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Optimum Structural Design for High Rise Building

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***ABSTRACT** Humanity has an obsession for high rise structure. In the 20th century the focus was on strength, rigidity, massive structural members like the Empire State Building. However, in 21st century structural engineers are looking for innovative structural designs for tall building. Various techniques like Tubular system, tube in tube, outrigger with belt truss, diagrid structural system have led to decrease in size of structural members. The objective of this Research paper is to look for optimum design for high rise building. For this purpose a typical building plan with same loading cases is analyzed for 7 different structural configuration. All the models are satisfying structural codes - IS 456-2000, IS 1893 - 2002, 2016, IS 132920, IS 875, NBC- 2016. The dead load on structure on the structure is reduced by use of innovative aerocon partition panels. Thus leading to optimization of the structure. The structural performance of Moment Frame, Moment frame with Shear wall at corners, Moment frame with Core Tubular, Tube in Tube Structure System, Outrigger Structure System, Outrigger with belt truss structure system have been compared at the end with parameters Base shear, storey response, Time period. Dynamic analysis has also been performed on all model.*

***Keywords:** - optimum Structural design, Moment Frame, Moment frame with Shear wall at corners, Moment frame with Core, Tubular, Tube in Tube Structure System, Outrigger Structure System, Outrigger with belt truss structure system.*

I. INTRODUCTION

Tall buildings have been in existence from ancient times. The bygone structures like - tower of Babel, Kutub Minar, Egyptian pyramids, Mayan temples, Colossus of Rhodes. While prime motive in ancient times was guided by ego and pride. The ancient structure sowed the seeds for present day tall buildings. These structures were not used as human habitats rather were monuments, place of worship. However, in contemporary times with rapid rise in population the demand for high rise buildings has increased. The purpose for high rise buildings is more utilitarian to inhabit more number of people. In contemporary times the trend in HRB started in New York in 1931 from the Empire State Building. Although in the 21st century the trend for High Rise Buildings has shifted to Asia and maximum tall buildings are being constructed in Asia. In past 120 years, there has been broadly 3 types of structures employed IN TBs.

- The first generation of TB was from 1850 to 1910 in this buildings were made of cast iron. The gravity loads were carried by exterior walls.
- The second generation began with the Home Insurance Building, Chicago (1883)b followed by Woolworth Building (1913) and Empire State Building (1931). These are framed structure. The Skelton of the building consists of steel columns and beams welded / riveted.
- Past 1960, the structure were designed such that tubes with closely spaced columns were introduced in the perimeter inside this a core of steel, concrete or hybrid and two consisting of services like staircase, elevators etc.

II. DEFINITION

IS 16700 : 2017 defines Tall building as building whose height are above 50 Mtr but less than or equal to 250 Mtr. The code has classified Tall Building as: -

- Structural wall system
- Moment frame System
- Moment frame, structural wall system
- Structural wall - Flat slab floor
- Structural wall - framed tube system
- Framed tube system
- Tube in the tube system.
- Multiple tube system.
- Hybrid system
- Any of above with additional framing system- ex. Outrigger trusses, belt truss.

III. JOURNEY OF HIGH RISE BUILDINGS

The advances in structure design of High Rise Building started in the 20th Century while its formation was laid during 1880's with use of cast iron as a building material which was lighter and also better than masonry. Gradually, elevators cemented the way for high rise buildings.

The design in High Rise Building were largely of three unique elements: -

- New design of bold lines, rectangles where heavy structures made up of steel defining power and prestige.
- The amalgamation of interior spaces and exterior facade as a one unit.
- Use of steel and concrete as structural and members.

IV. LATERAL LOAD DESIGN PHILOSOPHY

The lateral load such as wind load, eq. load are the dominating one in tall buildings. While gravity loads increases with height linearly. Lateral loads on the other hand vary in proportional to the square of height of the building. Thus to balance the lateral load the tall building should be stable, rigid, stiff also as per the desired codes. The 2 factors - rigidity and stability in HB are very crucial. While to make the structure more rigid, the size of structural members are increased whereas for increasing the strength the structural configuration is altered by using innovative techniques like bracings, tubes etc.

