Seismic comparison of flat slabs and conventional slabs for structures with irregular shapes

Shruti A. Brahme[1], Pramod B. Salgar[2]
[1]Student M. Tech Structure, Rajarambapu Institute of Technology, Rajaramnagar
[2]Professor, Department of Civil Engineering, Rajarambapu Institute of Technology, Rajaramnagar
[1]brahme.shruti@gmail.com, [2]pramod.salgar@ritindia.edu

Abstract

For a building to perform well during an earthquake, its configuration is crucial. The parameters behave differently in flat slab structures compared to conventional slab structures. A significant factor in the collapse of many high-rise structures is seismic load. Devastation is also caused by structural irregularity, which worsens the effects of earthquakes. This study investigates a comparison between the conventional slab and flat slab buildings considering the effect of structural irregularity on them. The study is carried out for a 14-storey building using response spectrum analysis. The zones considered for analysis are IV and V. The shapes of buildings considered are L-shape, T-shape and Cross-shape. Also, the effect of various parameters like storey displacement, storey shear, storey drift, etc. on the structures has been studied. Results have shown that cross-shape building is having good overall performance with conventional slab system. For flat slab system, T-shape building has performed well.

Keywords: *conventional slab; flat slab; storey displacement; storey drift; storey shear; structural irregularity*

1. Introduction

Since the inception of earthquake engineering, earthquake-resistant design of RC buildings has become a highly investigated field [7]. Due to the significant loss of life and property caused by recent earthquakes, it is now necessary to build structures that are earthquake resistant or cause the least amount of damage [9]. The multistoreyed building is becoming a necessary part of our polished and tasteful living with increase in request for space [2]. A high-rise, multi-storey building's seismic assessment is essential for analysing how an earthquake may affect the structure.

When subjected to seismic excitation, the conventional slab system and flat slab system behave differently. Seismic analysis of their behaviour considering parameters like storey displacement, storey drift, storey shear is therefore absolutely required [5]. Unlike the traditional slabs system, which uses beams, the flat slab is a beamless slab with or without drops supported by columns, with or without flare heads. From the slab to the columns and then immediately to the footing, the load is transferred directly [8]. The flat slabs are typically expanded near the columns to increase shear strength and decrease the amount of negative reinforcement in the support region. In malls, theatres, and other buildings that demand broad beams and open spaces, flat slabs are offered. Types of flat slabs: a) Flat slab with drop panel, b) Flat slab with column head, c) Flat slab with drop panel and column head, d) Flat slab without drop panel and column head [3]. When compared to flat slab constructions, conventional slabs have more expensive and complex formwork since the load from the slabs is first transferred to beams and then to columns, increasing the weight of the structure [4].

Punching shear is one of the main issues with flat slab construction. The flat slab connections become a weak link in the entire flat slab structure because of unbalanced moment and vertical shear carried by the slab column connection, that will result in catastrophic damage or even collapse. Buildings with flat slabs frequently experience unbalanced moments, which are brought on by uneven spans or stress on each side of the column. When such situations occur, the punching phenomenon becomes asymmetrical, and the slab's punching strength decreases. As a result, the column pierces the slab's outermost layer. Diagonal tension fractures that develop around the loaded area give rise to a conical failure surface, which causes punching shear failure. Utilize strong concrete, carefully design the reinforcement to strengthen each potential failure plane, deepen the slab, increase the size of the column, add drop panels, or use flared column heads to prevent punching shear failure. Typically, vertical reinforcement is installed across a potential failure line [6].

Earthquake-resistant design of reinforced concrete buildings is an ongoing research topic. The structural configuration system has played a crucial role in catastrophe despite all the flaws in the structure, whether they be imperfections in the code or errors in analysis and design. Section 7 of IS 1893(Part-1):2016 recommends a building configuration system for improved earthquake performance of RC buildings [10]. Different types of structural irregularities are as follows:

1.1 Vertical Irregularity

1.1.1. Stiffness Irregularity: A soft storey has lateral stiffness that is less than 70% of that of the storey above or less than 80% of the average lateral stiffness of the three storeys above.

An extreme soft storey has lateral stiffness that is less than 60% of that of the storey above or less than 70% of the average stiffness of the three storeys above. This includes structures like buildings that are raised on stilts.

