Seismic Response of Setback RC Buildings with Shear Wall

Yash Verma and Rama Debbarma

Abstract Construction of tall buildings is now becoming popular because of the increment in the population and due to limited space in urban areas. Irregular buildings are mostly in fashion because of their aesthetic view and their functional efficiency. A G+10 storeyed setback building with a fixed base and shear wall is considered for the present study. In this study, two types of shear walls, i.e. L-shape and T-shape have been considered. For comparative study, a regular RC building with and without shear walls is also considered. Analysis has been made for both types of building as per IS1893:2016. The responses of some parameters like storey drift, storey displacement, storey shear, bending moment, and base shear are obtained for comparative study. The time period and modal participation factor have been checked for all the models.

Keywords Earthquake loading · Regular building · Setback building · And Shear wall

1 Introduction

In recent years, due to limited space, economical requirements and advanced construction techniques have caused a significant increase in the height of structures. The buildings have become considerably more flexible, lighter, and inherent low damping due to the use of high-strength materials that leads to the possibility of more sway as compared to the high-rise buildings built earlier which can be dangerous during seismic activities, i.e. earthquake loading and wind load. An earthquake exerts lateral as well as vertical forces so to dissipate those forces and vibration in structure, an earth-quake-resistant system has to be designed. Shear walls are one of the best means to provide earthquake resistance in a multistorey building. Shear walls incorporated in the building reduce the effect of an earthquake by improving the effectiveness of the building and ensuring adequate lateral stiffness to resist lateral

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loads [1]. Tidke et al. (2016) analyzed the effect of seismic loading on a building with different locations of a shear wall to check the effectiveness of the shear wall and stated that the presence of a shear wall can affect the seismic behaviour of the frame structure to large extent and it increases the strength of stiffness of structure [2]. Anshuman et al. (2011) analyzed the multistorey building to find out the most suitable location for the shear wall based on its elastic and elastoplastic behaviours [3]. Aktar et al. (2017) acknowledge the effect of P-delta in designing a structure rather than the first-order effect and also help to minimize the pounding action between two tall buildings [4]. Chittiprolu and Kumar (2014) discussed the significance of shear walls in high-rise irregular buildings and show that it can be used to reduce the effect of torsion and provide more resistance to lateral loads [5]. El-Sokkary and Galal (2012) investigate the behaviour of RC shear wall rehabilitated using carbon fibre-reinforced polymer (CFRP) composite sheets to enhance the shear behaviour of the rehabilitated panels [6]. Anya and Ghosh (2021) shown that the position of the shear wall in the core, as well as the corners, shows minimum storey drift and displacement [7].The objective of this paper is to study the seismic response of a G+10 storeyed setback building with two different types of shear walls. In this paper, response spectrum analysis and time history analysis are used to estimate the expected seismic response of the building. For the comparative study, results from a regular building have also been drawn.

2 Methodology

In this present work, all the models are analyzed by both linear and static method which is also known as equivalent static force method and linear dynamic methods that are response spectrum analysis and time history analysis. The details related to all the analysis method are provided below.

2.1 Equivalent Static Force Method (ESFM)

To analyze the models in ESFM, all the load combinations mentioned in IS 1893 (Part 1): 2016 [8] for the limit state design of reinforced and pre-stressed concrete structures are taken.

2.2 Response Spectrum Analysis Method (RSM)

Response spectrum analysis is the linear dynamic method, in which modes of vibrations are considered. The total sum of the modal masses should be more than 90% of the total seismic mass. All the modes are combined by using complete quadratic combination method (CQC), and the directional combination is done using square root of the sum of the squares (SRSS) method. The scaling for the response spectrum load case is done according to the IS1893 (Part 1): 2016 guidelines, i.e. equating the base shear obtained from ESFM to that obtained from RSM.

2.3 Time History Analysis (THA)

For the time history analysis, the ground motion data of Northwest Calif-02 earthquake are considered of 6.6 magnitude.

