Effective Lateral Design of Modern High Rise Structure Using Outriggers with Belt Truss System

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Abstract—* High-rise buildings provide distinct challenges in terms of their construction and design. Managing lateral loads, especially lateral displacement, constitutes a considerable challenge in the design of high-rise buildings. Over the past century, researchers have devised numerous structural methods to control the sideways movement of a building. The outrigger structural system is a choice that involves placing deep beams, commonly referred to as outrigger beams, at various intervals across the building's height. These beams have a depth that matches the height of each level. The core, often positioned in the middle, securely bonds to the beams. Outrigger beams and a firmly attached core reinforce the structure's structural integrity. Belt trusses connect the entire perimeter of the system at the outrigger installation levels, increasing rigidity and creating a unified structure. Outrigger beams and a firmly attached core reinforce the structure's structural integrity. Without the need to expand any component, the structure reduces its lateral swings. Selecting the appropriate placement for these outrigger beams is of utmost importance for structural engineers. The number and placement of outriggers determine the outrigger structural system's overall effectiveness. Researchers have conducted several previous studies to determine the optimal location of outriggers on a steel building structure. However, we found no information about the construction of reinforced concrete outrigger systems in India. Additionally, we found no substantial literature demonstrating the effective use of this method in modern high-rise buildings, where increasing floor space exploitation is of the highest priority. This study examines the structural analysis of a reinforced concrete structure in Mumbai, India. The analysis entails introducing outriggers with a belt truss, but only at refuge levels. This design guarantees unrestricted human movement during a fire escape, making the analysis practical. Two models have been examined, one employing a traditional modelling system without outriggers and the other incorporating outriggers and a belt truss around each refuge floor. We conducted gravity, seismic, and wind analysis using the essential Indian codes. The structure was modelled and analysed using ETABS 19 software. We meticulously recorded and subsequently compared the response parameters of greatest significance, which included displacement, natural frequency, and overturning moment at the core. We can determine, based on these response parameters, that present-day high-rise structures can efficiently implement outriggers with belt trusses without compromising any utility requirements.

Index Terms—* outrigger, belt truss, uplift, core, diaphragm, flagged walls, optimum outrigger locations, Fire norms, special moment resisting frames (SMRF), refuge floor

I. INTRODUCTION

In recent decades, there has been an increase in the number of tall and slender structures. The need to accommodate expanding populations in limited land areas and the desire to construct buildings that contribute to the local environment and attract tourists are responsible for this pattern. Tall constructions often use flat plate, infill, outrigger, rigid frame, shear wall, braced wall, and flat slab systems as structural approaches. The adoption of outriggers employing a belt truss system occurred during the 1980s and 1990s. A typical outrigger structural system consists of three main components: a beam, columns, and a core. Applying lateral loads causes the external columns of the core to experience axial tension on one side and axial compression on the other. This connection mechanism enhances the rigidity of the structure by minimising the rotational movement in the central core wall. This system replaces the conventional tubular system, which includes closely spaced columns with deep spandrel girders. As a result, the new system's members are smaller, and the structures are more cost-effective. The current construction has significantly increased the plane's effective stiffness. The tie-down action in the core walls creates a point of inflection, which reverses the core's deflection curve and reduces its bending. Consequently, as we move upwards, the bending force on the core decreases. Buildings with both moment-resistant and laterally braced internal beams can also selectively activate the outside columns using the outrigger system. The outriggers somewhat counteract the reduction of base settlements and differential column settlements. The fundamental purpose of an outrigger system is to serve as a connecting mechanism between the peripheral and internal cores of a structural system. A conventional structural system that uses lightweight beams to connect the external and internal frames effectively separates the two components, with cantilevers serving as the primary method for the structure to withstand horizontal forces. The beams in an outrigger system possess greater depth and width. These beams transfer the horizontal forces from the outer structure to the central core. As a result, the building functions as a cohesive entity. High-rise construction worldwide commonly employs outrigger structural systems. Some notable examples include the Taipei Tower, standing at a height of 438 meters, which utilizes a damped outrigger system. The Shanghai World Financial Centre, reaching a height of 474 meters, employs a belt truss outrigger system. Lastly, the Burj Khalifa, the world's tallest tower, incorporates an outrigger system on its mechanical floors. The objective of this research project is to examine the current body of literature on outrigger structural systems and verify the findings by applying the design principles of an outrigger with belt truss structural system to a residential high-rise building.

II. LITERATURE REVIEW

The advantages of implementing an outrigger system to reduce story drifts are widely recognised. Researchers have conducted various experimental and analytical studies to understand the effectiveness of employing outriggers in high-rise structures.

