Structural Performance Optimization of G+12 Reinforced Concrete Buildings Using Belt Truss and Outrigger Systems

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Abstract. Urban areas have developed at a rapid pace which has created a demand for multistory buildings that can resist wind and earthquake induced lateral forces. The conventional concrete reinforced frame system exhibits major lateral movement and vertical space displacement between floors in mid-rise buildings which negatively impacts both structural performance and operational conditions. In order to improve both lateral stiffness and structural efficiency, the current study looks at the structural response for the G+12 concrete with reinforcement building that incorporates the belt truss with outrigger system. The ETABS platform was used to create the three-dimensional structural model, which included several outrigger configurations at various building height elevations. The structural analysis considered the gravity loads together with wind loads evaluated according to the provisions of the IS 875 as well as the seismic loads defined by the IS 1893. The analytical outcomes show that the conventional frame configuration produced the roof displacement of 112.6 mm under the seismic excitation. When the single outrigger was installed at the mid-height level corresponding to 0.5H, the displacement decreased to 76.8 mm which reflects the reduction of nearly 31.8%. The dual-outrigger arrangement generated the minimum displacement value of 69.2 mm and increased the overall structural stiffness by approximately 66.5% relative to the baseline structural model. The results show that the belt truss with outrigger system's optimal placement greatly enhances the mid-rise building's lateral performance while maintaining the effective use of structural material.

Keywords. Structural optimization, Outrigger system, Belt truss, Multistory buildings, Seismic performance, Lateral load resistance etc.

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1 Introduction

Increased density population due to rapid urban expansion has made it necessary for multistoried-fix urban residential and commercial buildings. As the urban land becomes limited, the vertical construction has emerged as the practical solution for accommodating the expanding infrastructure requirements. The structural response of the multistory building becomes progressively complex when the building height increases. In particular, the lateral forces produced by wind and earthquake actions strongly influence the structural stability as well as the serviceability performance [1]. These forces generate the horizontal displacement together with the inter-story drift, which may influence the occupant comfort as well as the structural safety. Consequently, The creation of an effective lateral load-resisting system is now a crucial factor in contemporary structural engineering practice [2].

1.1 Background

The modern building is frequently designed with greater height and slenderness, which increases the sensitivity to the lateral loading conditions. The wind forces generate the continuous pressure on the exposed surfaces of the tall structure, whereas the seismic activity produces the dynamic inertial forces that propagate through the structural system [2]. These actions result in the substantial lateral deformation, particularly in the building that relies solely on the conventional frame system. Excessive lateral displacement combined with interstory drift may result in non-structural component failure and structural damage, as well as the functional interruption during the extreme loading conditions. Therefore, the engineers must implement the structural systems that provide the sufficient stiffness and stability while maintaining the controlled utilization of the structural materials [3][4].

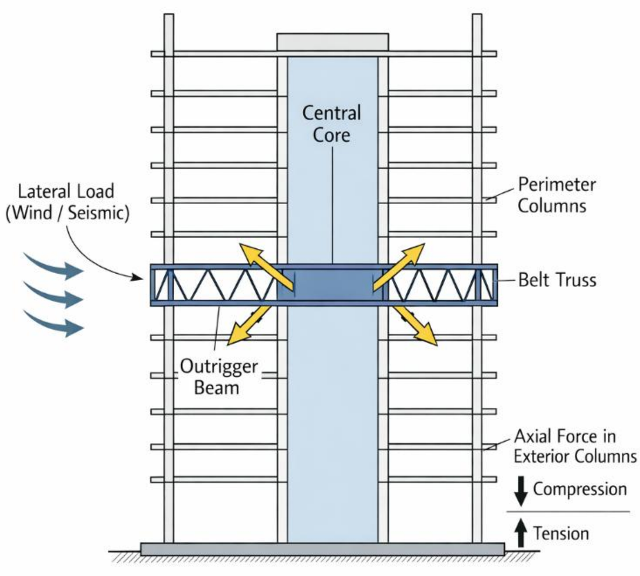

Fig. 1. Conceptual diagram of a multistory building's belt truss as well as outrigger structure demonstrating how the center core and outer columns are connected for increased lateral stiffness.

The structural configuration of the outrigger as well as belt truss system in the multistory building is illustrated in Fig 1. The central core is connected to the perimeter columns through the horizontal outrigger members where the belt truss system distributes the axial forces along the building perimeter. The external columns can contribute to the resistance of the moment that overturned due to the structural arrangement, which enhances the lateral stiffness as well as reduces the overall structural displacement.