3 Structure Modelling

In order to evaluate the seismic response of the buildings with and without shear wall, two buildings (G+10 storeys with basement) have been modelled [9] in ETABs software version 17.0.1. The details of the building are (Fig. 1):

• Plan (Regular building) (Setback building)	27 m × 16 m 432 m^2 (up to 4th storey) 272 m^2 (5th to 8th storey) 160 m^2 (9th to terrace)
• Height of each storey	3.2 m
• Height of basement	3.5 m
• Grade of concrete	M35 (For column) M30 (For beam) M25 (For slab)
• Grade of steel for rebar	HYSD 415 (tie bars) HYSD 550 (longitudinal bars)
• Size of beam	300 mm × 450 mm
• Size of column	450 mm × 450 mm
• Thickness of slab	140 mm
• Live load on floors:	3 kN/m^2
• Live load on roof:	1.5 kN/m^2
• Wall load:	12.88 kN/m^2
• Floor finish:	1.2 kN/m^2 2 kN/m^2 (for terrace)
• Seismic zone:	V
• Zone factor (Z):	0.36
• Soil type:	Type II (medium soil)
• Damping ratio:	5%

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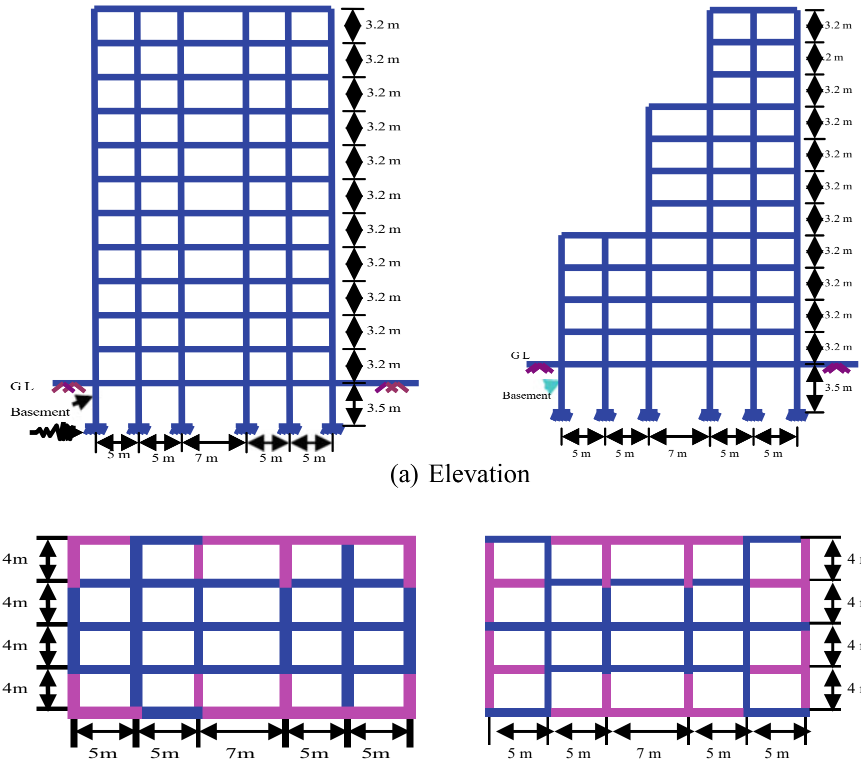
• Frame type:	Special moment resisting frame
• Response reduction factor:	5
• Importance factor (I):	1.2
• Attributes of real earthquake records:	The real earthquake ground motion, Northwest Calif-02 of 6.6 magnitude is used for the present study



(a) Elevation

(b) Plan with L-shape and T-shape Shear wall

Fig. 1 G+10 storeyed regular and setback RC buildings with shear wall

4 Results and Discussion

4.1 Regular Building Model

- **Storey Displacement**: The variation of displacement of regular RC buildings with or without shear wall is shown in Fig. 2. The displacement is controlled with the shear wall. From the graph, it can be seen that the displacement reduction is more in L-shape shear wall compared to T-shape shear wall.
- **Storey drift**: The storey drift ratio is the relative displacement between the adjacent floors. The results obtained by both methods are shown in Figs. 3 and 4. It is observed that the L-shape shear wall is more effective to reduce the storey drift as compared to T-shape shear wall.
- **Storey stiffness**: It is observed from the Fig. 5 that the building with L-shape shear wall has the maximum storey stiffness, whereas the building model without shear wall shows the minimum.