In 1991, Bryann Stafford Smith and Alex Coull published a book on Tall Building Structures and Design. In this book, they provide the optimal placement of outriggers for n-outrigger structures. Their findings suggest positioning the outriggers at height locations of 1/ (n+1), 2/ (n+1), and up to n/ (n+1). The book also covers the technique of analysis, the generalised solution for forces and deflections, and the evaluation of outriggers in terms of their placement, flexibility, efficiency, and loading conditions. In her 2008 work titled 'Effect of Perimeter Frames in Seismic Performance of Tall Concrete Buildings with Shear Wall Core and Flat Slab System', Alpa Sheth investigated the impact of perimeter frames on structural systems that have a flat slab structure and shear wall core. Their study examined various locations of the shear wall core as well as different heights and spans of three concrete towers. The impact of a perimeter frame with an outrigger system was also examined. The study determined that outriggers have a greater impact on irregularly shaped structures with fewer stories compared to rectangular buildings with more levels. In 2011, S. Fawzia, A. Nasir, and T. Fatima conducted a study on the impact of cyclonic wind on buildings with outriggers at heights of 28, 42, and 57 stories. The study focused on controlling deflection and optimizing frequency. The researchers concluded that the 28-story model had both frequency and deflection levels that were within acceptable limits. In the 42-story structure, the achievable frequency limitations were met; however, the deflection limits necessitated the use of a belt truss. To achieve the desired frequency and deflection constraints, the 57-story model necessitated the implementation of a truss system and additional stiffness in the shear walls. The findings revealed that the plan's dimensions determine the overall height of the construction. Keeping the plan dimensions constant reduces the structure's lateral integrity. To improve stiffness, one can increase the bracing dimensions and use outriggers.

Srinivas Suresh Kogilgeri and Beryl Shanthapriya conducted 'A Study on Behaviour of Outrigger System on High Rise Steel Structure by Varying Outrigger Depth' in 2015. The study aimed to analyse the static and dynamic behaviour of the outrigger structural system on a steel structure by decreasing the depth of the outriggers. The Etabs software simulated a 40-story steel structure with a 5x5 bay configuration. The study revealed that reducing the depth of the outrigger to 2/3rd of the story height resulted in a decrease of 4%–5% in the reduction of lateral displacement and story drift compared to using an outrigger with the full story height. Similarly, reducing the depth of the outrigger to 1/3rd of the story height resulted in a decrease of 6%–7% in the reduction of lateral displacement and story drift. Goman W. M. Ho provided a concise description of the theory, concept, and ideal arrangement of outriggers in 2016 [5]. In addition, the presentation covered the techniques for adjusting outriggers, including the cross-jack system and shim-plate approach. The presentation described the retro-casting method, which allows the core wall to continue its original cycle without interruption from outrigger installation.

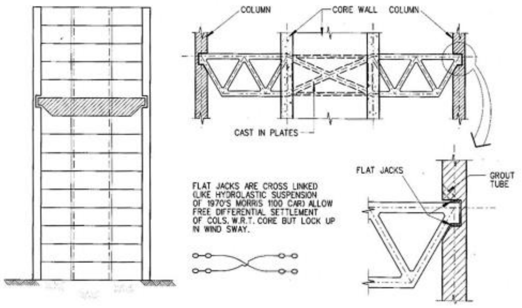

Figure 1: Cross Jack System

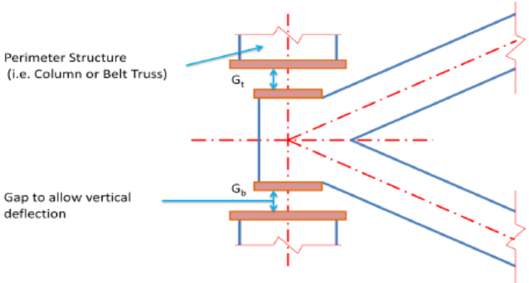

Figure 2: Shim Plate System

Sreelekshmi S. and Shilpa In 2016, Sara Kurian conducted an analysis of a 40-story steel building under the title 'Study of Outrigger Systems for High-Rise Buildings'. Sara Kurian conducted a time history analysis, incorporating outriggers at various heights inside the structure: a) at the top, b) at the top and one-fourth of the height, c) at the top and mid-height, and d) at the top and three-fourths of the height. An earthquake reduces the structure's base shear, displacement, and story drift, according to the study. The study determined the optimal placement of outriggers to be 0.75 times the building's height, and included a cap truss at a depth of three stories. The study conducted by Charles Besjak, Preetam Biswas, Georgi I. Petrov, Matthew Streeter, and Austin Devin [7] examined the impact of the connectivity between the perimeter and core of tall buildings on their behaviour. The study specifically explored the impacts of creep and shrinkage on two structural systems of varying heights. The first structure is the Pertamina Energy Tower, while the second structure is the Manhattan West North Tower. The initial structure included a firm linkage between the perimeter and core, incorporating three sets of outriggers. On the other hand, the second design featured elevated perimeter columns that still transferred the load to the core. The research provided a comparative analysis of several systems in order to examine the variations in structural behaviour in relation to the long-term impacts of creep and shrinkage. The paper demonstrated the variations in the impacts of creep and shrinkage, which are contingent upon the specific structural system, material composition, and tower height. In 2017, Kyoung Sun Moon conducted a comparative study titled 'Comparative Evaluation of Structural Systems for Tall Buildings: Diagrids vs. Outrigger Structures' to determine the structural efficiency of two systems: rectangular structures and twisted and tilted buildings. The study revealed that diagrid systems outperform outrigger systems in terms of lateral stiffness in rectangular and twisted buildings. However, we discovered that in slanted buildings, the rigidity of outriggers exceeded that of diagrid.In 2017, Akash Kala, Madhuri Mangulkar, and Indrajeet Jain studied a 60-story slender skyscraper with a 'L' form. The building had a storey height of 3.5m and was subjected to wind load using ETAB software. Prior studies primarily focused on steel structures, with limited research on slender concrete structures, according to the author. Research has determined that the most effective position for an outrigger on a tall building, when subjected to wind forces, is between 0.25-0.33 times the building's height from the bottom. By adding an outrigger on the 20th floor, the displacement was reduced from 493mm to 385mm.

