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Review Paper on Research Done in Effects of Outrigger Systems in High Rise Buildings in Siesmic Zones

Abu Talha Anwar Pasha Deshmukh[1], Dr. Durgesh H. Tupe[2]
[1, 2]Deogiri Institute of Engineering and Management, India

I. INTRODUCTION

A. General

Outrigger is a term and method in the design of tall structures that refers to one of the best ways to meet the design requirements of such structures. It is a structural system that connects the inner core wall to the outer edge columns by horizontal cantilever arms that are very rigid and bend- resistant. Typically, these arms are deep beams that are one level tall in depth. The edge columns are connected by a belt truss, which can be a steel beam or a reinforced wall. These arms use a belt truss to connect the edge column to the core wall.

The outrigger system is used to make the high-rise structure more resistant to sideways forces, such as earthquakes and wind. Thin high-rise buildings are often the application for this technique. One side use and one side not use, as shown in figure 1.1. The core wall is braced by the outrigger arms, which reduce the impact of sideways forces and make the core wall stiffer.

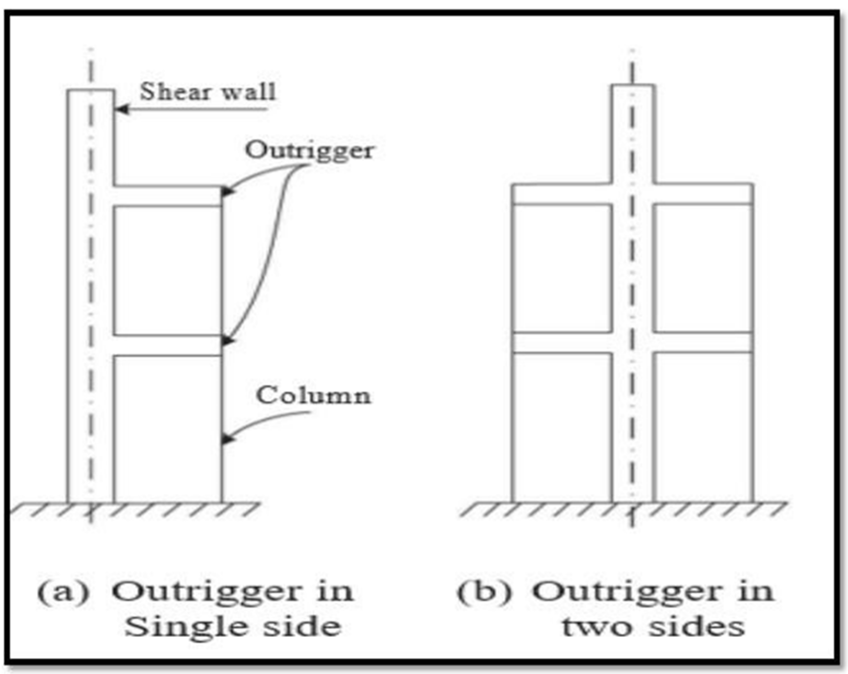

Figure 1.1 : a) Outrigger in Single Side, b) Outrigger in Two Sides

Outrigger arms are used to brace the core wall and make it more resistant and rigid to the sideways forces. Belt truss connects the edge column to the core wall and helps to decrease the sideways movement by changing the tension and compression. This means that when the structure faces sideways forces, it will bend and create tension on one side and compression on the other side, as shown in Figure 2. The structure with outrigger has less bending than the structure without outrigger. Outrigger also reduces the pressure on the structure from sideways forces like wind and cyclone. This is shown in Figure 1.2.

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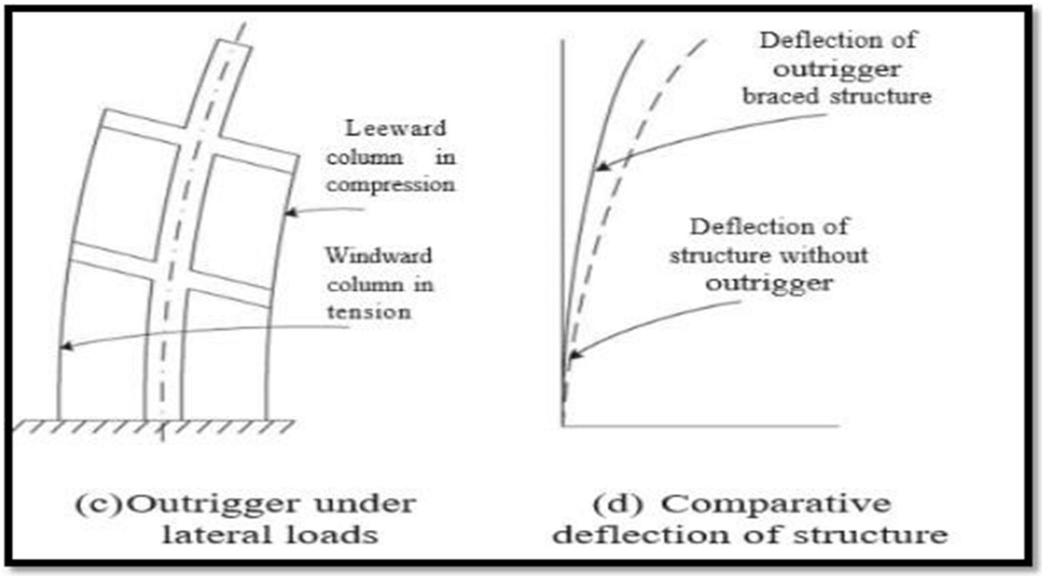


