An Approach to Analyzing an Unsymmetrical Structure with Applications of Various Bracing Configurations

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Abstract: **Structural asymmetry is a common challenge in modern engineering, particularly in buildings and frameworks where irregular geometry leads to uneven load distribution and increased susceptibility to lateral forces. This study presents a comprehensive analytical approach to evaluating the behavior of unsymmetrical structures by incorporating various bracing configurations to enhance stability, minimize displacement, and improve overall structural performance. This study aims to assess the impact of different bracing systems, including X-bracing, V-bracing and K-bracing, on the structural response under static and dynamic loading conditions. Using ETABS to study models and analyzes multiple structural configurations to determine the most effective bracing arrangement. Key performance indicators such as story drift, base shear, lateral displacement, inter-storey drift ratio, and stress distribution are examined to understand the influence of bracing on the stiffness and strength of unsymmetrical frames. The results highlight that strategic bracing placement significantly enhances lateral rigidity and improves load-bearing capacity in asymmetrical structures. In this study, a G+24 high-rise structure with an unsymmetrical plan is designed and analyzed under seismic loading conditions in Zone-III, as per the Indian Standard (IS) code. To enhance structural stability and control various performance parameters, three different bracing configurations K-bracing, X-bracing, and V-bracing are incorporated. The modeling and analysis of the structure are carried out using ETABS software, allowing for a detailed evaluation of the bracing effects. The results are then compared to assess the influence of each bracing type on the overall performance of the unsymmetrical structure. Future studies should focus on optimizing and hybridizing bracing systems to balance strength and flexibility. X-bracing, showing the best performance, should be tested under dynamic and seismic conditions. Use of advanced materials, experimental validation, and consideration of architectural impact are recommended. These systems also hold promise for retrofitting and can benefit from intelligent design tools.**

Keywords: Unsymmetrical Structure, Bracing Configuration, Structural Stability, Finite Element Analysis, Lateral Stiffness, Load Resistance and Earthquake-Resistant Design etc.

I. INTRODUCTION

Structural analysis is a fundamental aspect of civil engineering that ensures the stability, safety, and efficiency of buildings and infrastructure. One of the key challenges in structural engineering is dealing with unsymmetrical structures, which exhibit irregularities in geometry, mass distribution, and stiffness. Unlike symmetrical structures, where loads and forces are evenly distributed, unsymmetrical structures behave unpredictably under various loading conditions. These irregularities make them more susceptible to lateral forces such as wind loads, seismic activities, and other dynamic forces, increasing the need for advanced analytical techniques to accurately predict their performance.

Unsymmetrical high-rise structures are buildings that do not have uniform mass, stiffness, or shape, leading to an unbalanced response to external forces.

Bracing in High Rise Structure
Bracing is a vital structural element in high-rise buildings, improving stability and resistance to lateral forces like wind and earthquakes. These systems enhance stiffness and strength without significantly increasing weight, making them essential for modern skyscrapers. Various bracing systems are employed, each offering distinct advantages and applications.

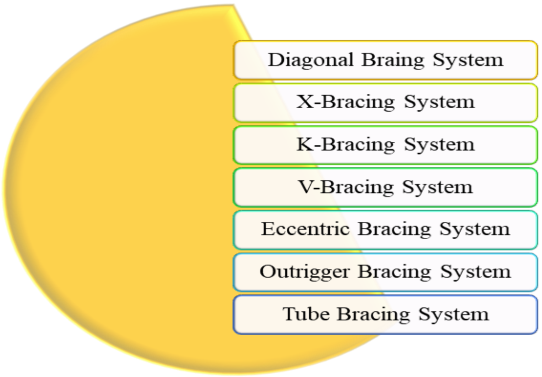


Figure 1. Various Type of Bracing System

Aim of Study

- Analyze how the symmetrical and unsymmetrical layout of a structure impacts the distribution of lateral forces such as seismic loads.
- Compare the effectiveness of various bracing systems (e.g., X-bracing, K-bracing, V-bracing) in enhancing the lateral stiffness and overall stability of symmetrical and unsymmetrical buildings.
- Investigate how each bracing configuration addresses the challenges posed by a symmetrical and unsymmetrical layout, such as torsional motion and unequal force distribution.
- Evaluate different bracing placements can mitigate the negative effects of structural eccentricity and torsion under lateral loads.
- Study the nonlinear behavior of symmetrical and unsymmetrical structures, especially the interactions between bracing systems and structural components under extreme loads.
- Investigate the effects of bracing in mitigating torsional motion and how different configurations impact the overall stability and safety of the structure.

