Seismic Response of Multi-storey Building with Different Plan Configuration Using X-Bracing

Shaik Shaista Farheen and B. Rohini

Abstract In recent times, it is seen that RCC buildings which appear strong in appearance may collapse in the blink of eye during earthquakes. This raises the question of its capability to withstand the strong motion. In order to study the performance of buildings subjected to seismic loads, evaluation is carried out in both linear and nonlinear static methods. Also the bracing systems which have good structural importance when it comes to the RCC building are also considered in the present study. To study the objective, a (G + 5) building structure is considered, with and without X-bracing for Rectangle, L and T shape plan configurations and the analysis is carried out in ETABS. The parameters considered for the comparison are storey displacement, overturning moment, base shear and storey drift.

Keywords Building · Earthquake · Bracing · Base shear · Storey displacement · Storey drift · Overturning moment

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1 Introduction

Structures undergo ground motion when subjected to seismic waves caused by the earthquake effect and the consequences are huge destruction of property and loss of life. While it is of major concern for the structural designers to provide structural safety with good serviceability, adequate stability and strength to the building under severe earthquake. Hence, one needs to understand a building under seismic loading requires the keen knowledge of the structural performance under large inelastic deformations.

In a recent development, the nonlinear static analysis called pushover analysis has been followed. Nonlinear static analysis is carried out by applying a lateral load in increasing the level of a structure up to ultimate strength to approximately know the strength of a structure beyond its elastic limit up to its ultimate strength in a post-elastic range. Equivalent Static Analysis is linear analysis where the loads are factored to give design force in a single shot. Therefore, to handle this issue, procedures in analytical mode should be developed which ensures the structure to withstand the occurrence of minor earthquakes and indicate caution when prone to major earthquake events.

Mani Deep et al. [1] studied a G + 9 Building in all seismic zones and analysed it by pushover analysis in SAP 2000 Software. From the results, it was observed that when zone varies base shear, displacement, and time period were increased indicating the severity of seismic activity. It is concluded that damage in the building is less and columns in bottom storeys can be retrofitted.

Mohod et al. [2] carried out work on a 12 storied building considering 9 different irregular plan configurations the effect of irregularity on the structure was analysed in STAAD PRO Software. From the study, the irregular plan configurations such as L, C, H, T and E shapes have shown higher deflection than regular geometries. Hence, it is concluded that simple geometry attracts less force and must be adopted as they perform well during the effect of earthquake.

Haamidh et al. [3] analysed RCC frame structure incorporated with various bracings. The structural response of bracings like X, V and inverted V is analysed for 8, 12 & 16 storey buildings by pushover analysis using ETABS Software. Therefore, it can be concluded that the X-bracing frame performs good with less displacement and the base shear of bracings is satisfactory and for development of plastic hinges which hold high importance compared to other frames.

Balappa and Malagavelli [4], investigated a (G + 10) multi-storey building for 4 models with and without bracings by nonlinear static analysis using SAP-2000 software. A parametric study of different parameters has been carried out. Therefore, it is seen that storey displacement and storey drift decreased in case of models with bracings especially model 2 have shown effective reduction. Time period obtained was less for building with bracings compare to unbraced model. Also base shear was found to be minimum with provision of bracing as they have high lateral stiffness. Hence, RC Frame without bracing got (CP) level. Model 2 performed better compared to other models.

G. Sai Prasanna Kumar Reddy and Dr. V. Ranga Rao [5] carried out analysis of a (G + 10) multi-storey building for four models using SAP-2000 Software. The parameters studied are base shear, displacement, pushover curve and location of hinges. Hence, it was concluded that the time period obtained was less for building with bracings compared to unbraced model. Storey displacement and storey drift was reduced in case of models with bracings especially model 2 has shown effective reduction. While base shear was found to be minimum with presence of bracing as they have high lateral stiffness. Hence, RC Frame without bracing got collapse prevention (CP) level. Model 2 performed well compared to other models.

Teruna [6] studied the response of a six-storey building of three-bay RC Frame with different mass introduced at second storey (M2), fourth storey (M4) and sixth storey (M6) and stiffness irregularity at first floor (Mo) by pushover analysis and time history analysis (THA) using SAP 2000 software. The response is studied and development of plastic hinges is discussed. The pushover analysis generated damage control performance level, while THA exhibited limited safety range performance level for the whole frame and after evaluating frames in plastic hinge status it was indicated that frame M6 varies from Immediate occupancy to the collapse prevention level and in both methods it has shown poor performance level. Hence, it can be concluded that the results obtained from pushover analysis are lesser than the results of time history analysis, while time history analysis provides us with accurate results.