Figure 1.2 : Outrigger under Loads

II. OUTRIGGER EXISTENCE

Elevators are often housed in a core located in the center of towering buildings. Nevertheless, this core must withstand horizontal loads placed on the structure; otherwise, it becomes ineffective at a given height. As the building gets taller, the resistance of the core system to the overturning component of the drift diminishes approximately with the cube of the height, suggesting that the core system becomes less efficient. Furthermore, the foundation cost can rise due to excessive uplift caused just by the core structure. For example, the foundation must be a mat or rock anchors rather than more straightforward foundation options because of uplift. Architects are also concerned about the free rentable area that should exist between the external columns and the core. The structural engineers developed the outrigger solution, which includes the external columns in the lateral structural system, for these two reasons.

III. BEHAVIOR OF OUTRIGGER

An outrigger system comprises a central core, typically constructed of concrete or bracing, connected to the outer columns via rigid horizontal elements known as outriggers.. These outriggers are meant to make the structure more rigid in both bending and cutting aspects. They usually have a depth of one or two floors, along with the belt truss shown in figure1.3. Besides the columns at the ends of the outriggers, it is also normal to use other columns around the edge to support and balance the outriggers. This joint effort makes sure the outrigger system works well. Figure 1.3 shows how the outrigger behaves.

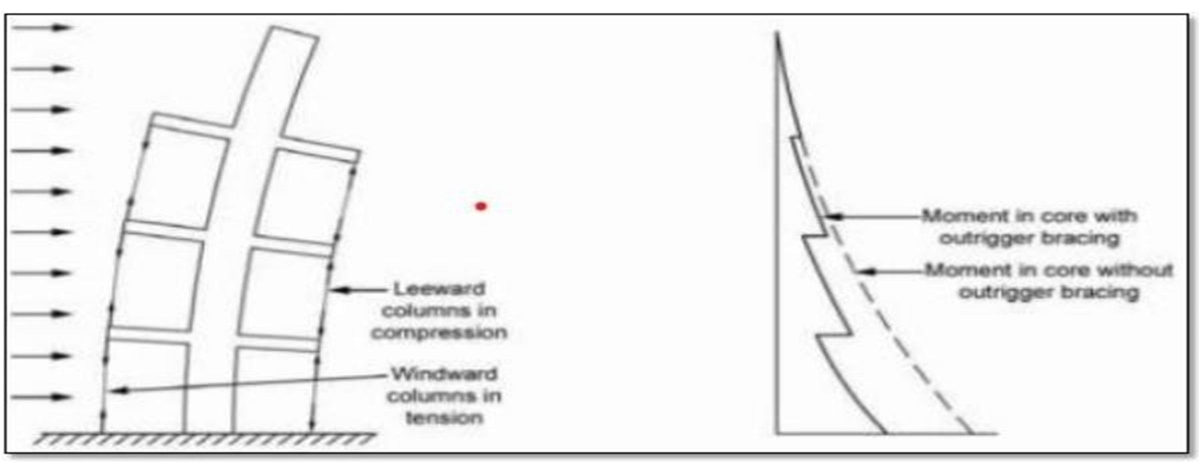


Figure 1.3 : Outrigger Behavior

An outrigger system is a structural design that has a central core of concrete or braces that is joined to the columns at the outer edge by rigid horizontal members of braces or concrete called outriggers. These outriggers are made to give enough rigidity in both bending and cutting aspects. They usually have a height of one or two floors, along with the belt truss addition to the columns situated at the ends of the outriggers, it is common practice to utilize additional columns positioned around the perimeter to support and stabilize the outriggers. This joint effort makes sure the outrigger system works well. The fundamental structural behavior of the system is relatively straightforward. The outriggers work as rigid arms, connecting with the outer columns. This connection helps to spread forces and moments, improving the overall steadiness and performance of the structure. When the center attempts to rotate, causing a moment at the outrigger level, it induces tension and compression forces in the outer columns, countering this rotational motion.

IV. STUDIES AS PER STATIC AND DYNAMIC ANALYSIS

Structural engineers only do analysis and design of structures. Various fundamental structural systems are employed for tall buildings, considering the cost and architecture of contemporary infrastructures. These include the pendulum tuned mass damper system (PTMD), outrigger braced frame (OBF) system, building frame system (BF), and moment resisting frame system (MRF). Every system is used on a structure and offers an economical and efficient design for the tall structure. Both static and dynamic structural analysis are used in four systems. In the static analysis, the MRF, BF, and OBF were represented by a sway frame. Both straightforward gravity loads and complicated loading scenarios, such as wind and earthquakes, were tested for the structural systems. An examination of the OBF system's dynamic behavior was conducted in comparison with popular vibration control systems, such as the pendulum tuned mass damper system (PTMD). The OBF and PTMD's displacement response under the higher modes as well as their velocity and acceleration response were examined. The outrigger system frame (OBF) is prioritized for seismic resistance.

V. TYPES OF OUTRIGGER STRUCTURAL SYSTEM

Two types of outrigger systems exist outrigger systems.

