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ENHANCINGLATERALLOADRESISTANCEIN HIGH-RISE BUILDINGS USING OUTRIGGER- BELT TRUSS SYSTEMS

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Research Article

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ABSTRACT

High-rise buildings are becoming necessary parts of contemporary cities due to urbanization and limited land availability, requiring sophisticated engineering solutions to handle the substantial lateral pressures brought on by seismic and wind activity. Outrigger systems have become a viable way to improve the structural performance of tall structures by carefully connecting the central core to the outer columns. In this work, a 40-story high-rise structure with belt trusses and a core-outrigger system under lateral loads is parametrically analyzed using ETABS software. According to the analysis, the building's height has a direct impact on the quantity and positioning of outriggers. Notably, 0.4 H from the bottom of the structure is the ideal place for a single outrigger with a belt truss, optimizing lateral load resistance and reducing deflections. These results advance high-rise structural engineering and give useful guidance for attaining maximum efficiency in tall buildings by delivering crucial insights into the strategic design and deployment of outrigger systems.

1. OVERVIEW Due to the combined needs of urbanization and limited land supply, high-rise buildings have become essential in contemporary cities and metropolises. High-rise buildings are intrinsically more complicated than low-rise ones because of their complex structural elements and the wide range of variables that affect how well they operate. In order to maintain a delicate balance between stability, stiffness, and strength, the interaction of gravity and lateral forces in skyscrapers poses a special engineering issue that calls for creative solutions. Engineers must make sure that these imposing structures are resilient and useful, able to resist natural forces and survive the test of time.

Seismic activity and wind exert considerable lateral stresses on tall structures. Conventional solutions, such as moment-resisting frames and shear walls, are not very good at delivering the necessary stability and stiffness at higher elevations. One of the best ways to improve structural performance is to use outrigger systems, which strategically connect central cores to periphery columns. 2. REVIEW OF LITERATURE The development and improvement of outrigger systems has been essential to improving high-rise structures' structural performance, especially in reducing lateral stresses brought on by seismic and wind activity. This overview of the literature charts the evolution of outrigger systems, emphasizing significant advancements and optimization techniques. With regard to the outrigger system, Hi Sun Choi [1] concentrated. Outriggers have traditionally been employed in sailing and ship construction to withstand sudden waves as depicted in figure 1. It has been noted that tiny ama flotation, which provides upward resistance, or weight, which provides downward resistance, operating via outrigger leverage, are adequate to avoid overturning of a narrow boat hull when shaken by abrupt waves. The similar idea has been used as a lateral load-resisting mechanism in high-rise buildings.

Fig.1Samoanoutrigger canoe© Teinesavali

A comprehensive perspective on the development of structural systems for tall structures was held by Ali and Moon [2]. Outrigger structures are the kind of system that Ali and Moon have chosen, and they have an effective height restriction of up to 150 stories. Well-known tall buildings that use outrigger systems include the Guangzhou CTF Tower (520 m), Taipei 101 (509 m), Hong Kong Cheung Kong Center (290 m), Hong Kong IFC2 (380 m), and Hong Kong ICC (450 m). According to research by Gunel and Ilgin [3], the belt truss and outrigger system is basically a development of the shear wall-framed system. The outrigger system is a creative and effective structural configuration that consists of a central core with a shear wall and horizontal outrigger trusses connecting the core to the outside columns.
The column-restrained outrigger stops the core from rotating when the building experiences lateral loads. As shown in Figure 2, the outriggers and belt girders should normally span at least one stone and sometimes two stories in depth to provide sufficient rigidity. They are often placed at plant levels to reduce the impediment they cause because of this.

