iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: V Month of publication: May 2025

DOI: https://doi.org/10.22214/ijraset.2025.71607

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Comparative Analysis on Wind and Seismic Behaviour of Tall Structure Building with Outrigger System

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Abstract: With the ongoing trend of urban densification, the development of high-rise structures has been widely adopted as a solution to limited land availability. Structural performance under lateral forces such as wind and earthquakes has been regarded as a primary concern in the design of these tall buildings. To address this, outrigger systems have been employed as an effective method to enhance lateral stiffness and control structural displacement. In recent studies, shear walls have been proposed to function as outrigger elements, offering a more integrated and efficient approach to resisting lateral loads. In this research work, it has necessary to compute the outrigger shear wall should be applied at different floor level with a view of comparative analysis of seismic and wind effects which has not been observe yet. Simulations are conducted using an analysis software to assess the response of the selected tall structure (G+79). Different models have generated and comparative analysis has conducted to show the effects of wind and seismic forces and there intensity for that, one case without outrigger and five cases of with outrigger has applied over the structure. The response of the structure to see the performance including displacement, base shear and fundamental time period of entire structure has plotted in graphs and tables to show the percentage variations both horizontal comparative analysis. Finally in conclusion, remarks for each output has inscribe with comparative observations. At last, recommendations has given based on adaptability of the outriggers applications on tall structures based on Taranath's method.
Keywords: Wind load, Gust Factor Method, Seismic Effects, Taranath's Method, Outrigger system, Tall Structure, Fundamental Natural Period

I. INTRODUCTION

In tall buildings, lateral stiffness improvement and drift control under wind and seismic forces are achieved using the outrigger system, which is a structural mechanism commonly applied. The outer columns are connected to the central core—typically housing stairwells and elevators—through horizontal structural elements known as outriggers, by which the system functions. Lateral forces are distributed and overturning moments are reduced by these elements acting like stiff arms. Due to efficient structural behavior, ease of integration, and simplicity, the wall outrigger system has been increasingly recognized among truss-type, belt-type, and hybrid configurations. As outrigger elements, vertical shear walls extending horizontally from the core are used in this configuration. Overturning forces are resisted more effectively, and lateral load sharing is enabled by these walls engaging the perimeter columns. Mechanical and usable spaces are often uninterrupted because deep truss structures are avoided in wall outrigger systems, making them advantageous in architectural and structural coordination. Interior layouts are made more adaptable by aligning wall outriggers with service shafts or partition walls. Due to monolithic behavior and material continuity, wall outriggers offer considerable benefits in reinforced concrete high-rise buildings, although they are less flexible than steel truss outriggers for long-span axial force transfer. Drift and moment demand on the core can be significantly reduced when wall outriggers are placed at one-third or two-thirds of the building height. Interaction with perimeter framing or belt walls, proper detailing, and stiffness balancing are factors upon which their performance depends. Especially in regions sensitive to seismic and wind activity, lateral load control in reinforced concrete tall buildings is efficiently supported by wall outriggers, which provide a practical structural solution.

II. RESEARCH OBJECTIVES

Following heads shows the point of comparison of result parameters between various models during earthquake forces and wind forces for tall structure cases. They are divided into two different sections:-

A. Section I: Obtaining Results for all individual case

1) To determine the maximum displacement obtained for both X and Y direction for all tall structure cases.
2) To examine the base shear obtained for both X and Y direction for all tall structure cases.
3) To examine the time period of entire structure to show the stiffness for all tall structure cases.

B. Section II: Discussion on comparative analysis of effect of wall outrigger usage on entire structure with seismic and wind cases

1) Maximum Displacement in X direction
   a) To conduct a cumulative percentage wise comparative analysis of effect of using outrigger system on Maximum Displacement in X direction for seismic and wind cases.
   b) Comparison on Maximum Displacement in X direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method.
2) Maximum Displacement in X direction
   a) To conduct a cumulative percentage wise comparative analysis of effect of using outrigger system on Maximum Displacement in Y direction for seismic and wind cases.
   b) Comparison on Maximum Displacement in Y direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method.
3) Base Shear in X direction
   a) To conduct a cumulative percentage wise comparative analysis of effect of using outrigger system on Base Shear in X direction for seismic and wind cases.
   b) Comparison on Base Shear in X direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method.
4) Base Shear in Y direction
   a) To conduct a cumulative percentage wise comparative analysis of effect of using outrigger system on Base Shear in Y direction for seismic and wind cases.
   b) Comparison on Base Shear in Y direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method.
5) Fundamental Time Period
   a) To conduct a cumulative percentage wise comparative analysis of effect of using outrigger system on Fundamental Time Period for seismic and wind cases.
   b) Comparison on Fundamental Time Period for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method.

At last the observations and recommendations will be provided.

III.PROCEDURE AND 3D MODELING OF THE STRUCTURE

There are different cases considered in G+79 storey tall structure of same height cases has fixed so that response of the seismic and wind behaviour of the structure by the implementation of with and without wall outrigger member at different floor levels that could be analysed with input parameters taken shown in table 1, table 2 and table 3 shows list of models framed with assigned abbreviation for seismic and wind analysis as mentioned below:-

Table 1: Description of parameters taken for analysis

Parameters	Values used
Building configuration – Tall Structure	G + 79
Building type	Residential apartment
Total constructed plan area	30m x 30m = 900 m^2
Height of building	328 m from ground level
Height of each floor and depth of footing	4 m each and 4 m deep
Beam dimensions	900 mm x 700 mm 750 mm x 500 mm
Shear wall thickness	150 mm

Outrigger wall thickness	150 mm
Slab thickness & Staircase waist slab	155 mm both
Column dimensions	1250 mm x 1250 mm 950 mm x 950 mm 650 mm x 650 mm
Material properties	Concrete (M30) Steel (Fe 500)