1) Convention outrigger system
2) Virtual outrigger system

A. *Convention Outrigger System*

The conventional outrigger system has the outriggers attached to the core structure, and the column at the edge of the structure. Usually, but not always, the columns are at the corners of the building. The outriggers can be one, two, three or more along the building's heights. The core can rotate at the outrigger due to the changes in the length of the columns and the shape of the trusses.

B. *Virtual Outrigger System*

The virtual outrigger system does not have a direct link between the core structure and the columns that resist the overturning moment. This way, the trusses and the core do not have the issues that outriggers usually cause. The main idea of virtual outrigger system is to use floor diaphragms, which are normally very rigid and powerful in their own plane, to move moment as a horizontal pair from the core to trusses or walls that are not directly attached to the core. The trusses then change the horizontal pairs into vertical pairs in columns or other structural parts outside of the core as shown in figure 1.4 and 1.5.

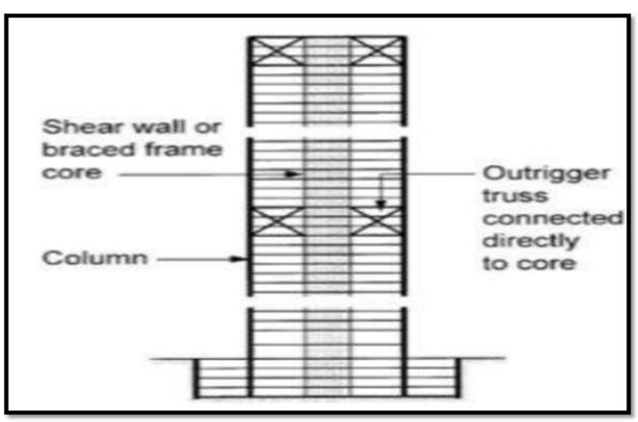


Figure 1.4 : Outrigger connected to core

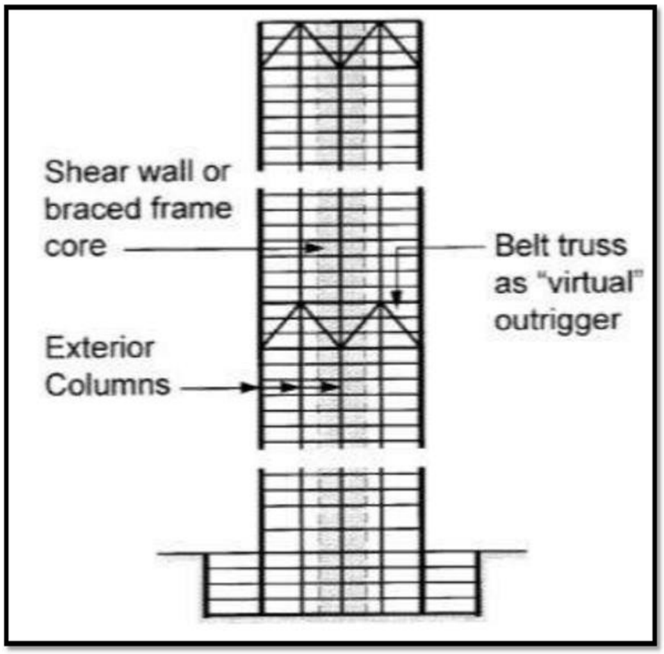


Figure 1.5: Belt truss

VI. ADVANTAGES AND DISADVANTAGES OF OUTRIGGER

Outriggers are structural elements that connect the core of a building to the exterior columns, providing lateral stability and reducing overturning moments. Outriggers have both advantages and disadvantages, as discussed below.

A. Advantages Of Outriggers

1) Outriggers offer the following benefits:
2) They increase the effective width of the structure, which reduces the overturning moment of the core.
3) By utilizing the external columns as the lateral resisting system, they lessen the structure's lateral movement.
4) They reduce the cost of the structure, by allowing simple beam and column framing without rigid connections, instead of a structure made with rigid connections.
5) They reduce the uplift and the cost of the foundation, by transferring some of the vertical loads to the exterior columns.
6) They include the intermediate gravity columns in the system that resists lateral loads.
7) Which leads to a more economic structure, especially for rectangular plan buildings.

B. Disadvantages Of Outriggers

Outriggers have the following drawbacks:

1) They may be two stories deep, which means they take up a lot of lettable area. Placing the outrigger in the mechanical level will solve this issue.
2) They have a negative impact on the erection of the structure, as they disrupt the repetitive nature of the optimal erection process. By giving the building workers precise erection guidelines, this might be lessened.

VII. NECESSITY OF PRESENT WORK

Outriggers are indispensable components in many industries, serving primarily to enhance stability and safety. Whether on construction sites or maritime vessels, outriggers extend the base of structures or equipment laterally, effectively distributing weight and reducing the risk of tipping or imbalance. By providing a broader footprint, they enable heavy machinery like cranes to operate safely on uneven terrain or in confined spaces where a stable foundation is essential. This not only improves operational efficiency but also ensures compliance with stringent safety standards, making outriggers integral to modern construction and industrial practices.

