IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

COMPARATIVE ANALYSIS ON BEHAVIOUR OF SINGLE COLUMN STRUCTURE WITH WAFFLE SLAB AND FLAT SLAB

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Abstract:Multi-storied building has been incorporated with waffle and flat slab individually in our research on ETABS for structural analysis to explore one such unmatched contrivance substitute could be used in the structures constructed in near future. Flat slabs are routinely being constructed only using the column, omitting the construction of beams, therefore affecting different aspects like the effectiveness, floor to floor height ratio, construction cost and freedom to the engineer whereas Waffle slabs are generally adopted in those structures having a smaller number of columns, wider span of floors, requires more stability, are light weight. We here in this research are analyzing the feasibility of G+3 building with a single column, alternatively applying the flat and waffle slab in place of the conventional one at a time to check the difference in the characteristics of a building like bending moment, end moments, deflection, shear force, etc. The interpretative study between both the slabs along with the G+3 single column building with varying floor span, slab span, slab thickness, column thickness, adding dome like structure on bottom has been carried out under the influence of loading via a software specially used for the analysis of the multi-storied building named as ETABS.

Index Terms **- ETABS, Flat Slab, Multi-storied Building, Single Column, Structural Analysis, Waffle Slab.**

1. INTRODUCTION

We all are pretty much aware that since urbanization and industrial revolution outreached to the farthest corner and among the different section of the civilization on this earth, we have extensively experienced the migration of large masses of the people from the less developed places to the more organized and well occupied with all the services inclined to provide better opportunities of living standards. This has been a well proven fact in many researches done by economists and scientists that this transfer of population have resulted in construction of tall buildings and sky scrapers in the urban areas majorly influencing the surrounding space and climatic conditions of that area which weren't considered as much as it should've been in the recent past.

The basic aim that civil engineers and architects had in mind while designing and constructing of multi-storied/high rise/sky scrapers building was to increase the floor area by many folds without affecting the land area thus saving the cost in terms of the people accommodated to the cost of the land. Since then thousands of such buildings have been well planned and constructed all over the world with some of them reaching the never thought heights and architectural variations but the constant ascending of the populations have always been the driving factor for the researchers and engineers to come up with new solutions to make the primary structures more effective in numerous factors like economy in the current scenario.

The proposed design of multi-storied building in our research involves the engagement of the single column at the center with alternatively applying the flat and waffle slab to the design which would represent the difference of structural properties that both the variants brings in the single column multi-storied building, and importantly checking it against the standards profile mentioned in the Indian Standards.

With the evolution of the computer's hardware and software in the recent times, it has made possible for the engineers and researchers to test their structural designs with all the prevailing conditions (like static and dynamic loading, earthquake shocks, wind load, etc.) that any structure experiences in the practical world, providing a facility to the user to make the necessary changes in the primary draft that was making it to be non-constructible in the real world.

The software we used here is ETABS which does analysis purely according to the Limit Design Method and the Indian Standards majorly followed, it also offers pretty well constructed user interface allowing the designers to input the design and apply the load dimensions conforming to the region of constructed. ETABS also has the key feature enabling the user to generate easily, conducting checks by inputting different loads, conditioned design visualization and result verification to the standards predefined.

For the successful execution of the structural analysis of our proposed design of multi-storied building with the help of ETABS we have designed three models each of single column multi-storied building with flat slab and waffle slab to do the complete analysis of the design. Furthermore, to deduct the value of displacement to make it come under the safe limit we introduced the outer columns and drop panels in the design. So, the varying factor here is the floor size, type of slab and the outer column in our proposed design of single column multi-storied design to verify its structural possibility in the real world.

The software utilized for this research, ETABS although has all the built-in specifications and standards necessary for an individual to design a multi-storied building but again we have to manually insert some data like wind load, seismic zone, terrain category, etc. for checking the structural properties of the design. For the same purpose, the IS 1893:2002, IS 456:2000, IS 875 (Part I, II, III) has been referred here in this research project.

The main backbone of the idea behind the structure design is the theoretical conformation of the primary design, and testing through the ETABS in this research paper to decrease the construction period, comparatively decrease the construction cost and mainly modifying the conventional design of the multi-storied building into the structurally sound with aesthetical significance that apparently would determine the way of designing and constructing multi-storied building in the near future.

2. LITERATURE REVIEW

2.1 E K Mohanraj et. al. (2002): analysed a single column is supporting structure, in which all other members are acting as cantilevers. To reduce the cantilever span for the structural beams converting two-third of the length as simply supported by providing the two ring beams and inclined beams. The structure is analysed and designed using STRAP (Structural Analysis Package), which is based on Stiffness Matrix method. Conclude that if maximum space utilisation is considered while planning and designing then it will surely serve its maximum serviceability.