In 2019, C. Bhargav Krishna and V. Rangarao conducted a "Comparative Study of Usage of

Outrigger and Belt Truss Systems for High-rise Concrete Buildings." They examined three thinly reinforced concrete (RCC) buildings with rectangular, C-shaped, and Y-shaped geometries and compared outrigger and belt truss systems. Analysing lateral displacement, maximum story drift, story shear forces, story moments, and story overturning moments helped comprehend earthquake and wind pressures on the tall building. The seismic analysis followed Indian standards. Since it had the lowest displacements and bending moments, the Y-shaped building was the best.

In 2018, Prof. N. G. Gore and Miss Purva Mhatre compared the traditional outrigger system with a virtual outrigger system and discussed the advantages. Virtual outriggers differ from conventional ones in that they do not require deep beams to connect the core to the perimeter columns. Alternatively, floor diaphragms determine the connectivity. Floor diaphragms are rigid flooring systems used in storeys that feature belt trusses along the perimeter. Skyscrapers can enhance their functionality and cost-effectiveness by appropriately constructing the virtual outrigger system.In 2018, Kurdi Mohammed Suhaib, Sanjay Raj A, and Dr. Sunil Kumar Tengli conducted a study on flat slab structures with outriggers. The research project involved the modelling of high-rise flat slab buildings using ETABS software, and a comparison was made between conventional and virtual outriggers. The largest reduction reported across all models was 20%. Furthermore, we determined that traditional outriggers outperform virtual ones, and establishing a direct connection between the core wall and the outer columns yields superior outcomes.

In 2019, Han-Soo Kim, Yi-Tao Huang, and Hui-Jing Jin presented a work on the influence of multiple openings on reinforced concrete outrigger walls in a tall building. They discussed the use of reinforced concrete outrigger walls with multiple openings as a replacement for conventional steel outrigger trusses in tall building structures. Finite element analysis using a strut and tie model determined the rigidity and durability of the outrigger wall, which contains many openings. They concluded that outriggers with an opening ratio below 20% do not have an impact on the overall stability of the structure.In 2019, Manoj Pillai and Roshni John conducted a study on the performance of a G+65 RCC high-rise building with and without flag walls. The study noted that the flag wall system outperforms the traditional RCC structural system and can serve as a viable alternative to the conventional outrigger system due to its space-saving capabilities.In 2019, F. AFSARI conducted a study on the ideal placement of an outrigger system for tall structures. The study utilised a building model with 30 floors and employed ETABS software and the BNBC code. We determined that placing an outrigger at the 2/5th position of tall buildings is an effective strategy after conducting a comparative analysis of different places.

Abdulaziz Alanazi [16] explored the economic benefits of core and outrigger systems for high-rise steel structures in 2019. He analysed and designed a 3-dimensional, 40-story steel building using STAAD Pro software to compare moment frames, braced cores, and outrigger systems. Finding out how each structural system affected the building's stiffness against lateral stresses. Each structural model's steel measurement revealed economic benefits. At 1/3rd spans, the outrigger system was stiffer, lowering steel requirements by 1500 MT. In 2020, Donny Morris [17] examined the "Effects of Outrigger and Belt Truss Systems on High-rise Building Structure Performance" using four G+62 models in e-tabs. Building A had no outriggers, but Building B had. The A and B materials were R.C.C. Building D had outriggers and belt trusses, while C did not. C and D were steel. Buildings A and B were less stiff, and their concrete portals absorbed more shear stresses than buildings C and D. Buildings B and D had less displacement than A and C.

