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Evaluating the Seismic Performance of Tall Structures through Advanced Bracing Techniques

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Reinforced Cement Concrete (RCC) plays a crucial role in the construction of high-rise buildings, particularly in enhancing their resistance to seismic activities. To achieve this, various RCC-based bracing systems are integrated into the building's design. Common bracing configurations include the V-type, X-type, and inverted V-type, strategically positioned between columns to counteract lateral forces induced by seismic events. These bracing systems are favored for their ease of installation, cost-effectiveness, and minimal space requirements, making them a practical choice for modern construction. The structural performance of these buildings, equipped with different bracing types, is rigorously analyzed using advanced software like ETABS. This analysis is conducted across various seismic zones, including zones II, III, IV, and V, each representing different levels of seismic intensity. The comparison between braced and unbraced structures provides valuable insights into the effectiveness of these systems.Among the different bracing configurations, the X-type bracing emerges as the most effective in minimizing the overturning moment and displacement of the building. This characteristic makes it particularly advantageous in enhancing the overall stiffness of the structure, thereby improving its ability to resist overturning forces during seismic events. Consequently, the X-type bracing system is considered the optimal choice for ensuring the stability and integrity of high-rise buildings in earthquake-prone regions.

Keywords: Firmness, Bracing System, Story Drift, IS 1893:2002, ETABS.

1. Introduction

In tall reinforced concrete (RC) structures, bracing systems serve as a critical mechanism for improving structural stability, strength, and energy dissipation, especially under the influence of horizontal loads such as those induced by seismic forces. Various bracing configurations—such as V-type, inverted V-type, K-type, and X-type—are integrated into the building's framework to provide sufficient lateral resistance, making the structure more resilient to seismic and wind loads [3], [19]. These strategically placed systems enhance the seismic performance of RC buildings by efficiently redistributing lateral forces, thereby improving their capacity to withstand earthquake-induced ground motion [19].

The use of bracing between columns offers a straightforward and cost-effective solution, minimizing the space required while significantly increasing the structure's ability to resist lateral displacements [19], [21]. By employing axial stress in diagonal members, these bracing systems can achieve considerable stability and strength with minimal material usage, thereby making them an economical choice for both new constructions and retrofitting existing buildings [3], [19].

In this study, we assess the effectiveness of bracing systems in RC buildings by analyzing their performance across different seismic zones—Zones II, III, IV, and V—as per the IS 1893:2002 standards. Using advanced computational tools such as ETABS 2019, the seismic response of braced structures is evaluated, focusing on their ability to displace without experiencing structural failure [3], [15]. Bracing systems, particularly X-type and V-type, are analyzed in G+13 multi-storey buildings, with identical floor plans in both the X and Y directions to ensure consistent load distribution. The study provides insight into how bracing configurations can improve the seismic resilience of tall structures, particularly in regions like India where seismic activity poses a significant threat [3], [18], [22].

The importance of robust bracing systems in seismic design is further underscored by the complex and unpredictable nature of earthquakes. Seismic waves propagate in multiple directions, causing ground shaking that imposes dynamic loads on structures [14], [15], [22]. Without adequate bracing, buildings may experience catastrophic failure due to the lateral forces generated during an earthquake [15], [18]. The need for enhanced seismic resistance in multi-storey buildings is critical, as these structures are particularly vulnerable to lateral forces [14], [15]. Hybrid systems, combining reinforced concrete frames with various types of bracing, are increasingly being adopted to address this vulnerability [15], [19], [22].

Seismic analysis, especially in regions prone to earthquakes, has become an area of intense research and development, driven by the need to minimize the risk of structural damage and loss of life [15], [22]. India, with its history of devastating earthquakes, has placed significant emphasis on seismic design, leading to the development of modern design codes and practices [14], [15]. However, despite advances in earthquake engineering over the past five decades, seismic design remains a challenging field due to the unpredictable nature of seismic events and the multitude of variables involved in earthquake dynamics [22].