Table 2: List of models framed with assigned abbreviation for seismic analysis

S. No.	Models framed for analysis for seismic effects	Abbreviation
1.	G+79 storey Residential Apartment with no outrigger application and considering seismic analysis	TS-SN
2.	G+79 storey Residential Apartment with single outrigger application and considering seismic analysis	TS-SA
3.	G+79 storey Residential Apartment with two outrigger application and considering seismic analysis	TS-SB
4.	G+79 storey Residential Apartment with three outrigger application and considering seismic analysis	TS-SC
5.	G+79 storey Residential Apartment with four outrigger application and considering seismic analysis	TS-SD
6.	G+79 storey Residential Apartment with five outrigger application and considering seismic analysis	TS-SE

Table 3: List of models framed with assigned abbreviation for wind analysis

S. No.	Models framed for analysis for wind effects	Abbreviation
1.	G+79 storey Residential Apartment with no outrigger application and considering wind analysis	TS-WN
2.	G+79 storey Residential Apartment with single outrigger application and considering wind analysis.	TS-WA
3.	G+79 storey Residential Apartment with two outrigger application and considering wind analysis	TS-WB
4.	G+79 storey Residential Apartment with three outrigger application and considering wind analysis	TS-WC
5.	G+79 storey Residential Apartment with four outrigger application and considering wind analysis	TS-WD
6.	G+79 storey Residential Apartment with five outrigger application and considering wind analysis	TS-WE

A. *Outrigger Calculation*

Outrigger used single or multiple were selected and applied to the structure considering height from top of the tall structure as mentioned in the previous chapter as (1/n + 1), (2/n + 1), (3/n + 1),……(n/n + 1) respectively as per requirements. The table 4 shown below consist of outrigger case fixation and its story application calculation.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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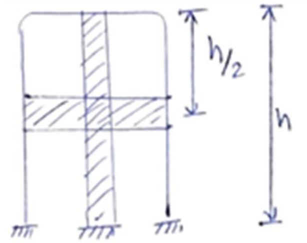
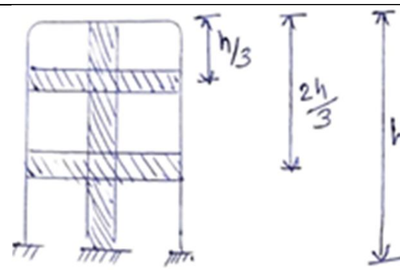
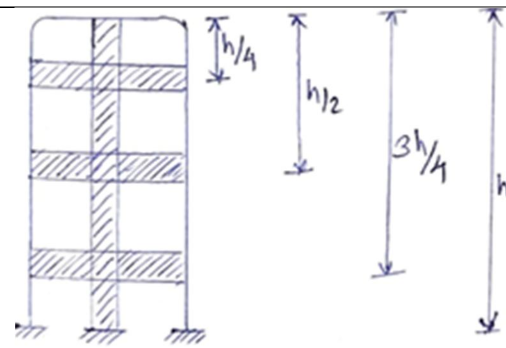
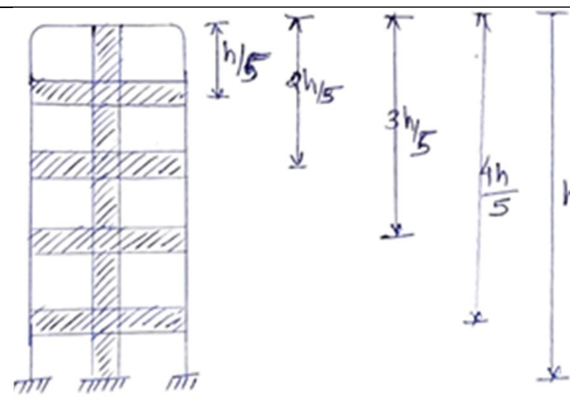
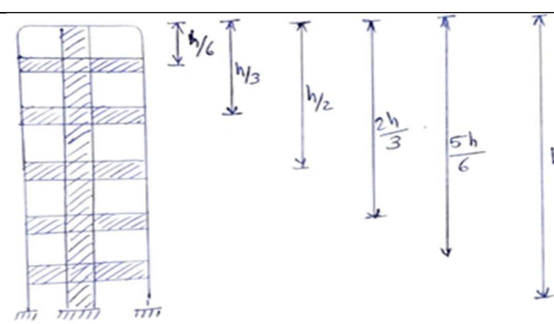
Table 4: Details of outrigger case fixation

Number of outriggers	Part divisions calculations	Outrigger diagram
Single Outrigger	$\frac{h}{2}$ & h	
Two Outriggers	$\frac{h}{3}, \frac{2h}{3}$ & h	
Three Outriggers	$\frac{h}{4}, \frac{h}{2}, \frac{3h}{4}$ & h	
Four Outriggers	$\frac{h}{5}, \frac{2h}{5}, \frac{3h}{5}, \frac{4h}{5}$ & h	
Five Outriggers	$\frac{h}{6}, \frac{h}{3}, \frac{h}{2}, \frac{2h}{3}, \frac{5h}{6}$ & h	