- Due to the action of wind load the TB can collapse due to P-delta effect. Crushing of columns can occur due to increase in gravity load because of eccentricity.

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- The inter storey drift should be minimized in order to curtail the lateral deflection. The inter storey drift should be minimized.
- The building should be ductile in nature for better structural performance under seismic conditions.

V. STRUCTURAL COST OF HIGH RISE BUILDINGS.

Typically structural cost for tall buildings is around 20-30% of the total project cost. Generally cost of lateral bracings is building above 50 storeyes is almost 30% of the total cost of structure. Hence, the structural cost for resisting the lateral load is around 7% - 10%. Tall buildings leads to saving in areas, thus, it is suitable for metropolitan cities like Mumbai, Delhi, Bangalore.

VI. INNOVATION DESIGN

Structure Engineers are looking for innovative methods to reset the lateral loads. Some of them can be: -

- Increase width of subsystem to resist overturning.
- Use of exterior / interior bracings.
- Arranging the framing in such a way that gravity loads are carried by lateral load carrying structural members.
- Providing truss to avoid bending in columns.
- Providing structural core i.e. connected to the peripheral columns.
- In order to reduce the drift the peripheral columns can be curvilinear.
- Designing the structural member in such a way that entire structure behaves in an integrity manner and the load transmission is transferred holistically in most efficient way.
- Designing hybrid structures in such a way that both concrete and steel are used together e.g. RCC columns having steel sections such as I-section in order to increase the strength.
- Designing the building plan is one of the most crucial part in tall building design. Building plans like round plan having setback helps in reducing the wind pressure.
- Providing regular columns at a spacing of around 3-3.5 mtr at the perimeter of the structure, it reduces the lateral as well as gravity load on the building. These columns act as tubes.
- Use of welding instead of bolting to reduce weight of steel by 8% to 15%.
- Providing use of light gauge steel can reduce the dead load on structure and also help in increase its strength.
- Providing steel plate as external wall can reduce the lateral load on building.
- Reduction in dead load by using aerocon panels for partition walls instead of conventional brick walls.

VII. VARIOUS TECHNIQUES USED FOR OPTIMIZATION OF STRUCTURE

- Use of light weight aerocon panels as a substitute for brick wall in partition. The load of aerocon panel (75 mm) is on 3.75 Kn / M whereas that of 230 mm brick wall is 15 KN/M. Thus, reducing the DL on structure loading to optimization.
- Various methods of HYB have been modeled in ETAB with innovative techniques like use of bracings.
- The building is symmetrical throughout and follows a grid pattern. Thus, reducing the loading to a better load dispersion and also optimization in structural performance in countering lateral loads.

VIII. MODELING AND ANALYSIS

A 50 storey building is modeled with a floor height of 3.50 Mtr each. The building has been designed for the following parameters: -

Zone	IV
Zone factor	0.24
Soil type	Medium
Response reduction factor	5
Importance factor	1.5
Span of building	39 x 24 Mtr
Floor height	3.50 Mtr
Height of the building	175 Mtr

8.1 Moment Frame Structure

It is a conventional RCC framed structure consisting of beams and columns. The properties of the structure is as under: -

C1	-	1000 x 600 mm
B1	-	750 x 600 mm
Slab	-	150 mm

The span between the columns varies such as 6.0 x 6.0 Mtr and 7.50 x 6.0 Mtr. The load considered are as follows: -

Live load	-	3 KN / Sqm
Super dead load	-	1 KN / Sqm
Partition load (aerocon panels)	-	1.76 KN / Mtr

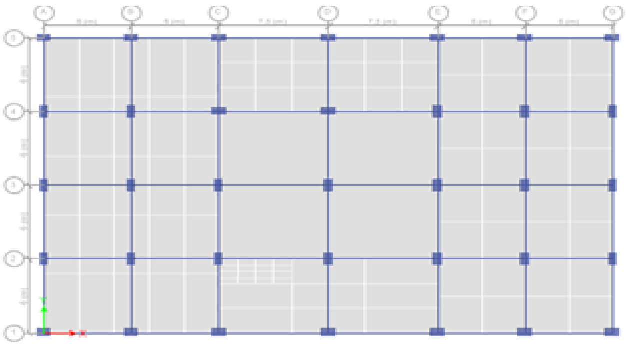

Figure 1 -Plan of Moment frame Structure

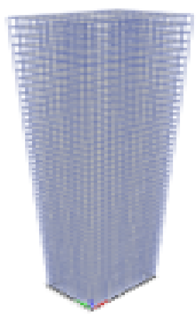

Figure 2 -3D view

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8.2 Moment Frame Structure with Shear Walls at Corners