II. LITERATURE REVIEW

Ashrafi, Abolfazl and Ali Imanpour, 2025 [1] Authors study focused on the seismic design of multi-tiered steel eccentrically braced frames (EBFs), specifically with the use of built-up tubular links. The paper aimed to improve the seismic performance of EBFs, particularly with multi-tiered systems, where the interaction of different floors can lead to complex lateral displacement patterns and torsional effects under earthquake loading. The study concluded that this approach significantly outperforms conventional EBFs in reducing inter-storey drift, torsional motion, and lateral displacement while maintaining structural integrity. The findings suggested that the use of built-up tubular links can be a promising solution for high-rise buildings in earthquake-prone regions.

Noor Khaleel Ibrahim, et al., 2025 [2] Authors explored the integration of cross-strip dampers (CSDs) with single diagonally braced frames (DBFs), aiming to enhance the performance of braced frames under lateral loads, particularly seismic and wind forces. The research indicated that incorporating energy dissipation devices such as cross-strip dampers (CSDs) in bracing systems enhances building damping and stiffness, effectively reducing displacements and structural damage during lateral load events. It evaluated how CSDs, as passive energy dissipation devices, improve the lateral load resistance of ductile braced frames (DBF) by decreasing structural response amplitudes and minimizing forces transmitted through the frame. The study emphasized the significance of integrating damping devices in bracing systems to bolster structural resilience without adding to the building's mass or complexity.

Zhou, Chen, et al., 2025 [3] investigated the hysteretic behavior of a multi-story Y-shaped eccentrically braced steel frame (EBF) integrated with a Block Slit Damper (BSD). The focus of the study was on improving the energy dissipation and nonlinear hysteresis performance of this advanced bracing system under seismic loading. The key challenge for high-rise buildings under earthquake loading was controlling the lateral displacement and maintaining the structural integrity of the system. The study highlighted that this innovative configuration can mitigate torsional effects and reduce displacement in high-rise structures during large seismic events. The research concluded that combining Y-shaped EBFs with BSDs offers significant improvements in the seismic resilience of buildings, offering a more robust solution for tall buildings in earthquake-prone areas.

Tank Rajan B., et al., 2025 [4] In this study, Tank et al. compared the structural performance of the bundled tube system and traditional bracing systems for high-rise buildings. The study used finite element analysis to compare the two systems in terms of lateral load resistance, material efficiency, and constructability.

The findings indicate that while the bundled tube system excels in resisting lateral forces and providing enhanced stability, it was more material-intensive and expensive compared to traditional bracing systems.

Kant, Ravi and M. S. Thakur, 2024 [5] investigated the use of Buckling Restrained Braces (BRBs) to improve the seismic performance of reinforced concrete (RC) high-rise buildings. The research evaluated the seismic response of RC buildings with BRBs under earthquake loading, using nonlinear time-history analysis to simulate real earthquake conditions. Study also emphasized the cost-effectiveness of using BRBs, particularly in retrofit applications, where their ease of installation and minimal disruption make them an attractive solution for strengthening existing structures.

Kontoni, Denise-Penelope N. and Ahmed Abdelraheem Farghaly, 2023 [6] performed a parametric study using a range of structural configurations to assess the combined impact of these elements on the building's lateral resistance. Their analysis showed that while shear walls were effective in improving lateral stiffness, the use of bracing systems and TMDs significantly reduces structural displacements and enhances the damping of the building. The study highlighted that combining TMDs with bracing systems is an effective approach to reducing earthquake-induced vibrations and improving building stability, especially on soft soil. It emphasized the need to consider soil-structure interaction (SSI) in seismic design and provided a framework for engineers to select the most suitable lateral load-resisting systems based on the specific conditions of the site and building.

