

Deflection Control In Composite Building By Using Belt Truss And Outriggers

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Abstract- The purpose of this research study was to evaluate the seismic performance of a high-rise G+20 RCC structure, with an emphasis on the effectiveness of structural upgrades using outrigger and belt truss systems. The outrigger and belt truss model systems, on the other hand, demonstrated a significant decrease in displacement and drift. The combined outrigger and belt truss model fared the best, reducing top-storey displacement by roughly 50% and significantly improving base shear resistance. The storey drift results revealed that inter-storey deformation was most apparent in the conventional model's mid-levels, possibly causing severe levels of structural instability and damage to non-structural features such as walls and facades. The incorporation of structural systems brought drift values well below allowed limits, resulting in increased structural safety and performance during seismic events. The base shear analysis revealed a considerable improvement in the building's ability to bear horizontal forces using the upgraded models. The combined system model has the greatest base shear values, emphasising the importance of extra lateral stiffness in high-rise buildings. This shows that buildings using outrigger and belt truss systems may better absorb and disperse energy under dynamic loads, such as earthquakes and wind forces, while maintaining structural integrity. The study of natural time periods and frequency responses demonstrated the structure's better dynamic behaviour. The natural time period was reduced with the addition of structural systems, showing increased stiffness and quicker structural reaction. Overall, this study demonstrates the importance of including outrigger and belt truss systems into the design of high-rise structures in order to enhance their seismic performance. These systems not only decrease lateral displacements and inter-storey drift, but also improve load redistribution, resulting in increased stability and less damage from seismic loads. Findings provide a good platform for formulating design standards for tall buildings in seismically prone locations.

Keywords- High-rise buildings, outrigger system, belt truss system, seismic performance, storey displacement, storey drift, base shear, time period, structural stability, ETABS simulation, lateral load resistance.

I. INTRODUCTION

A lot of people think that the outrigger and belt-truss method is one of the best ways to build big buildings. It works as a mixed horizontal load-resisting system because it has solid parts on the inside and outside. The outside structure, which could have frame tubes and giant columns, is linked to the inside structure, which could have concrete cores or steel-braced cores, by outriggers, which are rigid horizontal beams. The belt truss, which is another horizontal beam, connects the core to the outside columns at key points, and the outriggers connect the core to the outside columns at set levels. Large buildings are more stable and rigid because of this combined system. This is especially true for horizontal pressures like wind and earthquake loads.

The outrigger and belt-truss system offers multiple configuration options, including variations in the types of materials and structural systems used. The adaptability of the system allows it to be optimized for specific design requirements, making the selection of the optimum layout and dimensions crucial to achieving efficient and effective structural performance.

As urbanization intensifies, particularly in densely populated metropolitan areas, buildings are being constructed taller and with smaller footprints due to limited land availability. This tendency leads to a decline in structural stiffness, needing extra measures to withstand lateral stresses. Traditional solutions like moment-resisting frames, shear walls, braced frames, and tubular constructions may not be adequate for extremely tall buildings. To overcome this, outrigger beams are often used to provide the required lateral stiffness by connecting shear walls to external columns. This strategy increases the building's overturning resistance and strength, particularly under lateral stresses caused by wind or seismic activity.

When a tall building is subjected to lateral forces, the outriggers act as a stabilizing mechanism. The exterior columns resist the rotation of the shear walls, effectively reducing lateral displacement and base rotation. This

mechanism is analogous to a ship's sail and mast system, where the outriggers act like spreaders, providing stability against external forces. The core of a tall building can be likened to a ship's mast, with outriggers functioning similarly to spreaders and outer columns to stabilize the structure against wind loads. This system redistributes lateral forces, transferring them from the core to the foundation through external supports, thereby improving the building's overall resistance to seismic forces.

Outriggers and belt trusses are very useful in high-rise constructions to reduce lateral displacement at the top and regulate base movement. The use of cantilever beams (outriggers) allows the passage of overturning moments from the core to the outside columns, stabilizing the whole structure. When exposed to lateral loads, the combined action of walls and outrigger trusses causes compression on the leeward side columns and tension on the windward side columns, spreading stresses throughout the structure.

