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Seismic Analysis of Flat Slabs in a High-Rise Building

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ABSTRACT: The construction of building structures by using conventional reinforced concrete slabs has been a staple for decades. Although it has higher rigidity and minimizes the large moment caused by the applied load, it has no advantages in structural flexibility, lighter formwork and shorter construction time when compared to flat slab systems. This method of developing flat slab structures improves the aesthetics and structural appearance of high-rise buildings, hospitals, shopping centres, etc. Since the panel is considered to be beam-free, its shear strength and rigidity are lower than that of traditional RC Slabs. The objective of this experiment is to compare and observe the seismic behavior of multiple configurations of flat slabs in Earthquake zone V. The considered 15 storey building models were analyzed with simple flat plate, flat slab with drop panel, flat slab with column head and combination of column head & drop panel by using Etabs 19 software. Non-linear time history analysis was carried out to observe the different parameters like storey displacement, storey shear, storey drift and base shear by adopting the guidelines of IS 1893 (Part 1): 2016.

KEYWORDS: Structural flexibility, Beam-free, Non-linear time history analysis, Lighter formwork, Flat slab systems.

I. INTRODUCTION

Flat slabs are reinforced concrete slabs that are directly supported by concrete columns without the use of beam structures. A flat slab is defined as a single-sided or double-sided support system in which the total load of the slab is concentrated on a support column and a rectangular slab called a "drop panel". Drop panels play an important role here as they increase the overall capacity and robustness of vertical load underfloor systems and increase the cost-effectiveness of construction. Generally, the height of the drop panel is about twice the height of the slab. Flat slabs are considered suitable for most architecture and asymmetric column layouts such as floors that contain curved shapes and slopes. The advantage of flat slab application is that the depth reduction, flat floors and the flexibility of the design layout. Making flat slabs can be costly, but it offers architects and engineers a tremendous amount of freedom to offer design luxury. The advantages of using flat slabs are not only diverse in terms of expected design and layout efficiency, but also particularly useful for the entire construction process, especially simplifying the installation procedure and saving construction time. When possible, maximize the thickness of the flat slab without maximizing the drop panel. The reason is to allow the advantage of a flat bottom to maintain the floor surface and allow the drop panels to form as part of the pillars.

Types of flat slab structures

The types of flat slab structures are as follows:

1. Simple flat slab
2. Flat slab with drop panels
3. Flat slab with column heads
4. Flat slab with both drop panels and column heads

DROP PANEL

The drop panel is a rectangular piece provided under the slab above the column to prevent the slab from being sheared and bursting. The drop panel increases the contact surface area between columns and slabs, allowing for better load distribution from slab to column. Therefore, the possibility of slab breakage due to imbalance moments can be reduced.



COLUMN HEAD

The column head is an enlarged cross section of the top of the column on which brackets or other structural members on the top of the column can be placed. It provides an additional base area (rather than the cross-sectional area of the column) that serves as the base for other structural members.

BENEFITS OF USING FLAT SLAB

1. Indoor layout flexibility.
2. Reduced building height.
3. Saves construction time.
4. Easy to install Mechanical and electrical services.
5. Prefabricated welded mesh can be used.

DISADVANTAGES OF FLAT SLABS

1. It is not possible to build a large span in a reputation system.
2. Large mechanical ducts can be interfering with drop panels.
3. Not suitable for brick walls (brittle partitions).
4. The thickness of flat slab will be higher than that of a regular RCC two-way slab.

II. OBJECTIVES

1. To perform the time history analysis for different building configurations with multiple types of flat slabs as per 1893 (Part 1): 2016 for Zone V.
2. To study and compare seismic behaviour of regular and irregular building with different types of flat slabs.
3. To check the seismic parameters like, storey drift, storey shear, base shear and lateral displacement of different structural configurations.
4. To identify the most efficient configuration among all the models considered for the analysis.

