A Comprehensive Review on Belt Truss Systems and Their Optimum Positioning in High-Rise Buildings Under Wind and Earthquake Loading

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***Abstract*—This study presents a comprehensive assessment of research carried out on belt truss systems for high-rise reinforced concrete buildings. The study critically examines the evolution of belt truss systems, their structural behaviour, load-transfer mechanism, influence on lateral displacement, inter-storey drift, base shear, overturning moment, and dynamic characteristics under wind and seismic loading. Particular emphasis is placed on investigations related to the optimum vertical positioning of belt trusses and the influence of building slenderness ratio on structural efficiency. The review further summarizes recent developments in finite element modelling, optimization methodologies, and performance-based analytical techniques adopted by various researchers.**

A comparative evaluation of previous investigations indicates that although belt truss systems considerably improve the lateral performance of tall buildings, the optimum location varies depending upon structural configuration, stiffness distribution, loading characteristics, and aspect ratio. Existing studies predominantly investigate combined outrigger–belt truss systems, whereas independent evaluation of belt trusses acting as virtual outriggers remains relatively limited.

Moreover, systematic investigations considering different slenderness ratios under combined wind and earthquake loading are comparatively scarce.

The paper identifies important research gaps and future research opportunities for optimizing belt truss systems in reinforced concrete high-rise structures. The review provides a consolidated knowledge base for researchers and practicing structural engineers involved in the analysis and design of tall buildings subjected to lateral loading.

***Index Terms*—Belt truss, lateral load-resisting system, slenderness ratio, inter-storey drift.**

I. INTRODUCTION

Rapid urbanization and limited land availability have led to the widespread construction of high-rise buildings. As building height increases, lateral loads induced by wind and earthquakes become the governing design criteria, resulting in increased lateral displacement, inter-storey drift, and structural vibrations. Therefore, an efficient lateral load-resisting system is essential to ensure the stability, serviceability, and safety of tall buildings.

Among various structural systems, the belt truss system has emerged as an effective solution for enhancing the lateral stiffness of high-rise structures. Acting as a virtual outrigger, the belt truss transfers lateral forces from the central core to the perimeter columns through floor diaphragm action, thereby reducing lateral displacement and inter-storey drift while minimizing architectural constraints associated with conventional outrigger systems.

Recent advances in finite element analysis and software such as ETABS have enabled detailed evaluation of belt truss systems under wind and seismic loading. Previous studies have investigated the influence of belt truss location, stiffness, and configuration on the structural response of tall buildings. However, most investigations have focused on combined outrigger–belt truss systems, while limited research has addressed the independent behaviour of belt trusses and the influence of building slenderness ratio under combined wind and earthquake loading.

This review paper presents a comprehensive assessment of previous research on belt truss systems for reinforced concrete high-rise buildings. The review summarizes recent developments, compares key findings, identifies existing research gaps, and highlights future research directions for determining the optimum location of belt truss systems to improve the lateral performance of tall buildings.

II. LITERATURE REVIEW

Sunil Khadka et al. [1] investigated the structural performance and optimum location of outrigger and belt truss systems in a 32-storey reinforced concrete building using ETABS and Response Spectrum Analysis. The study demonstrated that the outrigger–belt truss system with a top cap truss significantly reduced lateral displacement, inter-storey drift, and fundamental time period, with the optimum belt truss location identified at 0.5H. However, the investigation considered only seismic loading and excluded wind loading, soil–structure interaction, and irregular building configurations.

Gunda and Anthugari [2] performed a numerical investigation on the seismic performance of tall buildings with different aspect ratios by varying outrigger locations. Linear dynamic analysis showed that buildings with moderate aspect ratios achieved maximum efficiency when outriggers were located at approximately 65–80% of the building height, whereas more slender buildings required lower outrigger positions. Although the study established valuable guidelines for outrigger placement, it did not specifically investigate belt truss systems.

Abdollahzadeh et al. [3] investigated the optimum location and configuration of outrigger arms and belt trusses in steel high-rise buildings using nonlinear time-history analysis. The proposed arrangement improved lateral stiffness and reduced roof displacement and inter-storey drift through optimized outrigger spacing and modified diagonal bracing. However, the study considered only seismic loading and did not evaluate wind effects or construction feasibility.

Chawardol and Shinde [4] reviewed the application of belt truss systems at different elevations in reinforced concrete buildings. The study highlighted the effectiveness of virtual outriggers in reducing lateral displacement and inter-storey drift, indicating that a single belt truss performs efficiently between 0.4H and 0.5H of the building height. However, the review did not include finite element validation or quantitative optimization for varying slenderness ratios.