VIII. RESEARCH PERFORMED BY VARIOUS INVESTIGATORS

Mohammed Sanaullah Shareef et. al (2022) the studies today's era of rapid urbanization and modernization, the demand for tall buildings with multistory is steadily increasing. As buildings become taller and narrower, the field of structural engineering faces growing challenges in ensuring their stability. Among the various structural systems employed in tall buildings, the outrigger system stands out as an efficient solution.

This study seeks to evaluate the effectiveness of outrigger shear walls and determine the optimal placement of outriggers in multistory structures subjected to lateral loads. The outrigger system is crucial for providing additional stiffness and damping, serving as a structural safeguard against severe earthquake and wind conditions.

The research focuses on dynamic analysis, examining two regular buildings, one with 36 storeys and the other with 50 storeys. These buildings, situated in seismic zone V, maintain a consistent area of 900 square meters (30 meters by 30 meters) and a typical storey height of 3 meters. The analysis is conducted using ETABS 2018 software.

By studying the dynamic behavior of high-rise structures equipped with outrigger systems, this research aims to enhance our understanding of their performance under various loading conditions. This knowledge can ultimately inform the design and construction of safer and more resilient tall buildings. [1]

Gurkirat Singh et. al (2022) By investigated, there's a growing demand for tall structures that not only stand out with unique designs but also prioritize stability and safety. However, the pursuit of architectural innovation often introduces irregularities in structural design, increasing vulnerability to instability.

To address this challenge, modern engineering employs advanced techniques such as shear walls, belt walls, and dual systems. These methods provide effective solutions to enhance the stability of buildings with unconventional shapes and designs.

This study focuses on analyzing the structural performance of G+9 composite frame structures of various shapes. Utilizing ETABS software, we conduct both static and dynamic analyses, considering seismic loads through the Response Spectrum method. Additionally, parameters such as story drift, story displacement, and base shear are examined to assess the effectiveness of outriggers and belt trusses in improving structural stability.

By investigating these aspects, we aim to gain valuable insights into optimizing the design of tall structures to ensure both aesthetic appeal and structural integrity in the face of seismic events. [2]

Kiran Kamath et. al (2022) studied of the experiment was to check how well outriggers can lower the lateral loads on tall buildings. An outrigger outrigger system that had a normal and a virtual outrigger at different levels was suggested. By varying the stiffness of the outrigger arm, the building's height, the outrigger beam and belt wall, and the core, the outrigger system's static and dynamic behavior was examined. The ideal outrigger locations were established after the outrigger system was exposed to wind and seismic loads. The static wind and earthquake response were computed using Indian Standard codes, whereas the dynamic behavior was evaluated using nonlinear time history analysis. For the parametric investigation, analytical models of 40, 60, and 80 stores with building heights of 140 m, 210 m, and 280 m, respectively, were utilized.

The optimal locations for the outrigger system were determined using the reaction from the absolute maximum interstory drift ratio, roof displacement/(displacement roof), roof acceleration (acc roof), and base bending moment. The optimal location for the outrigger system was determined using a performance index criterion, which took into account the combined effects of the acc roof, disp roof, and ISD max under each load. Compared to the thickness of the outrigger and the core, the outrigger arm's length had the greatest effect on the outrigger system's performance, suggesting that extending the arm's length can increase the outrigger's rigidity. [3]

Arsalan Alavi et. al (2021) provided an authors suggested a stiffness-based method for the initial design of skyscrapers with outrigger braces. The method was based on the idea of a uniform deformation distribution. This idea came from the minimum-compliance optimization, in which the structure’s layout was made as stiff as possible with a given amount of material. Design variables were the core structure’s flexural stiffness, the outrigger-belt height, and peripheral column sizes. These variables were determined by keeping the curvature constant and low, while still meeting the stress and displacement limits.

The authors showed the resulting procedure with a simplified hand-calculation algorithmic framework, which could help estimate the element sizes and evaluate the structural behavior at the preliminary design stage. To show how the proposed method worked in practice, they used the algorithm to design a structure with one outrigger. The comparison of the results showed that the proposed method was quite accurate.

The numerical example demonstrated that the curvature does not change in the design domain, indicating that the normal stress is nearly constant along the height of the structure, so validating the suggested method.

The numerical example indicated that the roof displacement of the structure is close to the acceptable design value with a small error of 13.5%; meanwhile, the strength requirement is easily met, with the normal stresses much lower than the allowable value. This situation shows how displacement criteria control the design of tall buildings.

Looking at the design diagram shows that the method accurately estimates the location of the inflection point, where the core elements need the smallest dimension. Because of a reversed moment at the outrigger position, the size of elements just below the outrigger drops suddenly. [4]

Alaa Habrah et. al (2021) studied an analytical procedure was undertaken to derive a general equation describing the top lateral displacement of a core-outrigger system, incorporating up to four outriggers. The investigation considered various forms of static lateral loading distribution, including uniform, triangular, and parabolic distributions. Furthermore, optimal outrigger positions were identified to achieve maximum reduction in top displacement.