III. MODELLING AND ANALYSIS

Among the various structural elements of the building, if the design and analysis are improper, the slab is one of the important reasons for the failure of the building. This study uses the time history analysis method to determine the seismic behaviour of different configurations with different types of slabs. Here, a 15-storey building is modelled and analysed for multiple configurations to determine the best possible combination. The analysis was conducted as per Indian Standards Specifications. The preliminary data assumed are here below:

- Plan dimension = 36m x 36m
- No. of stories = 15 (G+14)
- Height of the floor = 3m
- Grade of concrete = M30
- Grade of steel = Fe500
- Spacing of grids in X direction = 6m
- Spacing of grids in Y direction = 6m
- Size of column = 500mm (circular)
- Slab thickness = 200mm
- Drop thickness = 250mm
- Width of drop = 2.5m
- Column head thickness = 1.20m
- Width of column strip = 3m
- Live loads = 3kN/m²
- Floor loads = 1kN/m²
- Seismic zone = Zone V
- Type of soil Type = II (medium soil)
- Importance factor = 1.0
- Response reduction factor = 5
- Zone factor = 0.36



Below are the four different building configurations such as a Simple Square (Fig. a), U-Shaped (Fig. b), Plus-Shaped (Fig. c) and T-Shaped (Fig. d) used in this analysis. They are all displayed in plan view below.