It is a RCC framed structure with shear wall at the corner for better structural efficiency. The properties of the structure is as under: -

C1	-	1000 x 600 mm
B1	-	750 x 600 mm
Coupling beam	-	1000 x 600 mm
Slab	-	150 mm
Shear wall	-	350 mm

The span between the columns varies such as 6.0 x 6.0 Mtr and 7.50 x 6.0 Mtr. The load considered are as follows: -

Live load	-	3 KN / Sqm
Super dead load	-	1 KN / Sqm
Partition load (aerocon panels)	-	1.76 KN / Mtr

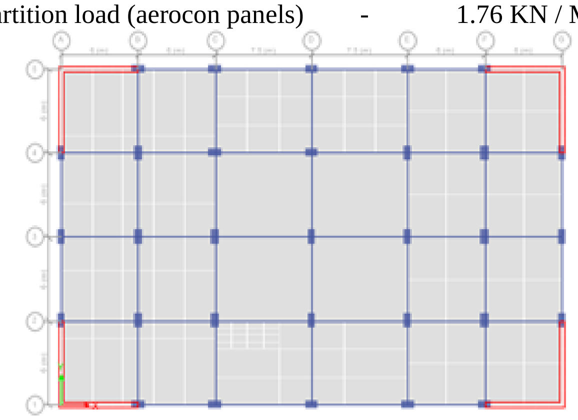

Figure 3 -Plan of Moment frame with shear wall at corner

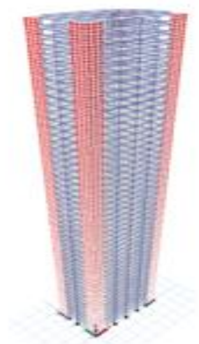

Figure 4 -3D view

8.3 Moment Frame structure with the central Core

It is a RCC framed structure with central core resisting both the lateral as well as the gravity load. The properties of the structure is as under: -

C1	-	1000 x 600 mm
B1	-	750 x 600 mm
Coupling beam	-	1000 x 350 mm
Slab	-	150 mm
Shear wall	-	350 mm

The span between the columns varies such as 6.0 x 6.0 Mtr and 7.50 x 6.0 Mtr. The load considered are as follows: -

Live load	-3 KN / Sqm
Super dead load	-1 KN / Sqm
Partition load (aerocon panels)	-1.76 KN / Mtr

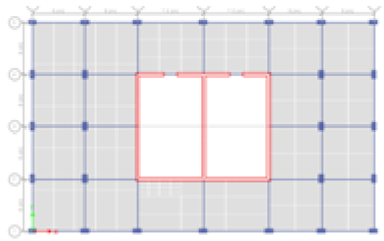

Figure 5 -Plan of Moment frame with Core

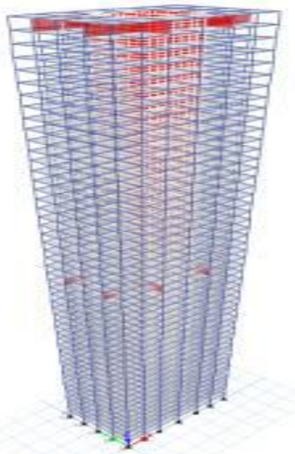

Figure 6 -3D view

8.4. Tubular Structural System

It consist of closely spaced columns at the peripheral of the building acting as tubes. Thus, resisting both gravity as well as lateral load. The properties of the structure is as under: -

C1 outer columns (tubes)	-	1000 x 600 mm
C2 (inner gravity columns)	-	900 x 900 mm
B1 (Spandrel beam)	-	1200 x 600 mm
B2 (Inert beam)	-	900 x 600 mm
Slab	-	150 mm