Additionally, the research proposed criteria for determining the maximum height of tall buildings based on displacement limits, considering the number of outriggers and their positions. To facilitate practical application, the study provided curves for preliminary design stages, offering guidance on allocating top displacement and determining the required number of outriggers based on building height and a suggested rigidity factor. This factor demonstrated significant influence on core-outrigger systems in tall buildings. [5]

Lilin Wang et. al (2021) studied suggested a a straightforward engineering technique for quickly determining the quantity and placement of outriggers in extremely tall structures. The sensitivity vector algorithm, or SVA, was first presented. which adhered to restrictions about the maximum interstory drift while using the vector dot-product approach to determine the optimal outriggers in extremely tall buildings. The SVA was subsequently verified using the exhaustive search algorithm (ESA) and tested on a very tall building with wind load management. The optimal outriggers for an extremely tall building in a high-seismic region were then determined using the SVA. The findings demonstrated that position and number, not just number, were important factors in determining the optimal outrigger arrangement.

Adding more outriggers could lower interstory drift near the added outrigger but could raise interstory drift in other areas. The sensitivity vector algorithm was a useful tool for outrigger finding, not only for wind load in single-mode cases but also for seismic loads affected by multiple modes. This flexibility is very helpful for the early design stages of super-tall buildings. The proposed SVA was applied to a 138-story 623-meter super-tall building under the constraint of maximum interstory drift. The target 138-story 623-meter composite structure had a central core wall, mega columns, corner posts, outrigger trusses, and belt trusses, and was a typical mega frame core wall structural system with eight possible outriggers. Since the structure was sensitive to wind, the goal was to keep the maximum interstory drift under the wind load. In the structural design of this project, the stiffness design used a 50-year return period wind load, which was about 47.0 m/s in wind speed and 4% in damping ratio. The wind load for stiffness design was close to the level of a 20-year return period wind load, with a gradient wind speed of 43 m/s and a damping ratio of 1.5%. The parameters for the target building were a shape factor of 1.0, a Strouhal number of 0.15, a damping ratio of 4%, a basic wind pressure of 0.6 kN/m2, and a terrain roughness of type D. The study mainly looked at the effect of outrigger installation on structural stiffness, without considering wind-structure interaction for simplicity. More details about this 138-story building could be seen in Ref. [4]. It's important to note that, for the concrete structure part of the super-tall building over 250 meters in height, the maximum interstory drift had to be less than 1/500. [6]

Rajesh S Londhe et. al (2021) represented an outrigger was a stiff beam that connected external columns to the shear wall. When the structure was subjected to wind stress, the outrigger and column stopped the core from spinning, which greatly decreased the base moment and lateral deflection. The study looked at a 60-story reinforced concrete structure that was subjected to lateral load both with and without an outrigger system. Models with no outriggers, one outrigger, two outriggers, and three outriggers underwent a three-dimensional study. By adjusting the outrigger position within the framework, the optimal placement for a single, double, and triple outrigger was identified. The 20th floor from the top of the structure was the ideal site for an outrigger system, which reduced deflection by 10.2%.

In comparison to the structural model without outriggers, deflection decreased by 16% for a triple outrigger system and 11.5% for a double outrigger system at the optimal level. Additionally, it found that when a triple outrigger system was used, the maximum storey drift fell by 11%. [7]

Kashif Salman et. al (2020) studied had included both static and dynamic analyses of a high- rise structure under lateral loads. In the first phase, static analysis had been done on four different structural systems, such as the moment-resisting frame, building frame, and the outrigger braced frame (OBF) system. The investigation had shown that the outrigger braced system had given the best control for high-rise structures under the same static loading conditions.

These findings had come from an analytical procedure that had emphasized the efficiency of the bracing system. In the next phase, dynamic analysis had been carried out to evaluate the vibration response of the tall building. In this situation, the outrigger system had been contrasted with Pendulum Tuned Mass Dampers (PTMD). A parametric analysis had been performed, looking at the benefits of the outrigger system in terms of lowering top displacement and drift response in the structure. The results had pointed out a significant improvement, with a decrease of 33% in the case of one outrigger and 60% with two outriggers in the top displacement and drift response of the structure. This change in response had been confirmed through analytical solutions applied to both the top and middle parts of the structure. The outriggers had shown an acceleration reduction ability of 40%, while PTMD had reached a reduction of 35%.

Both static and dynamic analyses had shown that the outrigger braced frame (OBF) had been a good supplement to the sway frame, enhancing the structural performance of high-rise buildings significantly.Using dynamic and static methods, the design showed that the response was cut by 35% with one outrigger and by 60% with two outriggers, according to the analytical solution. The numerical solution revealed that the response dropped by 37% with one outrigger and by 58% with two outriggers. Both solutions agreed with previous studies. [8]

Ying Zhou et. al (2019) involved the development of analytical techniques to assess the seismic response of a traditional outrigger system, a contemporary means of lowering the dynamic response of tall structures. Additionally, the best place for the outriggers was identified. Initially, a basic theoretical model was created using dynamic time-history loads. Subsequently, a mode-superposition response spectrum approach was employed to enhance it. Model calibration was accomplished by contrasting it with an ANSYS model.Parametric evaluations were conducted using the simplified model to determine the best outrigger location for various scenarios. The best outrigger location was then determined by combining all of the data from the parametric analyses into a fitting equation. Ultimately, a comparison of the spectrum analysis and time-history analysis results demonstrated that the simplified model based on spectrum analysis accurately captured the seismic behavior of outrigger-equipped structures. The fitting equation also gave a good approximation of where such structures should place their outriggers in order to minimize seismic forces. By contrasting it with a FEM, the study's simplified model of high-rise structures with an outrigger under spectrum analysis is confirmed. By employing a new fitting equation that is derived from multiple parametric analyses, the ideal outrigger site is found.