Ritu Khandelwal and Raghvendra Singh [18] conducted a study in 2020 to determine the ideal shape and position of an outrigger system for high-rise buildings subjected to earthquake loading. The analysis examined three structures that were vertically uniform, consisting of 30, 45, and 60 stories. These buildings were constructed using reinforced concrete and had symmetrical designs along both the X and Y axes. The buildings exhibited a square configuration and were evaluated using three distinct truss designs: X, V, and N. the X-shape outrigger belt truss system was shown to be more efficient than both the V-shape and N-shape outrigger belt truss systems.A study was conducted in 2020 by V. Swamy Nadh, B. Hema Sumanth, K. Vasugi, and Manish.R. Shirwadkar [19] on the optimal placement and effectiveness of outrigger systems for asymmetrical tall buildings subjected to lateral loads. The study entailed a comparison between a 30-story asymmetrical tall skyscraper in etabs, with outriggers placed at different elevations, and another building with a single fixed outrigger at the top. We found that placing one outrigger system at the highest level and another at a position equal to 0.50 times the building's height was the most advantageous placement. This arrangement reduced lateral displacement by approximately 26.69%.

Existing research focuses on determining the optimal placement of outriggers along the structure's length and comparing this system with conventional methods. However, the practical feasibility of this system is often overlooked during modeling and design. Therefore, the paper “Lateral design of modern high rise structure using outriggers with belt truss system: an overview” by Huzefa Attarwala and S.A. Rasal [20] suggests that future research should adopt a practical approach to ensure that utility is maintained without disruption while maximizing the benefits in terms of lateral stability, strength, and economy.

III. STUDY OBJECTIVES

Regarding the aforementioned literature research, it has been observed that outrigger systems play a vital role in reducing story drifts in high-rise buildings. Researchers have carried out multiple investigations to comprehend the efficacy of utilising outriggers in tall buildings. A group of researchers discovered that decreasing the depth of the outrigger in relation to the story height led to a reduction in lateral displacement and narrative drift, as opposed to employing an outrigger with the entire story height. Researchers have found that diagrid systems demonstrate superior lateral stiffness compared to outrigger systems in rectangular and twisted buildings. However, in slanted buildings, the rigidity of outriggers surpasses that of diagrid systems.

A thorough review of the existing literature established the aims of the current study. These objectives are as follows:

1. The primary aim of this research is to investigate the impact of outriggers on modern tall buildings without compromising the total floor space.
2. The dimensions of the outriggers and belt truss will be chosen to ensure that they can be effectively utilised within the available height and area. We will only raise the belt trusses to the height of the sill and lintel levels.
3. The building to be modelled will have a circular floor plan and will include numerous lift cores separated by a tunnel.
4. The model with outriggers and belt truss will be contrasted with the conventional system, which solely relies on shear walls.
5. This comparison will demonstrate that the use of outriggers with belt trusses is an efficient solution in modern high-rise buildings without compromising the building's functionality or usable space.

IV. METHODOLOGY AND MODELLING

We conducted a thorough analysis following a qualitative investigation. We conducted a thorough examination of numerous peer-reviewed journals and notable books that specifically examined outrigger systems and their effectiveness, with a particular focus on qualitative or secondary investigations. The literature inquiries have employed the subsequent subheadings:

- The benefits of using an outrigger system;
- Various varieties of outrigger systems;
- Criteria for improving outrigger performance;
- Simplification of the outrigger system.

To validate the research findings and evaluate the efficiency of several outrigger systems, two building prototypes are being considered. Each prototype comprises 50 stories and has a height of 145 meters. We will analyses the original design using a traditional approach that does not incorporate outriggers or belt trusses. In contrast, the second type will incorporate outriggers and a peripheral belt truss at each 7th story, extending all the way to the terrace. Only every seventh story is considered, as all of these stories must have a refuge floor in accordance with India's fire regulations. Then we conducted an evaluation to determine the effectiveness of the outrigger in conjunction with the belt truss system. We have examined numerous reaction parameters, such as story displacement, natural frequency, time period, and forces at the base of the core wall, considering that these attributes frequently determine the behavior of tall edifices when subjected to lateral forces. We have selected a residential block in Mumbai, India, for our examination. In the following chapter, we will present the estimations for the dead, live, and gravitational loads of the investigated structure. We will create the building's structural model using ETABS. The structure has an RC ductile Special Moment Resistant Frame. Initially, we will perform human calculations to validate the correctness of the analysis's findings. We will use the model for further investigation once the validation procedure is complete.

V. PARAMETERS OF THE MODEL

The analysed model features an elliptical layout of 46.35 x 32.5 meters at its furthest points. The columns are strategically positioned according to the architectural specifications to minimize any deviation in the alignment of the rooms and hallways. The core walls comprise 8 lift walls arranged in a manner where a tunnel separates 5 lifts from 3 elevators. Figures 3 and 4 below depict the floor plan that ETABS generated.

