



International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 11, November 2025



**International Journal of Multidisciplinary Research in
Science, Engineering and Technology (IJMRSET)**
(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Buckling Restrained Braces in Seismic Retrofitting: A Comparative Analysis with Steel Bracing for Irregular RCC Structures

Ganta Kalyan¹, DR. M Swaroopa Rani²

PG Student, Dept. of Civil Engineering, University College of Engineering Kakinada, JNTUK, Andhra Pradesh, India¹

Professor, Dept. of Civil Engineering, University College of Engineering Kakinada, JNTUK, Andhra Pradesh, India²

ABSTRACT: This study examines the seismic retrofitting of G+15 reinforced concrete (RCC) buildings with irregular plan shapes—rectangular, L-shaped, C-shaped, and H-shaped—using buckling-restrained braces (BRBs), compared to conventional steel bracing. Analyses were performed in ETABS 22 software as per IS 1893:2016 guidelines for Seismic Zone V, employing both Equivalent Static and Response Spectrum methods in X and Y directions. Four bracing configurations (X, V, Inverted V, and Multistory-X) were assessed across 36 analytical models, with key parameters including fundamental time period, inter-story drift, lateral displacement, base shear, and story stiffness.

Results show that unbraced irregular structures are highly vulnerable, exhibiting greater time periods and drifts beyond code limits. Incorporating BRBs led to significant improvements: reductions in time periods by up to 40%, inter-story drifts by 50–60%, and lateral displacements by up to 60% compared to unbraced condition, alongside notable enhancements in base shear (8–15% higher) and stiffness (10–25% higher) compared to steel bracing. The Multistory-X BRB configuration was found most effective, especially for C and L-shaped buildings, with retrofitted performance surpassing even regular frames due to superior energy dissipation and resistance to buckling. The study advocates BRBs, particularly in Multistory-X arrangements, as a preferred seismic retrofit for irregular high-rise RCC buildings.

KEYWORDS: Buckling Restrained Braces (BRBs), Equivalent Static Method, Irregular RCC Buildings, Response Spectrum Analysis, Seismic Retrofitting.

I. INTRODUCTION

Earthquake engineering has long grappled with the challenges posed by irregular building configurations in high-seismic zones. Reinforced concrete structures, particularly those exceeding 15 stories, often incorporate plan irregularities—such as L, C, or H-shaped layouts—to accommodate functional requirements like open spaces or architectural aesthetics. These irregularities introduce torsional effects and uneven mass distribution, which can amplify seismic demands and lead to premature failures during ground shaking. Historical records from events like the 2001 Bhuj earthquake in India underscore this vulnerability, where irregular structures suffered disproportionate damage due to concentrated stresses and inadequate lateral resistance.

In Seismic Zone V, as defined by IS 1893:2016, peak ground accelerations can reach 0.36g, demanding retrofitting solutions that enhance ductility and energy absorption without compromising the existing framework. Conventional steel bracing, while cost-effective, tends to buckle under compressive cycles, limiting its hysteretic performance and overall contribution to seismic resilience. This limitation becomes pronounced in tall, irregular RCC frames, where torsional modes dominate the response. Buckling-restrained braces (BRBs) offer a targeted remedy by providing stable, symmetric behavior in both tension and compression, thereby distributing seismic forces more evenly and reducing inter-story drifts.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

This study examines the application of BRBs in retrofitting G+15 RCC structures across rectangular (regular) and irregular (L, C, H-shaped) geometries. The focus lies on quantifying improvements in key response metrics under equivalent static and response spectrum analyses, aligned with Indian code provisions. By comparing BRBs against traditional steel bracing in identical models, the work aims to inform practical retrofitting strategies for regions prone to intense seismic activity in India.

