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Seismic Response of Irregular High Rise Building in Kathmandu with Shear Wall

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Abstract

Rapid population growth is one of the common problems in city areas like Kathmandu. This rapidly growing population demands a large land area. The limitation of land and as a matter of prestige for organizations, construction of high-rise buildings is increasing. Because of aesthetics, ventilation, and land availability these buildings may be irregular in shape. An analytical study is carried out to determine the most suitable location of the shear wall in the irregular high-rise building that had Pre-existing torsion. The objective of the study is to determine the suitable position of the shear wall and the effect of curtailment and thickness of the shear wall in irregular high rise structures. Model response spectrum analysis is carried in the building using Etabs version 16. Seismic design code NBC 105:2020 is used for analysis. Maximum story displacements, story drift, base shear and model time period are taken as the parameter for analysis. According to the result, it is concluded that the proper location of shear wall can remove torsion in the building. The wall can also be curtailed by 60% of the height keeping torsion and other codal provision within the limit. From the analysis, it is found that for full height shear wall, deflection of building decreases about 1% for 50mm increase in shear wall thickness.

Keywords

High Rise Building, Shear wall, Torsional Irregularity, Curtailment, Wall thickness

1. Introduction

In the present context of rapid urbanization, the trend of constructing high-rise buildings is increasing in city areas. Nepal being the country in the seismically active belt of Himalayas has faced several minor and some major earthquakes. The Himalayas are the youngest chain on the planet and is believed to still evolving thereby not having stabilized from geological and geomorphological considerations [1]. This geological condition of Nepal makes it vulnerable to frequent occurring earthquake. Earthquakes are natural hazards that may occur at any time without any warning. These earthquakes affect civil engineering structures to a great extent when they are ignored in the design of structures and also cause the loss of life due to the destruction of these structures. So, it is always important to study the seismic capacity of the structures so that loss of life and property can be minimized.

High rise buildings are defined as the buildings that are 9 to 39 stories or between 25m to 100m [2]. Irregularity exists in the structure because of aesthetics, available land and many other reasons. Studies have shown that irregularity in structure reduces the performance of the structure and should be considered during analysis [3]. In the analysis of buildings by changing orientation of column and adding shear wall, that had torsion earlier, can be minimized. After making fundamental modes as translational, the major requirement in building in flexure and it results in optimal plastic mechanism [4]. Shear walls at exterior perimeter shows better performance to seismic loading [5]. The study on the effect of a shear wall to floor area ratio between 0.51 and 2.17% showed that at least 1% shear wall area ratio is required for drift control [6]. The study on curtailment of shear wall on 12 story building showed, shear wall can be curtailed to tenth level by making the drift within the limit [7]. The deflected shape of the wall-frame structure has two regions. A lower region with flexure dominant and upper region with shear dominant. Curtailing wall in the upper region where the frame is effectively stiffer allows the frame to be almost vertical at the top [8].

The objective of the study is to determine suitable position of shear wall, the effect of the shear wall thickness and curtailment in the existing irregular high rise building.

2. Building Description

For the study, an existing irregular apartment building is taken into consideration. It is ten story building including one basement. The significance of taking this building as a case study building is because of its asymmetric plan dimension and torsional irregularity. The description of model is given below.

Column size: 400mm*400mm, 400mm*600mm, 400mm*700mm, 400mm*800mm

Size of beam: 400mm*550mm

Slab: 125mm

Grade of concrete: M25

Grade of rebar: HYSD500 TMT

Dead load: As per IS875 (Part 1)

Live load: As per IS875 (Part 2)

