SEISMIC BEHAVIOUR OF FLAT SLABS IN MULTI-STOREY BUILDINGS

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ABSTRACT

The growth of population has influenced the construction of multistorey 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. The main motive of the present work is to compare and observe the seismic behavior of G+13 storey of regular and different plan irregular buildings (Plus, T and U shape) by using different types of flat slabs (flat plate, drop panel, column head and combination of column head & drop panel) with the help of E-tabs 17.0.1 software. Later, conventional slab was adopted in the both regular & irregular models and analyzed in the similar way and compared with flat slab models intended for zone V. The nonlinear time history method was carried out to observe the different parameters like storey displacement, storey drift, 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

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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 type of system. This punching shear is about to occur once the entire shear force goes above the shear resistance of the slab and hence the slab gets pushed down just about the column. This leads to the breakage of the column through the part of the encircled slab and to overcome this type 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 exist, 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.

OBJECTIVES OF THE STUDY

- To perform the nonlinear time history analysis for all considered regular and plan irregular buildings having flat slabs and conventional slabs as per the guidelines of 1893(Part1):2016 for zone V.
- To check seismic parameters as storey displacement, storey drift, base shear and time period of conventional and flat slabs models for zone V.
- To understand & study the overall seismic performance of the conventional slab buildings in zone V.
- To compare the seismic behavior of all flat slabs models with conventional slabs models intended for zone V.
- To recognize the most effective & weak model between the models considered for seismic evaluation for zone 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. In this current work, the analysis has been done on the G+13 storey of regular and three types of plan irregular buildings (Plus, U, and T shape) having different sorts of flat slabs (i.e. flat plate, drop panel, column head and column head with drop panel)) with the help of E-tabs 17.0.1 software. Later, conventional slab was adopted in the both regular & irregular models and analyzed and compared with flat slab models considered for zone V. The Non-linear time history analysis has been adopted for evaluation and observation to know the seismic behavior of the entire considered models in zone V. The considered seismic parameters have been studied and compared carefully with one another to understand the actual behavior of the models during seismic action. Altogether 20 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 1: Preliminary Data for Flat Slab Buildings

S.N	Particulars	Dimension/Size/Value
1	Plan dimension	30m*30m
2	No. of stories	G+13
3	Floor height	3m
4	Number of grids in X- dir.	7
5	Number of grids in Y- dir.	7
6	Spacing of grids in X- dir.	5m
7	Spacing of grids in Y- direction	5m
8	Size of the column	600mm (circular)
9	Size of beam for conventional building	450mm*450mm
10	Slab thickness	200mm
11	Grade of concrete	M30
12	Grade of steel	Fe 415
13	Drop thickness	280mm
14	Width of drop	2.5m
15	Column head thickness	1.25m
16	Width of column strip	2.5m
17	Live loads	3kN/m ²
18	Floor loads	1kN/m ²
19	Roof live	1.5kN/m ²
20	Zone	V
21	Soil type	Type II (medium soil)
22	Importance factor	1.0
23	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.

Figure 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.

Figure 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.

Figure 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.

Figure 4: Plan of 'U' Shape Building.

Case 5: The all considered regular and plan irregular models (regular shape, plus shape, U shape and T shape) having conventional slabs were analyzed. Altogether 4 models were analyzed.

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.

Storey Displacement

It is total displacement of i^{th} storey with respect to ground. 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 directions are as follows:

Table 2: Storey Displacement along X-Direction (in mm)

Types of Structures	Regular Shape	Plus Shape	U Shape	T Shape
Flat plate Sytem	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 Column head having drop panel	64.307	65.485	67.775	70.607
Conventional building	54.812	54.239	58.204	58.93

Table 3: Storey Displacement along Y-Direction (in mm)

Types of Structures	Regular Shape	Plus Shape	U Shape	T Shape
Flat plate Sytem	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 Column head having drop panel	64.288	65.485	62.599	65.36
Conventional building	54.812	54.239	53.944	55.385

Figure 5: Storey Displacement vs. Types of Structures in X-dir.

Figure 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.

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 four types of flat slabs buildings and conventional slab buildings along X and Y direction are as follows:

- Flat Plate Structures**

Figure 7: Comparison of Storey Drifts along X-dir.

Figure 8: Comparison of Storey Drifts along Y-dir.

- Flat Slab with Column Head Structures

Figure 9: Comparison of Storey Drifts along X-dir.

Figure 10: Comparison of Storey Drifts along Y-dir.

- Flat Slab with Drop Panel Structures

Figure 11: Comparison of Storey Drifts along X-dir.

Figure 12: Comparison of Storey Drifts along Y-dir.

- Flat Slab with Drop Panel and Column Head Structures

Figure 13: Comparison of Storey Drifts along X-dir.

Figure 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.

