International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

Seismic Behaviour of Flat Slabs in High Rise Building

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Abstract**:** ***In the modern era, the growth of population has influenced the construction of high rise buildings day by day. The construction of the building structures with conventional RC slabs are in the public eye since many decades. Although it has more stiffness and minimizes the large moments occurred due to the applied loads, it does not have the advantages in terms of architectural flexibility, easier formwork and shorter construction period compared to the flat slabs. This developing technique of flat slabs construction improves aesthetical and structural aspect of tall building, offices, hospitals, shopping malls etc. As this is considered to be beamless slab, it has less shear strength and less stiffness compared to the conventional slabs. Due to its huge advantages, it is common in both the construction of regular and irregular buildings nowadays. From Structural engineer's point of view, the flat slabs should be adopted with other structural component like shear walls and bracings for better results. The main motive of the present work is to compare and observe the seismic behaviour of regular and different configuration of irregular building in zone V by using different types of flat slabs. The considered G+13 storied buildings were analyzed with flat plate, drop panel, column head and combination of column head & drop panel by using E-tabs 17.0.1 software. The nonlinear time history method was carried out to observe the different parameters like storey displacement, storey drift, storey shear, base shear and time period following the guidelines of IS 1893 (Part 1): 2016***

Keywords: flat plate, drop panel, column head, nonlinear time history analysis, irregular building, storey displacement.

I. INTRODUCTION

The construction of buildings using conventional RCC slabs is common since many years. Although it increases the shear capacity and stiffness of the structure; it is being replaced by the developing construction technique (i.e. flat slabs) which was invented by C.A.P. Turner in U.S.A in 1906. These slabs are resting directly on the columns due to which loads are directly transferred to columns. These are considered to be beamless slabs and claim 20% cost reduction in comparison to conventional RCC slabs. It can be designed and built by both the conventional RCC and post-tensioning. Due to the several advantages like aesthetic appearance, better illumination, flexibility in room layout, shorter construction period, easier formwork, placement of reinforcement has become easier in this type of construction. Since the slab does not have beams, it results in plain ceiling thus providing the aesthetic view from architecture point of view. These types of slabs avoid the beam column clogging due to its speedy and typical type of construction. These are considered to be more flexible than the conventional slabs thus becoming more vulnerable to seismic loading conditions. Generally two types of failure (i.e. flexure failure and punching shear failure) exists in this types of system and to overcome this types of failure, the additional component like drop panel, column head, shear walls, shear reinforcement, bracings etc. are adopted in the structures.

Like regular building, these slabs are very common even in irregular buildings. The irregular buildings are considered to be one of the major motives of failure of buildings during earthquake. The irregular buildings are categorized as plan irregularities and vertical irregularities.

Plan irregular structures: It consists of the asymmetrical plan shapes (like T,U,C,O,E etc.) and diaphragms like large openings, cut-outs, re-entrant corners and other sudden changes taking place in diaphragm deformations, stress concentration and torsion.

Vertical irregular structures: When the abrupt changes like stiffness, geometry strength, mass, and geometry exists, it results in distribution of forces and said to be vertical irregular structures.

Though the technique of flat slab construction is new for the south Asian countries, it is very common and popular in developed countries like America, Australia, Norway, Switzerland etc. These are generally used when we need large space inside structures like parking garages, ware house, auditorium, theatres, go-downs, shopping malls, mills, hotels etc.

II. TYPES OF FLAT SLABS SYSTEM

a) **Flat plate system**: It refers to the flat slabs without any additional component like drop panel or column head between the slab and column. It is considered to be vulnerable for the high rise buildings and for higher seismic zones (like zone3, zone4, zone5).

b) **Flat slab with drop panel**: It refers to the flat slabs with drop panel which is a part of the slab around the supports like column i.e. of greater thickness than the rest of the slab. It increases the negative moment capacity and the shear strength of the slab. Similarly, it stiffens the slab and thus helps in reducing the deflection.

Revised Manuscript Received on February 28, 2020.
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c) **Flat plate with column head**: In this system, the flat slabs consist of column head which acts as an enlarged cross section of the column on which other structural components rest. Its cross sectional area is larger than the cross sectional area of the column. It helps to increases the shear strength and rigidity of the slab. Likewise, by reducing the clear span it also reduces the moment in the slab.

d) **Flat slabs with drop panel and column head**: In this system, the slabs consists of both drop panel and column head. It increases the shear strength, moment capacity, rigidity and stiffens the slabs and reduces the moment in the slab simultaneously. It acts as shear wall and bracings and should be adopted in the seismic zone like IV and V strictly.