Importance factor: 1

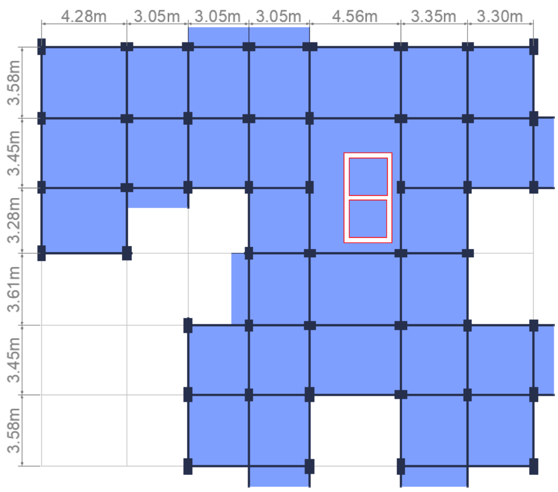


Figure 1: Plan of existing building

3. Methodology

The analysis of the building has been carried out using Etabs. Model Response Spectrum Method is used as the method of analysis. NBC 105:2020 is used for analysis. For the study, existing irregular high rise building is considered. First the actual building is modeled and analyzed. It is observed that there is torsion in the first mode which is not desirable. Torsional irregularity is removed by coinciding center of mass and rigidity in the structure. This is done by adding shear walls in the building as shown in Figure 2 and 3. After getting the required result, shear wall height is curtailed from the top to determine the effective height of shear wall without affecting the performance of the building. Further shear wall thickness was also varied as: 200mm, 250mm and 300mm to determine the optimum thickness required. All the results are tabulated below.

The model which is exactly like the existing building is named ’A’. Model with shear wall thickness 200mm with a full height of shear wall is named ’2A-0’. For model with shear wall reduced for one story from the top is ’2A-1’, for two stories is ’2A-2’ and so on.

The model with shear wall thickness 250mm with full height of shear wall is named ’2.5A-0’. Model with shear wall reduced for one story is ’2.5A-1’, for two stories is ’2.5A-2’ and so on.

The model with shear wall thickness 300mm with full height of shear wall is named ’3A-0’. Model with shear wall reduced for one story is ’3A-1’, for two stories is ’3A-2’ and so on.

Codal Data

Height of building (H) = 30m

Time period form empirical formula = $0.05H^{0.75}$ =0.6409s

Increment of time period (Cl 5.1.3) = 1.25*0.6409 =0.8012s

Spectral shape factor for soil type D, Ch(T) = 2.25

Seismic zoning factor, Z = 0.35

Importance factor, I = 1.0

Elastic site spectra, C(T) = Ch(T)ZI = 0.7875

Elastic site spectra for serviceability limit state, Cs(T) = 0.20C(T) = 0.1575

Ductility factor ($R\mu$) for Ultimate limit state = 3.5

Ductility factor (Rs) for Serviceability limit state = 1

Over-strength factor (Ωu) for Ultimate limit state = 1.4

Over-strength factor (Ωs) for Serviceability limit state = 1.2

Horizontal base shear coefficient for ultimate limit state, Cd(T1) = C(T)/($R\mu$ x Ωu) = 0.161

Horizontal base shear coefficient for serviceability limit state, $C_d(T_1) = C_s(T)/(R\mu \times \Omega u) = 0.131$

