Seismic Response Of Base Isolated High Rise Steel Buildings With Different Framing Systems And Height

Sharath DH[1], Dr. Chethan K[2]

[1]P.G. Student, department of Civil Engg., Major: Prestressed Concrete, University of Visvesvaraya College of engineering, Karnataka, India, Email: sharath8927@gmail.com
[2]Associate professor, department of Civil Engg., University of Visvesvaraya College of engineering, Karnataka, India

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Abstract *This study evaluates the seismic performance of a 40-storey steel building using finite element analysis (FEA) in accordance with IS 1893:2016 provisions. The building was analysed under fixed-base and base-isolated conditions with Lead Rubber Bearings (LRB), considering Tube-in-Tube, Outrigger, Outrigger with Belt Truss, and a model with a central core. Modal, Equivalent Static, Response Spectrum, and Time History analyses were performed to determine fundamental time period, base shear, displacement, drift, and. Results show that base isolation increases the natural period and significantly reduces seismic forces compared to fixed- base models. The Outrigger with Belt Truss combined with LRB provides the best overall seismic performance, demonstrating improved stability and resilience for high-rise steel buildings in seismic regions.*

Keywords: Lead Rubber Bearing (LRB), Outrigger system, Belt truss, Tube-in-tube structure, Response spectrum analysis, Time history analysis, Interior structures, Exterior structures

1. INTRODUCTION

A 40-storey steel building is an efficient solution for rapid urban growth and limited land availability, enabling safe vertical development. As height increases, the structure becomes more sensitive to wind and earthquake forces, making lateral stability and dynamic behavior critical in design. Steel is widely used for high-rise buildings due to its strength and ductility; however, seismic safety remains a major concern in earthquake-prone regions. Base isolation systems such as Lead Rubber Bearings (LRBs), which consist of layered rubber, steel plates, and a central lead core, help reduce earthquake forces by increasing the natural time period and dissipating energy. This significantly improves the seismic performance and overall resilience of tall steel buildings.

1.1 Classification of structural system

Four steel high-rise buildings with 20, 30, 40, and 50 storeys and a constant storey height of 3.0 m are modeled using structural analysis software. For each height, different structural systems such as tube-in-tube, outrigger, and outrigger with belt truss with core are used to study their structural behavior. The buildings are modeled and analysed according to the provisions of IS 1893 (Part 1): 2016.All the buildings are analysed under fixed-base and base-isolated conditions. In the base-isolated models, Lead Rubber Bearings (LRB) are provided at the foundation level and modeled using nonlinear link elements to represent their stiffness and damping behavior. This helps to understand how base isolation affects the seismic performance of the buildings. All models have a 30 m × 30 m base plan with 5 × 5bays and are analysed under identical loading and seismic conditions.

1.2 Objective of the study

This study develops analytical models of 20-, 30-, 40-, and 50-storey steel buildings to understand how building height affects seismic performance. Modal Analysis, Response Spectrum Analysis, and Time History Analysis are carried out to study the dynamic behavior of the structures. A Lead Rubber Bearing (LRB) base isolation system is designed and added to the models to improve earthquake resistance. The seismic response of fixed-base and base-isolated buildings is compared to check the effectiveness of base isolation. The performance of Tube-in-Tube, Outrigger, and Outrigger with Belt Truss systems is also evaluated under both conditions. Important results such as storey displacement, storey drift, base shear, time period, and acceleration are compared to identify the best structural system for seismic safety and overall performance.

2. PRELIMINARY DATA CONSIDERED FOR ANALYSIS

Building Models and Geometry

Six Steel building models were developed for the 40-storey (G+40) structure, incorporating , systems with core for both fixed base and LRB base to assess seismic performance.

Table -1: 6 STRUCTURAL SYSTEMS NOMENCLATURE

S.L. No.	Structural System	Nomenclature
1	40 Tube in Tube with core	40 TTC
2	40 Outrigger with core	40 OTC
3	40 Outrigger with belt truss with core	40 OBTC
4	40 Tube in tube with core with LRB	40 TTCWLRB
5	40 Outrigger with core with LRB	40 OTCWLRB
6	40 Outrigger with belt truss with core with LRB	40 OBTCWLRB

Building Dimensions:
•Total Height: 120 m (40 storeys)
• Storey Height: 3 m
• Plan Dimension: 30m × 30m (square)
• Bay Width: 5 m

