Effectiveness of Various Bracing System in Multi-Storey Buildings with Irregular Geometry under different Seismic Loads

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Abstract - *This study evaluates the seismic performance of 12-storey irregular buildings using various configurations of X-bracing systems. Sixteen different models were analyzed with X-bracing applied at the front, back, front and back, and on all three sides of four types of irregular buildings. The results demonstrate that the placement and distribution of X-bracing significantly affect structural behavior under seismic loads. Models with bracing on all three sides consistently showed reduced displacements and improved lateral stability. Model-8 exhibited the lowest resultant displacement, indicating optimal efficiency, while Model-16 recorded the highest bending moments, highlighting superior energy absorption and structural engagement. Beam force reactions and membrane stress analysis further confirmed that well-distributed X-bracing enhances internal load distribution and reduces stress concentrations. Overall, comprehensive X-bracing configurations not only improve global seismic resilience but also optimize local beam performance. The findings provide valuable insights for designing earthquake-resistant structures, especially in geometrically irregular high-rise buildings.*

Key Words: Seismic, irregular, X-bracings, structural, resilience, beam, drift control

1. INTRODUCTION

In regions susceptible to earthquakes, ensuring that buildings are structurally resilient against seismic forces is a fundamental priority for architects and civil engineers. Structures in such areas must endure dynamic loading without incurring major structural failures. To address this, engineers frequently employ bracing systems to bolster seismic resistance. Among these, X-bracing is especially favoured for its straightforward design, material efficiency, and strong performance in resisting lateral forces. It significantly improves lateral stiffness and helps in minimizing deformation while absorbing and dissipating seismic energy. Nevertheless, its performance in buildings with non-uniform shapes remains a subject of ongoing investigation, as irregular configurations introduce unique complexities in structural behaviour during earthquakes.

Modern architectural trends often involve irregular designs—such as asymmetric layouts, mass eccentricities, and unconventional floor plans—for both aesthetic and functional reasons. While these design choices enhance the visual and spatial appeal of structures, they also increase vulnerability to seismic effects. Irregularities cause uneven distribution of stiffness and mass, which may lead to localized stress concentrations and unpredictable structural responses under earthquake loads. As a result, evaluating how X-bracing interacts with such irregularities is crucial for developing safer, more reliable buildings in seismically active zones.

Numerous studies have highlighted that X-bracing, when strategically positioned, can help mitigate some of the adverse effects caused by structural irregularities. It redistributes lateral forces more evenly throughout the structure, helping to reduce torsional responses and story drifts. The efficiency of X-bracing also depends on factors such as bracing location, the number of stories, material type, and the nature of irregularities. For instance, placing X-braces near the building's core or symmetrically along the perimeter tends to yield better overall stability compared to random or asymmetric arrangements.

Moreover, advanced modelling and analysis tools like finite element simulations and dynamic time-history analyses have become instrumental in assessing how different bracing configurations perform under seismic loading. These tools allow engineers to simulate real-world earthquake conditions and predict the behaviour of irregular buildings equipped with X-bracing. Experimental studies using shake tables and full-scale models further support computational findings, validating that proper X-bracing can significantly improve structural resilience even in complex geometrical layouts.

As urban development continues to push the limits of architectural creativity, the challenge of balancing aesthetics with structural safety becomes more pressing. Engineers and designers must work in tandem to ensure that visually striking, irregular buildings are also structurally sound. In this context, X-bracing emerges as a reliable, cost-effective solution to enhance seismic performance without compromising architectural intent. Continued research and innovation in this area will help refine design guidelines and standards for irregular buildings, ultimately contributing to safer and more sustainable construction practices in earthquake-prone regions.

2. LITERATURE REVIEW

A considerable amount of research has been conducted to evaluate the role of various bracing systems in improving the earthquake resistance of buildings. Abdulridha, A. J. identified X-bracing as especially beneficial for enhancing a structure's lateral rigidity and minimizing displacement during seismic activity.[1] The study also shed light on how X-bracing distributes seismic forces efficiently, reinforcing its effectiveness in medium to high seismic risk areas.[1]

Structures with non-regular layouts face distinct stability issues under earthquake loading. Ahasan–ul–Haque noted that buildings with irregular configurations, such as L or T-shapes, experience heightened stress concentrations and torsional effects, increasing their vulnerability. [2] Their findings emphasized the importance of customized structural approaches to manage these dynamic challenges effectively. [2]

Al-sabaeei examined how different X-bracing placements affect structural performance in multi-story buildings. They concluded that positioning braces near the building's core or using balanced, symmetrical layouts enhances stability and energy absorption more effectively than uneven or random arrangements. [3]

Similarly, Al-Safi explored how varying seismic zone intensities influence design requirements. Their research highlighted that buildings located in more active seismic regions need increased ductility and lateral stiffness, and that bracing systems must be adapted accordingly to suit the seismic demands of specific locations.[4]

In summary, X-bracing has emerged as a consistently effective technique for boosting the seismic performance of high-rise buildings, especially those with irregular shapes. It offers notable improvements in terms of stiffness, energy dissipation, and drift mitigation, proving to be a reliable strategy for structural safety in earthquake-prone regions.