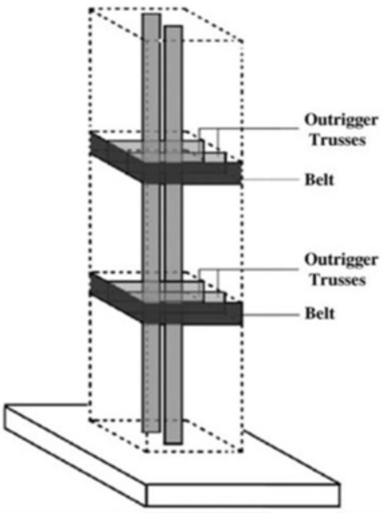
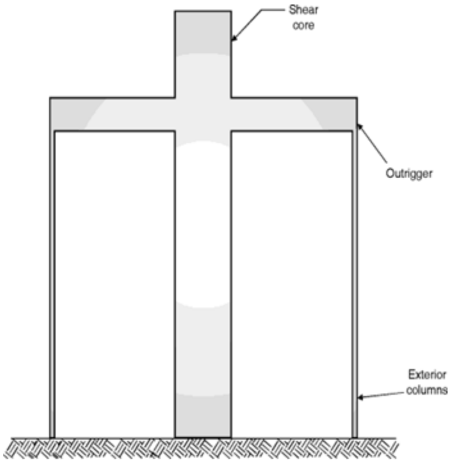


Fig.2OutriggerandBeltTruss [3]

According to Taranath [4], an outrigger system is made up of a primary concrete core that is joined to external columns by horizontal elements that are moderately rigid. These members are outriggers, which are one- or two-story deep walls. As shown in Figures 3 and 4, the core may be positioned on one side of the structure or in the middle, with outriggers reaching to the building columns on each side. According to Stafford Smith et al. [5], the rigid outrigger arms rotate when lateral stress occurs along the plane of the outrigger bent. This is caused by the cantilever core bending. This rotation creates compression in the downwind column and tension in the upwind column. As shown in Figure 5, these column forces acting at the outrigger arms' extremities form a coupling that limits the core's bending and deflection.



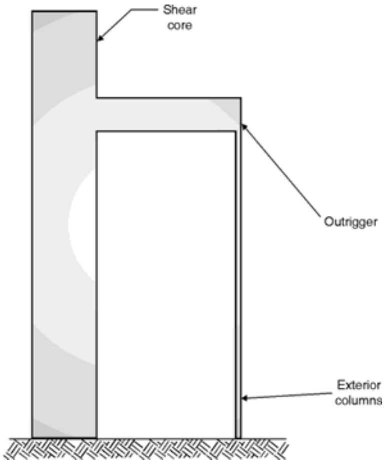


Fig.3Outriggeron both sideofcentralcore Fig.4Outriggeron onesidewithoffsetcore[4]

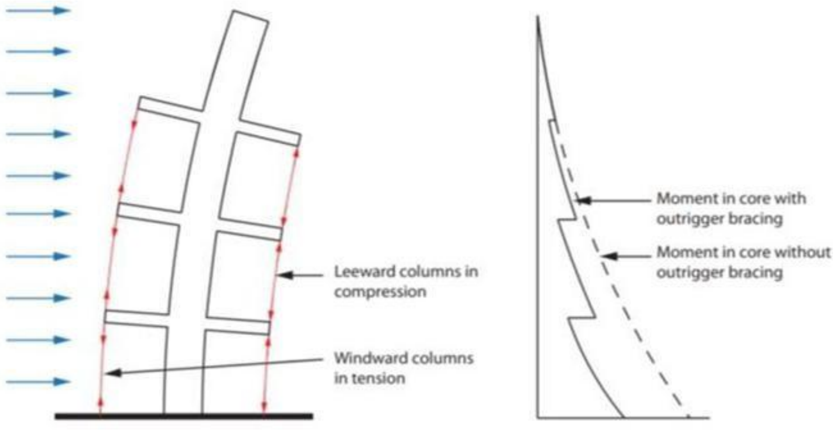


Fig.5Interactionofcore andoutriggers[5]

