IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

SEISMIC BEHAVIOUR OF HIGH-RISE BUILDING WITH OUTRIGGER

[1]Ritika R. Patil,[2]Sachin P. Patil,[3]Ravindra M. Desai

[1]P.G. Student of Sanjay Ghodawat university,[2&3]Assistant Professor of Sanjay Ghodawat university,
[1]Civil Engineering, [1]Sanjay Ghodawat university, Kolhapur, India

Abstract: The High-rise buildings are particularly susceptible to lateral forces from earthquakes and wind loads. To ensure these structures remain safe, various structural systems are employed, one of which is the outrigger system. This research involves conducting both linear and nonlinear dynamic analyses of outrigger systems in 20 and 40-storey buildings. To enhance ductility and provide adequate stiffness, concrete outriggers will be installed between shear walls and external columns. The outrigger system will include X and V type bracings, with and without belt truss systems, positioned according to Taranath's theory for a three-outrigger system, they should be at the one-quarter, one-half, and three quarter heights, Analytical models were created using finite element modeling software, categorized into two sets. This paper compares the most effective outrigger structural system, the conventional outrigger, with the virtual outrigger system. The primary goal is to model a building to determine the optimal outrigger locations under earthquake loads. Key parameters such as lateral displacement, base shear, and story drift are examined. The study concludes that the virtual outrigger system, by mitigating the disadvantages of conventional outriggers, proves to be the most effective among all outrigger types in various aspects

Keywords–*Belt truss system, High-rise & tall building, Linear and Non-linear method, RCC framed structure, Outrigger system,*

1. INTRODUCTION

Earthquake-resistant construction necessitates that buildings are securely grounded and firmly connected to the earth through their foundations. It's important to avoid constructing on loose sands or clays, as these materials can lead to significant movement and uneven stresses during an earthquake. With the rapid expansion of infrastructure to support modern society, cities are seeing an increase in tall buildings. As buildings rise higher, ensuring their lateral stability and managing sway becomes a critical engineering challenge. Structural systems have been continuously developed to address these issues, with the outrigger and belt truss system emerging as a particularly effective solution. Popular in construction since the 1980s due to its unique combination of architectural flexibility and structural efficiency. This system has shown great promise in enhancing lateral stability and reducing sway in high structures.The outrigger and belt truss system is widely recognized as an effective structural approach to control excessive drift caused by lateral loads, such as wind or earthquake forces. This system is particularly beneficial in high-rise buildings located in seismic zones or areas dominated by strong wind loads, as it minimizes the risk of damage to both structural and non-structural components during small to moderate lateral events.

Researchers have examined how incorporating outriggers with different setups in tall buildings' frames under varying loads can effectively manage and minimize deflections and stresses. Mistry and Dhyani (2015) [11] carried out a study on the best placement of outriggers in the structural system of high-rise buildings. They recommended that the first outrigger be located at the building's mid-height, the second at one-quarter of the height, and the third at three-quarters of the height of the structure. Nanduri et al.(2013) [17] investigated the optimal placement of an outrigger system with belt trusses for high-rise reinforced concrete buildings subjected to earthquake loads. They determined that the best location for the outrigger is roughly at half the building's height. Iqra Bano Ayaz Ahmad Khan et al. (2018) [10] found that the virtual outrigger system outperforms conventional outriggers, overcoming their limitations. Their research highlighted concrete and steel as superior materials for outrigger construction, affirming virtual outriggers as the most effective choice across all evaluated criteria. Nima Sthapit (2023) [15] [22]. study evaluates outrigger beam effectiveness in a 35-story building, finding that the most efficient arrangement includes belt and cap trusses positioned around the mid-height. The research also indicates that elevating outriggers is more effective for buildings with a smaller slenderness ratio in controlling horizontal movement.The optimum location for outriggers was given by (1/n+1), (2/n+1), (3/n+1), (4/n+1) . . . (n/n+1) of height . In real life, the building is shaking with multiple earthquakes in a life span of structure and subjected to MCE, Therefore the performance of the structure under these MCE is studied, Sachin Patil et al. 2021 [19]. Current practice codes, such as IS1893-2016 [9], EUROCODE 8 [6], FEMA 368 [7], IS456:2000 [8]. Patricia M. Putri et al. (2023) [18] investigated outrigger structural systems and determined that taller floor heights increase drift, displacement, and stiffness, while reducing overall performance. Additionally, they found that structural member failures decrease with higher stiffness, highlighting the comparative effectiveness of virtual outrigger systems over conventional designs.

The main purpose of this paper to assess the impact of X-type and V-type bracing systems within an outrigger configuration for high-rise buildings. I aim to analyze and design the dynamic behavior of both conventional RCC frame buildings with outriggers and virtual outrigger buildings. Additionally, I plan to conduct a comparative study between conventional and virtual outrigger systems to determine their performance differences. Lastly, I will evaluate and recommend the most suitable outrigger system for dynamic analysis based on the findings.