2.2 Ambati Venu Babu et. al. (2016): Analysed a triangular shape building in which mono column situated at the edge of triangle not its centre & they found that a Single column structure is a critical one when it is being to a symmetrical and eccentric loading condition. Since single column is supporting whole structure, all other members will act as cantilevers. To reduce the cantilever span for the structural beams converting two - third of the length as simply supported by providing the two ring beams and inclined beams. The structure is analysed and designed using STAAD pro (structural analysis package), which is based on stiffness matrix method. The above structure has been analysed for various possible loading conditions and the critical has been selected for design purpose.

2.3 B.B. Babicki (1972): give detail about structural system & material used in the Westcoast Office Building is located in Vancouver Canada in a very picturesque setting and on one of the major arteries of the city connecting the downtown business core to the residential areas. This building has a total of 152,000 square feet of office area and covered parking accommodations for 200 cars. It was designed for Westcoast Transmission Co. by Bogue Babicki & Associates, Consulting Engineers of Vancouver and construction completed in 1970. The concept of the building was, the least interference with the natural setting and earthquake resistance since Vancouver is located on one of the severest earthquake zones extending from California to Alaska. The building in its final form has 277-foot-high concrete centre core 36 x 36 feet in plan area and accommodating 21 levels from foundation to top. Three Underground parking levels, equivalent of three levels of open plaza space, twelve levels of typical office floors, 110 x 110 feet in plan area suspended from the centre core above the plaza space plus, three levels within the core above the roof for mechanical and elevator equipment.

2.4 Badikala Sravanthi et. al. (2016): design and analysis of RCC structure supported on a single column is done in this project. Cost Comparison is done between RCC single column and RCC multi column structure. This paper presents structural modelling, stress, bending moment, shear force and displacement design considerations for a structure and it is analysed using STAAD Pro. Various steps involved in designing of RCC structure supported on a single column using STAAD pro and comparison of RCC single column and RCC multi column Structure. They conclude following: - a) Single column structure has been designed successfully to withstand all loads including earthquake and wind load, b) Single column structure is 20% more costly when compared with multi column structure, and c) Single column structure provides better architectural view and free ground space even though it costs bit more than multi column structure.

2.5 Madireddy Satyanarayana (2016): analyse and design of multi-storey building resting on the single column by using different code provisions. A lay out plan of the proposed building is drawn by using AutoCAD 2010. The structure consists of ground floor plus five floors, He planned building as per Indian standard code provisions. The building frames are analysed manually by Limit state method and give structural detailed for critical and typical R.C.C. members.

2.6 Donald MacLeod et. al. (2011): researched a technology in which mono-column is supported directly on the existing jacket pile at the sea bed and uses the platform's existing redundant pile capacity to economically extend the space available for the new compression facilities. A simple spigot interface between the mono-column and existing pile also negates the need for grouting, temporary fixings and any subsea intervention. Traditional approaches to increasing real estate on offshore platforms involve the installation of cantilevers or shoe horning equipment into inefficient spaces leading to extensive offshore hours and lengthy shutdowns. The critical design consideration for this structure is its ability to survive a ship impact scenario. To address this, the structure adopts technology developed for the transport of nuclear materials. Energy absorbing technology and analysis expertise have been utilized to create a 'crumple zone' to protect the new structure. This innovative mono-column structure by appearance is deceptively simple yet complex when it comes to balancing the design for ship impact, fatigue and extreme environmental loading. Many iterations have been undertaken to optimize the design as far as possible whilst keeping the structure free from components that are challenging to fabricate or costly to maintain. The final solution, has realised considerable cost savings and had a significant

positive influence on the project economics thereby helping to extend production from a North Sea field that might otherwise have been abandoned sooner.

3. RESEARCH OBJECTIVE

The feasibility of using single column in forms other than it has been already utilized in building the single column multi-storied building i.e. square or rectangular, could be improve its functionality even more than the present design of single column multi-storied building.

Again, this is the matter of further designing, analysing and testing before concluding anything theoretically.

Restraining and then adding some modern-day inventions might open the door for a new characteristic property like it did for the single column multi-storied building when single column was incorporated in the multi-storied building to observe the structural changes.

Challenging the caliber of single column multi-storied building to be employed in the place of other designs of buildings, skyscrapers, bungalows, flats, etc. like in dense cities where it wouldn't be easily adopted in place of original designs but again we can't jump to the conclusion before conducting proper research and study behind it through softwares we have in hand.

4. PROPOSED DESIGN OF SINGLE COLUMN MULTI-STORIED BUILDING

The following two designs that has been proposed in this research have been mainly designed to affect the structural properties of a conventional multi-storied building by changing the structural properties:

4.1 SINGLE COLUMN MULTI-STORIED BUILDING WITH FLAT SLAB

This G+3 multi building has only single column and no other columns except the outer ones along with the flat slab comparing to the traditional design of multi-storied building to test if this has any impact on the structural properties where as we are ensured about the construction aspects.