Belt trusses are positioned around the building's perimeter and are linked to the outside supports, providing additional resistance to lateral stresses. These trusses increase the building's lateral rigidity by reducing side deflection and providing a wider radius for force distribution. Outrigger and belt-truss systems work together to provide a strong structure that can resist external stresses, maintain stability, and reduce lateral movement.

The lateral pressures caused by seismic and wind loads offer considerable problems to the stability and integrity of high-rise buildings. In buildings higher than 20 storeys, conventional structural systems such as moment-resisting frames and shear walls often fail to reduce lateral deflection and storey drift. Modern structural solutions such as outrigger and belt truss systems are increasingly being employed to address these difficulties. However, further research is needed to determine the best location, design configuration, and performance characteristics of these systems in high-rise reinforced concrete (RCC) buildings. The purpose of this study is to examine the seismic response of a G+20 RCC structure with different configurations of outrigger and belt truss systems in order to establish their effectiveness in minimising lateral displacement and storey drift under seismic conditions. The study aims to give insights into enhancing lateral stability and structural performance in seismic zones by assessing the impact of various configurations using ETABS simulations.

In seismic zones, this research examines the seismic performance of high-rise buildings using outrigger and belt truss systems. The study comprises the simulation and analysis

of a G+20 RCC structure in ETABS software using the response spectrum approach. Several structural models, including standard RCC, belt truss-only, outrigger-only, and mixed systems, are evaluated for their effectiveness in limiting lateral displacement and story drift. To improve structural stability, minimise base shear, and increase overall seismic resistance, the research attempts to find the best configurations and placements of these systems. The findings will give engineers and architects with realistic design ideas for incorporating sophisticated systems into high-rise buildings located in urban seismic zones.

The objective of this study is to analyze the seismic performance of a high-rise RCC G+20 building equipped with an outrigger and belt truss system. It aims to determine the optimal placement of outriggers within the structure to enhance lateral stability and minimize seismic deflections. Additionally, the study compares different structural configurations, including conventional RCC, models with only outriggers, models with only belt trusses, and models combining both, to evaluate their effectiveness in resisting seismic loads. To achieve this, a response spectrum analysis model will be developed using ETABS to simulate and measure the seismic resilience of various structural designs under different earthquake intensities and configurations.

II. LITERATURE REVIEW

2.1 General

The literature review chapter examines the present state of knowledge about the structural performance of high-rise buildings under seismic and lateral loads, with a particular emphasis on outrigger and belt truss systems. Several studies have demonstrated that these systems greatly increase lateral stiffness, minimise storey drift, and improve overall structural stability in tall buildings. The potential for these systems to reduce seismic damage has been highlighted by research on the best location and design of these systems, especially when strategically integrated at key structural levels. However, variances in materials, building heights, and seismic zones have led to varying judgements about their effectiveness.

This chapter analyses and synthesises findings from previous research on structural size, including the use of shear walls, belt trusses, and outriggers, to discover effective risk mitigation techniques. It also emphasises advances in analytical methods for studying complex systems, such as finite element modelling and response spectrum analysis. The assessment addresses current research gaps, such as insufficient studies on reinforced concrete structures and the combined impacts of belt truss and outrigger systems. These

gaps serve as the foundation for this study's emphasis on optimising the performance of high-rise RCC buildings using extensive seismic analysis.

2.2 Previous studies

Chawardol and Shinde (2021) analyze the seismic response of reinforced concrete (RCC) structures equipped with belt trusses positioned at varying heights. Their study highlights that both shear walls and belt trusses are crucial in enhancing structural stiffness and resistance to lateral forces such as earthquakes. Their findings suggest that strategically placed belt trusses can effectively minimize story drifts and overall structural displacement. Similarly, Reddy and Devi (2021) emphasize the importance of multi-outrigger systems in modern tall buildings for resisting lateral forces from wind and seismic activities. Their research indicates that optimal placement of outriggers at the top and middle height levels can reduce maximum displacement by up to 18%, stressing the growing necessity of such structural innovations in rapidly urbanizing areas.