1.2 Structural Systems for Tall Buildings

To increase the multistory building's lateral resistance, a number of structural layouts have been created. One often used method in which the columns and beams are firmly joined to withstand lateral forces using a bending mechanism is the moment resistant frame [6]. Despite the fact that the system offers architectural flexibility, the stiffness may become insufficient when the building height increases.
The shear wall system provides the enhanced lateral resistance through the introduction of the vertical reinforced concrete wall which carries the significant amount associated with the lateral load. Deep spandrel beams join the closely spaced border columns that make up the tube system where the structural configuration behaves as the hollow cantilever to resist the lateral forces in the tall building. In addition to these structural mechanisms, the outrigger and belt truss system has received considerable attention because the configuration connects the central core with the exterior columns which increases the overall structural stiffness [7][8].

1.3 Problem Statement

Despite the availability of several lateral load resisting systems, the conventional framed structure often exhibits the considerable lateral displacement when applied to the mid-rise building. In the structure such as the G+12 building, the combination of the moderate height and the structural flexibility may produce the drift values that approach the allowable design limits [9]. The condition emphasizes the necessity for the improved structural configuration which enhances the stiffness thereby avoiding the substantial rise in both the structural weight and the expense of construction. The method of structural optimization that takes into account auxiliary systems like the belt truss and outrigger may provide the effective solution for controlling the lateral deformation.

1.4 Research Motivation

Through the stiff structural parts, the outrigger system connects the building's central core to its outer columns. The outrigger transfers some of the resulting overturning moment between the core to the external columns when lateral load acts upon the structure which resist the load through the axial force mechanism. The belt truss system further strengthens the structural action by distributing the forces among the perimeter columns along the building perimeter [10]. Although the structural system has been extensively implemented in the high-rise construction, the optimal placement of the outrigger in the mid-rise structure such as the G+12 building remains the subject that requires further investigation. The determination of the most effective placement level can significantly influence the overall structural performance.

1.5 Objectives of the Study

Examining the strength of the structure of the G+12 concrete with reinforcement structure with the belt truss with outrigger system is the study's main goal. The study creates a comprehensive computer model of the structure that incorporates outriggers at various elevation levels. The structural responses are evaluated under the wind and seismic loading conditions in order to assess the lateral displacement, the drift behavior, as well as the overall structural stability. Another important objective is the determination of the most effective outrigger placement level which provides the improved structural efficiency for the mid-rise building.

1.6 Contributions of the Study

The research presents the systematic comparison of multiple outrigger configurations applied to the mid-rise reinforced concrete structure. The study evaluates how the different placement levels influence the displacement control as well as the drift reduction. In addition, the analysis highlights the role of the belt truss in distributing the forces across the perimeter columns which improves the global structural stiffness.

2 Methodology

The study applies the complete modeling procedure incorporating the structural parameters, the loading assumptions, as well as the analysis procedures. The methodology has been structured to ensure the reproducibility of the structural model together with the numerical results. The ETABS platform, which engineers employ for the design and analysis of the multistory building, facilitates the development of the G+12 reinforced concrete structural model incorporating the outrigger and belt truss system. The structural model is analyzed under the gravity load, the wind load, as well as the seismic loading condition according to the provisions of the relevant Indian structural design standards.

2.1 Building Description

The G+12 concrete reinforced building with a regular plan configuration that includes the central core is the structure taken into consideration in the study. The building represents the typical residential or mixed-use mid-rise structure. The plan geometry is maintained as the square configuration which eliminates the torsional irregularity as well as ensures the uniform load distribution throughout the structural system.

The building consists of the ground floor together with the twelve upper floors where the story heights remain identical throughout the structure. Each story incorporates the reinforced concrete beams and columns forming the moment resisting frame. The central reinforced concrete core is provided for the elevator and staircase functions which also contributes to the lateral rigidity of the structural framework. Table I displays the building model's geometric characteristics.

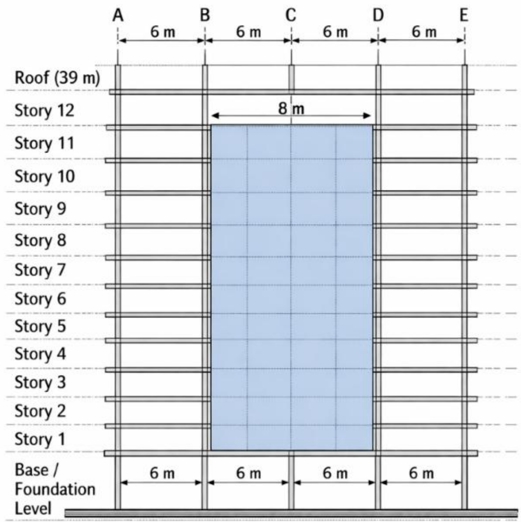

Fig. 2. The G+12 structural model's elevation view displays the bay spacing, central core, and beam-column frame.

