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Review Paper On Innovative Structural Systems For High-Rise Buildings By Enhancing Seismic And Wind Resilience

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Abstract
This review explores the advancements in structural systems for high-rise buildings, focusing on enhancing resilience against seismic and wind forces. It examines various composite construction techniques, such as concrete and lightweight steel, and their applications in buildings and bridges to improve structural robustness. Key lateral load-resisting systems, including the diagrid structural system and base isolation techniques, are discussed for their effectiveness in mitigating seismic impacts. The review also highlights the evolution of structural systems for tall buildings, categorizing them into rigid frame systems, braced frame systems, outrigger systems, framed-tube systems, and bundled-tube systems. Furthermore, the study underscores the significance of space efficiency in skyscrapers, the use of high- performance column composites, and the growing trend of timber high-rise buildings. The integration of innovative technologies and renewable energy sources in building design is emphasized for achieving sustainability. The review concludes by addressing the optimization of passive design strategies and energy efficiency measures in existing buildings. This comprehensive analysis provides valuable insights for architects, engineers, and policymakers involved in sustainable high-rise construction.
Keywords: *High-rise buildings, Composite construction, Seismic resilience, Structural systems, Sustainable design*

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I. Introduction

The rapid urbanization and the increasing demand for vertical expansion in cities have led to significant advancements in the design and construction of high-rise buildings. These structures face unique challenges, particularly in terms of resilience to seismic and wind forces. This review explores the latest developments in structural systems for high-rise buildings, emphasizing the integration of innovative construction materials and techniques to enhance structural robustness and sustainability. Composite construction, which combines materials such as concrete and lightweight steel, has emerged as a pivotal solution to improve the load-bearing capacity and energy dissipation of high-rise structures. Various lateral load- resisting systems, including the diagrid structural system and base isolation techniques, have been developed to mitigate the impact of seismic activities. Additionally, the evolution of structural systems in tall buildings has led to the classification of different systems, such as rigid frame, braced frame, outrigger, framed-tube, and bundled-tube systems, each offering distinct advantages in specific construction scenarios.

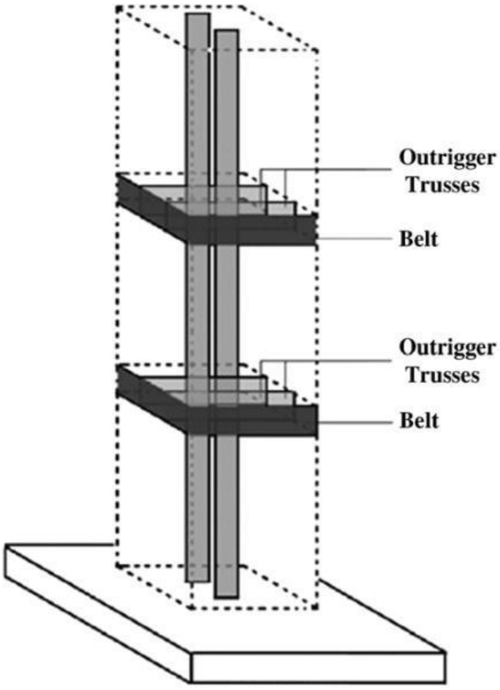

Figure 1: Schematic representation of a high-rise building with outrigger trusses and belt trusses [2].

Furthermore, the importance of space efficiency in skyscraper design has been highlighted, with studies focusing on maximizing usable space to address modern urban challenges. The growing trend of high-rise timber buildings, particularly in Europe, underscores the industry's shift towards sustainable construction practices as shown in figure 1. This review aims to provide a comprehensive overview of these advancements, offering valuable insights for architects, engineers, and policymakers involved in high-rise building design and construction.