Rofooei et al. [7] analysed five different special moment-resisting steel frames, namely two, five, ten, fifteen and twenty storey buildings with different load patterns and new approach by static and dynamic pushover analysis using Drain-2dx nonlinear analysis programme. Therefore, it was concluded that the dynamic pushover with a trilinear approximation of pushover curve and the newly defined effective modal load pattern (SRM) possessed the least error in resembling the target displacements, specifically in both 15 and 20 stories structural models, while nonlinear static pushover analysis was satisfactory, no precise inclination is observed in using static procedure as per code.

The main aim of the study is to perform analysis of a (G + 5) multi-storey building subjected to seismic load by equivalent static method and pushover method considering Rectangular building, L shape building and T shape building in ZONE V, with and without bracings by providing the bracings at the outer side of the plan configuration using ETABS Software. And also to study and compare the response in the terms of storey displacement, storey overturning moment, base shear and storey drift. Finally, the shape desired for construction in seismic zones is found from the analysis.

2 Methodology and Description of Building

Structure type	SMRF (G + 5) building
Plan area	(30 × 20) m^2
Each floor height	3 m
Bottom floor height	4 m
Type of concrete	M25
Type of steel	Fe415
Beam Dimensions	300 mm × 450 mm 400 mm × 500 mm 400 mm × 550 mm 450 mm × 600 mm
Column Dimensions	500 mm × 500 mm 600 mm × 600 mm 700 mm × 700 mm 800 mm × 800 mm
Slab details	150 mm (Shell-Thin) M25 Grade
Live load (on slab)	5 kN/m^2
Diaphragm	Rigid diaphragm
Bracing considered	ISWB (Pinned) X-Bracing
Masonry wall thickness	230 mm
Poisson's ratio of concrete	0.2
Seismic Zone	Zone V
Importance Factor	1
Parapet wall dimensions	Height—0.90 m Thickness—115 mm
Site Type	Type II
Density of concrete	25 kN/m^3
Response Reduction Factor	5
Damping Ratio	5%
RCC Design Code	IS 456:2000
Earthquake Design Code	IS 1893:2002

DEAD LOAD (On frame):

2.1 Wall Load Calculations

(1) Wall load on other floors:

Unit weight of brick × thickness of masonry wall × height of the floor

$$= 20\ \text{kN/m}^3 \times 0.230\ \text{m} \times 3\ \text{m} = 13.8\ \text{kN/m}.$$

(2) Wall load (Top floor—on parapet wall):

Unit weight of brick × thickness of masonry wall × height of the floor

$$= 20\ \text{kN/m}^3 \times 0.115\ \text{m} \times 0.90\ \text{m} = 2.07\ \text{kN/m}.$$

2.2 Building Models in ETABS Software

Figure 1 represents rectangular plan configuration in ETABS. Figures 2 and 3 represent 3D view of building with rectangular plan without and with X-bracings respectively. Figure 4 represents L-shape plan configuration in ETABS. Figures 5 and 6 represent 3D view of building with L-shape plan without and with X-bracings respectively. Figure 7 represents T shape plan configuration in ETABS. Figures 8 and 9 represent 3D view of building with T-shape plan without and with X-bracings respectively.

