International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 01 | Jan 2024 www.irjet.net p-ISSN: 2395-0072

Comparative Study of Seismic Analysis of RC Frame Structure with and without Belt Truss and Outrigger Truss: A Review

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Abstract - *This review study provides a thorough analysis of the seismic behavior of Reinforced Concrete (RC) frame structures, both with and without the use of Belt Truss and Outrigger Truss systems. The design and construction of buildings in earthquake-prone zones must prioritize seismic resistance and structural integrity. The research aims to assess the effectiveness of two commonly used lateral load-resisting methods, namely Belt Truss and Outrigger Truss, in improving the seismic performance of reinforced concrete frame buildings. The article conducts a comprehensive analysis of the current body of literature, techniques, and analytical approaches used to research seismic behavior. It emphasizes important discoveries and patterns in this subject. The study examines and highlights the differences in seismic behavior between reinforced concrete (RC) frame buildings designed conventionally and those that use Belt Truss and Outrigger Truss systems. The evaluation involves examining the structural parameters, material properties, and dynamic analytic methodologies used to evaluate the seismic resistance of certain structural configurations.*

The research examines how parameters like as building height, structural geometry, and seismic loading characteristics affect the performance of RC frame buildings, both with and without extra truss systems. The purpose of this study is to provide helpful insights for structural engineers, researchers, and practitioners who are engaged in the seismic-resistant design and retrofitting of structures. This research enables educated decision-making in optimizing the seismic performance of reinforced concrete (RC) frame structures by recognizing their strengths and limits. Ultimately, this enhances the resilience and safety of buildings when exposed to seismic pressures.

***Key Words*:** Seismic Analysis Reinforced Concrete Frame, Belt Truss, Outrigger Truss, Comparative Study, And Dynamic Analysis.

1. INTRODUCTION

A high-rise RC (Reinforced Concrete) Frame is a structural method often used in the construction of tall structures, providing robustness, longevity, and adaptability. The frame is composed of reinforced concrete components that are linked vertically and horizontally. Reinforced concrete is a composite material that combines concrete and steel. Columns serve as vertical supports, whereas beams distribute weights and link the columns. This structure is crucial for resisting the stresses imposed by gravity, wind, and seismic activity.

The building procedure entails encasing steel reinforcing bars with poured concrete, resulting in a sturdy and durable structure. High-rise reinforced concrete (RC) frames are highly preferred due to their capacity to withstand significant vertical loads and provide versatility in design. Architects can design inventive and visually appealing buildings while still guaranteeing their structural soundness. Engineers meticulously construct these frameworks to fulfill precise load and safety criteria, taking into account variables such as the height of the structure, occupancy, and local climatic conditions. Regular inspections and maintenance are essential for guaranteeing the ongoing stability and safety of high-rise reinforced concrete frames during their lifetime. These constructions have a crucial impact on contemporary urban environments, enabling the construction of distinctive and practical skyscrapers throughout the globe.

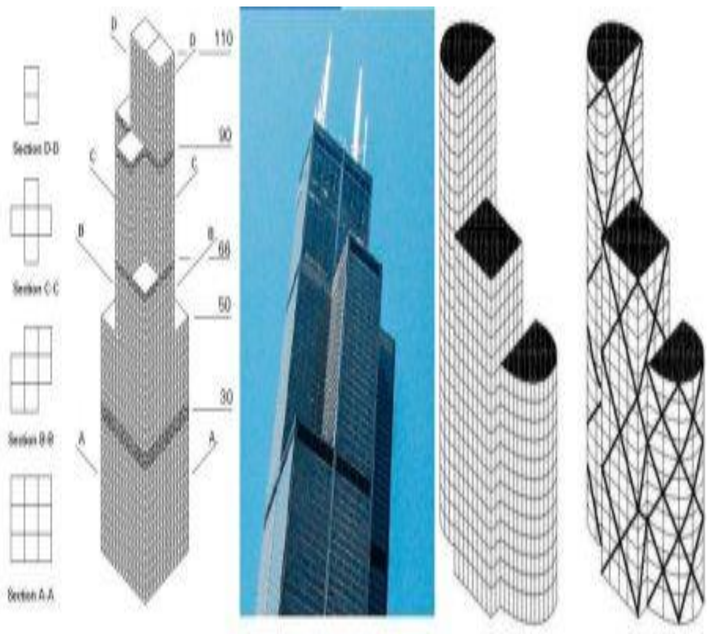

Figure 01: High Rise RC Frame Structure.

