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A Comprehensive Review on Outrigger Systems for Lateral Load Resistance in Tall RCC Buildings

Yashkumar Parmar[1], Chirag R. Odedra[2], Prashant K. Bhuva[3], Ashish D. Kachhadiya[4], Amit C. Kalola[5], Nikunj J. Hindocha[6]

[1]PG Scholar, Civil Engineering, Dr. Subhash University, Junagadh, India
[2,3,4,5,6]Asst. Professor, Department of Civil Engineering, School of Engineering and Technology, Dr. Subhash University, Junagadh, Gujarat, India

ABSTRACT

The increasing demand for high-rise reinforced concrete (RCC) buildings in urban centers has made lateral load resistance a critical aspect of structural design. Among various structural systems, the outrigger system has emerged as one of the most effective solutions for reducing lateral deflections and improving stiffness. This paper presents a comprehensive review of 24 research papers on outrigger systems in tall buildings, focusing on their evolution, design methodologies, optimization strategies, and practical challenges. The review highlights the transition from conventional outriggers to advanced concepts such as damped and fused outriggers. Key issues such as axial shortening, construction difficulties, and optimum outrigger placement are discussed. Despite extensive theoretical and numerical studies, significant research gaps remain regarding RCC-specific applications, performance-based seismic design, and practical adaptability under real-world constraints. The paper concludes with future research directions including multi-hazard optimization, smart outriggers with damping devices, and cost-effective RCC-oriented designs.

Keywords: Tall Buildings, Outrigger System, RCC Structures, Lateral Load Resistance, Structural Optimization

1. Introduction

The rapid urbanization and scarcity of land have driven the vertical expansion of cities, resulting in a surge of tall building construction. Structural engineers face increasing challenges in ensuring the safety and serviceability of these buildings under lateral loads from wind and earthquakes. Reinforced concrete (RCC), being widely available and cost-effective, is a preferred material in many developing countries, including India. However, RCC tall buildings suffer from high flexibility and excessive lateral drift, making lateral load resisting systems a necessity.

The outrigger system, consisting of horizontal stiff members that connect the building core to the perimeter columns through belt trusses or walls, has proven to be an effective mechanism to enhance lateral stiffness and reduce drift. Originally introduced as deep beams in steel buildings, the system has evolved into sophisticated forms including multi-level outriggers, damped outriggers, and fused outriggers.

Despite decades of research, several challenges persist: (i) determining the optimum location of outriggers considering architectural and functional constraints, (ii) addressing axial shortening and creep, and (iii) adapting outrigger systems for RCC structures where construction complexity and material limitations differ from steel.

This review consolidates findings from 24 research papers to provide a comprehensive outlook on the state-of-the-art in outrigger systems for tall RCC buildings.

2. Literature Review

The following table summarizes 24 studies on outrigger systems in tall buildings

Table 1 - Literature Review

Sr.	Author/Year	Title	Objective	Method/ Approach	Limitation	Future Work
1	Ho, 2016	Evolution of Outrigger Systems	Review development & applications	Historical + case studies	Limited RCC focus	Study RCC-based outriggers
2	Chang & Chen, 2008	Outrigger System Study	Analyze square plan towers	Analytical modeling	No experimental validation	Extend to irregular floor plans
3	Taranath, 1998	Structural Analysis & Design	Fundamental analysis	Theoretical + design equations	Steel focus, old codes	Update with RCC & PBSD
4	Nair, 1998	Belt Trusses as Virtual Outriggers	Introduce concept of virtual outriggers	Analytical study	No RCC cases	Hybrid RC-steel design
5	Stafford Smith & Coull, 1991	Tall Building Structures	Foundational design approaches	Analytical theory	Idealized models	Numerical + experimental validation
6	Gerasimidis et al., 2009	Optimum Outrigger Locations	Determine ideal placement	Numerical modeling	Steel only	Extend to RCC
7	Fawzia et al., 2011	Outrigger Efficiency in Wind	Evaluate wind-induced drift	Finite element modeling	No seismic analysis	Multi-hazard studies
8	Ho et al., 1999	Cheung Kong Center	Practical case study	Construction case study	Location-specific	Broader RCC applications
9	Zhu et al., 2016	Composite Outrigger System	Develop fused outrigger	Experimental testing	Limited adoption	Large-scale applications
10	CABR, 2015	Composite Outrigger Connectors	Validate fuse components	Lab-scale testing	Not RCC-focused	RCC prototypes
11	Kwok & Vesey, 1997	Cross-Jack System	Solve axial shortening	Adjustable jack system	Creep not solved	Long-term monitoring