1.1.2. Mass Irregularity: Mass irregularities exist when the effective mass of any storey exceeds 150 % of the effective mass of an adjacent storey.

1.1.3. Vertical Geometric Irregularity: Geometric irregularity exists when the horizontal dimension of the lateral force resisting system in any storey is more than 150% of that in an adjacent storey.

1.1.4. Discontinuity in capacity - Weak Storey: A weak storey is one whose storey lateral strength is less than 80% that of the storey above. The strength of all seismic force-resisting elements that share the storey's shear in the considered direction makes up the storey's lateral strength.

1.1.5. In-Plane Discontinuity in Vertical Elements Resisting Lateral Force: An in-plane offset of the lateral force resisting parts greater than their length.

1.2 Plan Irregularity

1.2.1. Torsion Irregularity: When the maximum storey drift, calculated with design eccentricity, at one end of the structure transverse to an axis is greater than 1.2 times the average of the storey drifts at the two ends of the structure, torsional irregularity is considered to exist.

1.2.2. Re-Entrant Corners: Re-entrant corners are present in the plan configurations of a structure and its lateral force resisting system when both of the structure's projections beyond the corner exceed 15% of the plan dimension in the given direction. Re-entrant, lack of continuity, or "inside" corners, which are frequent features of overall building layouts that, in a plan, assume the shape of an L, T, H, +, or combination of these shapes, come from the absence of tensile capacity and force concentration [1].

1.2.3. Diaphragm Discontinuity: Diaphragms with abrupt discontinuities or fluctuations in stiffness, such as those with cut-out or open portions larger than 50% of the total enclosed area or changes in effective diaphragm stiffness of more than 50% from one level to the next.

1.2.4. Out-of-Plane Offsets: Inconsistencies in a lateral force resistance path, such as offsets of vertical elements that aren't in the plane.

1.2.5. Non-parallel Systems: An in-plane offset of the lateral force resisting parts greater than their length.

2. Objective of the Study

The following are the objectives of this study.

1. To analyze building with two different alternatives: conventional slab and flat slab for irregular-shaped buildings in seismic zone IV and V.

2. To compare results on the basis of seismic stability and various factors.

3. To find the optimal type of slab for L, T and cross (+) shaped building.

3. Details of structure

This study deals with the analysis of multi-storeyed structures in ETABS software by using response spectrum analysis. The support conditions are considered fixed. In analysis IS 875 (Part 2): 1987 is used for defining imposed loads on models. Imposed load is taken as 3kN/m2. The floor finish load is considered 1.2 kN/m2. Wind loads are defined as per specifications in IS 875 (Part 3): 2015. Wind speed of 47 m/s and 50 m/s is considered.

Table 1. Geometrical Data of Building

Typical Storey Height	3.15m
Bottom Storey	3.15m
Total Height of Building	44.1m

Table 2. Material Properties

Grade of Concrete	M30
Grade of Reinforcement	Fe500
Unit Weight of Concrete	$25kN/m^3$
Unit Weight of Brick	$18kN/m^3$

