



# Study on earthquake induced torsional irregularity and lateral displacement of RC building with shear wall

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## Abstract

Buildings with shear walls have substantially less sway in the direction of their orientation, which results in significantly less damage to the building. Additionally, shear walls keep the roof or floor from swaying to and from by providing lateral stiffness. Walls may be particularly effective in resisting lateral stresses from wind and earthquakes when they are placed in strategic locations within a building. In this study, we model and analyze the building with varying shear wall positions using ETAB Ver. 0.2 in an effort to discover the optimal site of the shear wall in an asymmetric, irregular, star-shaped G + 14 building in zone IV. Two models, one with a shear wall and one without, have been analyzed. The bare frame model has been compared to analytical results for top story displacement, base shear, time period, static eccentricity, story drift, and torsional moment.

**Keywords** Irregularities · Asymmetric · Stiffness · Optimum location · Torsional moment · Static eccentricity

## Introduction

A minimum amount of lateral stiffness is required of earthquake-proof structures. In order to prevent excessive swinging even when slight shaking occurs. Major requirements in the seismic design of multistory irregularly asymmetric buildings include keeping lateral storey displacement within code-prescribed limits and minimizing torsional effect. Unless a significant amount of shear walls are included for the building, which boosts the lateral stiffness of the building, it will be challenging to meet the aforementioned requirements (Dahesh et al., 2015). Floor area to shear wall area ratio affects the seismic response of RC buildings, as determined by Burak and Comlekoglu (2013). The minimal wall thickness needed

to achieve adequate plane lateral strength was determined using the method outlined by Chai and Kunnath (2005). To make reinforced concrete buildings more earthquake-resistant, Tuken and Siddiqui suggested an analytical method to calculate the required shear wall thickness. In order to determine characteristics like story drift and displacements (Tuken & Siddiqui, 2013), Agarwal and Charkha (2012) conducted a study on a 25-story structure in zone V after conducting preliminary research. Different arrangements are used to build structures so that they serve their intended purpose and look good too. There are essentially two types of configurations. (1) Asymmetry occurs when the locations of the centre of stiffness and the centre of mass do not coincide. Even if the ground shaking is purely translational, lateral-torsional coupled vibration can occur in buildings with asymmetry if the mass and stiffness distribution are such that the centre of stiffness ( $C_S$ ) and the centre of mass ( $C_M$ ) do not coincide (Burak & Comlekoglu, 2013; Kaveh et al., 2010). Jain et al. indicated that buildings with irregular shapes of plan, such as the English letters Z, T, X, Y, or L, or other irregular forms, were more likely to sustain damage during the Bhuj earthquakes of 2001 in Gujarat, India (Jain et al., 2001). According to the some researchers concrete materials are also responsible for resistance of earthquake (Gudainiyan & Parihar, 2021; Kishore & Gupta, 2020;

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Parashar & Gupta, 2020; Tomar et al., 2021). Such structures may have a distorted, convoluted shape that causes great stress concentration at different corners, leading to rapid deterioration (Ali Kaveh & Ilchi Ghazaan, 2017). Many buildings were damaged in the recent Nepal earthquakes of 2015 and the Imphal (India) earthquakes of 2016 because of their asymmetry and abnormalities (Chintanapakdee & Chopra, 2003; Demir et al., 2010; Dutta et al., 2017; Riddell et al., 1987). In order to meet the rigid diaphragm condition, it is recommended that structures in the shape of an L, C, H, I, or X be examined closely to see if their lateral branches are as stiff as the central part. This is per Euro Code:8 Part 1 (CEN-2004). Slenderness in plan, defined as the ratio between the largest and smallest orthogonal dimensions of the building wings, should be no more than 4. According to S.K. Jain and U.K. Mandal, both a rigid and a flexible floor mode exist for Y-shaped buildings if the total stiffness of the building in both directions is equal. This means that if the structure is designed so that the transverse and longitudinal stiffness of each wing are equivalent, the problem of stress concentration at the junction can be avoided (Jain et al., 2001).