One of the primary challenges in seismic design lies in managing the intensity of earthquake-induced forces [3], [19]. These forces can be so severe that designing structures to remain undamaged during major seismic events is neither economically feasible nor practically achievable [15], [19]. Current design philosophies focus on achieving a balance between structural safety and practicality [19], [21]. While the goal is to prevent collapse during a major seismic event, the design also accepts that some damage may occur, as long as it does not endanger the occupants or compromise the building's overall integrity [15], [22]. This approach ensures that, even in the event of a significant earthquake, the primary load-bearing components remain intact, reducing the risk of catastrophic failure and providing life safety [14], [19].

In conclusion, this study aims to contribute to the growing body of knowledge on the seismic performance of braced RC structures [3], [19], [21]. By focusing on the effectiveness of different bracing configurations in improving lateral resistance, this research offers valuable insights into the optimization of bracing systems for seismic resilience [3], [14]. The findings of this study have practical implications for the design of earthquake-resistant buildings, particularly in high-seismic regions like India [3], [19], [22].

Objectives:

- To understand various types of structures and bracing systems and their behavior.
- To identify the most suitable bracing system for efficiently resisting lateral loads in seismic zones II, III, IV, and V.
- To determine story displacement, story drift, and overturning moments under seismic loading across different zones.
- To study the behavior of structures with masonry infill when subjected to seismic loads.
- To explain the advantages of braced systems and analyze the limitations of braced frames.

Modelling

In this study, building grids were meticulously created using ETABS software [15], [19]. The structural components, including columns, beams, bracing systems, and shear walls, were defined within the software environment [15], [19]. Once these elements were precisely defined, they were strategically positioned in their designated locations to form the building model [3], [19]. A total of sixteen distinct models were developed, each featuring an identical number of stories, specifically designed with a ground plus thirteen stories (G+13) configuration [19], [3]. All models shared the same floor plan, ensuring consistency across the analysis [19].

The floor plans for these models were organized into a grid of 5 by 3 bays, providing a clear framework for the structural analysis [19]. The elevation and floor plan layouts are illustrated in Figures 1 and 2. For this study, the height of each floor in the building was uniformly assumed to be 3 meters, maintaining consistency in vertical dimensions across all floors [19]. This uniformity in design allowed for a comprehensive and comparative analysis of the structural behavior of the models under various conditions [3], [15], [19].

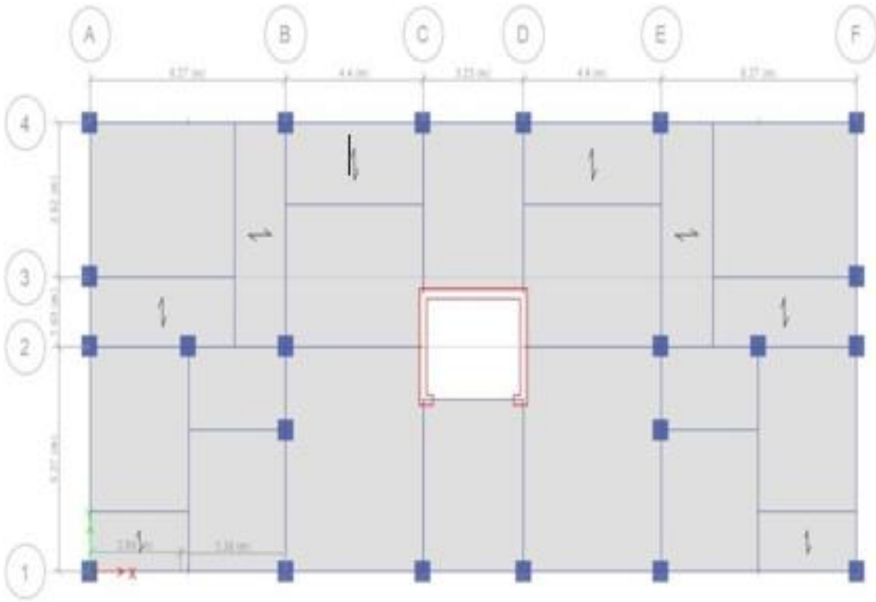

Figure 1. Plan of building

Figure 2. Elevation of building

Analysis considered for the given problem

The primary objective of this study is to analyse a structure's ability to withstand earthquakes, focusing on the need for seismic-resistant design. This project aims to compare structures with conventional bracing systems against those using concrete columns. In high-rise buildings, bracing is one of the most effective methods for resisting earthquakes. Various analysis and design software can be employed to evaluate and design earthquake-resistant structures. The structure chosen for this project is a residential building and modelled in ETAB as shown in FIG 3, 4, 5 and 6 with the various bracing patterns outlined below.