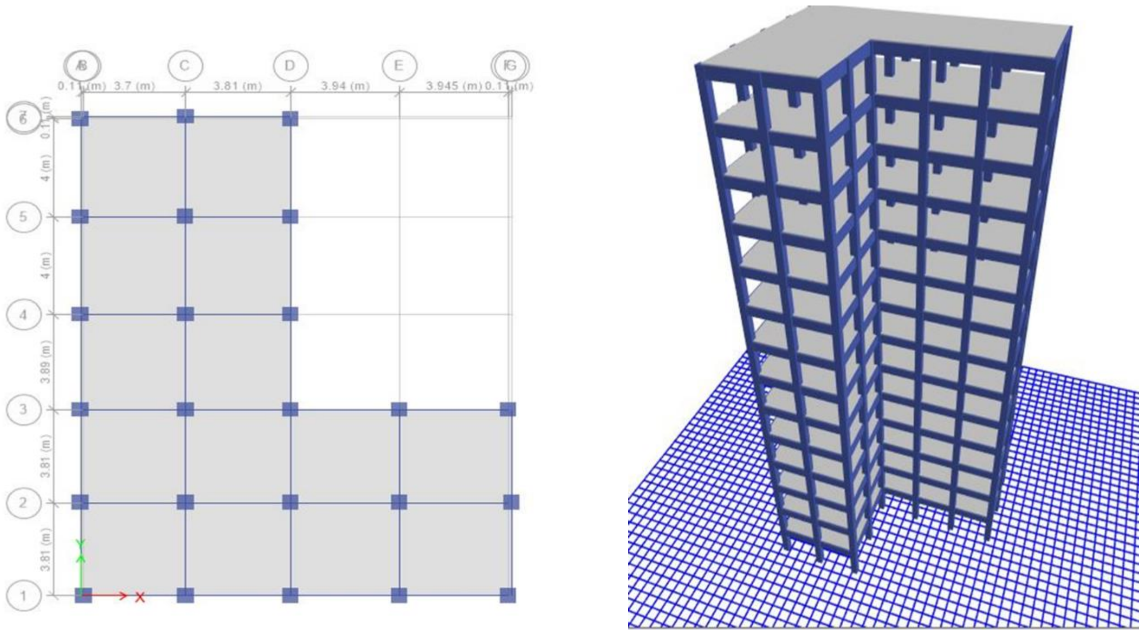
Table 3. Specification of Structure

Type of structure	RCC Framed Structure (14 Storeyed)
Size of column	750 mm x 750 mm 600 mm x 600 mm
Size of beam	300 mm x 750 mm 300 mm x 550 mm
Slab thickness	125 mm 200 mm
Wall thickness	0.23m (External), 0.15m (Internal)
Earthquake load	As per IS-1893, part 1 (2016)
Wind load	As per IS-875, part 3 (2015)
Live load	$3kN/m^2$
Seismic zones	IV, V

Importance factor	1.2
Response reduction factor	3, 5
Types of soil	Soft
Basic wind speed	47, 50 m/s
Terrain category	III

Table 4. Names of the building models and their respective slab system

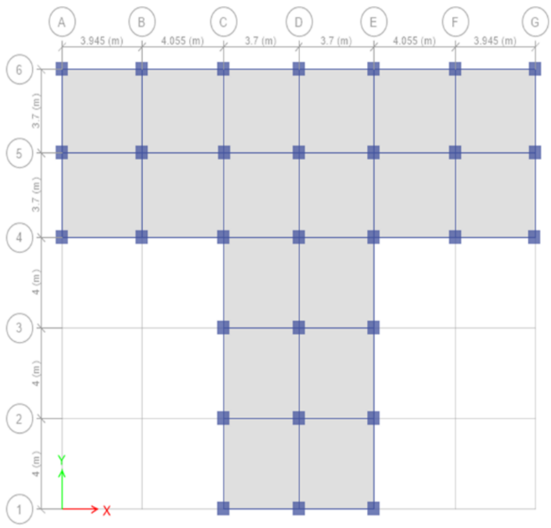
Building Model Name	**Description**
L-shape	Conventional slab system
T-shape	Conventional slab system
Cross-shape	Conventional slab system
L-shape	Flat slab system
T-shape	Flat slab system
Cross-shape	Flat slab system

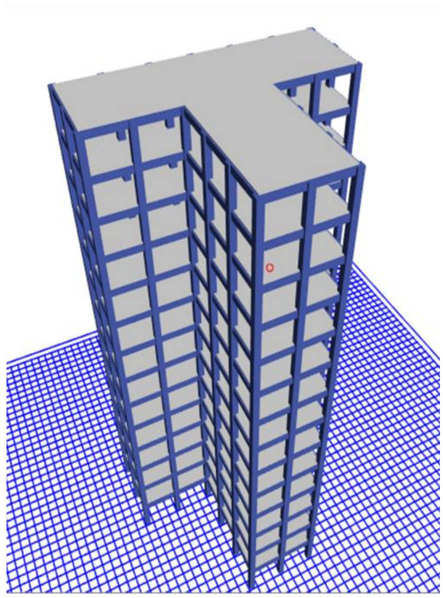


(a) Plan view **(b) 3D elevation view**

Figure 1. Plan view and elevation view of L-shape model (conventional slab)

Figure 1. shows the plan and 3D view of 14 storeyed RCC high rise structure with L-shape model (conventional slab).