III. TIME HISTORY ANALYSIS

It is an analysis of the dynamic response of the structures at each increment of time, when its base is subjected to a specific ground motion time history. In this method, the structure is subjected to real ground motion records. This makes the analysis quite different from all of the other approximate analysis methods as the inertial forces are directly determined from these ground motions Time History involves the linear or Non-linear evaluation of the dynamic response of the structure to a specified loading which may vary according to time. In time history analysis the structural response is computed at a number of subsequent time instants. It is a detailed analysis in which response is calculated for each time step. It requires more time but gives a good result.

IV. OBJECTIVES OF THE STUDY

- To perform the time history analysis for regular and irregular building with all types of flat slabs as per 1893(Part1):2016 for zone V.
- To check the seismic parameters like lateral displacement, storey drift, storey shear, base shear & time period of regular & irregular buildings for zone V.
- To study and compare seismic behaviour of regular and irregular building with different types of flat slabs in zone V.
- To identify the most efficient and vulnerable model among the models considered for seismic analysis in zone V.

V. MODELING AND ANALYSIS

Among the several structural elements of the building, the slab is one of the causes of building failure if it is not designed and analyzed accordingly. The present study focuses on the seismic behaviour of regular and irregular building with different types of flat slabs by using time history analysis in zone V. In this present work, the regular and different types of irregular buildings of G+13 storey building were analyzed with all types of flat slabs (flat plate system, drop panel, column head and combination of drop panel with column head).

Altogether 16 models were analyzed in the present research The loads like dead load, live load, earthquake load etc. were considered as per Indian standards. The preliminary data of the flat slab buildings are tabulated below.

Table-I: Preliminary data for flat slab buildings

S.N	Particulars	Dimension/size/value
1	Plan dimension	30m*30m
2	No. of stories	G+13
3	Height of the floor	3m
4	No. of grids in X dir.	7
5	No. of grids in Y dir.	7
6	Spacing of grids in X dir.	5m
7	Spacing of grids in Y dir.	5m
8	Size of column	600mm(circular)
9	Slab thickness	200mm
10	Grade of concrete	M30
11	Grade of steel	Fe 415
12	Drop thickness	280mm
13	Width of drop	2.5m
14	Column head thickness	1.25m
15	Width of column strip	2.5m
16	Live loads	3kN/m^2
17	Floor loads	1kN/m^2
18	Roof live	1.5kN/m^2
19	Seismic zone	V
20	Type of soil	Type II (medium soil)
21	Importance factor	1.0
22	Response reduction factor	5

The models considered for the analysis are divided into four cases as follows:

Case 1: Regular building with flat plate, drop panel, column head and combination of drop panel with column head. Altogether 4 models were analyzed in this case.

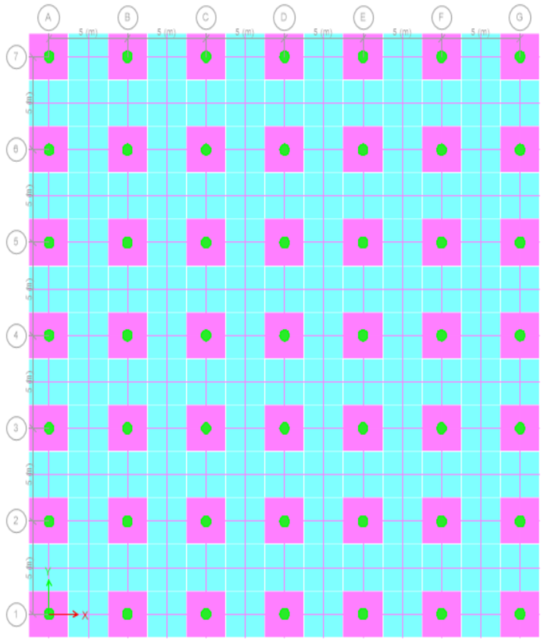

Fig 1: Plan of regular shape building

Case 2: Plus (+) shaped irregular building with flat plate, drop panel, column head and combination of drop panel with column head. Altogether 4 models were analyzed in this case.

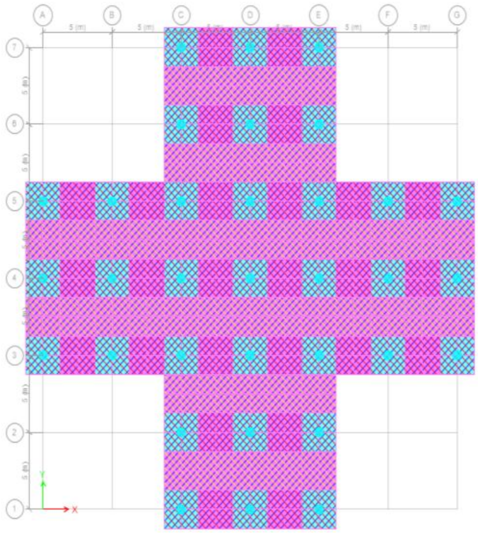

Fig. 2: Plan of Plus (+) shape building

Case 3: 'T' shaped irregular building with flat plate, drop panel, column head and combination of drop panel with column head. Altogether 4 models were analyzed in this case.