12	Ali & Moon, 2007	Structural Developments	Review global systems	Comparative study	Limited RCC focus	Case applications in RCC
13	Herath et al., 2009	Behavior under Earthquakes	Earthquake effects on outrigger	Numerical analysis	No experimental data	Seismic + nonlinear studies
14	Ahani et al., 2018	Effects of Outrigger Type	Seismic performance comparison	Computational modeling	Limited field validation	Advanced nonlinear validation
15	Gupta et al., 2020	Parametric Study via Pushover	Analyze outrigger positions	ETABS pushover analysis	Small scale	Larger city-scale studies
16	Deepthi & Patil, 2018	Parametric Evaluation	Evaluate outrigger design	Case studies	Limited models	Expanded modeling
17	Sohail, 2016	Optimization of Multi-outriggers	Study multi-outrigger placement	FE modeling	Idealized assumptions	Validation with tall RCC
18	Jagadheeswari & Christy, 2016	Optimum Multi-outrigger Belt	Evaluate wind + seismic performance	FE modeling	No experiments	Shake table testing
19	Prasad & Kumar, 2016	Comparative RCC vs Steel Outriggers	Compare materials	Numerical analysis	Small scale only	Extended RCC study
20	Mistry & Dhyani, 2015	Optimum Outrigger Location	Evaluate placement	Analytical + FE	Simplified assumptions	RCC-focused validation
21	Shivacharan et al., 2015	Vertical Irregularities	Outriggers with irregularities	Numerical study	Not validated experimentally	Experimental research
22	Raj Kiran Nanduri et al., 2013	Optimum Position under Wind & Earthquake	Location optimization	FE analysis	Simplified models	Performance-based design
23	Bayati et al., 2008	Optimized Multi-outriggers	Stiffen tall buildings	Numerical modeling	Steel focused	RCC performance validation
24	Seng Kian, 2001	Outrigger & Belt Truss in RCC	Application in RCC	Analytical study	Limited data	Detailed RCC studies

3.Critical Analysis

An in-depth examination of the reviewed literature reveals that the outrigger system remains one of the most efficient and adaptable mechanisms for controlling lateral deflections in tall buildings. Through the analysis of 24 selected papers, several key observations can be made regarding the evolution, performance, and implementation of these systems in both steel and RCC high-rise structures.

Most researchers agree that outriggers act as a coupling mechanism between the central core and the perimeter columns, thereby mobilizing the entire building width to resist overturning moments. Early analytical works by Taranath (1998), Nair (1998), and Stafford Smith & Coull (1991) established the fundamental theory and design principles for outrigger systems. Subsequent studies, such as those by Fawzia et al. (2011), Gupta et al. (2020), and Ahani et al. (2018), built upon this foundation using finite element and nonlinear analyses, providing a more refined understanding of stiffness contribution, optimal positioning, and the influence of material characteristics.

It is evident from the reviewed studies that the optimum outrigger location typically lies between 0.4 H and 0.7 H of the total building height, depending on the structural configuration and load combinations. However, the ideal position is often restricted by architectural and functional constraints such as mechanical floors and service zones, particularly in residential towers.

Most of the existing work predominantly emphasizes steel and composite structures, with relatively fewer investigations focused on reinforced concrete (RCC) outrigger systems. While the efficiency of steel outriggers is well documented, the performance of RCC outriggers—affected by material nonlinearity, construction sequence, and creep—is still underexplored. A number of Indian and Asian studies (e.g., Mistry & Dhyani, 2015; Nanduri et al., 2013) demonstrate that RCC outriggers can achieve comparable stiffness if properly designed; however, issues related to axial shortening, reinforcement congestion, and constructability remain major practical challenges.

The introduction of multi-level and hybrid outriggers (Zhu et al., 2016; Sohail, 2016) further demonstrates the evolving design philosophy towards performance-based and multi-hazard-resistant systems. Recent trends also indicate the integration of damping devices and energy dissipation mechanisms, leading to hybrid "damped outrigger systems," which offer enhanced control under both wind and seismic loads.