Table 1. Geometric properties of the building model

Parameter	**Value**
Building type	Reinforced concrete
Number of floors	G+12
Floor height	3 m
Total structural height	39 m
Plan dimensions	30 m × 30 m
Structural grid spacing	6 m
Structural system	RC moment frame with central core
Core wall dimension	8 m × 8 m
Slab thickness	150 mm

The building plan includes the five structural bays in both directions with the uniform spacing of 6 m. In order to reduce torsional effects under lateral loading circumstances, the central core is placed near the center of gravity of the plan. The core connects to the surrounding beams at each floor level, extending continuously from the basis level to the roof's level. The structure's overall height is given as [11]:

$$H = N_s \times h_s \quad (1)$$

Where H= the total building height (m), N_s= the number of stories, and h_s= the story height (m)

For the present structure:

$$H = 13 \times 3 = 39 \text{ m}$$

T Fig. 2 shows the building model's geometric arrangement, which shows the central core together with the perimeter columns and the beam layout. The structural grid system as well as the complete building height dimension used for the numerical analysis is presented through the figure.

2.2 Material Properties

The structural components are designed using the commonly adopted reinforced concrete materials utilized in the mid-rise construction. The mechanical properties follow the provisions of the Indian structural design practice.

Table 2. The model's material properties

Material	Property	Value
Concrete	Grade	M30
Concrete	Characteristic compressive strength (f_{ck})	30 MPa
Concrete	Elastic modulus (E_c)	25 GPa
Steel reinforcement	Yield strength (f_y)	415 MPa
Steel reinforcement	Elastic modulus (E_s)	200 GPa
Unit weight of concrete	(γ_c)	25 kN/m³

The empirical connection suggested by Indian design standards is used to evaluate the concrete's elastic modulus [12]:

$$E_c = 5000\sqrt{f_{ck}} \tag{2}$$

Where E_c= the modulus of elasticity of concrete (MPa), and f_{ck}= the characteristic compressive strength of the concrete (MPa)

For M30 concrete:

$$E_c = 5000\sqrt{30} \approx 27386 \text{ MPa}$$

However, for the modeling simplicity the value of 25 GPa is adopted.

Table 3 lists typical cross-sectional dimensions utilized in the model.

Table 3. Cross-sectional dimensions

Structural element	Size
Columns	600 mm × 600 mm
Beams	300 mm × 500 mm
Core wall thickness	250 mm
Outrigger beam depth	700 mm

2.3 Structural Modeling

The structural model is developed using the ETABS version 20. The modeling procedure follows the three-dimensional frame approach.

The main structural components are included in the model are:

- Reinforced concrete beams
- Reinforced concrete columns
- Central shear core
- Outrigger beams
- Belt truss elements

The shell elements are used to simulate the central core walls, while the frame elements are used to represent the columns and beams. It is believed that the floor slabs act as stiff diaphragms that evenly disperse lateral loads throughout the structural structure.

The team models outrigger members as deep reinforced concrete beams which connect the central core to exterior columns. The belt truss system uses truss elements which extend along the perimeter columns at predetermined floor locations to display its structure. By transferring axial loads between the circumference columns, these truss components increase the structural system's overall stiffness.

The stiffness matrix of the structural system is expressed as [13]:

$$[K]\{u\} = \{F\} \qquad (3)$$

The global stiffness matrix is represented by [K] and the nodal displacement vector is represented by {u} and the external load vector is represented by {F}.

The ETABS solver determines nodal displacements through matrix equation solutions which encompass the complete structure.

2.4 Outrigger Configurations

Table IV presents the results of an analysis of five distinct structural configurations to assess the impact of outrigger location on building performance.