Table 1 Single column multi-storied Building with flat slab

Case A: Single column multi-storied building with flat slab (without outer column)	**Case B:** Single column multi-storied building with flat slab (with outer column)

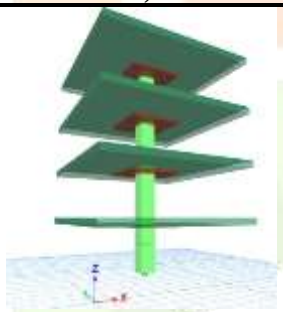
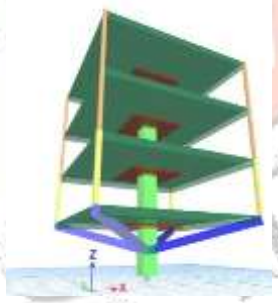

	

Figure 1 Without outer column	**Figure 2** With outer column

4.2 SINGLE COLUMN MULTI-STORIED BUILDING WITH WAFFLE SLAB

The below stated multi-storied building has the same single column like in the above design with the difference of using the waffle slab instead of the flat slab likewise with or without outer column differing than the old-fashioned building only to have a comparative study between them.

Table 2 Single column multi-storied Building with waffle slab

Case A: Single column multi-storied building with waffle slab (without outer column)	**Case B:** Single column multi-storied building with waffle slab (with outer column)

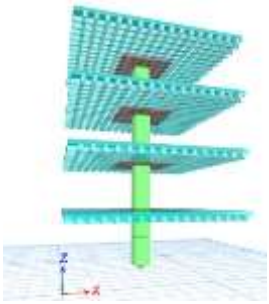
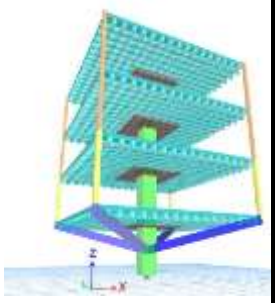

	

Figure 3 Without outer column	**Figure 4** With outer column

4.3 FRONT AND TOP ORTHOGRAPHIC VIEW OF A SINGLE COLUMN MULTI-STORIED BUILDING IN BOTH THE CASES

Table 3 Single column multi-storied Building (without outer column)

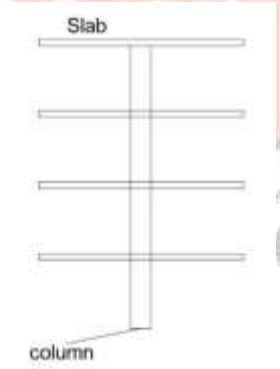
Top Elevation	**Front Elevation**
	
Figure 5 Top Elevation (without outer coulmn)	**Figure 6** Front Elevation (without outer column)

Table 4. Single column multi-storied Building (with outer column)

Top Elevation	Front Elevation

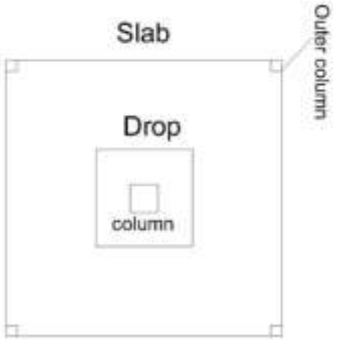
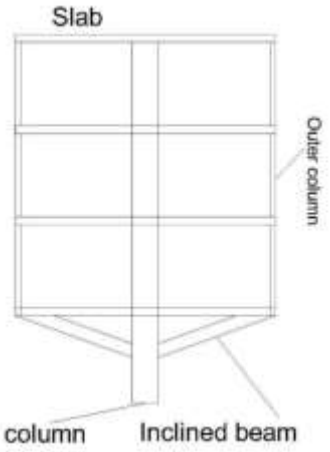

	

Figure 7 Top Elevation (with outer coulmn)	**Figure 8** Front Elevation (with outer coulmn)

5. PLANNING

5.1 PLANNING DETAILS OF SINGLE COULMN MULTI-STORIED BUILDING WITH FLAT SLAB

Table 5 Attributes with dimensions

S.No	Attributes	Design of Single Column Multi-Storied Building with Flat Slab
1	No. of Stories	G+3 (4 Stories)
2	Floor to Floor Height	3.5 m
3	Flat Slab Plan Size	I. 6x6 m II. 8x8 m III. 10x10 m
4	Flat slab (6x6) thickness	220 mm
	Drop thickness	300 mm
	Drop size	2000x2000 mm
5	Flat slab (8x8) thickness	280 mm
	Drop thickness	360 mm
	Drop size	2700x2700 mm
6	Flat slab (10x10) thickness	350 mm
	Drop thickness	430 mm
	Drop size	3350x3350 mm
7	Central Column Size	1000x1000 (mm)
8	Building Height	14 m
9	Type of Construction	RCC Structure
10	Live Load	4 KN/m^2
11	Super Dead Load	1 KN/m^2
12	Wind Load	
	Wind Speed	39 m/s
	Terrain category	3
	Class	A
13	Earthquake Load	
	Zone	2
	Zone factor	0.10
	Reduction factor	3