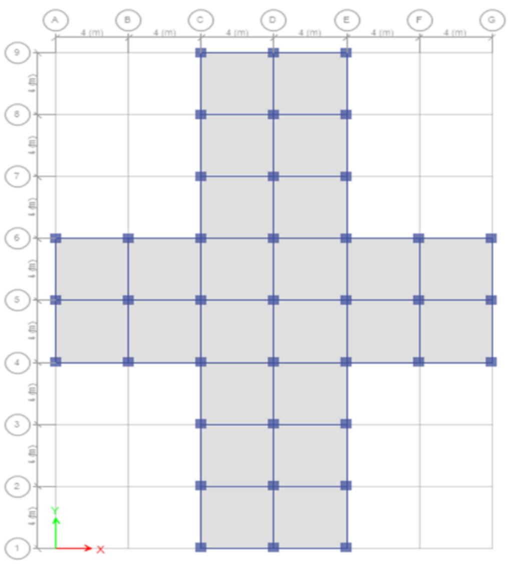


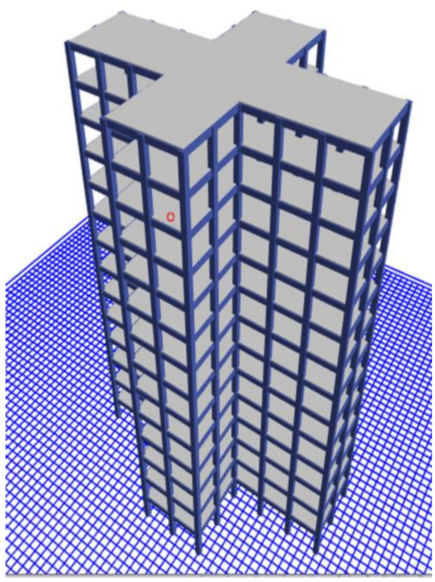


(a) Plan view **(b) 3D elevation view**

Figure 2. Plan view and elevation view of T-shape model (conventional slab)

Figure 2. shows the plan and 3D view of 14 storeyed RCC high rise structure with T-shape model (conventional slab).

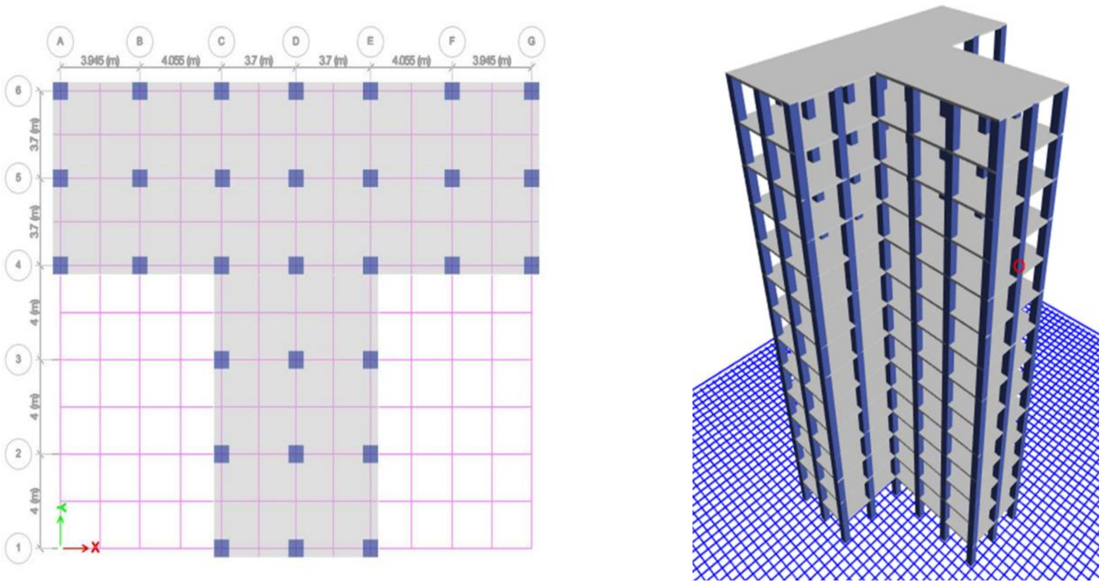




(a) Plan view **(b) 3D elevation view**

Figure 3. Plan view and elevation view of Cross-shape model (conventional slab)

