

Analysis Of Outrigger System For Frame Structures Subjected To Lateral Load

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ABSTRACT

Outrigger structural systems are widely used in tall buildings to improve lateral stiffness and control excessive drift generated by earthquake and wind actions. This article converts the thesis study into a journal-style manuscript and presents a comparative seismic assessment of a 32-storey reinforced concrete high-rise building modeled in ETABS. Ten analytical models were evaluated using the Equivalent Static Method and Response Spectrum Method for Seismic Zone V. The study focused on key response parameters including top-storey displacement, storey drift, base shear, fundamental natural time period, and overturning response. The results show that the inclusion of core walls, outriggers, and X-braced outrigger arrangements improves the lateral performance of the structure. Compared with the bare/reference frame, the thesis reports 21.71% reduction in top-storey displacement with a core wall, 29.73% reduction with outriggers, and 41.29% reduction when outriggers and X-bracing are combined. The corresponding maximum drift reductions were 21.65%, 25.77%, and 45.87%, respectively. The combined outrigger and X-bracing system increases base shear and overturning resistance while substantially reducing lateral deformation. The study confirms that properly configured outrigger systems are effective for enhancing seismic performance of high-rise RC buildings.

Keywords: Outrigger system; X-bracing; RC high-rise building; ETABS; Equivalent static method; Response spectrum analysis; Storey drift; Base shear.

I. INTRODUCTION

High-rise construction has become an important response to rapid urbanization and scarcity of land in urban regions. As the height of a structure increases, the demand produced by lateral loading also becomes more critical. Earthquake and wind forces cause sway, storey drift and overturning effects that can affect both structural safety and serviceability. Conventional frame and core-wall systems may become insufficient for tall structures when deformation control is the governing design condition.

Outrigger systems are introduced to connect the central core with exterior columns so that lateral loads can be resisted through a coupled core-perimeter mechanism. When the core tends to overturn, outriggers mobilize axial tension and compression in the exterior columns, thereby increasing the overall moment arm and reducing lateral displacement. In practice, braced outriggers and belt truss arrangements are often selected because they can improve stiffness without requiring a complete change in the architectural plan.

The present article focuses on a 32-storey reinforced concrete building analyzed in ETABS under seismic Zone V conditions. The work compares ten alternative structural models, including a reference model and models with core wall, outrigger and X-braced outrigger configurations. The main aim is to identify how these systems influence displacement, drift, base shear, fundamental period and overturning response.

II. LITERATURE REVIEW

Recent studies consistently indicate that the number and placement of outriggers govern their effectiveness in tall buildings. Hidayat and Wirabuana [1] found that dual-outrigger arrangements can improve structural period, base shear, lateral displacement and storey drift control in 60-storey high-rise buildings. Shareef et al. [2] also demonstrated that regularly spaced multiple outriggers offer better stiffness and stability in 36- and 50-storey buildings under seismic and wind loading.

Several researchers have compared conventional frames with outrigger and braced outrigger alternatives. Syed Amir and Syed Arfat [3] reported notable reductions in displacement and storey drift in a G+30 reinforced concrete frame equipped with outrigger systems. Salman et al. [4] observed that outrigger braced frames outperformed conventional moment-resisting frames and other vibration-control alternatives. Dedeoğlu et al. [5] showed that outriggers reduce core-wall bending moment and drift while increasing axial force participation in exterior columns.

The literature further confirms that multiple-outrigger and belt-truss systems are especially useful for very tall buildings. Bhargavi and Santhi Devi [6] reported progressive improvement as the number of outriggers increased, while Sharma and Singh [7] and Nasir and Patil [8] highlighted the superior response of braced outriggers combined with belt trusses. Badami and Suresh [9] and Nanduri et al. [10] emphasized that optimizing outrigger position is essential for reducing lateral deformation in high-rise buildings.