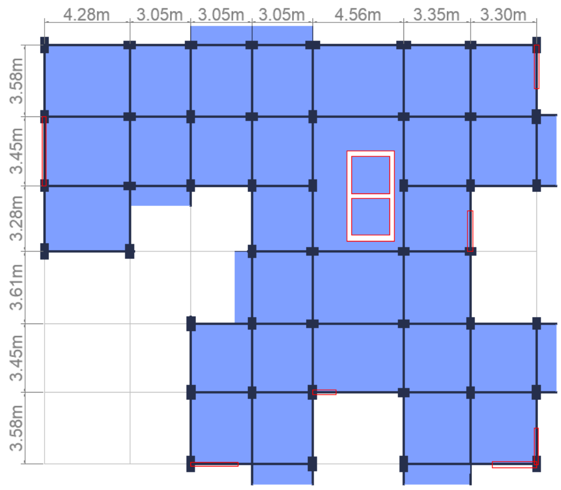


Figure 2: Plan of building with shear wall

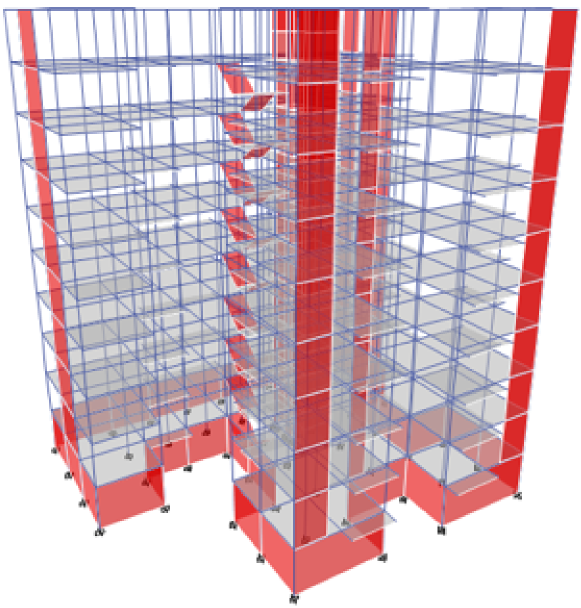


Figure 3: 3D of building with wall

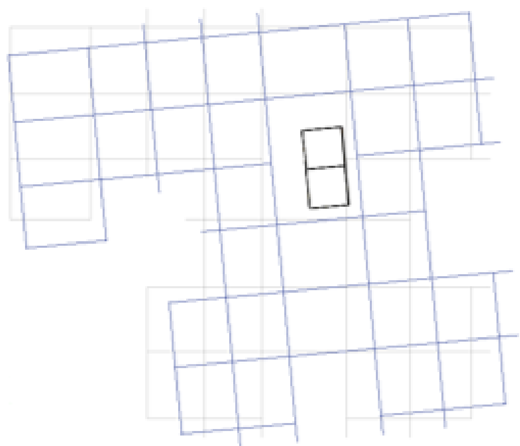
4. Result and Discusssion

The result from the modal response spectrum analysis is obtained and tabulated as shown in the table below. From the modal participation mass ratio and the deformed shape of the building at different modes, the first mode is dominated by torsion in the existing building. In the second mode, there is coupling of two translational mode. This is not desirable in the building. To make the first two modes translational in each direction shear walls are added to the building as shown in Figure 2 and 3. The position of shear wall is finalized such that center of mass and rigidity coincides in the structure. First the thickness of shear wall used is 200mm. Shear wall initially is used to the full height. The response of the building with the shear wall is noted. Then the shear wall is curtailed one by one at each story starting from the top story, to determine the effect of curtailment on the shear wall. The shear wall was curtailed until the building had first two mode translational. After curtailing wall, mass participation in reducing in translation direction and increasing in rotation. This is due to decrease in torsional rigidity after curtailment. From the table, it can be seen that shear wall can be curtailed to six level from top. The data for the each cases is shown in the table. The thickness of the shear wall is also increased to 250mm and 300mm to see the effect of increasing thickness in the building. These wall are also curtailed similarly as the 200mm thick wall. The result for modal participating mass ratio is shown in the table below.

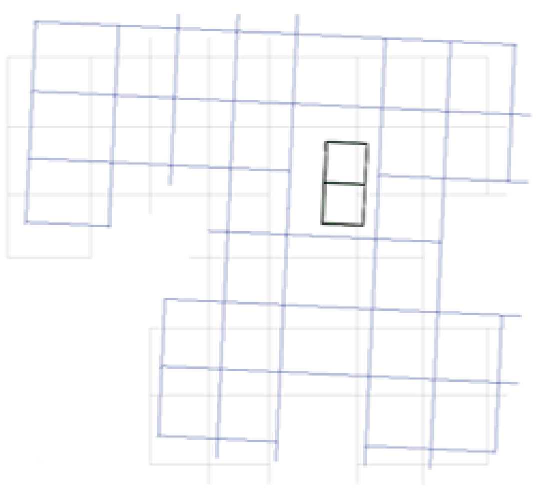
Table 1: Modal Participating mass ratio

	Building 'A'			Building '2A-0'		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.276	0.029	0.418	0.720	0.002	0.000
2	0.272	0.385	0.068	0.002	0.708	0.001
3	0.179	0.307	0.235	0.000	0.000	0.695