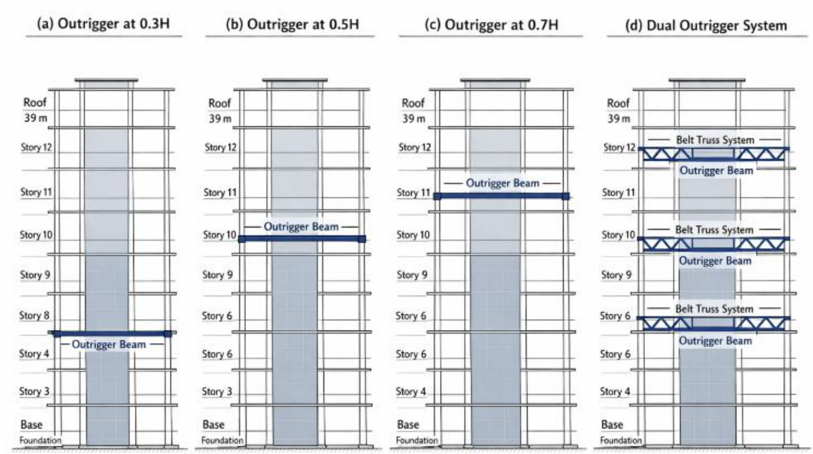

Fig. 3. the situation of having an outrigger of a height of 0.3H, 0.5H, 0.7H, and a dual outrigger is taken into consideration.

Table 4. Structural models analyzed

Model	Configuration
Model 1	Conventional frame without outriggers
Model 2	Single outrigger at 0.3H
Model 3	Single outrigger at 0.5H
Model 4	Single outrigger at 0.7H
Model 5	Dual outriggers at 0.3H and 0.7H

The outrigger location is determined using the height ratio [14]:

$$h_o = \alpha H \qquad (4)$$

Where h_o= the outrigger elevation, H= the total building height, and α= the height ratio parameter

For example,

$$h_o = 0.5H = 0.5 \times 39 = 19.5 \text{ m}$$

which corresponds approximately to the 6th floor level.

The objective of the configurations is the identification of the placement level which provides the most efficient control of the lateral deformation. The building elevation diagram presented in Fig. 3 illustrates the outrigger positions used by the different structural models. The visualization demonstrates how the outrigger placement influences the load distribution between the core and the perimeter columns.

2.5 Loading Conditions

The structure is analyzed under gravity and lateral loads according to Indian design standards.

Relevant design codes include:

- IS 875
- IS 1893

The following load types are considered.

2.5.1 Dead Load

Dead load is made up of both the permanent structural loads and the self-weight of the structural elements [15]:

$$DL = \gamma_c \times V \tag{5}$$

Where DL= the dead load (kN), γ_c= the unit weight of concrete, V= volume of the structural element, and Additional floor finish load of 1.5 kN/m² is included.

2.5.2 Live Load

The floors are subjected to an evenly distributed living load of 3 kN/m² based on the building usage categorization.

2.5.3 Wind Load

Wind load is calculated using [16]:

$$P_z = 0.6V_z^2 \tag{6}$$

Where P_z= the design wind pressure (N/m²), and V_z= the design wind speed (m/s).

For this study:

- Basic wind speed = 44 m/s
- Terrain category = II

2.5.4 Seismic Load

According to IS 1893, seismic the base shear is computed using [17]:

$$V_b = \frac{ZIS_a}{2Rg} W \quad (7)$$

V_b is the design base shear, Z is the seismic zone factor, I is the importance factor, R is the response reduction factor, S_a/g is the spectral acceleration coefficients, and W is the building's seismic weight.

For the present model:

- Seismic zone = III
- Importance factor $I = 1.0$
- Response reduction factor $R = 5$

2.6 Structural Analysis

Two different kinds of structural evaluation are carried out.

2.6.1 Linear Static Analysis

The structural reaction under static loading circumstances is ascertained using linear static analysis. The equation of motion that governs motion is [18]:

$$[K]\{u\} = \{F\} \quad (8)$$

This analysis provides the displacement, internal forces, as well as the reactions.

2.6.2 Response Spectrum Analysis

Dynamic seismic effects are evaluated using the response spectrum analysis.

The equation of motion is [19]:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F(t)\} \quad (9)$$

The equation defines displacement vector u and time-dependent load F t and damping matrix C and stiffness matrix K and mass matrix M.

The first step to achieve natural frequencies and mode shapes requires the execution of modal analysis.

2.7 Performance Evaluation Metrics

The effectiveness of each structural configuration is evaluated using the several performance indicators.

2.7.1 Maximum Lateral Displacement

Maximum roof displacement is expressed as [20]:

$$\Delta_{max} = u_{top} \quad (10)$$

where u_{top} is the displacement at the roof level.

2.7.2 Inter-Story Drift Ratio

$$\theta_i = \frac{\Delta_i - \Delta_{i-1}}{h_s} \quad (11)$$

Where θ_i= the story drift ratio, Δ_i= the displacement of story i, and h_s= the story height

2.7.3 Base Shear

The entire horizontal reaction at a basis level is represented by base shear.

