IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 6, Issue 3, April 2026

Impact Factor: 8.2

Design and Seismic Analysis of Core-Suspended High-Rise Tower

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Abstract: *This study presents the structural design and seismic analysis of a 32-storey core-suspended high-rise tower in Mumbai, India. The system utilizes a central reinforced concrete core with floor slabs suspended through high-strength steel hangers connected to outrigger trusses, eliminating conventional columns and providing column-free spaces. The structure is designed in accordance with IS 1893:2016, IS 875, IS 456:2000, and IS 800:2007. Structural analysis is carried out using ETABS software, including response spectrum and wind load analysis. The results indicate efficient structural performance with a maximum storey drift of 0.0028 and roof displacement of 185 mm, both within permissible limits. Comparative analysis with a conventional framed structure shows improved performance, including 35% reduction in storey drift, 28% reduction in lateral displacement, and increased space utilization. The study demonstrates that core-suspended systems are an effective solution for high-rise construction in seismic regions.*

Keywords: *seismic analysis*

I. INTRODUCTION

Rapid urbanization in metropolitan cities such as Mumbai has significantly increased the demand for efficient high-rise construction. Due to limited land availability and rising real estate costs, vertical development has become essential. Conventional structural systems such as reinforced concrete frames and shear wall structures are widely used; however, they often require column grids that reduce usable floor space and limit architectural flexibility.

To overcome these limitations, innovative structural systems have been developed, among which the core-suspended system has gained attention. In this system, a central reinforced concrete core acts as the primary load-resisting element, and floor slabs are suspended using high-strength steel hangers connected to outrigger trusses. This configuration eliminates the need for columns at lower levels, resulting in large column-free spaces and improved structural efficiency.

The present study focuses on the design and seismic analysis of a 32-storey core-suspended high-rise tower located in Mumbai, Maharashtra. The structure is analyzed using ETABS software as per relevant Indian Standard codes, including IS 1893:2016, IS 875, IS 456:2000, and IS 800:2007. The performance of the system is evaluated in terms of storey drift, lateral displacement, and overall structural behavior under seismic and wind loads. A comparative study with a conventional framed structure is also carried out to assess the advantages of the core-suspended system.

The structural configuration of the core-suspended system is illustrated in Fig. 1.

DOI: 10.48175/IJARSCT-32516

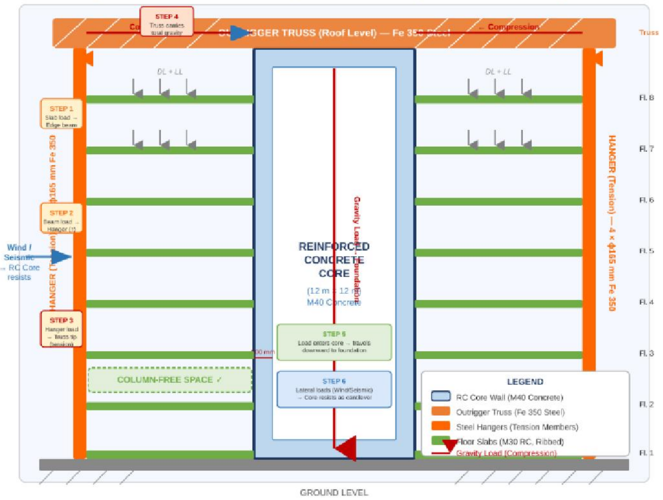

Fig. 1 Core-Suspended Structural System (Load Path)

II. LITERATURE REVIEW

Several researchers have studied the behavior of high-rise structures under lateral loads. Smith and Coull (1991) discussed the structural design of tall buildings and emphasized the importance of efficient lateral load-resisting systems. Taranath (2010) highlighted the role of wind and seismic forces in high-rise design and the need for innovative structural systems.

Recent studies have focused on outrigger systems and core-based structures. Moon (2009) analyzed the performance of high-rise concrete buildings and demonstrated the effectiveness of outrigger systems in reducing lateral displacement. Gupta and Rao (2019) compared conventional frame structures with advanced structural systems and concluded that core-based systems provide better drift control.

The core-suspended structural system has gained attention due to its ability to provide column-free spaces and improved structural efficiency. However, limited research has been conducted in the Indian context, particularly for seismic regions such as Mumbai. Therefore, this study aims to analyze and evaluate the performance of a core-suspended system using Indian Standard codes.