In this study, we examine the dynamics of star-shaped, horizontally offset buildings where the floors are assumed to be stiff in their own (Kaveh et al., 2020; Kaveh & Zakian, 2014; Mottaghi et al., 2020). Large open-air atriums are common in multi-story commercial buildings because people like the fresh air and natural light they provide. Common areas, such as an elevator and stairwells, could be located at the intersection of the several wings. Because of the localized stress concentration there, re-entrant, cornered buildings are more susceptible to damage during earthquakes (Zakian & Kaveh, 2022; Ali Kaveh & Zakian, 2014). Most building codes recommend isolating the wings with separation joints to fix this issue, but this is not the best solution because bonding between the two blocks has made the building susceptible to damage. A substantial separation distance would have to be implemented to prevent this from happening, which would be aesthetically unappealing.

Because shear walls contribute substantial lateral stiffness, strength, overall ductility, and energy dissipation capacity, they can be a structurally efficient solution to stiffen a building structure system by minimizing displacement, storey drift, and torsional effect when introduced at advantageous locations. In this study, we checked the effect of lateral force on high-rise irregular buildings and analyzed an irregular, asymmetric structure (a star-shaped, G + 14-story building) having shear walls placed at different locations and compared it with the bare model in seismic zone IV.

## Methodology

### Model formulation

The purpose of this research is to examine the impact of seismic forces on multi-story RC (G + 14) irregular building frames with various shear wall configurations. In seismic zone IV, the Response Spectrum technique is used for the seismic analysis.

This case study examines a G + 14 star-shaped asymmetric and irregular commercial building with an approximate floor area of 4335 m<sup>2</sup>. and a typical floor-to-floor height of 3 m. There is a 5-m gap between each frame. M25-grade concrete and Fe415-grade rebar are used for the structure. For this analysis, we selected 15 different models to test. The shear wall's location is analyzed in comparison to a blank model. The structural properties of RC building are (Table 1).

### Modelling of structural frame

The research takes into account a commercial building with a G + 14 (15-story) star-shaped structure and a typical floor height of 3 m. The Indian code of practice for earthquake-resistant building design was followed in the construction of these structures. The structure is assumed to be grounded. The shear wall thickness and width are uniform across all models. The sheer wall is as tall as the building. In the models, the shear wall is depicted by the red line. 15 models, including a bare model, were analyzed to see how shifting the position of the shear wall in the building frame affected the results of the analysis performed in ETABS version 18.0.2. The configuration of the building's attributes is taken into account, as shown in Table 1. It is assumed that the structural materials are isotropic and homogeneous. A diaphragm has been modeled as a constraint at the connection point between beam and column in the structural model. Figure 1 was indicated the shear walls at different places in star shaped model.

**Table 1** Geometric properties

S. no	Parameter	Values
1	Type of building	Commercial
2	No. of bays in X direction @ 4 m each	5
3	No. of bays in Y direction @ 4 m each	5
4	Slab depth	150 mm
5	Thickness of Shear wall	230 mm
6	Column inner diameter	450 mm
7	Column size	400 mm × 600 mm
8	Inner beam size	300 mm × 300 mm
9	Beam size	300 mm × 400 mm