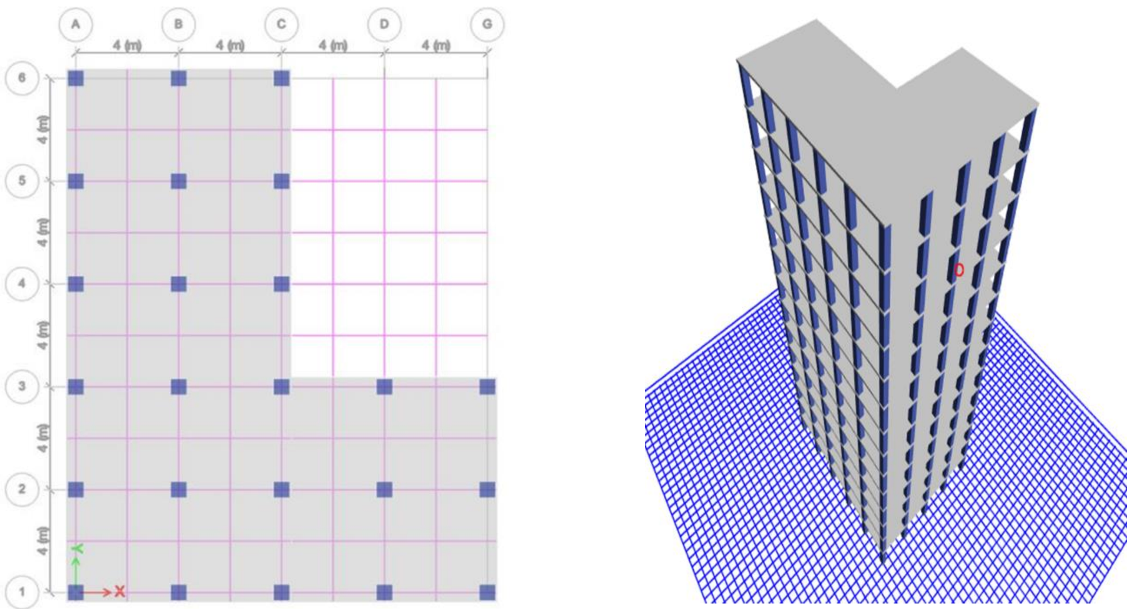
Figure 3. shows the plan and 3D view of 14 storeyed RCC high rise structure with Cross-shape model (conventional slab).



(a) Plan view (b) 3D elevation view

Figure 4. Plan view and elevation view of T-shape model (flat slab)

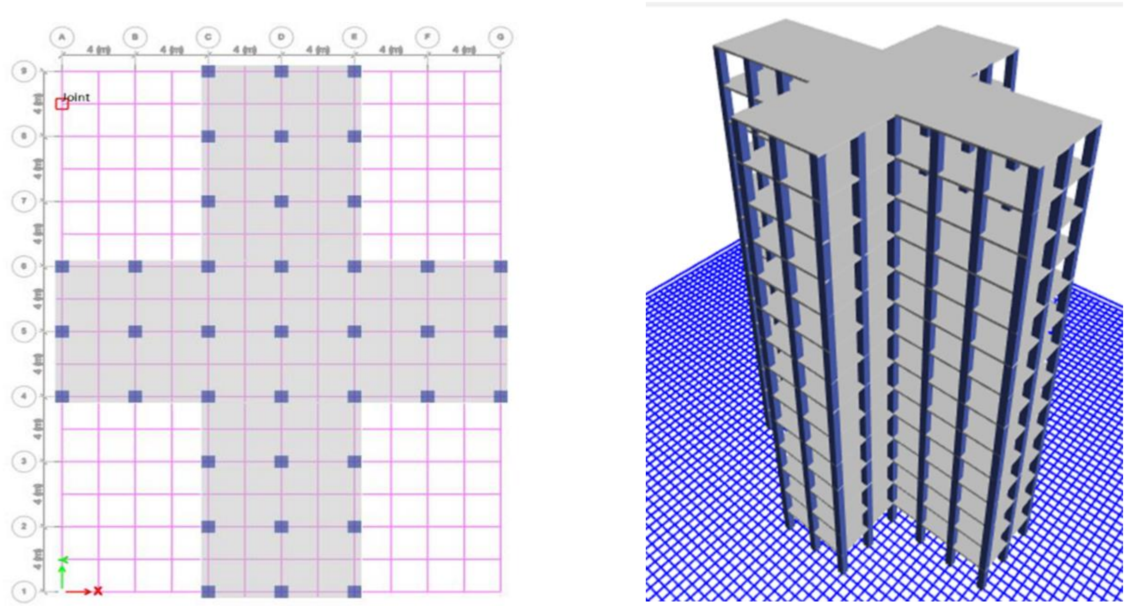
Figure 4. shows the plan and 3D view of 14 storeyed RCC high rise structure with T-shape model (flat slab).