2. BELT AND OUTRIGGER TRUSS IN RC FRAME STRUCTURE

In a Reinforced Concrete (RC) Frame Structure, belt and outrigger trusses are key components designed to enhance

the overall stability and lateral resistance of high-rise buildings. These elements play a crucial role in mitigating the effects of lateral forces such as wind and seismic loads.
The belt truss is a horizontal truss typically located at or near the mid-height of a building. It encircles the structure and serves to redistribute lateral loads, preventing excessive sway and promoting uniform distribution of forces to the vertical elements. This results in increased stiffness and overall stability.
Outrigger trusses, on the other hand, are inclined or horizontal structural elements that connect the core of the building to the exterior columns. These trusses extend beyond the building perimeter and act as braces, effectively tying the core and the exterior columns together. Outriggers are strategically positioned at different heights to create a balanced force distribution, enhancing lateral stability and reducing structural deformations. The combination of belt and outrigger trusses in an RC frame structure significantly improves its resistance to lateral forces, making it more resilient in the face of external pressures. Engineers carefully analyze and design these trusses to ensure that the structure meets stringent safety standards, providing occupants with a secure and stable environment, especially in tall buildings where lateral forces are more pronounced.

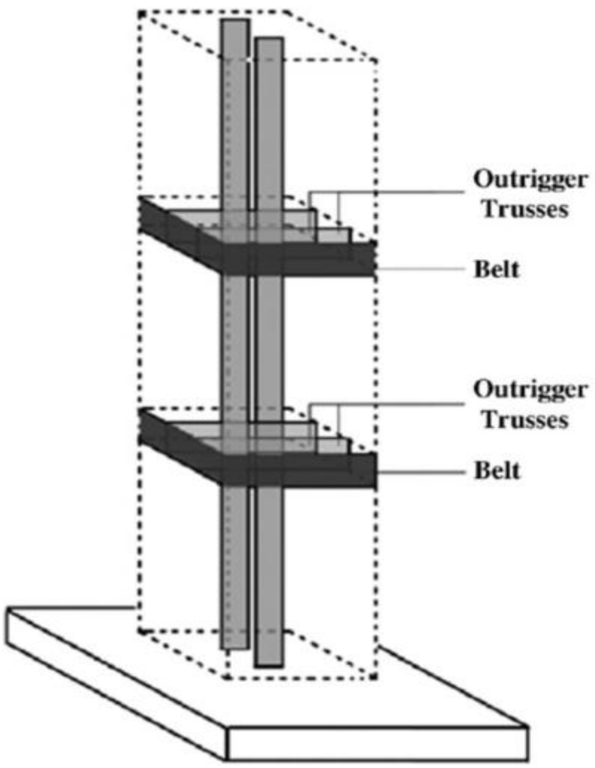

Figure 02: Belt and Outrigger Truss in RC Frame Structure

2.1 Purpose of Belt and Outrigger Truss in the Structure

The belt and outrigger trusses in a structure serve to enhance its overall stability and resilience against lateral forces, such as wind and seismic loads. The belt truss, positioned at or near the mid-height, helps redistribute lateral loads, minimizing sway, and ensuring a more uniform distribution of forces on the structure. Outrigger trusses, connecting the core to exterior columns, act as braces, balancing forces and reducing deformations caused by lateral loads. Together, these elements significantly improve the structure's ability to withstand external forces, ensuring safety and stability.

2.2 Technique for improving the stability of the RC Frame Structure

To enhance the stability of a reinforced concrete (RC) frame structure, several key techniques can be employed. Incorporating shear walls strategically throughout the building, particularly at its periphery and core, is essential. Shear walls effectively resist lateral loads, contributing significantly to stability, especially in seismic regions. Additionally, implementing bracing systems, such as diagonal or X-bracing, enhances lateral stiffness, distributing loads and preventing sway. Ensuring ductility in the design allows controlled deformation during seismic events, while meticulous detailing of reinforcement, including ties and spirals, enhances the structure's ability to withstand lateral forces. Proper foundation design, considering soil conditions and seismic parameters, is crucial, as it prevents differential settlements and contributes to overall stability. Adequate column design, utilizing sufficiently sized columns with proper detailing, is also imperative. Consideration of base isolation systems can further reduce lateral forces transmitted during earthquakes. Diaphragm action, where floor slabs act as horizontal diaphragms, aids in distributing lateral loads. Regular maintenance, high-quality construction materials, and advanced analysis techniques, such as finite element analysis, play integral roles in ensuring the durability and stability of the RC frame structure. This holistic approach, coupled with consultation with structural engineers and adherence to building codes, is paramount for achieving and maintaining structural stability over time.

