Wind Analysis of Super Tall Structures with Double Layer Space Structure

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Abstract: **High demand for residential and business spaces and advancements in construction techniques have resulted in the massive construction of tall/high-rise buildings all around the world. According to the Council of Tall Buildings and Urban Habitat (CTBUH), there the number of tall buildings has an increasing trend with a projected addition of 175 tall buildings in 2020. As buildings become taller and with advances in construction techniques resulting in lighter and more flexible buildings, they become more susceptible to large-amplitude vibration. The slenderness for a tall building is defined by the ratio of the building's height to the smallest plan dimension. It was found that the large-amplitude vibration can easily occur for tall buildings whose slenderness is greater than five or those that have a fundamental frequency of less than 0.2 Hz.**

Double-layer space structures, also known as space frames, have developed from the triangle concept as the most rigid geometry (Ambrose, 1994). The applications of this concept are commonly found in trusses as two-dimensional structures and in space structures as three-dimensional structures. Stevens (1975) categorizes space structures into single-layer and double-layer space structures. The three-dimensional action of single-layer space structures relies on their curved geometries, whereas the connection of the dual layers of space structures by diagonal members also create two-way action. Double-layer space structures have been commonly used for long-span horizontal structures such as domes, roofs and canopies because of their structural advantages. In these structures, gravity loads travel in two directions in the plan through all members to columns and then the foundations. This makes double-layer space structures more effective compared with planar trusses, which distribute loads in one way only

In this present work we designed vertical double-layer space structures positioned on the (G+60,80 and 100) building perimeters in order to maximize their capacity to resist lateral load. In this work the aim is to analyses force distribution in the structure and determine appropriate structural member sizes. The second stage investigates and compares the impacts of wind and seismic loads on the structures. The next stage evaluates the sensitivity of changing structural geometry on structural weight and lateral deflection.

I.INTRODUCTION

In general, Tall buildings are not described in terms of number of floors or height but relies more on its appearance compared to adjacent buildings. The Council of Tall Buildings and Urban Habitat (CTBUH) defined Tall buildings as a building of 14 or more storeys (or over 50 metres / 165 feet in height).

Tall buildings have high risk towards lateral loads, to overcome this issue many structural systems have been developed. Structural systems are classified into interior structures rigid frames, shear wall frames, and outrigger structures etc) and exterior structures (tubular systems, diagrid structures, space truss structures, space frames etc) based on the position of the majority of the lateral load resisting structural members in the building.

As buildings rise higher, designers face two major issues. Firstly, how to design efficient structures to resist the lateral loads that impact so greatly on tall buildings. Secondly, how to effectively integrate building systems, which often consume large amounts of space in taller buildings and potentially detract from the building aesthetics.

The four structural systems have a similarity with each other, the majority of their structural components are located at the building perimeter.

However, they also have different and unique characteristics in resisting lateral loads:

- Double layer space structure
- Diagrid
- Outrigger
- Tube in tube

1.DOUBLE LAYER SPACE STRUCTURE

The basic idea of space structures comes from the concept of a triangle, the most rigid geometric structure (Ambrose, 1994). It is a three dimensional space structure consist of two parallel layers that are spaced at a specific distance connected by diagonal members working together as structure.

From a structural point of view, positioning a double- layer space structure at the building perimeter maximises its capacity to resist lateral loads that are more dominant in taller buildings.

double- layer space structures also have benefits in terms of systems integration. The space between the two structural layers can be used for the distribution of building services components like pipes and ducts.

2.DIAGRID

The diagrid concept is a combination of the two words diagonal and grid. in diagrid systems all vertical columns at the periphery of building are removed and replaced by inclined columns. The inclined diagrid members are capable to carry gravity load and lateral loads due to the triangular module configuration.

Diagrid structures are not only efficient in resisting lateral loads, but also can achieve an aesthetically pleasing structural expression (Moon, 2009). particularly when they are complex geometries and curved shapes.

3. OUTRIGGER

Outriggers are interior lateral structural system functions in a high-rise building consist of two systems that are,

1. Core system
2. Perimeter system

The core system is a combination of units like lifts, staircases, ducts, etc. Whereas the perimeter system is a combination of mega columns. The core system and mega columns located at the perimeter are connected using outriggers to resist the lateral load.

4.TUBE IN TUBE

Tube-in-tube structural system is also known as "hull and core" arrangement. Here, a core tube is surrounded by an exterior tube.

The core tube holds the critical elements of a high-rise building like lifts, ducts, stairs, etc . The exterior tube is the usual tube system that takes the majority of gravity and lateral loads.