III. METHODOLOGY

The study investigates a G+24 unsymmetrical height building in seismic zone III, following the Indian Standard IS code. Four models were analyzed: one with general bracing and three with K, X, and V-bracing configurations to evaluate stability and performance, using ETABS software for modeling and design.

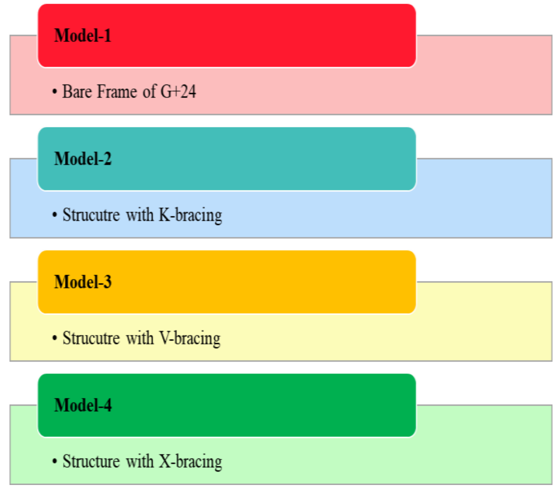
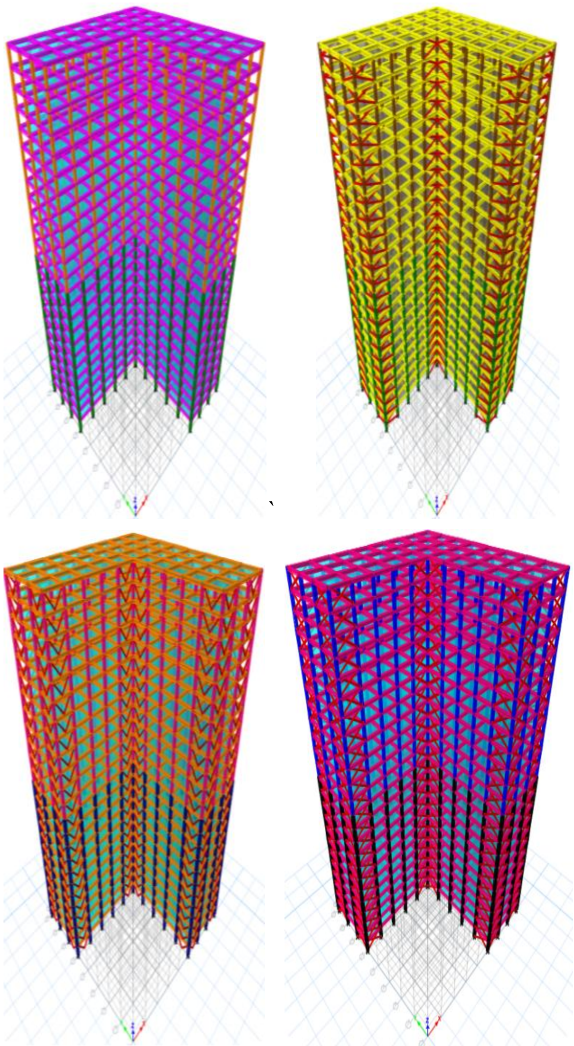


Figure 2. Research Cases

Model Geometry

Table 1 Geometrical Data

S No.	Data	Value
1	Rebar	HYSD 500
2	Grade of concrete	M 40
4	No. of bay along X-direction	8
5	No. of bay along Y-direction	8
6	Span along X-direction	5m
7	Span along Y-direction	5m
8	Storey Height	3m
9	Column size	600*600 mm
		500*500 mm
10	Beam size	500*400 mm
11	Slab	200mm
10	Dead load on Beam	13.5 KN/m
13	Live load	3 KN/m^2
14	Software	CSI ETABS
15	Seismic load	IS 1893-2016
16	Seismic zone	III
17	Soil Type	2
18	Importance factor	1
19	Response Reduction	5
20	Seismic Analysis Method	Response Spectrum method
21	Bracing	Fe-250
22	Bracing type	K, V, X
23	Load Combinations	1.5 (DL+LL+EQL-X)
		1.5 (DL+LL+RS-X)