- **Storey Drift-Conventional Building**

Figure 15: Comparison of Storey Drifts along X-dir.

Figure 16: Comparison of Storey Drifts along Y-dir.

As seen above, it is clearly understood that the drift is lesser in both regular and irregular types of buildings. The plus shape has very less storey drift whereas the T shape has more storey drift compared to other models. The maximum storey was obtained in storey 4 for regular and plus shape and storey 5 for U and T shaped building. Since the beam slab system reduces the storey drift to a greater extent, it is very much suitable for the zone like V if one has not to go with flat slab structures.

Base Shear

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

Table 4: Base Shear along X-Direction (in kN)

Types of Structures	Regular Shape	Plus Shape	U Shape	T Shape
Flat plate structure	2357.411	1588.44	2260.397	1545.407
Flat slab with column head	2447.868	1656.026	2350.835	1611.096
Flat slab with drop panel	3737.895	2304.963	3194.256	2298.805
Flat slab with column head and drop panel	3802.062	2306.679	3260.892	2350.225
Conventional building	5012.162	2980.67	3771.203	2953.999

Table 5: Base Shear along Y-Direction (in kN)

Types of Structures	Regular Shape	Plus Shape	U Shape	T Shape
Flat plate structure	2357.411	1562.192	2264.681	1544.318
Flat slab with column head	2447.868	1629	2356.766	1610.719
Flat slab with drop panel	3743.931	2304.963	3313.682	2342.646
Flat slab with column head and drop panel	3807.726	2360.679	3383.905	2396.463
Conventional building	5012.162	2980.67	4001.795	2976.723

Figure 17: Base Shear vs. Types of Structures in X-dir.

Figure 18: Base Shear vs. Types of Structures in Y-dir.

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.

Table 6: Time Period (in sec)

Types of Structures	Regular Shape	Plus Shape	U Shape	T Shape
Flat plate system	3.17	2.99	2.967	3.024
Column head System	2.887	2.707	2.69	2.738
Drop panel System	2.195	2.23	2.224	2.24
Column head and drop panel System	1.977	2.005	1.996	2.011
Conventional Building	1.703	1.667	1.714	1.682

Figure 19: Time Period vs. Types of Structures.

CONCLUSIONS

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

- The lateral displacement of the whole thought models for drop panel system & drop panel having column head are within limiting value (i.e. $h/500$) except for flat plate systems and column head systems.
- Since flat plate and column head system go above the limiting value (i.e. $h/500$), these types of flat slab system should be avoided for construction in zone V.
- Plus shape building with both Flat plate and column head system has very less storey displacement whereas it seems to be slightly decreasing in drop and drop panel with column head & more heavily in conventional slab system. T shape seems to have more storey displacement even in the drop, column head with drop and conventional building
- Regular shape has more displacement than other models in both flat plate and column head system whereas it goes on decreasing in drop and drop panel with column head system. Likewise, it constitutes very minimum storey displacement in beam slab system compared to flat slab systems.
- In comparison to other models, storey drift for regular shape and plus shape is more & minimum in flat plate and column head system respectively. The storey drift keeps on decreasing in drop & column head with drop to a great extent.
- The considered models having beam slab system constitutes very less storey drift compared to flat slab systems. The regular building has very less storey drift in conventional system whereas T shape has more storey drift.
- The base shear is more in combination of column head and drop panel than the other three types of flat system. However, the base shear in conventional system is more in comparison to flat slab system. The base shear is more in regular building and less in T shape in both systems.

- In flat slab systems, the regular shape was found to be effective in drop panel & drop with column head system since the time period is very less comparison to other considered models.
- The time period is less in conventional slab system and more in flat plate system. In conventional system, the plus shape has the minimum time period than other models. With addition of drop panel & column head, the time period goes on decreasing to a great extent.
- Among all, T shape has more time period even in drop & column head with drop panel system while the regular form shows the less time period in that systems.

From the above results and graphs, it can be concluded that the conventional system is far better for the region like zone V since it is very severe. If a contractor has to go with the flat slab system, then structure having drop and column head having drop is considered as the safest and effective system. From the overall seismic factors, the plus model was seen more effective in flat plate and column head system though this both practice of construction should be avoided in the region like zone V. The regular building shows good results in drop panel and drop panel with column system whereas the T shape fails to achieve good seismic performance in both flat systems and conventional systems. Moreover, the models can be added having further external structural elements like shear wall, bracings & by post-tensioning to diminish the consequences of danger throughout the shaking of the earth. The U shape and T shape structure was not seen good option for the zone V by observing the seismic parameters. Out of all these four types of flat slab system, the regular and plus shape was seen performing well appropriate for zone V. The drop & drop with column head system shows the effective result in flat slab system in reducing the displacement, drift and time period. Overall, the regular structure shows very good seismic behavior than the irregular structures in all aspects in both the flat slab system and conventional system.

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