2.3 Principle of the Belt and Outrigger Truss

The concepts of the Belt Truss and Outrigger Truss entail strategically integrating structural components to improve the stability of structures, especially when subjected to lateral pressures like wind or seismic stresses. The Belt Truss utilizes a configuration of horizontal and diagonal trusses organized in a belt-shaped framework around the outside edge of a building. This structure functions as a resilient support system, efficiently dispersing horizontal stresses and reducing excessive motion. Conversely, the Outrigger Truss system employs horizontal outrigger components that stretch from the core of the structure to the exterior columns. These components are joined by diagonal trusses. This design promotes the equitable dispersion of horizontal stresses, improving the overall structural robustness of tall structures, particularly in areas susceptible to strong winds or seismic events. Both the Belt Truss and Outrigger Truss systems demonstrate inventive technical ideas designed to strengthen structures against the lateral forces they face.

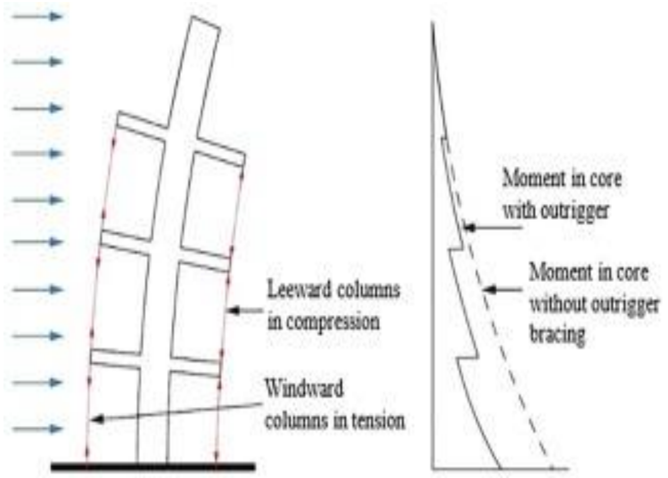

Figure 03: Principle of belt and Outrigger truss.

3. LITERATURE REVIEW

In this section of the literature study, we have examined the previous research work that was concerned with the enhancement of the high-rise structure using a variety of techniques. Below is a summary of all of the prior research papers that have been published:

Bayati et.al: The exploration of outriggers for high-rise structures has considered both belt trusses and basements. Belt trusses, when employed as outriggers, offer advantages similar to traditional outriggers without their associated drawbacks. On the other hand, basements used as outriggers can provide a broader and more stable foundation, enhancing resistance to tipping. An illustrative example showcases the effective use of belt trusses as virtual outriggers, demonstrating the overall effectiveness of the outrigger concept. However, the study notes that the lower stiffness of the indirect force transfer mechanism makes traditional direct outriggers more effective than virtual outriggers with identical column sizes and placements.

Kiran et.al: Based on the findings of this investigation, it is concluded that high-rise structures experience enhanced structural rigidity and improved lateral load efficiency through the incorporation of outriggers and belt trusses. The utilization of these elements reduces the maximum drift at the structure's top, particularly evident when employing the right lateral system. Specifically, the placement of a cap truss outrigger results in a maximum drift of 48.20 mm with a belt truss and 47.63 mm without one, indicating minimal impact on drift reduction by the belt truss. Introducing a second outrigger with a cap truss reduces the structure's weight by 18.55 percent, while the absence of a belt truss results in a weight reduction of 23.01 percent. The optimal location for the second outrigger is determined to be at the center of the structure, with the ideal placement falling between 0.5 and 1.5 times its height.

Daril et.al: To ensure consistency and meaningful comparisons, only results generated by the program's computed period are considered. Buildings utilizing exclusively belt trusses demonstrate superior performance in terms of base shear and lateral stresses compared to those relying solely on outriggers or a combination of outriggers and belt trusses. outperforming structures with only outriggers. Additionally, in terms of drift between floors, a structure employing both outriggers and a belt truss system surpasses buildings equipped with either system in isolation.