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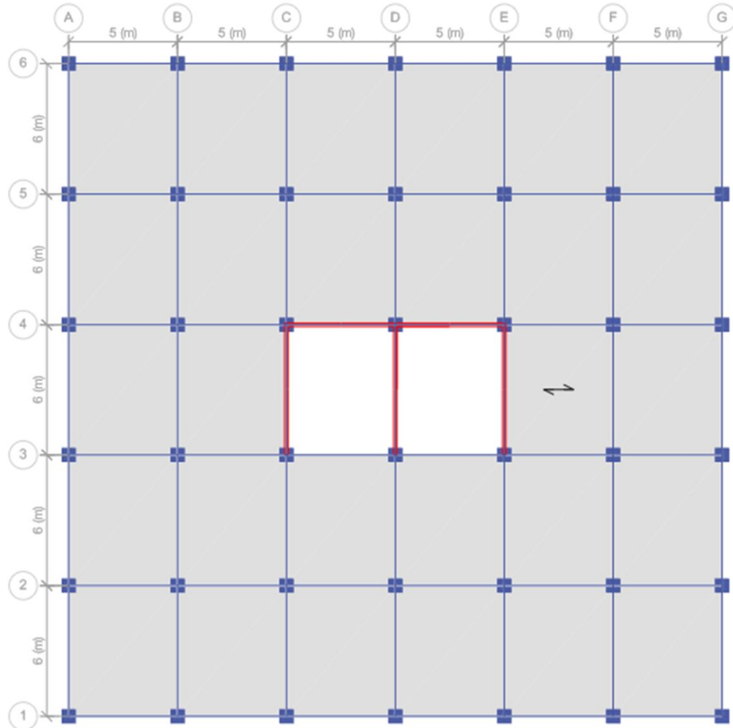