**Fig. 1** Star shaped with shear walls

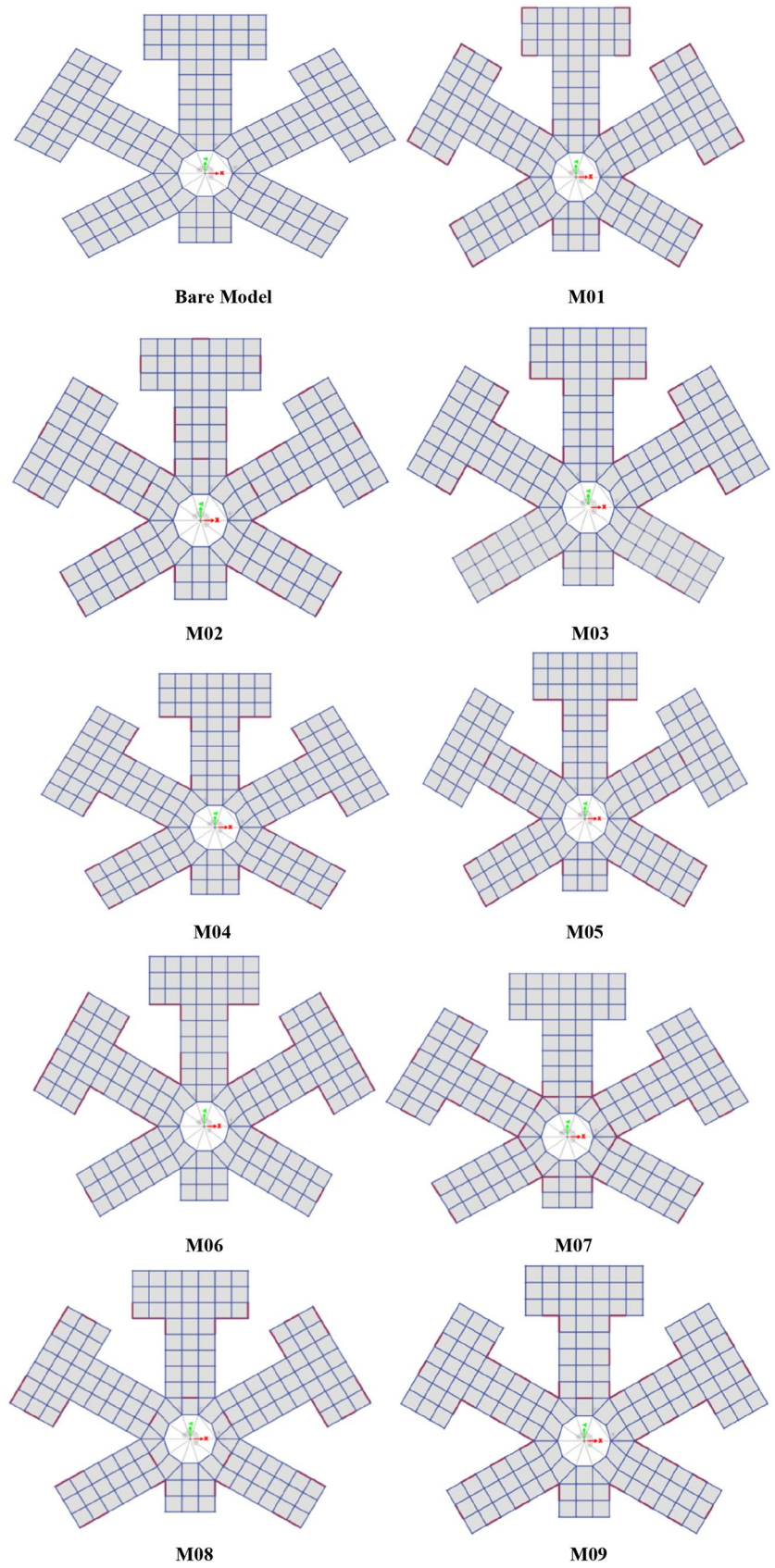
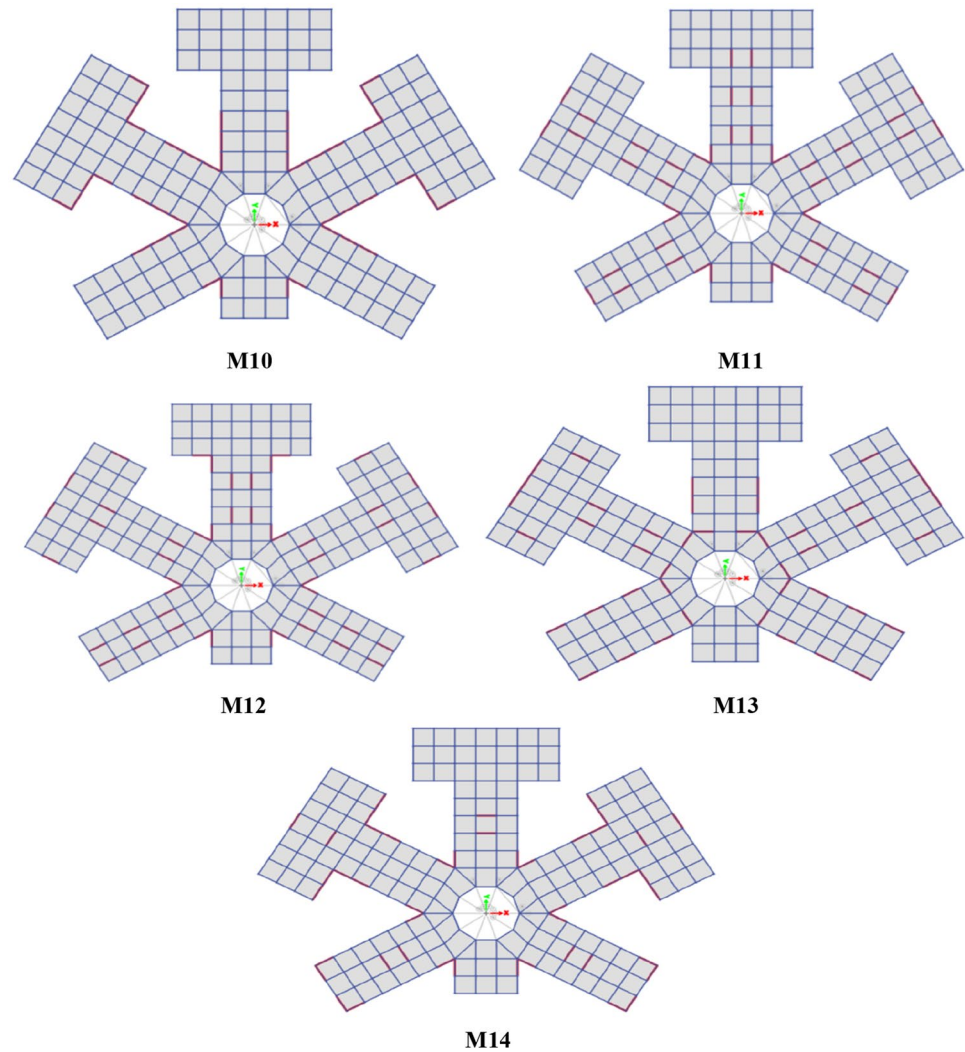