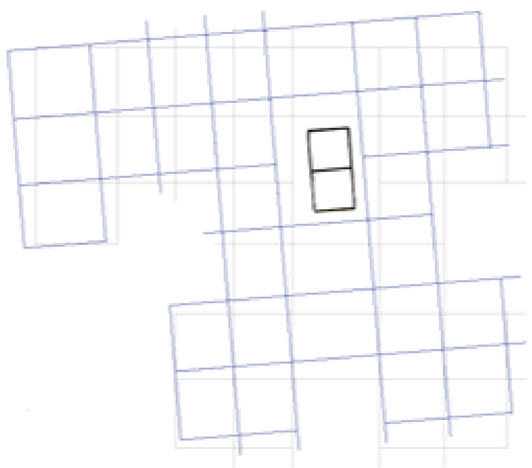
	Building '2A-6'			Building '2A-7'		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.680	0.002	0.018	0.399	0.020	0.266
2	0.001	0.680	0.004	0.255	0.240	0.207
3	0.029	0.002	0.710	0.058	0.436	0.203



Mode 1

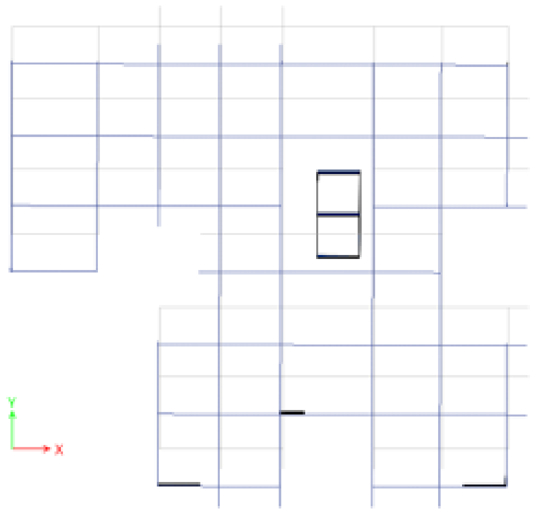


Mode 2

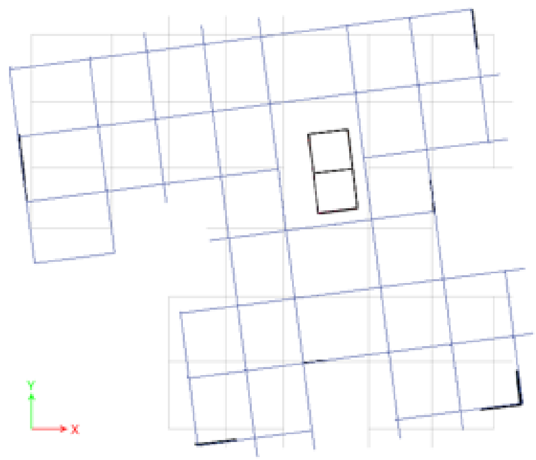


Mode 3

Figure 4: Deformed shape of Building 'A'

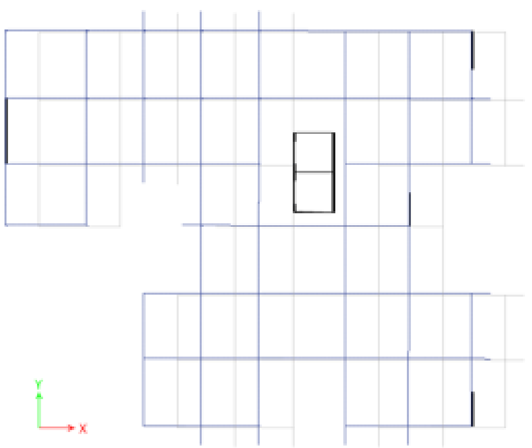


Mode 2



Mode 3

Figure 5: Deformed shape of Building '2A-0'



Mode 1

Table 2: Modal Participating mass ratio

	Building 'A'			Building '2.5A-0'		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.276	0.029	0.418	0.717	0.002	0.001
2	0.272	0.385	0.068	0.002	0.705	0.000
3	0.179	0.307	0.235	0.000	0.000	0.691

	Building '2.5A-6'			Building '2.5A-7'		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.683	0.002	0.012	0.400	0.021	0.258
2	0.002	0.676	0.002	0.260	0.221	0.218
3	0.021	0.001	0.706	0.050	0.450	0.194