Fig. 1: Without wall outrigger – Plan of the tall structure

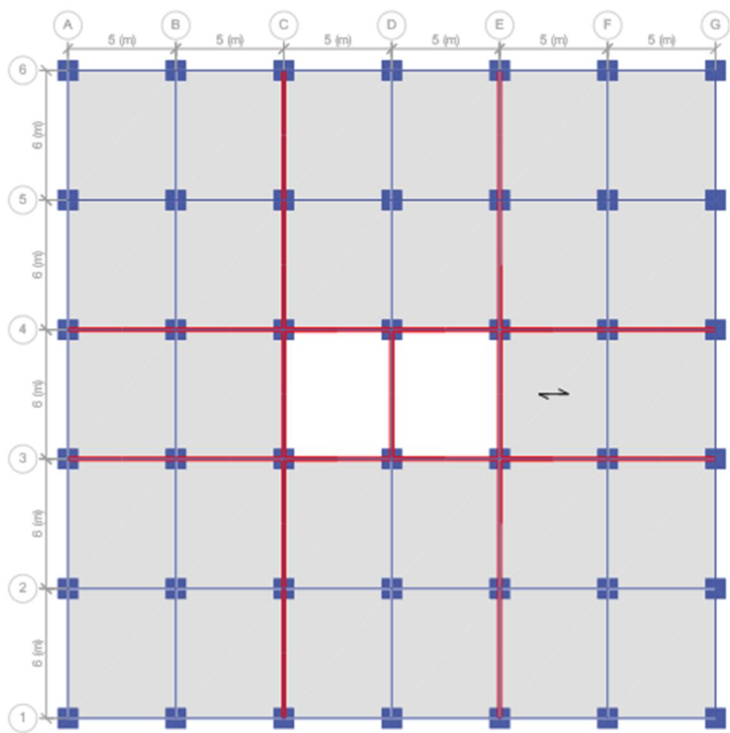

Fig. 2: With outrigger - Plan of the tall structure

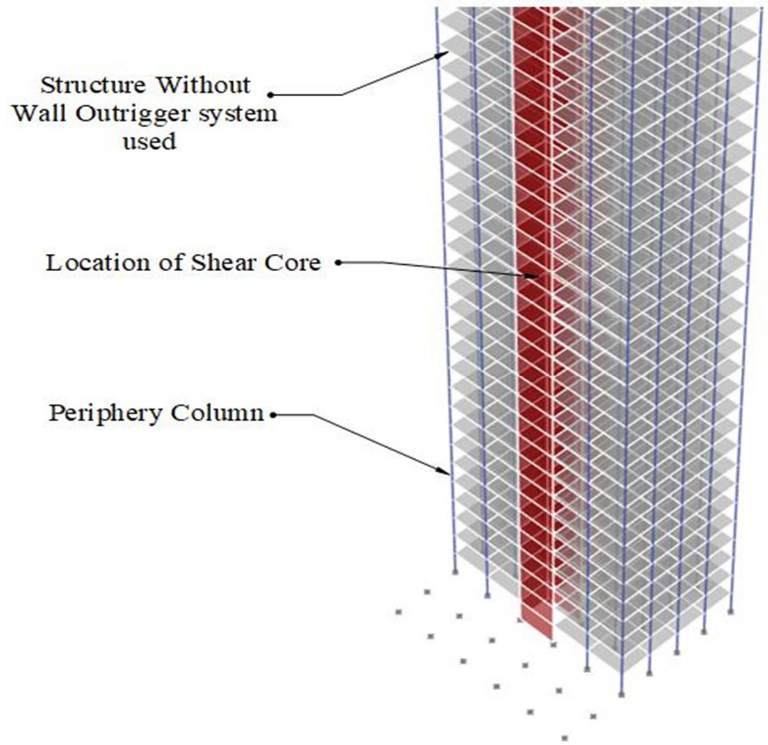

Fig. 3: Without wall outrigger - 3D cutout view of the tall structure

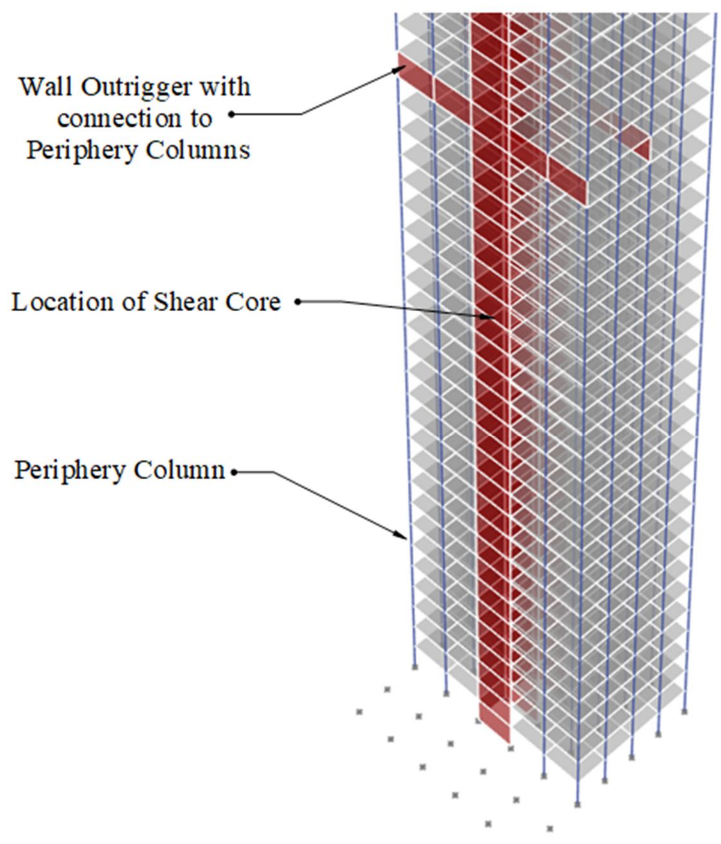

Fig. 4: With wall outrigger - 3D cutout view of the tall structure

IV. RESULTS AND DISCUSSION

Results are shown in graphical form are as follows:

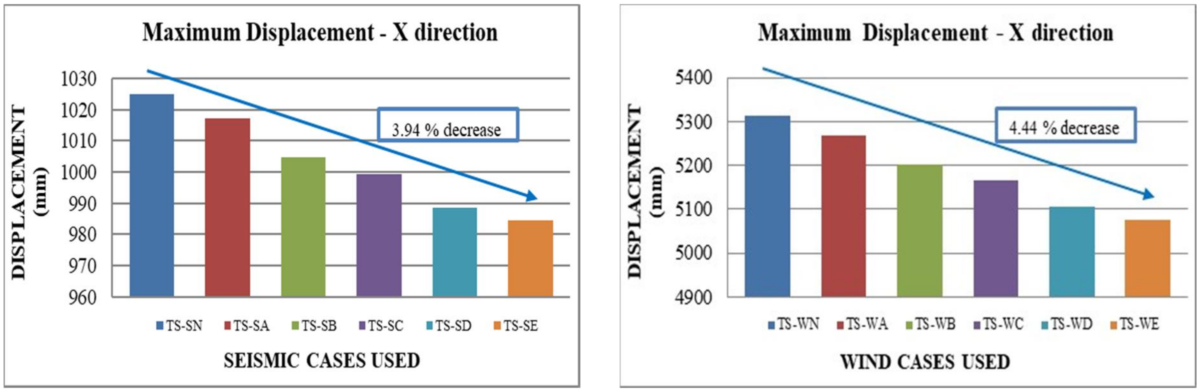

Fig. 5: Comparative analysis of effect of using outrigger system on Maximum Displacement in X direction for all cases

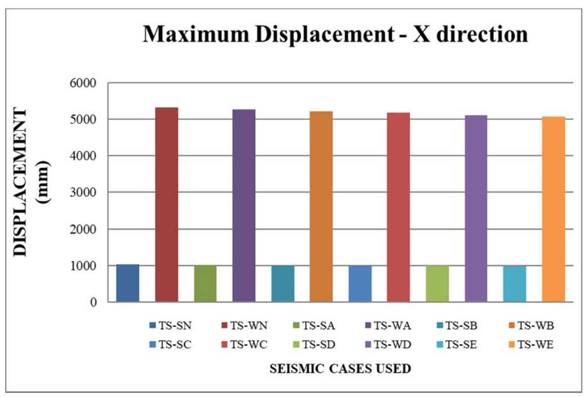

Fig. 6: Comparison on Maximum Displacement in X direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method

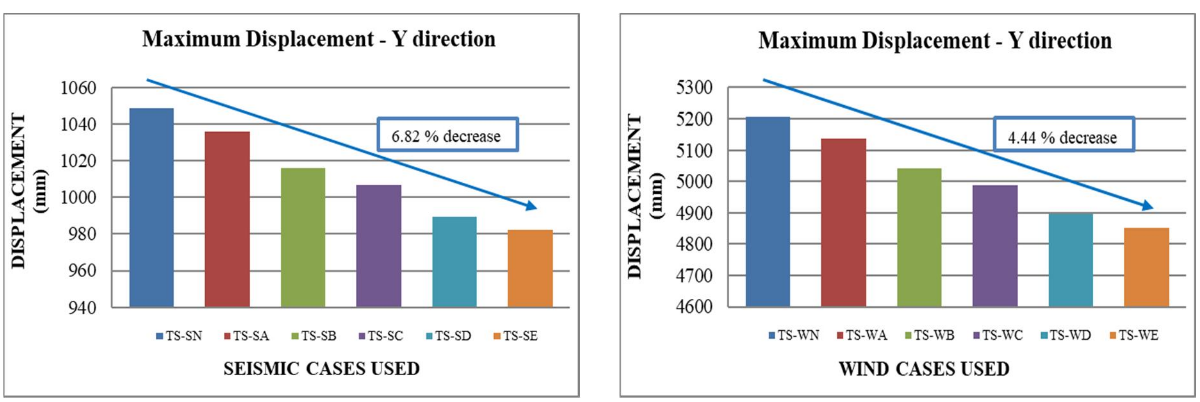

Fig. 7: Comparative analysis of effect of using outrigger system on Maximum Displacement in Y direction for all cases