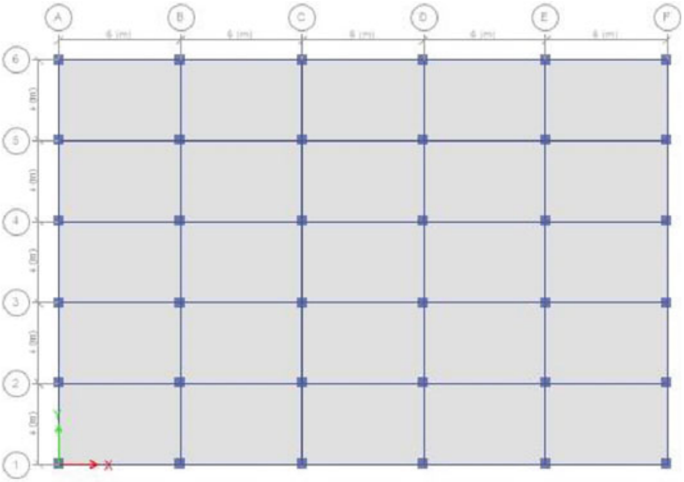


Fig. 1 Rectangle plan shape

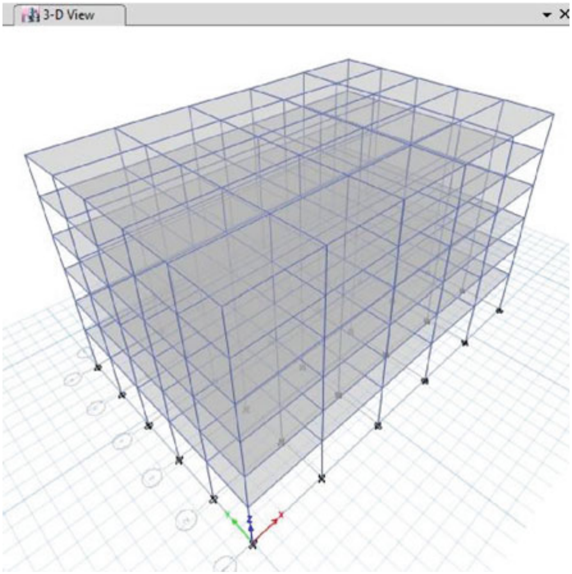


Fig. 2 3D view of rectangle plan shape

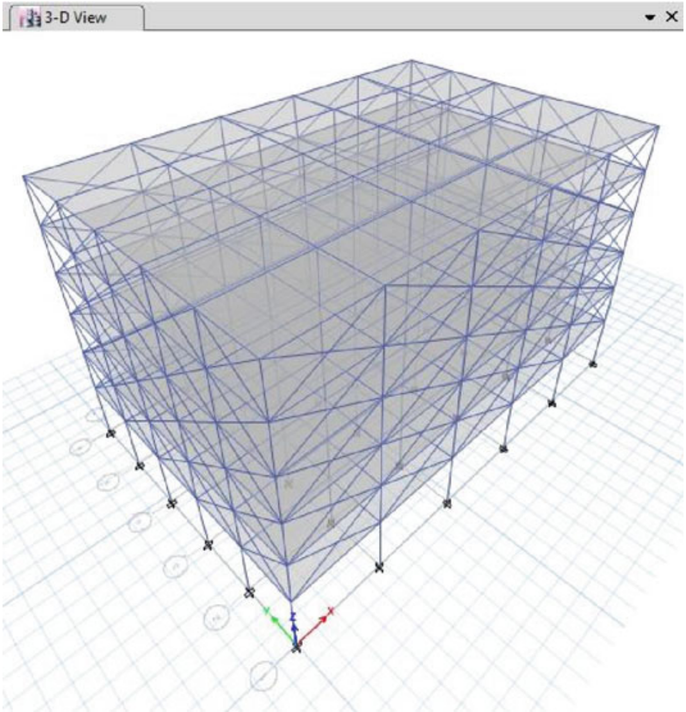
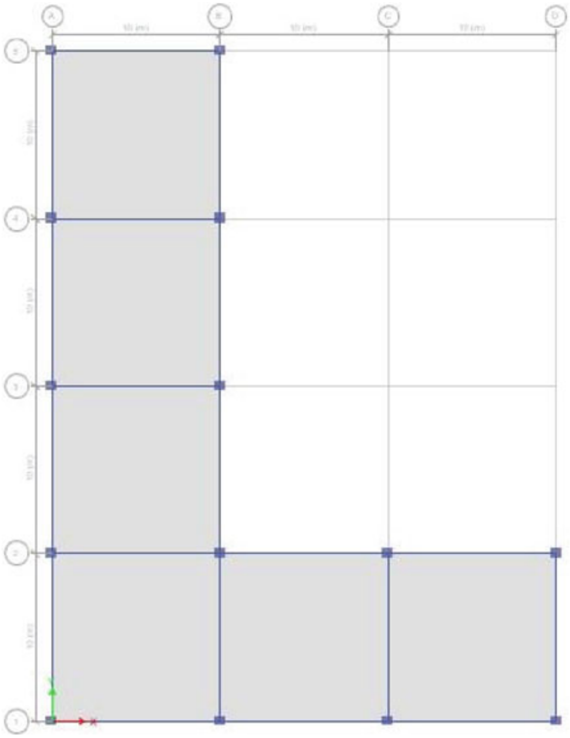