Sandesh et.al: To analyze temporal patterns, outriggers were strategically placed on the 15th, 20th, and 30th floors. Introducing outriggers on the 20th floor significantly minimized the building's displacement, decreasing from 81.59 mm to 17.31 mm. Without outriggers, the speed dropped from 68.72 mm/sec to 59.48 mm/sec, while the acceleration increased from 231.86 mm/sec^2 to 622.43 mm/sec^2. The base force, in the absence of outriggers, decreased from 1873.35 kN to 110.52 kN. Notably, the use of outriggers enhanced the building's story stiffness by a factor of 2.27 when compared to a configuration without outriggers. Compared to a building lacking outriggers, a structure equipped with them demonstrated a 34.1 percent reduction in maximum storey displacement and a 19.7 percent reduction in maximum storey shear. Additionally, the overturning moment in a structure with outriggers was found to be reduced by 17.18% when compared to a building without outriggers.

Bishal et.al: When utilized together, outriggers and dampers contribute to enhanced rigidity and increased efficiency of the auxiliary frame in tall buildings subjected to lateral loads. The maximum drift at the top level significantly influences tenant comfort and plays a crucial role in realizing the structural vision. An analysis of five model buildings revealed that the combination of outrigger belt trusses and dampers can improve a building's seismic performance by reducing lateral displacement during seismic ground motion. Notably, structures equipped with dampers surpass those with outrigger belt truss frames in terms of seismic performance. Additionally, buildings employing dampers for energy dissipation exhibit more consistent inter-story drift compared to those relying on outrigger belt truss frames.

Premalatha et.al: Through a comprehensive analysis involving time history and response spectrum analyses, the optimal placement of an outrigger belt truss system in a 30-story reinforced concrete irregular structure was determined. Performance metrics, including storey displacements, drifts, and accelerations, were evaluated for all frame models. The RC frame incorporating two belt trusses, positioned at 0.6h and 0.4h, outperformed other models. This configuration exhibited a notable 28.93%

reduction in maximum displacement caused by wind forces, along with decreases of 13.23% and 15.5% in response spectrum analysis and static earthquake forces, respectively, compared to the bare frame. The heightened rigidity of the building structure was evident in the reduced story drifts observed in this frame with trusses at two levels.

İbrahim et.al: The research revealed that the addition of outrigger and belt-truss systems to a shear-wall framed structure resulted in a reduction in translational and torsional periods, leading to improved lateral and torsional rigidity. Outrigger systems proved more influential in enhancing lateral stiffness, while belt-truss systems were more significant for torsional stiffness. Incorporating outriggers into a shear wall-framed system effectively minimized horizontal displacements under lateral static stresses. However, in dynamic analysis, the lateral displacements were not reduced as much as predicted by static analysis findings. This discrepancy is hypothesized to be influenced by dynamic reactions, considering the structure's stiffness, mass, damping, and ground motion features. The outriggers and belt trusses were observed to reduce lateral drifts in the attached stories by enhancing their lateral rigidity through strategic placement.

4. CONCLUSION

To summarise, the comparative analysis of seismic analysis discussed in this review article provides valuable insights into the substantial influence of integrating belt truss and outrigger truss systems in reinforced concrete frame buildings. The thorough examination of the structural performance under seismic stresses has shown that these inventive structural components have a vital impact on improving the overall seismic resistance and stability of reinforced concrete frame constructions. The results emphasize that incorporating belt truss and outrigger truss systems results in significant enhancements in lateral stiffness, decreased inter-story drifts, and improved energy dissipation capacity. The beneficial results are credited to the efficient dispersion of horizontal forces, leading to a more equitable distribution of the load inside the structure. Furthermore, the analysis highlights the significance of meticulous evaluation of many design factors, including truss geometry, material qualities, and connection details, to enhance the seismic performance of reinforced concrete frame structures. Both belt truss and outrigger truss systems possess notable earthquake mitigation qualities. However, the selection between them should be based on project objectives, site circumstances, and design limitations. Further research in this domain might explore parametric analyses, taking into account various building arrangements and degrees of seismic risk, to get a more nuanced comprehension of the performance of reinforced concrete frame buildings equipped with these truss systems.

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