(a) Plan view (b) 3D elevation view

Figure 5. Plan view and elevation view of L-shape model (flat slab)

Figure 5. shows the plan and 3D view of 14 storeyed RCC high rise structure with L-shape model (flat slab).



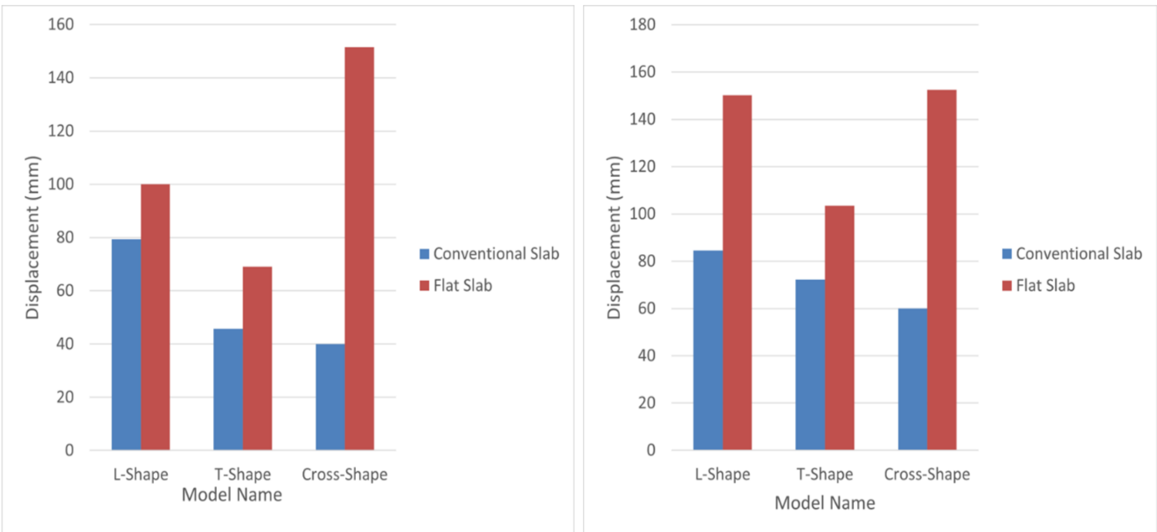
(a) Plan view **(b) 3D elevation view**

Figure 6. Plan view and elevation view of Cross-shape model (flat slab)

Figure 6. shows the plan and 3D view of 14 storeyed RCC high rise structure with Cross-shape model (flat slab).