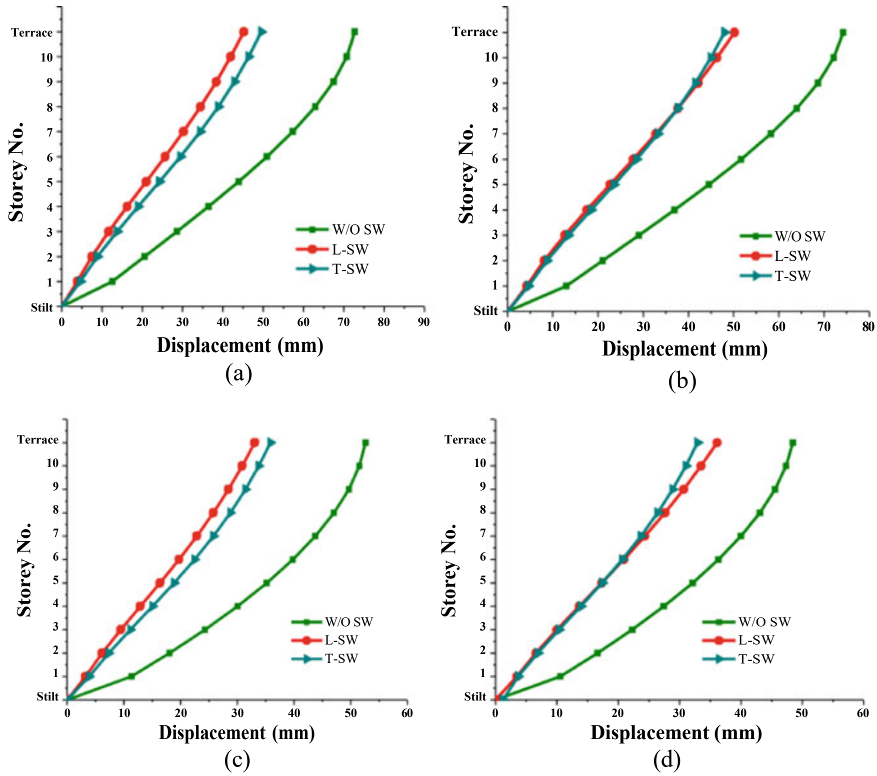


Fig. 2 Variation of displacements of regular buildings in **a** x-direction by ESFM, **b** y-direction by ESFM, **c** x-direction by RSM, and **d** y-direction by RSM