III. OBJECTIVES AND SCOPE

The study objectives retained from the thesis are: (i) to evaluate the behavior of high-rise buildings affected by dynamic loading after providing outriggers; (ii) to study the effect of a core wall and reinforced outriggers on the building response; (iii) to identify an effective outrigger location for a tall structure; (iv) to investigate the influence of X-bracing in outriggers; and (v) to compare response parameters including displacement, drift, base shear, time period and overturning moment.

The scope is limited to a computational structural analysis of a 32-storey RC building using ETABS. The article retains the thesis results and does not introduce new experimental data, revised numerical values or additional simulations. The study uses Equivalent Static Method and Response Spectrum Method results as reported in the thesis.

IV. METHODOLOGY

4.1 Building description

The modeled building is a reinforced concrete high-rise structure with 32 storeys. The plan is kept constant for all models so that the influence of the lateral-load-resisting system can be compared directly. The bottom storey height is 2.5 m and the typical storey height is 3.2 m. The model is located in Seismic Zone V and medium soil conditions are adopted in the thesis. Table 1 summarizes the major modeling parameters.

Table 1. Structural modeling parameters used in ETABS.

Parameter	Specification
Number of storeys	G+30 / 32 storeys
Storey height	3.2 m typical; 2.5 m bottom storey
Seismic zone	Zone V ($Z = 0.36$)
Soil type	Type II (Medium)
Importance factor	1.50
Response reduction factor	5.0
Concrete grade	M30
Column sizes	0.75 m $\times$ 1.0 m and 0.6 m $\times$ 0.8 m
Beam size	0.3 m $\times$ 0.55 m
Outrigger brace	ISA 200 $\times$ 200 $\times$ 12 mm, Fe 345

4.2 Analytical models

Ten ETABS models were considered in the thesis. Model numbering has been preserved to avoid changing the source data. The models include a reference/bare frame, a core-wall model and alternative outrigger and X-braced outrigger arrangements. Representative plan and three-dimensional views extracted from the thesis are shown in Figure 1.

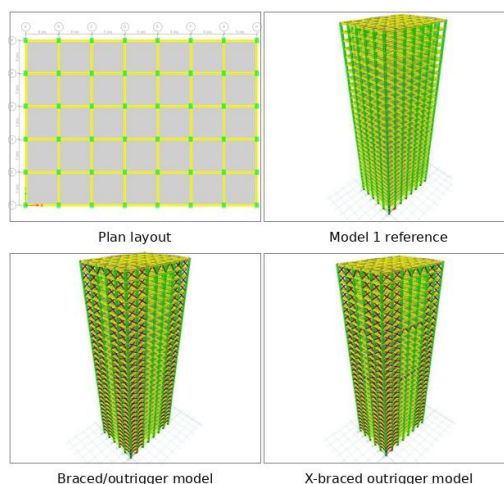


Figure 1. Plan layout and representative ETABS model views retained from the thesis.

4.3 Analysis methods

The Equivalent Static Method represents seismic action as code-based static horizontal forces distributed along the height of the structure. The method is useful for regular buildings where higher-mode effects are limited. In the thesis, lateral loads were calculated according to IS 1893 provisions and applied along the principal X and Y directions.

The Response Spectrum Method was used as the linear dynamic analysis procedure. Natural vibration modes were extracted and combined to estimate maximum modal response under the design spectrum. This method is more suitable for tall structures because it captures the contribution of dynamic modes to displacement, drift and base shear.

V. ANALYSIS AND RESULTS

5.1 Roof displacement

Lateral displacement increased along the height of all models, with the maximum values occurring at the roof level. The displacement profiles demonstrate that the reference model has the highest roof displacement and that the outrigger and X-braced alternatives reduce the lateral movement significantly. Table 2 summarizes roof displacement values obtained from the extracted thesis tables.

Table 2. Roof displacement summary for Models 1–10.