III. STRUCTURAL SYSTEM DESIGN SPECIFICATIONS

A. Building Configuration and Geometric Parameters

The proposed structure is a 32-storey high-rise tower with a total height of 128 m above ground level, having a typical storey height of 4.0 m. The building has a square plan of 30 m × 30 m, providing a symmetrical layout with efficient load distribution.

The central reinforced concrete core measures 12 m × 12 m and acts as the primary load-resisting element. The core wall thickness varies along the height, with 600 mm thickness from the 1st to 10th floor, 500 mm from the 11th to 22nd floor, and 400 mm from the 23rd to 32nd floor. The structural system adopted is a core-suspended system, where floor slabs are supported through high-strength steel hangers connected to an outrigger truss located at the roof level.

TABLE 1: BUILDING CONFIGURATION PARAMETERS

Parameter	Details / Value
Number of Storeys	32 storeys (above ground level)
Typical Floor Height	4.0 m per floor
Total Building Height	128 m

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Plan Dimensions	30 m × 30 m
RC Core Dimensions	12 m × 12 m (hollow section)
Core Wall Thickness (Lower)	600 mm (1st–10th floor)
Core Wall Thickness (Middle)	500 mm (11th–22nd floor)
Core Wall Thickness (Upper)	400 mm (23rd–32nd floor)
Structural System	Core-suspended system
Building Usage	Commercial office building
Concrete Grade (Core)	M40 — IS 456:2000
Concrete Grade (Slabs/Beams)	M30 — IS 456:2000
Reinforcement Steel	Fe 500 — IS 1786:2008
Structural Steel	Fe 350 — IS 2062:2011
Slab Thickness	175 mm
Slab Type	Two-way RC slab
Edge Beam Size	300 mm × 600 mm
Outrigger Location	Roof level
Outrigger Depth	4.0 m
Outrigger Arm Length	9.0 m
Hanger Material	Steel rods (Fe 350)
Seismic Zone	Zone III — IS 1893:2016
Zone Factor (Z)	0.16
Importance Factor (I)	1.0
Response Reduction Factor (R)	3.0
Soil Type	Medium soil (Type II)
Basic Wind Speed	44 m/s
Terrain Category	Category 3
Seismic Method	Response Spectrum Method
Wind Method	Gust Factor Method
Software (Primary)	ETABS
Software (Verification)	STAAD.Pro

B. Load Cases and Design Loads

The structure is designed considering dead load, live load, wind load, and seismic load as per relevant Indian Standards. Dead loads are calculated as per IS 875 (Part 1): 1987, and live loads as per IS 875 (Part 2): 1987. Wind load analysis is carried out as per IS 875 (Part 3): 2015, considering a basic wind speed of 44 m/s for Mumbai and Terrain Category 3. Seismic analysis is performed as per IS 1893 (Part 1): 2016 for Seismic Zone III, with a zone factor of 0.16, importance factor of 1.0, and response reduction factor of 3.0. Load combinations are applied in accordance with IS 456:2000 and IS 800:2007.

IV. METHODOLOGY

The study involves the structural modeling and analysis of a 32-storey core-suspended high-rise building using ETABS software. The building geometry, material properties, and loading conditions are defined as per relevant Indian Standards.

- The methodology includes the following steps:
- Preparation of building plan and structural configuration.
- Modeling of the central RC core, slabs, and structural elements.

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- Application of dead load, live load, wind load, and seismic load.
- Analysis using response spectrum method for seismic loading.
- Evaluation of results such as storey drift, lateral displacement, and base shear.
- Comparative analysis with a conventional framed structure.

The results obtained from ETABS are verified and interpreted to assess the structural performance of the system.

V. STRUCTURAL ANALYSIS AND RESULTS

A. Structural Modelling

The structural model of the 32-storey core-suspended building was developed using ETABS software. The reinforced concrete core was modeled using shell elements, while beams and outriggers were modeled as frame elements. Floor slabs were considered as rigid diaphragms at each level to ensure uniform lateral load distribution. Steel hangers were modeled as tension-only elements to represent actual structural behavior.

The developed analytical model of the core-suspended structure is shown in Fig. 2.