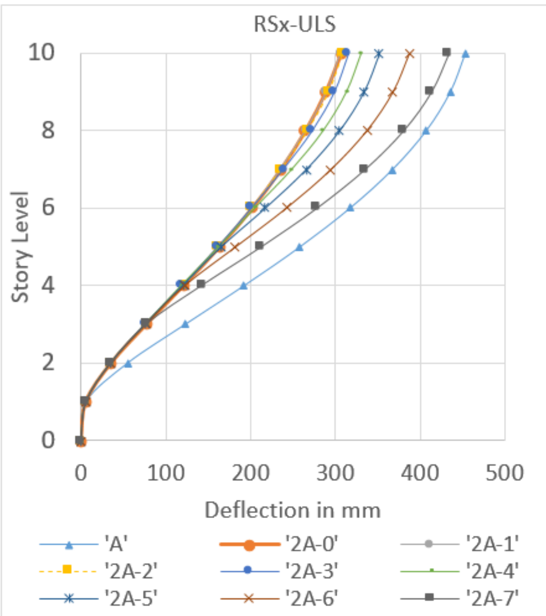
Table 3: Modal Participating mass ratio

	Building 'A'			Building '3A-0'		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.276	0.029	0.418	0.713	0.003	0.002
2	0.272	0.385	0.068	0.003	0.702	0.000
3	0.179	0.307	0.235	0.001	0.000	0.686

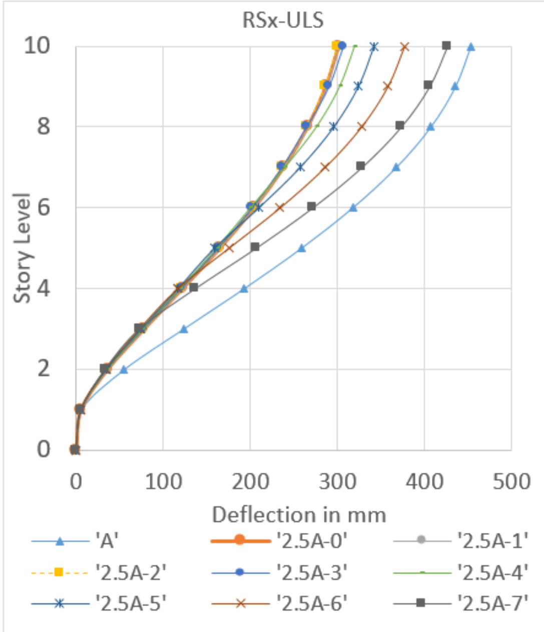
	Building '3A-6'			Building '3A-7'		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.683	0.003	0.008	0.398	0.022	0.254
2	0.003	0.672	0.001	0.264	0.207	0.226
3	0.016	0.000	0.702	0.043	0.459	0.186

Deformation

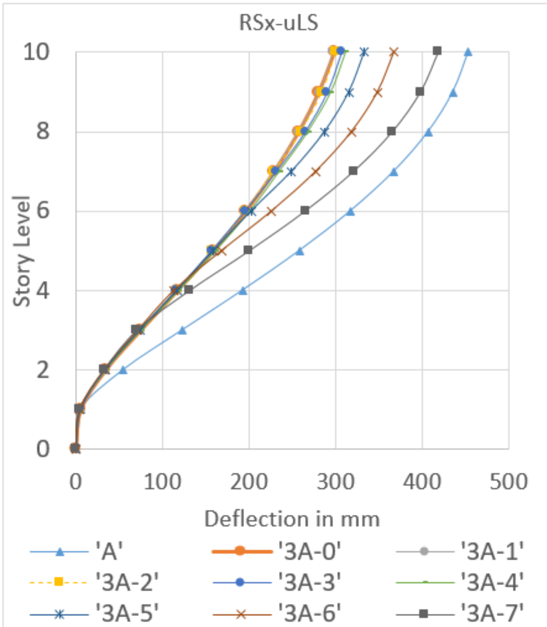
The deformation of the building with and without shear wall is shown below. The deflection of building decreases after addition of shear wall to full height by 32.3%, 33.4% and 34.2% in X direction for 200mm, 250mm and 300mm wall respectively. Higher decrease for thicker wall is due to higher stiffness of thick wall. After curtailment in wall, top deflection of building starts to increase. But the increase in deflection is less than 1% for first two layer of curtailment in X direction. The increment is low. This is because shear wall has insignificant contribution in reducing deflection at higher stories.