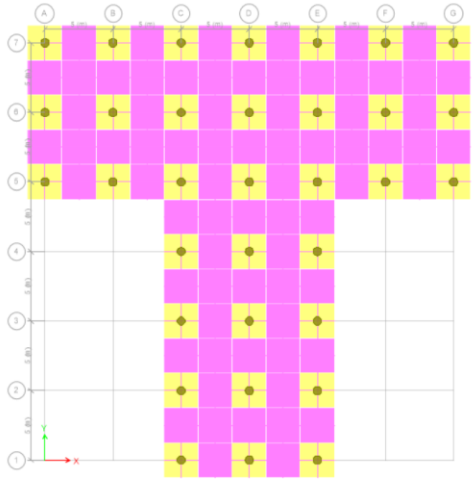

Fig. 3: Plan of 'T' shape building

Case 4: 'U' shaped irregular building with flat plate, drop panel, column head and combination of drop panel with column head. Altogether 4 models were analyzed in this case.

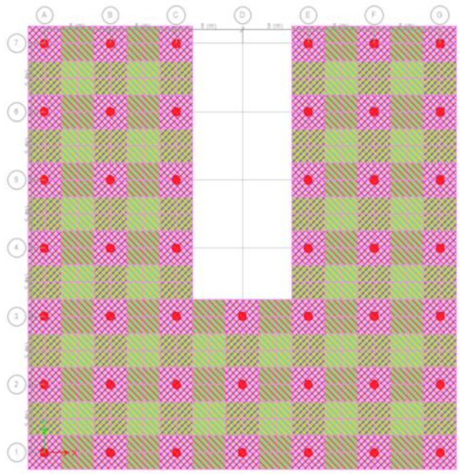

Fig. 4: Plan of 'U' shape building

VI. RESULTS AND DISCUSSION

Non-linear time history analysis was performed for analyzing the flat slabs structures in zone V as per Indian standard code. Based on the seismic parameters like storey displacement, storey drift, storey shear, base shear and time period, the effect of the different components like drop panel, column head, and combination of drop panel & column head has been observed and tabulated below.

A. Storey displacement

It is total displacement of i^{th} storey with respect to ground. The storey displacement is an important parameter when the building structures are subjected to seismic and wind loads. It is directly proportional to the height of the structure and also depends on the slenderness of the building structures. The storey displacements of different types of considered models along X and Y direction are as follows:

Table-II: Storey displacement along X-direction (in mm)

Types of flat slabs	Regular shape	Plus shape	U shape	T shape
Flat plate structure	103.641	96.62	98.953	101.746
Flat slab with column head	94.816	87.733	90.278	92.177
Flat slab with drop panel	71.31	72.782	75.597	78.439
Flat slab with drop panel and column head	64.307	65.485	67.775	70.607

Table III: Storey displacement along Y-direction (in mm)

Types of flat slabs	Regular shape	Plus shape	U shape	T shape
Flat plate structure	103.641	98.368	98.512	101.603
Flat slab with column head	94.816	89.355	89.81	92.445
Flat slab with drop panel	71.192	72.782	69.689	72.581
Flat slab with drop panel and column head	64.288	65.485	62.599	65.36

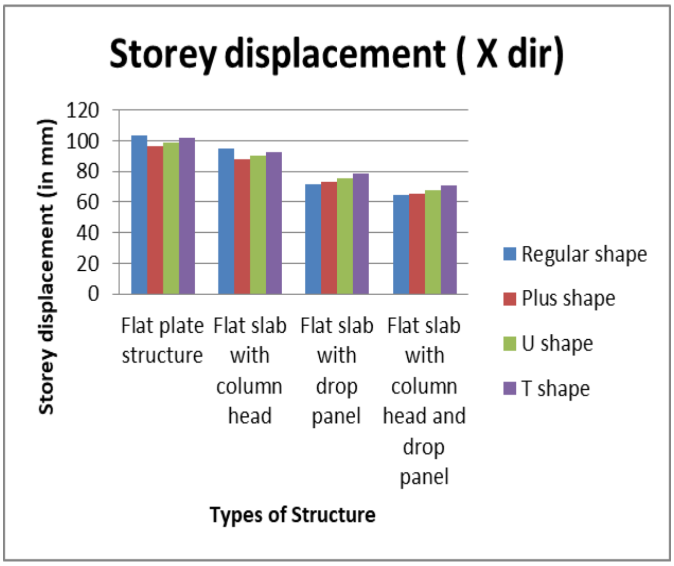

Fig. 5: Storey displacement vs. types of structures in X-dir.