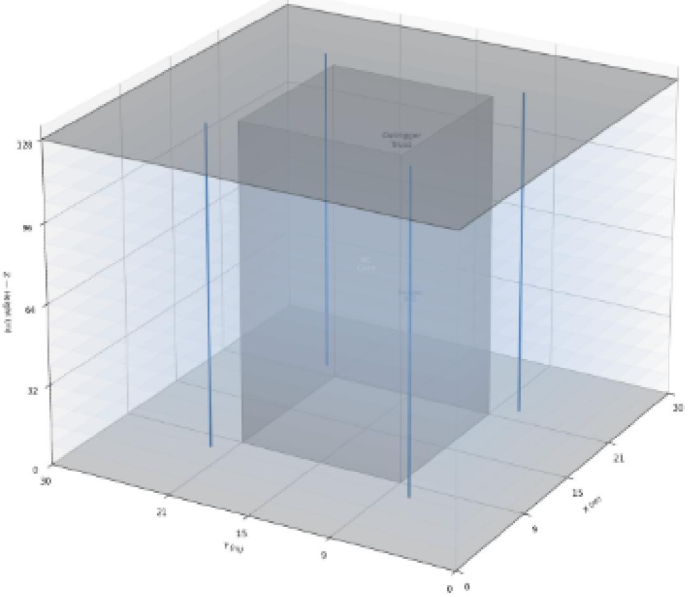

Fig. 2 3D ETABS Model of the Core-Suspended High-Rise Tower

B. Load Analysis

The structure was analyzed under dead load, live load, wind load, and seismic load. Wind loads were applied as per IS 875 (Part 3): 2015, considering a basic wind speed of 44 m/s and Terrain Category 3. Seismic loads were applied using the Response Spectrum Method as per IS 1893 (Part 1): 2016 for Seismic Zone III.

C. Results and Discussion

The analysis results indicate that the structure performs efficiently under lateral loading conditions. The maximum storey drift obtained under seismic loading is 0.0028, which is within the permissible limit of 0.004 specified in IS 1893:2016. The maximum lateral displacement at the top of the structure is 185 mm, which is also within acceptable limits.

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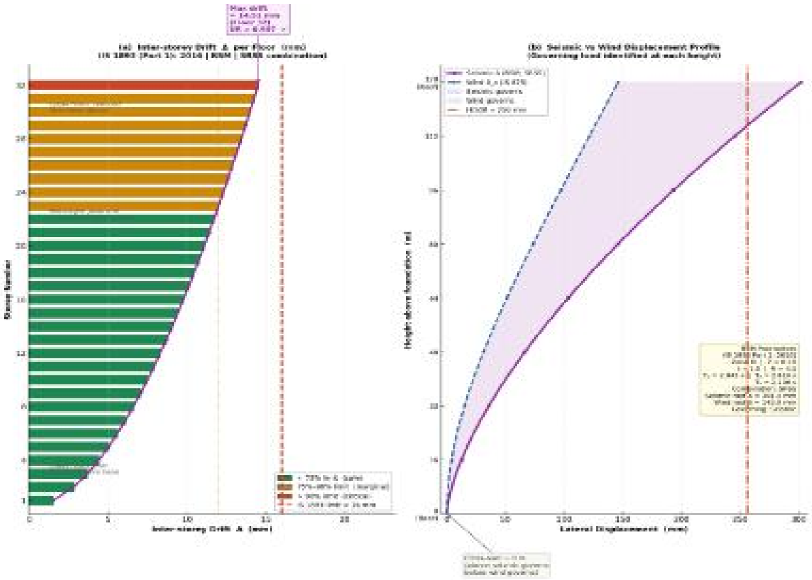

Fig. 3 Storey Drift Distribution under Seismic Loading

The fundamental natural time period of the structure is observed to be approximately 4.2 seconds, indicating flexible behavior typical of core-suspended systems. The results confirm that the structural system is safe and suitable for high-rise construction in seismic regions.

D. Interpretation of Results

The results obtained from the structural analysis indicate that the core-suspended system exhibits efficient performance under both wind and seismic loading conditions. The storey drift values increase gradually along the height of the building and reach a maximum at the top storey, which is consistent with expected structural behavior.

The lateral displacement profile shows a smooth and continuous variation, indicating proper distribution of stiffness and stability of the structural system. The maximum displacement values are within permissible limits, ensuring serviceability requirements are satisfied.