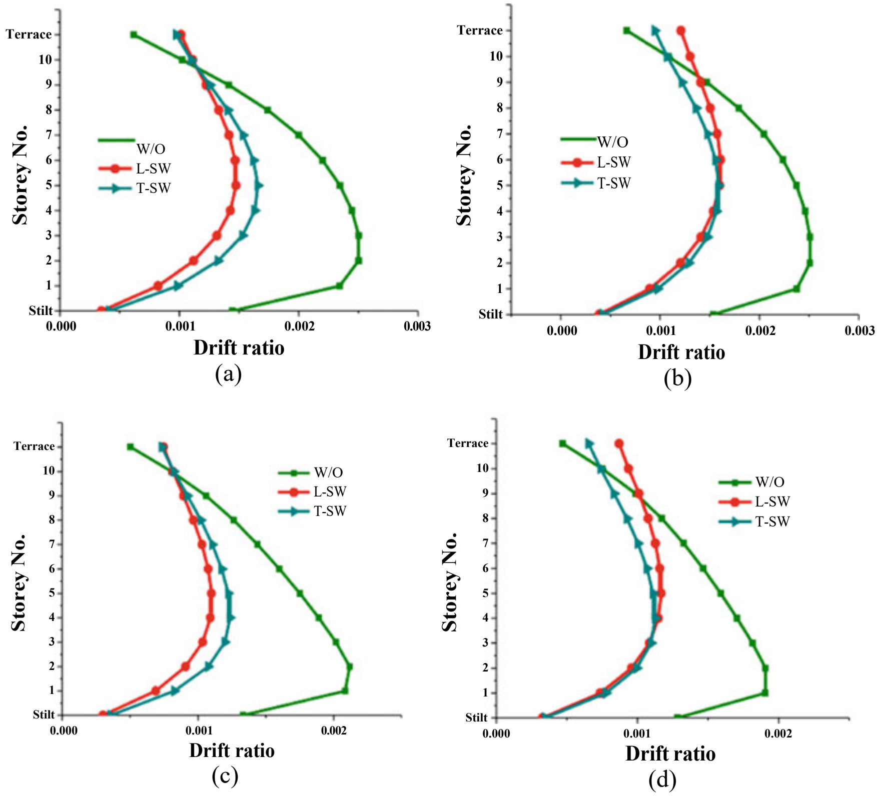


Fig. 3. Variation of inter-storey drift of regular buildings **a** x-direction by ESFM, **b** y-direction by ESFM, **c** x-direction by RSM, and **d** y-direction by RSM

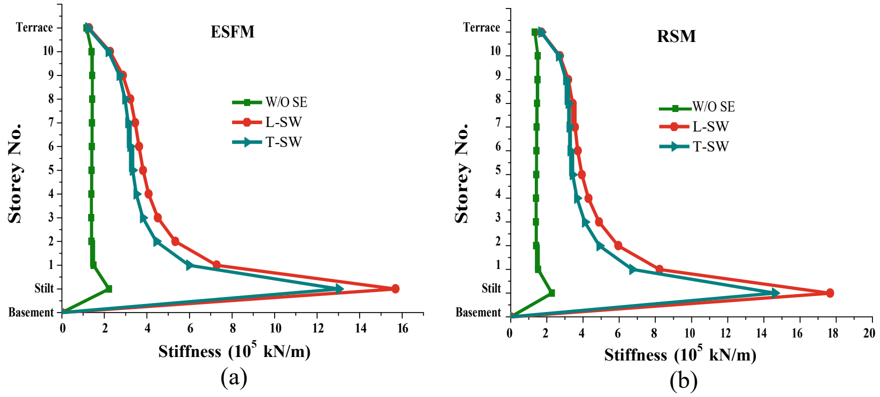


Fig. 4. Variation of stiffness for regular buildings **a** in ESFM and **b** in RSM

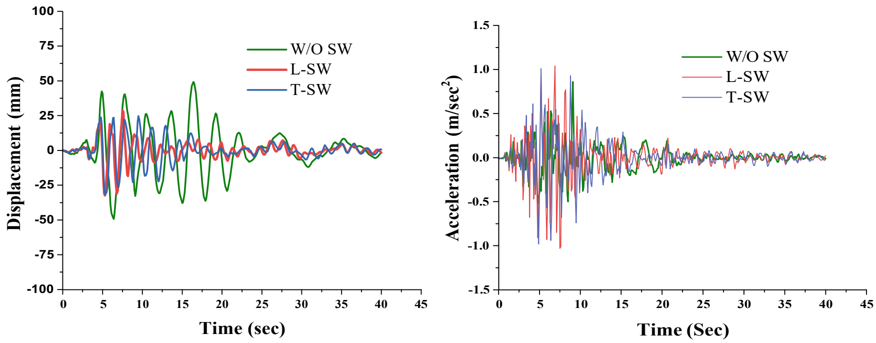


Fig. 5 Variation of displacement and acceleration of regular buildings considering real earth- quake ground motions

- **Time history results**: From the figure, it can be observed that L-SW is more effective to reduce the top storey displacement of the building considering the 5% damping ratio of the structure. The variation in the acceleration of the structure with time is shown in Fig. 6. From the figure, it can be observed that the acceleration is maximum for L-SW, and the significant duration of the earthquake is 5–10 s.