The tubular columns have a spacing of 3 mtr c/c whereas the gravity columns have a spacing of 9 mtr x 9 mtr and also 12 mtr x 9 mtr. The load considered are as follows:

Live load	-	3 KN / Sqm
Super dead load	-	1 KN / Sqm
Partition load (aerocon panels)	-	1.76 KN / Mtr

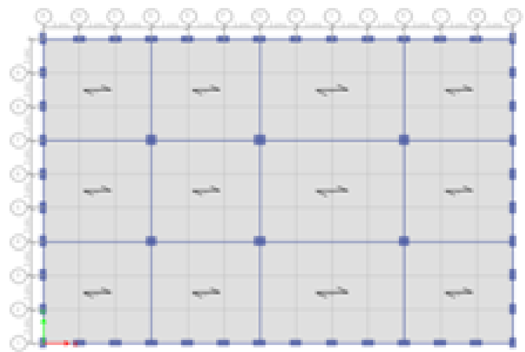

Figure 7 -Plan of Tubular Structure system

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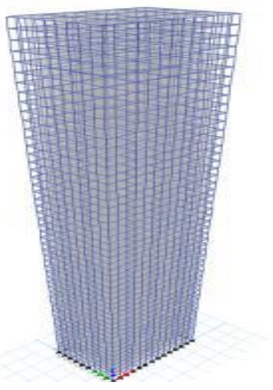

Figure 8 -3D view

8.5. Tubes in Tubular Structural System

It consist of closely spaced columns at the peripheral as well as inner gravity columns of the building acting as tubes. Thus, resisting both gravity as well as lateral load. The properties of the structure is as under: -

C1 outer columns (tubes)	-1000 x 600 mm
B1 (Spandrel beam)	-1200 x 00 mm
B2 (Inert beam)	-900 x 600 mm
Slab	-150 mm

The tubular columns have a spacing of 3 mtr c/c whereas the gravity columns have a spacing of 9 mtr x 9 mtr and also 12 mtr x 9 mtr. The load considered are as follows:

Live load	-3 KN / Sqm
Super dead load	-1 KN / Sqm
Partition load (aerocon panels)	-1.76 KN / Mtr

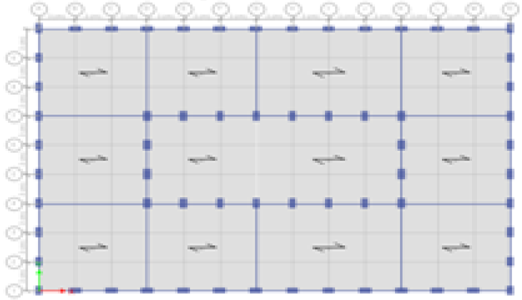

Figure 7 -Plan of Tubes in Tubular Structure system

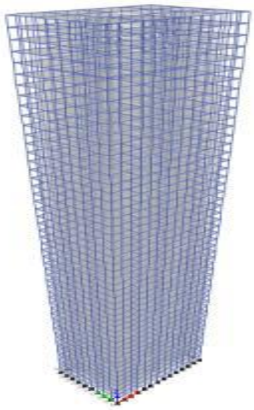

Figure 8 -3D view

8.6. Outrigger Structural System

It consist of a central core connected to the peripheral column with stiff and rigid structural members. The lateral load is distributed from the peripheral columns to the central core and the gravity load is transferred from the core to the peripheral columns, thus, leading to integrated structural system. The properties of the structure is as under: -

C1 outer columns (tubes)	-1000 x 600 mm
B1 -	750 x 600 mm
CB (coupled beam)-	1000 x 350 mm
Slab -	150 mm
Shear wall -	350 mm

The column spacing of 6 mtr x 6 mtr and 7.50 mtr x 6.0 Mtr. The load considered are as follows: -