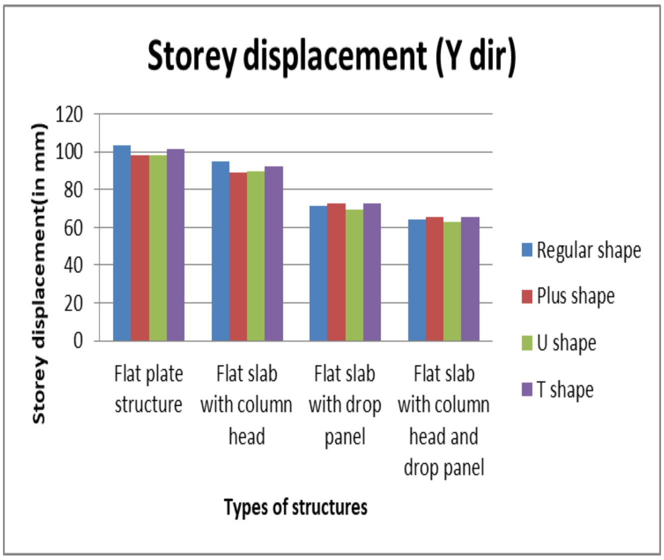

Fig. 6: Storey displacement vs. types of structures in Y-dir.

From the above table and graph, it can be easily observed that as the height of the building increases, the storey displacement gets increased. It was seen that the lateral displacement is more in the case of flat plate structure and flat slab with column head. With addition of drop panel, the storey displacement was reduced to a greater extent. Likewise, the combination of flat slab with column head & drop panel results effectively in reducing the storey displacement in comparison to others.

B. Storey drift*:* It is defined as ratio of displacement of two consecutive floors to height of that floor. The storey drift in any storey shall not exceed 0.004 times the storey height as per the guidelines of IS 1893(Part1):2016. It is very important term used for research purpose in earthquake engineering. The storey drift in all 4 types of flat slabs structures along X and Y direction are as follows:

1) Flat plate structures

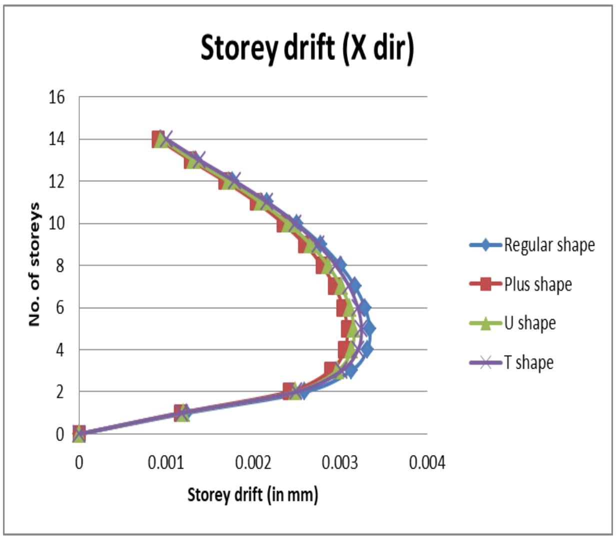

Fig. 7: Comparison of storey drifts along X-dir.

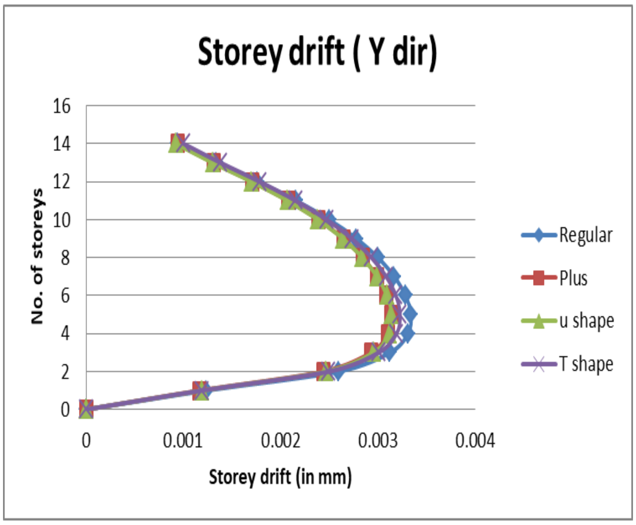

Fig. 8: Comparison of storey drifts along Y-dir.