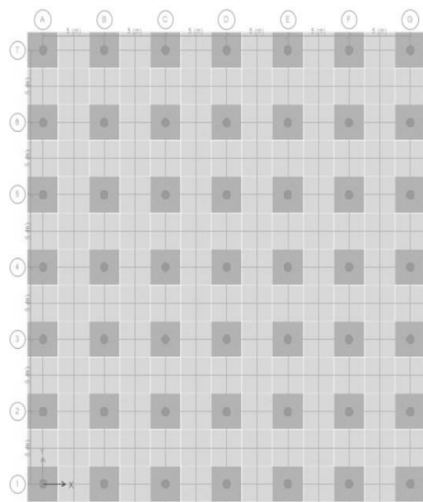


Fig. (a) Square Shaped

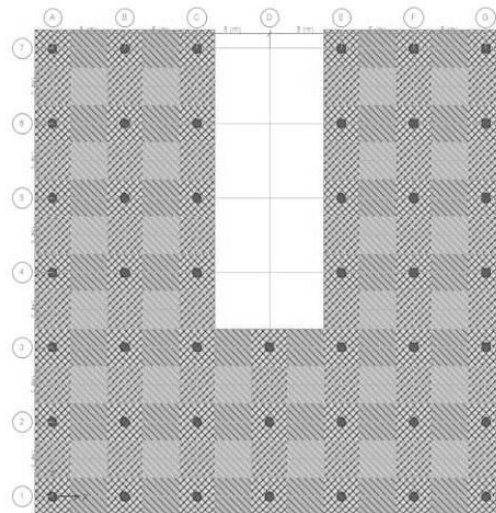


Fig. (b) U-Shaped

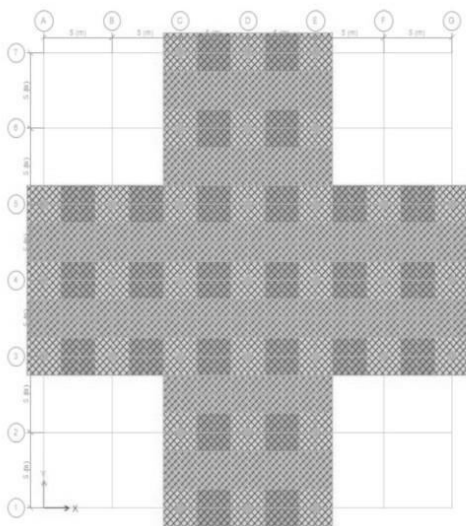


Fig. (c) Plus Shaped

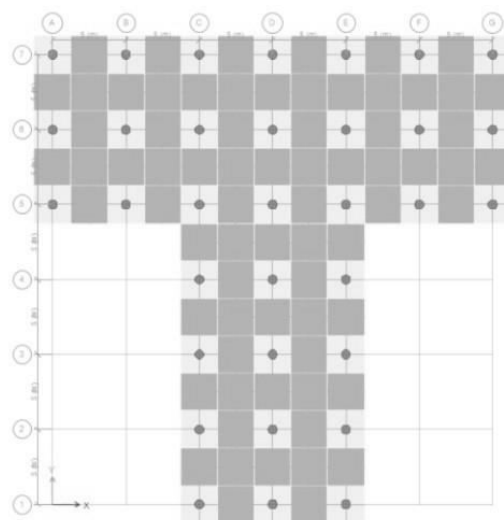


Fig. (d) T-Shaped

EARTHQUAKE DATA

For the analysis, El-Centro Earthquake (19-05-1940) ground acceleration data was used as the input value for the Time History Analysis.



IV. EXPERIMENTAL RESULTS

According to the Indian Standard specifications, a nonlinear dynamic time history analysis was performed to analyze the flat slab structure in earthquake zone V. According to seismic parameters such as Storey displacement, Storey Shear, Base Shear and Storey drift, the effects of various components such as drop-panels, column head and the combination of both are interpreted below.

1. STOREY DISPLACEMENT

It can be defined as the total displacement of the "i"th floor relative to the ground floor. When the building structure is subjected to earthquake and wind loads, ground displacement is an important parameter. It is directly proportional to the height of the structure and also depends on the slender length of the building structure. The storey displacement of various configurations in the X and Y directions are listed (Table 1 and 2) below:

Table. 1 - Storey Displacement (X) in mm

Table. 2 - Storey Displacement (Y) in mm

STOREY DISPLACEMENT (X) IN MM					STOREY DISPLACEMENT (Y) IN MM				
TYPE OF SLAB CONFIGURATION	SQUARE SHAPE	U-SHAPED	PLUS SHAPED	T-SHAPED	TYPE OF SLAB CONFIGURATION	SQUARE SHAPE	U-SHAPED	PLUS SHAPED	T-SHAPED
FLAT SLAB ONLY	104.773	99.052	97.521	102.047	FLAT SLAB ONLY	104.773	99.638	98.512	101.603
FLAT SLAB WITH COLUMN HEAD	95.274	91.430	87.993	93.185	FLAT SLAB WITH COLUMN HEAD	95.274	90.761	89.810	92.445
FLAT SLAB WITH DROP PANEL	73.011	77.182	74.510	79.665	FLAT SLAB WITH DROP PANEL	72.948	72.782	69.689	72.581
FLAT SLAB WITH DROP AND COLUMN HEAD	65.750	69.310	66.185	71.396	FLAT SLAB WITH DROP AND COLUMN HEAD	65.526	65.485	62.599	65.360

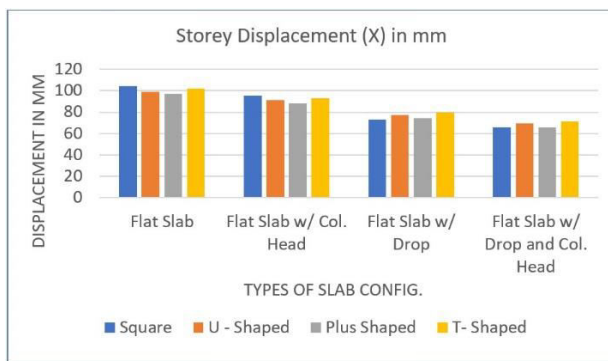


Fig. 1- Storey Displacement (X) in mm

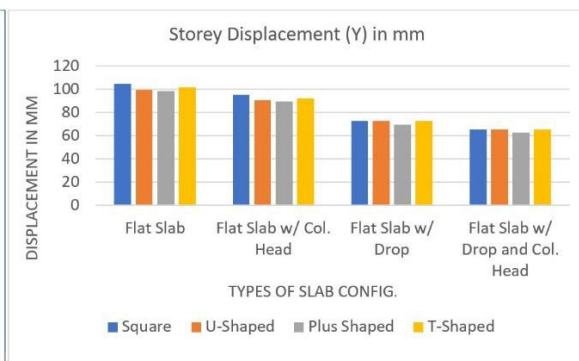


Fig. 2- Storey Displacement (Y) in mm

It can be clearly seen from the above tables and graphs that, as the height of the building increases, the floor displacement increases. It has been found that the lateral displacement is greater for flat slabs and slabs with column head config. The displacement of the panel and floor has been greatly reduced on the addition of drop panel. Similarly, the combination of flat slab with column head & drop panel results in large reduction of storey displacement in comparison.