Live load
- 3 KN / Sqm

Super dead load -	1 KN / Sqm
Partition load (aerocon panels)-	1.76 KN / Mtr

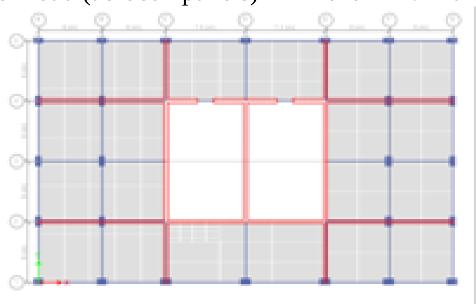

Figure 9 -Plan of Outrigger Structure system

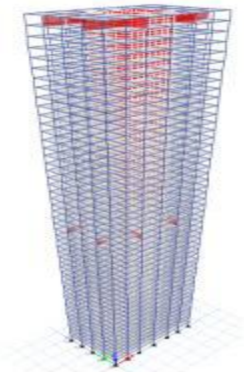

Figure 10 -3D view

8.7. Outrigger with Belt Truss Structural System

It consist of a central core connected to the peripheral column with stiff and rigid structural members along with bracings to limit the drift due to the lateral load. The properties of the structure is as under: -

C1 outer columns (tubes)	-1000 x 600 mm
B1	-750 x 600 mm
CB (coupled beam)	-1000 x 350 mm
Slab	-150 mm
Shear wall	-350 mm
I Section	-ISHB450

The columns spacing of 6 mtr x 6 mtr and 7.50 mtr x 6.0 Mtr. The load considered are as follows: -

Live load	-3 KN / Sqm
Super dead load	-1 KN / Sqm
Partition load (aerocon panels)	-1.76 KN / Mtr

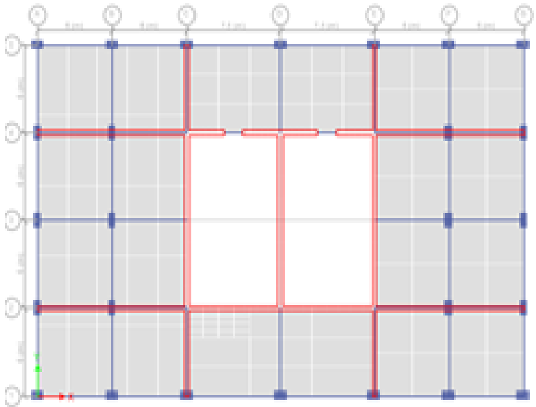

Figure 10 -**Plan of Outrigger with belt Truss Structure system**

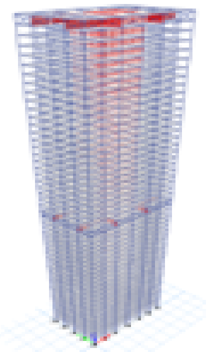

Figure 11-**3D view**

IX. RESULTS

The following table depicts the comparison of all the seven models: -

Sr. No	Structural system	Base Shear In X KN	Base Shear In Y KN	Max. Storey response in X direction mm	Max. Storey response in Y direction mm	Time period Sec.
1	Moment Frame	8315.2692	8204.6089	710.485	830.751	8.402
2	Moment Frame with shear wall at corners	8259.414	8364.2828	448.192	487.425	6.191
3	Moment frame with central core	8197.899	8892.1484	240.464	328.404	4.923
4	Tubular system	8321.99	8162.86	207.608	327.043	5.21
5	Tubes in tubular system	9014.6212	8573.212	185.191	306.178	5.003
6	Outrigger system	8243.3206	8988.3956	213.79	300.377	4.722
7	Outrigger with belt truss	8260.0312	8995.3068	213.239	296.53	4.695

X. CONCLUSION

All these seven models have been analyzed by both static dynamic analysis and the response spectrum has been scaled up by more than 85% of static base shear. After analyzing all the seven types of structural systems of a typical building, it can be concluded that outrigger structural system has lesser displacement, lesser time period, thus, the performance of outrigger system will be more efficient amongst the all structural system. Also, outrigger with belt truss system is more stable and rigid in compare to the outrigger system. Therefore, optimization of structural design for high rise building has been achieved by firstly using light weight aerocon partition panels instead of conventional brick walls, thus reducing the dead load on the buildings. Secondly, optimization in terms of structural performance is achieved by outrigger belt truss structural system leading to better efficiency of the structure

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