3. METHODOLOGY

The present study focuses on evaluating the seismic performance of multi-storey buildings with irregular geometries using X-bracing systems, modeled and analyzed in STAAD.Pro software. A total of 16 models are developed, representing various bracing configurations applied to different types of geometric irregularities in a 12-storey building frame.

3.1 OBJECTIVE

1. To assess the effect of different X-bracing placements on the seismic performance of irregular multi-storey buildings.
2. To assess the impact of bracing system placement and configuration on reducing lateral displacements and improving structural stability under seismic loads.

3.2 SOFTWARE USED

STAAD.Pro – for structural modeling and seismic analysis in accordance with IS 1893 (Part 1): 2016.

3.3 BUILDING CONFIGURATION

1. All models are 12-storey reinforced concrete (RC) structures.
2. Four distinct irregular geometries are considered:
   - Building 1: Irregularity Type A
   - Building 2: Irregularity Type B
   - Building 3: Irregularity Type C
   - Building 4: Irregularity Type D

3.4 BRACING SYSTEM

1. Only X-bracing systems are used for uniformity.
2. Bracing is applied at different positions:
   - Front face only
   - Back face only
   - Front and back faces
   - Front, back, and side faces

3.5 MODEL DESCRIPTION

The following table 3.1 shows the model description in detailed:

Table 3.1 Model Description

Model No.	Building Type	Bracing Location
Model-1	Irregular Building-1	Front
Model-2	Irregular Building-1	Back
Model-3	Irregular Building-1	Front, Back
Model-4	Irregular Building-1	Front, Back, Side
Model-5	Irregular Building-2	Front
Model-6	Irregular Building-2	Back
Model-7	Irregular Building-2	Front, Back
Model-8	Irregular Building-2	Front, Back, Side
Model-9	Irregular Building-3	Front
Model-10	Irregular Building-3	Back
Model-11	Irregular Building-3	Front, Back
Model-12	Irregular Building-3	Front, Back, Side
Model-13	Irregular Building-4	Front
Model-14	Irregular Building-4	Back
Model-15	Irregular Building-4	Front, Back
Model-16	Irregular Building-4	Front, Back, Side

3.6 LOADING CONDITION

- Dead Load (DL) and Live Load (LL) as per IS 875.
- Seismic Load (EQ) as per IS 1893 (Part 1): 2016, for selected seismic zones.
- Response Spectrum Analysis is used for dynamic response under seismic excitation.

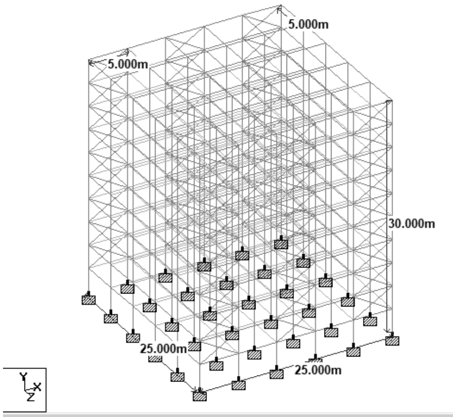

Fig 3.1 Geometry of Model

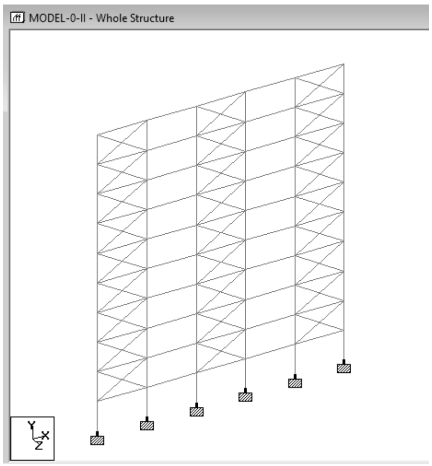

Fig 3.2 X-Bracing Assign to the structure

4 RESULTS & DISCUSSION

The table 4.1 below summarizes the horizontal, vertical, and resultant displacements observed in 16 structural models under seismic loading. The models differ by bracing configuration and building geometry.

Table 4.1 Horizontal, vertical, and resultant displacements observed in 16 structural models under seismic loading

Models	Horizontal	Vertical	Horizontal	Resultant
	X mm	Y mm	Z mm	mm
Model-1	31.695	15.05	46.957	47.746
Model-2	31.93	15.005	56.357	56.708
Model-3	19.229	15.006	55.066	55.412
Model-4	19.306	15.012	50.663	51.171
Model-5	31.472	15.424	37.94	39.139
Model-6	33.568	15.419	37.918	39.076
Model-7	21.743	15.42	37.838	39.048
Model-8	21.61	15.415	33.99	35.262
Model-9	33.103	15.155	36.923	38.18
Model-10	32.409	15.151	37.029	38.268
Model-11	28.37	15.151	37.562	38.608
Model-12	27.751	15.143	35.676	37.416
Model-13	32.115	15.057	52.235	53.265
Model-14	37.386	15.012	64.903	65.216
Model-15	25.719	15.016	63.075	63.749
Model-16	28.141	15.022	59.821	61.127

Figure 4.1 illustrates the horizontal displacement values (in mm) for 16 structural models subjected to seismic loading. The horizontal axis represents the individual models (Model-1 through Model-16), while the vertical axis indicates the horizontal displacement magnitude in millimeters.

