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Seismic Analysis of RCC Building with Different Shape of Shear Wall and Without Shear Wall

R.C.Bush [1, *], Anoop I. Shirkol[2], J.S. Sruthi [3,]

[1]Research Scholar, Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur Rajasthan, India
[2]Assistant Professor, Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur Rajasthan, India
[3]M.Tech Department of Civil Engineering, Vit University, Chennai, India

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Abstract

Shear walls are earthquake-resistant structural components used in structures at different locations to resist lateral loads. Shear walls possess large in-plane stiffness that aids in the resistance of lateral loads. In this study, dynamic analysis was carried out on a (B+G+26) storey building and the outcome is studied for varying locations of shear walls. The models considered have been analysed and modelled using FEM integrated software ETABS wherein the models are assumed to be present in the seismic zone IV of INDIA as per IS1893-2016. The models are regular in plan and are assumed to be on type -II (i.e., medium soil). The observations made post analysis through the response spectrum method conclude that a regular structure with uniformly placed shear walls at the centre performs better in comparison to structures without shear walls or structures with other positions of shear walls. The result parameters such as storey drift, storey displacement, storey stiffness, time period and base reactions of the models are compared.

Keywords: Shear wall, ETABS, Natural time period, Storey displacement, Base shear, Storey drift

1. Introduction

An earthquake can be defined as the shaking of the ground caused by the sudden release of energy [1]. The vibration generated plays a vital role the in design and analysis of earthquake-resistant structures. There are several methods to reduce the impact of an earthquake on structures. Earthquake imparts both lateral and vertical forces on a structure. Designing an earthquake-resistant structure is of higher importance to dissipate forces. The ultimate goal of an earthquake-resistant structure is to provide adequate stiffness and strength to prevent inelastic deformations[2]. The greater the height of the structure, greater the lateral load acting on the structure and lesser the stiffness[3]. In order to tackle this situation, certain elements are added to the structure such as cross braces, moment resisting frames and shear walls.The importance of shear walls is well explained in this paper. Shear walls are placed based on the center of mass and center of gravity of a structure. There are very few research papers available to understand the effect of shear walls in different locations of a building. However, it has been noted in past research papers that the available locations for the placement of shear walls in a structure are very limited. An attempt has been made in the current study to widen the possible locations of shear walls in a structure. A G+26 storey building has been modeled with various possible locations of shear walls and analyzed using the response spectrum method to understand the effect of the position of shear walls in different seismic parameters.

1.1 ShearWall

A shear wall is a structural component capable of resisting lateral and gravity loads (Earthquake and Wind loads). Shear walls are vertical structural members provided along the height of the building. The thickness of the shear wall usually varies between 150 mm to 400 mm[4].The significant value of the thickness of the shear wall to be provided entirely depends upon various factors such as –the number of story, thermal insulation and design period[5]. RCC shear wall has higher in-plane stiffness in comparison with out-of-plane stiffness. Hence they can resist huge horizontal loads and can also resist vertical loads along the direction of the orientation of the wall [6]. The above attribute of shear walls serves to be advantageous in many structures and can possibly reduce the risk of damage to the structure. Shear walls offer extensive lateral stiffness to the structure thus preventing the roofs and floors from excessive side sway movements

*Corresponding author. Tel: ++919664105045; E-mail address: 2021rce9516@mnit.ac.in

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Fig.1. Illustration of the Champlain tower after its collapse [4].

1.2 Advantage of shear wall

Shear walls offer certain advantages to the structure. Addition of shear walls in a structure can reduce sway during earthquakes by increasing the stiffness and stability of a structure. Figure.1 shows a partially collapsed structure called Champlain towers. The structure situated in Florida collapsed on 24th June 2021 due to the weakening of the reinforcements. Corrosion of the failed reinforcements occurred due to the long term penetration of water from the swimming pool present in one of the floors. A certain portion of the structure failed while the other half had no visible damages. Upon observation it was found that the portion without damages has shear wall installed that may be responsible for extra stability. The collapse of Champlain towers is a great case study to show the importance of shear walls[7]. Shear walls are capable of resisting lateral and powerful torsional forces that can rip a structure apart.