2. DESCRIPTION OF MODEL & SEISMIC INPUT

Two different types of structure were considered to represent high structure for analysis and design purposes. The model has G+20, G+40 storied with regular configurations for detailed analysis. The outrigger system will consist of X-type and V-type bracings, along with & without belt truss system. The CSI SAP2000 program is used to design these structures. To examine the performance of the structure under seismic forces in accordance with applicable requirements, perform response spectrum analysis. Conduct a nonlinear analysis of the time history to assess the structures dynamic reaction to actual ground motion. Utilize load combinations that adhere to IS 1893 and Eurocode standards to replicate practical loading scenarios.

Table No.1 Modeling Parameter

Plan Dimension	25m X 25m
No of stories	20story ,40 story
Height of storey	3m
Type of bracing	X and V Type
Size of Column	800X 800,700X700 600X600,500X500
Size of Beam	300X550,300x500,300x450
Size of Slab	150mm
Shear Wall	200mm
Concrete Outriggers & Belt Truss	300x450
Concrete Grade	M30, M50

Table No. 2 Loading & Seismic Parameters

Floor Finish	1.5 KN/Sqm.
Live Load on floors	3 KN/Sqm.
Wall Load (External and internal)	12 KN/m.
Parapet Wall Load	4 KN/m.
Seismic zone	V
Seismic zone factor - Z	0.36
Soil Type	Hard rock - I
Response Reduction factor	3
Importance factor – I	1
Damping Ratio	5%

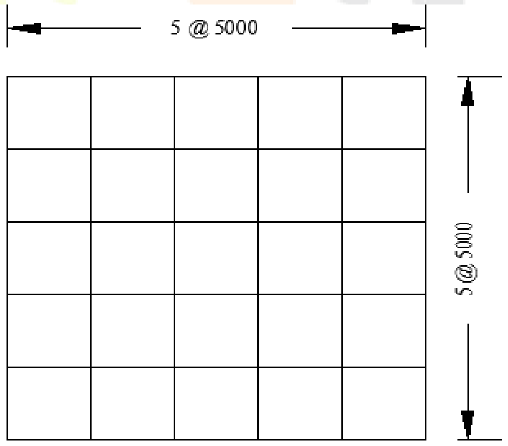


Fig.1- Plan of RC Building Frame

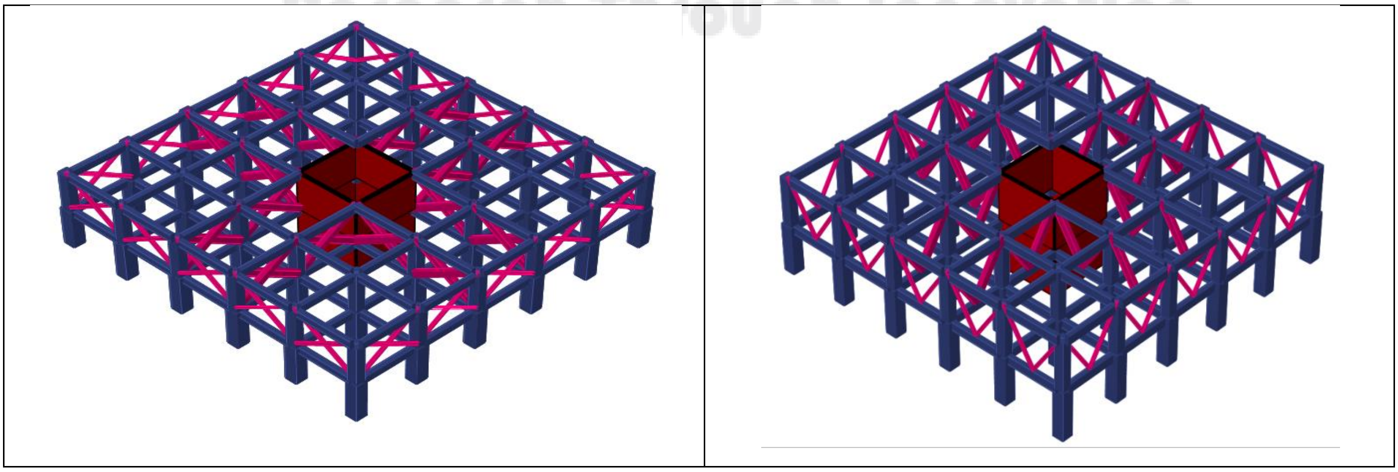


Fig.2- X-type and V-type Braced Concrete Outrigger- With Belt Truss

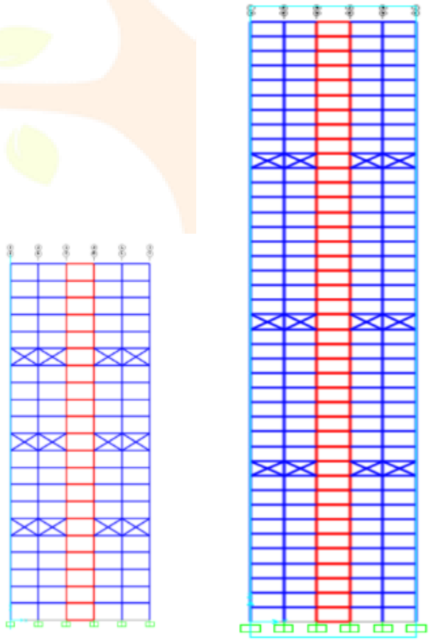
Hinges are critical junctures in a building where cracks and weakening are more likely to happen. This is due to the fact that hinges can experience significant flexural (or shear) movements without a significant decrease in strength. Hinges, commonly located at the edges of beams and columns, are usually recognized by the existence of cross-diagonal cracks. In Pushover Analysis (POA), it is crucial to assess plastic hinges along with the capacity curve in non-linear static analysis. The default hinge model defined in SAP2000 is used to model plastic hinges.