Model	ESM-X roof displacement (mm)	RSM-X roof displacement (mm)	RSM-Y roof displacement (mm)	RSM-X reduction vs Model 1 (%)
Model 1	148.821	112.797	115.821	0.00
Model 2	116.951	80.544	84.192	28.59
Model 3	114.950	79.028	83.032	29.94
Model 4	112.103	77.683	82.033	31.13
Model 5	109.851	75.984	80.754	32.64
Model 6	104.729	72.993	77.907	35.29
Model 7	92.159	62.858	63.884	44.27
Model 8	91.399	62.818	63.885	44.31
Model 9	91.399	63.515	64.350	43.69
Model 10	87.366	63.016	64.894	44.13

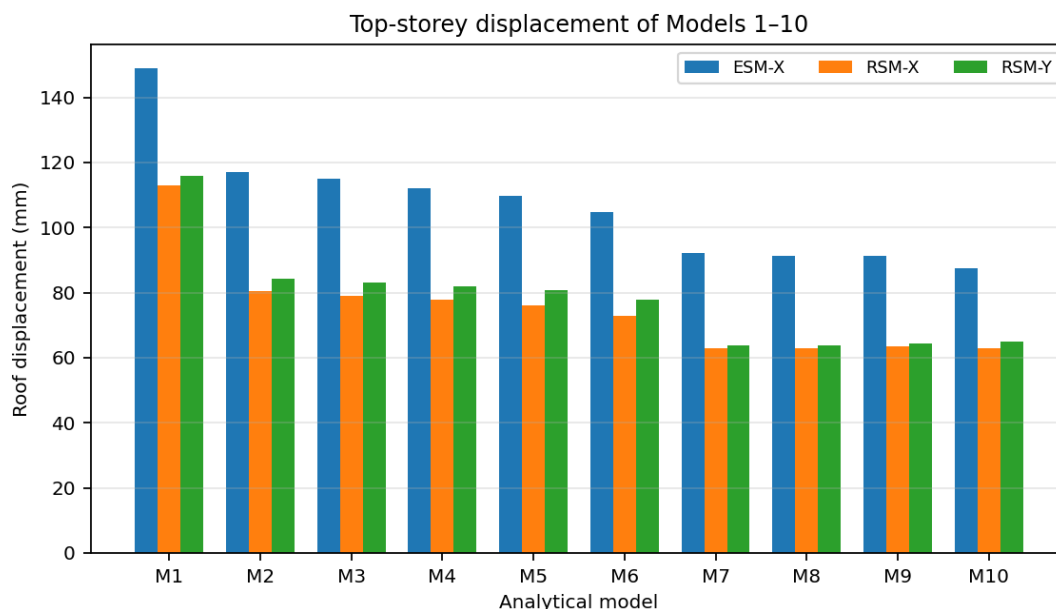


Figure 2. Top-storey displacement comparison by Equivalent Static and Response Spectrum methods.