Fig. 3 : Model without Bracings

Fig. 4 : V Braced Model

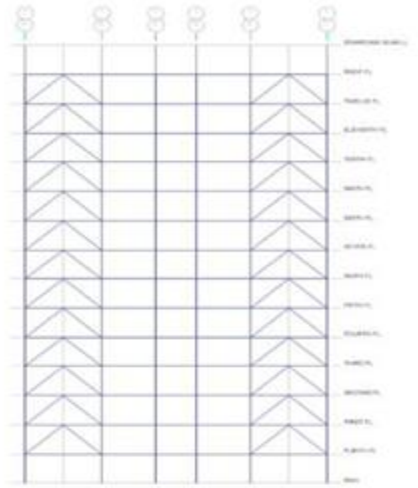

Fig. 5 : Inverted V Braced Model

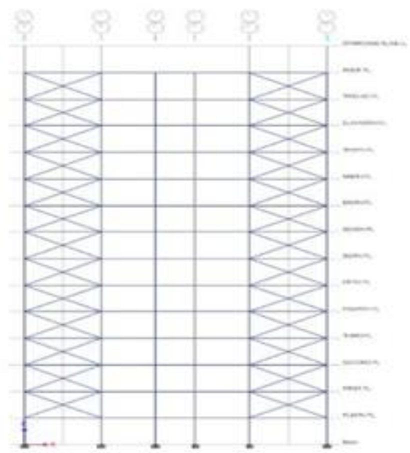

Fig. 6: X Braced Model

Table 1. Parameters considered for analysis and design of for Building

Description of structure	Values
Grade of concrete	M30
Grade of steel	FE500
Number of bays in X direction and its width	6
Number of bays in Y direction and its width	4
Story height	3 m
Number of storey	15
Depth of foundation from ground level	2.4 m
Plinth height	600 mm

Column size	500 mm X 500 mm
Beam size	300 mm X 450 mm
Thickness of Slab	150 mm
Live Load on Floors	4 KN/m2
Live Load on Roof	2 kN/m2
Brick wall on peripheral	230 mm
Brick wall on internal beams	150 mm
Density of brick wall	20 KN/m

2. RESULTS AND DISCUSSION

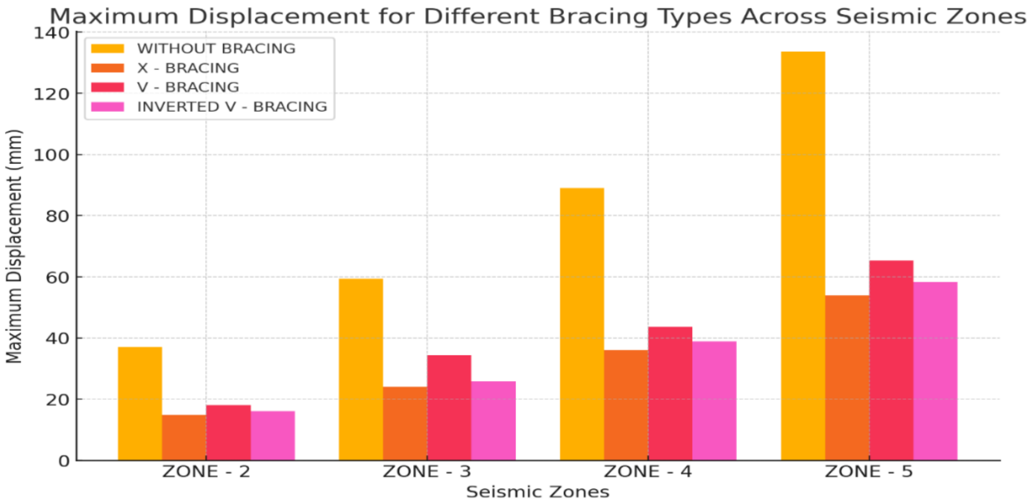

Fig. 7: Story Displacement

The implementation of a bracing system significantly mitigates lateral displacement in a structure, achieving a reduction of up to 75% when compared to a bare frame without bracing. This substantial decrease in displacement underscores the effectiveness of bracing in enhancing the structural integrity and stability of buildings subjected to lateral forces, such as those experienced during seismic events.