In a computer simulation, hinges are depicted as points where the stiffness of the element is decreased to zero, enabling the model to accurately replicate the significant displacements observed at hinges. The moment M3 hinge type is utilized for beam sections, and the interacting P-M2-M3 hinge type is used for column sections. The structural performance can be assessed by examining the characteristics of plastic hinges with a colour-code and their corresponding performance levels. By observing the colour coding, the damage status of the structure can be assessed

2.1 LIST OF MODEL:

Listed below are the details of different established software models, which includes story height, bracing system type, outrigger type, and belt truss placement at various levels, that were considered for the analysis.

- **20 story building & outriggers is located at 5th , 10th, 15th story .**
- **40 story building & outriggers is located at 10th , 20th , 30th story**
- Model 1 - Conventional frame model without outriggers & belt truss.
- Model 2 - X-CO: With X-type braced concrete outrigger - without belt truss.
- Model 3 - V-CO: With V-type braced concrete outrigger - without belt truss.
- Model 4 - X-CO + BT: With X-type braced concrete outrigger - with belt truss.
- Model 5 - V-CO + BT: With V-type braced concrete outrigger – with belt truss



a)20-story b) 40-story

Fig. No.3- 2D Framed Structure With X-type Braced Concrete Outrigger

3 TIME HISTORY ANALYSIS

Non-linear Time History Analysis is crucial for seismic evaluation of structures, especially when their response displays non-linear characteristics. This method consists of a detailed analysis of how a structure reacts over time to changing loads, usually depicted by the seismic activity's timeline. Nonlinear time history analysis is necessary to accurately investigate the nonlinear response of structures. This method involves utilizing genuine ground motion recordings on the structure. This particular analysis technique stands out from other approximate analysis techniques because it considers the dynamic properties of the structure and calculates the building's responses in terms of forces or deformations over time. Inertial forces originate from ground movements. Analyzing past patterns and trends is referred to as time history analysis. It can be utilized to predict upcoming events or to comprehend the motives behind specific actions or decisions. To complete the nonlinear time-history analysis in SAP2000, follow these steps: First, define member properties, nonlinear behaviors, and vertical loads (including live and dead loads) for the building models. A function showing acceleration over time can describe the ground motion recorded. Following this, the time history and analysis parameters are established to conduct a nonlinear time history analysis. The overall duration is the result of the output time-step size multiplied by the number of output time steps.

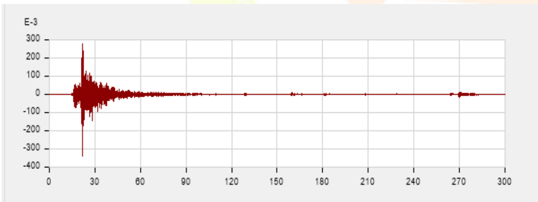
3.1 EARTHQUAKE EVENTS-

Table No.3. Earthquake Events

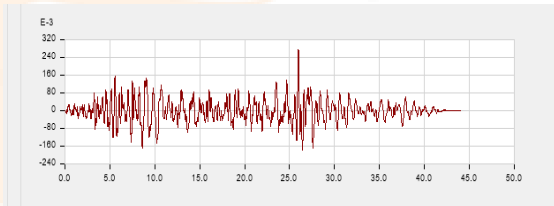
SR. NO	EVENT NAME	EVENT STATION	DATE	MW	DISTANCE FROM EPI.	MECH NISM	PGA
1.	Iwate Japan	Yoneyamac-ho Tome City	13/06/2008	6.9	38.95	Reverse fault	0.30
2.	Landers	Toshua Tree	28/06/1992	7.28	11.03	Strike Slip	0.27
3.	Tabas Iran	Boshrooyeh	16/09/1978	7.35	24.07	Reverse fault	0.20
4.	Chuetsu-oki	MatsushiroTokamach i	16/07/2007	6.8	18.16	Reverse fault	0.22
5.	Friuli, Italy-01	Tolmezzo	06/05/1986	6.5	14.97	Reverse fault	0.38
6	Imperial Valley-06	El Centro Array #8	15/10/1979	6.53	30.86	strike slip	0.6
7.	Taiwan Smart 1(45)	Smart1 MO1	14/11/1986	7.3	56.87	Reverse fault	0.44