2. STOREY SHEAR

It is the lateral force acting on a storey due to the forces such as seismic and wind force. In story shear, you can visualize the possible governing lateral load on a certain floor at a given direction. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building. Below are the observed values (Table 3 and 4) and charts (Fig. 3 and 4) for storey shear.



Table. 3 - Storey Shear (X) in kN

STOREY SHEAR (X) IN kN				
TYPE OF SLAB CONFIGURATION	SQUARE SHAPE	U-SHAPED	PLUS SHAPED	T-SHAPED
FLAT SLAB ONLY	2789.750	2564.580	1836.650	1792.550
FLAT SLAB WITH COLUMN HEAD	2577.180	2458.740	1719.730	1685.940
FLAT SLAB WITH DROP PANEL	4079.910	3463.810	2511.170	2478.520
FLAT SLAB WITH DROP AND COLUMN HEAD	3921.840	3344.380	2423.580	2420.830

Table. 4 Storey Shear (Y) in kN

STOREY SHEAR (Y) IN kN				
TYPE OF SLAB CONFIGURATION	SQUARE SHAPE	U-SHAPED	PLUS SHAPED	T-SHAPED
FLAT SLAB ONLY	2789.750	2567.840	1861.750	1837.150
FLAT SLAB WITH COLUMN HEAD	2577.180	2451.620	1762.830	1699.920
FLAT SLAB WITH DROP PANEL	4083.910	3480.410	2589.370	2493.740
FLAT SLAB WITH DROP AND COLUMN HEAD	3927.140	3361.840	2473.940	2476.110

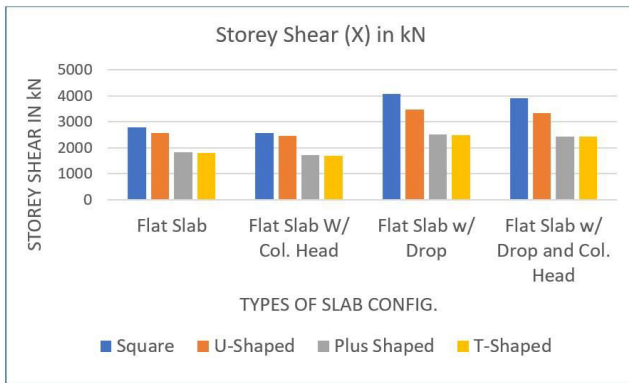


Fig. 3 - Storey Shear (X) in kN

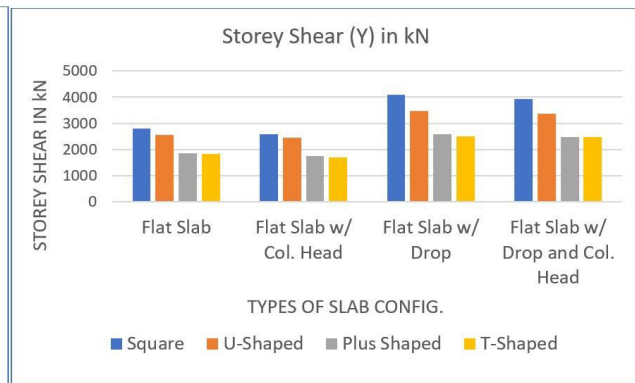


Fig. 4 - Storey Shear (Y) in kN

From the above graphs, it was seen that the storey shear is higher in the case of flat slabs with drop panel structures in both X and Y direction and minimum in the flat plate configuration

3. STOREY DRIFT

It is the ratio between the offset of two consecutive floors and the height of that floor. According to IS 1893 (Part 1): 2016 recommendations, the deflection between floors should not exceed 0.004 times the floor height. This is an essential term in earthquake research. The storey drift of all 4 types of flat slab configurations are plotted in graphs (Fig 5 – 12) below.