	Importance factor	1
14	Grade of Steel	Fe 500
15	Grade of Concrete	M 40

5.2 PLANNING DETAILS OF SINGLE COULMN MULTI-STORIED BUILDING WITH WAFFLE SLAB

Table 6 Attributes with dimensions

S.No	Attributes	Design of Single Column Multi-Storied Building with Waffle Slab
1	No. of Stories	G+3 (4 Stories)
2	Floor to Floor Height	3.5 m
3	Waffle Slab Plan Size	I. 6x6 m II. 8x8 m III. 10x10 m
4	Waffle slab (6x6) total thickness	275 mm
	Slab thickness	75 mm
	Bottom and top width	200 mm
	C/C spacing between ribs	600 mm
	Drop thickness	275 mm
	Drop size	2000x2000 mm
5	Waffle slab (8x8) total thickness	325 mm
	Slab thickness	75 mm
	Bottom and top width	200 mm
	C/C spacing between ribs	600 mm
	Drop thickness	325 mm
	Drop size	2700x2700 mm
6	Waffle slab (10x10) total thickness	400 mm
	Slab thickness	75 mm
	Bottom and top width	200 mm
	C/C spacing between ribs	600 mm
	Drop thickness	400 mm
	Drop size	3350x3350 mm
7	Central Column Size	1000x1000 (mm)
8	Building Height	14 m
9	Type of Construction	RCC Structure
10	Live Load	4 KN/m^2
11	Dead Load	1 KN/m^2
12	Wind Load	
	Wind Speed	39 m/s
	Terrain category	3
	Class	A
13	Earthquake Load	
	Zone	2nd
	Zone factor	0.10
	Reduction factor	3
	Importance factor	1
14	Grade of Steel	Fe 500
15	Grade of Concrete	M 40

6. STRUCTURAL ANALYSIS

6.1 ANALYTICAL METHOD ADOPTED

ETABS has emerged as an excellent software tool for conducting a structural analysis of a multi-storied building over the years which allows the designer to select from a wide variety of materials to structural components to structural members that could be used in a single design and further tested by inserting the value of dynamic loads and seismic loads on different areas or individual points.

ETABS has already been coded in such a way that the Indian Standards, orientations of structural components, visualization of load application and result verification could be done in no time as it provides a hustle free operation without doing hand calculations like the old days.

ETABS is a tool chosen by the professionals to there was no doubt about its accuracy and carrying a full test of structural design to evaluate its compatibility in the real world with all the loads striking in almost the same that has been instructed in the ETABS.

Structural analysis is a process followed by every designer with physical laws, mathematical calculations, software tools for checking the soundness and practicality of the structure without having to depend on the actual construction to verify the same allowing to save the construction time and cost.

The complications and errors while a designer might have faced in hand calculations is also omitted while testing using the ETABS which otherwise would have taken a longer duration of time and dismissing the possibility of primarily missing the verification of structural design that might have proven to be the main reason for its failure.

6.2 DESIGN COMPLICATIONS

The foremost design fault that was observed there in the proposed one while conducting structural analysis on ETABS was in the displacement value on each floor of the multi-storied building showing more than the allowable according to the Indian Standards.

It has to be dealt with before moving to other loads as the former could have resulted to more deformation if the other loads where applied without doing the essential enhancements in the proposed design of multi-storied building.

6.3 DESIGN ENHANCEMENTS

The complications or the problems encountered were mainly stated in the above paragraph which was the sole reason for questioning the compatibility and the practicality of the proposed design.

Therefore, the incorporation of other structural members like flat slab, waffle slab, inclined beams and outer column members was the solution we came up with to tackle the design complications that appeared earlier.

Furthermore, the flat and waffle slabs were used was of different plan sizes and depths along with the addition of inclined beams and outer columns, again to check if these all has changed the displacements value and made the structure possible to constructed in the selected seismic zone and under the other static and dynamic loading.

6.4 CALCULATION OF LOAD

The following two equations that have been majorly picked up while conducting structural analysis manually and on software is as follows:

6.4.1 Load combination (A) = 1.2x(Live Load) + 1.2x(Dead Load) + 1.2x(Super Dead Load) + 1.2x(Earthquake Load)**[Equation 1]**
6.4.2 Load combination (B) = 1.5x(Live Load) + 1.5(Dead Load) + 1.5x(Super Dead Load) **[Equation 2]**

7. RESULTS

7.1 SINGLE COLUMN MULTI-STORIED BUILDING WITH FLAT SLAB

7.1.1 Single column multi-storied building with flat slab (without outer column)

Table 7 Observed displacement values

Slab Size (m)	Load Combination A		Load Combination B
	Direction y (mm)	Direction z (mm)	Direction z (mm)
6x6	10.649	9.406	7.682
8x8	14.674	17.392	14.237
10x10	19.642	29.109	23.818