Alhaddad et al. (2020) present an in-depth overview of outrigger and belt-truss systems as efficient solutions for lateral load resistance in tall and super-tall buildings. Their paper categorizes different system configurations based on building requirements and structural materials, highlighting global applications such as the Burj Khalifa and Taipei 101. They stress that these systems improve architectural flexibility while maintaining structural integrity under extreme loading conditions. In another study, Alhaddad et al. (2020) provide guidelines for the optimal design of outrigger and belt-truss systems in tall buildings, focusing on material distribution and component size. They analyze the environmental impact of tall building construction and emphasize the significance of lateral load-resisting systems for sustainable urban structures. Their study concludes that optimizing configurations and design variables can minimize lateral displacement and maximize structural efficiency.

Pal and Dubey (2023) investigate the performance of various lateral load-resisting systems, including outrigger, wall belt, and truss belt systems, in a G+10 residential structure. Using CSI-ETABS, they compare models under seismic loads, focusing on base shear, lateral displacement, and story drift. Their results indicate that integrating outrigger and belt systems enhances overall building stiffness and reduces deformation under horizontal forces. Similarly, Nissanka et al. (2024) evaluate multiple outrigger configurations and structural materials in reinforced concrete buildings, conducting a parametric study that shows integrating outriggers and belt trusses can reduce lateral

displacement and story drift by 29.7% and 28.5%, respectively, thereby improving structural performance against wind loads.

Ahmed and Shazeb (2019) analyze seven models of a 44-story structure with different outrigger configurations under wind and seismic loads using ETABS. Their findings demonstrate that strategic placement of outriggers significantly reduces lateral deflection and improves seismic stability. Meanwhile, Dedeoğlu and Calayır (2020) explore seismic responses of tall buildings with shear wall-framed systems enhanced by traditional and virtual outriggers. Through time-history analysis, they find that belt trusses, acting as virtual outriggers, provide comparable stability while overcoming design challenges posed by traditional systems. Ahmed and Patil (2024) evaluate the impact of shear walls and belt truss systems in a G+20 building subjected to seismic loads in zones II and V. Using ETABS, they analyze base shear, story drift, and lateral displacement, concluding that shear walls and belt trusses enhance lateral stability, particularly in high-seismic regions.

Abdollahzadeh et al. (2022) explore the optimal positioning of outrigger arms and belt trusses in tall buildings. Their study, employing nonlinear time history analysis, determines that strategic placement significantly reduces both roof displacement and inter-story drift. They emphasize that deformation control in the outrigger location enhances overall structural performance under severe lateral loads. Kamgar and Rahgozar (2019) apply the energy method to determine the optimal locations for belt truss and outrigger systems in high-rise buildings. Utilizing a cantilever beam model, their study shows that multi-rigid outrigger systems significantly reduce roof displacement and axial forces, achieving a 2.3% reduction in displacement and a 4% reduction in axial forces when two belt-outrigger systems are used. Their research highlights the importance of system placement in maximizing energy dissipation and improving lateral stiffness.

III. PROBLEM STATEMENT AND MODELING

3.1 General

The methodology for analysing and designing a tall structure with an outrigger and belt system in a seismic zone using the response spectrum method was systematically developed as follows:

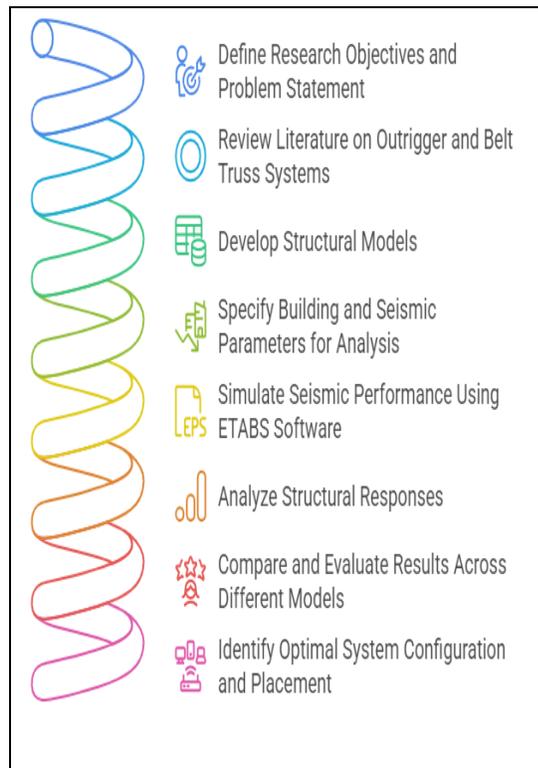


Figure 3. 1 Flow chart of Methodology

A system of coupled shear walls is frequently employed to resist the lateral loads that earthquakes induce in high-rise buildings. Outrigger beams are employed between the shear walls and external columns to enhance the ductility of the building structure and to ensure that it is sufficiently rigid. The analysis of a G+20 story RCC structure with an outrigger structural system that is subjected to seismic forces is proposed for this study. The responses, including lateral displacement, storey drift, and base shear, are to be computed using a outrigger system in conjunction with a belt truss system, as proposed for the analysis. The optimal location of outriggers within the high-rise building is to be determined.

The study considers a high-rise RCC G+20 story building with an X-type outrigger bracing system using square tube sections. The structural components include beams of 300x600 mm and columns of 1000x1000 mm, with a uniform floor height of 3m. Material properties include M40 grade concrete with a modulus of elasticity (E_c) of 27,386.12 MPa and Fe500 steel with a modulus of elasticity (E_s) of 200,000 MPa. The applied loads consist of a dead load of 2 kN/m², a live load of 3 kN/m², and a super dead load of 3 kN/m², leading to a total slab load of 8 kN/m². Additionally, wall load calculations for a 230 mm thick brick wall with a unit weight of 19 kN/m³ and a height of 3m yield a distributed load of 13.11 kN/m, amounting to 22.5 kN per meter of slab length.

3.2 Model details:

To investigate seismic response, a high-rise structure consisting of a G+20 storied RCC building with an outrigger structural system is taken into account. The ETABS software is proposed for the modelling and analysis of labour. ETABS is a comprehensive and potent research software that is designed to facilitate the design and analysis of RCC building structures.

The study examines a G+20 storied RCC building with an ordinary braced frame, featuring a 25m x 25m plan layout with five bays of 5m each in both X- and Y-directions. The structure is located in Seismic Zone III, with a seismic zone factor of 0.16, built on medium soil with an importance factor of 1 and a response reduction factor of 5. Each floor has a height of 3m, and the slab thickness is 150mm. The building incorporates an outrigger bracing system using tube sections with a thickness of 70mm and a brace size of 500x500mm. Four models are analyzed: a conventional model (Model 1), a model with only a belt truss (Model 2), a model with only outriggers (Model 3), and a model incorporating both belt truss and outriggers (Model 4).

3.3 Modeling images:

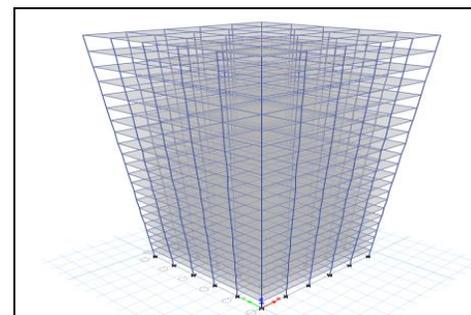
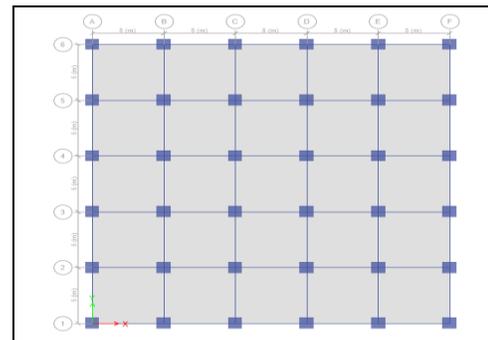