4. Results and Discussion

4.1. Maximum storey displacement

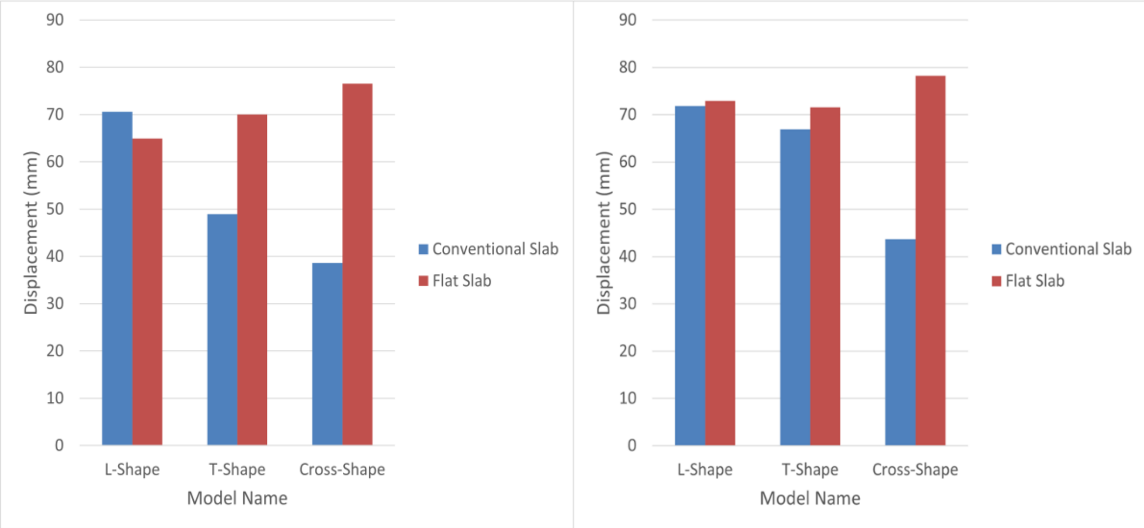


(a) Zone IV **(b) Zone V**

Figure 7. Maximum Storey Displacement

Maximum storey displacement values of earthquake load case for building models of all shapes in zone IV and V with conventional and flat slabs are presented in Figure 7. The maximum storey displacement is increased in models with flat slabs when compared with the model with the conventional slab. Percentage decrease in maximum storey displacement for models with conventional slab when compared with models with flat slab having L, T and Cross shape for zone IV is 20.7%, 33.8%, 73.6% and for zone V is 43.7%, 30.3%, 60.6% respectively. The percentage decrease of storey displacement is least for T shape and highest for cross shape.

4.2. Maximum storey displacement

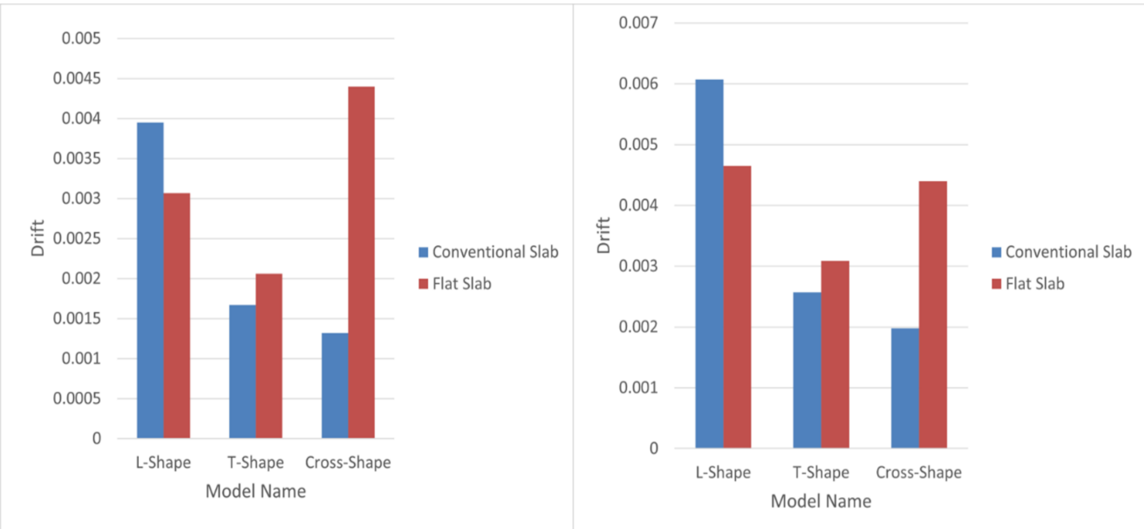


(a) Zone IV (b) Zone V

Figure 8. Maximum Storey Displacement

Maximum storey displacement values of wind load case for building models of all shapes in zone IV and V with conventional and flat slabs are presented in Figure 8. The maximum storey displacement is increased in models with flat slabs when compared with the model with the conventional slab. Percentage decrease in maximum storey displacement for models with conventional slab when compared with models with flat slab having L, T and Cross shape for zone IV is 8.1%, 30.1%, 49.6% and for zone V is 1.5%, 6.5%, 44.2% respectively. The percentage decrease of storey displacement is least for L shape and highest for cross shape.