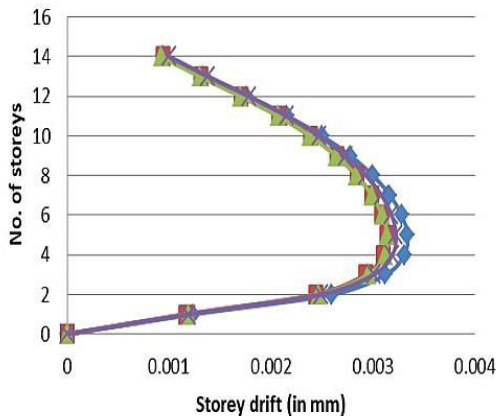


Fig. 5 Storey Drift (X) in simple flat slab

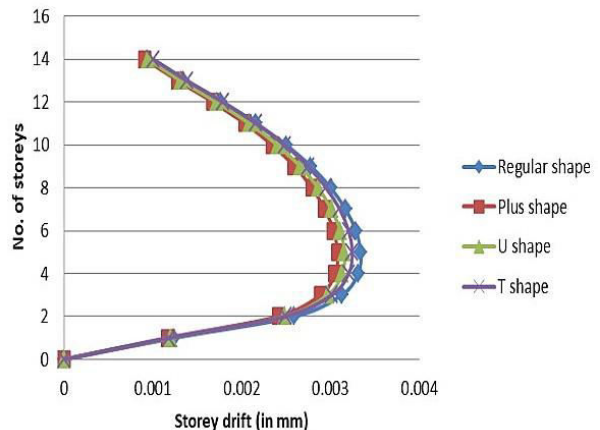


Fig. 6 Storey Drift (Y) in simple flat slab

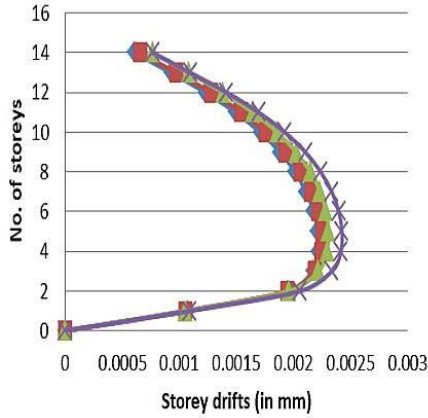


Fig. 7 Storey Drift (X) in flat slab with drop panel

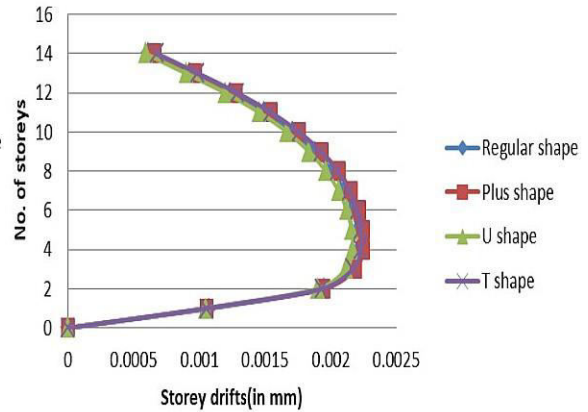


Fig. 8 Storey Drift (Y) in flat slab with drop panel

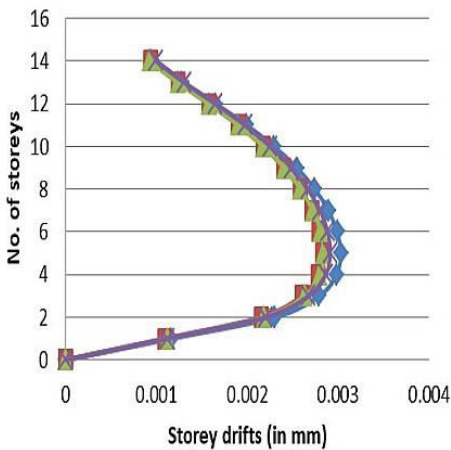


Fig. 9 Storey Drift (X) in flat slab with column head

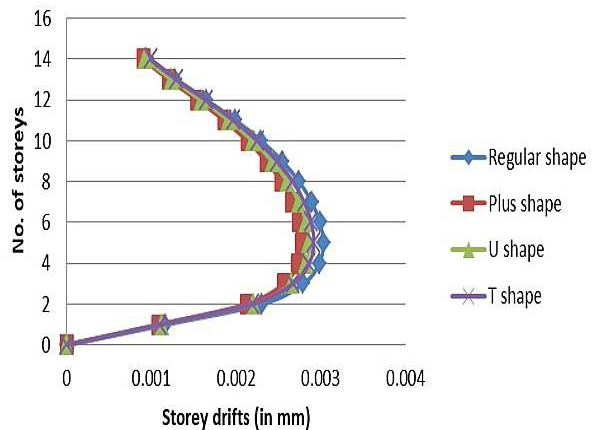


Fig. 10 Storey Drift (Y) in flat slab with column head

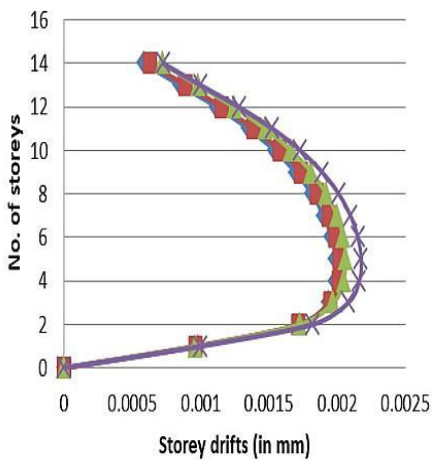


Fig. 11 Storey Drift (X) in flat slab with drop panel and column head

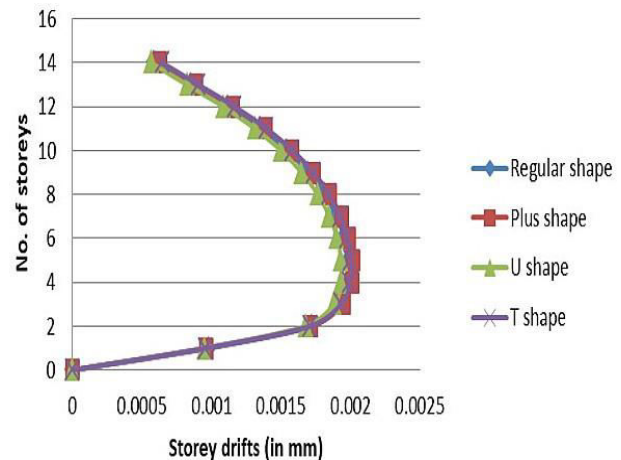


Fig. 12 Storey Drift (Y) in flat slab with drop panel and column head

As can be seen from the above figure, according to the recommendations of IS1893 (Part 1): 2016, the drift values of all types of slab structures are within the specified limits (floor height * 0.004). The storey drift was found to



be more in storeys 3 to 5 for all the considered models. The storey drift in flat plate structures was seen more than other types of flat slab structures whereas the combination of flat slab with drop panel and column head seems to have very less storey drift along both X and Y direction.

4. BASE SHEAR:

It is the total lateral force acting on the building at its base which occurs due to the seismic ground motion. It is calculated using the soil material, seismic zone, and building codes equations. The observed values of base shear are tabulated (Table 5 and 6) and plotted in graphs (Fig. 13 and 14) below.