2. Literature Review

Khadri[7] researched on different shapes of shear wall at various locations in a structure subjected to seismic loads. The conclusion states that the optimum positions of shear wall are the intermediate position (core shear wall) and around the periphery of the building.The performance of a structure with shear wall subjected to seismic loads was well elaborated by the researcher Hosseini [8]. The study conducted by the above researcher included rigid framed, wall framed and couple framed structures. Interestingly, the walls not designed for seismic performance did not collapse due to well distributed reinforcements. Tarigan[9] researched on the impact impaled in a structure when position of shear wall is different. The author further observed the change in parameters such structure drift, axial load and displacement when different shapes of shear walls are added to a structure. The study shows that the member forces increases when shear walls are placed farthest from the center of gravity. The above-mentioned position causes high eccentricity, an increase in non-uniform movement of the building due to excessive torsion and member forces. The study conducted Shaik Akhil Pratap [10] emphasizes the importance of distributing shear walls symmetrically based on a careful observation of center of mass and center of stiffness of a structure. The respective researcher modeled three G+20 storied structures with shear walls placed uniformly at the corners on both ends and the same model with shear walls place only at one side of the building. The author concluded that placing the shear walls in a certain way so as to establish uniformity in stiffness reduces the storey displacement, storey drift and torsion in a building thus improving the resistance of a building towards seismic loads. In addition to stiffening the buildings, shear walls can reduce the impact of axial forces too. A theoretical study conducted by Dipika [11] to find the optimum location of the shear wall concludes that the central core shear walls placed symmetrically reduce the storey displacement in a building up to 95% in a regular building. Core type shear walls are more popular in modern days for the provision of lifts that provide additional stability to the structure [12]. However, a study conducted by GokhanTunc[13] shows that the structural performance during a seismic event is increased when the shear walls are placed in a symmetric manner farther away from the geometric center.

3. Objectives of the Study

- The purpose of this study is to evaluate a B+G+26-story structure with a different shape of shear wall profiles installed at various location.
- The purpose of this shear wall analysis is to determine the best placement and form for the proposed building model.
- To compare factors including base shear, natural Period, store shear, store displacement, and store drift.

Table.1 Analysis Data

Floor Area	35.5 X 35.5
No of Story in the structure	B1+G+26
Height of a single storey	3 m
Column size (1 to 5th storey)	750*750 (mm)
Column size (6th to 15th storey)	650*650 (mm)
Column size (16th to 26th storey)	600*600 (mm)
Beam size (1st to 12th storey)	500*600 (mm)
Beam size (13th to 26th storey)	400*600 (mm)
Slab Thickness	200 mm
Wall Thickness	230 mm
Zone	IV
Soil Type	II
Importance Factor	1.2
Response Reduction factor	5

Table.2. Loading data on building

Floor Finish	$3kN/m^2$
Floor Finish on the Roof	$4kN/m^2$
Live Load on floors	$4kN/m^2$
Live load on roofs	$1.5kN/m^2$
Wall Load on the floor beam	15kN/m
Wall Load on the roof beam	5kN/m

4. Modeling & Analysis of the Structure

For the purpose of this research, ETABS is used to create a model of a 26-story skyscraper with 3-meter-high floors [14]. Location Delhi is considered to be in seismic zone IV, the models are considered to be permanently fixed in the base. One bare frame model and six models with varying shapes and placements of shear walls are explored in this research. Compare factors including base shear, natural Period, store shear, store displacement, and store drift.

4.1 Modelling

In this study, six different shapes of shear walls with 6 different locations are taken into consideration. The orientation and shapes of shear walls implemented in this study is shown in Figure 2 to Figure 8. The floor area of the models is 35.5 X 35.5 m^2. The concrete grade is M-35, and the reinforcing grade is Fe-415. The respective thicknesses of slabs and walls are 200 mm and 230 mm. The importance and response reduction factor are taken to be 1.2 and 5. Columns and beams used in the models are given in Table.1. The gravity loads applied on the building such as live load, floor finish, wall load, etc. is given in Table.2

4.2 Analysis method

According to the Indian Code IS1893:2016, the dynamic method is a mandatory analysis procedure that needs to be performed in a structure if the height of the building exceeds 15 meters or if the structure is located in Zone IV [15]. Both the response spectrum method and the time history method are suitable for dynamic analysis. In this paper, a G+26-story skyscraper was evaluated in this study using the response spectrum technique. Maximum response versus the natural frequency of a single-degree-of-freedom system is graphically represented in what is known as the system's response spectrum. The response spectrum approach is used to determine the building's design parameters such as storey displacement and member forces, based on smooth design spectra.The primary limitation of response spectrum analyses is that they can only be applied to linear systems in general [16].