Models such as Model-3 and Model-4 exhibit the lowest horizontal displacement, suggesting effective lateral load resistance, likely due to optimized bracing configurations. In contrast, Model-14 shows the highest displacement, indicating poor seismic performance in the horizontal direction. The trend highlights the significant impact of bracing systems and building geometry on lateral stiffness and seismic response.

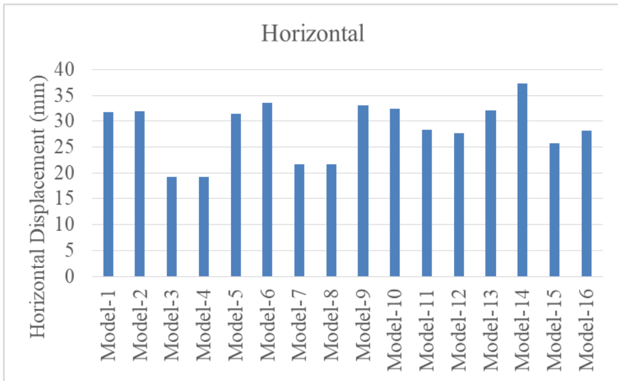

Fig 4.1 Horizontal Displacement Values

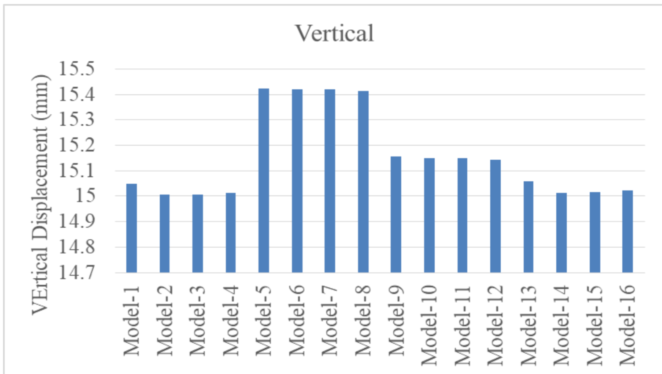

Fig 4.2 Verticle Displacement for 16 Structural models

Figure 4.2 displays the vertical displacement (in mm) for 16 structural models under seismic loading. The horizontal axis lists the models from **Model-1 to Model-16**, while the vertical axis shows the corresponding vertical displacement values.

Overall, vertical displacements remain relatively uniform across all models, ranging narrowly between 14.9 mm and 15.4 mm, indicating that vertical seismic effects are less influenced by the bracing configurations or geometric irregularities compared to horizontal displacements. Models 5 to 8 exhibit slightly higher vertical displacements (~15.42

mm), possibly due to the interaction of bracing with vertical irregularities or mass discontinuities.

Fig 4.3 Resultant Displacement Values of 16 Structural Models

This bar chart presents the resultant displacement values (in mm) for 16 structural models subjected to seismic loading. The x-axis lists the models (Model-1 to Model-16), while the y-axis indicates the magnitude of total displacement combining horizontal and vertical components. The chart clearly shows that Model-8 has the lowest resultant displacement (~35.26 mm), suggesting superior overall performance under seismic conditions. In contrast, Model-14 experiences the highest resultant displacement (~65.22 mm), indicating the poorest seismic resistance among all models. The variation in resultant displacement underscores the importance of selecting appropriate bracing systems and addressing geometric irregularities in seismic design.

CONCLUSION

This study evaluated the seismic performance of 16 different structural models with varying bracing systems and irregular geometries. Displacement data in horizontal, vertical, and resultant directions was analyzed to assess structural response under seismic loading.

From this analysis we understand that bracing system significantly improves seismic performance. All the braced models exhibit lower displacement compared to their un-braced counter parts. X-bracing was effective in reducing horizontal and resultant displacements. Irregular geometries, such as re-entrant corners and vertical setbacks, showed increased vulnerability to seismic loads. Horizontal displacements varied widely among models, with Model-8 demonstrating the least (most effective) and Model-14 the greatest (least effective) horizontal displacement. Vertical displacements were relatively consistent across all models, indicating less sensitivity to bracing variation. Resultant displacements followed the trend of horizontal behavior, highlighting the dominance of lateral forces in seismic design.Model-8, with the lowest resultant displacement, likely had an optimal bracing configuration and layout for the given irregularity type. Models such as Model-3, 4, 7, 12 also performed well, suggesting that bracing should be tailored specifically to the type and location of geometric irregularity.

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