Tumialan, J. Gustavo, et al. have discussed the significance of high-rise structures and the challenges associated with their design, particularly in the context of seismic and wind forces. It emphasises using composite construction, such as concrete and lightweight steel, in buildings and bridges to enhance structural resilience. Various lateral load-resisting systems for high-rise structures are highlighted, including the diagrid structural system and base isolation technique to mitigate the impact of seismic waves. The Research article analyses a composite column structure incorporating a diagrid system and base isolation, demonstrating improved rigidity and enhanced seismic response control with the latter [1]. Halis Gunel, M., and H. Emre Ilgin discuss the evolution of structural systems for tall buildings to resist wind and earthquake loads. It presents a classification of structural systems for steel, reinforced concrete, and composite buildings, including rigid frame systems, braced frame systems, outrigger systems, framed-tube systems, braced-tube systems, and bundled-tube systems. The text also explains the characteristics and examples of each system, highlighting their application in different types of construction. It concludes by mentioning the potential for new structural classifications in the future, such as mixed and bundled systems [2]. Ilgın, Hüseyin Emre, and Özlem Nur Aslantamer where discuss the importance of space efficiency in prismatic skyscrapers and present findings from a study analysing 35 supertall towers. It emphasises the significance of spatial optimisation in addressing the challenges of modern urban living, including the maximisation of usable space and the economic, environmental, and aesthetic benefits of space efficiency. The study explores the interrelationships between building function, structural systems, and materials in achieving space efficiency. It also highlights the prevalence of residential usage and the outrigger frame system in these structures. The findings underscore the potential for enhancing sustainability in skyscraper design by optimising space efficiency and exploring alternative materials and structural systems. Furthermore, incorporating innovative technologies and renewable energy sources can contribute to the sustainability of skyscraper design [3].

II. Advancements In Structural Systems For High-Rise Buildings

Sojobi, A. O., and K. M. Liew underline the significance of high-performance column composites in construction, particularly in seismic resilience. It highlights the advantages of employing these composites, such as increased load-bearing capacity, energy dissipation, and ductility. The research includes a scientific metric analysis demonstrating China's dominance in earthquake resilience research. The outcomes of a multi-objective optimization study using response surface methodology suggest that strip wrapping with two layers of CFRP is the most effective configuration for enhancing the mechanical performance of concrete columns. This study emphasizes the significance of external CFRP reinforcement in boosting the energy dissipation and ductility of both concrete and steel structures as displayed in figure 2. However, the study has limitations, including the small size of the columns due to resource constraints [4].

Figure 2: Preparation and application of Carbon Fibre Reinforced Polymer (CFRP) composites on concrete columns.

Issa, Mohsen A., et al. studied circular short reinforced concrete (RC) columns that were strengthened with carbon fiber-reinforced polymers (CFRP) when they were loaded only in one direction. For the study, 55 experiments were done with different configurations of CFRP layers, and 96 columns were modeled using nonlinear finite-element analysis (NLFEA). The NLFEA did a parametric study that looked at how the ultimate axial stress of the CFRP- confined RC columns related to the unconfined strength of concrete, the volume percentage of CFRP, and the effect of size. The findings showed that increasing the volume percentage of CFRP and the unconfined strength of concrete made the ultimate strength and flexibility higher. Moreover, the size effect was more pronounced for columns with lower strength. The study also emphasizes the significance of the number of CFRP layers, CFRP orientation, unconfined strength of concrete, column size, and their impact on the behavior of the columns. Overall, the experimental and NLFEA results offer valuable insights into the behavior and strengthening of RC columns using CFRP composites [5]. Ilgın, Hüseyin have discusses the growing trend of constructing high-rise residential timber buildings, particularly in Europe, and these buildings' architectural and structural design aspects. The study delves into data collected from 55 case studies and presents key findings, including the prevalence of central cores, prismatic shapes, pure timber construction, and the utilization of shear walled frame and shear wall systems. The results highlight the dominance of high-rise timber buildings in the Nordic region and the increasing adoption of timber and concrete composite materials. The study also emphasizes the need for further research in areas such as economic analysis, architectural design, regulatory policies, and public perception. Overall, the findings provide valuable insights for architects, engineers, and policymakers involved in sustainable construction projects [6].

III. Seismic And Wind Resilience Techniques

Leon, Roberto T. research and documentation of composite construction techniques have led to the formulation of design provisions and specifications for structural steel and concrete buildings. These provisions include slenderness limits for filled circular steel tubes as well as design provisions for various loading conditions for composite columns and beam-columns. The study of composite columns and beam-columns has resulted in the establishment of these design provisions. Ongoing research continues to explore future trends in composite construction, including the consideration of seismic provisions and the development of new design provisions for composite columns and beam columns [7].

