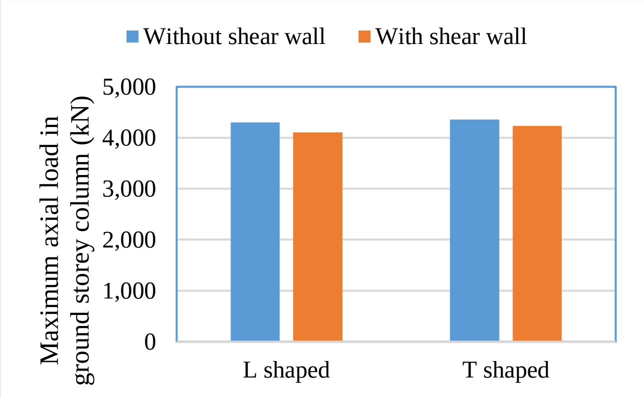

Fig. 19: Axial Load comparison with shear wall provided building

VI. CONCLUSION

1. Asymmetric buildings are more susceptible to damage during earthquakes.
2. The extent of damage will increase with the height of the structure.
3. The seismic coefficient method is found to be more conservative than the response spectrum method for all the shapes of the building although the IS code recommends the use of response spectrum method in asymmetric buildings with a height greater than 12 sm.
4. Shear walls can be used in order to decrease lateral loads in columns, but the selection of the position of the shear wall has to be done carefully.
5. Shear walls do not reduce axial load carried by columns.

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