The function of outrigger systems in lowering horizontal displacement in tall, reinforced concrete structures was examined by Jain and Londhe [6]. According to their research, outriggers positioned strategically might reduce lateral displacement by up to 30%. The research underlined how crucial it is to place outriggers as optimally as possible to optimize their structural advantages. A thorough analysis of the development of outrigger systems was given by Choi and Kim [7], who emphasized the significance of the systems' positioning within the structure. According to the assessment, the outrigger system performs far better when it is positioned between 30 and 40 percent of the building height from the base; in normal arrangements, this may reduce drift by up to 25 percent. The usefulness of various outrigger systems in various structural configurations was examined by Borah and Choudhury [8]. According to their findings, inter-story drift and displacement are reduced by 20–35% when twin outrigger systems are installed at one-third and two-thirds of the building height. The research emphasizes how load conditions and structural geometry affect these gains. Outrigger systems positioned close to mid-height or at one-third intervals offered an ideal balance between lateral stiffness and material efficiency, achieving up to a 28% decrease in drift and improved stability under wind and seismic loads, according to Kavyashree and Rao's [9] investigation into the impact of lateral stiffness on structural framing systems. Optimizing multi-story structures using outrigger systems was stressed by Shivacharan and Rao [10]. According to their investigation, the greatest results were obtained when the outrigger was positioned at the mid-height of the structure. This reduced base moment by 15% and lateral displacement by 30% while keeping costs down. A mathematical method was put out by Haghollahi and Rahgozar [11] to find the best place for flexible outriggers. According to their study, installing outriggers at 40–50% of the building height may significantly increase the overall structural stiffness and reduce top-story displacement by 25–40%. In their investigation of non-linear damped outrigger systems, Sattar and Livaoglu [12] found that base shear may be reduced by 15–20% and peak drift by 20–30% with the right design parameters and outrigger positioning. The research emphasized the extra advantages of damping devices in dynamic situations. A smart outriggerdamper system was created by Kim and Shin to lessen reactions in tall structures. The efficacy of modern systems was proved by the research, which showed that installing damped outriggers at important stress zones—typically at 30 to 50% of the building height—reduced total displacement by 35% and drift by 25%. Despite these developments, there is still disagreement on the exact ideal location, with differences seen because of factors including building height and structural stiffness. This variation indicates a substantial research gap that calls for further investigations using cutting-edge modeling approaches and a range of structural conditions. More research is necessary.

to provide thorough recommendations for the best use of outrigger systems so they may be used as effectively as possible to mitigate structural issues in high-rise structures.

1. TECHNIQUE This research evaluates the performance of outrigger systems in tall structures using parametric analysis and computer modeling. ETABS software is used to create a 40-story high-rise model that includes reinforced concrete core and periphery columns. Analysis is done on core-outrigger systems with belt trusses under lateral loads like seismic and wind forces. To determine the best designs, important factors including the number and location of outriggers as well as structural performance indicators like storey drift and lateral displacement are evaluated. The findings are intended to provide useful recommendations for improving high-rise structures' lateral load resistance and structural efficiency. The analytical method's assumptions The following assumptions have been used to simplify the analysis: The structure exhibits linear elastic behavior. The vertical cantilever core is permanently anchored at the base and resistant to shear. Outriggers feature hinged connections to the outer columns to only create axial forces, are fastened to the core solidly, and are resistant to flexure and shear. the constant lateral load over the building's height.

The core, columns, and outriggers all have identical sectional characteristics over the building's height.

For the core and outriggers, only bending deformation is taken into account. The core wall's shear deformation is disregarded. Examination of the Outrigger System When outriggers are attached to the peripheral columns via hinges, as shown in Figure 6 shows that bending moments cannot be transferred from the outriggers to the columns. By increasing the columns' axial load capacity, this arrangement enables the system to fully use the shear core's moment-carrying capability. Therefore, by optimizing the use of both the axial capacity of the columns and the moment-resisting capacity of the shear core, hinged connections between outriggers and perimeter columns improve system efficiency [12].