The longer fundamental time period of the structure reflects increased flexibility, which helps in reducing seismic forces. Comparative results further indicate that the core-suspended system performs better than conventional framed structures in terms of drift control and lateral stability.

Overall, the analysis confirms that the adopted structural system is safe, efficient, and suitable for high-rise construction in seismic regions.

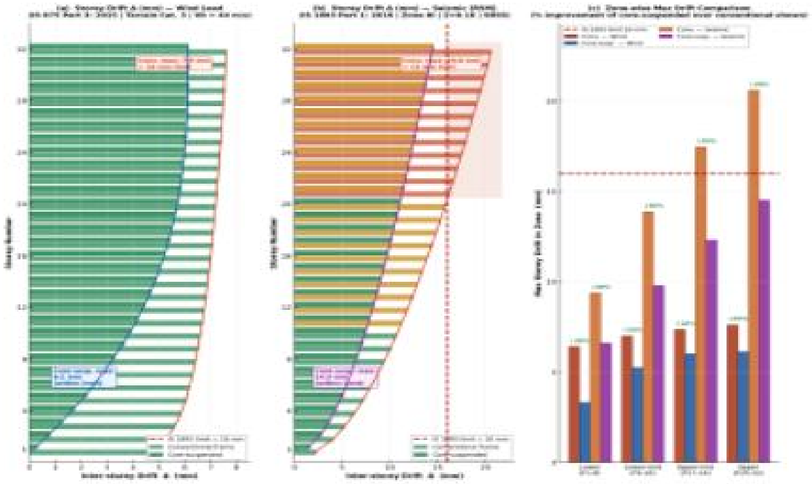

Fig. 4 Comparison of Core-Suspended and Conventional Structural System

VI. DETAILED DESIGN OF STRUCTURAL MEMBERS

A. Central Reinforced Concrete Core

The central reinforced concrete (RC) core is designed as the primary load-resisting element of the structure. The core has plan dimensions of 12 m × 12 m and extends throughout the height of the building. The wall thickness varies along the height, with 600 mm thickness in the lower storeys, 500 mm in the middle storeys, and 400 mm in the upper storeys.

The core is designed using M40 grade concrete and Fe 500 reinforcement as per IS 456:2000. The design is based on bending moment and shear force obtained from structural analysis. The maximum bending moment and shear force occur at the base of the core due to lateral loads.

Adequate longitudinal reinforcement is provided on both faces of the core wall to resist bending, while shear reinforcement is designed to resist transverse forces. The reinforcement detailing ensures sufficient strength, ductility, and confinement, particularly in critical regions near the base.

B. Steel Suspension Hangers and Outrigger Trusses

The floor slabs are supported using high-strength steel hangers connected to the outrigger truss system. The hangers are designed to carry axial tensile forces resulting from suspended loads. Steel rods of suitable diameter and grade (Fe 350) are used to ensure adequate tensile capacity with appropriate safety factors.

The outrigger truss is provided at the roof level and connects the central core to the outer structural system. The truss members are designed to resist axial forces and bending moments developed due to load transfer. Standard steel sections are selected based on force requirements and designed as per IS 800:2007.

Proper connections are provided between hangers and truss members to ensure effective load transfer. The overall design ensures stability, strength, and efficient performance of the core-suspended structural system.

VII. CONCLUSION

The present study demonstrates the effectiveness of the core-suspended structural system for high-rise buildings in seismic regions. The structural analysis of the 32-storey building using ETABS software indicates that the system performs efficiently under both wind and seismic loading conditions.

The maximum storey drift and lateral displacement are found to be within the permissible limits specified by IS 1893:2016, ensuring structural safety and serviceability. The structural behavior observed from the analysis shows a smooth variation of displacement along the height, indicating proper stiffness distribution.

The comparative analysis with a conventional framed structure highlights significant advantages of the core-suspended system, including reduced storey drift, lower lateral displacement, and improved structural efficiency. Additionally, the system provides increased column-free space, enhancing functional and architectural flexibility.

Overall, the study concludes that the core-suspended structural system is a safe, efficient, and practical solution for modern high-rise construction in densely populated urban areas such as Mumbai.

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DOI: 10.48175/IJARSCT-32516