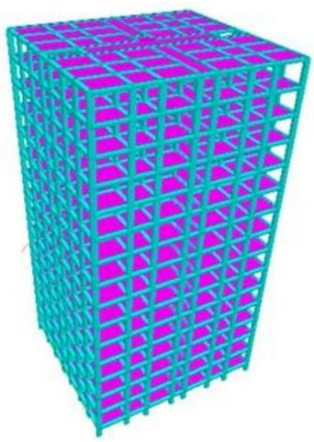

Figure 3: Structural model of a high-rise building using STAAD.Pro [8]

Saha, Sowrav, et al has delves into the design and analysis of a multi-storey residential building that stands at a height of G+14, using STAAD.Pro and AutoCAD software as shown in figure 3. The authors stress the significance of accurate and time-saving structural engineering in today's competitive market. They outline the process of designing and analyzing the building, taking into consideration crucial factors such as dead load, live load, and wind loads, as per the Indian Standard Codes. The study provides a comprehensive overview of the software used, the building specifications, design criteria, structural analysis, and foundation details. Additionally, the article offers insights into the beams, columns, slabs, and the overall displacement, shear, and bending of the structure. The authors conclude that STAAD.Pro, in conjunction with AutoCAD, is a highly effective and time-efficient tool for the design and analysis of multi-storey buildings [8]. Jung, Yujun, et al. established a novel method combining building model simplification and meta-model development was proposed for accurate and fast optimization of passive design strategies in multi-story residential buildings. Based on the sensitivity analysis, the most important design factors for reducing energy use, environmental impact, and cost were found to be airtightness, occupants, and the ratio of windows to walls. The study showed that multi-objective optimization of passive design strategies can make multi-story residential buildings 52.7% more energy efficient, 39.5% less harmful to the environment, and 36.9% more cost-effective.

The use of multi-objective optimization in passive design strategies not only improves energy efficiency but also has a positive impact on the environmental and economic feasibility of multi-story residential buildings [9].

IV. Composite And Timber Construction Materials

Bonakdar, Farshid, et al. have emphasizes the significance of implementing energy efficiency measures in existing buildings to decrease energy consumption and carbon dioxide emissions, particularly in light of the European Union's energy performance directive. The case study conducted in Sweden focuses on a multi-story residential building and examines the cost- effective energy renovation measures for building components, such as exterior walls, basement walls, attic floor, and windows. The study delves into various factors, including discount rates, energy price increases, and the lifespan of the measures, and presents insights into the economic and environmental implications of different scenarios. The results reveal that the cost-optimal measures are influenced by economic factors and vary for different building elements, with investment costs and lifespan playing crucial roles. The study recommends considering a balance between investment costs and energy savings when choosing energy efficiency measures for renovation [10]. Islam, A. B. M. Saiful, et al. have written about how to use base isolation in building construction in places where earthquakes are likely to happen. The study looks at how Lead Rubber Bearings (LRB) and High Damping Rubber Bearings (HDRB) can be used as base isolators. Linear static analysis, free vibration analysis, and nonlinear dynamic time domain analysis are some of the things that are talked about. The study shows that base isolation can greatly lower the effects of earthquakes and keep buildings from falling down in places with soft to medium soil. The study provides insights into the effectiveness of base isolation systems and concludes that base isolation is a viable recommendation for medium rise buildings in seismic vulnerable areas[11].

V. Sustainability And Space Efficiency In Skyscraper Design

Tettey, Uniben Yao Ayikoe, et al. talked about a study that compared how much primary energy different building frame materials in multi-story apartment buildings use. The study looked at the flows of energy and materials during the different stages of a building system's life, such as when materials are made, when the building is built, when it is used, and when it is finally taken down. The research found that compared to concrete alternatives, wood building systems used less primary energy for production and left behind more biomass. The building systems used most of their primary energy during the operation phase, with space heating being a big part of that. The results showed that the resource efficiency of the built environment could be affected by the materials used for building frames, the design of low- energy buildings, and the use of efficient energy supply systems. Overall, the study focused on the possible advantages of using wood building materials for conserving resources and making the construction industry more environmentally friendly [12]. Papavasileiou, Georgios S., and Dimos C. Charmpis have talked about how to make the best designs for steel-concrete composite buildings. They have focused on making multi-story buildings that can withstand earthquakes with steel-concrete columns, like the ones in figure 4. The study considers using the Evolution Strategies algorithm to minimize material costs while meeting design requirements and seismic performance criteria. The results include optimized designs for 6-storey buildings with different bay widths and bracing configurations and a 4-storey building. The optimization process yields various column and beam section combinations, and the effect of bracing placement on the overall building design is also analysed. Overall, the study provides insights into the cost-effective design of composite buildings and the impact of various design parameters on the final structural solutions [13].