II.OBJECTIVE OF THE STUDY

To investigate the behavior of buildings i.e. double layer space structure, tube in tube, outrigger with belt truss and adiagrids under the seismic zone VI using the seismic and wind loads.

To study various responses such as story stiffness, story displacement, story drift and time period of different structural systems.

To Know the impact of wind and seismic load on various structural system such as diagrid ,tube in tube , outrigger and double layer structure.

III.NEED OF STUDY

At present, tall building are more referred as a result of enormous growth of population and shortage of available land.

tall buildings are subjected to different forces and environmental conditions, such as wind loads, seismic activity, and structural loads. Understanding different structural systems helps ensure that these buildings can withstand these forces and remain safe for occupants.

Different structural systems have varying levels of efficiency in terms of material use, construction time, and cost. Studying these systems helps in selecting the most cost-effective and resource-efficient.

Overall, a thorough study of various structural systems for tall buildings is essential for advancing engineering practices, ensuring safety, and promoting sustainable and innovative building solutions.

IV.SCOPE OF THE STUDY

To study the shear lag effect on tall structure exhibit a considerable degree of shear-lag with consequential reduction in structural efficiency.

To study the effect of different cross section and angles of diagonal member.

Further research can be carried out by considering the effect of lateral loads on irregular shaped structures and also by considering the torsion effects due to the lateral wind forces.

V.METHODOLOGY

In this work, ETABS 2020 is used to evaluate the seismic and wind responses of a structure subjected to earthquake and wind loading. We have analyzed all of these buildings using a non-linear dynamic analysis [time history analysis] and gust factor method . For all models, the typical story height is 3 meters. To perform non-linear time history analyses, "Bhuj" earthquake data is used as ground motion data. The Plan configuration consists of Total 12

models were studied in seismic zone IV.
DIA-60, DIA-80, DIA-100 (DIA- Diagrid)
TB-60, TB-80, TB-100 (TB- Tube in tube)
OUT-60, OUT-80, OUT-100 (OUT- Outrigger)
DL-60, DL-80, DL-100 (DL- Double Layer)

VI.MODEL INFORMATION

General data for g+60, g+80, g+100 structural systems

S. No.	Description	Information	Remarks
1	Plan size	48x48 m	-------
2	Building heights	180 m,240 m,300m	-------
3	Number of story above ground level	G+60, G+80, G+100	-------
4	Type of Structure	Diagird, tube in tube, outrigger, double layer	-------
5	Shear Wall thickness	8mm	-------
6	Type of building	Regular frame	IS-1893:2016 Clause 7.1
7	Horizontal floor system	Beams & Slabs	-------
8	Software used	ETABS 2020	-------

S. No.	Specifications	G+60, G+80, G+100
1	Slab Thickness	150mm
2	Column Dimensions Diagonal member dimension	2500x2500x100mm, 2000x2000x100mm, 1750x1750x100mm,1500 x1500x100mm 750x750x75mm
3	Beam dimension	ISWB550-1
4	Grade of concrete	M30
5	Grade of steel	Fe-345
6	Unit weight of concrete	25kN/m^3
7	Live loads SDL Wall load	3kN/m^2(IS 875 PART2) 2kN/m^2(IS 875 PART1) 12 KN/m2
8	Importance factor	1.5
9	Zone factor	0.24
10	Seismic zone	IV
11	Wind speed	50 m/sec
12	Response reduction factor	5