4.3. Maximum Storey Drift

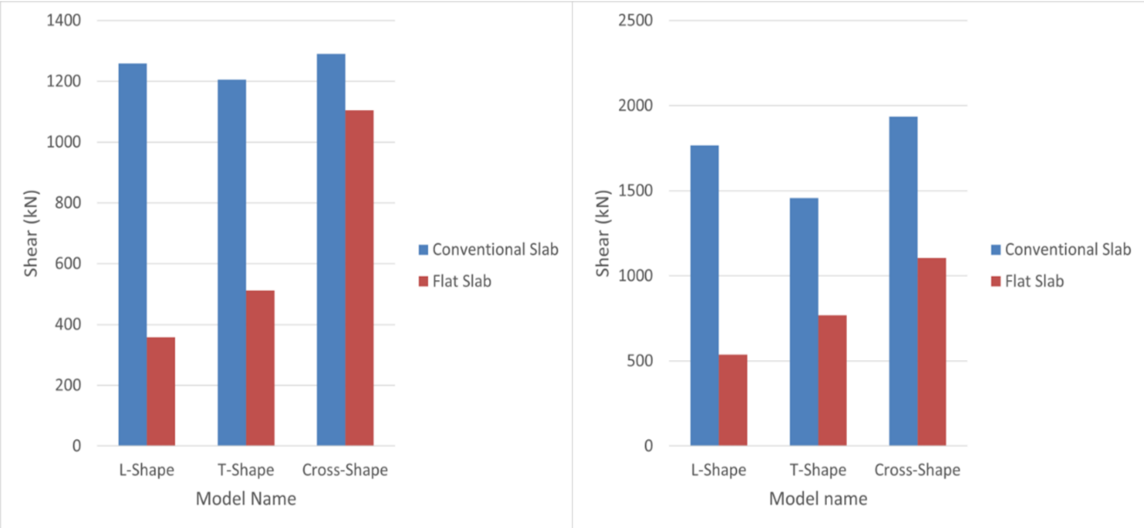


(a) Zone IV (b) Zone V

Figure 9. Maximum Storey Drift

Maximum storey drift values of building models for all shapes in zone IV and V with conventional and flat slabs are presented in Figure 9. The maximum storey drift is increased in models with flat slabs when compared with the model with the conventional slab. Percentage decrease in maximum storey displacement for models with conventional slab when compared with models with flat slab having T and Cross shape for zone IV is 18.9%, 76% and for zone V is 16.83%, 55% respectively. For L shape decrease from the conventional slab to the flat slab are 22.3% and 23.4% for zone IV and V respectively. The percentage decrease of storey displacement is least for L shape and highest for cross shape.

4.4. Maximum storey shear



(a) Zone IV **(b) Zone V**

Figure 10. Maximum Storey Shear

Maximum storey shear values of building models for all shapes in zone IV and V with conventional and flat slabs are presented in Figure 10. The maximum storey drift is increased in models with flat slabs when compared with the model with the conventional slab. Percentage decrease in maximum storey displacement for models with conventional slab when compared with models with flat slab having L, T and Cross shape for zone IV is 71.6%, 57.5%, 14.3% and for zone V is 69.6%, 47.3%, 42.9% respectively. The percentage decrease of storey displacement is least for Cross shape and highest for L shape.

5. Conclusions

In this paper, analysis of 14 storeyed RC buildings is carried out by using response spectrum analysis method. The following conclusions are drawn:

- For zone IV and V, the decrease in maximum storey displacement of earthquake load case for flat slab model compared to conventional slab model is 20.7%, 33.8%, 73.6% and 43.7%, 30.3%, 60.6% for L, T and Cross shape respectively.
- For zone IV and V, decrease in maximum storey displacement of wind load case for flat slab model compared to conventional slab model is 8.1%, 30.1%, 49.6% and 1.5%, 6.5%, 44.2% for L, T and Cross shapes respectively.
- For zone IV and V, the decrease in maximum storey drift for the flat slab model compared to the conventional slab model is 18.9%, 76% and 16.83%, 55% for T and Cross shape resp. For L shape, reduction from the conventional slab to the flat slab is 22.3% and 23.4% for zone IV and V respectively.
- For zone IV and V, the decrease in storey shear for the flat slab model compared to the conventional slab model is 71.6%, 57.5%, 14.3% and 69.6%, 47.3%, 42.9% for L, T and Cross shape respectively.

- After analysis and comparing all parameters for zone IV and V, it is observed that for conventional slab models, cross shape configuration is more efficient.
- T shape configuration is more effective and well-behaved in case of flat slab models for zone IV and V.

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