Fig. 1 (continued)



## Method of analysis of structural frame and results

### Response spectrum analysis

Response Spectrum Analysis and Time History Analysis are two approaches used to analyze dynamic structure. The Response Spectrum Analysis technique involves finding the response for each possible vibration mode and then superimposing these responses to get the full response. All structures undergo a Response Spectrum Analysis in accordance with IS 1893 (Part 1): 2016 to determine their seismic vulnerability. Assuming a special moment-resisting frame, the remaining parameters of seismic analysis are zone factor (0.24), response reduction factor (5.0), seismic zone (IV), damping ratio (5.0), and importance factor (1.2). The earthquake force was exerted along the  $X$  and  $Y$  axes. There is no eccentricity in the  $X$  direction for the seismic load, and

there is 5% eccentricity in the  $Y$  direction. Tables 2, 3 and 4 were indicated the material properties, load type and seismic parameter.

### Time period

The time it takes for a structure to go through one oscillation cycle is its natural period, denoted by the "T." After the dynamic analysis from ETABS, we evaluated time period from the mode shape of the test models. It is observed from Fig. 2 that the time periods of Models No. 10 and 14 are equal to 1.18 s and are the least among all models. The maximum value of time period is found to be 2.506 s for the bare model, which is 53% more than the time period of Model 10. The results are shown in the figure below between the bare frame and M10. It is shown that the time period of the bare frame is the maximum and M10 is the minimum.

**Table 2** Material properties

Material property	Grade of concrete	Grade of rebar	Concrete density
<b>As Per IS 456:2000</b> (Bureau of Indian Standards (BIS), 2000)	M 30	Fe 415	25 KN/m <sup>3</sup>

The time period of the bare model is 52.9% maximum from M05. Because of the maximum stiffness in M10 due to the shear wall.