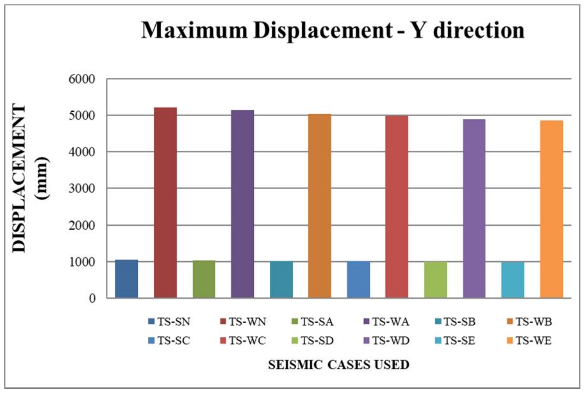

Fig. 8: Comparison on Maximum Displacement in Y direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method

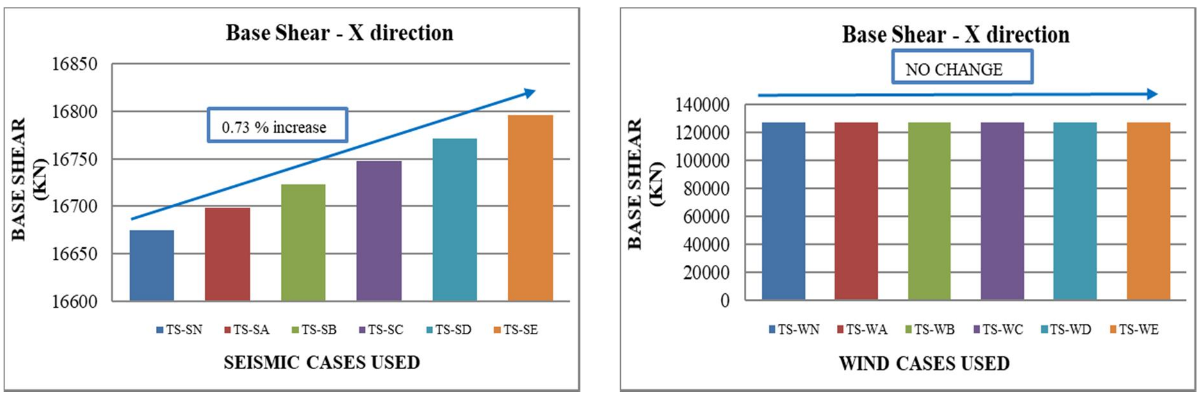

Fig. 9: Comparative analysis of effect of using outrigger system on Base Shear in X direction for all cases

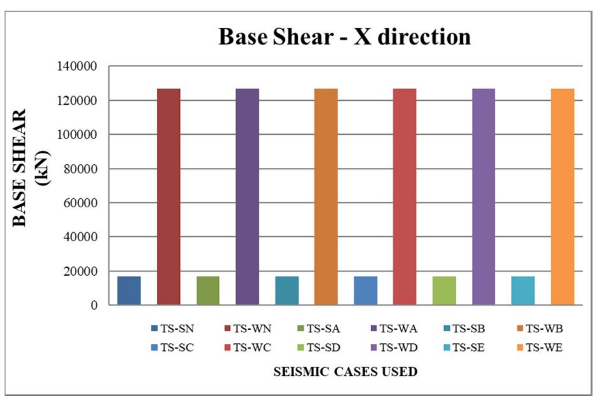

Fig. 10: Comparison on Base Shear in X direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method

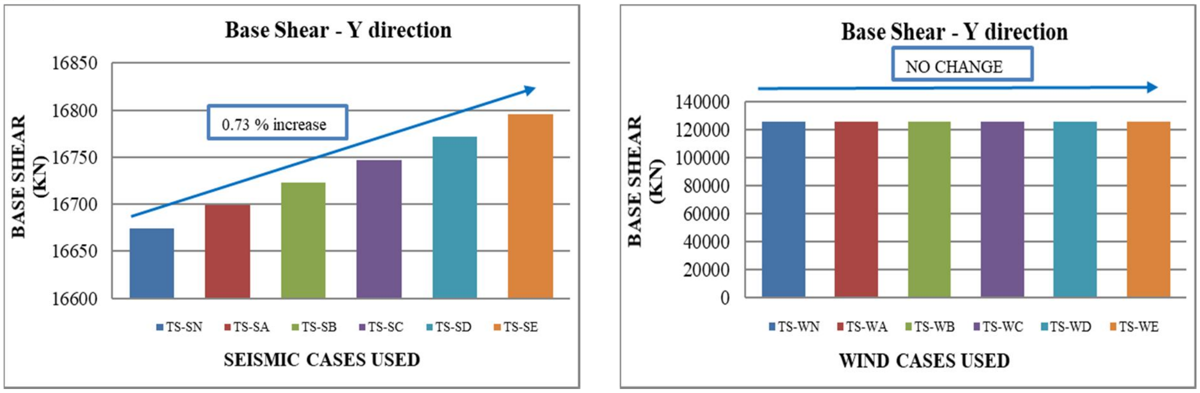

Fig. 11: Comparative analysis of effect of using outrigger system on Base Shear in Y direction for all cases