Table. 5 - Base Shear (X) in kN

Table. 6 - Base Shear (Y) in kN

BASE SHEAR (X) IN kN					BASE SHEAR (Y) IN kN				
TYPE OF SLAB CONFIGURATION	SQUARE SHAPE	U-SHAPED	PLUS SHAPED	T-SHAPED	TYPE OF SLAB CONFIGURATION	SQUARE SHAPE	U-SHAPED	PLUS SHAPED	T-SHAPED
FLAT SLAB ONLY	2454.670	2366.890	1673.070	1642.250	FLAT SLAB ONLY	2454.670	2381.840	1663.160	1641.250
FLAT SLAB WITH COLUMN HEAD	2373.530	2273.420	1602.780	1563.470	FLAT SLAB WITH COLUMN HEAD	2373.530	2279.530	1598.280	1561.570
FLAT SLAB WITH DROP PANEL	3853.070	3283.320	2332.640	2383.540	FLAT SLAB WITH DROP PANEL	3865.740	3291.830	2327.940	2379.510
FLAT SLAB WITH DROP AND COLUMN HEAD	3756.710	3242.660	2363.880	2314.720	FLAT SLAB WITH DROP AND COLUMN HEAD	3774.390	3342.660	2361.820	2309.810

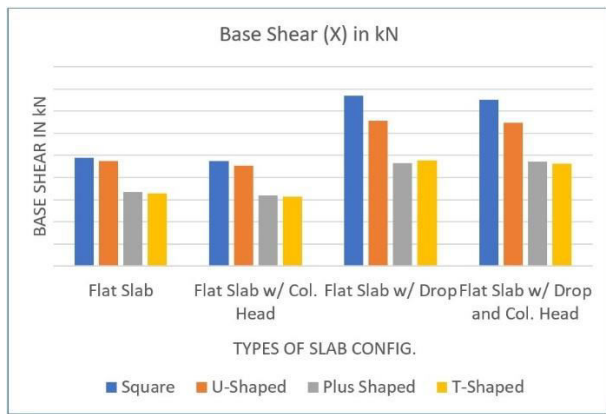


Fig. 13 - Base Shear (X) in kN

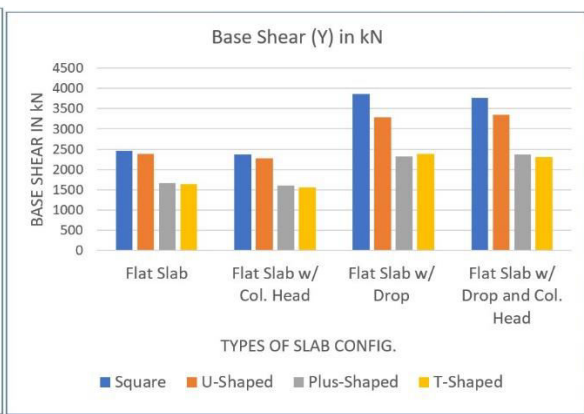


Fig. 14 - Base Shear (Y) in kN

From the tables and the charts above, we can see that the value of base shear is the highest in the case of flat slab with drop configuration and the least values were observed in the case of simple flat slab configuration.

V. CONCLUSION

1. The storey displacement of all the considered models are within the limiting value for flat slab with drop panel and the combination of flat slab with drop panel & column head. (i.e., h/500).
2. The flat plate structures and flat slab with column head structures should not be recommended for construction in Earthquake zone V since the storey displacement values exceed the limiting value (i.e. h/500).
3. The storey shear is more in flat slab with drop panel structures and less in flat slab with column head structures. The square shape structures have more storey shear compared to other models in both directions.
4. The storey drift is more in square and T-shape for flat plate structures whereas in regular and all irregular shaped structures, the displacement is heavily reduced while considering the drop panel with column head configuration.



5. The base shear is less in flat slab with column head structures and higher in flat slab with drop panel structures. The T shape has very less base shear in case of flat plate structures and flat slab with drop panel whereas the square shaped structure has more base shear in all types of flat slabs.
6. Plus shaped structure was found to be more efficient model in case of flat plate and column head system. Square shape structures were found more effective in case of drop panel and combination of column head and drop panel system.
7. T- shaped structures were found to be least efficient and vulnerable among all models because the results of the seismic parameters were not effective.

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