a) Model-1 b) Model-2 c) Model-3 d) Model-4

Figure 3 Structures in Three Dimensional views

IV. RESULT AND DISCUSSION

This section presents the project results through tables and graphs, followed by an explanation of their significance. A detailed analysis is provided to interpret the findings, along with comparisons to previous studies where relevant to highlight key implications.

Results of Storey Displacement

Storey displacement for various building models resulting from the load combination 1.2 (DL + LL + EQL-X). The results illustrate how different bracing configurations affect the lateral displacement under seismic loading in the X-direction.

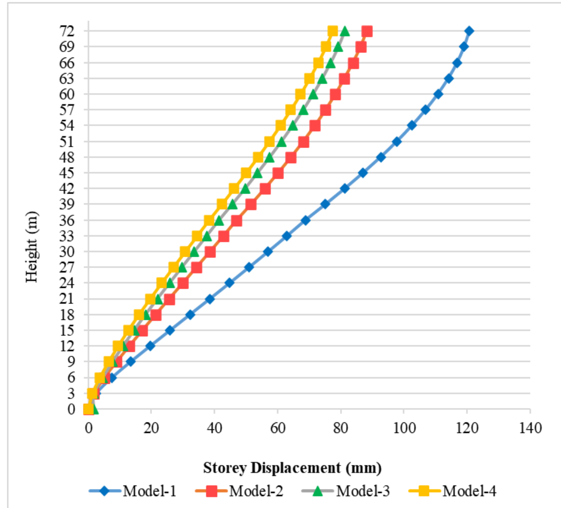


Figure 4. Storey displacement of All Models causes from 1.2 (DL+LL+EQL-X)

Results of Storey drift

Storey drift for various building models resulting from the load combination 1.2 (DL + LL + EQL-X).

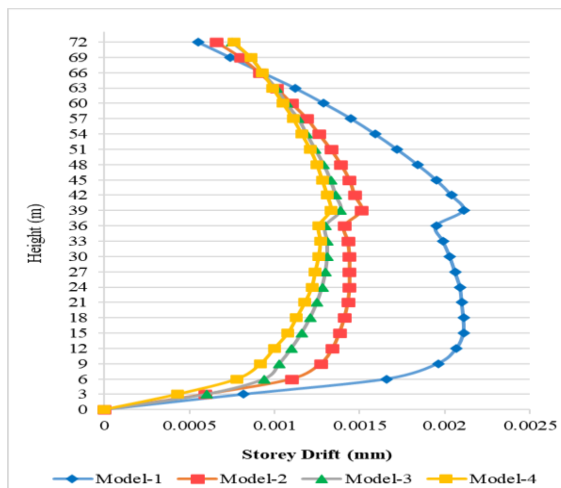


Figure 5. Storey drift of All Models causes from 1.2 (DL+LL+EQL-X)

Results of Bending Moment

Bending moment for various building models resulting from the load combination 1.2 (DL + LL + EQL-X).

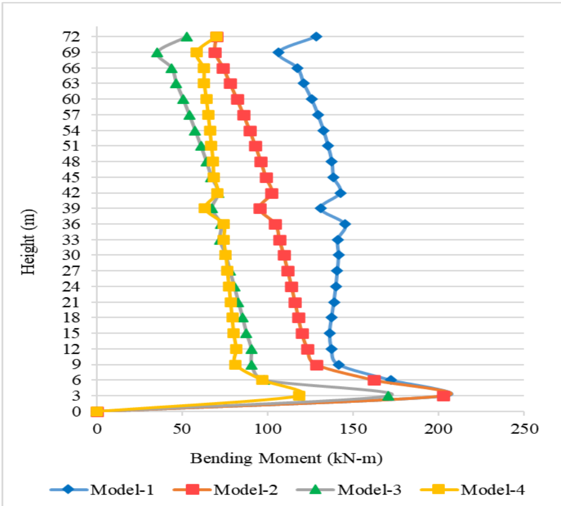


Figure 6. Bending moment of All Models cause from 1.2 (DL+LL+EQL-X)

Results of Shear Force
Shear force for various building models resulting from the load combination 1.2 (DL + LL + EQL-X).