Fig: Conventional model

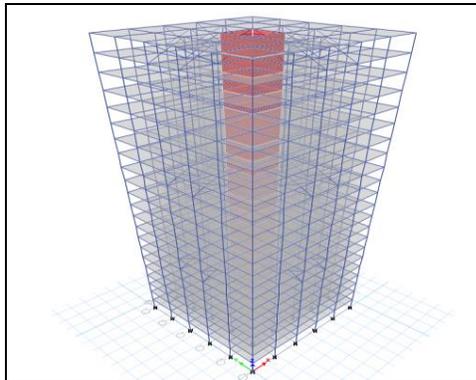
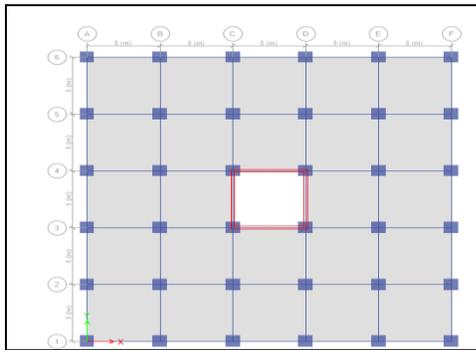


Fig: Model with outrigger

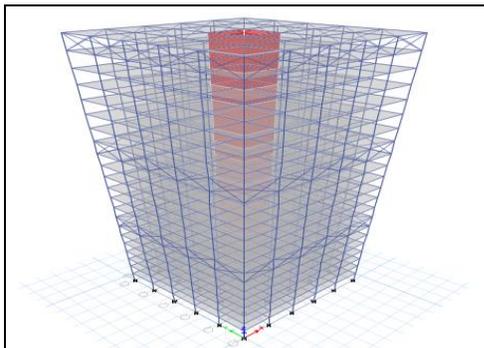


Fig: Model with belt truss

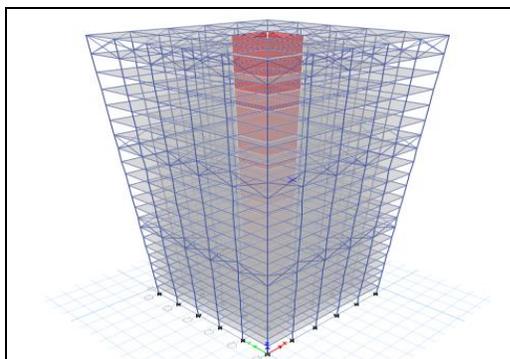
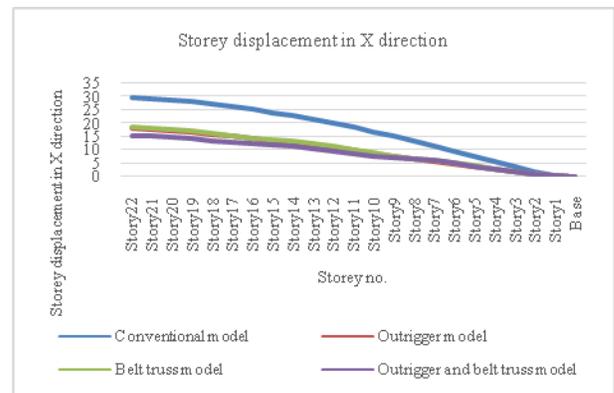