The main conclusions are:

The simplified model based on theoretical spectrum analysis is suitable for the seismic study of an outrigger system and represents the system's dynamic response, including the outrigger's ideal location, natural period, and modes.

The outrigger's ideal location gradually decreases as its stiffness rises, and it gradually increases when the core or column's stiffness rises. Nonetheless, the core stiffness has a greater influence on the response than the column stiffness. Additionally, when r grows, the ideal outrigger site increases unless there is a very tiny distance between the column and the core. Furthermore, the ideal position decreases as the total height rises from the perspective of total height. [9]

Li Xian1, Wang Wei et. al (2016) studied employing numerous steel angles to investigate the seismic behavior of a particular kind of concrete wall shear connection strengthened by outrigger trusses is given. Six large-scale shear connection models were built and tested under the combined effects of eccentric shear and cyclic axial stress. Each model comprised a section of a reinforced concrete wall and a shear tab welded onto a steel endplate with three steel angles. Investigations were conducted into the impacts of endplate thicknesses, wall boundary elements, anchor plate types, and embedment lengths of steel angles.

According to the test results, correctly specified connections fail because of the ductile fracture of steel angles and show desirable seismic behavior. Wall boundary elements provide the concrete surrounding steel angles with useful confinement, which enhances the strength and stiffness of connections. Whereas connections with thin endplates have a relatively low strength and fail because of large inelastic deformations of the endplates, full anchor plate connections are more likely to experience concrete pry-out failure.

The existing design equations greatly underestimate the capacity of the connecting models, as indicated by Chinese Standard 04G362 and Code GB50011.A new design approach was created to take the influence of the test factors that were previously discussed into consideration. [10]

J. M. Mirhom et. al (2012) explained how an outrigger and belt system, which primarily withstood lateral wind and seismic loads, affected the progressive collapse study of a 52-story high-rise building. The reinforced concrete core located in the center of the structure served asits primary means of resisting lateral loads. Two outrigger and belt systems were built to the top and middle of the building in addition to the RC core walls. Four steel trusses connected the façade columns to the reinforced concrete core located in the middle of each system. Every façade column was joined to each outrigger system's outrigger trusses by a belt truss.

Every façade column was joined to each outrigger system's outrigger trusses by a belt truss. The purpose of the article was to investigate other load routes that could have limited local structure failure and damage while preventing the building's complete collapse. A nonlinear dynamic progressive collapse study was carried out by abruptly removing a few ground level columns. This replicated an unintentional explosion close to a building's exterior.

ELS software (Extreme Loading for Structures) with applied element technique was utilized for the nonlinear dynamic analysis. The study examined and documented several aspects that influenced the way the building behaved under scenarios of increasing collapse. Based on stiffness, a preliminary design approach for outrigger braced skyscrapers was proposed. The homogeneous distribution of deformation served as the foundation for the technique. This concept originated with the minimum-compliance optimization, which determined the stiffest architecture of the structure for a given quantity of material. The design factors included the size of the outer columns, the outrigger-belt elevation, and the flexural stiffness of the core structure.

As long as the permitted stress and displacement constraints were satisfied, these parameters were established by maintaining a minimal and constant curvature. A basic hand-calculation algorithmic framework was utilized to demonstrate the concept. This framework might be used to estimate element sizes and provide a preliminary assessment of structural behavior during the preliminary design phase. The suggested algorithm was used to construct a structure with one outrigger in order to illustrate the usefulness of the provided approach. In practice, the suggested procedure proved to be highly accurate, as demonstrated by the comparison of the findings. The location of the outrigger belt that worked best was 114.8 meters from the summit. The displacement requirement was the primary design factor, and this led to the computation of the external column area.

The interplay between the outrigger-belt and external columns caused a notable change in the cross-sectional area of the core column at the 27th storey. At the 22nd storey, where the core bending moment was almost nil, an inflection point was discovered. The study also emphasized how crucial it is to take vertical loads—such as gravity—into account when calculating the size of members, particularly in seismic design, where gravity loads may have a significant impact on the effectiveness of the uniform-deformation-design technique. [11]

P.M.B. Raj Kiran et. al (2013) carried out the study of outrigger and belt truss system in tall buildings under lateral forces from wind or earthquake. This technique is a popular method for limiting the structure's excessive drift and increasing lateral stiffness, which can lower the chance of damage to the structure and its constituent parts. This technique is particularly appropriate for tall buildings located in seismically active areas or with a predominant wind load. When three outriggers are employed in the construction, the thesis attempts to analyze the behavior of the outriggers, optimize their placement, and assess the effectiveness of each outrigger individually. Nine thirty-story three-dimensional models of belt truss and outrigger systems are subjected to earthquake and wind loads, and the decrease of their lateral displacement is compared.