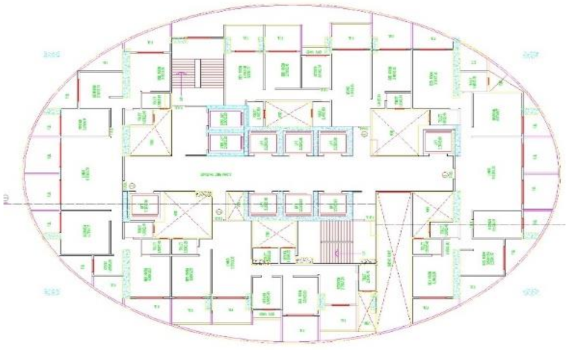

Figure 3: Architectural Floor plan

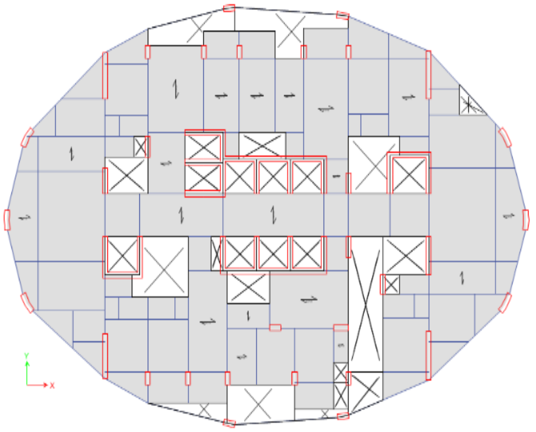

Figure 4: Floor plan of Structural Model created in ETABS 2019

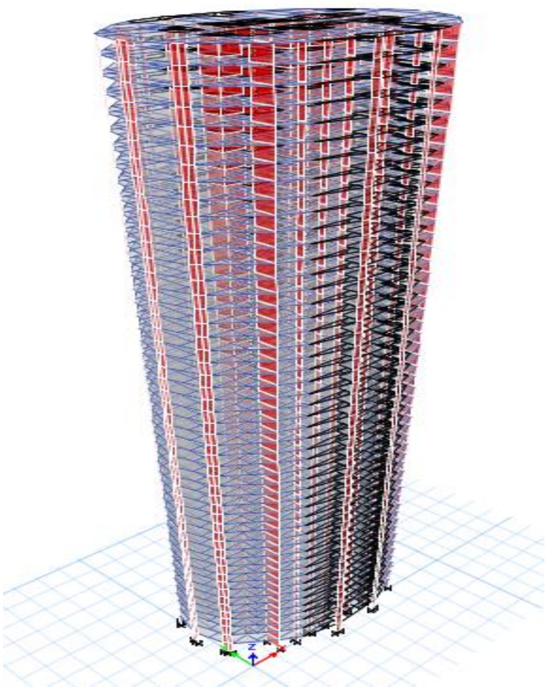

Figure 5: Rendered View of Structural Model

Table 1: presents the modelling parameters utilized in the current study.

Properties	Corresponding values
Grade of concrete	Beams and slabs : M40
	Shear walls: M80 to M60.
Grade of steel	Fe550
Column dimensions	Vary depending on architectural feasibility
Beam	300 x 700
Slab	The thickness of the slab varies depending on the span, with a minimum thickness of 150mm and a maximum thickness of 200mm.
Density of the concrete (KN/m^3)	25
Density of the steel reinforcement (KN/m^3)	78.5
DL including FF (KN/m^2)	1.5
The live load for occupancy in residential buildings is 2 KN/m2 for rooms, kitchen, and toilets, and 3 KN/m2 for passages and staircases, according to IS 875 (Part 2) - 1987.	

Seismic parameters:

The seismic analysis requires the application of the following seismic parameters to the model. The proposed structure has undergone equivalent static analysis. The seismic parameters specified in IS 1893:2016 have been taken into account.

Seismic zone factor (Z) = 0.16
(Cl 6.4.2 of IS 1893:2016) – Mumbai Location
Site type = 1
(Cl 6.4.2.1 of IS 1893:2016) – Rocky soil considered
Importance factor (I) = 1.2
(Cl 7.2.3 of IS 1893:2016) – Residential building with occupancy more than 200 persons
Response reduction factor (R) = 5
(Cl 7.2.6 of IS 1893:2016) – RC buildings with special moment resisting frames (SMRF)

Time period for X direction (T)x = 1.944
Time period for Y direction (T)y = 2.322
(Cl 7.6.2 of IS 1893:2016) – T = 0.09* h/(√d)
Where h = total height of building
d = base dimension of the building at the plinth level in the direction of earthquake considered

The wind parameters required for doing wind analysis on the model are as follows: The proposed structure has undergone a static wind study. What follows the wind parameters have been evaluated in accordance with the specifications specified in IS 875: Part 3 (2015).