Table No. 4. Ground Motion

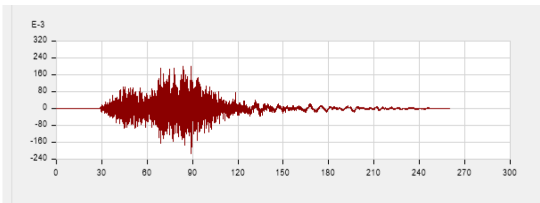
a) GM of Iwate Japan earthquake



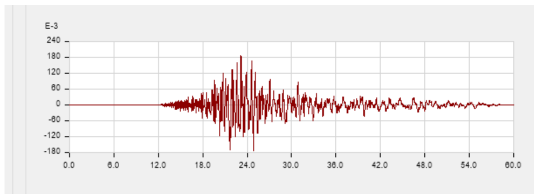
b) GM of Landers earthquake



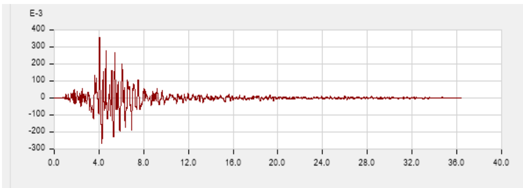
c) GM of Tabas Iran earthquake



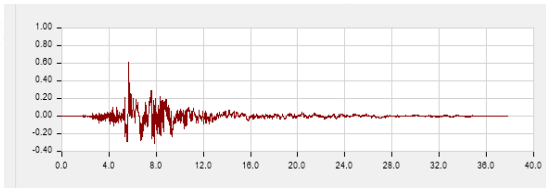
d) GM of Chuetsu-oki earthquake



e) GM of Friuli, Italy-01 earthquake



f) GM of Imperial Valley-06 earthquake



4.0 RESULT AND DISCUSSION.

Table No. 4. Time Period

Model	**Model Arrangement**	**Time period (sec)**		
		T1	**T2**	**T3**
G+20	Without OT & BT	2.39	2.31	1.98
	V-CO	1.98	1.94	1.93
	X-CO	1.95	1.84	1.82
	V-CO + BT	1.86	1.85	1.80
	X-CO + BT	1.81	1.79	1.78
G+40	Without OT & BT	4.03	3.94	2.91
	V-CO	3.45	3.41	2.89
	X-CO	3.36	3.33	2.89
	V-CO + BT	3.22	3.19	2.65
	X-CO +BT	3.19	3.16	2.64

Table No. 5. Base Shear

Model	**Model Arrangement**	**Time period (sec)**
G+20	Without OT &BT	7467.40
	V-CO	8983.52
	X-CO	9451.44
	V-CO + BT	9490.735
	X-CO + BT	10024.39
G+40	Without OT & BT	9778.957
	V-CO	11131.679
	X-CO	11299.538
	V-CO + BT	11665.613
	X-CO + BT	12007.366

4.1 **Maximum Lateral Displacement and Story Drift from Linear Dynamic Analysis**

Table No.6. Maximum Lateral Displacement

Model	Model Arrengment	Max.displacement (mm)	Reduction (%)
G+20	Without OT & BT	121.24	
	V-CO	109.19	9.94
	X-CO	107.18	11.60
	VCO+BT	101.7	16.11
	XCO+BT	100.21	17.34
G+40	Without OT & BT	337.545	
	V-CO	290.96	13.81
	X-CO	281.14	16.71
	VCO+BT	268.92	20.33
	XCO+BT	253.72	24.83

Table No.7 Maximum Story Drift

Model	Model Arrengment	Max.Story Drift
G+20	Without OT & BT	0.000927
	V-CO	0.000857
	X-CO	0.000837
	VCO+BT	0.000820
	XCO+BT	0.000810
G+40	Without OT & BT	0.001940
	V-CO	0.001900
	X-CO	0.001883
	VCO+BT	0.001707
	XCO+BT	0.001503