Material Properties and Sections
Concrete and Steel Properties:
• Grade of Concrete: M25
• Compressive Strength of Concrete: 25N/mm^2
• Grade of Steel : Fy 345
• Yeild Strength: 345 N/mm^2
Section Dimensions (Common for all systems):
• Beam: ISWB 600
• Column: 600 x 600 x50 mm
• Slab: 150 mm thickness
• Core 400 mm thickness
Special Elements:
• Steel plate: 400× 25mm as built section
• Outrigger (OT): 300x300x20mm
• Belt Truss System (BTS): 300x300x20mm

Loading Conditions
Gravity Loads (as per IS 875-1987 Part I & II):
• Super Imposed Dead Load: 1.5 kN/m^2
• Live Load: 3.0 kN/m^2
• Mass Source: 100% dead load + 25% live load

Seismic Load Parameters (as per IS 1893-2016):

- Seismic Zone: Zone V
- Zone Factor (Z): 0.36
- Soil Type: medium Soil
- Importance Factor (I): 1
- Response Reduction Factor (R): 5
- Damping Ratio: 5%

MODELS USED FOR FE ANALYSIS

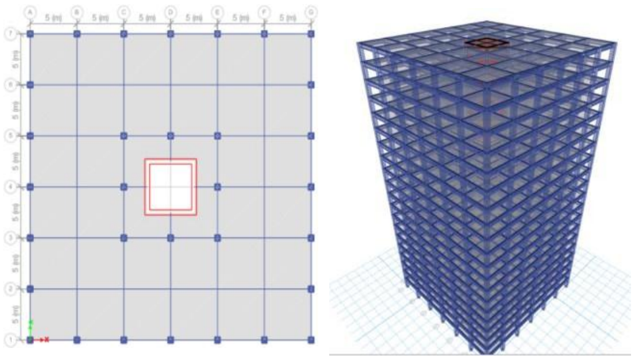

Fig -1: Plan and 3D view of 40TTC

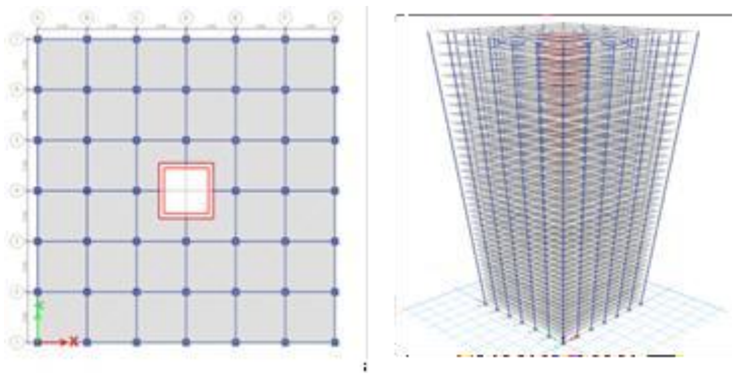

Fig -2: Plan and 3D view of 40 OTC

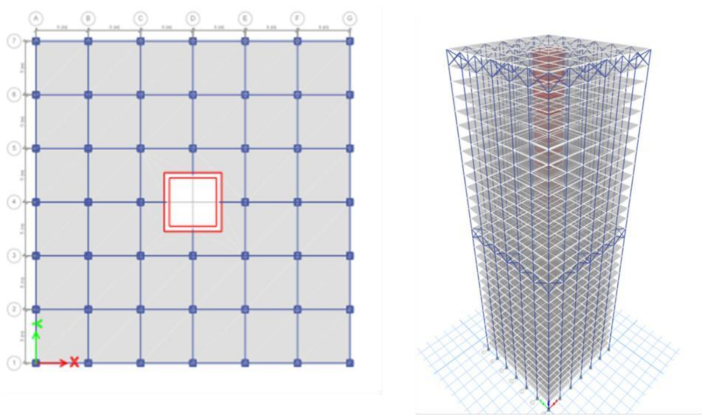