2) Flat slab with drop panel structures

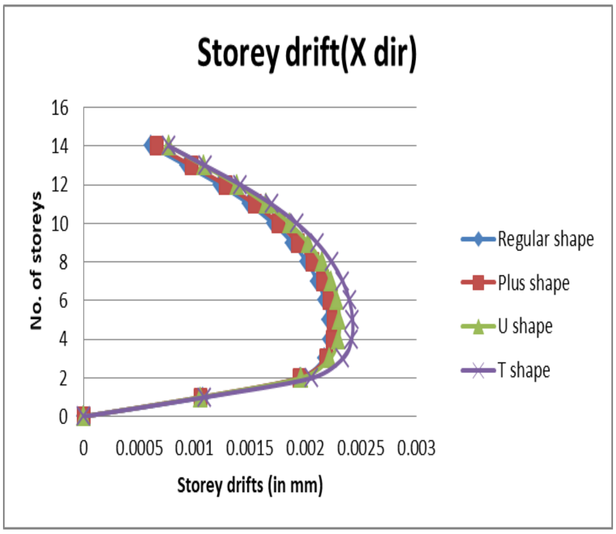

Fig. 9: Comparison of storey drifts along X-dir.

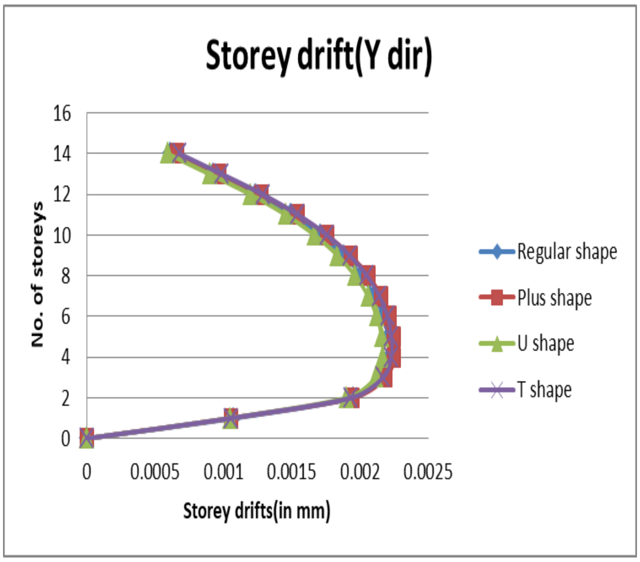

Fig. 10: Comparison of storey drifts along Y-dir.

3) Flat slab with column head structures

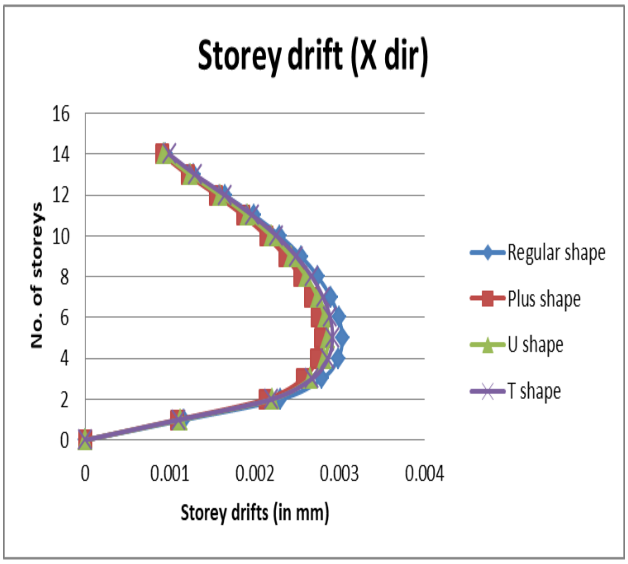

Fig. 11: Comparison of storey drifts along X-dir.

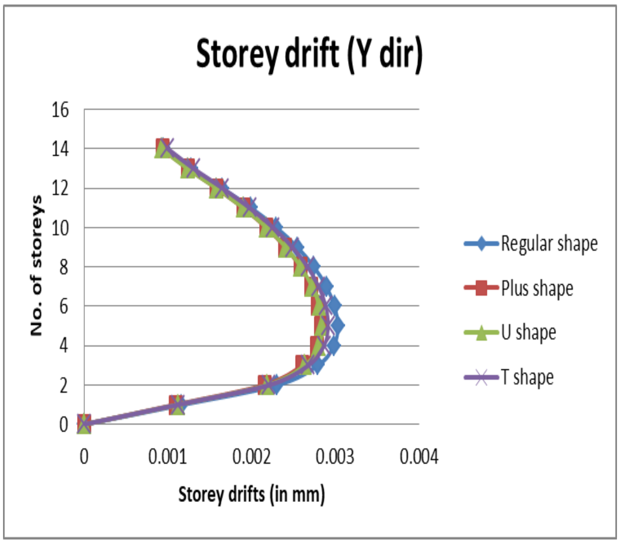

Fig.12: Comparison of storey drifts along Y-dir.