2.7.4 Structural Stiffness

Global stiffness can be estimated as [21]:

$$K_{global} = \frac{V}{\Delta} \quad (12)$$

Where V= the base shear, and Δ= the roof displacement.

2.7.5 Structural Material Efficiency

By comparing the movement reduction to the structural weight, material efficiency is assessed.

3 Results and Discussion

This section presents the structural reaction results from the computational modeling conducted with the ETABS platform. The five models of structure outlined in the approach were examined under conditions of earthquake, wind, and gravity loads. Key performance parameters such as the maximum lateral movement, the base shear responses, the inter-story - drift ratio, and the improvement in structural stiffness are highlighted in the comparison. The parameters show how the outrigger system and belt truss affect the G+12 concrete reinforced building's overall structural performance.

3.1 Lateral Displacement Analysis

The key measure of the multistory building's structural flexibility is the maximum lateral displacement. During extreme loading circumstances, excessive a horizontal motion may result in both structural damage and serviceability problems. The ETABS analysis findings, which are shown in Table 5, provided the roof movement values for the typical structural arrangements.

Table 5. Maximum roof displacement under seismic loading

Model	Outrigger Configuration	Roof Displacement (mm)
Model 1	Conventional frame	112.6
Model 2	Outrigger at 0.3H	91.4
Model 3	Outrigger at 0.5H	76.8
Model 4	Outrigger at 0.7H	82.5
Model 5	Dual outriggers (0.3H + 0.7H)	69.2

At 112.6 mm, the standard framework without outriggers exhibits the most roof movement. This behavior results from the frame system's insufficient lateral stiffness and the core's inability to successfully withstand overturning moments.

The roof displacement decreases to 91.4 mm when an outrigger is added at 0.3H, which is 18.8% less than the traditional form. Because the outrigger distributes some of the overturning energy from the core to the surrounding columns, this improvement takes place.

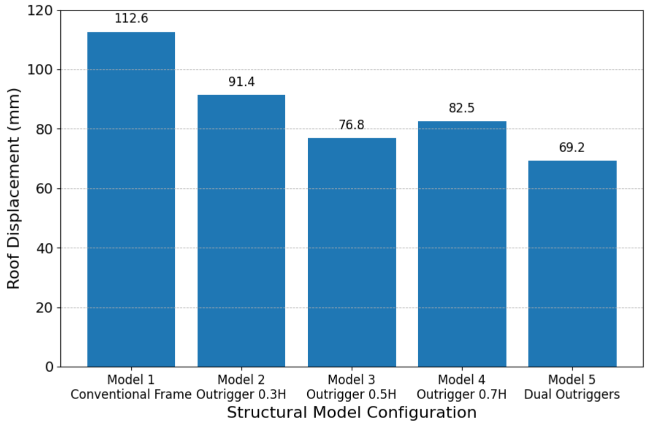

Fig. 4. Comparison of roof displacement values for all structural models.

Displacement decreases additional amount when outrigger operates at its mid-height point which corresponds to the 0.5H measurement. The roof displacement in this configuration reaches 76.8 mm which represents a 31.8% decrease when compared to Model 1 results. The improvement shows that mid-height outrigger system creates equal moment distribution between core structure and outer column elements.

The outrigger positioned at 0.7H level causes a small displacement increase which reaches 82.5 mm when compared to 0.5H system. Although the reduction remains considerable, the stiffness contribution becomes less effective because the outrigger location shifts closer to the roof level.

The dual-outrigger configuration provides the highest structural performance with the roof displacement of 69.2 mm which represents the reduction of 38.5% relative to the conventional frame structure. Fig 4 presents the maximum roof displacement for the structural configurations which illustrates the substantial reduction achieved through the introduction of outrigger as well as the belt truss system.

3.2 Inter-Story Drift Analysis

The relative movement between successive floors is represented by the inter-story drift. Both structural instability and damage to non-structural elements could result from severe drift. The permissible drift limitation for the concrete reinforced structure is as stated in IS 1893:

$$\theta_{max} = 0.004h$$

Where h= the story height.

The allowable drift limit for a story height of three meters becomes:

$$\theta_{max} = 0.004 \times 3000 = 12 \text{ mm}$$

Table 6. Maximum inter-story drift

Model	Maximum Drift (mm)	Code Limit (mm)
Model 1	10.4	12
Model 2	8.3	12
Model 3	6.9	12
Model 4	7.4	12
Model 5	6.2	12

The conventional structural configuration produces the maximum inter-story drift of 10.4 mm which remains within the permissible limit but approaches the upper boundary specified by IS 1893. When the outriggers are incorporated into the structural system, the drift value decreases significantly as presented in Table VI.