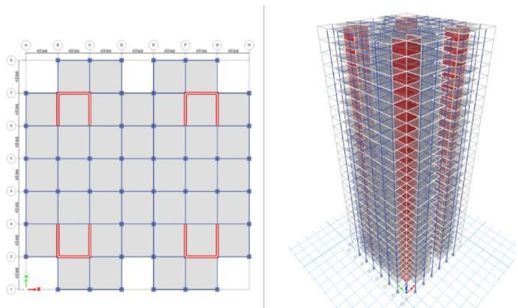

Fig.2. Plan of Structure Box- Shape shear Wall (Model 1)

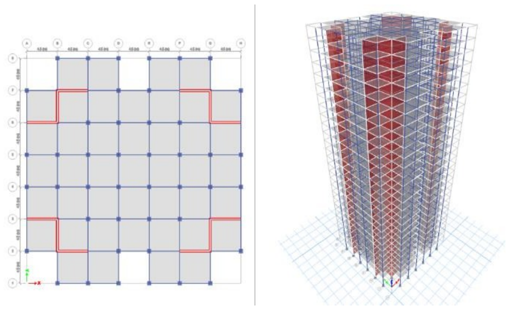

Fig.3. Plan of Structure Z- Shape shear Wall (Model2)

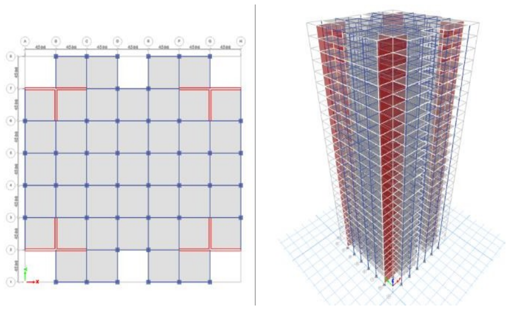

Fig.4. Plan of Structure T- Shape shear Wall (Model3)

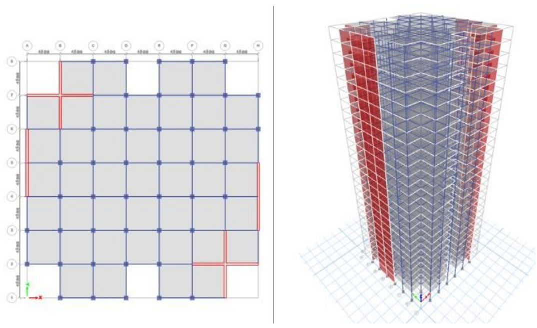

Fig.5. Plan of Structure Plus- Shape shear Wall (Model 4)

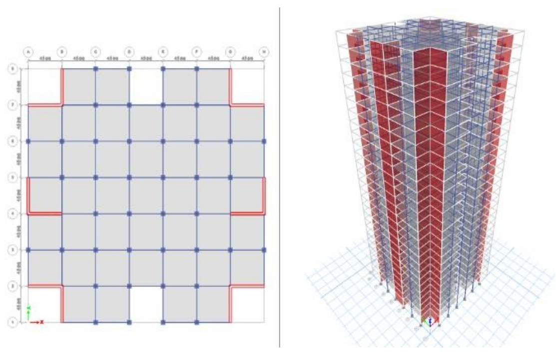

Fig.6. Plan of Structure L- Shape shear Wall (Model 5)

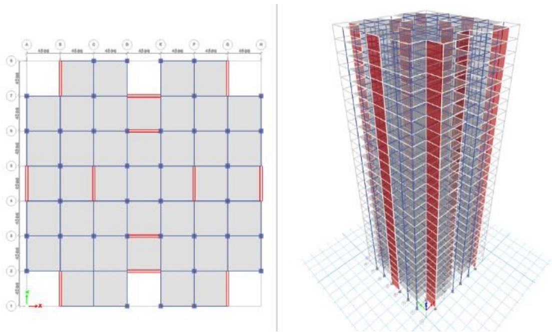

Fig.7.Plan of Structure Side Shear Wall (Model 6)