Wind load parameters:
Basic wind speed (Vb) = 44 m/s
[Cl 6.2 of IS 875: Part3 (2015)] – As per Fig. 1 – Region Mumbai

Terrain Category = Category 2
[Cl 6.3.2.1 of IS 875: Part3 (2015)] – Open terrain with well scattered obstructions having heights between 1.5 – 10m
Design Factors-
Risk Coefficient factor (k1) = 1
[Cl 6.3.1, Table 1 of IS 875: Part3 (2015)] – All general buildings and structures with mean probable design life of 50 years

Terrain and height factor (k2) = varies as per table 2
[Cl 6.3.2.2, Table 2 of IS 875: Part3 (2015)]

Topography factor (k3) = 1
[Cl 6.3.3.1 of IS 875: Part3 (2015)]
Importance factor for cyclonic region (k4) = 1
[Cl 6.3.4 of IS 875: Part3 (2015)]

Wind directionality factor (kd) = 1
[Cl 7.2.1 of IS 875: Part3 (2015)] – For circular or near circular forms of building, factor recommended is 1

The model will undergo additional analysis and comparison by incorporating outriggers with belt trusses on every 7th floor (refuge floors). Various parameters that affect the lateral design of the structure will be analyzed. We will construct the outriggers to extend the full height of the building at selected areas, ensuring public mobility remains unobstructed during a fire emergency.

Table 2: Parameters varied for outrigger modelling

Sr. No.	Model name	Height (m)	Number of stories	Outrigger location
1	A	147.1	50	Not Applicable
2	B	147.1	50	At 7 /14/ 21/ 28/ 35/ 42 and terrace story

The next section provides an explanation of the study's findings.

VI. RESULTS AND DISCUSSIONS:

a. *Analysis Results for Model A*

The initial model that was analysed consisted of a conventional structural system featuring moment-resisting frames and shear walls located at the core. Table 2 presents the analytical results for the first 12 modes of the structure, displaying the modal mass participation ratios. Table 3 shows the forces exerted at the core wall's foundation. Figures 6 and 7 illustrate how lateral loads during seismic stimulation cause the structure to shift in the X and Y directions. Similarly, Figures 8 and 9 show how lateral loads during wind stimulation cause the structure to shift in both X and Y directions.

Table 3: Modal mass participating ratios for Model A

Case	Mode	Period sec	UX	UY	SUM RZ
Modal	1	4.303	0.0403	0.6413	0.0162
Modal	2	3.869	0.5113	0.0164	0.1711
Modal	3	3.456	0.1121	0.0389	0.7428
Modal	4	1.34	0.0002	0.1408	0.754
Modal	5	1.185	0.0228	0.014	0.853
Modal	6	0.999	0.1348	0.0055	0.8687
Modal	7	0.665	0.0003	0.0418	0.8708
Modal	8	0.501	0.0397	0.0022	0.8782
Modal	9	0.436	0.0167	0.0176	0.8792
Modal	10	0.327	0.0178	0.0152	0.8832
Modal	11	0.244	0.0501	0.0082	0.8881
Modal	12	0.157	0.0075	0.0302	0.8882

The table indicates that the first mode of vibration for the structure is in a straight line along the Y direction, the second mode of vibration is in a straight line along the X direction, and the third mode of vibration is in a twisting motion known as torsional mode.

Table 3: Core forces in Model A

Story	Pier	Output Case	V2 kN	V3 kN	M2 kN-m	M3 kN-m
Story 1	LC1	WINDX	7224.03	-200.65	-13671.57	314489.76
Story 1	LC1	WINDY	-198.34	5768.3	148976.4	14670.13
Story 1	LC1	EQX	3225.33	-90.38	-7425.290	169298.3
Story 1	LC1	EQY	-43.385	1509.8	42715.09	5211.51
Story 1	LC4	WINDX	4138.44	45.016	1370.792	151217.3
Story 1	LC4	WINDY	88.4609	3284.4	48205.33	9724.93
Story 1	LC4	EQX	1838.90	19.99	693.589	79192.08
Story 1	LC4	EQY	14.29	857.91	13569.55	2780.53