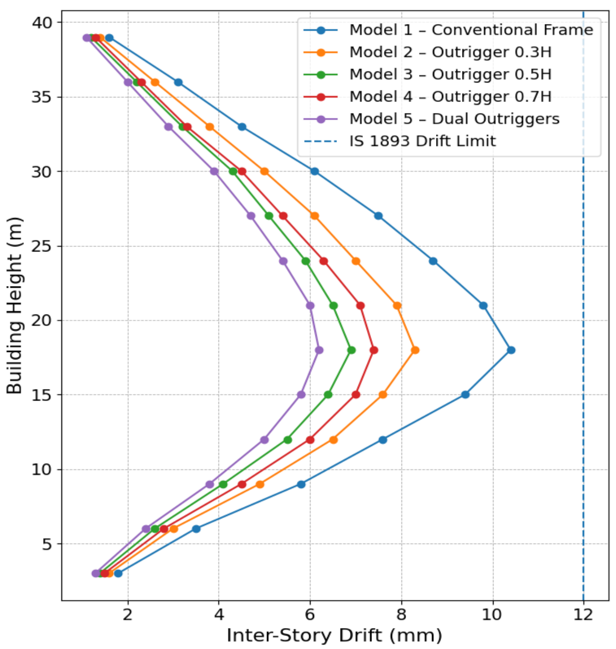

Fig. 5. Inter-story drift distribution along building height for different structural models.

The configuration at 0.5H reduces the maximum drift to 6.9 mm. The dual-outrigger system produces the minimum drift value of 6.2 mm. The results indicate that the outrigger system significantly improves the story stiffness while reducing the differential displacement which develops between the consecutive floors.

Fig. 5 illustrates the drift variation along the entire height of the building where the results demonstrate that the outriggers reduce the drift concentration occurring in the middle floor levels.

3.3 Base Shear Analysis

The entire horizontal force applied to the foundation throughout the seismic event is represented by the base shear. According to IS 1893's guidelines, the seismic the base shear is assessed using [22,23]:

$$V_b = \frac{ZIS_a}{2Rg} W \quad (13)$$

The equation requires W to represent seismic weight and Z to represent seismic zone factor and I to represent importance factor and R to represent response reduction factor and S_a/g to represent spectral acceleration coefficient.

Table 7. Base shear results

Model	Base Shear (kN)
Model 1	1284
Model 2	1298
Model 3	1306
Model 4	1299
Model 5	1315

The base shear values remain relatively consistent across the structural configurations because the seismic weight of the structure does not change significantly as presented in Table VII. However, the slight increase is observed when the outriggers are incorporated because the improved stiffness of the structural system produces the marginal increase in the seismic force demand.

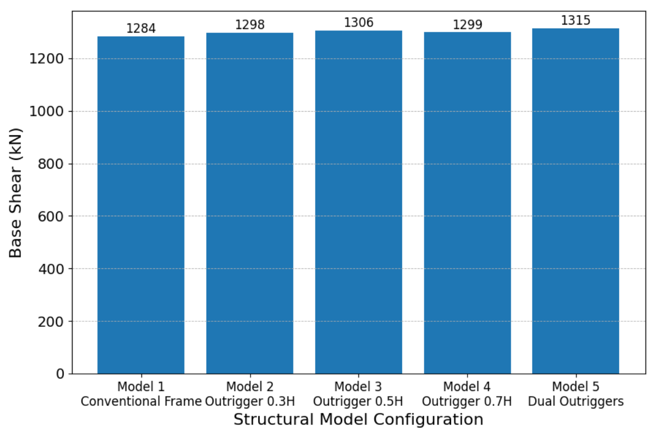

Fig. 6. Comparison of base shear values for different structural models.

Figure 6 displays the base shear coefficients for the various structural layouts, which demonstrates that the introduction of the outriggers in the structure does not significantly alter the total seismic load while improving the distribution of the seismic forces throughout the building.

3.4 Structural Stiffness Improvement

Global structural stiffness can be approximated as the ratio between the base shear as well as roof displacement [24]:

$$K = \frac{V}{\Delta} \quad (14)$$

Where K= the global stiffness, V= the base shear, and Δ= the roof displacement.