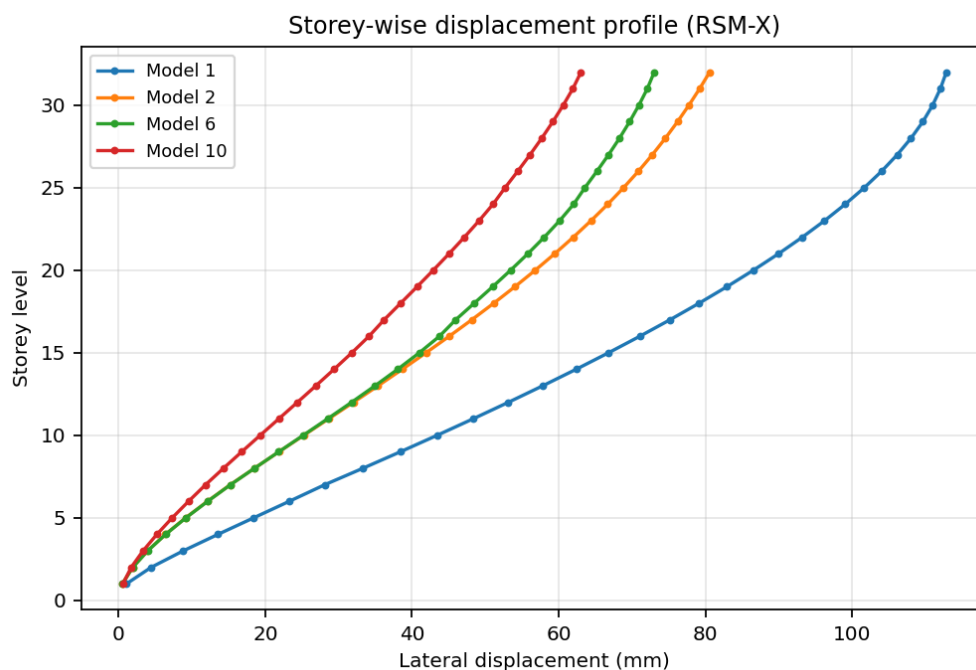


Figure 3. Storey-wise displacement profile for selected models under RSM-X.

The roof displacement obtained from the ESM-X table decreased from 148.821 mm for Model 1 to 87.366 mm for Model 10. This corresponds to the 41.29% top displacement reduction reported in the thesis conclusions for the outrigger and X-bracing arrangement. In the RSM-X results, the largest reduction among the available tables is obtained for Models 7–10, where roof displacement falls to approximately 62.858–63.016 mm.

5.2 Storey drift

Storey drift is the relative lateral displacement between adjacent floor levels and is a critical serviceability and damage-control parameter. The thesis follows the IS 1893 drift limit of 0.004 times the storey height. The ESM drift values in both longitudinal and transverse directions remain below this limit for all models, with lower drift values observed in the braced/outrigger models.

Table 3. Maximum storey drift summary under Equivalent Static Method.

Model	ESM-X max drift	ESM-Y max drift	ESM-X reduction vs Model 1 (%)	ESM-Y reduction vs Model 1 (%)
Model 1	0.001945	0.002089	0.00	0.00
Model 2	0.001520	0.001645	21.85	21.25
Model 3	0.001518	0.001643	21.95	21.35
Model 4	0.001510	0.001635	22.37	21.73
Model 5	0.001441	0.001575	25.91	24.61
Model 6	0.001446	0.001569	25.66	24.89
Model 7	0.001157	0.001206	40.51	42.27
Model 8	0.001150	0.001199	40.87	42.60
Model 9	0.001110	0.001197	42.93	42.70
Model 10	0.001103	0.001186	43.29	43.23

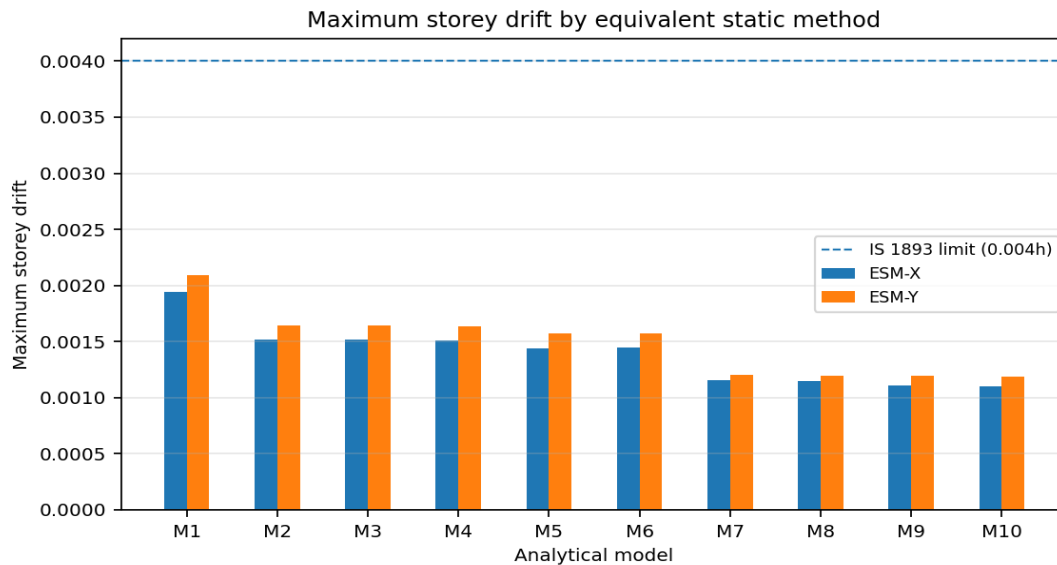


Figure 4. Maximum storey drift by Equivalent Static Method.