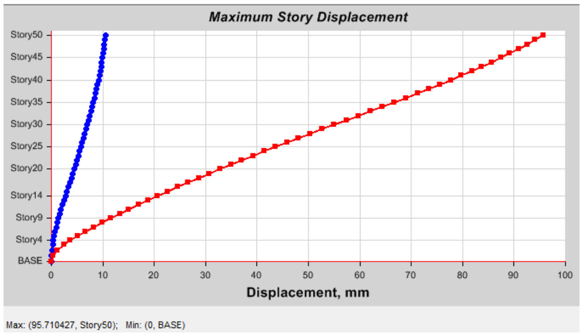

Figure 6: Story Displacement for EQX in Model A

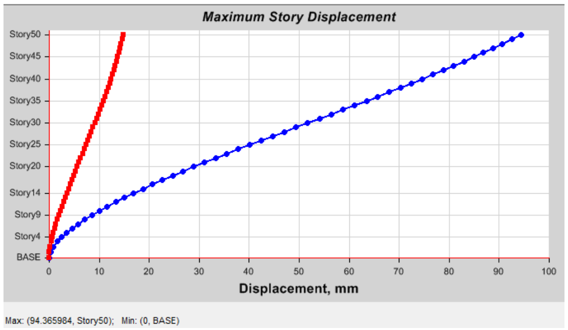

Figure 7: Story Displacement for EQY in Model A

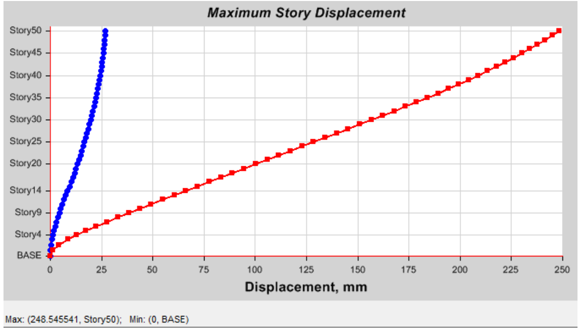

Figure 8: Story Displacement for Wind X in Model A

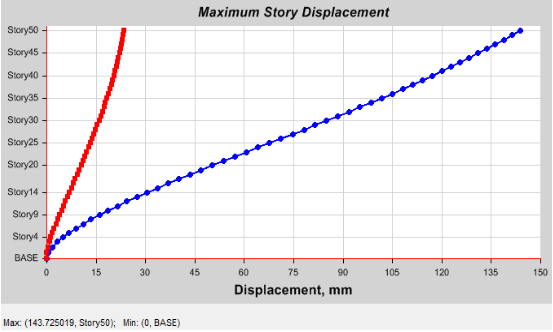

Figure 9: Story Displacement for Wind Y in Model A

b. *Analysis Results for Model B*

The Model A undergoes reanalysis by incorporating an outrigger with a belt truss system on every seventh-story building. We measured the outrigger beam's depth across the entire height of the building. The results of the analysis of the modal mass participation ratios are shown in Table 4. These show that the structure's natural time period is shorter than it was in Model A. Table V illustrates the forces at the core. The lateral displacement of the structure was significantly minimised, as evidenced by Figures 10 to 13.

Table 4: Modal mass participating ratios for Model B

Case	Mode	Period sec	UX	UY	SUM RZ
Modal	1	3.877	0.3738	0.3107	0.0012
Modal	2	3.714	0.2592	0.3603	0.078
Modal	3	3.215	0.0377	0.0305	0.7529
Modal	4	1.157	0.0001	0.1432	0.7718
Modal	5	1.089	0.0503	0.0185	0.8473
Modal	6	0.976	0.106	0.0119	0.8816
Modal	7	0.566	0.0006	0.0397	0.8825
Modal	8	0.474	0.0585	0.0001	0.8849
Modal	9	0.363	0.0006	0.0188	0.8852
Modal	10	0.281	0.0122	0.0128	0.9023
Modal	11	0.237	0.0553	0.0008	0.9028
Modal	12	0.134	0.0009	0.0291	0.9096

Table 5: Core forces for Model B

Story	Pier	Output Case	V2 kN	V3 kN	M2 kN-m	M3 kN-m
Story1	LC1	WINDX	7226.85	-196.829	-14262.99	304346.52
Story1	LC1	WINDY	-184.393	5841.27	131846.56	4311.408
Story1	LC1	EQX	3321.92	-90.7299	-7933.693	168123.04
Story1	LC1	EQY	-41.8543	1575.82	38632.478	1944.3148
Story1	LC4	WINDX	4146.37	46.52	1067.4617	146057.71
Story1	LC4	WINDY	87.1603	3303.12	43946.005	6424.5642

Story1	LC4	EQX	1894.95	21.395	547.2683	78448.089
Story1	LC4	EQY	15.7307	888.361	12640.105	1903.9441