Fig -3: Plan and 3D view of 40 OBTC

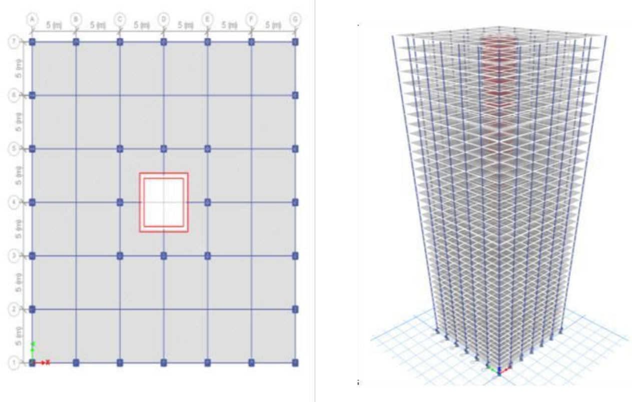

Fig-4: Plan and 3D view of 40TTCWLRB

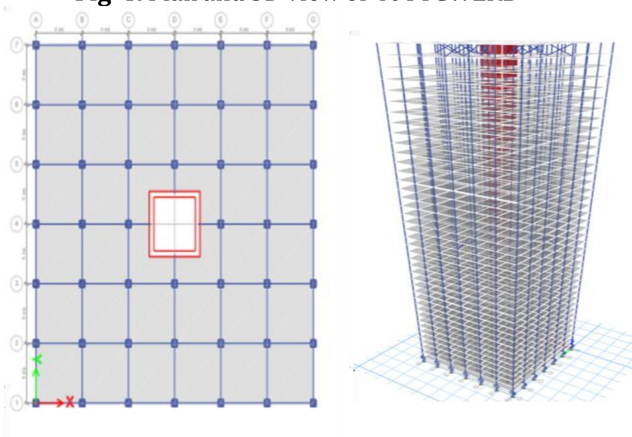

Fig-5: Plan and 3D view of 40 OTCWLRB

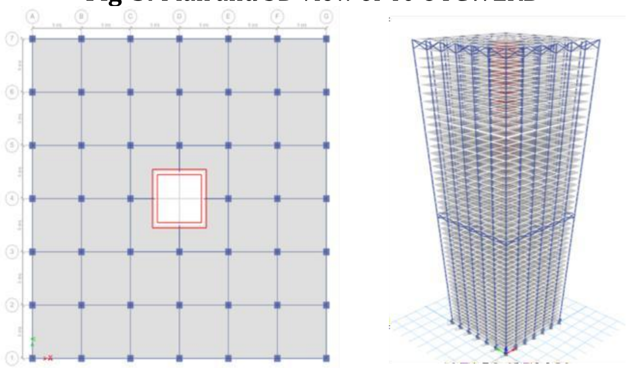

Fig-6: Plan and 3D view of 40 OBTCWLRB

3. RESULTS AND DISCUSSION

3.1 Modal Analysis

Table-2: MODE 1 TIME PERIOD OF ALL STRUCTURES

Sl. No.	Model	Computed Period (s)	IS 1893:2016 (s)
1	40TTC	3.28	3.08
2	40OTC	2.98	3.08
3	40OBTC	2.95	3.08
4	40TTCWLRB	3.39	3.08
5	40OTCWLRB	3.09	3.08
6	40OBTCWLRB	3.07	3.08

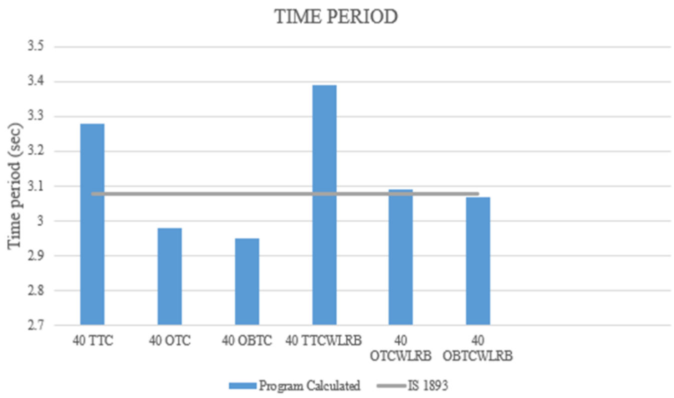

Chart -1: Modal time period of all structure

3.2 Base Shear from Time History Analysis

Table-3: Corrected Dynamic Base shear for all models (10^6) IN kN

Model	Corrected Dynamic Base Shear (kN)
40TTC	8864.50
40OTC	8288.93
40OBTC	8311.49

40TTCWLRB	9034.24
40OTCWLRB	8469.40
40OBTCWLRB	8488.21

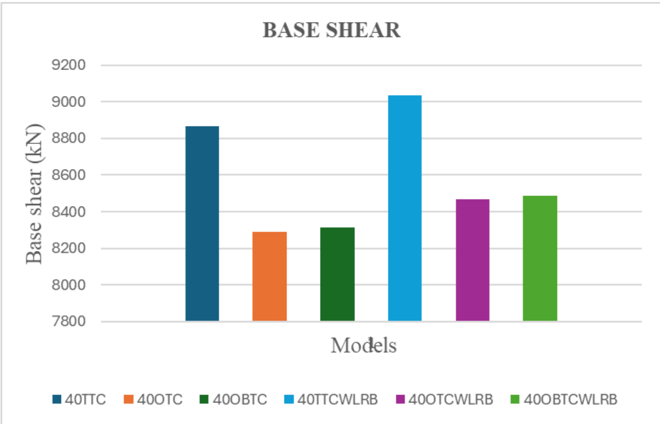

Chart -2: Max Base shear of All Structure

3.3 Storey Displacement

Table-4: MAX STOREY DISPLACEMENT IN (mm)