Fig. 3 3D view of rectangle plan shape with X-bracing

Fig. 4 L-Plan Shape



3 Results and Discussions

3.1 Comparison of Storey Displacement in Equivalent Static Analysis

In Fig. 10, the variation of the storey displacement for different plan configuration along with storey number is plotted. It is studied that in the absence of bracing for the three plan configurations the storey displacement correspondingly increases with the storey number. For rectangle plan configuration, there is a decrease of 75% of storey displacement when X-bracing is used. While for L shape plan configuration with bracing (w/b), the storey displacement reduces by 64.28% similarly there is a decrease of 56.5% displacement for T shape plan configuration. According to IS 456-2000 and IS 1893(Part-1) 2002, maximum storey displacement is limited to $H/500$, where H indicates total height of the building. Hence, it is concluded that storey displacement did not exceed the limits and is recorded highest for L shape plan configuration with (w/b) and without (w/ob) X-bracing.

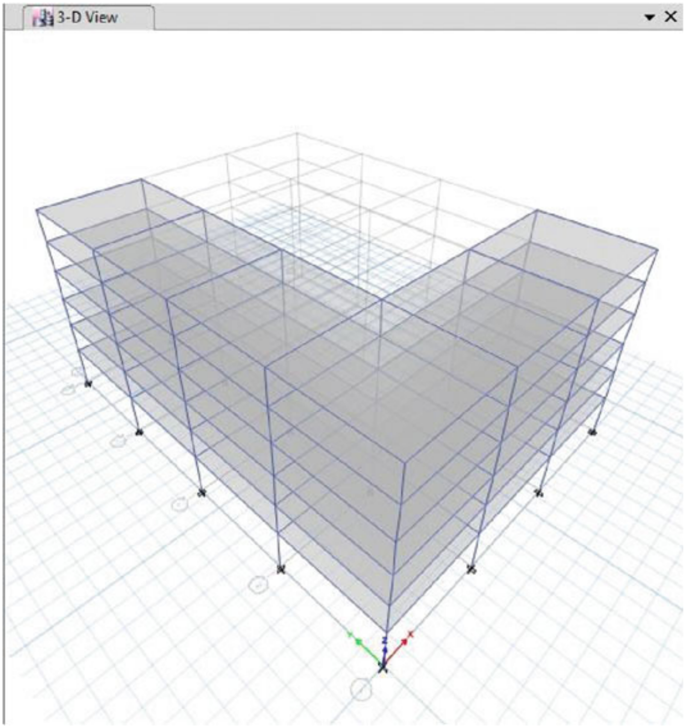


Fig. 5 3D view of L-plan shape

3.2 Comparison of Storey Overturning Moment in Equivalent Static Analysis

The storey overturning moment variation for different plan configuration in the presence of bracing is shown in Fig. 11. It can be observed that there is marginal change in the presence of bracing. *T* shape plan configuration with bracing (*w*/*b*) records highest value and the least value is found in rectangular buildings without bracings (*w*/ob) which indicates that less moment is required to overturn the storey.

3.3 Comparison of Storey Drift in Equivalent Static Analysis

From Fig 12, it can be seen that the storey drift varies in parabolic manner with storey number. It can be observed that maximum drift is at storey 2 thereafter it goes on reducing up to storey 6. In the presence of X-bracing storey drift is found to be maximum at storey number 1 for every plan configuration considered. As per the code IS 1893(Part-1)2002 the maximum drift limit is 0.004*h*, where *h* indicates