**Base Shear**

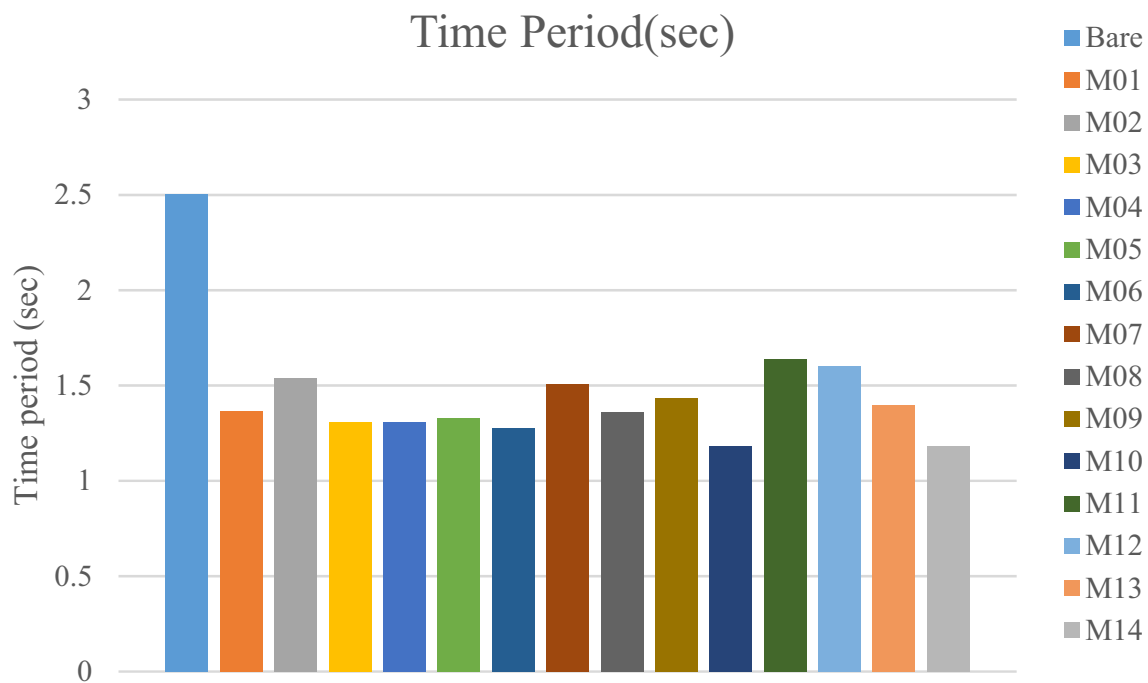
The maximum lateral force that can be predicted to act on the foundation of a building as a result of seismic ground motion is known as base shear. The X- and Y-base shear forces for the bare model shown in Fig. 3 are 8502 and 8580 KN, respectively. Model 10 is seen to have values of 25,230 KN in the X direction and 26,386 KN in the Y direction. Among models showing T-T-R, it ranks highest. For this reason, the shear wall placement proposed by Model 10 might be the best option. The dynamic response of base shear is shown in the figure below, in which the base shear of M10 is a maximum of 66.3% in the X-direction and 67.48% in the Y-direction from the bare frame.

**Table 3** Load type

Loads types	Dead load	Roof live load	Floor live load
<b>As pr IS 875 Part-1 &amp; 2</b> (Kisan et al., )	Self-weight	1.5 KN/m <sup>2</sup> (Clause 4.1, Table 2)	3.5 KN/m <sup>2</sup>

**Table 4** Seismic parameter

Seismic parameter	Zone	Zone factor (Z)	Importance factor (I)	Soil type	Response reduction factor (R)	Damping ratio	Earthquake load
<b>As per IS 1893 (Part-1):2016</b> (Standard, 2016)	IV (Table no. 2)	0.36 (Clause 6.4.2, Table 3)	1.2 (Clause 7.2.3, Table 8)	Type II (stiff soil)	5 (SMRF) (Clause 7.2.6, Table 9)	5% (Clause 7.2.4)	As per IS 1893 (part-1):2016