4) Flat slab with drop panel and column head structures

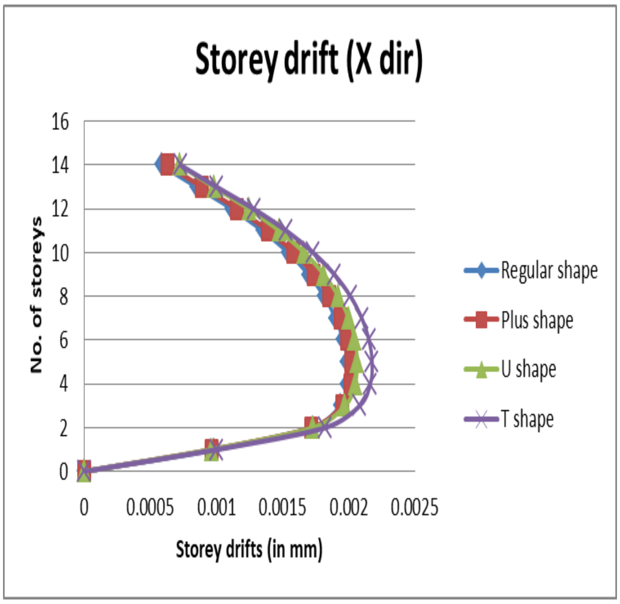

Fig. 13: Comparison of storey drifts along X-dir.

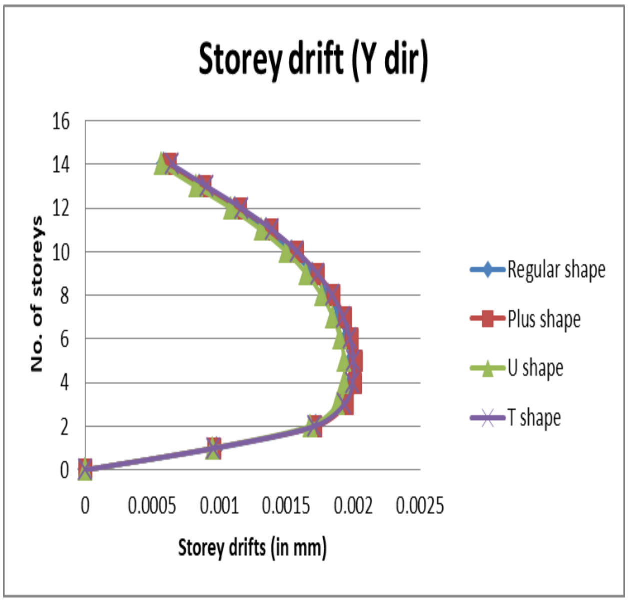

Fig. 14: Comparison of storey drifts along Y-dir.

From the above graphs, it was seen that the storey drift in all types of flat slabs structures are within the specified limit (i.e. 0.004 times the storey height) as per the guidelines of IS 1893 (Part 1): 2016. 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. The storey drift was found to be more in storey 4 and 5 for all the considered models.

C. Storey shear: It is the lateral force acting on a storey due to the forces such as seismic and wind force. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building.

Table IV: Storey shear along X-direction (in kN)

Types of flat slabs	Regular shape	Plus shape	U shape	T shape
Flat plate structure	2736.8342	1824.4538	2593.5814	1783.6673
Flat slab with column head	2587.3784	1720.2865	2451.3865	1680.5483
Flat slab with drop panel	4021.7262	2501.1094	3452.499	2488.5503
Flat slab with drop panel and column head	3912.5614	2415.4019	3345.0103	2407.5769

Table V: Storey shear along Y-direction (in kN)

Types of flat slabs	Regular shape	Plus shape	U shape	T shape
Flat plate structure	2736.8342	1800.0117	2603.2089	1781.8647
Flat slab with column head	2587.3784	1696.0736	2459.0327	1678.2235
Flat slab with drop panel	4027.9535	2501.1091	3570.72	2536.0712
Flat slab with drop panel and column head	3918.9964	2415.4019	3460.5086	2452.5068