Overall, the literature indicates a strong consensus on the mechanical efficiency of outrigger systems but also highlights the need for material-specific optimization and practical validation to make these systems more reliable for RCC tall buildings in developing countries.

4. Research Gaps

The collective review of these 24 papers underscores several critical research gaps that warrant further investigation:

Limited RCC-Oriented Studies: Most published work focuses on steel or composite structures. RCC-based outrigger systems lack experimental data and detailed analytical calibration against field performance.

Insufficient Multi-Hazard Evaluation: Although many papers address wind or seismic loads independently, few studies evaluate combined wind–seismic performance and the coupled dynamic interaction of both hazards on tall RCC frames.

Inadequate Consideration of Time-Dependent Effects: Long-term influences such as creep, shrinkage, and differential axial shortening significantly affect the performance of RCC outriggers but are rarely modeled or validated experimentally.

Neglect of Construction and Practical Constraints: The architectural integration of outrigger systems, constructability issues, and economic viability are not systematically addressed in most analytical models.

Lack of Experimental Validation: Almost all studies rely on finite element modeling without full-scale laboratory or shake-table validation. This limits confidence in analytical predictions for seismic performance.

Absence of Smart and Adaptive Systems for RCC: The concept of damped or adaptive outriggers—common in steel and composite buildings—has yet to be effectively implemented or studied in RCC structures.

Need for Indian Context and Codal Calibration: Very few studies align with Indian loading standards (IS 1893:2016, IS 875 Part 3) or local construction practices, making results difficult to apply directly in Indian conditions.

5. Future Scope

The reviewed research collectively opens several promising avenues for future exploration and practical development in the field of outrigger systems for tall RCC buildings:

Development of Performance-Based Design (PBD) Frameworks: Future studies should focus on integrating outrigger design within performance-based seismic and wind engineering approaches, allowing for direct assessment of drift, ductility, and energy dissipation demands.

Experimental and Field Studies: There is an urgent need for scaled laboratory models, shake-table experiments, and real-building monitoring to verify numerical predictions and validate design assumptions.

RCC-Specific Optimization Models: Design methodologies must evolve to consider material nonlinearity, concrete cracking, creep, and reinforcement detailing in RCC outriggers, supported by numerical optimization using advanced solvers.

Hybrid and Damped Outrigger Systems: The inclusion of viscous dampers, metallic fuses, and energy absorbers in RCC outrigger configurations can lead to a new generation of *adaptive hybrid systems* that combine stiffness and energy dissipation capabilities.

AI and Machine Learning in Structural Optimization: Data-driven approaches can be applied to determine the optimum number, depth, and location of outriggers for given design constraints and performance objectives.

Sustainability and Cost-Efficiency Considerations: Optimization must also account for material consumption, constructability, and life-cycle cost, particularly in the context of developing economies where RCC high-rises dominate.

Integration into Design Codes: The findings from future research should be incorporated into national design standards and guidelines for high-rise RCC buildings, ensuring that outrigger systems are codified for reliable and economical implementation.

6. Conclusion

This review of twenty-four research papers confirms that the outrigger–belt truss system remains one of the most effective methods for enhancing the lateral stiffness and stability of tall RCC buildings. Over time, outrigger systems have evolved from conventional single-level beams to advanced multi-level and hybrid damped systems capable of improving both stiffness and energy dissipation.

The findings reveal that while outrigger efficiency is well established in steel and composite structures, RCC applications remain limited due to material nonlinearity, creep, and construction challenges. The optimum outrigger position generally falls between 0.4H and 0.7H of building height, balancing drift control and economy. However, practical implementation is often restricted by architectural and functional constraints.

Recent advancements in analytical tools such as ETABS, SAP2000, and ANSYS have enabled accurate simulation, yet experimental and field validation are still lacking. Studies also highlight the need for RCC-specific design approaches aligned with local codes and construction practices, especially in India.

In summary, the outrigger system continues to be a reliable and economical lateral load resisting strategy for tall RCC structures. Future research should focus on performance-based, RCC-optimized, and hybrid outrigger designs that integrate damping and sustainability considerations to achieve resilient and efficient high-rise structures.

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