7.1.2 Single column multi-storied building with flat slab (with outer column)

Table 8 Observed displacement values

Slab Size (m)	Load Combination A		Load Combination B
	Direction y (mm)	Direction z (mm)	Direction z (mm)
6x6	9.526	3.170	1.966
8x8	12.347	7.211	5.293
10x10	15.964	14.847	12.217

7.2 SINGLE COLUMN MULTI-STORIED BUILDING WITH WAFFLE SLAB

7.2.1 Single column multi-storied building with waffle slab (without outer column)

Table 9 Observed displacement values

Slab Size (m)	Load Combination A		Load Combination B
	Direction y (mm)	Direction z (mm)	Direction z (mm)
6x6	10.082	8.822	7.173
8x8	13.250	16.783	14.208
10x10	17.631	25.378	20.617

7.2.2 Single column multi-storied building with waffle slab (with outer column)

Table 10 Observed displacement values

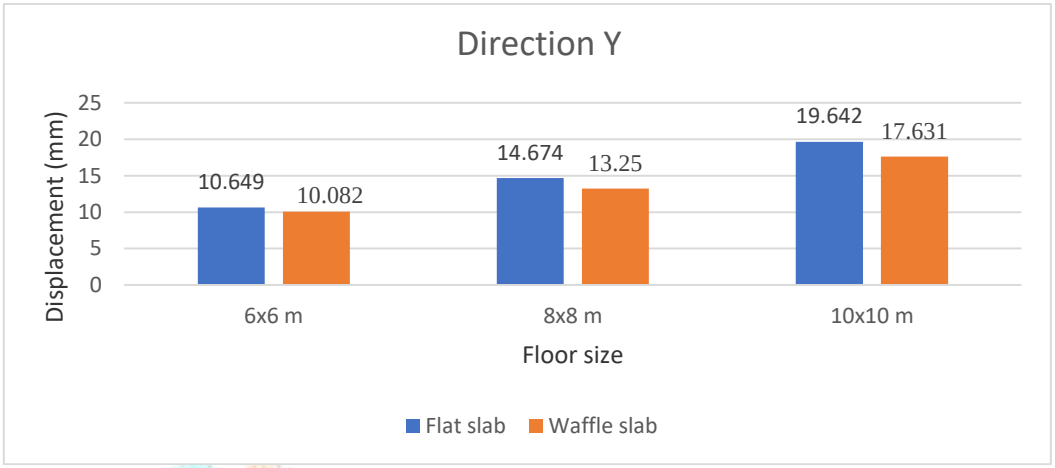
Slab Size (m)	Load Combination A		Load Combination B
	Direction y (mm)	Direction z (mm)	Direction z (mm)
6x6	9.267	2.932	1.806
8x8	11.591	6.265	4.553
10x10	14.463	11.929	9.371

7.3 GRAPHICAL REPRESENTATION OF THE OBERVED DATA

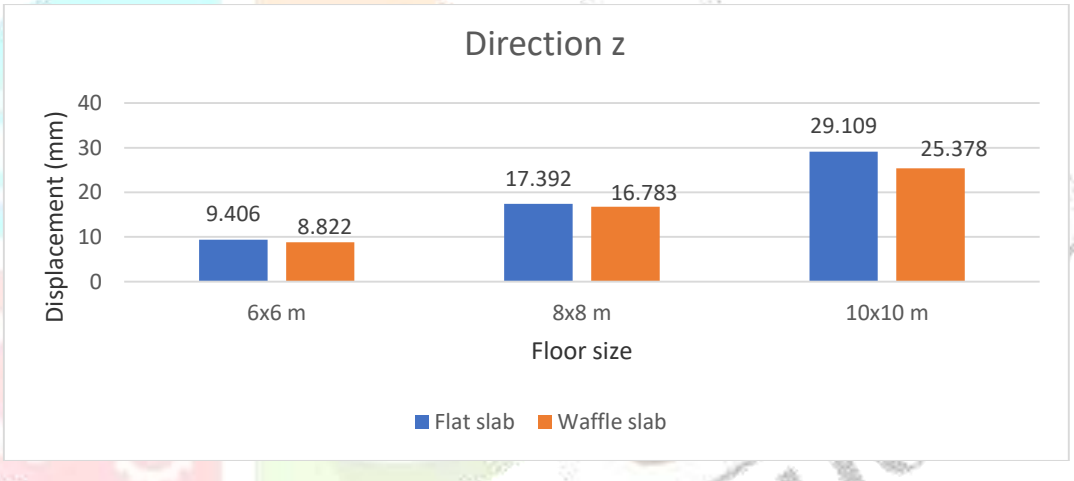
The same data (above) has been incorporated in the graphs below

7.3.1 SINGLE COLUMN MULTI-STORIED BUILDING (WITHOUT OUTER COLUMN)

Load Combination A: The load distribution here in this combination acts in two directions, i.e., Vertical and Horizontal Direction. Major portion of this load lies in the horizontal direction where as some of it lies in the Vertical Direction.