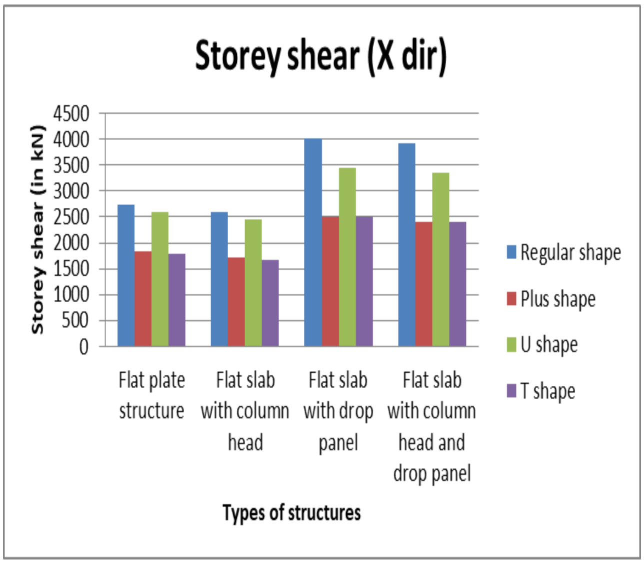

Fig. 15: Storey Shear vs. types of structures in X-dir.

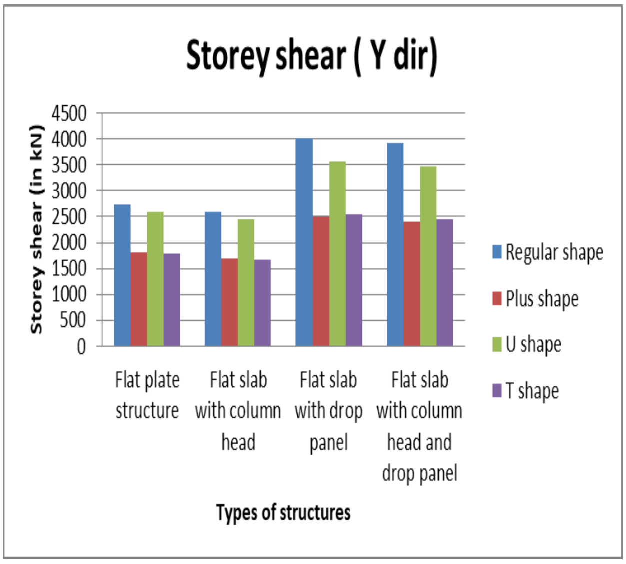

Fig. 16: Storey Shear vs. types of structures in Y-dir.

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

D. Base shear: It is the total lateral force acting on the building at its base which occurs due to the seismic ground motion.

Table VI: Base shear along X-direction (in kN)

Types of flat slabs	Regular shape	Plus shape	U shape	T shape
Flat plate structure	2447.8675	1656.0263	2350.8346	1611.0961
Flat slab with column head	2357.4106	1588.4398	2260.3966	1545.4073
Flat slab with drop panel	3802.0621	2306.6794	3260.8922	2350.225
Flat slab with drop panel and column head	3737.895	2304.9631	3194.2558	2298.8053

Table VII: Base shear along Y-direction (in kN)

Types of flat slabs	Regular shape	Plus shape	U shape	T shape
Flat plate structure	2447.8675	1628.9996	2356.7655	1610.7185
Flat slab with column head	2357.4106	1562.1915	2264.681	1544.318
Flat slab with drop panel	3807.7263	2360.6794	3383.9052	2396.4633
Flat slab with drop panel and column head	3743.9305	2304.9631	3313.6815	2342.6463

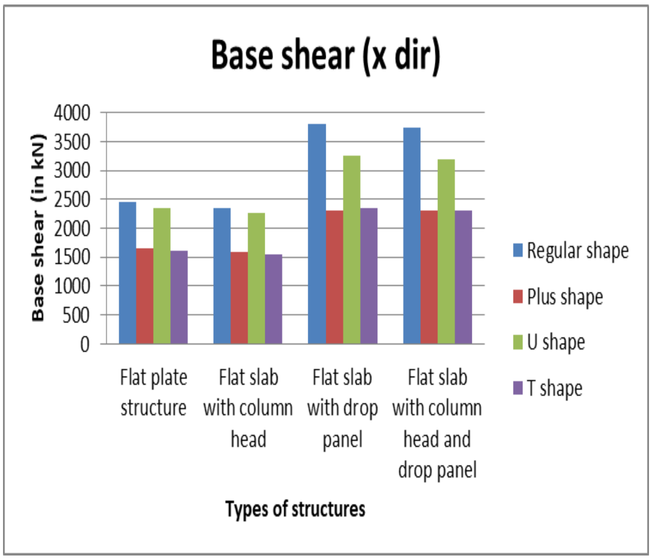

Fig. 17: Base Shear vs. types of structures in X-dir.