Model	Max Storey Displacement IN (mm)
40TTC	99.22
40OTC	82.57
40OBTC	81.17
40TTCWLRB	104.93
40OTCWLRB	88.39
40OBTCWLRB	87.12

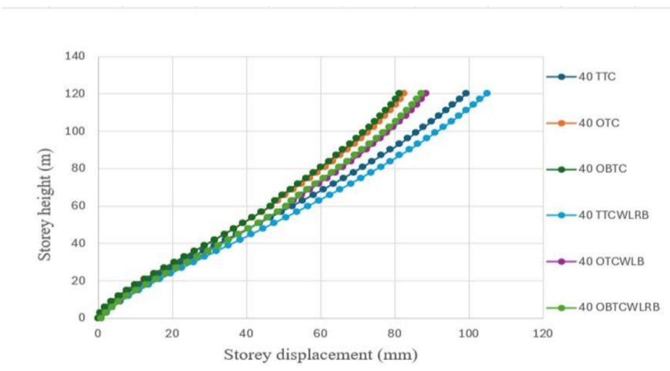

Chart -3: Max Displacement of All Structure

3.4 Inter Storey Drift Ratio

Table-5: MAX INTER STOREY DRIFT RATIO (10^{-3})

Model	'OREY DRIFT RATIO (10-3)
40TTC	1.058
40OTC	0.931
40OBTC	0.926
40TTCWLRB	1.093
40OTCWLRB	0.969
40OBTCWLRB	0.971

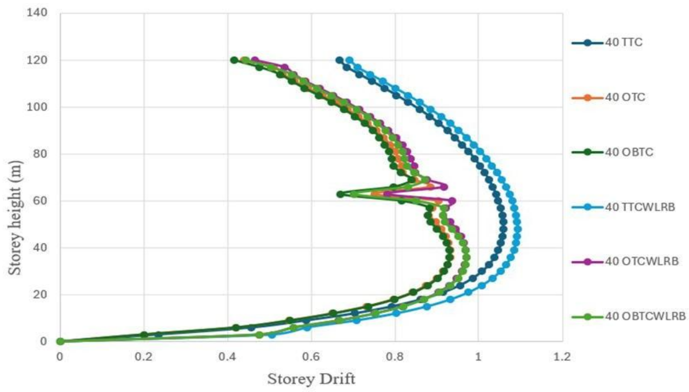

Chart -4: Max Inter Storey Drift of All Structure

4. CONCLUSIONS

Modal Analysis

The tube-in-tube models show slightly higher time periods, with the base-isolated configuration exhibiting the maximum increase of about 10%, indicating greater flexibility. In contrast, the outrigger and outrigger with belt truss systems show small reductions of about 3–4%, reflecting improved structural stiffness. Among all models, the base-isolated outrigger systems perform better, as their time periods vary by around 1% from the IS code value, showing very close results to the IS code value and stable structural performance.

Base Shear Response

Introducing Lead Rubber Bearings (LRB). The 40TTCWLRB model shows an increase of about 1.9% compared to 40TTC. Similarly, 40OTCWLRB increases by about 2.2% compared to 40OTC, and 40OBTCWLRB increases by about 2.1% compared to 40OBTC.Among all models, 40TTCWLRB shows the maximum base shear, while 40OTC shows the minimum value. In general, the increase after using LRB is small (around 2%), showing stable seismic performance.

Lateral Displacement

The variation in maximum storey displacement shows the influence of different structural systems and the effect of Lead Rubber Bearings (LRB). The 40OTC and 40OBTC models reduce displacement by about 16.8% and 18.2%, respectively, compared to the 40TTC model, indicating improved stiffness due to the outrigger systems. After implementing LRB, the 40TTCWLRB, 40OTCWLRB, and 40OBTCWLRB models show displacement increases of about 5.8%, 7.0%, and 7.3%, respectively, compared to their corresponding fixed-base models, due to increased flexibility from base isolation.Among all configurations, the 40OBTC model shows the least displacement, indicating greater stiffness and better control of lateral movement.