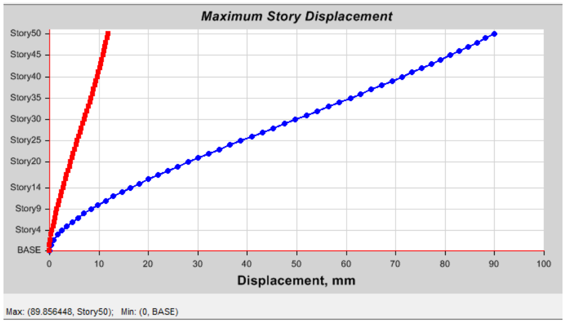

Figure 10: Story displacement for EQX in Model B

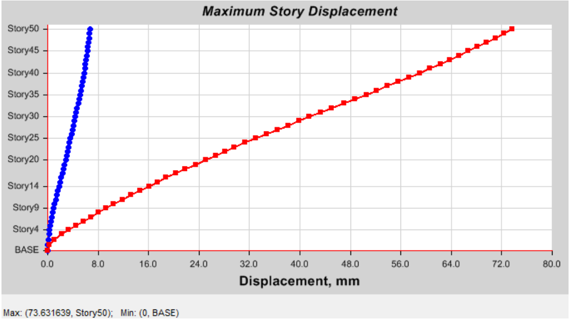

Figure 11: Story displacement for EQY in Model B

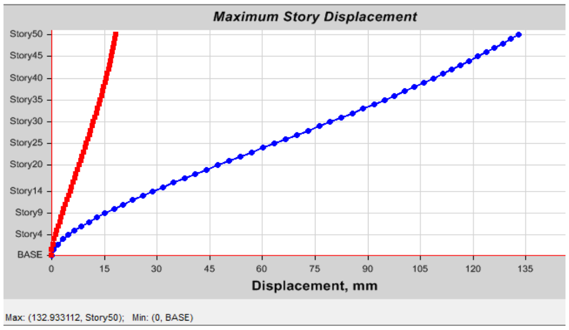

Figure 12: Story displacement for Wind X in Model B

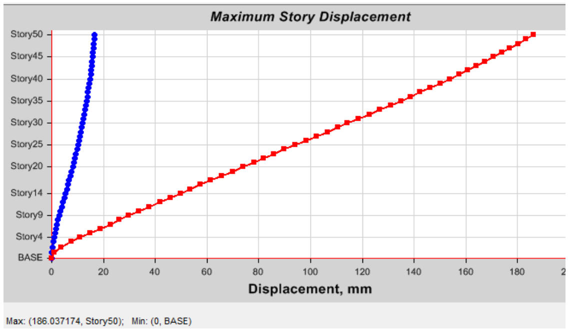

Figure 13: Story displacement for Wind Y in Model B

c. Major contribution from present work -

The research analysed two structural models. The height, configuration, and elevation in both plans remained the same. We evaluated the initial model using traditional beam slabs and ductile walls, while the second model incorporated deep full-story outriggers at every 7th level. With that exception, all other characteristics remained unaltered. We observed significant variations in the time period and displacement values after conducting a thorough analysis of key characteristics such as the time period, forces in the core at the base, and the displacement of the structure. When adding outriggers, the time period decreases, despite a significant decrease in story displacement. This reduction clearly indicates an increase in the structure's stiffness.

Significant alterations were noted in the wind-induced displacement in the y direction force, primarily because outriggers were installed in the lateral Y direction to facilitate the movement of the public during a fire emergency. The initial model exhibited higher displacement values in the Y direction compared to the X direction due to the building's elliptical floor plan.

Table 6: Summary of analysis conducted

Model name	Height (m)	Outrigger	Natural period (sec)	Max drift X (mm)	Maximum drift Y (mm)
A	147.1	No	4.303	144	249
B	147.1	At every 7th story	3.877	133	186

The reviewed literature confirms the findings from earlier researchers. The implementation of outriggers and the overall stiffness of the core and outrigger beam were the main factors that contributed to the decrease in drift value.

VII. CONCLUSION

The analysis yields the following overarching conclusions:

1. Rigid lateral structures, referred to as outriggers, join the structure's core to its external columns, enabling the whole width of the structure to contribute to lateral load resistance.
2. For steel construction, outriggers can be supplied as a truss belt system. Alternatively, you can attach outrigger beams, resembling concrete deep

beams with depths up to the building's floor height, to concrete core walls.

3. By reducing the structure's natural time period, outriggers lessen the structural acceleration that causes the building to shake under lateral loads.
4. The number of outriggers, where they are located, the building's overall height, and other variables all affect how effective an outrigger is.
5. Numerous studies have previously examined the effects of various outrigger positions and numbers. All the studies showed that outriggers were effective; however, practical feasibility was missing in all of the previous research.
6. The gaps in the previously mentioned literature are filled and validated in this research for a building located in Mumbai, India. Two structural models were prepared using ETABS 19, and the concrete outriggers with steel belt trusses were provided at every 7th floor, i.e., the refuge floor in the Y direction, considering the practical feasibility and forces governing in that direction. We validated the model through a manual analysis process. Seismic and wind analysis was carried out considering the building's location in Mumbai, India. The analysis indicated that the maximum lateral displacement under seismic and wind loads was reduced with the introduction of outriggers with belt trusses at every seventh floor.
7. It is concluded from the study that the maximum lateral displacement in the Y direction due to wind loads originally was 249 mm, which got reduced to 186mm with the provision of outriggers with belt trusses, which indicates that a considerable 25% reduction is achieved in the displacement.
8. This finding will be helpful for all practicing engineers in the current modern era of high rises, where this system can be used without disturbing any architectural elements or occupying any extra space, thus providing the client with efficient design, which is the need of the hour.

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