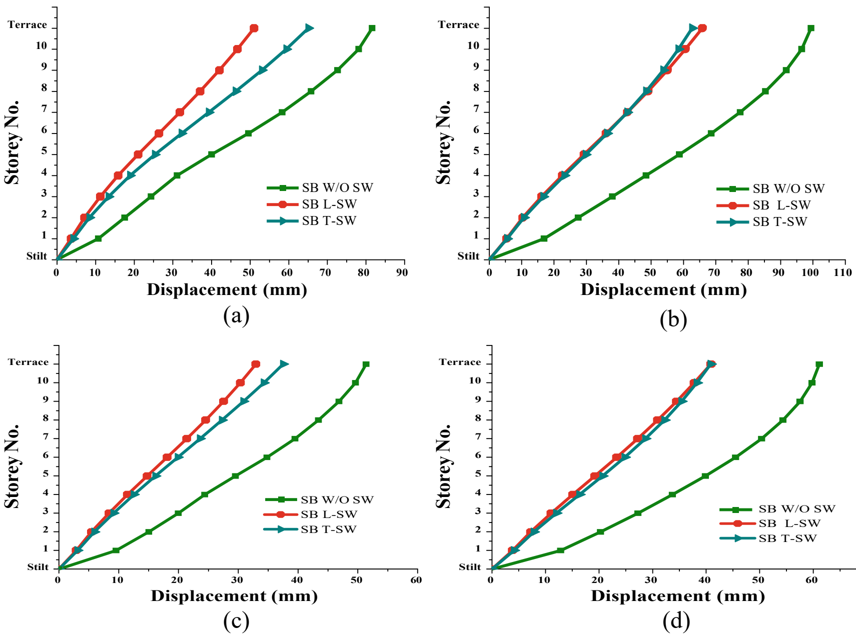


Fig. 6 Variation of displacements of setback buildings in **a** x-direction by ESFM, **b** y- direction by ESFM, **c** x-direction by RSM, and **d** y-direction by RSM

Table 1 Fundamental time period of regular buildings

Regular building	Mode	Time period	Model mass participating ratio	
			Sum Ux	Sum Uy
Without shear wall	1	2.774	0.8164	0
	2	2.548	0.8164	0.8175
	3	2.455	0.8164	0.8175
L-shape shear wall	1	1.482	0.7274	0
	2	1.39	0.7274	0.7109
	3	1.07	0.7274	0.7198
T-shape shear wall	1	1.668	0.7397	0
	2	1.497	0.7397	0.7429
	3	1.232	0.7397	0.7429

- **Time period**: The time period of all the models for the first three modes is shown in the Table 1.

4.2 Setback Building Model

- **Storey displacement**: In the direction of the force and transverse direction, the maximum displacement is recorded for without shear wall model, because of lesser vertical geometric irregularity and lesser stiffness caused by the absence of shear wall. Out of both the shear walls, the L-shape shear wall has shown minimum dis- placement in y-direction, whereas in x-direction, both shear walls have shown almost equal displacement control, with L-SW being minimum as shown in Fig. 7.
- **Storey drift**: The results are shown in Fig. 8. It is observed that the L-shape shear wall is more effective to reduce the storey drift as compared to T-shape.
- **Storey Stiffness**: It is observed from the Fig. 9 that the building with L-shape shear wall has the maximum storey stiffness, whereas the building model without shear wall shows the minimum.
- **Time history results**: The time history results also reveal the vulnerability of without shear wall setback structure as the top storey displacement and acceleration are maximum in Fig. 10. The other two models have been excellent in displacement control.
- **Time period**: The time period of all the models for the first three modes is shown in the Table 2.