Drift Ratio and Damage Control

The storey drift results for the G+40 building models show that the outrigger and belt truss systems reduce the drift compared to the conventional tube system. The 40OTC and 40OBTC models reduce drift by about 12% and 13% compared to the 40TTC model, showing better lateral stiffness and improved control of deformation. Among the base-isolated models, the 40OTCWLRB and 40OBTCWLRB models reduce drift by about 11% and 12% compared to the 40TTCWLRB model, indicating improved performance with base isolation. he 40OBTC model shows the lowest drift among the fixed-base systems, indicating better control of lateral deformation.

System Ranking & Performance

Adding Lead Rubber Bearings (LRB), the time period increases by about 2% and displacement increases by about 6–7% due to increased flexibility, which helps absorb earthquake energy. The increase in base shear is very small around 2%, showing stable seismic performance.The outrigger and belt truss systems improve the seismic performance of the G+40 building by increasing stiffness and reducing movement. The 40OTC and 40OBTC models reduce displacement by about 16.8% and 18.2% and reduce storey drift by about 12–13% compared to the 40TTC model, showing better control of lateral movement. The 40OBTC model performs the best, as it shows minimum displacement and storey drift, giving better stability during earthquakes.

5. REFERENCES

[1] A. B. M. Saiful Islam, Mohammed Jameel and Mohd Zamin Jummat (2011), "Study on Optimal Isolation System and Dynamic Structural Responses in multi- storey buildings", International Journal of the Physical Sciences, Vol. 6(9), pp.2219-2228.

[2] Akshay Khanorkar (2016), "Outrigger and Belt Truss System for Tall Building to Control Deflection", Global Research and Development Journal for Engineering Volume 1.

[3] A.Shruthi and S.Mallikarjun (2022), "A Study on Dynamic Response of High-Rise Buildings using Lead Rubber Bearing Isolator", CVR Journal of Science and Technology, Volume 23.

[4] Avinash and Lingeshwaran (2024), "Review on base and inter storey seismic isolation systems for high rise buildings",Research on engineering structures and materials.

[5] Dedeoglu and Yusuf Calayir (2020)," Effectiveness of Outrigger and belt truss systems on the seismic behavior of high-rise buildings", Journal of Structural Engineering and Applied Mechanics, Vol.3, Issue 3, 180-203.

[6] Gerasimidis,S , Efthymiou, E., & Baniotopoulos, C. C. (2009), "Optimum outrigger locations of high-rise steel buildings for wind loading" , The Structural Design of Tall and Special Buildings (Wiley).

[7] Jason A. Cook (2006), "Structural Steel Framing Options for Mid-and High Rise Buildings" .

[8] Kamath, K., Shetty, N. Divya, Asha U Rao (2012), "A study on static and dynamic behaviour of outrigger structural system for tall buildings", Bonfring International Journal of Industrial Engineering and Management Science, Vol. 2, No. 4

[9] M. R. Jahanshahi, R. Rahgozar, M. Malekinejad, "A Simple Approach to Static Analysis of Tall Buildings with a Combined Tube-in tube and Outrigger-belt Truss System Subjected to Lateral Loading", International Journal of Engineering, Vol. 25, No. 3

[10]Mohammed Babaei, Yaghoub Mohammadi and Amin Ghannadiasl (2021)," Calculation of Vibration Period of Tall Pyramidal Buildings Structures with Tube Systems, Tube in Tube, Bundled Tube and Hybrid Tube Systems with Shear Wall, Iranian Journal of Science and Technology, Transactions of Civil Engineering

[11]Mohammed Sarcheshmehpour, Homayoon E. Este Kanchi and Hashem Moosavian, "Optimum seismic design of steel framed tube and tube in tube tall buildings". Structural Design of Tall and Special Buildings, e1782

[12]Raj Kiran Nanduri and B Suresh (2020)," Optimum position of outrigger system for High Rise Reinforced Concrete Buildings under wind and earthquake loadings", American Journal of Engineering Research, Vol-02, Issue-08.76-89, e- ISSN:2320- 0847.

[13]Fawzia, S and Fatima, T. (2010),"Deflection control in composite building by using belt truss and outriggers systems", the Structural Design of Tall and Special Buildings (Wiley)

[14]Sahil and Eknath laste (2019), "Seismic performance evaluation of multi-storey building with and without base isolation" , International Research Journal of Engineering and Technology.

[15]Shirule P A (2012), "Time history analysis of base isolated multi storey building".