In the case of the 30-story model, positioning the first outrigger at the top and the second outrigger in the middle of the structure height results in a maximum displacement reduction of 23%. Important findings from the analysis of the second outrigger system's impact are displayed in tables and graphs. It is discovered that the outrigger is best placed 0.5 times its height. [12]

NAVAB ASSADI ZEIDABADI et. al (2002) concluded uses the continuum approach to analyze the behavior of a structure with coupled shear walls, an outrigger, and a heavy beam at various heights. We performed a thorough parametric study to reveal the key factors that affect the structure's performance. One of the main findings of our study is the significant influence of the outrigger's location on the structural behavior. In most common cases, our results indicate that the best position for reducing top drift is between 0.4 and 0.6 of the structure's height. While we acknowledge that this method is not a substitute for the finite element analysis, it provides a simple and initial tool for deciding the size and location of outriggers, stiffening beams, and coupled shear walls during the early design phase. The study presented here evaluates the structural performance of coupled shear walls, strengthened with an internal beam and an outrigger at different heights in the structure. This study examines the beneficial effect of the outrigger on the structural response and lateral drift of the coupled shear walls. The outcomes from the parametric study demonstrate the considerable decrease in lateral drift achieved by adding an outrigger to the structural system. Moreover, our findings emphasize the crucial role of the outrigger's location in affecting the overall behavior and lateral drift of the structure. It is important to note that the internal beam in the structure has a minor impact on the shear stress when the outrigger is used. The study shows that the column and outrigger stiffness play major roles in determining the optimal outrigger location, while the internal beam stiffness has a negligible effect. Finally, our study recommends that the optimal outrigger location usually lies between 0.4 and 0.6 of the structure's height from the base. **[13]**

IX. REFINED LITERATURE SURVEY SUMMARY

Numerous researchers have investigated the application of outrigger systems in tall structures to enhance their stability under lateral loads. A summary of key studies is presented below:

1) Mohammed Sanaullah Shareef et al. (2022) examined the dynamic behavior of 36- and 50-storey buildings using ETABS, emphasizing the role of outrigger shear walls in seismic zones. The study identified optimal outrigger placements that enhance damping and stiffness.
2) Gurkirat Singh et al. (2022) analyzed G+9 composite frames with different architectural forms. Using ETABS and Response Spectrum analysis, they concluded that outriggers and belt trusses significantly improved story drift and base shear resistance.
3) Kiran Kamath et al. (2022) evaluated hybrid outrigger systems with normal and virtual outriggers under wind and seismic loads. A performance index was developed using roof acceleration, displacement, and ISD_{max} to determine the best outrigger configurations.
4) Arsalan Alavi et al. (2021) proposed a stiffness-based preliminary design framework for skyscrapers with outriggers. Their simplified algorithmic method efficiently estimated element sizes and inflection points in the structural core.
5) Alaa Habrah et al. (2021) developed analytical equations for top lateral displacement in core-outrigger systems with up to four outriggers under varying static load distributions. The study also proposed height-based design guidelines.
6) Lilin Wang et al. (2021) introduced the Sensitivity Vector Algorithm (SVA) for optimizing outrigger placement in a 138-storey building. Their study highlighted that outrigger position impacts inter-storey drift more than quantity alone.
7) Rajesh S Londhe et al. (2021) used 3D models of a 60-storey RC structure to evaluate single, double, and triple outrigger configurations. A triple outrigger system reduced lateral deflection by 16% and drift by 11%.
8) Kashif Salman et al. (2020) conducted static and dynamic analysis on various structural systems, concluding that the outrigger-braced frame system outperformed others, achieving a 60% reduction in drift with dual outriggers.
9) Ying Zhou et al. (2019) developed and validated a simplified seismic analysis model for outrigger systems using ANSYS. A fitting equation for optimal placement was derived from multiple parametric studies.
10) Li Xian and Wang Wei et al. (2016) studied reinforced shear wall connections with outrigger trusses. Experimental results emphasized the importance of boundary elements and recommended updated design equations for better strength prediction.
11) J.M. Mirhom et al. (2012) assessed progressive collapse resistance in a 52-storey structure with outrigger-belt systems. Using ELS software, the study emphasized the importance of alternate load paths and displacement-based design criteria.
12) P.M.B. Raj Kiran et al. (2013) analyzed 30-storey buildings with different outrigger placements. The maximum reduction in displacement was achieved with an outrigger at the top and middle of the building.
13) Navab Assadi Zeidabadi et al. (2002) used the continuum approach to evaluate shear wall-outrigger systems. Findings showed that the optimal outrigger location typically lies between 0.4 and 0.6 times the total height of the structure.

X. SUMMARY ON LITERATURES

Based on the reviewed literature, it is evident that no prior research has focused on provided outrigger system in buildings. Therefore, the current study aims to conduct seismic analysis on a G+17 building by provided outrigger system, employing response spectrum analyses. The rationale behind this approach is to mitigate seismic effects by utilizing materials with higher stiffness. Used by outrigger system, potentially reducing seismic impacts on structures during earthquakes. Previous studies suggest that employing materials like utilizing outrigger systems and belt can effectively enhance overturning resistance and optimize working space in designs. Additionally, integrating outrigger system in structural frames o within core walls or columns has shown promise in minimizing lateral displacement and storey drift while maximizing usable space. Reduced the displacement of building.