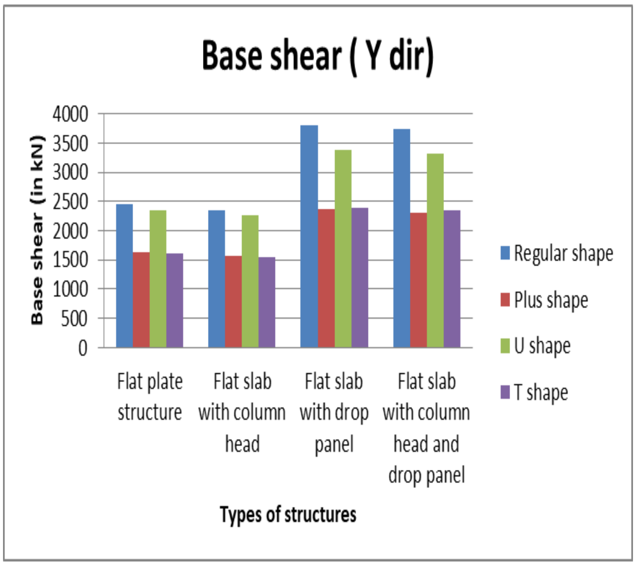

Fig. 18: Base Shear vs. types of structures in Y-dir.

E. Time period: It is defined as the time taken (in sec) by the structure to complete one cycle of oscillation in its natural mode of oscillation.

F.

Table VIII: Time period (in sec)

Types of flat slabs	Regular shape	Plus shape	U shape	T shape
Flat plate structure	3.17	2.99	2.967	3.024
Flat slab with column head	2.887	2.707	2.69	2.738
Flat slab with drop panel	2.195	2.23	2.224	2.24
Flat slab with drop panel and column head	1.977	2.005	1.996	2.011

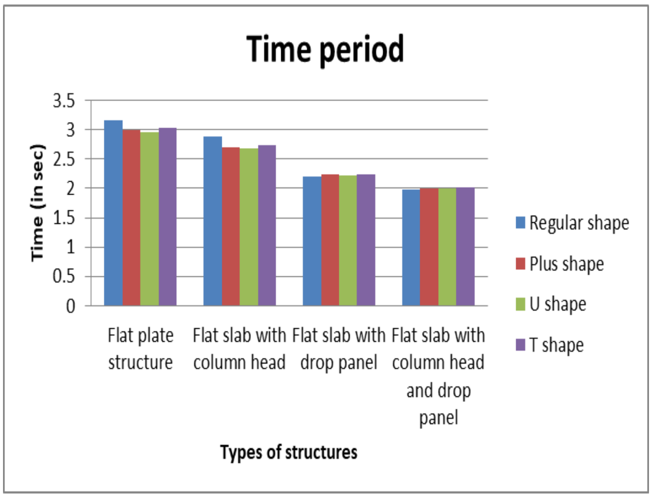

Fig. 19: Time period vs. types of structures

VI. CONCLUSION

From the above results, the various conclusions on the flat slabs have been summarized as follows:

1) The storey displacement of all the considered models are within the limiting value for flat slab with drop panel and combination of flat slab with drop panel & column head except for flat plate structures and flat slab with column head structures.
2) The flat plate structures and flat slab with column head structures should not be recommended for construction in zone V since it exceeds the limiting value (i.e. h/500).
3) The plus shape has very less storey displacement compared to other models and the drop panel, column head and drop panel with column head seems to be reducing the displacement more effectively in regular shaped structure than irregular structures.
4) The storey drift is more in regular shape and T-shape for flat plate structures whereas in regular and all irregular shaped structures, the displacement is heavily reduced while adopting drop panel with column head.
5) The storey shear is more in drop panel structures and less in flat slab with column head structures. The regular shape structures have more storey shear compared to other models in both X and Y direction.
6) 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 regular shaped structure has more base shear in all types of flat slabs.
7) Regular shape has more time period for flat plate structures and flat slab with column head whereas the U shape has less time period in overall all types of flat slabs.
8) Based on the considered seismic parameters, Plus shape was found to be more efficient model in case of flat plate and column head system.
9) Likewise regular shape structures were found more effective in case of drop panel and combination of column head and drop panel system whereas T shape was found to be vulnerable among all models because the results of the seismic parameters were not effective compared to other considered models.

Since the seismic zone like V is very severe, we can conclude that these models are only appropriate for this region if these are adopted with drop panel or combination of column head with drop panel system. For better results the considered models can be adopted with other components like shear wall and bracings in order to minimize the risks during earthquake.

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