Alhaddad et al. [5] presented a comprehensive review of outrigger and belt truss systems used in tall buildings to improve resistance against lateral loads. The study discussed the evolution of various outrigger configurations and optimization techniques for enhancing structural efficiency under wind and seismic loading. The authors concluded that outrigger–belt truss systems significantly reduce lateral displacement and overturning moments while improving structural stiffness. However, the study was primarily a review of existing research and did not establish generalized design recommendations for the optimum location of belt trusses.

Dedeoğlu and Calayır [6] reviewed the seismic performance of outrigger and belt truss systems in tall buildings using findings from previous analytical investigations. The study discussed the concept of virtual outriggers and demonstrated that belt trusses effectively improve lateral stiffness by mobilizing perimeter columns through floor diaphragm action. The authors concluded that belt truss systems overcome several architectural limitations associated with conventional outriggers. However, no quantitative assessment of optimum belt truss location under varying building configurations was presented.

Kim, Lim, and Lee [7] developed a gradient-based optimization technique combined with finite element analysis to determine the optimum location of outrigger systems in high-rise buildings. The study demonstrated that optimization algorithms effectively reduce lateral displacement while improving structural efficiency. The authors reported that the optimum outrigger position varies depending on structural stiffness and building geometry. However, the investigation focused on conventional outrigger systems rather than standalone belt truss systems.

Haghollahi et al. [8] reviewed analytical and numerical approaches used for optimizing outrigger and belt truss systems in tall buildings. The study summarized previous research concerning outrigger stiffness, member rigidity, and structural efficiency under lateral loading. The findings indicated that optimum outrigger location depends on structural height, stiffness distribution, and loading characteristics. However, the review did not examine the influence of building slenderness ratio on belt truss performance.

Ali and Moon [9] reviewed the evolution of structural systems for high-rise buildings, including framed tubes, diagrids, mega-frames, and core-outrigger systems. The study emphasized that increasing building height requires advanced lateral load-resisting systems to improve stiffness and reduce displacement. However, limited attention was given to the independent performance of belt truss systems.

Tavakoli et al. [10] investigated the optimum location of belt truss systems in a 30-storey steel building subjected to blast loading using nonlinear dynamic analysis in OpenSees. The study reported that the optimum belt truss location varies with the selected performance criterion, significantly improving roof displacement, base forces, and energy dissipation. However, the analysis was limited to blast loading and did not consider wind or earthquake effects.

Kamgar and Rahgozar [11] developed a critical excitation method to determine the optimum belt truss location in tall buildings under seismic loading using linear dynamic analysis and sequential quadratic programming. The study identified the optimum location near the upper storeys (approximately 0.9H) and eliminated variations caused by different earthquake records. However, the method assumed linear elastic behaviour and excluded nonlinear and wind-induced responses.

Babaei [12] performed a multi-objective optimization of steel outrigger–belt truss systems for 20- to 50-storey buildings using ETABS. The study demonstrated that the optimum number and location of belt trusses depend on building height and design objectives, resulting in improved lateral stiffness and drift control. However, the optimization considered only equivalent static seismic loading and neglected wind loading and nonlinear structural behaviour.

Bayati et al. [13] investigated the optimization of multi-outrigger systems for improving the lateral performance of tall buildings under wind and seismic loading. The study concluded that increasing the number of outriggers effectively reduces lateral displacement and overturning moments, thereby enhancing structural stiffness. However, the investigation focused on outrigger systems and did not evaluate the independent behaviour of belt truss systems.

Khanorkar et al. [14] reviewed the performance of outrigger and belt truss systems for controlling lateral displacement and inter-storey drift in tall buildings. The study reported that a single outrigger performs efficiently between 0.4H and 0.6H, while multiple outriggers provide improved lateral stiffness at different elevations. However, the review was qualitative and lacked numerical validation under combined wind and seismic loading.

Moragaspitiya and Thambiratnam [15] investigated the seismic and wind response of damped outrigger systems for high-rise buildings under multi-hazard loading. The study demonstrated that negative stiffness damped outriggers provide superior energy dissipation and reduce seismic drift and wind-induced acceleration compared to conventional systems. However, the research focused on damping mechanisms and did not investigate the optimum positioning of independent belt truss systems.

Rahgozar and Sharifi [16] developed an analytical continuum model for framed tube–shear core buildings strengthened with belt truss systems and validated the results using SAP2000. The study reported that locating the belt truss between 0.167H and 0.25H effectively minimizes roof displacement in framed tube structures. However, the proposed model was limited to static analysis and did not consider dynamic wind or earthquake loading.

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