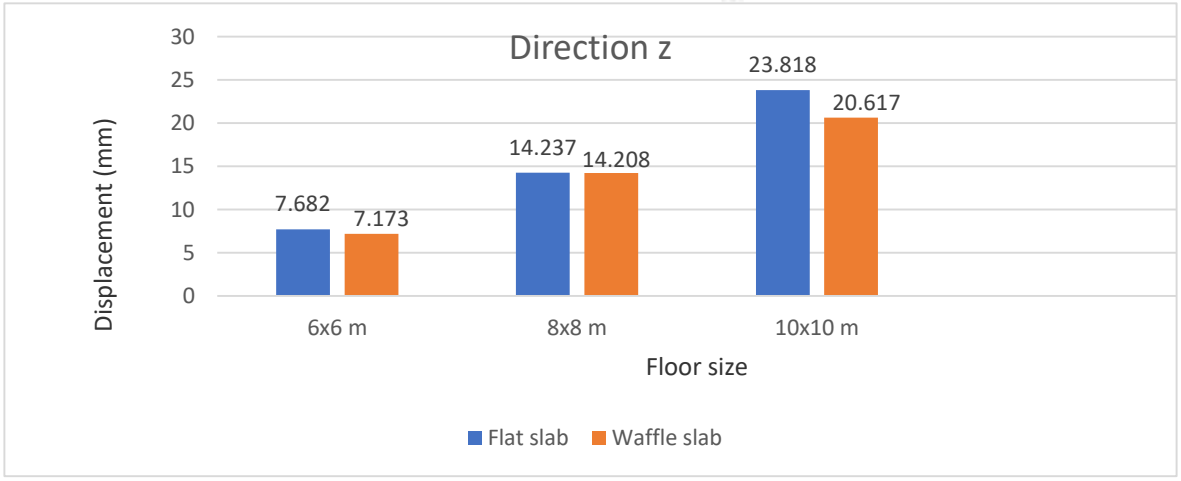


Graph 1 Displacement values in Direction Y



Graph 2 Displacement values in Direction Z

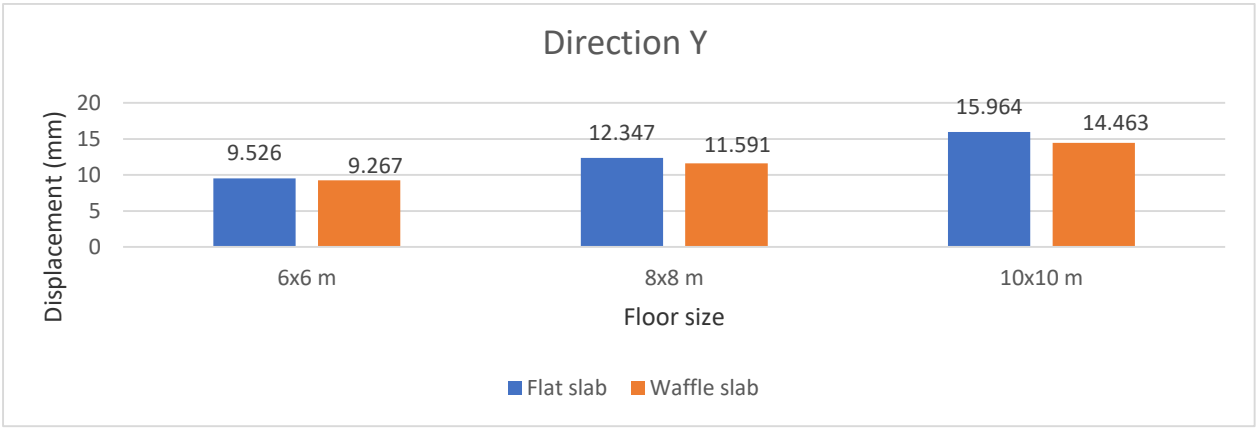
Load Combination B: The load distribution here in this combination acts in one direction, i.e., Vertical Direction. The complete load lies in the Z Direction.