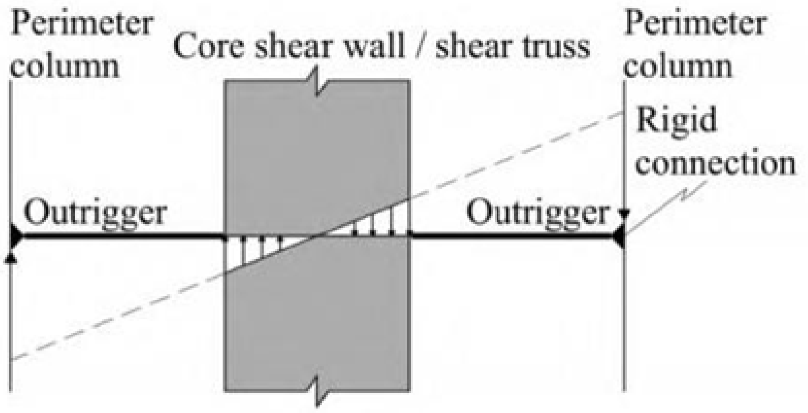


Fig.6OutriggertoPerimeterColumnConnection [12]

Analytically simplified model An outrigger frame system's behavior under lateral loads, as seen in Figure 7, may be broken down into two parts in a simple analytical model: the vertical cantilever core under lateral loads and the same core with a restoring moment produced by the outrigger's levering action. By serving as a fulcrum and transferring the restoring moment to the core, the outrigger prevents the core from rotating under lateral loads by limiting the levering effect [16].

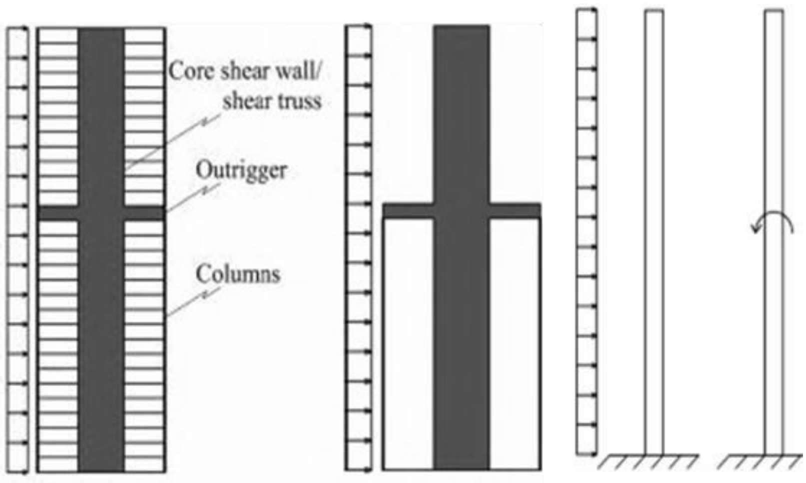


Fig.7Analytical modelofoutriggerframesystem underlateralload [16]

Both the lateral drift at the top of the building and the bending moment in the core, as seen in figure 8, are reduced by decreasing the rotation of the core. Axial tension or compression is applied to the columns on the two facades perpendicular to the bending direction, resulting in contraction on one side and elongation on the other.