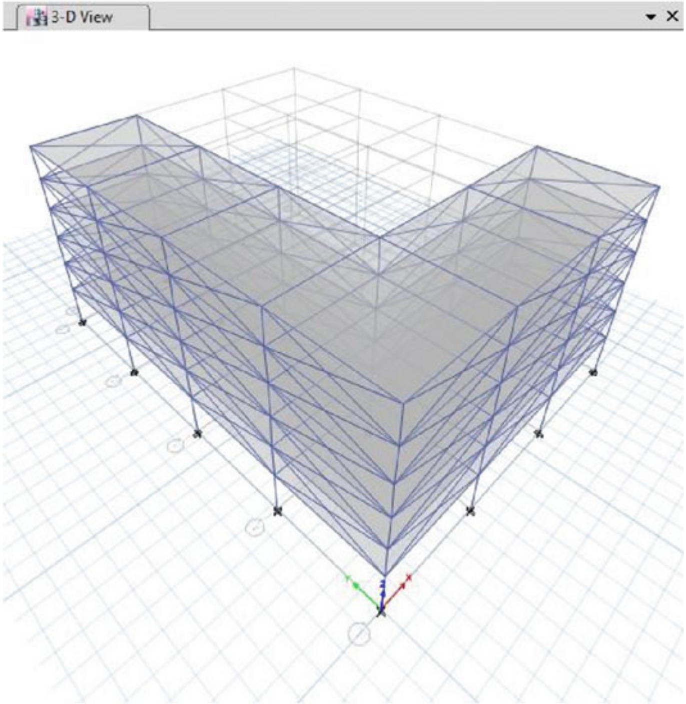


Fig. 6 3D view of L-plan shape with X-bracing

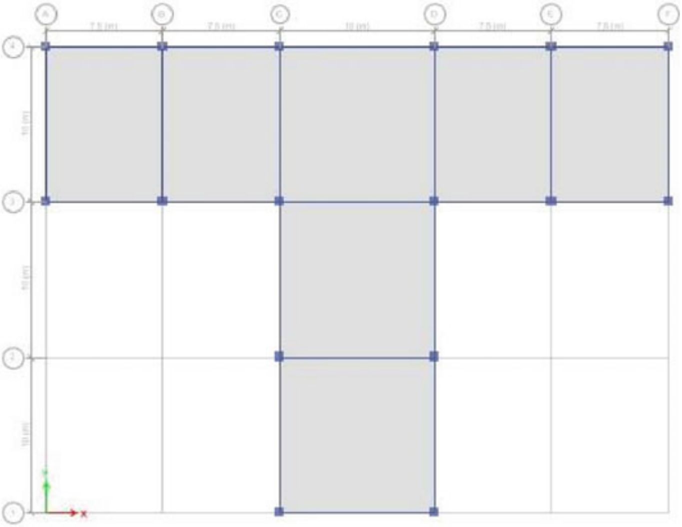


Fig. 7 T-PLAN Shape

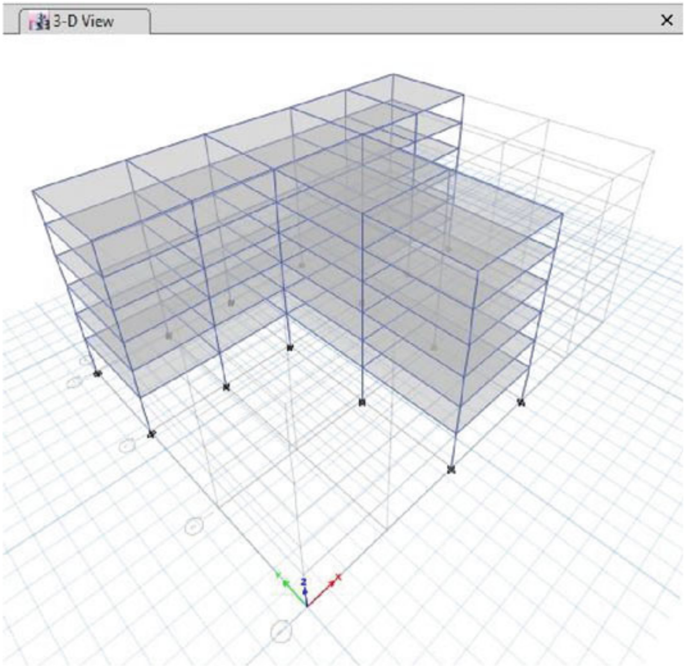


Fig. 8 3D view of T-plan shape

height of the storey. Storey drift here did not exceed the limits and is found to be highest in *L* shape plan configuration with bracings (*w*/b).

There is a percentage decrease of 14.28, 36 and 15% for rectangle, *L* shape and *T* shape plan configurations.

3.4 Comparison of Storey Displacement in Pushover Analysis

From Fig. 13, it is clear that in Push X load case the storey displacement is less in the case of *T* shape plan configuration without bracings (*w*/ob) while the highest value is seen in rectangular shape plan configuration with bracings (*w*/*b*). Hence, it can be concluded that the storey displacement here did not exceed the limits as per the code IS 456-2000 and its values correspondingly increase with increase in the height of structure.