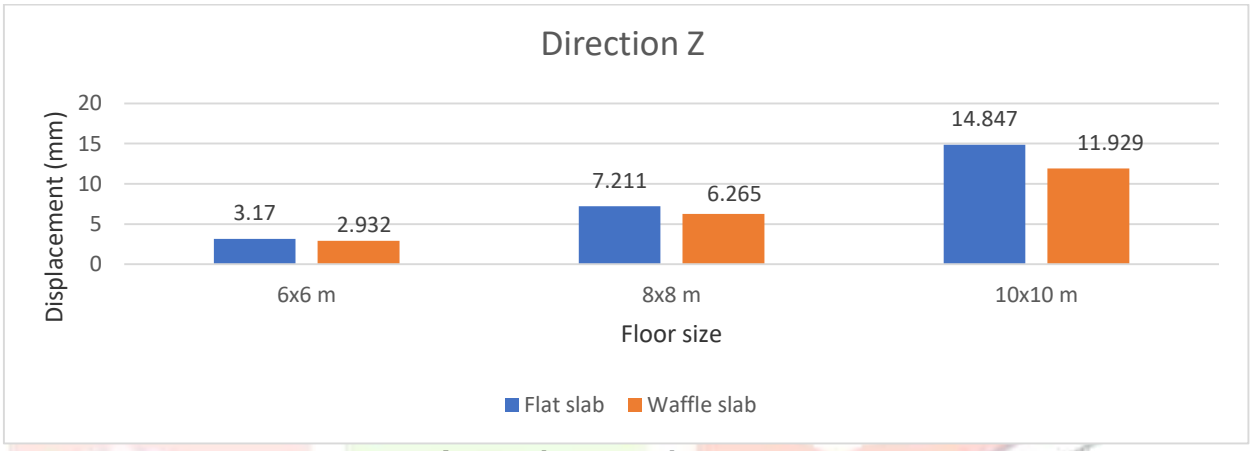
Graph 3 Displacement values in Direction Z

7.3.2 SINGLE COLUMN MULTI-STORIED BUILDING (WITH OUTER COLUMN)

Load Combination A: The load distribution here in this combination acts in two directions, i.e., Vertical and Horizontal Direction. Major portion of this load lies in the horizontal direction where as some of it lies in the Vertical Direction.

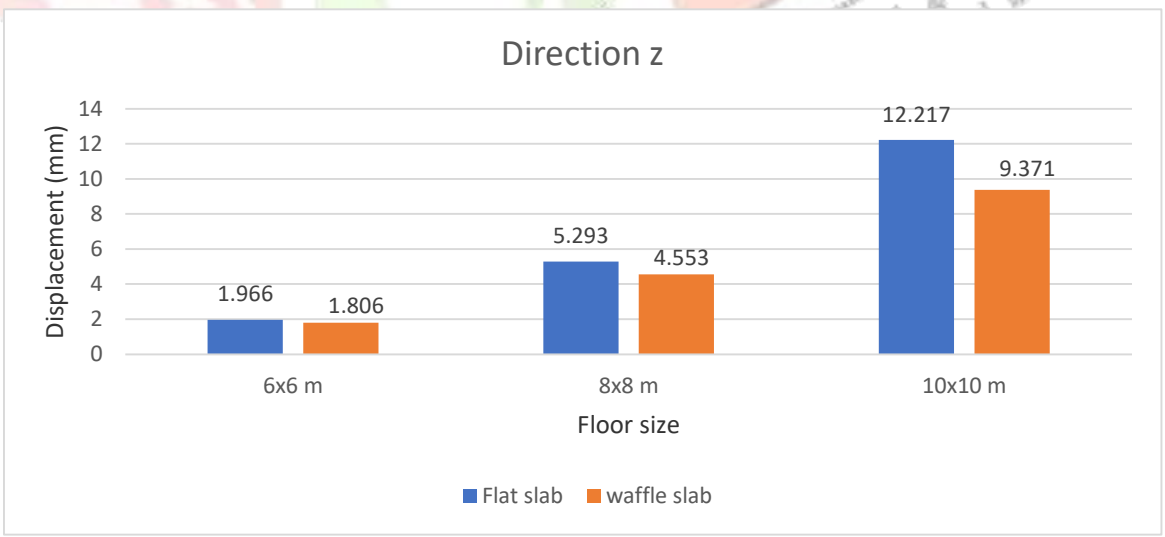


Graph 4. Displacement values in Direction Y



Graph 5. Displacement values in Direction Z

Load Combination B: The load distribution here in this combination acts in one direction, i.e., Vertical Direction. The complete load lies in the Z Direction.



Graph 6 Displacement values in Direction Z

7.4 REPRESENTATIVE OUTCOME OF G+3 BUILDING UNDER LOADING IN ETABS

Table 11 Comparative figure under displacement (with and without outer column)

3-D View of G+3 Building under Displacements (without outer column)	3-D View of G+3 Building under Displacements (with outer column)