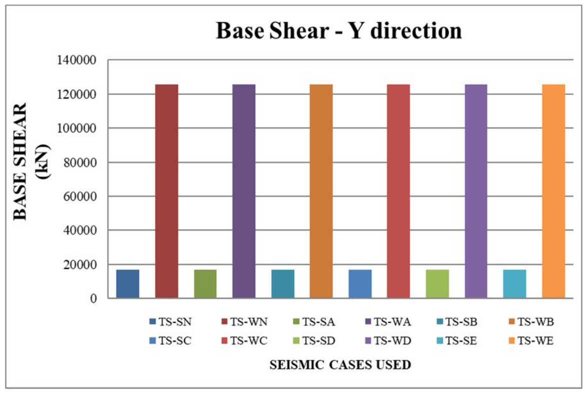

Fig. 12: Comparison on Base Shear in Y direction for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method

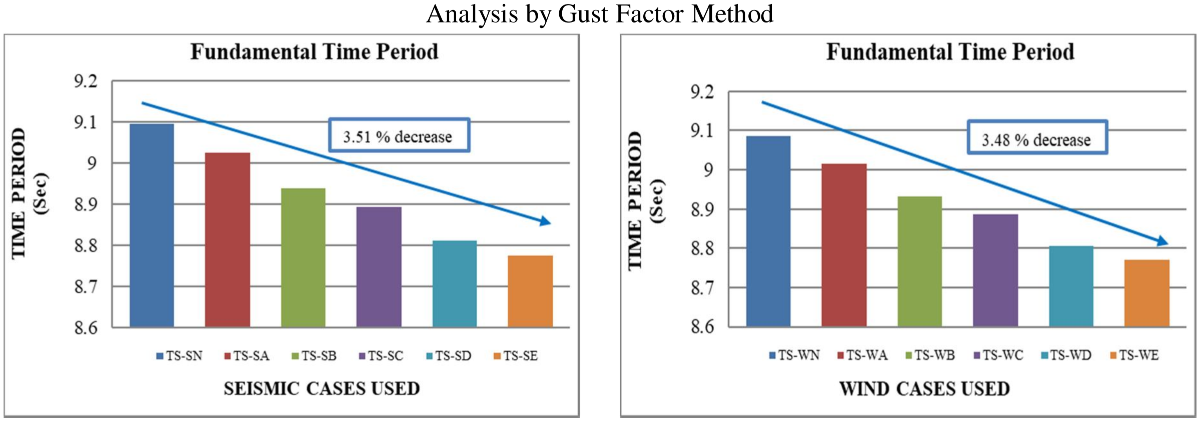

Fig. 13: Comparative analysis of effect of using outrigger system on Fundamental Time Period for all cases

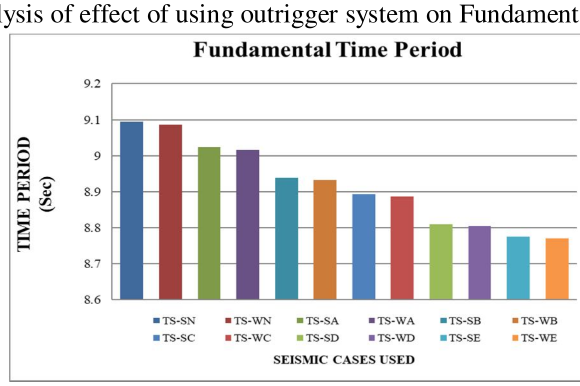

Fig. 14: Comparison on Fundamental Time Period for all cases of Response Spectrum Analysis and Wind Analysis by Gust Factor Method

V. CONCLUSION

The conclusion can be pointed out are as follows:-

1) Maximum Displacement in X direction
   a. In case of Maximum displacement in X direction, there has a cumulative percentage decrease obtained with a value of 3.94% when using multiple outriggers under seismic effects and 4.44% cumulative percentage decrease under wind effects.
   b. There has a percentage rise in maximum displacement in X direction observed from seismic to wind forces.

2) Maximum Displacement in Y direction
   a. In case of Maximum displacement in Y direction, there has a cumulative percentage decrease obtained with a value of 6.35% when using multiple outriggers under seismic effects and 6.82% cumulative percentage decrease under wind effects.
   b. There has a percentage rise in maximum displacement in Y direction observed from seismic to wind forces.

3) Base Shear in X direction
   a. In case of Base Shear in X direction, there has a cumulative percentage increase obtained with a value of 0.73% when using multiple outriggers under seismic effects and no change in cumulative percentage under wind effects with same values.
   b. There has a percentage rise in Base Shear in X direction observed from seismic to wind forces.

4) Base Shear in Y direction
   a. In case of Base Shear in Y direction, there has a cumulative percentage increase obtained with a value of 0.73% when using multiple outriggers under seismic effects and no change in cumulative percentage under wind effects with same values.
   b. There has a percentage rise in Base Shear in Y direction observed from seismic to wind forces.

5) Fundamental Time Period
   a. In case of Fundamental Time Period for entire structures, there has a cumulative percentage decrease obtained with a value of 3.51% when using multiple outriggers under seismic effects and 3.48% decrease in cumulative percentage under wind effects.
   b. There has a percentage fall in Fundamental Time Period for entire structures observed from seismic to wind forces.

Observing all the parameters, after the application of outrigger wall provided at different stories in tall structures, it has proved that the lateral forces resistance is more and depends on the usage. It has also observed that the wind forces and its effect is very high as compared to seismic forces. The use of multiple outriggers has observed to be a best approach as efficiency and stability of the structure increases accordingly and should be recommended when this type of stability enhancing system in tall structure will be provided.

VI. ACKNOWLEDGEMENTS

I, Sagar Jain, M. E. Student, would like to thank *Prof. Dr. Savita Maru,* Professor, Department of Civil Engineering, Ujjain Engineering College, Ujjain, (M.P.), India for her valuable guidance from the commencement of the work up to the completion of the work along with her encouraging thoughts.