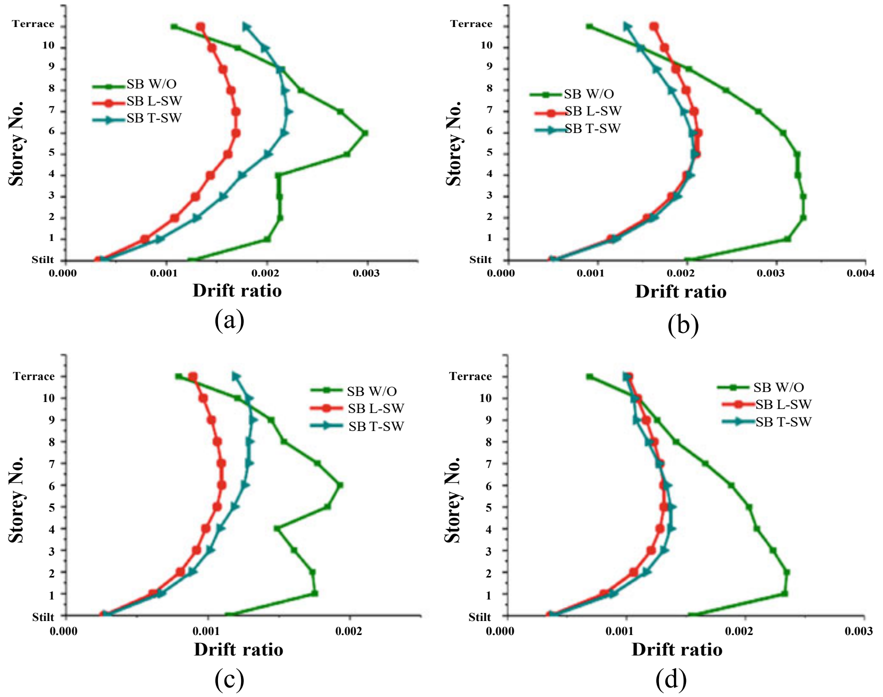


Fig. 7 Variation of inter-storey drift of setback buildings in **a** x-direction by ESFM, **b** y-direction by ESFM, **c** x-direction by RSM, and **d** y-direction by RSM

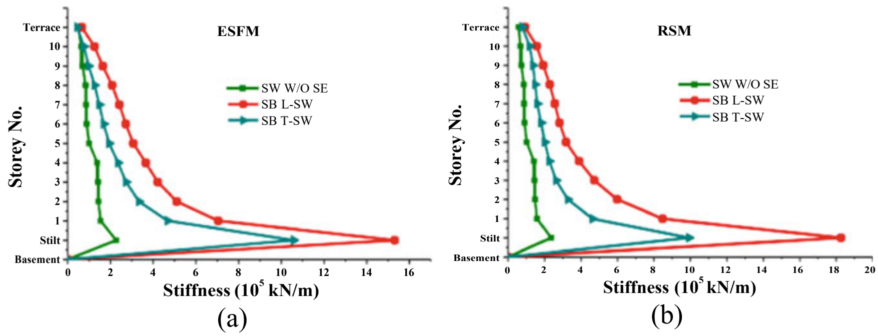


Fig. 8 Variation of stiffness for setback buildings **a** in ESFM and **b** in RSM

4.3 Comparative Study Between Both Buildings

- **Base shear**: Base shear due to earthquake force has been obtained in both of the methods ESFM and RSM are balanced by the scale factor as per IS 1893 (Part 1): 2002. For both the buildings, it has been observed that the base shear is a