Among the various bracing configurations analyzed across different seismic zones, the X-type bracing consistently exhibits the lowest displacement values. This indicates that X-type bracing is the most efficient in minimizing deformation and enhancing the stiffness of the building. The superior performance of X-type bracing highlights its critical role in fortifying structures against seismic activity, making it the preferred choice for ensuring maximum resistance to lateral forces compared to other bracing types. The study's results demonstrate the clear advantages of employing bracing systems, particularly the X-type, in reducing the lateral displacement of buildings. The data shows that structures with X-type bracing experience significantly less deformation across all seismic zones, thereby enhancing the building's stiffness and overall seismic resilience. This finding is critical in the design of earthquake-resistant buildings, as it suggests that incorporating X-type bracing can substantially improve a structure's ability to withstand seismic forces without compromising on stability.

Furthermore, the comparison between different bracing types reveals that while all bracing systems contribute to reducing lateral displacement, the X-type bracing stands out as the most effective. Its ability to provide superior lateral resistance and stiffness makes it an indispensable element in modern high-rise construction, particularly in regions prone to seismic activity. This conclusion is supported by the observed performance metrics, which consistently favor X-type bracing over other configurations.

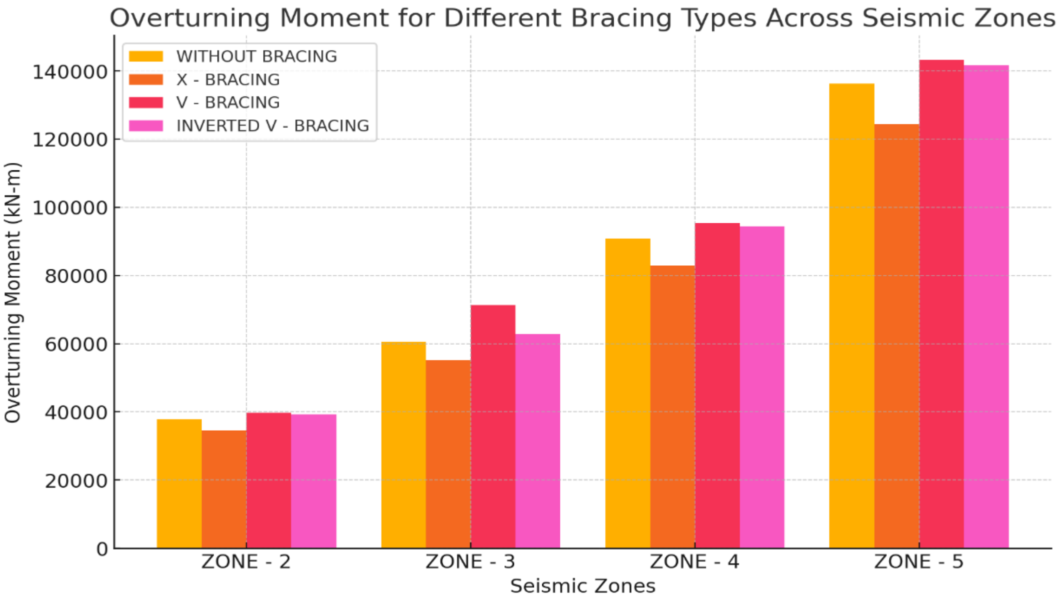

Fig. 8: Over turning moment for Different bracing types

Across all seismic zones, the X-type bracing consistently demonstrates the lowest overturning moment. This characteristic underscores the X-type bracing as the most effective solution for resisting overturning forces, significantly enhancing the stiffness of the structure compared to other bracing types. The superior performance of X-type bracing makes it the preferred choice for fortifying buildings against the destabilizing effects of seismic activity.