REFERENCES

[1] Abdul Karim Mulla, Srinivas B. N, “A Study on Outrigger System in a Tall R.C Structure with Steel Bracing”, International Journal of Engineering Research & Technology (IJERT), 2015

[2] Abeena mol N M,et. al., (2016), “Performance of Different Outrigger Structural Systems”, International Research Journal of Engineering and Technology (IRJET), ISSN 2395-0056, Volume: 03, Issue: 09, pp. 1104-1107.

[3] Archit Dangi et. al. (2019), “Determination of Seismic parameters of R.C.C. Building Using Shear Core Outrigger, Wall Belt and Truss Belt Systems”, International Journal of Advanced Engineering Research and Science (IJAERS), ISSN: 2349-6495, Vol-5, Issue-9, pp. 305-309.

[4] Archit Dangi et. al. (2019), “Stability Enhancement of Optimum Outriggers and Belt Truss Structural System”, International Research Journal of Engineering and Technology (IRJET), ISSN: 2395-0056, Volume: 06 Issue: 02, pp.772-780.

[5] Ashitha V Kalam et. al. (2019), “Dynamic Wind Analysis of RC Bundled Tube In Tube Structure Using Etabs”, International Research Journal of Engineering and Technology (IRJET), ISSN: 2395-0056, Volume: 06, Issue: 05, pp.7457-7462.

[6] Brown, T., & Davis, R. (2007). Effectiveness of outrigger systems in high-rise building stability. Journal of Structural Engineering, 133(8), 1234–1243.

[7] C. Bhargav Krishna, V. Rangarao “Comparative Study of Usage of Outrigger And Belt Truss System for High-Rise Concrete Buildings” International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-7, Issue-6C2, April 2019

[8] Dattaprasad Patil et. al. (2018), “Comparative Study of RC Framed Structure and Tubular Structures”, International Journal of Scientific Research in Science, Engineering and Technology, ISSN: 2394-4099, Volume 4, Issue 8, pp.475-481.

[9] Dey, Subhashish, G. T. N. Veerendra, and Obulasetti Aparna. "A systematic analysis of retrofitting tools in the residential buildings to improve the energy performances by using the 15. STAAD Pro Software." Innovative Infrastructure Solutions 8.8 (2023): 221.

[10] Ganatra, Viren P., P. R. A. Jhummarwala, and K. B. Parikh. "Study on Behaviour of Outrigger System on High Rise Structure by Varying Outrigger Depth." International Journal for Research in Applied Science & Engineering Technology (IJRASET) 5 (2017).

[11] Gerasimidis, S., C. C. Baniotopoulos, and E. Efthymiou. "Optimum Outrigger Locations of High-Rise Steel Buildings for Windloading." Optimum Outrigger Locations of High-Rise Steel Buildings for Windloading (2009): 1000-1003.

[12] Ho, Goman WM. "The evolution of outrigger system in tall buildings." International Journal of High-Rise Buildings 5.1 (2016).

[13] Jipa, Andrei, and Benjamin Dillenburger. "3D printed formwork for concrete: state-of-the-art, opportunities, challenges, and applications." 3D Printing and Additive Manufacturing 9.2 (2022).

[14] Joseph, Roshen, Aman Mwafy, and M. Shahria Alam. "Seismic performance upgrade of substandard RC buildings with different structural systems using advanced retrofit techniques." Journal of Building Engineering 59 (2022).

[15] Johnson, P. (2010). Optimization of outrigger placement for tall buildings. Structural Design International, 20(3), 189–200.

[16] Kumar, S., & Singh, A. (2006). Numerical and experimental studies on outrigger systems in high-rise buildings. Engineering Structures, 28(5), 719–728.

[17] Kiran Kamath et. al. (2012), "A Study on Static and Dynamic Behavior of Outrigger Structural System for Tall Buildings", Bonfring International Journal of Industrial Engineering and Management Science, ISSN 2277-5056, Vol. 2, No. 4, pp- 15-20.

[18] Kiran Kamath, N. Divya, Asha U Rao, "Study on Static and Dynamic Behavior of Outrigger Structural System for Tall Buildings". Bonfring International Journal of Industrial Engineering and Management Science, December 2012

[19] Kwang Rang Chung et. al., (2015), "Outrigger systems for Tall Buildings in Korea", International Journal of High Rise Buildings, Volume: 04 Issue: 03, pp. 209-217.

[20] Lee, C., & Park, J. (2009). Lateral displacement control in tall buildings using outrigger systems. International Journal of High-Rise Buildings, 12(2), 45–52.

[21] Maas, Andrew IR, et al. "Traumatic brain injury: integrated approaches to improve prevention, clinical care, and research." The Lancet Neurology 16.12 (2017). 10. Qiu, Xiaojie, et al. "Reversed graph embedding resolves complex single-cell trajectories." Nature methods 14.10 (2017).

[22] Mohammad Bilal Rasheed et. al., (2020), "An Efficient Approach to Determine the Effects of Different Grades of Concrete in Outrigger and Wall Belt Supported System", International Journal for Research in Applied Science & Engineering Technology, ISSN: 2321-9653, Volume 8, Issue VII, pp. 1833-1842.

[23] Mohammad Bilal Rasheed et. al., (2020), "Conceptual Approach on Effect of Various Concrete Grade in Outrigger and Wall Belt Supported System: A Perceptional Review", International Journal of Advanced Engineering Research and Science (IJAERS), ISSN: 2349-6495, Vol-7, Issue-5, pp. 100-104.

[24] Mohammed Mudabbir Ahmed et. al. (2022), "A Comparative Study on the Seismic Performance of Multi-storey Buildings with Different Structural Systems", IOP Conf. Series: Earth and Environmental Science, ICSDI-2022, 012010.

[25] Mohammed Sanaullah Shareef, et. al. (2022), "Dynamic Analysis of High-Rise Structures with Outrigger Structural System Subjected To Lateral Loads", IOP Conf. Series: Earth and Environmental Science, ICSDI-2022, 012010.