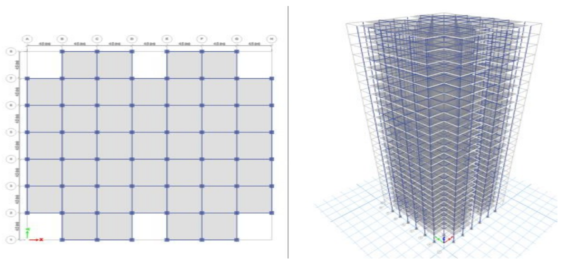

Fig.8. Plan of Structure Without shear Wall (Model 7)

5. Results and Discussion

5.1 Displacement

The displacement values obtained from analysis for all the 7 models and maximum displacement for all the models is shown in Figure.9 and Figure 10. It can be noted from the graphs that the provision of shear walls reduces the displacement in a building during an earthquake. In the case of X direction, the least displacement is found in the T-shaped shear wall model. In the case of Y direction, the least displacement is found in the plus-shaped shear wall model

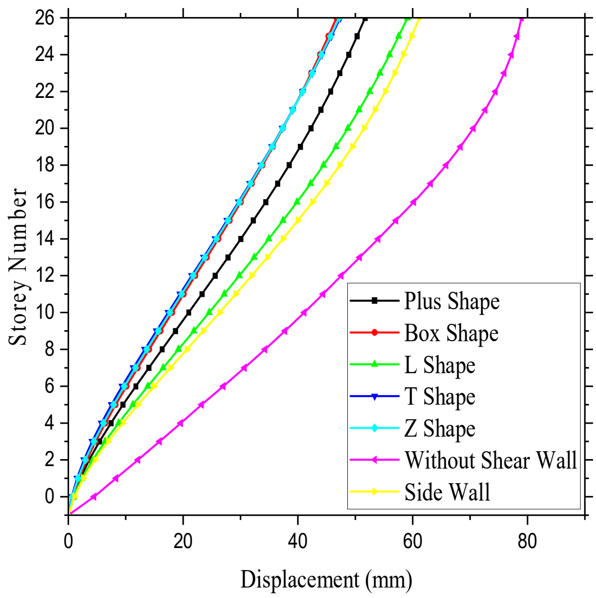

Fig.9. Comparison of storey displacement in X direction

5.2 Storey Drift Ratio

Storeydrift is defined as the difference in displacement among two successive stories divided by the height of a single storey. The values obtained post-analysis are represented in graphs shown in Figure.11 and 12. The above figures show that the provision of shear walls reduces storey drift. The maximum storey drift obtained in the X direction is the least in the case of the T-shaped shear wall in comparison with the other models considered. Similarly, in the case of Y direction, the lease value for maximum storey drift is found in the plus-shaped shear wall model.