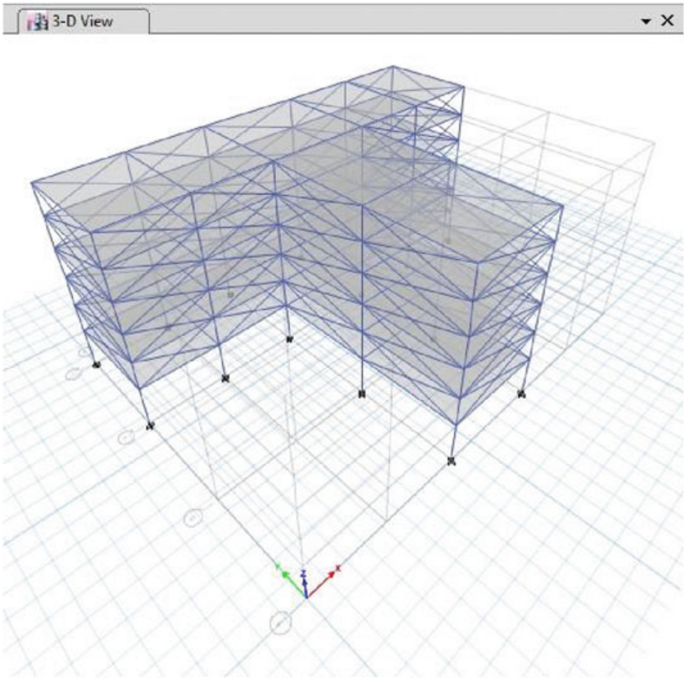


Fig. 9 3D view of T-plan shape with X-bracing

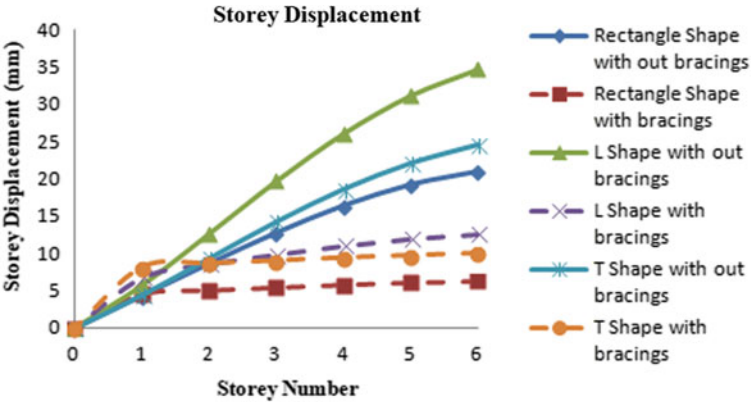


Fig. 10 Storey displacement

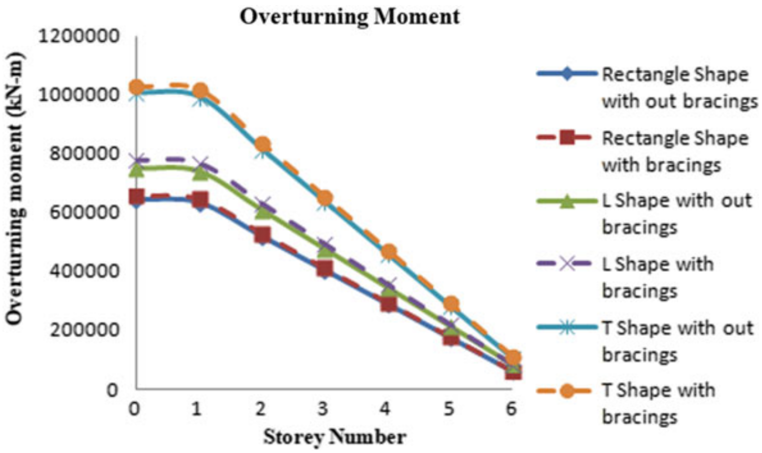


Fig. 11 Overturning moment

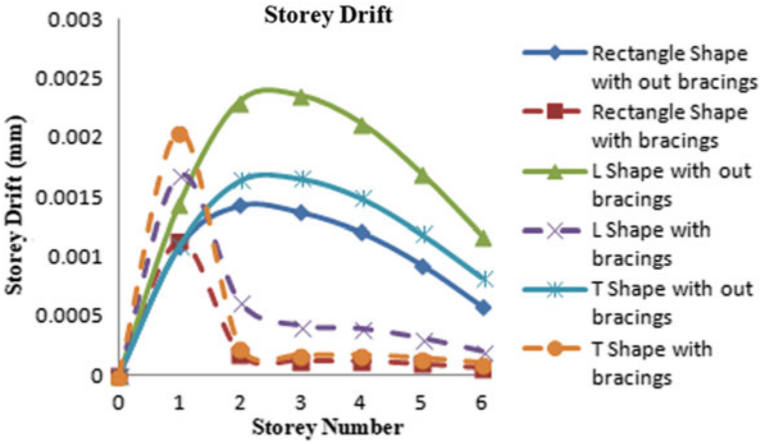


Fig. 12 Storey drift

3.5 Comparison of Storey Overturning Moment in Pushover Analysis

The storey overturning moment variation case for different plan configuration for Push X load case in the presence of bracing is illustrated in Fig. 14. And also storey overturning moment records the highest value in *T* shape plan configuration with bracings (*w*/*b*) and least in rectangular plan configuration without bracings (*w*/ob) which indicates that less moment is required to overturn the storey.