XI. CONCLUSION

1) Outriggers, particularly in double-sided configurations with shear walls, substantially enhance seismic performance in tall RCC buildings.
2) Performance gains are evident across stiffness, displacement, drift, and shear metrics, with maximum reductions in displacement exceeding 34% in the studied case.
3) Integration with shear walls further amplifies benefits, leveraging both systems' stiffness contributions.
4) Response Spectrum Method analysis confirms that outrigger systems can meet Indian seismic code requirements with improved efficiency compared to conventional framing.

5) Future research should explore optimal outrigger height placement under Indian seismic spectra, compare conventional vs. virtual outriggers experimentally, and assess cost-benefit trade-offs for varying building geometries.

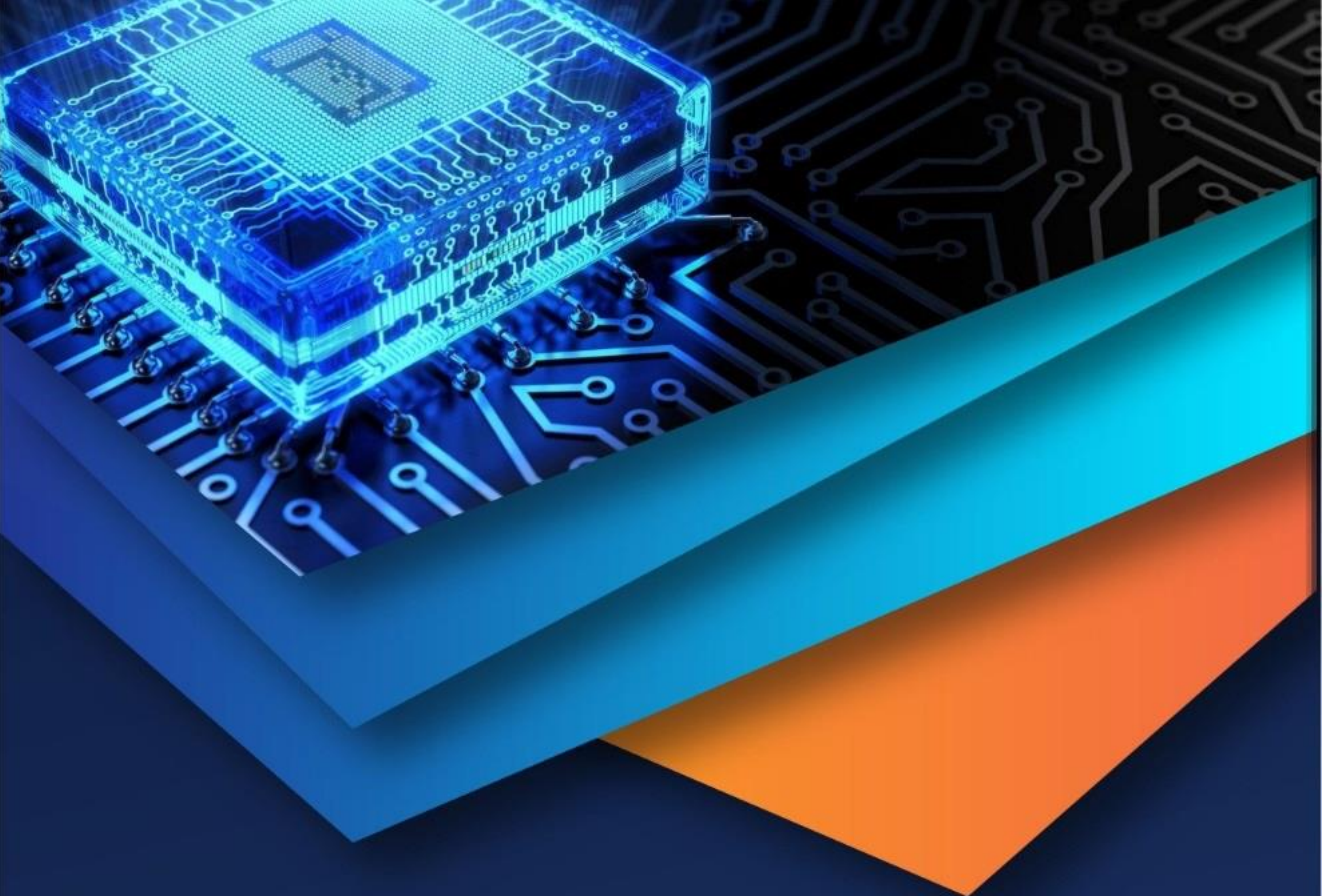
In conclusion, this research validates the outrigger system as a highly effective, code-compliant strategy for improving the seismic resilience of high-rise RCC structures in India. By quantifying its benefits through rigorous dynamic analysis, it provides designers with actionable insights into configuration selection, integration with shear walls, and performance optimization—offering a practical pathway for safer, stiffer, and more economical tall buildings in seismic zones.

XII. GAP IDENTIFICATION AND RESEARCH SCOPE

Despite the extensive research, limited studies focus specifically on the seismic analysis of G+17 buildings using hybrid outrigger systems under Indian standards. The current study addresses this gap by:

- Analyzing a 17-storey RC frame with conventional and virtual outriggers.
- Conducting response spectrum analysis for seismic evaluation.
- Investigating how outrigger stiffness, placement, and material properties influence seismic performance.

The goal is to reduce inter-storey drift and roof displacement, thereby enhancing building stability and resilience during seismic events.



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