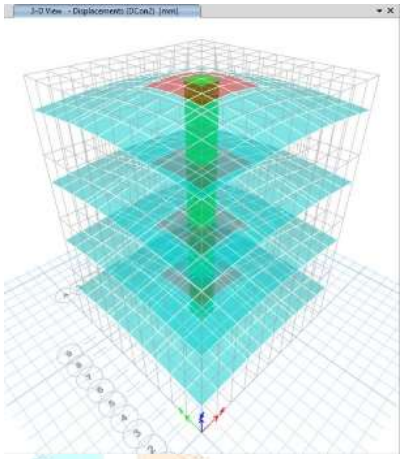
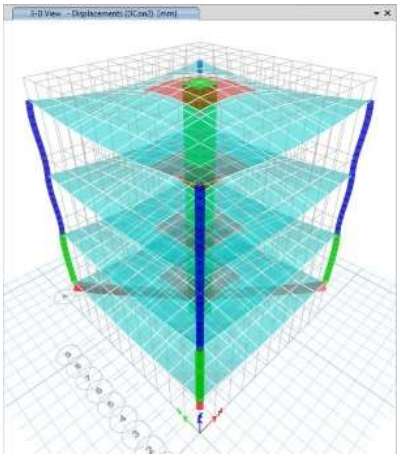

	

Figure 9 Without outer column	**Figure 10** With outer column

Table 12 Comparative figure under live and super dead load

3-D View of G+3 Building under Live Load	3-D View of G+3 Building under Super Dead Load

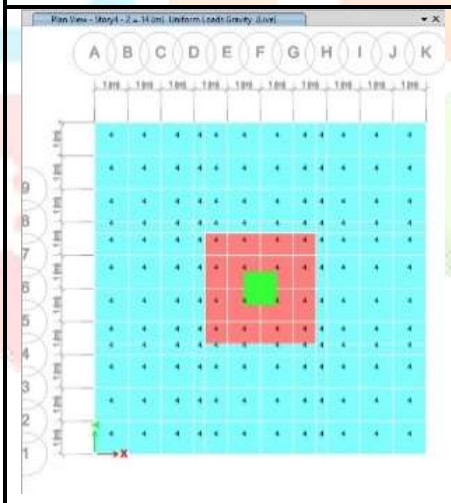
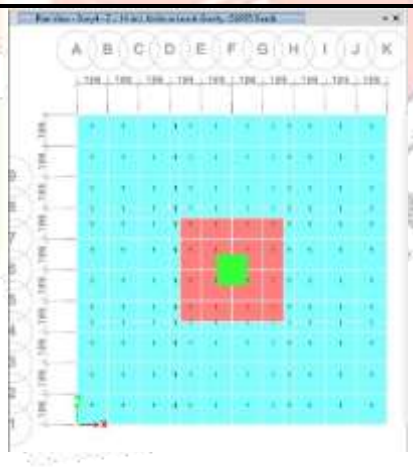

	

Figure 11 Under live load	**Figure 12** Under super dead load

The following several interpretations are drafted off when careful study of the data and graph have been done which we observed after analyzing the Single Column Multi-Storied Building with alternatively embedding the Flat and Waffle slab along with the outer column and the same without it.

1. It is clearly seen in the data and in the graph as well that we obtained after running the proposed design on the ETABS that the displacement value decreases very significantly when the waffle slab was used in the place of the normal slab as compared to the flat slab in both the cases where the outer column had also been included and also when removing the outer column.

2. Drop panels has been essentially indulged in the design at the center of slab as the structure of single column multi-storied building would have been failed in the punching shear in the absence of drop panels, counting as the one more structural component making the proposed design more structurally sound and safe when constructed practically.

3. Most important of all the observations that we had drawn from running the proposed designs in the ETABS was that all the structural members (i.e. single column, flat slab/waffle slab, floors, outer column) and the multi-storied building itself cleared the design specifications according to the codes. Therefore, making the proposed design vary feasible to be constructed in the real world at that particular static and dynamic loading considered here while doing all the checks in the ETABS.

8. CONCLUSION

The course of Single Column Multi-Storied Building is nothing different from the journey of any structural design when it comes to the point it was first developed and till now when it is near the edge of being completely adopted in the daily chores.

Single Column Multi-Storied Building demonstrates how contrasting structural members could also be assimilated into the traditional multi-storied building design to get the design of showing different properties having great impact in terms of environmental, structural, construction management aspect.

Flat Slab and Waffle Slab in one form (with or without outer column) have had noticeable effect in the properties of the multi-storied building design, enabling its utilization for different purposes of the building with keeping the factor of structural properties high as well.

In the world of construction, civil engineers and architects has the main concern about the strength of the Single Column Multi-Storied Building or any other member developed by the application of innovative idea and thought of integrating the modern invention with the old one, and Single Column Multi-Storied Building has surpassed this necessary challenge with the scope of future improvement.

The Single Column Multi-Storied Building has the bright future as it has the capability of fulfilling any reason for which a building structure is constructed with providing required structural properties to the structure and further more researches are going on like indulging (like what we did here) to it to assist the Single Column Multi-Storied Building in other properties widening its field of utilization in the construction world and beyond that.

Actuating force for increasing the broad adaptation of Single Column Multi-Storied Building in today's scenario of construction would definitely be its characteristics of contributing in degradation of ill effects of environment and the fact that it has the complete potential of a new structural design, and other properties but only needs some motivation and encouragement in the form of new researches and tests.

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