200mm wall



250mm wall

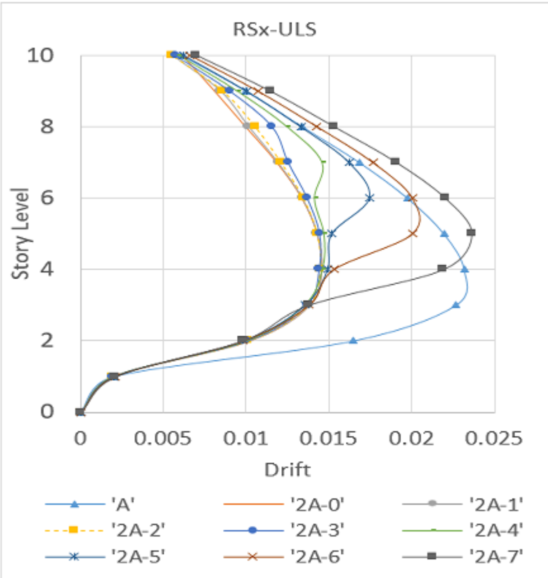


300mm wall

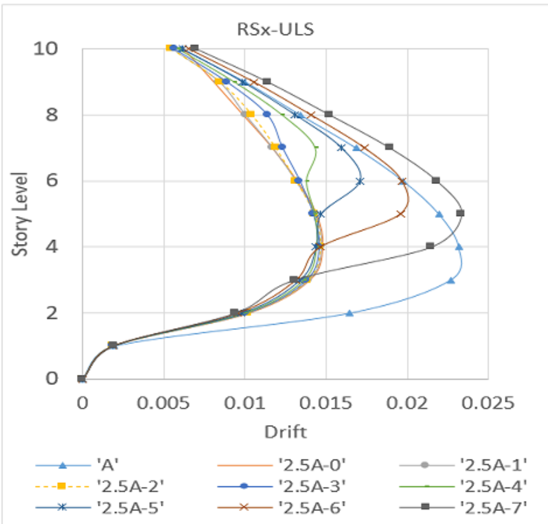
Figure 6: Deflection of buildings in X direction

Inter-story Drift Ratio

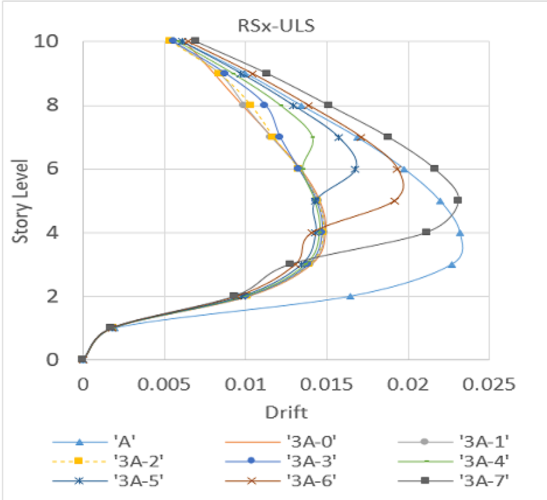
The drift ratio of buildings without shear walls and various condition of shear walls is shown in the figure below. After the addition of shear wall to full height, maximum value of drift ratio of building is reduced. As the curtailment is done, the value of inter story drift increased at the story just above where the curtailment was done. This is due to decrease in stiffness in the story at the level of curtailment. The change is not significant for 3 layer of curtailment from top. After the forth level of curtailment from the top, maximum inter story drift was observed at the level just above the curtailment. The building satisfies the value of inter drift ratio specified by Nepal Building code. For ultimate limit state the maximum value of inter story drift ratio is 0.025 [9]. There is not much difference in inter story drift with the increase in thickness of wall.