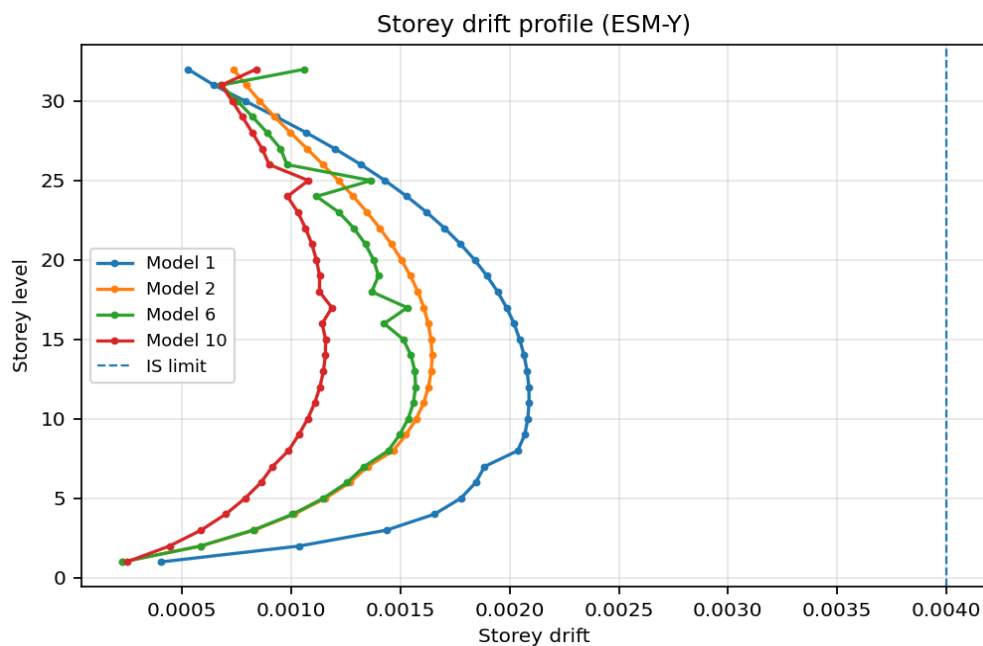


Figure 5. Storey drift profile for selected models under ESM-Y.

The thesis observations report that X-braced outriggers produce the maximum drift reduction among the compared alternatives. The reported RSM drift reductions are up to 25.45% in the transverse direction and 26.79% in the longitudinal direction, while the final conclusion reports a maximum drift reduction of 45.87% when outriggers and X-bracing are combined.

5.3 Base shear

Base shear was compared using equivalent static and response spectrum results along both principal directions. The base shear values indicate that models with higher lateral stiffness attract higher seismic force. Model 10 records the highest base shear in the extracted base shear table, while the thesis conclusion notes that Model 9 has the largest base shear among the compared model structures.

Table 4. Base shear comparison by Equivalent Static and Response Spectrum methods.