Fig No. 9. Maximum Lateral Displacement Of G+20 Structure

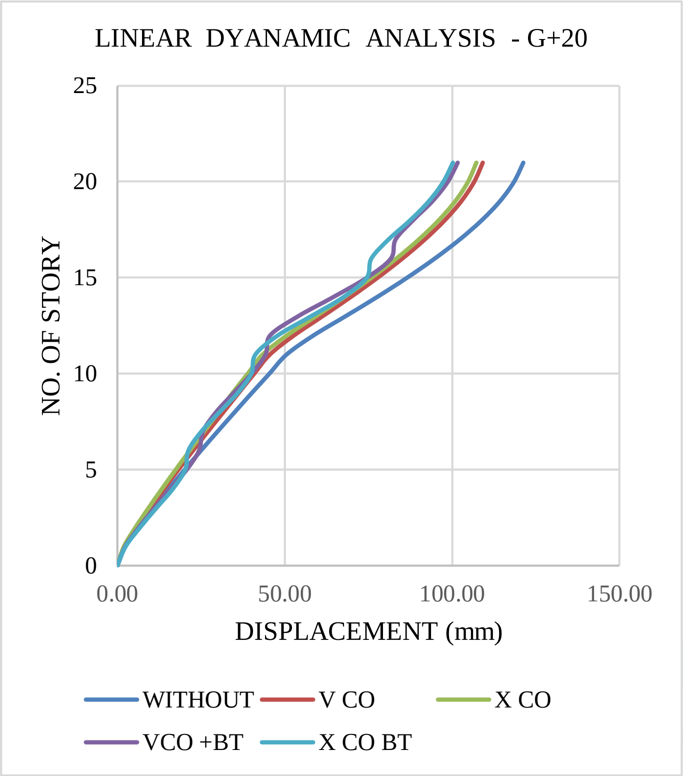


Fig No. 10. Maximum Story Drift Of G+20 Structure

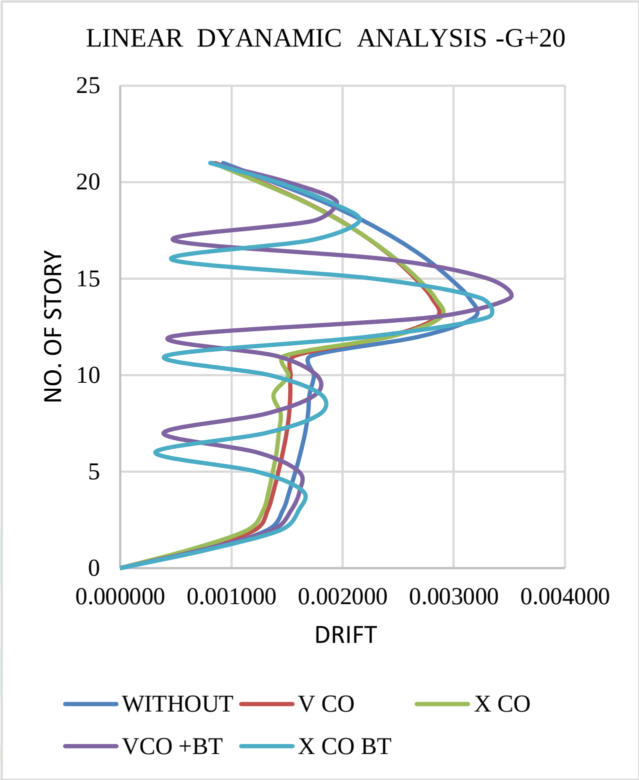


Fig No 11. Maximum Lateral Displacement Of G+40 Structure

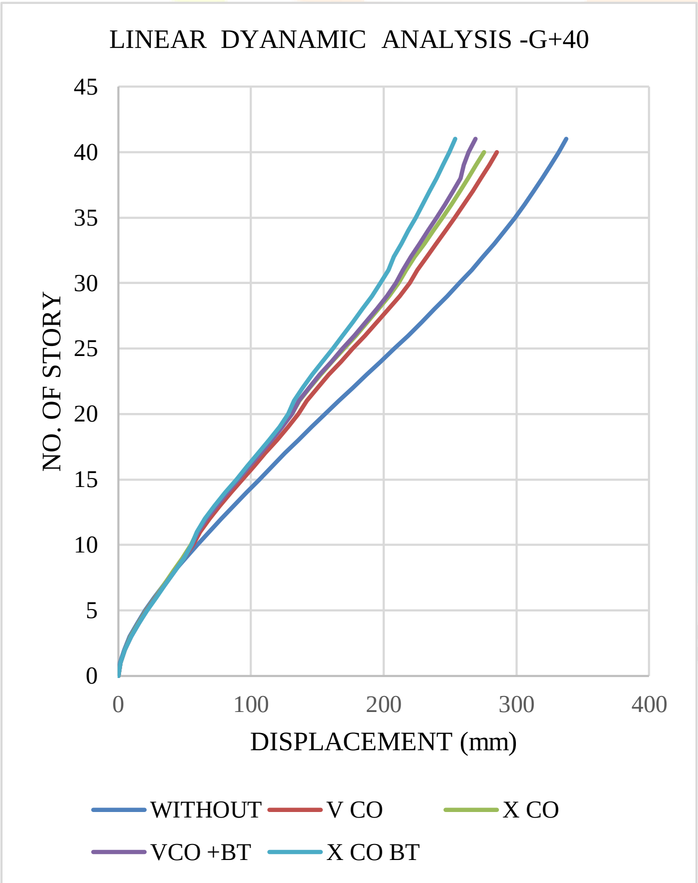
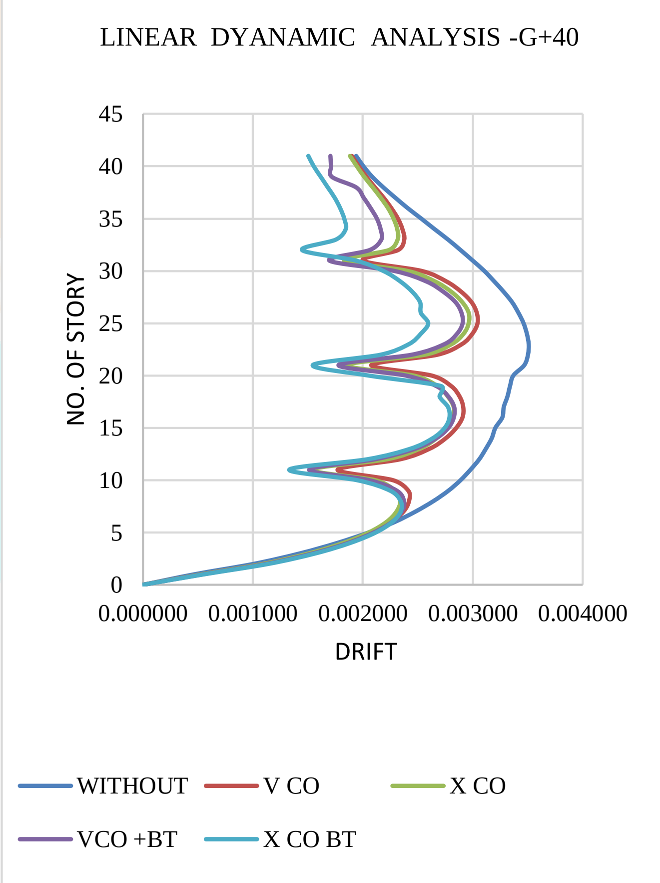