[26] Mousleh, Ibrahim, and Mustafa Batikha. "The cost efficiency by using outriggers in tall buildings." Proceedings of 9th International Conference on Contemporary Issues in Science. Engineering & Management, Dubai, UAE. 2018.

[27] Mustafa Hussaini, et. al. (2020), "Seismic Performance of Bracing, Diagrid and Outrigger System", International Journal of Innovative Technology and Exploring Engineering (IJITEE), ISSN: 2278-3075, Volume-9 Issue-7, pp. 32-36.

[28] N. Herath, N. Haritos, T. Ngo & P. Mendis, "Behaviour of Outrigger Beams in High rise Buildings under Earthquake Loads", Australian Earthquake Engineering Society Conference, 2009

[29] Nanduri, PMB Raj Kiran, B. Suresh, and MD Ihtesham Hussain. "Optimum position of outrigger system for high-rise reinforced concrete buildings under wind and earthquake loadings." American Journal of Engineering Research 2.8 (2013).

[30] Neeraj Patel et. al. (2019), "Use of Shear Wall Belt at Optimum Height to Increase Lateral Load Handling Capacity in Multistory Building: A Review", International Journal of Advanced Engineering Research and Science (IJAERS), ISSN: 2349-6495, Vol-6, Issue-4, pp. 310-314.

[31] Neeraj Patel et. al., (2019), "Use of Shear Wall Belt at Optimum Height to Increase Lateral Load Handling Capacity in Multistory Building", International Journal for Research in Engineering Application & Management (IJREAM), ISSN: 2454-9150 Vol-04, Issue-10, pp. 596-603.

[32] Palak Joshi et. al., (2021), "Dynamic Analysis of Tubular Systems in Tall Buildings", International Research Journal of Engineering and Technology, ISSN: 2395-0056, Volume: 08, Issue: 11, pp. 655-662.

[33] Pankaj Sharma et. al. (2018), "Dynamic Analysis Of Outrigger Systems In High Rise Building Against Lateral Loading", International Journal of Civil Engineering and Technology (IJCIET), ISSN Print: 0976-6308, Volume 9, Issue 8, pp. 61-70.

[34] Ramezani, Mahyar, et al. "Uncertainty models for the structural design of floating offshore wind turbines: A review." Renewable and Sustainable Energy Reviews 185 (2023).

[35] Rasheed Altouhami et. al. (2020), "Wind Effect on Difference Shear Wall Position with Different Shape Configuration", Third International Conference on Technical Sciences (ICST2020), 28 – 30 November 2020, Tripoli – Libya.

[36] Rob J. Smith and Michael R. Willford, "The Damped Outrigger concept for Tall buildings", The Structural Design of Tall and Special Buildings, 2007

[37] Saeed, Ahmed, et al. "A comprehensive study on the effect of regular and staggered openings on the seismic performance of shear walls." Buildings 12.9 1293, (2022).

[38] Sakshi Goyal et. al. (2020), "Analytical Practices to Obtain Efficient Concrete Grade in Outrigger Walls below Plinth Level in Multistorey Building", International Journal of Advanced Engineering Research and Science (IJAERS), ISSN: 2349-6495, Vol-7, Issue-7, pp. 367-374.

[39] Sakshi Goyal, et. al. (2020), "Stability Increment Practices using Wall Outrigger Members: A Review", International Journal for Research in Applied Science & Engineering Technology (IJRASET), ISSN: 2321-9653, Volume 8, Issue VI, pp. 1656-1661.

[40] Saxena, Ritik, S. P. Singh, and M. Abdul Akbar. "Determination of optimum design parameters of non-linear damped outrigger system for high-rise buildings." Asian Journal of Civil Engineering 24.2 (2023).

[41] Shareef, Mohammed Sanaullah, Khaja Musab Manzoor, and Mohammed Muqeem. "Dynamic Analysis of High-Rise Structures with Outrigger Structural System Subjected To Lateral Loads." IOP Conference Series: Earth and Environmental Science. Vol. 1026. No. 1. IOP Publishing, (2022).

[42] Smith, J. (2008). Seismic and wind load considerations in outrigger system design. Structural Engineering Review, 16(1), 30–39.

[43] Sridevi, G., et al. "Comparative study on dynamic behaviour of RC building with conventional and flat slab." Advances in Structural Engineering and Rehabilitation: Select Proceedings of TRACE 2018. Singapore: Springer Singapore, 2019.
[44] Srinivas Suresh Kogilgeri, Beryl Shanthapriya, “A study on Behavior of Outrigger System on High Rise Steel Structure by Varying Outrigger Depth”, IJRET: International Journal of Research in Engineering and Technology, 2015
[45] Suraj Nayak U et. al. (2016), “Effect of Static and Dynamic Wind Forces on RC Tall Structures at different Height, in different Zones and in different Terrain Category using Gust Factor Method As Per Is: 875 (Part 3) 1987”, International Journal of Modern Engineering Research, ISSN: 2249–6645, Vol. 6, issue 3, pp. 47-61.
[46] Thejaswini R M, Rashmi A R, “Analysis and Comparison of Different Lateral Load Resisting Structural Forms”, International Journal of Engineering Research & Technology (IJERT), 2015
[47] Wang, Y., Chen, L., & Zhang, H. (2005). Synergistic effects of core and outrigger systems on tall building stability. Earthquake Engineering & Structural Dynamics, 34(10), 1203–1217.
[48] Xi, Renqiang, et al. "Framework for dynamic response analysis of monopile supported offshore wind turbine excited by combined wind-wave-earthquake loading." Ocean Engineering 247 (2022).