**Fig. 2** Time duration (s)

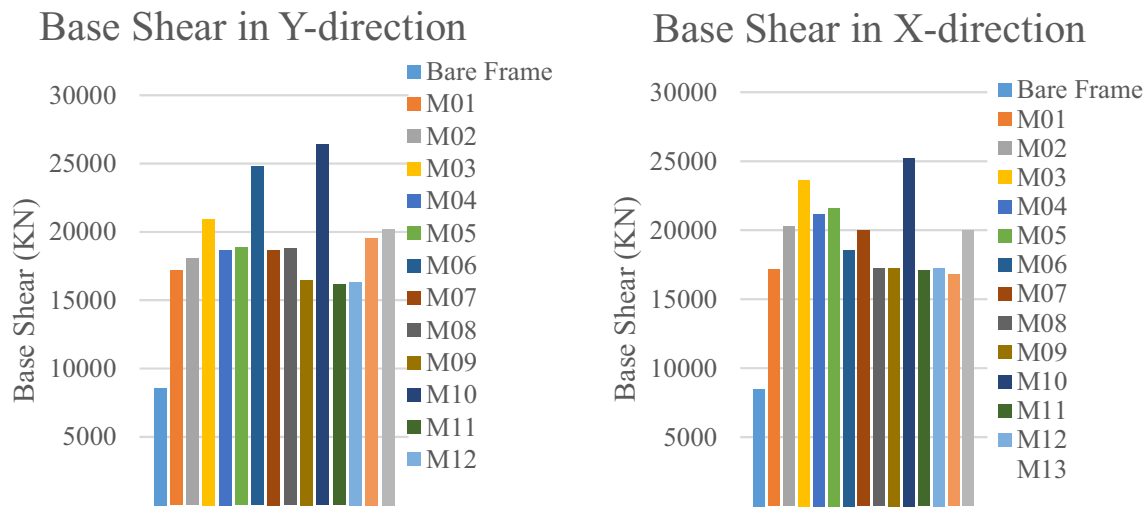


Fig. 3 Base shear

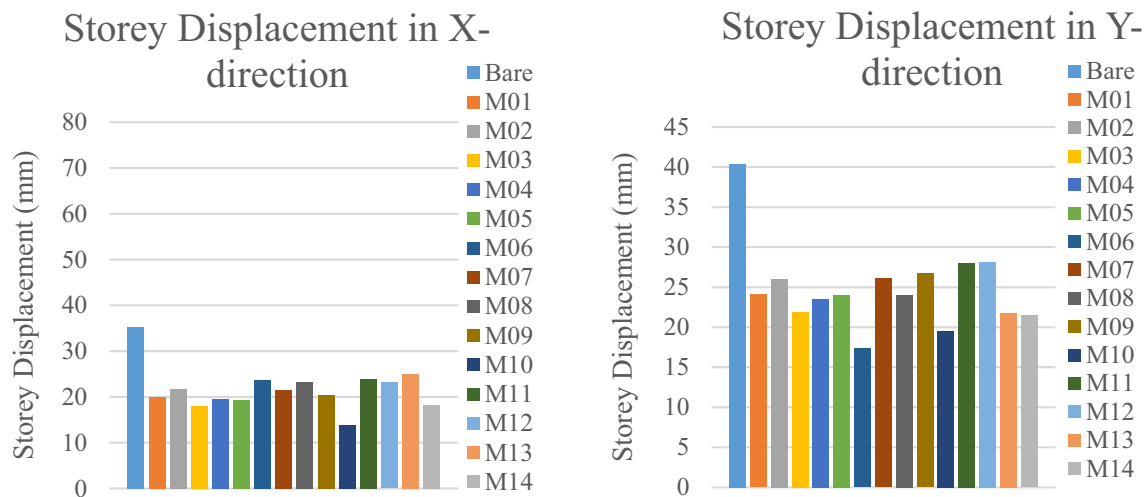


Fig. 4 Story displacement

**Story displacement (top)**

$H/250$  is the maximum displacement allowed in accordance with Eurocode-819, where  $H$  is the building’s vertical elevation above the ground. Based on the formula  $H/250$ , the maximum allowable displacement is determined to be 180 mm. Figure 4 displays the data for the storey displacement of several distinct models. Storey displacement in the X and Y axes was assessed for the test models after their dynamic analysis in ETABS was completed. As can be seen in Fig. 4, the amount of storey displacement along the X-direction for bare models is 10.88 mm, while the amount along the Y-direction is 19.51 mm.

The storey displacement can be greatly reduced by the addition of shear walls. It can be seen from the table that out of the three T-T-R models, Model 10 has the least amount of storey displacement. The dynamic response of storey displacement is shown in the figure below, in which the storey displacement of a bare frame is a maximum of 60.68% in the X-direction and 51.65% in the Y-direction from M10, and it is also within permissible limits.

**Story drift**

Story drift shall not exceed 0.004 times the storey height as per IS 1893:2016 (Part-I) (clause 7.11.1), which determines acceptable drift as per the above-mentioned code