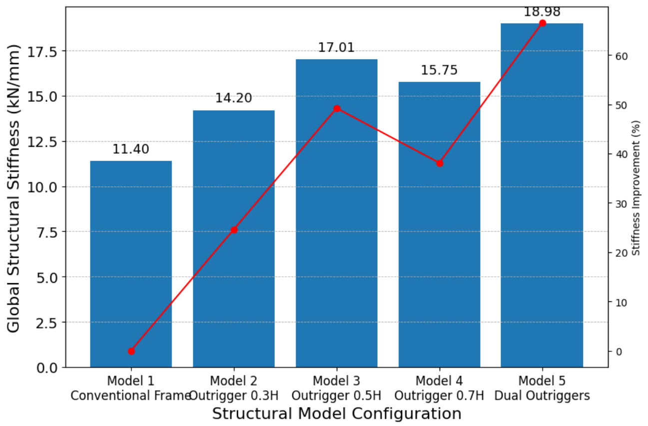

Fig. 7. Structural stiffness comparison among various outrigger configurations.

Table 8. Structural stiffness comparison

Model	Stiffness (kN/mm)	Improvement (%)
Model 1	11.40	–
Model 2	14.20	24.6
Model 3	17.01	49.2
Model 4	15.75	38.1
Model 5	18.98	66.5

The research findings show that structural stiffness substantially increases through the implementation of outrigger elements in building designs. The dual-outrigger setup shows the most improvement, with a 66.5% increase, which confirms that using multiple outriggers effectively enhances structural rigidity (see Table VIII). The various outrigger configurations show their ability to boost structural stiffness beyond what conventional frame buildings achieve, as shown in Fig 7.

3.5 Optimization of Outrigger Location

The final objective of the study is determination of the most efficient outrigger placement for G+12 buildingThe findings show that when the single paddleboard system is used, the mid-height outrigger at 0.5H offers the best performance. The configuration enables the balanced distribution of the overturning moment and significantly reduces the lateral displacement as well as the inter-story drift.

Although the dual-outrigger system delivers the highest structural performance, the configuration introduces the additional construction complexity together with the increased material utilization. Therefore, from the practical design perspective, the single outrigger located between 0.5H and 0.7H represents the optimal compromise between the structural efficiency and the construction feasibility.

The analysis shows that the mid-rise concrete reinforced building's lateral performance is much enhanced by the integration between the belts truss and outrigger system. The structural systems allow the perimeter columns to participate in the resistance of the overturning forces, which results in the improved stiffness, the reduced displacement, as well as the enhanced structural stability under the seismic loading conditions.

4 Structural Efficiency and Optimization

The fundamental goal of integrating the outrigger system and belt truss into the multistory building is to increase lateral resistance while using a fair amount of material. Therefore, it becomes vital to assess each configuration's structural efficiency in addition to the standard reaction metrics like displacement and inter-story drift. In the study, the structural optimization is assessed using three quantitative performance indicators which include the stiffness-to-weight ratio, the displacement reduction per unit structural weight, as well as the drift control efficiency. The indicators provide the balanced evaluation of the structural performance together with the material utilization.

The numerical model created with the ETABS platform was used to assess the building's overall structural weight. Because the extra beams and truss components are integrated at the designated floor levels, the inclusion of the outrigger and belt truss members somewhat increases the structural mass. However, the improvement in the lateral stiffness remains significantly higher than the corresponding increase in the structural weight.

The stiffness-to-weight ratio is calculated using the following relationship [25]:

$$\eta_s = \frac{K}{W} \tag{15}$$

Where η_s= the stiffness-to-weight efficiency, K= the global lateral stiffness (kN/mm), and W= the total structural weight (kN)

The displacement reduction efficiency measurement assesses the effectiveness of structural modifications in reducing roof displacement when compared to the standard structural design. The parameter is expressed as [26]:

$$\eta_d = \frac{\Delta_0 - \Delta_i}{W_i} \tag{16}$$

The equation calculates the roof displacement from conventional frame system through Δ_0 which stands as the reference point while Δ_i represents the displacement measurement for each model and W_i functions as the weight measurement of the earthquake-relief structure used in the ith model.

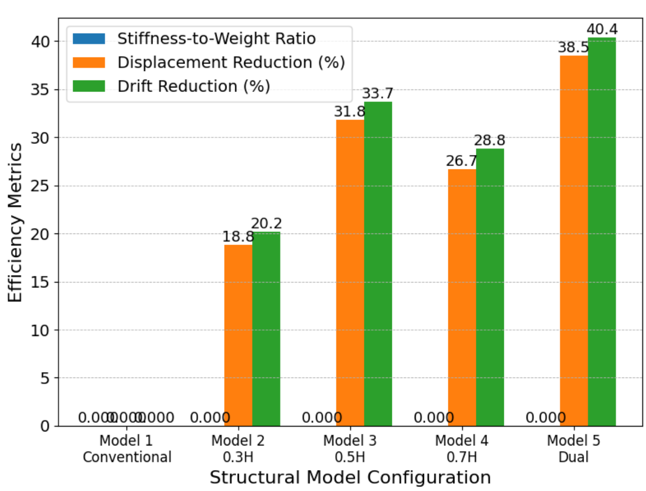

Fig. 8. Comparative efficiency chart illustrating the stiffness-to-weight ratio, displacement reduction, as well as the drift reduction for all structural models.