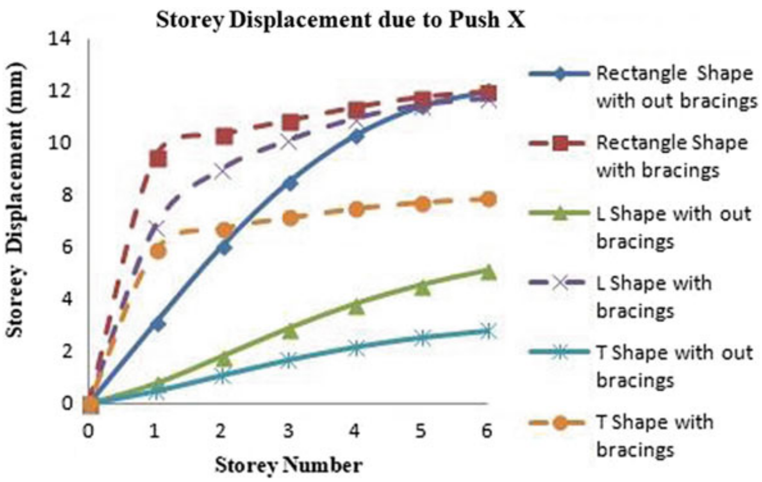


Fig. 13 Storey displacement due to Push X

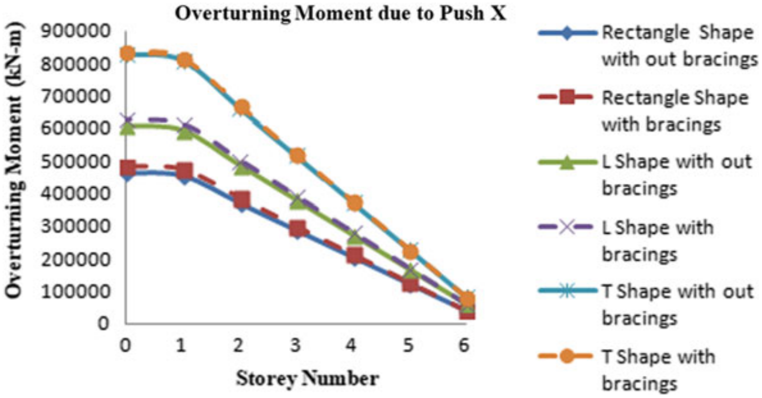


Fig. 14 Overturning moment due to Push X

3.6 Comparison of Storey Drift in Pushover Analysis

From Fig. 15, it can be observed that the maximum drift for Push X load case is maximum in rectangle shape with bracings (*w*/*b*) followed by *L* shape plan configuration with bracings (*w*/*b*). *T* shape plan configuration without bracing (*w*/ob) has shown least value. As per the code IS 1893(Part-1)2002, the maximum drift limit is given by 0.004*h* where *h* indicates height of the storey. Therefore, the drift of storey here did not exceed the limits in the Push X load case.