200mm wall



250mm wall



300mm wall

Figure 7: Inter story drift ratio in X direction

Base Shear (B S)

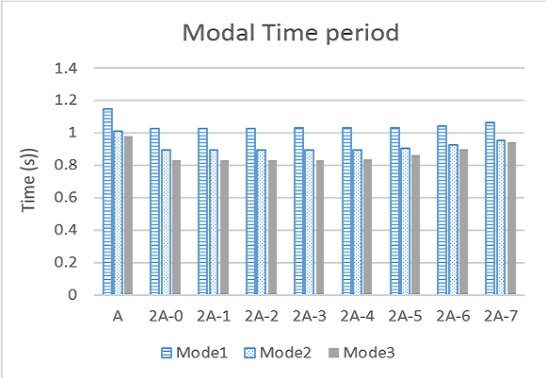
From the Table 4, percentage increase in base shear is 3.22%, 4.12% and 5.02% after addition of full height of shear wall of thickness 200mm, 250mm and 300mm respectively. For each layer of curtailment from the top base shear is reduced by 0.34%, 0.42% and 0.51% for 200mm, 250mm and 300mm of shear wall. Higher percentage increase and decrease of base shear for thick wall is due to more weight of thick wall as compared to thin wall.

Table 4: Base Shear

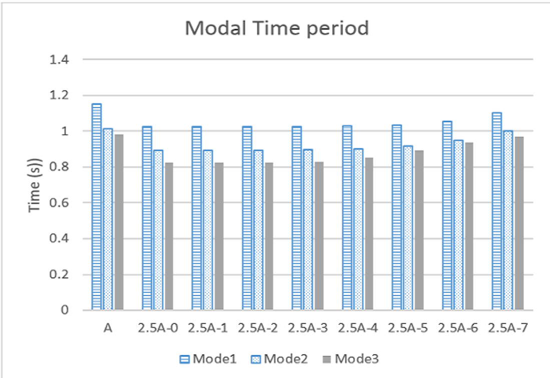
Type	B S(kN)	Type	B S(kN)	Type	B S(kN)
1’	9682	’1’	9682	’1’	9682
’2-0’	9994	’2.5-0’	10081	’3-0’	10169
’2-1’	9959	’2.5-1’	10038	’3-1’	10117
’2-2’	9925	’2.5-2’	9995	’3-2’	10065
’2-3’	9890	’2.5-3’	9951	’3-3’	10013
’2-4’	9855	’2.5-4’	9908	’3-4’	9961
’2-5’	9821	’2.5-5’	9865	’3-5’	9909
’2-6’	9786	’2.5-6’	9821	’3-6’	9857
’2-7’	9751	’2.5-7’	9778	’3-7’	9805

Modal Time Period

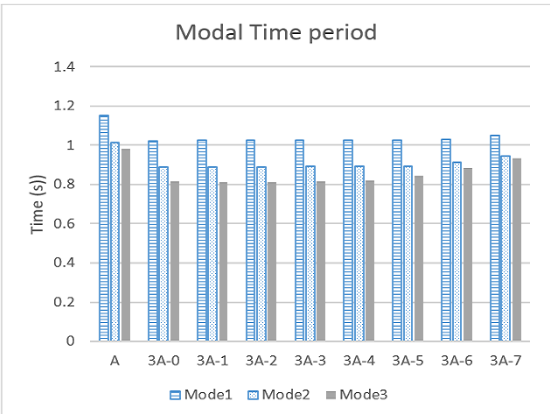
From the figure below, percentage decrease in first mode time period is 10.52%, 10.87% and 11.04% after addition of full height of shear wall of thickness 200mm, 250mm and 300mm respectively. For each layer of curtailment from top, the time period increases. The increase is below 0.5% up to 5 layer of curtailment from top and about 1% and 2% for 6th and 7th layer of curtailment from top.



200mm wall



250mm wall



300mm wall

Figure 8: Modal Time Period of Building

5. Conclusions

Equivalent static analysis and modal response spectrum analysis has been carried out to analyze ten story irregular building in plan. The building was analyzed and found to have torsional mode as first mode which is undesirable. So, shear walls was added to the building to make first two modes translational. Shear wall of three different thickness are added and each wall was curtailed starting from the top story to see the effect of curtailment. Following are the conclusions drawn from the analysis.

1. Shear wall at top stories has less contribution in reducing displacement in structure. Percentage increase in displacement for building is less than 1% for first two layers of curtailment in X direction.
2. Full height of shear wall may is not necessary for removing torsion in structures. For this building, it can be curtailed by 60% from top.
3. Thickness of shear wall has less contribution in reducing deflection in building. The decrease in deflection for (200 to 250)mm and (250 to 300)mm increase in shear wall thickness is about 1% in X direction.

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