Drift control efficiency measures the reduction in the maximum inter-story drift relative to the conventional structure (see Table IX).

Table 9. Structural efficiency comparison of different configurations

Model	Structural Weight (kN)	Stiffness (kN/mm)	Stiffness-to-Weight Ratio	Drift Reduction (%)	Displacement Reduction (%)
Model 1	38,950	11.40	0.000293	–	–
Model 2	39,620	14.20	0.000358	20.2	18.8
Model 3	40,110	17.01	0.000424	33.7	31.8
Model 4	40,050	15.75	0.000393	28.8	26.7
Model 5	41,020	18.98	0.000463	40.4	38.5

The results show that structural efficiency benefits from outrigger addition. The structural weight increases because of their implementation. The stiffness-to-weight ratio of Model 3 reaches 0.000424 through its mid-height single-outrigger design which operates at 0.5H. The dual-outrigger system demonstrates maximum stiffness efficiency but needs extra structural elements for its operation.

Model 3 provides the optimal configuration which achieves the performance improvement while minimizing the material utilization. The configuration produces more than the 30% reduction in the roof displacement while maintaining the moderate increase in the structural weight.

The efficiency indicators for the structural configurations are presented in Fig. 8, which demonstrates that the optimized outrigger placement provides the superior structural performance compared with the conventional frame structure.

5 Practical Design Implications

The study's findings provide a number of useful insights for the construction of reinforced concrete mid-rise structures.

The numerical analysis shows that using a belt truss and an outrigger system significantly improves the lateral stability of buildings with a moderate height.

Specifically, the results show that the most effective way to manage both the lateral displacement and the inter-story drift is to locate the outrigger close to the mid-height of the building. For the G+12 building under consideration in the study, the arrangement with the outrigger close to 0.5H results in a significant decrease in roof displacement and enhances the structural system's overall stiffness without adding undue structural complexity.

From the practical design perspective, the selection of the outrigger location should consider both the structural performance and the construction feasibility. The analysis results indicate that the single outrigger positioned between 0.5H and 0.7H provides the significant improvement in the stiffness together with the drift control. Although the dual-outrigger configuration demonstrates the highest stiffness enhancement, the increase in the structural components may result in the higher construction cost as well as the more complex detailing. Therefore, in the practical structural design scenario, the single mid-height outrigger system provides the balanced solution.

The cost–benefit consideration also remains important during the implementation of the outrigger system in the mid-rise structure. The additional beams together with the belt truss elements increase the quantity of the reinforcement as well as the concrete required at the outrigger levels. However, the increase in the material utilization remains relatively small compared with the structural advantages achieved through the displacement reduction and the improved structural stability. The improved stiffness may also enable the optimization of the column and beam dimensions in the other parts of the structure which partially compensates for the additional material required for the outrigger system.

The underlying safety under lateral loading circumstances is another significant implication. The outrigger system more efficiently distributes the forces throughout the structural framework by shifting part of the overturning moment form the heart to the peripheral columns. The structural mechanism reduces the stress concentration in the core walls and improves the load sharing among the structural members. As the result, the building incorporating the properly designed outrigger system demonstrates the improved resistance to the wind and seismic actions, which contributes to the enhanced structural reliability as well as the serviceability of the mid-rise construction.

6 Conclusion

Under lateral loading scenarios, the structural characteristics of a G+12 concrete reinforced building with an outrigger system and belt truss was investigated. Numerical simulations revealed that the incorporation of outriggers substantially mitigated lateral displacement and inter-story drift relative to a standard frame structure. These findings suggested that the outrigger beams' connection of the central core with the perimeter columns facilitates the exterior columns' contribution to resisting the overturning moment.

The structural mechanism improves the global stiffness of the building and enhances the distribution of the forces throughout the structural system. The analysis further showed that outrigger positions directly affect how structures perform their required functions. The building achieves efficient structural performance and reduced building movement through its mid-height single outrigger system. The study shows that the mid-rise building gains from outrigger and belt truss system which improves its lateral stability and makes its structural performance more secure.

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