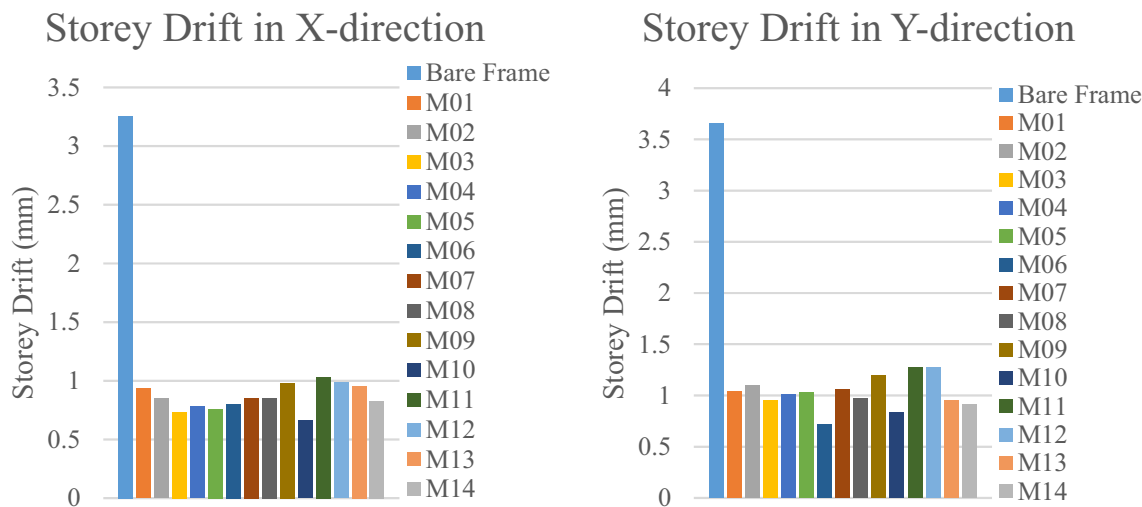


Fig. 5 Story drift

(0.004 times 3000 = 12 mm). This is the maximum allowable drift. Following the completion of the dynamic analysis in ETABS, the storey drift of the test models was measured in both the X and Y directions. Story drift along X and Y directions are found to be 3.257 mm and 3.655 mm, respectively, whereas story drift for model 10 is 0.665 mm and 0.833 mm along X and Y directions, respectively, which is the least among all the models and

also within the limit as per IS Code 1893-2016 (the limiting value is 12 mm).

The dynamic response of storey drift is shown in the Fig. 5, in which the storey drift of a bare frame is a maximum of 79.58% in the X-direction and 77.21% in the Y-direction, and it is also within permissible limits.

**Story shear**

It is observed that story shear for the bare model is found to be 7719 KN and 8002 KN along X and Y directions respectively in Fig. 6, whereas for model 10, story shear is found to be 19740 KN and 20,665 KN along X and Y directions respectively, which is the maximum among all the models.

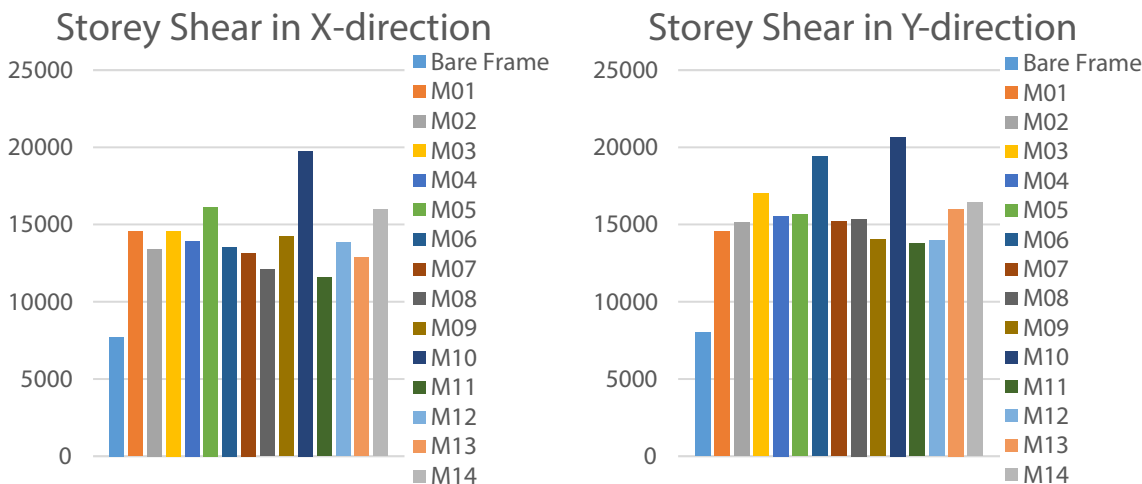
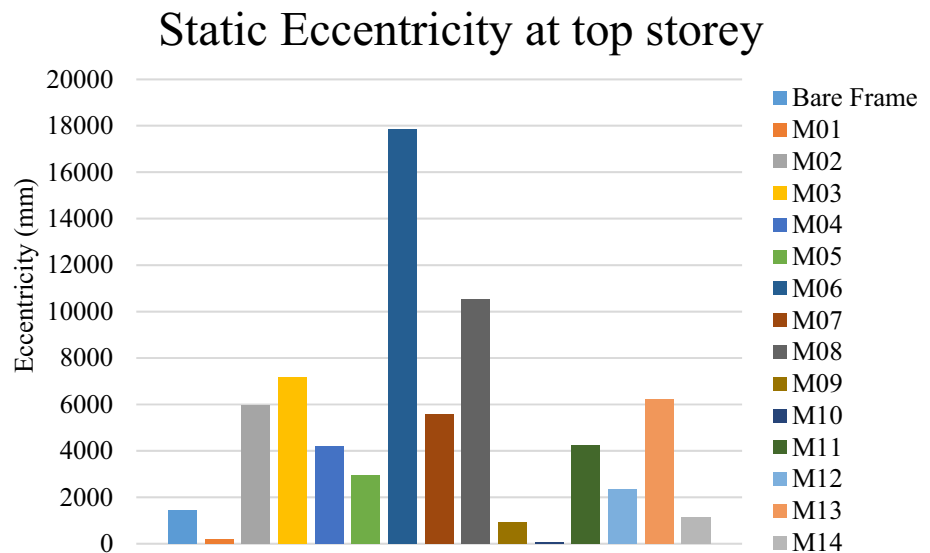