Fig: Model with outrigger and belt truss

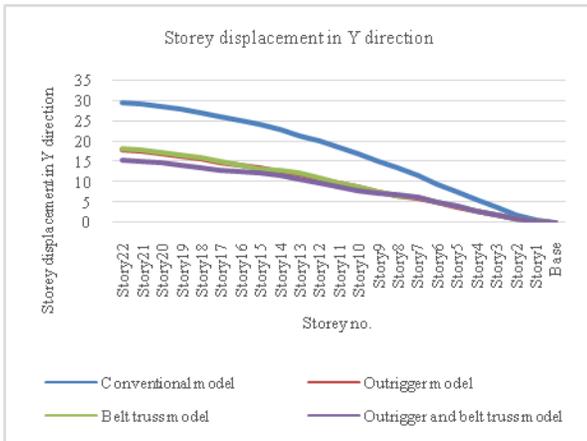
IV. RESULT AND DISCUSSION

The results and discussion chapter summarises the key findings obtained from seismic simulations of the G+20 RCC building models. This chapter provides a detailed analysis of the structural reactions, such as lateral displacement, storey drift, and base shear, under various seismic load conditions. Comparative assessments show the performance differences between conventional, belt truss-only, outrigger-only, and combination structural systems. The effectiveness of alternative system locations and design configurations is also explored, drawing on both simulation data and theoretical ideas. The findings are interpreted in terms of enhancing structural stability, with practical suggestions for optimising high-rise building designs in seismic zones.



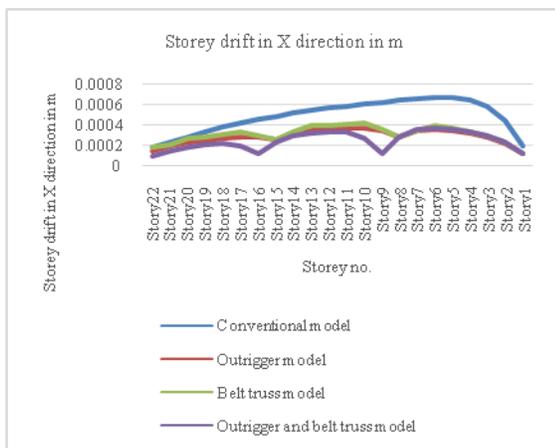
Graph: Storey displacement in X direction in mm

The storey displacement in the X direction indicates that the displacement values decrease from the structure's base to its top in all models. The conventional model has the biggest displacement at each storey level, with a maximum of 29.584 mm at Story 22 and a minimum of 0.587 mm at Story 1. The use of structural upgrades considerably lowers displacement. The outrigger model decreases displacement at the top storey by almost 40%, while the belt truss and combined outrigger-belt truss models cut displacement even further, with the outrigger and belt truss combination having the lowest top-storey displacement of 15.419mm.



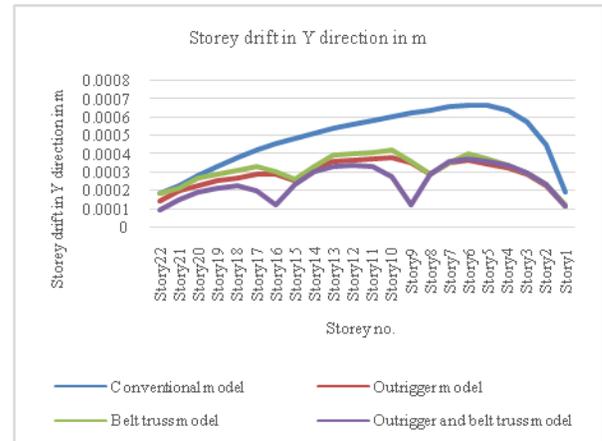
Graph: Storey displacement in Y direction in mm

The tendency for storey displacement in the Y direction (mm) is the same as in the X direction. The conventional model once again produces the greatest results, but displacement reduces with the use of outrigger and belt truss systems. The combined model yields the biggest decrease, lowering the top-storey displacement from 29.584 mm in the conventional model to 15.419 mm. This continuous trend indicates that the structural modifications increase the building's lateral stiffness and resistance to forces in both primary directions.



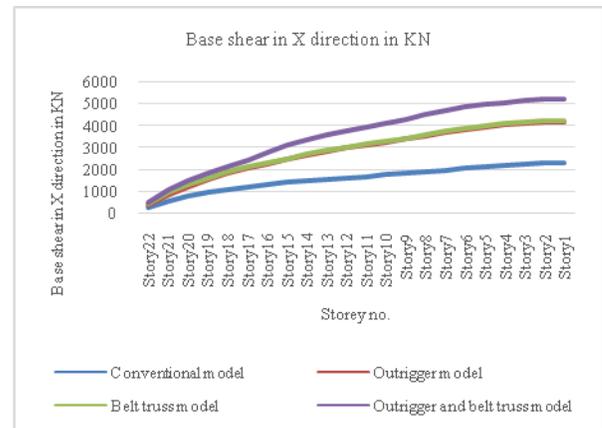
Graph: Storey drift in X direction in m

Storey drift, which measures inter-storey displacement, shows comparable patterns among models. The conventional model has the largest drift values, notably in the middle storeys, reaching a peak of 0.000668 m at Story 6. The drift is significantly reduced with the inclusion of structural systems. The combined outrigger and belt truss model has the least drift, with values consistently below 0.000371 m across all levels. Drift decrease shows increased inter-storey stability and deformation resistance.