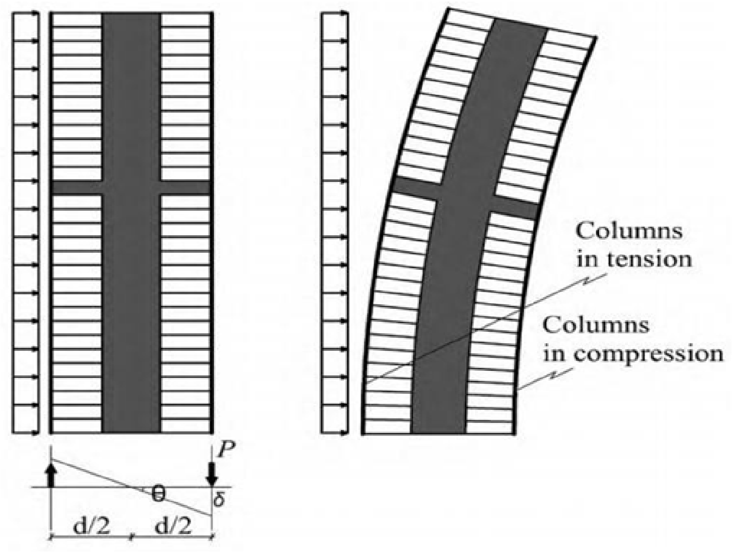


Fig.8Axil deformationofthe perimetercolumn [16]

Theoptimumlocation ofsingleoutrigger system

For a single outrigger positioned at a distance x from the top of the structure, as depicted inFigure 9, the lateral drift at this level is represented by

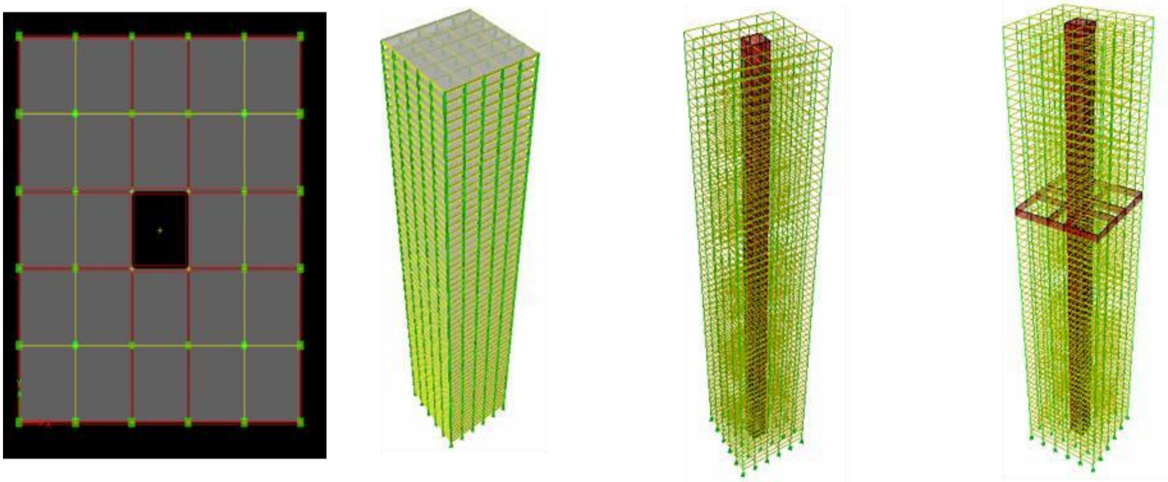
$y_{x=0}=$

$wL^4 8EI$

$12(EI)^2C(L^3-x^3)(L+x)$

The point at which the yx=0 function achieves its smallest value or the yrx=0 function reaches its highest value is the position of the outrigger level that has the most impact on decreasing lateral drift at the top of the structure. Thus, by dividing the rx=0 function with respect to x and equating to zero, the ideal position of a single outrigger level is found, resulting in x = 0.455L. Next, the single outrigger system's restoring moment is determined by:

2. MODELING M=$wl2$ 6EIC ETABS software was used to create a three-dimensional model of a forty-story reinforced concrete structure. The layout is 40 m x 40 m square, with a consistent floor



height of 3.5 and 8 m between columns. The assumption was that all bases were fixed and that the frame would be special moment-resisting with 5% damping. The model is situated on medium soil type in Mumbai, in seismic Zone III. While wind loads [19] were applied in line with IS 875, response spectrum analysis for seismic loads [18] was carried out in compliance with IS 1893. The slabs and beams are made of M30 concrete, whilst the columns and core wall are made of M40 concrete. Fe500 and Fe415 grade reinforcement bars were used. The dimensions of the interior and peripheral columns are 800 x 800 mm and 1000 x 1000 mm, respectively. Likewise, internal beams and peripheral beams measure 450 x 750 mm and 600 x 750 mm, respectively. The corewall is 200 mm thick, while the slab is 300 mm thick. According to IS875, a dead load of 8 kN/m³ and a live load of 4 kN/m² were applied to lightweight walls. In accordance with IS 16700: 2023, all property modifiers [20] were applied to the lateral and gravity systems to account for fractured section attributes during earthquakes.

ModelswithOutriggerBeltTruss System

a)Squareplan40 x40 m b)Bareframe c)corewall d)Singleoutrigger

Fig.10:Squaremodel withasingleoutriggerbelttruss

For this research, a square model of a tall structure with an outrigger system and central core was created, as shown in figure 10. One outrigger, designated OT10, OT20, OT30, and OT40, was positioned at 10-story intervals to ascertain the outrigger's ideal location. In order to fine-tune the placement, further critical analysis was carried out, assessing intermediate positions designated as OT14, OT16, and OT18 in order to determine the best location. Each outrigger placement level's structural performance was evaluated as part of the study, with particular attention paid to variables such story drift, time period, and lateral displacement under seismic and wind loads. The results provide light on where outriggers should be placed to maximize structural stability and reduce deflections.

2. OUTCOMES AND CONVERSATION

Table 1 displays the results of each model's analysis for the parameters of time period, storey drift, and displacement.

Table1 40 storey models with singleoutrigger

Parameter	Square Model	Optimum Location
TimePeriod (sec)	15.10 %	(OT_16)
StoreyDrift(EQ)	26.53%	(OT_18)
StoreyDrift(WL)	29.94 %	(OT_16)
Displacement (mm)	25.68 %	(OT_16)

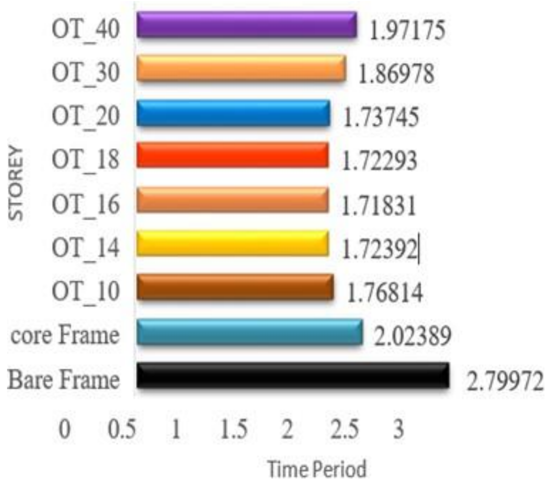


Fig.11 Timeperiodfor40 storey sqauremodel

The time period variation for a single outrigger positioned at 10-story intervals is seen in Figure 11. When the outrigger belt truss is positioned between OT_10 and OT_20, the study shows a considerable decrease in time period; the 16th storey is the ideal site. The time period drops by 15.10% at this level (OT_16) in comparison to the core-only model, indicating improved structural efficiency.