Fig. 6 Story shear

**Fig. 7** Static eccentricity at the top storey



The dynamic response of storey shear is shown in the figure below, in which the storey shear of M10 is a maximum of 60.9% in the  $X$ -direction and 61.27% in the  $Y$ -direction from a bare frame.

### Static Eccentricity

The addition and placement of shear walls impact  $C_m$  (the centre of mass) and  $C_R$  (the centre of rigidity). Torsion owing to static eccentricity along the  $Y$ -direction is nullified since the structure is mirror-symmetric around the  $Y$ -axis, as seen in Fig. 7. A maximum eccentricity of 1467.7 mm is seen in the naked model, but after shear walls are introduced in strategic locations, eccentricity is much reduced. It was measured that Model 10 is 36.8 mm eccentric. Among all the simulations, this is the worst-case scenario. Therefore, the shear wall configuration in Model 10 could be the optimal choice.

The static eccentricity is calculated by the difference between the center of mass and the center of rigidity. As shown in the Fig. 7, the static eccentricity of the bare frame is a maximum of 97.49% from M10 when the shear wall is placed.

### Conclusion

Based on the dynamic analysis of the star-shaped irregularity in the plan of a G+14-story building with different locations of the shear walls, The M10 has a sufficient distribution of shear walls in the building structure. The following are the conclusions:

1. It can be seen from the results and graph that variation in different parameters is dependent on the location of the shear wall.
2. Among all the models, including the bare model, the storey displacement is found to be least in the case of model 10.
3. The placement of shear walls at different locations as per Model 10 shows maximum base shear, which is advantageous for the building.
4. Placement of shear walls at different locations as per Model 10 shows a minimum time period, so the amplitude of the vibration will be less.
5. Placement of shear wall at different locations as per Model 10 shows the least storey drift among all other models, including the bare model.
6. It has been observed that static eccentricity is found to be least for model 10 in comparison to other 14 models, including the bare model, and is 36.6 mm; thus, in this case, the effect of twisting moments in the horizontal plane causing lateral torsional coupled vibration will be minimum.
7. The maximum drift limitation of 0.004 h as per IS CODE 1893-2016 is satisfied for all heights of the building using the linear response spectrum method.
8. In model 10, shear walls are placed at all the re-entrant corners of the wings and parallel to the direction of the wings.

After comparing all the parametric values of different model cases like storey displacement, storey drift, time period, base shear, and static eccentricity, It is concluded that Model 10 is the most suitable shear wall configuration in all the cases.



**Author contributions** RB, AKP and NG designed the study, analyzed the data, and drafted the article. JBS provided critical feedback and helped shape the research, analysis, and manuscript.

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**Data availability** Not available.

## Declarations

**Conflict of interest** The authors declare no competing interests.

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