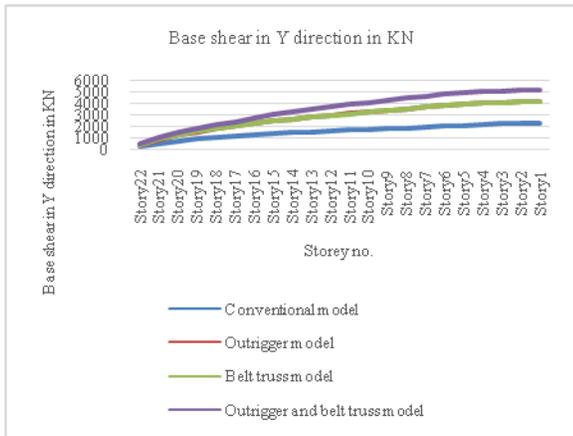
Graph: Storey drift in Y direction in m

All models show a decreasing tendency for storey drift in the Y direction. The conventional model records a high drift of 0.000668 m, but the combined outrigger and belt truss model decreases it to less than 0.000371 m. The use of outriggers and belt trusses greatly decreases lateral deformation, improving overall structural performance under lateral stress in both X and Y directions.



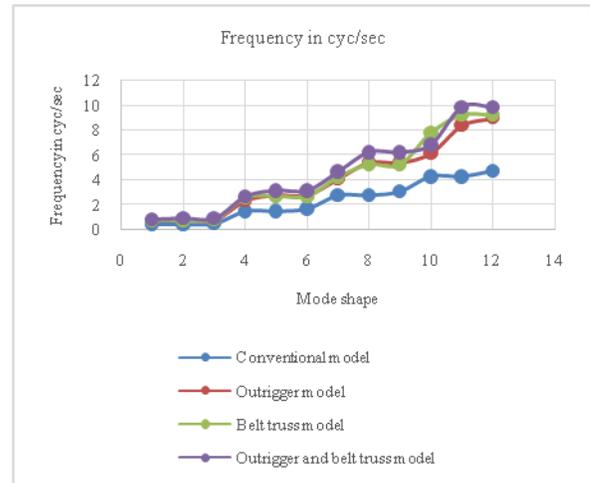
Graph: Base shear in X direction in KN

Introducing structural systems significantly improves base shear, which measures the total horizontal force exerted at the structure's base. The conventional model has lower base shear values, peaking at 2,300.385 kN in Story 1. However, the combined model withstands the largest base shear of 5,205.082 kN, suggesting that the increased stiffness provided by the outrigger and belt truss systems improves the structure's ability to tolerate horizontal forces.



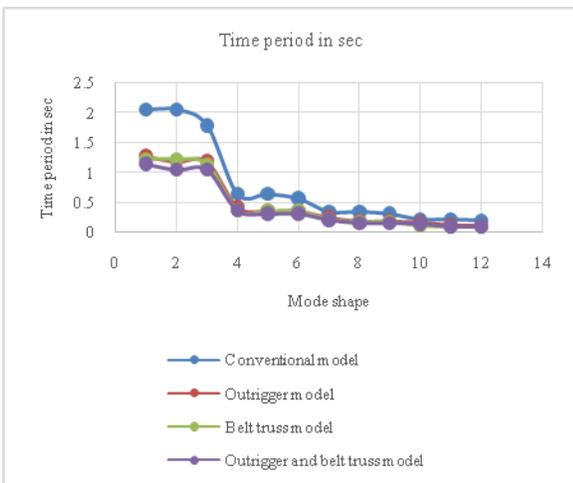
Graph: Base shear in Y direction in KN

The base shear in the Y direction shows comparable rates of improvement to the X direction. The conventional model indicates a peak base shear of 2,300.385 kN, but the combined outrigger and belt truss model has a substantially larger peak of 5,205.082 kN. This increase demonstrates the structural changes' enhanced ability to withstand seismic or wind stresses in both directions.