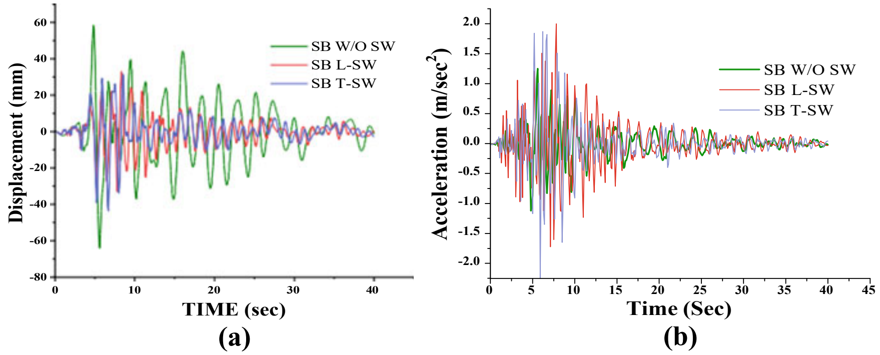


Fig. 9 Variation of displacement and acceleration of setback buildings considering real earth- quake ground motions

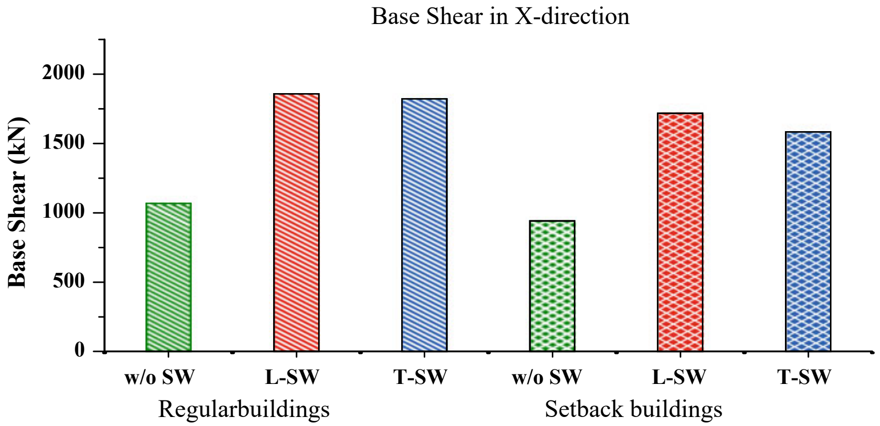


Fig. 10 Variations of base shear for all the models

Table 2 Fundamental time period of setback buildings

Setback building	Mode	Time period	Model mass ratio sum Ux	Participating sum Uy
Without shear wall	1	2.402	0	0.544
	2	2.303	0.7384	0.544
	3	1.548	0.7384	0.7617
L-shape shear wall	1	1.288	0	0.5401
	2	1.25	0.6571	0.5401
	3	0.656	0.6571	0.661
T-shape shear wall	1	1.385	0.6602	0
	2	1.319	0.6602	0.5694
	3	0.788	0.6603	0.6522

function of mass and stiffness of the structure, so except bare frame models, in all other models, the base shear has increased due to the stiffness and mass by the inducement of the shear walls.

4.4 Conclusions

A G+10 storeyed RC building with or without shear wall has been considered for the present study. The following conclusion has been drawn based on the present study which is as follows:

- The displacement of regular RC buildings is controlled with the shear wall. From the graph, it can be seen that the displacement reduction is more in L- shape shear wall compared to T-shape shear wall. The storey displacement is reduced to 38% by installing L-shape shear walls in the corners, whereas the storey displacement is reduced to 32% by installing T-shape shear wall at the intermediate sides of the building whereas in the y-direction, storey dis- placement is reduced to 32% for L-SW and around 35% for T-SW.
- In the case of the setback building, the storey displacement in x-direction is reduced to 37% by L-shape shear wall whereas T-shape shear wall was able to restrict it by 20%, whereas in the y-direction, storey displacement was restricted by 33% and 36% by L-shape and T-shape shear wall, respectively.
- The inter-storey drift ratio shows that the L-shape shear wall is more effective than T-shape shear wall for both buildings as it has the minimum drift ratio, all the models are under the maximum drift ratio limit stated by the IS 1893:2002, i.e. 0.004.
- The top storey displacement with time considering time history data of Northwest Calif-02 and 5% damping ratio is observed, and it is found out that L-SW minimizes the displacement very efficiently and considering variation in acceleration, buildings without shear wall has the minimum acceleration.

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