Model	EQX (kN)	EQY (kN)	RSX (kN)	RSY (kN)
Model 1	5044.197	5044.197	5141.745	5141.708

Model 2	4991.526	4991.526	5088.008	5088.192
Model 3	4992.382	4992.382	5088.965	5088.809
Model 4	4992.382	4992.382	5088.637	5088.892
Model 5	4992.382	4992.382	5089.008	5088.988
Model 6	5035.529	4994.094	5132.959	5090.698
Model 7	6035.629	5982.448	6152.477	6098.150
Model 8	6083.698	6014.666	6201.375	6130.695
Model 9	6143.699	6054.772	6262.730	6171.859
Model 10	6258.261	6127.999	6379.174	6246.661

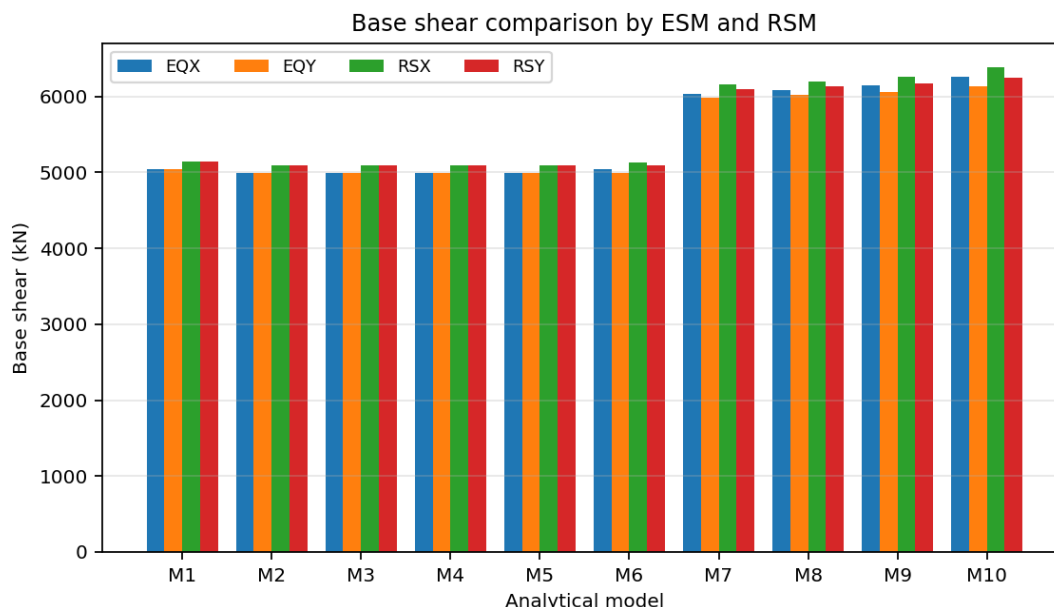


Figure 6. Base shear comparison for Models 1–10.

The results show that the response spectrum base shear values are generally higher than their corresponding equivalent static values. The base shear increases by approximately 25.37% when outrigger and X-bracing are provided compared with the core-wall model without outrigger/bracing, as stated in the thesis observations.

5.4 Fundamental natural time period

The fundamental time period reflects the overall flexibility of the structure. As lateral stiffness increases through the introduction of core wall, outrigger and bracing systems, the time period decreases. Table 5 and Figure 7 show the time period values extracted from the thesis.

Table 5. Fundamental natural time period of the analytical models.

Model	Time period (sec)
Model 1	4.825
Model 2	4.210
Model 3	4.203
Model 4	4.175
Model 5	4.115
Model 6	4.080
Model 7	3.355
Model 8	3.337
Model 9	3.315
Model 10	3.275