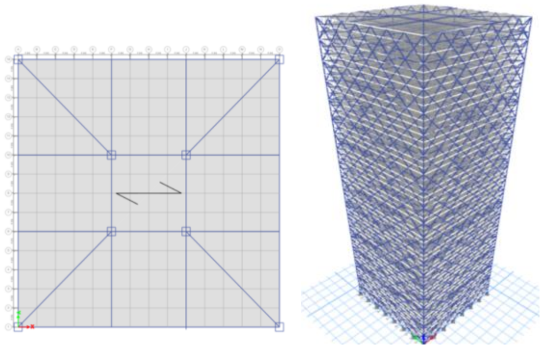


Fig.1 Plan view and 3-Dimensional view of Diagrid model

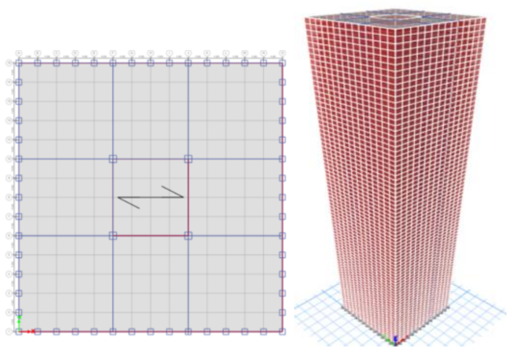


Fig.2 Plan view and 3-Dimensional view of Tube in tube model

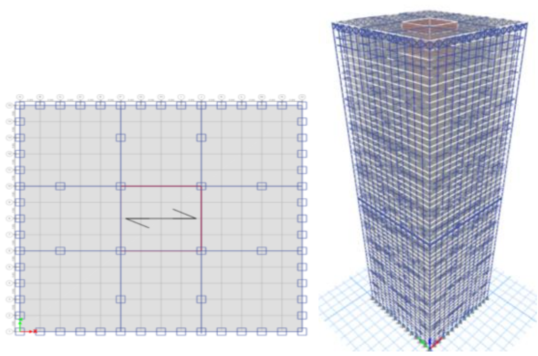


Fig.3 Plan view and 3-Dimensional view of Outrigger model

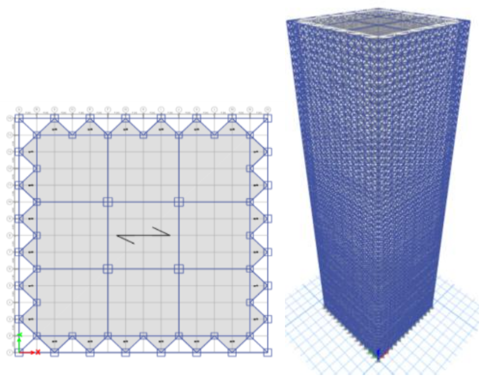
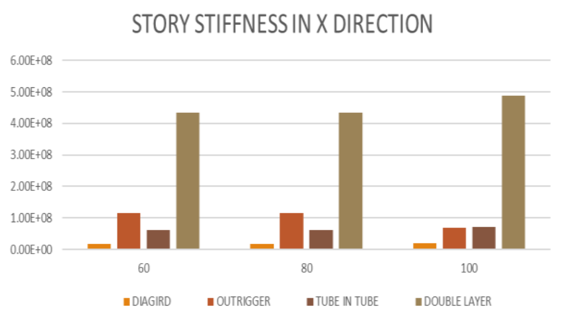


Fig.4 Plan view and 3-Dimensional view Double layer model

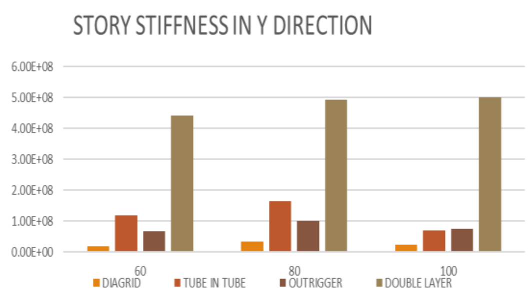
VII.RESULTS AND DISCUSSION

STORY STIFFNESS RESULTS
SEISMIC LOAD



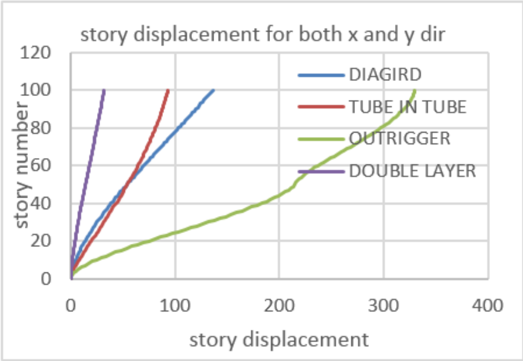
For diagrid model when compared to double layer the stiffness increases from 30571956 kn-m to 479802459 k-m, for tube in tube model 160484885 kn-m and for outrigger model 93576899 kn-m.

WIND LOAD



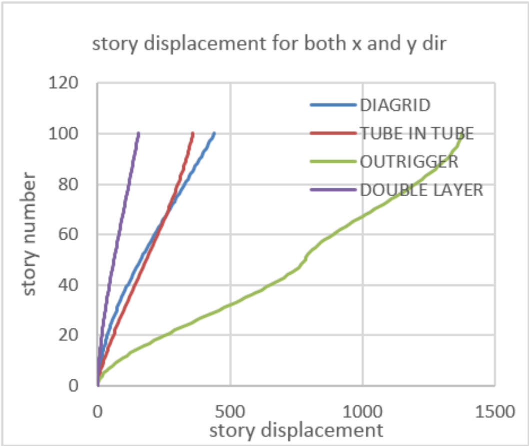
For diagrid model when compared to double layer the stiffness increases from 34270227 kn-m to 492996304 kn-m, for tube in tube model 164371761 kn-m and for outrigger model 101302935kn-m.