The analysis of overturning moments across different bracing configurations reveals a clear advantage for X-type bracing in mitigating seismic impacts. As illustrated in the provided data, the X-type bracing exhibits the smallest overturning moments in all seismic zones (II, III, IV, and V). For instance, in Seismic Zone 5, the overturning moment for a structure with X-type bracing is approximately 124,369.74 kN-m, which is notably lower than that of the V-bracing at 143,232.59 kN-m and the inverted V-bracing at 141,586.56 kN-m. Similarly, in Seismic Zone 2, the X-type bracing achieves an overturning moment of 34,547.15 kN-m, as opposed to the significantly higher values observed in other bracing types.

These results clearly indicate that X-type bracing not only minimizes the potential for overturning but also contributes to the overall stiffness of the structure. This enhanced stiffness is crucial for maintaining the integrity and stability of the building during seismic events, reducing the risk of structural failure. The reduced overturning moment in structures with X-type bracing signifies its ability to effectively distribute and absorb seismic forces, thereby preventing excessive displacement and potential collapse.

Moreover, the data underscores the importance of selecting the appropriate bracing system in the design of earthquake-resistant structures. While all bracing types contribute to some extent in resisting lateral forces, the X-type bracing proves to be the most efficient in this regard, providing a robust and reliable solution for high-rise buildings in seismic zones. The consistent performance of X-type bracing across all analyzed zones solidifies its position as the optimal choice for enhancing structural resilience against seismic activity.

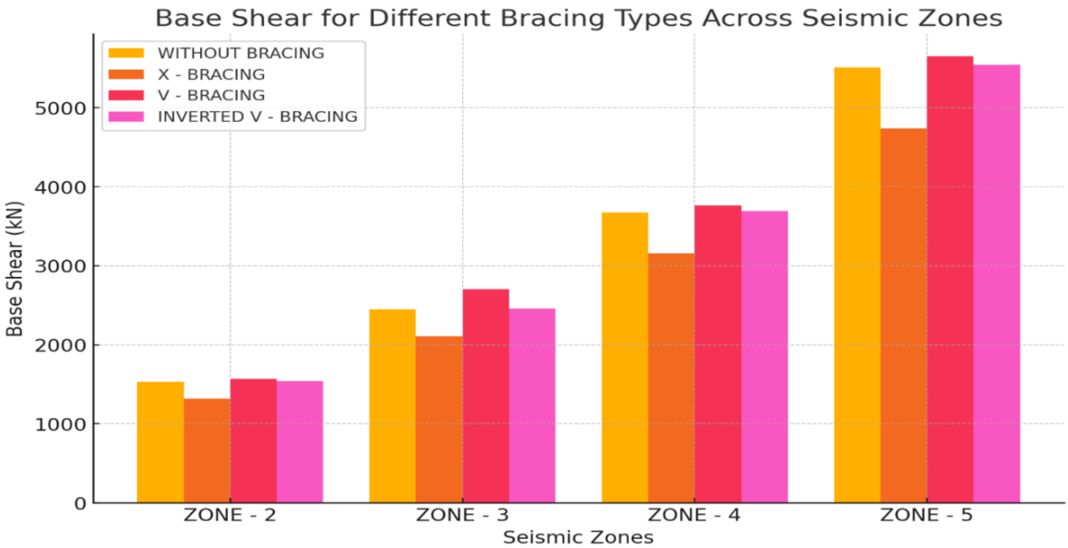

Fig. 9: Base Shear

The base shear experienced by buildings equipped with bracing systems generally shows an increase compared to structures without bracing, with the notable exception of buildings utilizing X-type bracing. This increase in base shear indicates a corresponding rise in the building's stiffness, reflecting the enhanced ability of the structure to resist lateral forces.

The analysis of base shear values across different bracing configurations reveals significant insights into the structural behavior of buildings in seismic conditions. As demonstrated in the data, buildings without any bracing exhibit lower base shear values, with a recorded 1,529.31 kN in Seismic Zone 2, escalating to 5,507.47 kN in Seismic Zone 5. This relatively lower base shear suggests a lack of sufficient stiffness in the unbraced structure, making it more susceptible to seismic forces.