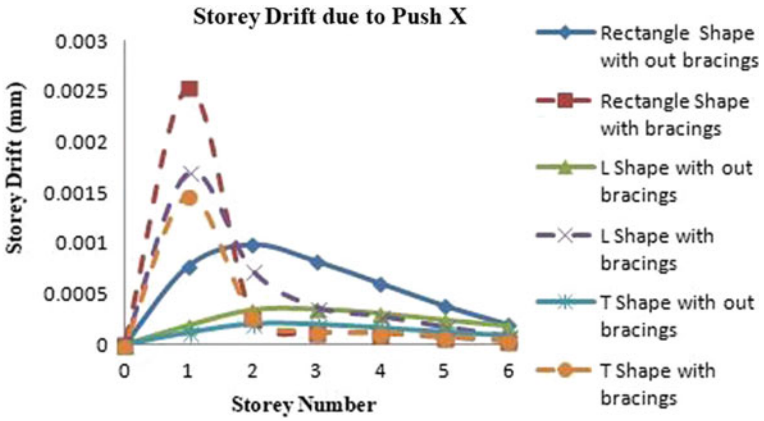


Fig. 15 Storey drift due to Push X

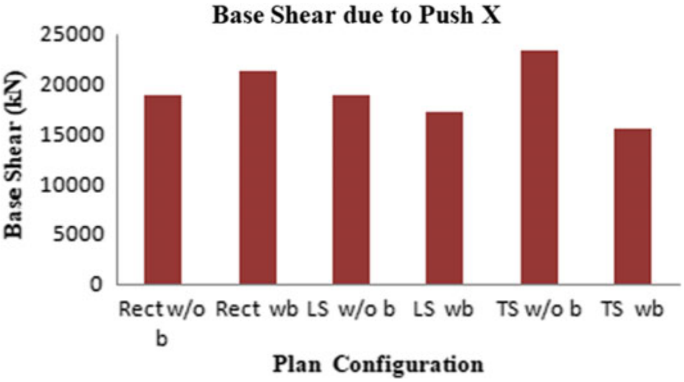


Fig. 16 Base shear due to Push X

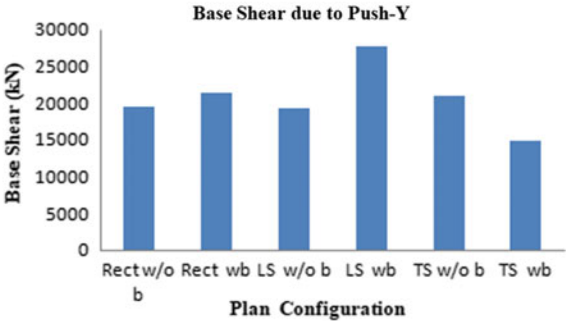
3.7 Comparison of Base Shear Due to Push X Load Case

Base shear due to Push X load case shown in Fig. 16. It is found to be higher in T shape plan configuration without bracings (*w*/ob) due to rise of lateral displacement in the building and least in T shape plan configuration with bracings (*w*/*b*). This is because of increasing formation of plastic hinges in the structure.

3.8 Comparison of Base Shear Due to Push Y Load Case

From Fig. 17, base shear due to Push Y load case is found to be higher in the L shape plan configuration with bracings (*w*/*b*) due to increase of lateral displacement

Fig. 17 Base shear due to Push Y



in the building and least in the *T* shape plan configuration with bracings (*w*/b). This is because of increasing formation of plastic hinges the structure.

4 Conclusions

From the observations and results, the following conclusions drawn are:

1. The storey displacement is found to be within limits and is least in rectangle shape building with bracing and without bracing in Equivalent static analysis.
2. The values of storey drift satisfy the permissible limits, and it was recorded highest in L shape building while the least in rectangular building in Equivalent static analysis while the storey drift values are almost equal in pushover analysis and equivalent static analysis.
3. Overturning moment got its highest values for *T* shape building with bracings and without bracings in both pushover and equivalent static load cases.
4. The values of base shear are found to be highest in *L* shape and *T* shape building while the least values were recorded in *T* shape model with bracings for both Push X and Push Y load cases.

From the results obtained it is concluded that the displacement, drift, overturning moment have drastically decreased in the case of models with bracings due to increase in stiffness and adequate ductility compared to the models without bracings. The base shear is higher due to irregularity in plan configurations and the structures of simple regular geometry with bracings are best sought after for construction in seismic zones.

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