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 aercon 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).

- 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.

These are framed structure. The Skelton of the building consists ofsteel columns and beams welded / riveted.

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.
• 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 storeys 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
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

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

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
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8.5. **Tubes in Tubular Structural System**
It consists 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 are 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

8.6. **Outrigger Structural System**
It consists of a central core connected to the peripheral column with stiff and rigid structural members. The load distribution 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 are 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

8.7. **Outrigger with Belt Truss Structural System**
It consists 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 are 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 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
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 all the structural systems. 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.

REFERENCES
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