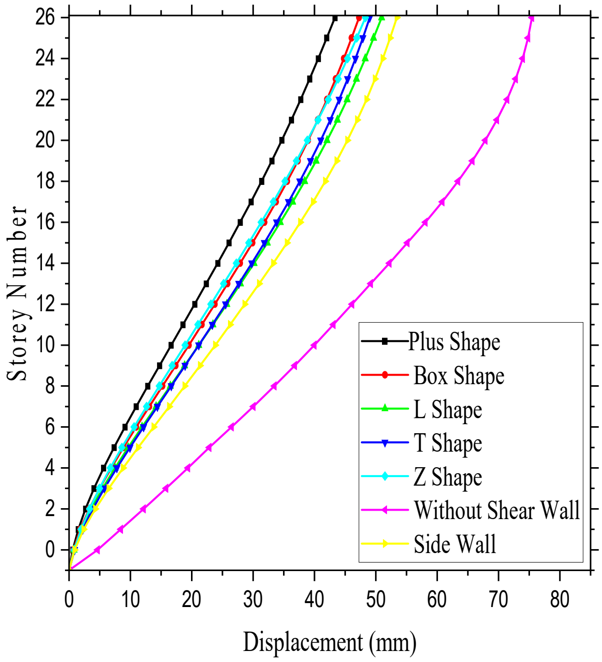

Fig.10. Comparison of storeydisplacement in Y direction

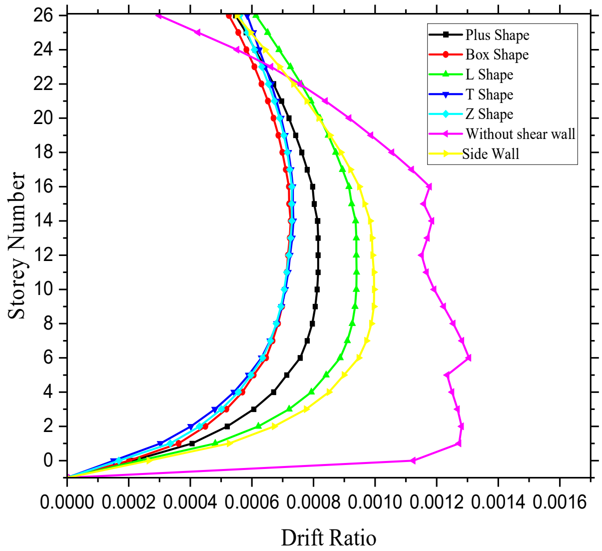

Fig.11. Comparison of storey drift in X direction

5.3 Storey Stiffness

The graphs plotted for storey stiffness for all 7 models are represented in Figure.13 and 14. It can be inferred from the graphs that the storey stiffness is highest in the case of T-shaped shear wall model under X direction. Similarly, the storey stiffness is found to be the highest in the plus-shaped shear wall under Y direction. The bare framed model without shear wall has the least storey stiffness among all the models considered.