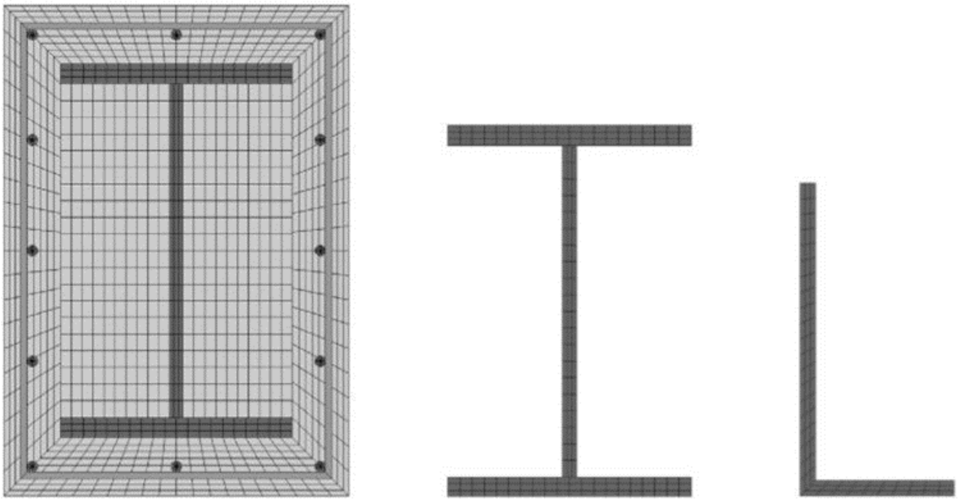

Figure 4: Cross-sectional views of various beam configurations used in high-rise building design.

Wasim, Muhammad, et al. have discussed the application of Design for Manufacturing and Assembly (DfMA) principles to prefabricated non-structural components of buildings, specifically focusing on a residential construction project in Melbourne, Australia. The study involves the analysis of timber frame walls and plumbing drainage systems using on-site and factory observations. It outlines the development of a computational tool to compare the time efficiencies of on-site, off-site, and DfMA-based prefabrication. The analysis shows that DfMA-based prefabrication resulted in significant time and cost savings compared to traditional manufacturing methods. The paper concludes by proposing a new framework for applying DfMA in large construction projects and highlights the potential benefits of DfMA in improving construction productivity[14]. Nishanth, Ch. Lokesh, et al. have examines the evaluation and planning of a commercial building's performance in the face of seismic and wind forces by considering different slab configurations. The research utilizes the ETABS software and takes into account various load combinations according to applicable building codes. The study reveals that the building with a grid slab is more stable and cost-effective in comparison to the other slab arrangements. Additionally, the research emphasizes the importance of factors like story displacement, base shear, and concrete quantity in determining the building's stability. In conclusion, the study demonstrates that the grid slab is a suitable option for resisting wind and earthquake forces. The research cites prior studies and Indian building codes, offering a comprehensive analysis of the building's structural design [15].

VI. Conclusion

This review has provided a comprehensive examination of the latest advancements in the design and construction of high-rise buildings, focusing on structural systems that enhance resilience, efficiency, and sustainability. The key findings and implications of the reviewed studies are summarized below:

1. Advanced structural systems like diagrid and base isolation techniques significantly improve the seismic performance and wind resistance of high-rise buildings.
2. These systems enhance the rigidity and stability of structures, ensuring better safety and performance during extreme weather events.
3. The use of composite materials, such as concrete and lightweight steel, has proven effective in increasing load-bearing capacity and energy dissipation.
4. The evolution of structural systems for tall buildings has led to various classifications, including rigid frame, braced frame, outrigger, framed-tube, and bundled-tube systems.
5. Space efficiency in skyscrapers is crucial for modern urban living, providing economic, environmental, and aesthetic benefits.
6. Further research is needed to explore economic analysis, architectural design, regulatory policies, and public perception of these innovative construction practices.

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