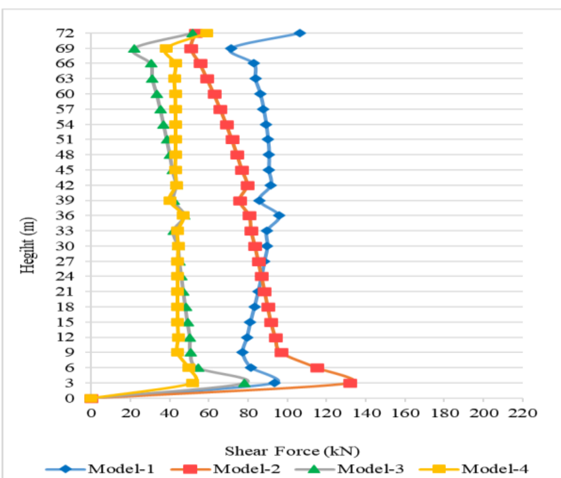


Figure 7. Shear force of All Models cause from 1.2 (DL+LL+EQL-X)

Results of Axial Force
Axial force for various building models resulting from the load combination 1.2 (DL + LL + EQL-X).

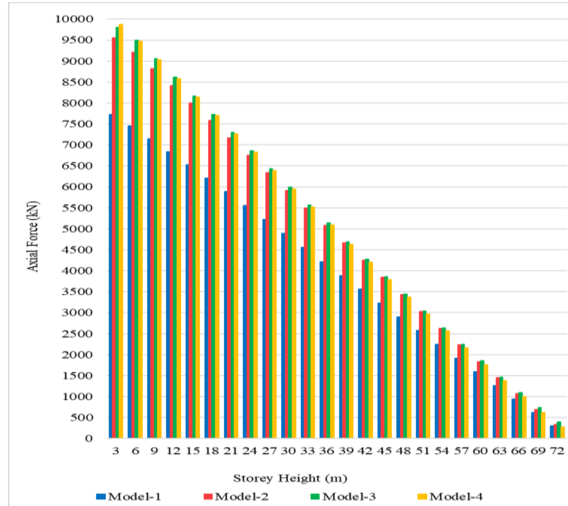


Figure 8. Axial force of All Models causes from 1.2 (DL+LL+EQL-X)

Results of Stiffness
Stiffness for various building models resulting from the load EQL-X.

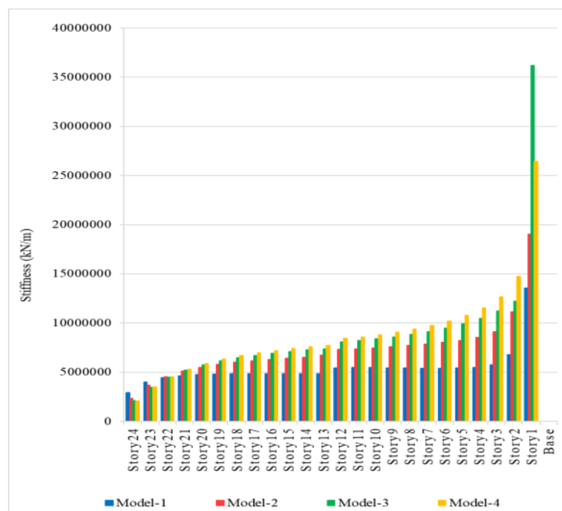


Figure 9. Stiffness of All Models cause from earthquake load (EQL-X)

Results of Base Reaction
Base reaction for various building models resulting from the load combination 1.2 (DL + LL + EQL-X).