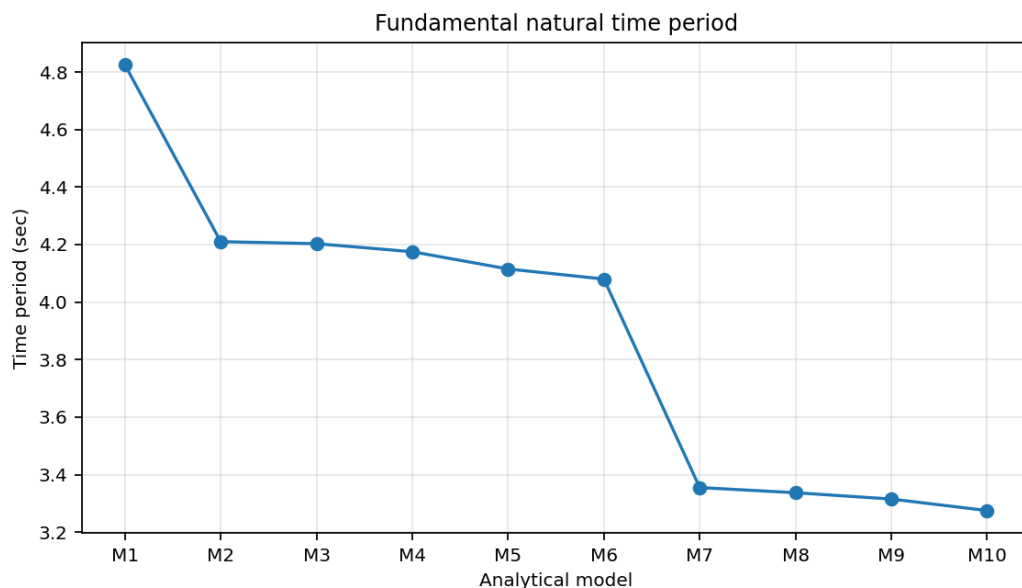


Figure 7. Fundamental natural time period of Models 1–10.

The time period decreased from 4.825 sec in Model 1 to 3.275 sec in Model 10. This trend confirms the increased lateral stiffness of the modified configurations and supports the reduction in roof displacement and storey drift observed in the preceding sections.

5.5 Overturning response

The thesis evaluates overturning moments for the compared models using both ESM and RSM. The detailed overturning moment tables were available in the thesis as result figures; therefore, the article retains the key numerical conclusion rather than recalculating values. The thesis reports that overturning moment increases by 25.37% when an outrigger with X-bracing is provided compared with the core-wall model without outrigger and bracing. This increase is consistent with the higher lateral load participation and stiffness of the braced outrigger system.

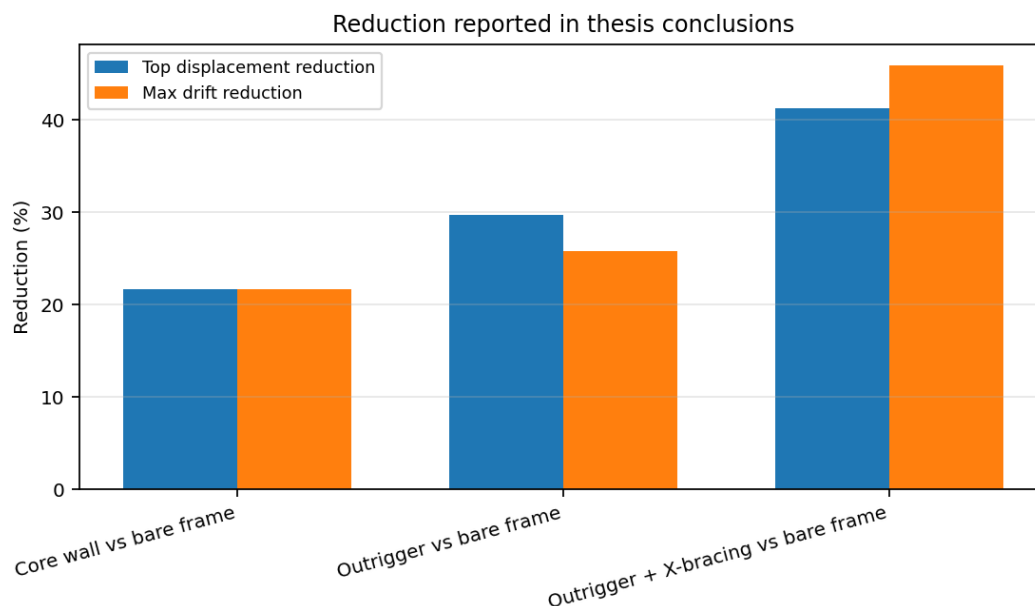


Figure 8. Reduction percentages reported in the thesis conclusions.