Fig No 12. Maximum story Drift Of G+40 Structure



4.2 Maximum Lateral Displacement and Story Drift from Non-Linear Time History Analysis

Fig No. 15. Maximum Lateral Displacement Of G+20 Structure

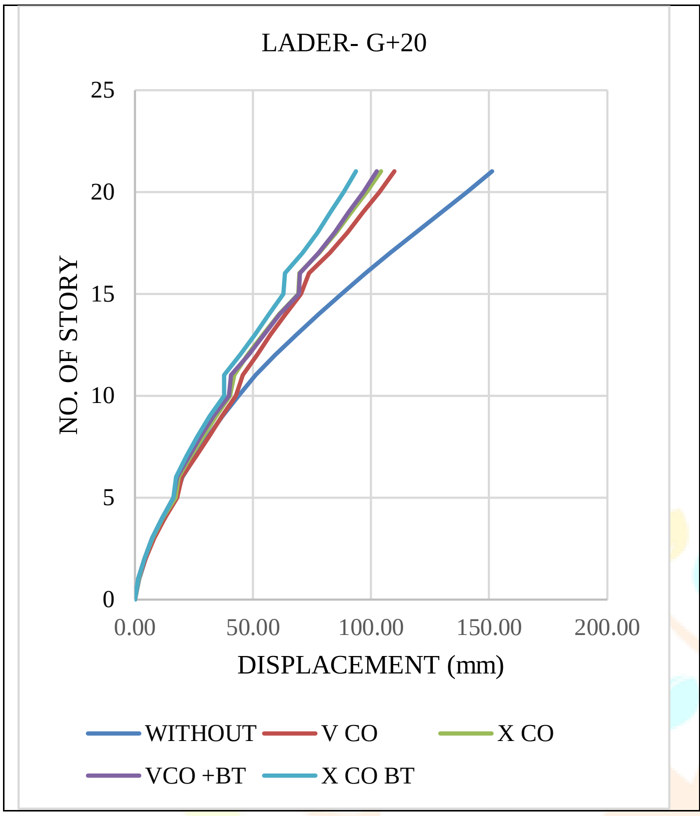


Fig No.16. Maximum Story Drift Of G+20 Structure

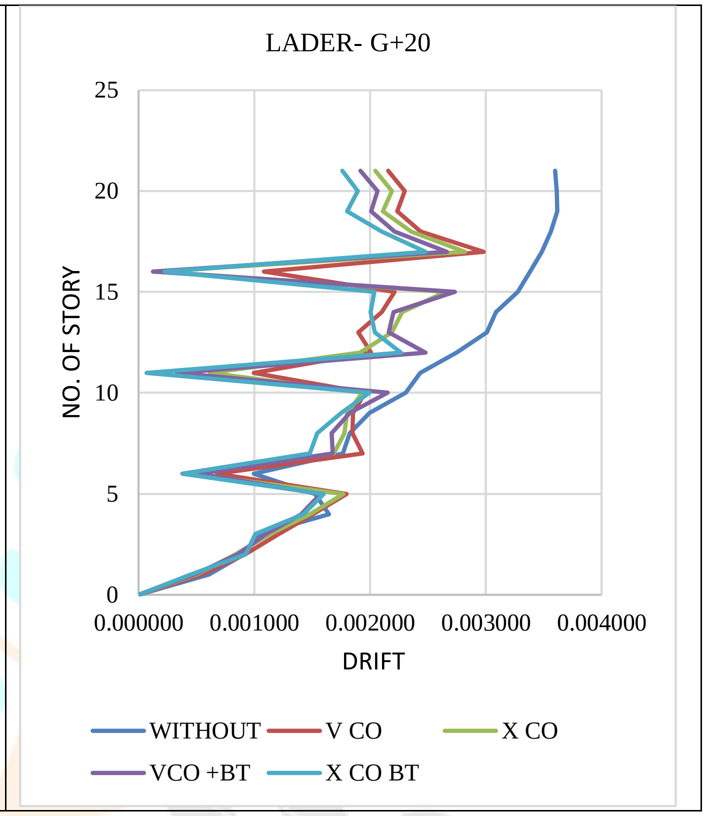


Fig No. 17 Maximum Lateral Displacement Of G+40 Structure

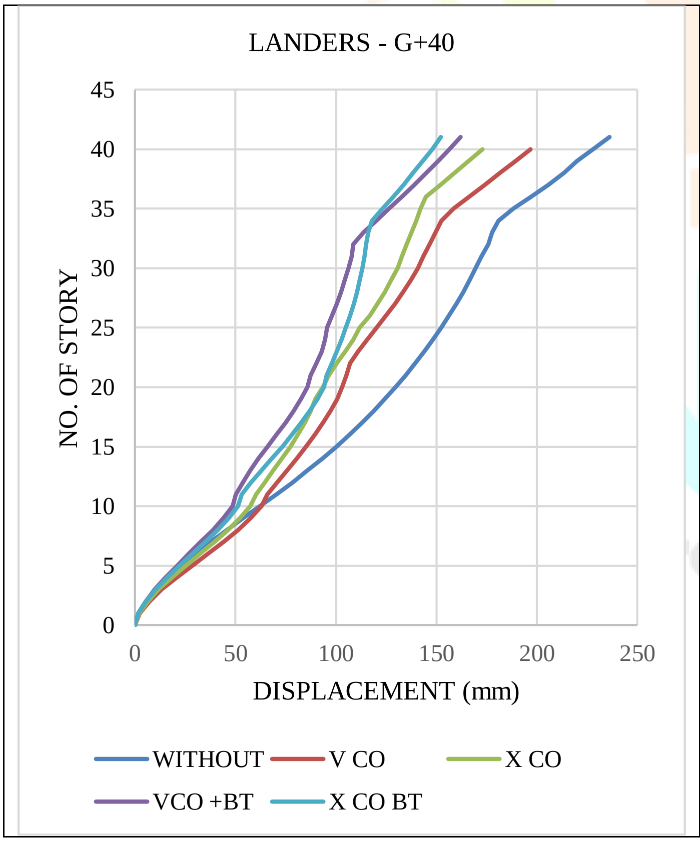
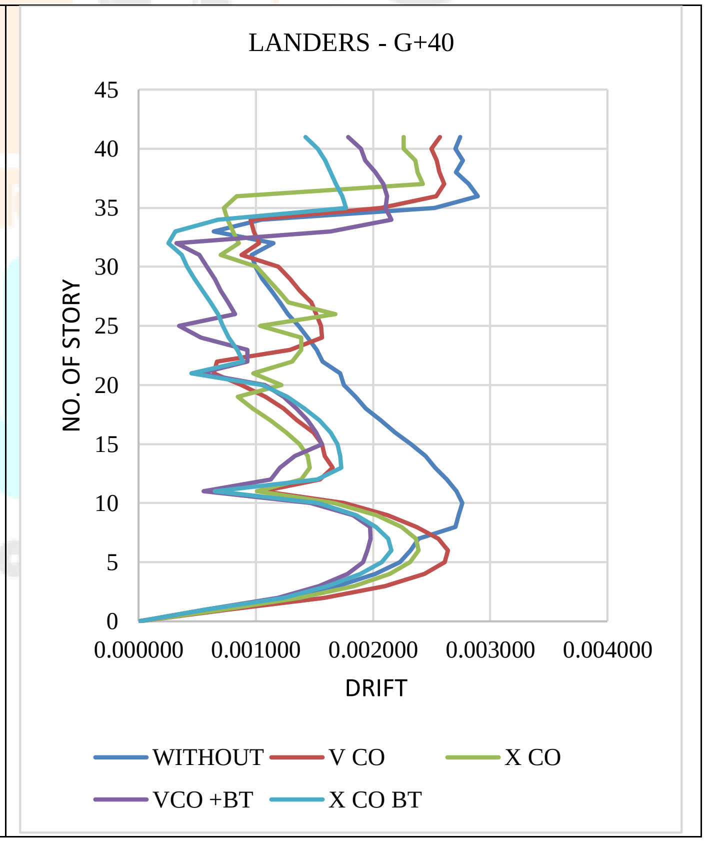


Fig No.18. Maximum story Drift Of G+40 Structure



5. CONCLUSION

Based on results obtained from seismic analysis of the 20, 40 storey RCC building, with and without the outrigger ansd belt truss structural system, yields following conclusions.

1. Linear and non-linear analysis of RCC building incorporating outrigger systems, utilizing both V and X type bracing, reveals that X type bracings exhibit superior performance compared to V type bracings. The observations indicate that X type bracings yield the minimum values for both displacement and drift under study

2. The Variation of displacement and story drift of 20 story building with outriggers and belt truss system for X-shape bracing is controlled by 17.34% and 12.62% as compared to Conventional frame model. The Variation of displacement and story drift of 40 story with outriggers and belt truss system for X-shape bracing is controlled by 24.83% and 22.53% as compared Conventional frame model.

3. The complete comparative analysis reveals that to know the behaviour of the tall structure under earthquake loadings, time history analysis must be performed as it gives more response to time history analysis as compared to linear dynamic analysis

4. Virtual outrigger systems show superior performance in reducing displacement, velocity, and acceleration compared to conventional outriggers, suggesting they are more effective for improving structural stability and dynamic response in buildings under various loading conditions

6. REFERENCES

1) B. G. Kavyashree , Shantharam Patil , Vidya S. Rao, (2021),"Evolution of Outrigger Structural System: A State-of-the-Art Review",Arabian Journal for Science and Engineering, Volume 46, PP10313–

2)B. Smith (1981) , "Parameter Study of Outrigger Braced Tall Building Structures", Journal of the Structural Division, Volume 107, No.10.