Conversely, the introduction of bracing systems generally leads to an increase in base shear, which is indicative of a more rigid and stable structure. For instance, V-bracing results in base shear values of 1,569.26 kN in Seismic Zone 2 and 5,649.32 kN in Seismic Zone 5, higher than those observed in the unbraced structure. Similarly, the inverted V-bracing system also shows elevated base shear, with values reaching 5,539.79 kN in Seismic Zone 5.

Interestingly, the X-type bracing stands out as an exception. The base shear for buildings with X-type bracing is lower than that of other bracing types, with values of 1,316.80 kN in Seismic Zone 2 and 4,740.49 kN in Seismic Zone 5. This lower base shear, despite the enhanced stiffness, highlights the efficiency of X-type bracing in distributing seismic forces throughout the structure, resulting in reduced overall stress and deformation.

The increase in base shear with other bracing types suggests a trade-off between stiffness and the magnitude of forces the structure must endure during an earthquake. While the added stiffness generally improves the building's resilience to seismic activity, it also leads to higher base shear forces that the foundation must withstand. In contrast, X-type bracing achieves an optimal balance by providing substantial stiffness without excessively increasing base shear, making it a highly effective solution for seismic resistance.

This analysis underscores the importance of selecting the appropriate bracing system in the design of earthquake-resistant structures. While all bracing systems contribute to enhanced stiffness, the unique characteristics of X-type bracing make it particularly advantageous for maintaining structural integrity and reducing potential damage during seismic events. The consistent performance of X-type bracing across various seismic zones solidifies its role as the most efficient and reliable bracing configuration for modern high-rise buildings.

In the current study, a comprehensive analysis was conducted using the civil engineering structural software ETABS, focusing on the design and evaluation of sixteen distinct models. Each model was meticulously crafted with an identical floor plan, ensuring consistency in the assessment process. The structural components, including columns, beams, slabs, and foundations, were uniform across all models, maintaining the same dimensions to allow for a controlled comparison of different bracing systems.

The integration of bracing systems significantly enhances the structural performance, particularly in reducing lateral displacement. The study reveals that bracing can reduce lateral displacement by up to 75% compared to a bare frame, underscoring the critical role bracing plays in maintaining structural integrity under lateral loads.

Among the various bracing configurations analyzed, X-type bracing consistently outperforms others across all seismic zones. It exhibits the lowest values in terms of lateral displacement, overturning moment, and base shear, making it the most effective bracing system for resisting deformation. This superior performance is attributable to the X-type bracing's ability to significantly stiffen the structure, thereby enhancing its overall stability and resilience against seismic forces.

The findings from this study provide valuable insights into the effectiveness of different bracing systems in improving the seismic performance of high-rise buildings. The uniformity in the structural dimensions across all models allowed for a precise evaluation of the impact of bracing on structural behavior.

- Lateral Displacement Reduction: The implementation of bracing systems resulted in a substantial reduction in lateral displacement, with X-type bracing leading to the most significant improvement. This reduction is crucial in minimizing the potential for structural damage during seismic events.

- Minimization of Overturning Moment: X-type bracing also demonstrated the lowest overturning moments across all seismic zones. This indicates its superior capacity to stabilize the building, reducing the risk of overturning during an earthquake.
- Optimization of Base Shear: The study found that while most bracing systems increase base shear, X-type bracing manages to maintain a balance by providing enhanced stiffness without excessively increasing the forces that the foundation must endure. This makes X-type bracing particularly efficient in optimizing the building's seismic performance.

3. Conclusion

In conclusion, the use of X-type bracing is highly recommended for the design of earthquake-resistant structures, especially in regions prone to seismic activity. Its ability to reduce lateral displacement, minimize overturning moments, and optimize base shear makes it the most effective solution among the bracing configurations studied. The consistent performance of X-type bracing across all seismic zones reinforces its role as a critical component in the structural design of high-rise buildings, ensuring safety and stability in the face of seismic challenges.

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