VI. DISCUSSION

The results confirm the expected behavior of outrigger systems in high-rise structures. The central core alone improves stiffness when compared with the bare/reference frame, but the addition of outriggers provides a more effective mechanism for resisting overturning. By coupling the core with exterior columns, the system mobilizes axial forces in the perimeter columns and reduces core rotation.

The X-braced outrigger alternatives show the strongest improvement in deformation control. This is evident from the reduced roof displacement, lower storey drift and shorter natural time period. Although the stiffer configurations attract larger base shear, the increase in base shear is accompanied by improved control of lateral deformation and overturning effects.

For a high-rise building in Seismic Zone V, the results indicate that drift and displacement should be treated as controlling criteria. The study supports the use of properly positioned outrigger and X-bracing systems where architectural planning allows the core and perimeter columns to be connected efficiently.

VII. CONCLUSIONS

- The provision of lateral-load-resisting systems significantly improves the seismic response of the 32-storey RC building modeled in ETABS.
- Compared with the bare/reference frame, providing a core wall reduced top-storey displacement by 21.71% and maximum storey drift by 21.65%.
- The outrigger system reduced top-storey displacement by 29.73% and maximum storey drift by 25.77% according to the thesis conclusions.
- The combined outrigger and X-bracing arrangement produced the strongest response improvement, with 41.29% reduction in top-storey displacement and 45.87% reduction in maximum drift.
- Base shear and overturning moment increased by 25.37% with the outrigger and X-bracing system compared with the core-wall model without outrigger/bracing, indicating higher stiffness and lateral-force participation.
- The fundamental time period decreased from 4.825 sec in Model 1 to 3.275 sec in Model 10, confirming the increased stiffness of the braced/outrigger configurations.
- X-braced outriggers are effective for high-rise buildings subjected to seismic lateral loads because they reduce lateral movement and improve overall structural control.

REFERENCES

- [1] Hidayat I, Wirabuana A. Performance assessment of outrigger systems in high-rise building structures. IOP Conference Series: Earth and Environmental Science. 2025;1564:012001–012010.
- [2] Shareef MS, Manzoor KM, Muqem M. Dynamic analysis of high-rise structures with outrigger structural system subjected to lateral loads. IOP Conference Series: Earth and Environmental Science. 2022;1026:012010.
- [3] Amir S, Arfat S. Analysis of outrigger system for frame structure subjected to lateral loads. International Research Journal of Engineering and Technology (IRJET). 2021;8(12):1120–1128.
- [4] Salman K, Kim D, Maher A, Latif A. Optimal control on structural response using outrigger braced frame system under lateral loads. Journal of Structural Integrity and Maintenance. 2020;5(1):1–13.
- [5] Dedeoğlu İÖ, Calayır Y, Arısoy B. An investigation on RC high-rise structures with and without outriggers under lateral static loads. Sigma Journal of Engineering and Natural Sciences. 2020;38(1):191–211.
- [6] Bhargavi V, Santhi Devi M. Analysis of outrigger structural system for high-rise building subjected to earthquake loads. International Journal of Innovations in Engineering Research and Technology (IJIERT). 2020;7(8):1–8.
- [7] Sharma P, Singh G. Dynamic analysis of outrigger systems in high rise building against lateral loading. International Journal of Civil Engineering and Technology (IJCET). 2018;9(8):120–132.
- [8] Nasir SR, Patil AS. Lateral stability analysis of high rise building with the effect of outrigger and belt truss system. International Research Journal of Engineering and Technology (IRJET). 2016;3(8):1045–1052.
- [9] Badami S, Suresh MR. A study on behavior of structural systems for tall buildings subjected to lateral loads. International Journal of Engineering Research and Technology (IJERT). 2014;3(7):1458–1465.
- [10] Nanduri PMBRK, Suresh B, Hussain MDI. Optimum position of outrigger system for high-rise reinforced concrete buildings under wind and earthquake loadings. American Journal of Engineering Research (AJER). 2013;2(8):76–89.