STORY DISPLACEMENT RESULTS
SEISMIC LOAD



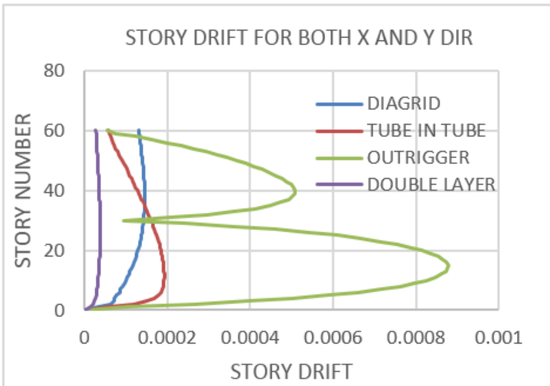
The story displacement for diagrid model when compared to double layer increases from 153 mm to 441 mm, for tube in tube model 359 mm and for outrigger model 1372 mm.

WIND LOAD



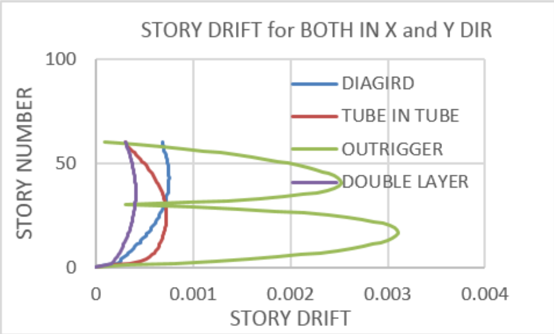
The story displacement for diagrid model when compared to double layer increases from 31 mm to 136 mm, for tube in tube model 93 mm and for outrigger model 329 mm.

STORY DRIFT RESULTS
SEISMIC LOAD



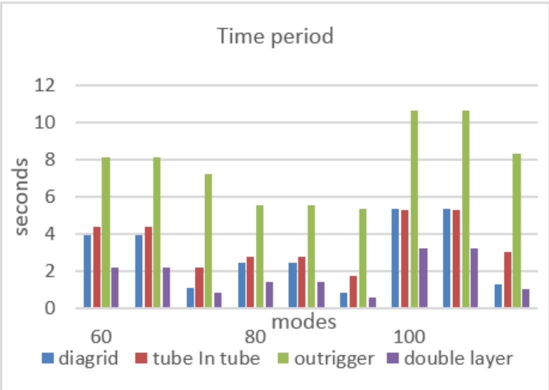
The story drift for diagrid model when compared to double layer increases from 0.000565 mm to 0.00184 mm, for tube in tube model 0.000754 mm and for outrigger model 0.000508 mm.

WIND LOAD



The story drift for diagrid model when compared to double layer increases from 0.00054 mm to 0.00011 mm, for tube in tube model 0.000164 mm and for outrigger model 0.000186 mm.

TIME PERIOD RESULT



The time period of the buildings in both x and y directions for double layer is least (1.462 sec) compared to diagrid model(2.456 sec), tube in tube(2.822sec) , outrigger (5.546 sec).

VIII.CONCLUSION

Story stiffness:

The story stiffness is analysed in both x and y directions for seismic and wind load .double layer stiffness is increased by 95 to 73%compared to diagrid, tube in tube and outrigger model.

Story displacement:

The story displacement is analysed in both x and y directions for seismic and wind load the double layer is decreased by 88 to 43% and 93% to 42% respectively compared to diagrid, tube in tube and outrigger model.

Story drift:

The story drift is analysed in both x and y directions for seismic and wind load the double layer is decreased by 79 to 11% and 81 to 11% respectively compared to diagrid, tube in tube and outrigger model.

As per the above results shows that the impact of wind load is more compared to seismic load as building rises high.

Time period:

The time period of the buildings in both x and y directions for double layer are reduced by79.27 to 40.46% compared to diagrid model, 90 to 48% for tube in tube and 95 to 73.6% for outrigger model.

It was found that, comparing all the different structural systems, vertical double layered system provides more effectiveness. In terms of lateral displacement, Storey drift, time period, Storey stiffness.

IX.FUTURE SCOPE

1. To study the shear lag effect on tall structure exhibit a considerable degree of shear-lag with consequential reduction in structural efficiency.
2. To study the effect of different cross section and angles of diagonal member.
3. Further research can be carried out by considering the effect of lateral loads on irregular shaped structures and also by considering the torsion effects due to the lateral wind forces.

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