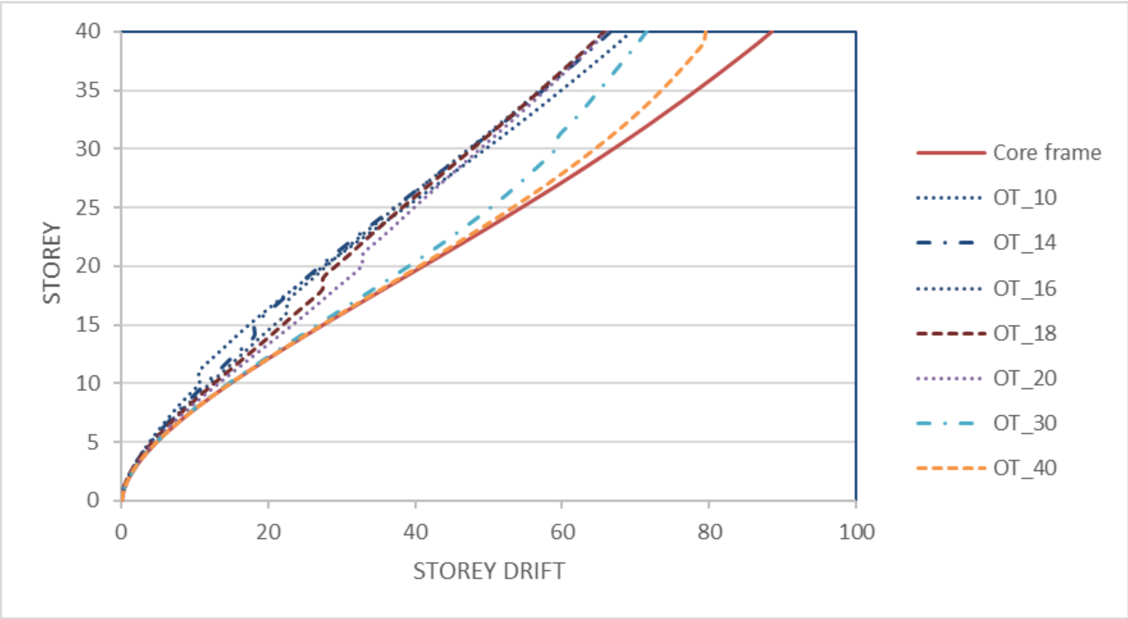
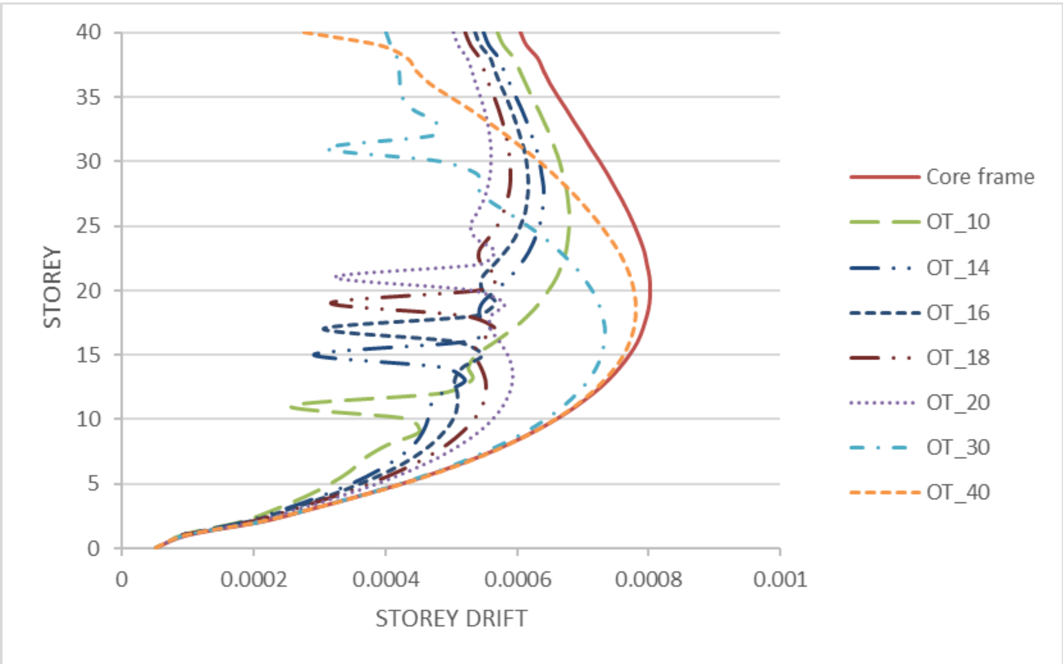


Fig.12Displacementfor 40storeysquaremodel

The displacement trends for a single outrigger system at 10-story intervals are shown in Figure 12. According to the research, the 16th story is the best spot since it achieves a 27% displacement reduction compared to the core-only arrangement, indicating enhanced resistance to lateral loads.