Graph: Frequency in cyc/sec

The frequency results exhibit an inverse connection with the time period. The conventional model has the lowest fundamental frequency of 0.486 cycles/sec, while the combined model has the highest frequency of 0.871 cycles/sec in the first mode. The rise in frequency represents the improved structural rigidity and dynamic stability gained by outrigger and belt truss integration. The potential for resonance effects is reduced by higher frequencies, which suggest quicker structural response to dynamic loads.



Graph: Time period in sec

Adding structural systems dramatically reduces the natural time periods of the structure, which are influenced by mode forms. The conventional model's basic mode takes the largest time of 2.058 seconds, whereas the combined model decreases it to 1.148 seconds. Lower time periods imply enhanced rigidity and decreased structural flexibility, resulting in improved performance under dynamic stress.

V. CONCLUSION

The purpose of this research study was to evaluate the seismic performance of a high-rise G+20 RCC structure, with an emphasis on the effectiveness of structural upgrades using outrigger and belt truss systems. The analysis included essential structural parameters such as storey displacement, storey drift, base shear, time period, and frequency. According to the results, the conventional model, which is based primarily on moment-resisting frames, is ineffective at mitigating the impacts of lateral loads, especially under seismic load conditions. This model saw the largest storey displacements and drifts, with values that potentially jeopardise the building's structural stability and serviceability. The outrigger and belt truss model systems, on the other hand, demonstrated a significant decrease in displacement and drift. The combined outrigger and belt truss model fared the best, reducing top-storey displacement by roughly 50% and significantly improving base shear resistance. The outrigger system efficiently dispersed lateral stresses by connecting the building's core to the exterior columns, minimising core overturning moments while boosting lateral stiffness. The belt truss system strengthened the perimeter structure, increasing its resistance to deformation from seismic stresses.

The storey drift results revealed that inter-storey deformation was most apparent in the conventional model's mid-levels, possibly causing severe levels of structural instability and damage to non-structural features such as walls and facades. The incorporation of structural systems brought drift values well below allowed limits, resulting in increased structural safety and performance during seismic events.

The base shear analysis revealed a considerable improvement in the building's ability to bear horizontal forces using the upgraded models. The combined system model has the greatest base shear values, emphasising the importance of extra lateral stiffness in high-rise buildings. This shows that buildings using outrigger and belt truss systems may better absorb and disperse energy under dynamic loads, such as earthquakes and wind forces, while maintaining structural integrity.

The study of natural time periods and frequency responses demonstrated the structure's better dynamic behaviour. The natural time period was reduced with the addition of structural systems, showing increased stiffness and quicker structural reaction. The upgraded models' higher frequency values represent a lower sensitivity to resonance, which is crucial for averting structural collapse during prolonged seismic excitation.

Overall, this study demonstrates the importance of including outrigger and belt truss systems into the design of high-rise structures in order to enhance their seismic performance. These systems not only decrease lateral displacements and inter-storey drift, but also improve load redistribution, resulting in increased stability and less damage from seismic loads. Findings provide a good platform for formulating design standards for tall buildings in seismically prone locations.

Future research on outrigger and belt truss systems should explore advanced materials like high-strength composites and fiber-reinforced polymers to enhance structural performance, optimize the number and placement of outriggers for efficiency, and analyze dynamic loading conditions through time-history analysis. The application of these systems in irregular structures and their integration with energy dissipation mechanisms should also be investigated. Based on findings, structural engineers should prioritize combined outrigger and belt truss systems for seismic stability, strategically place outriggers at mid-height and top levels, conduct regular seismic assessments, adhere to updated design codes, and utilize advanced software like ETABS for precise structural analysis.

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