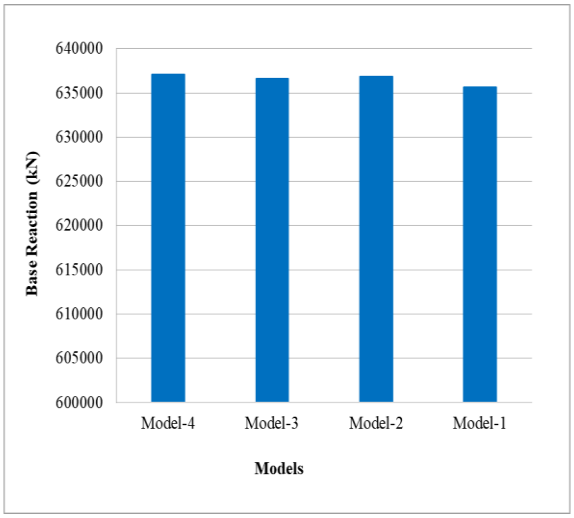


Figure 10. Base Reaction of All Models cause from 1.2 (DL+LL+EQL-X)

V. CONCLUSION

- The maximum storey displacement in the bare frame structure without bracing was 120.80 mm. With K-bracings, the displacement reduced by 27% to 88.18 mm. V-bracings further reduced it by 32.76% to 81.22 mm, and X-bracings achieved the greatest reduction of 35.94%, bringing it down to 77.38 mm. The results demonstrate the significant impact of bracing systems in minimizing displacement values.
- The bare frame structure had a maximum storey drift of 0.00211 mm. Introducing K-bracings reduced the drift by 28.43% to 0.00151 mm, while V-bracings brought it down by 34.12% to 0.00139 mm. X-bracings showed the highest reduction, decreasing the drift by 36.96% to 0.00133 mm. These findings highlight the efficiency of bracing systems in reducing drift.
- The bare frame exhibited a maximum bending moment of 203.90 kN-m. K-bracings resulted in a slight reduction of 0.75%, bringing it to 202.37 kN-m. V-bracings achieved a 16.41% reduction, lowering it to 170.42 kN-m, while X-bracings provided the most significant decrease of 41.93%, reducing it to 118.39 kN-m. Bracing systems were shown to effectively lower bending moments.
- The maximum shear force in the bare frame was 106.19 kN. K-bracings increased the value by 23.91% to 131.59 kN. Conversely, V-bracings reduced the shear force by 26.35% to 78.20 kN, and X-bracings achieved the largest reduction of 51.43%, bringing it down to 51.57 kN. These results illustrate varied effects of bracing systems on shear force.
- The bare frame recorded a maximum axial force of 7730.59 kN. With K-bracings, this increased by 23.11% to 9548.15 kN. V-bracings raised it by 26.83% to 9805.21 kN, while X-bracings caused a 27.80% increase, bringing it to 9880.17 kN. Bracing systems consistently increased axial forces.
- The bare frame's stiffness was 1,357,934.2 kN/m. K-bracings improved stiffness by 40.10%, raising it to 1,902,513.7 kN/m. V-bracings provided the highest enhancement, increasing stiffness by 166.41% to 3,617,163 kN/m, while X-bracings increased it by 94.88% to 2,646,346.6 kN/m. Bracing systems significantly enhanced structural stiffness.
- The maximum base reaction in the bare frame was 635,618.32 kN. K-bracings caused a slight increase of 0.19%, raising it to 636,863.56 kN. V-bracings resulted in a 0.15% increase to 636,592.23 kN, and X-bracings slightly increased it by 0.22% to 637,072.52 kN. The application of bracing systems minimally increased base reaction values.

VI. FUTURE SCOPE OF WORK

- Develop methods to optimize bracing systems for better performance and cost-efficiency in unsymmetrical structures.
- Investigate the behavior of unsymmetrical structures under dynamic seismic loads and compare bracing systems' effectiveness.
- Compare the study’s results with actual unsymmetrical buildings to validate the performance of different bracing configurations.
- Explore the environmental impact of various bracing systems, focusing on material efficiency and sustainability.

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