Fig.13Storeydrift forresponse spectrum



The story drift pattern for single outriggers placed at 10-story intervals under seismic stresses is seen in Figure 13. The 18th story is identified as the ideal placement, with enhanced seismic performance shown by a 26.53% reduction in story drift as compared to the core-only model.

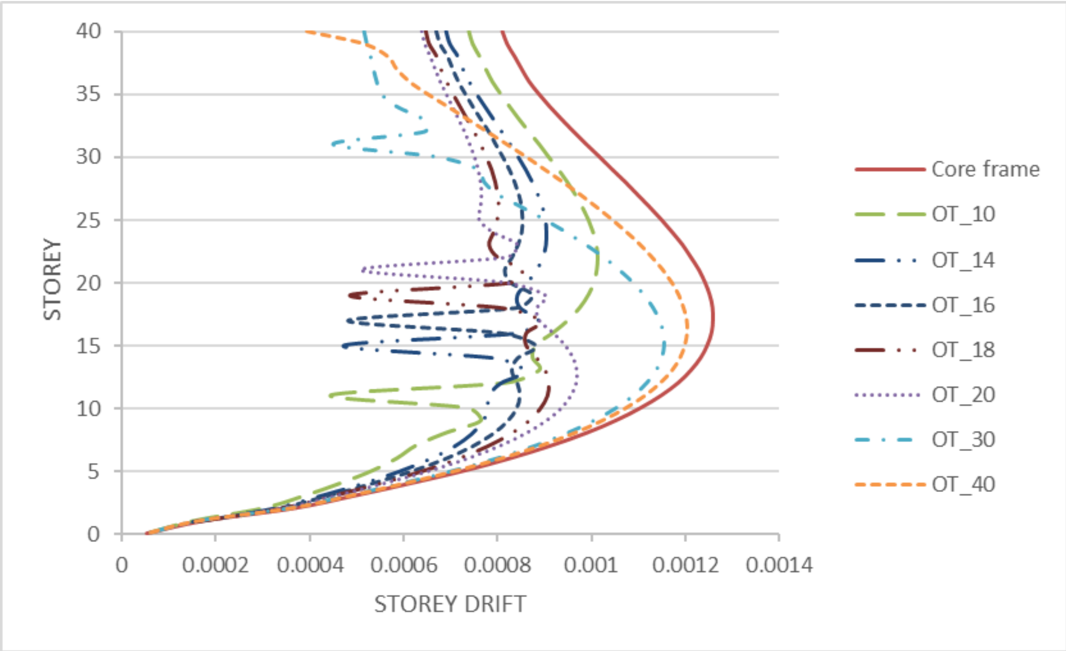


Fig.14 Storey drift for40storey squaremodel for wind

The story drift response to wind loads for single outriggers at 10-story intervals is shown in Figure 14. In this case, the 16th story is the ideal location since it reduces wind-induced story drift by 30% when compared to the core-only configuration, demonstrating its efficacy in mitigating wind loads.

2. FINAL RESULTS

The research shows that the structural performance of tall structures is greatly improved by the ideal placement of a single outrigger. The 16th story level, which is 0.44 stories above the base, is found to be the ideal location for a 40-story building, meeting all code requirements for displacement and story drift. The 18th story level is the best for minimizing seismically generated story drift, while its location successfully reduces time period, displacement, and wind-driven story drift. This study emphasizes how crucial outrigger and belttruss systems are to attaining lateral stability and how crucial accuracy is in structural design for tall structures under a range of loading scenarios.

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