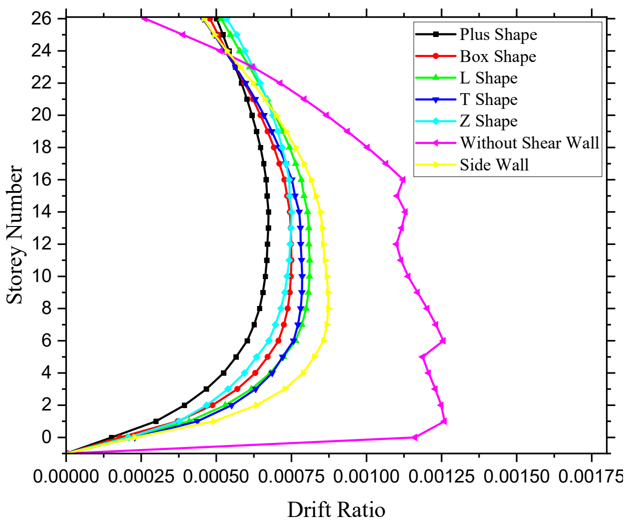

Fig.12. Comparison of story drift ratio in Y direction

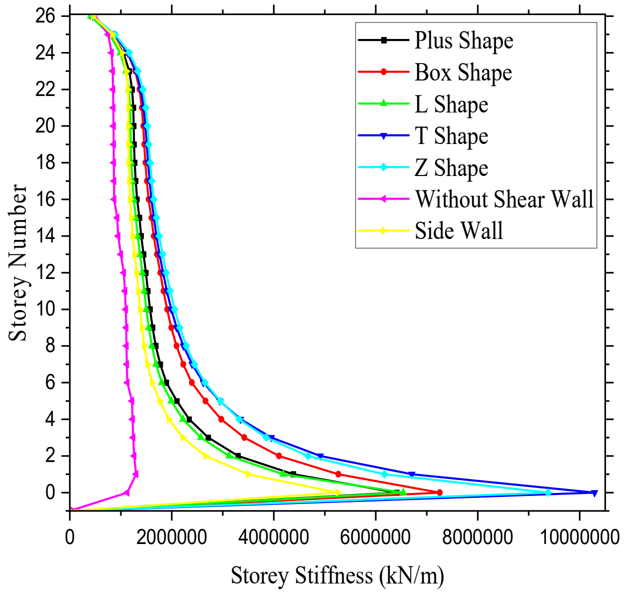

Fig.13. Comparison of Storey Stiffness inX direction

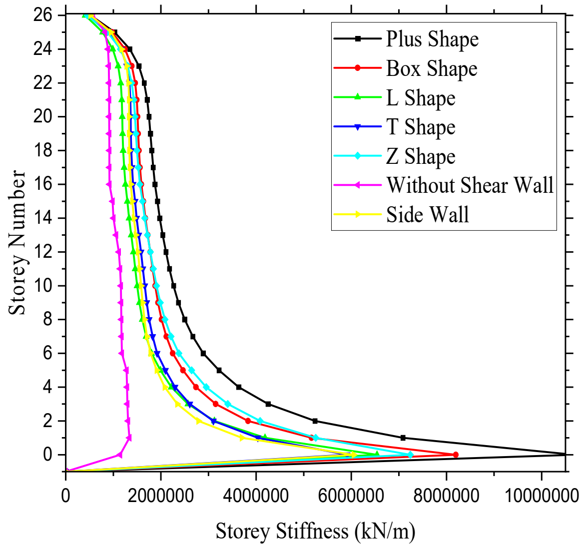

Fig.14. Comparison of Storey Stiffness inY direction

5.4 Base Shear for all Seven Buildings

Table.3 shows the base shear for all the models. With the help of the above table, base shear is found to be the highest in the Z-shaped shear wall model and the lowest in the bare framed model. The inference made from the above table is as follows- The stiffness and mass of the Z-shaped shear model are comparatively higher among all the models and the bare framed model possesses very less stiffness and mass.

5.5 Modal Time Period

Table.3shows the natural time period values obtained for all models. It can be inferred the time period obtained for Z-shaped shear model is the least in comparison with the other models. A lower time period results in lesser displacement and is invariably due to higher stiffness. Similarly bare framed model has the highest time period due to the least stiffness.

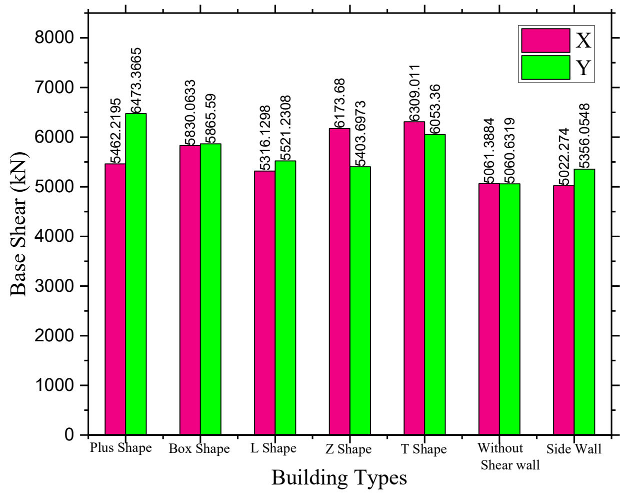

Fig15. Base shear for all models

Table.3. Modal Time period

		BOX SHAPE	Z SHAPE	T- SHAPE	QUADREN T SHAPE	L SHAPE	SIDE WALL	WITHOUT SHEAR WALL
CASE	MODE	Period (sec)	Period (sec)	Period (sec)	Period (sec)	Period (sec)	Period (sec)	Period (sec)
Modal	1	3.417	3.409	3.564	3.751	3.812	3.936	4.706
Modal	2	3.394	3.289	3.277	3.096	3.664	3.693	4.591
Modal	3	2.813	2.589	2.731	2.471	2.853	3.259	4.201
Modal	4	1.015	0.983	1.092	1.101	1.126	1.207	1.616
Modal	5	0.982	0.925	0.901	0.877	1.093	1.151	1.583
Modal	6	0.819	0.71	0.792	0.705	0.821	1.023	1.463
Modal	7	0.494	0.471	0.548	0.531	0.545	0.612	0.918
Modal	8	0.471	0.434	0.41	0.408	0.532	0.586	0.904
Modal	9	0.394	0.329	0.376	0.33	0.385	0.528	0.844
Modal	10	0.296	0.289	0.338	0.321	0.328	0.376	0.647

6. Conclusion

In this study, a B+G+26-storey model with different shapes at varying locations is studied and the conclusions obtained are as follows:

- Base shear is found to be higher in the Z-shaped shear model. A higher value of base shear represents higher stiffness. The base shear is found to be the least in the bare framed model. It can be inferred that the bare frame model offers lower stiffness to the structure in comparison with structures with shear walls.
- Storey stiffness is found to be maximum in the z shaped shear wall when compared to all the other models.
- The natural period is found to be highest in the Z-shaped shear wall model in comparison to all the other models.
- Storey displacement and storey drift is found to be the least in T-shaped shear wall.
- Parameters such as stiffness, base shear, time period, storey displacement and storey drift changes with respect to the location of shear wall. Hence it is important to find the optimum location for better performance.
- From the above observations, the optimum location of shear wall according to this study is to place the shear walls symmetrically at the center.

Disclosures

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