3) Dilrukshie I. Samarakkody, David P. Thambiratnam, Tommy H. T. Chan, Praveen H. N. Moragaspitiya, "Outrigger belt and frame interaction in composite tall buildings under differential axial shortening", ASCE, Journal of Architectural Engineering, 23(3)(2017), P-1-14

4) E. Brunes , R. Nascimben , L. Casagrande, (2016),"Seismic analysis of high-rise megabraced frame-core buildings", Engineering Structures, Volume 115, PP1–17

5) E. Bunesi, R. Nascimbene, L. Casagrande, "Seismic analysis of high-rise mega-braced frame-core buildings, ScienceDirect, Engineering Structures", 115(2016), P1-17.

6) EN 1998-1 Eurocode 8: Design of structures for earthquake resistance: Part 1: general rules, seismic actions, and rules for buildings 2005: European Committee for Standardization, Brussels n.d.

7)FEMA 368: Seismic regulations for new buildings and other structures, 2000 n.d

8) IS456:2000 Plain and Reinforced Concrete - Code of Practice is an Indian Standard code of practice for general structural use of plain and reinforced concrete

9) IS 1893 (Part I):2016, Indian standard criteria for earthquake resistant design of structures, Bureau of Indian Standards, New Delhi.

10) Iqra Bano Ayaz Ahmed Khan (2018) "Effect of outrigger structural system on high rise structure, subjected to lateral loads", IOSR Journal of Mechanical and Civil Engineering, Vol. 15, Issue 6, Ver. 1,PP 22-29. doi- (10.9790/1684-1506012229)

11) Krunal Z. Mistry and Proff. Dhruti J. Dhyani, "Optimum Outrigger Location in Outrigger Structural System for High Rise Building",International Journal of Advance Engineering and Research Development, vol. 2, no. 5, May 2015

12)Meisam Safari Gorji, J.J. Roger Cheng, (2016), "Steel plate shear walls with outriggers.Part II: Seismic design and performance", Journal of Construction Steel Research 137,PP311-324

13) Mistry, K. Z., & Dhyani, D. J. (2015). Optimum Outrigger Location In Outrigger Structural System For High Rise Building. International Journal of Advance Engineering and Research Development (IJAERD) Volume, 2

14) Meisam Safari Gorji, J. J. Roger Cheng, "Steel plate shear walls with outriggers. Part II: Seismic design and performance", ScienceDirect, Journal of constructional steel research, 37(2017), P-127-145

15) Nima Sthapit, Rajesh Kumar Shrestha, Satish Paudel, (2023) Seismic Response Analysis of High-Rise Reinforced Concrete Buildings Using Outrigger System,, J. Inst. Eng. India Ser. 104(4):943 –952

16) Osama Ahmed Mohamed, Onar Najm, (2016), "Outrigger Systems to Mitigate Disproportionate Collapse In Building Structures", Journal of the Department of Civil Engineering ,PP839-844

17) P.M.B. Raj Kiran Nanduri , B.Suresh , MD. Ihtesham Hussain (2013) " Optimum Position of Outrigger System for High-Rise Reinforced Concrete Buildings Under Wind And Earthquake Loadings" American Journal of Engineering Research (AJER) e-ISSN: 2320-0847 P-ISSN : 2320-0936 Volume-02, Issue-08, PP 76-89.

18) Patricia M. Putri, Tavio, "Analytical Behavior of Conventional and Virtual Outrigger Structural Systems by Using Modal Pushover Analysis," Civil Engineering and Architecture, Vol. 11, No. 5, pp. 2351 - 2364, 2023. DOI: 10.13189/cea.2023.110508.
19)Sachin P. Patil, Jagadish G. Kori. " A study of nonlinear behavior of multistoried structure for repeated earthquake. Reliability Engineering and Resilience 2-2 (2020) 17-29.

20) Sachin P. Patil, Jagadish G. Kori. "Performance Evaluation of RC Building Subjected to Repeated Earthquake Load". Reliability Engineering and Resilience 3-2 (2021) 01-20.

21) Syed Rizwan Nasir, Amaresh S. Patil (2016), " Lateral Stability Analysis of High Rise Building with the Effect of Outrigger and Belt Truss System", International Journal for Innovative Research in Science & Technology, Vol. 3, Issue: 03

22) Taranth, Bungale S. Reinforced concrete design of tall building. CRC press, 2009

23) V. P. Ganatra, P. R. A. Jhummarwala, and K. B. Parikh,"Study on behaviour of outrigger system on high rise structure by varying outrigger depth," Int. J. Res.Appl. Sci. Eng. Technol., vol. 5, no. Ix, pp. 2017–2022,2017.

24) Varsha Virde, Dr. R. Singh and Alok Rathore, (2020), "Analysis of High-Rise Building with Outrigger Using Non-Dimensional Parameter" , International Journal of Advanced Research in Engineering and Technology(IJARET),Volume11(3),PP360-370.

25) Vijay Kumara Gowada M R And Manohar B C (2015) "A Study On Dynamic Analysis Of Tall Structure With Belt Truss Systems For Different Seismic Zones", International Journal Of Engineering And Technology,

26)Ying Zhou, Lili Xing & Guangxin Zhou (2021) Spectrum Analysis-Based Model for the Optimal Outrigger Location of High-Rise Buildings, Journal of Earthquake Engineering, 25:12, 2406-2431.