1.2 Concept and Functionality of Buckling-Restrained Braces (BRBs)

Buckling-Restrained Braces (BRBs) are advanced structural components developed to address the limitations of traditional bracing systems, especially under seismic loads. Initially introduced in Japan during the late 1980s under the name “Unbonded Brace,” the technology has since evolved and gained global adoption. Companies like Star Seismic and Mover Star now manufacture a variety of BRB systems, providing detailed design tools and manuals to meet diverse structural demands.

At the heart of a BRB is a slender steel core, typically shaped as a flat plate or cruciform section, designed to resist axial forces through controlled plastic deformation. This core is encased within a steel tube filled with concrete or high-strength mortar, which serves as a restraining mechanism. A key feature of the design is the inclusion of an unbonding layer—often a polymer coating or grease—which isolates the core from the encasing material. This setup ensures that the core can expand and contract freely under cyclic loads without bonding to the concrete, effectively eliminating the risk of global or local buckling.

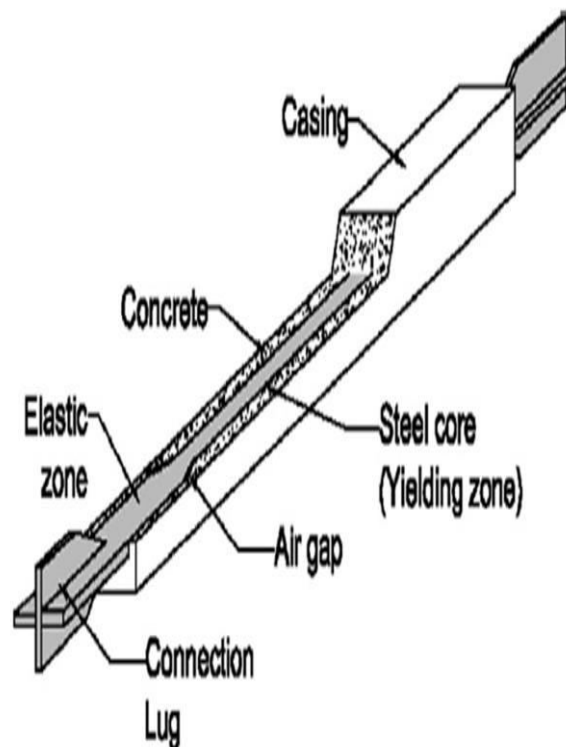


Figure 1: BRB Braces Concept Diagram



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

The performance advantage of BRBs lies in their ability to maintain nearly identical strength under both tension and compression, resulting in stable, symmetrical hysteretic behavior. Unlike conventional braces that tend to lose effectiveness after buckling, BRBs continue to dissipate energy reliably throughout seismic events. Their robust fatigue resistance makes them especially suitable for retrofitting older structures, as well as for use in irregular or multi-story frames where torsional balance is a concern.

Installation typically involves connecting the braces to beam-column joints, with configurations optimized for load distribution and stiffness. BRBs are now recognized in major seismic design codes, including ASCE 7 and IS 1893, underlining their growing role in modern structural engineering.



Figure 2: Images of Buckling-Restrained Braces

1.3 Analytical Tools (ETABS 22)

Structural analysis for this investigation relies on ETABS 22, a finite element platform tailored for multi-story building simulations. The software enables precise modeling of irregular geometries, incorporating nonlinear brace behaviors through user-defined hysteresis models, such as the Bouc-Wen formulation for BRBs. Material properties are assigned per Indian standards: M30 concrete with a characteristic strength of 30 MPa and Fe500 reinforcement yielding at 500 MPa.

Its capabilities include:

- **Advanced Modeling:** Accurately simulates irregular geometries (H/C/L-shaped plans) and material nonlinearity.
- **Response Spectrum Analysis (RSA):** Incorporates Bhuj's seismic parameters (IS 1893:2016) to replicate Zone V ground motion.
- **Hysteresis Modeling:** Uses the Bouc-Wen model to capture BRB behavior, including strength degradation and pinching effects.
- **Parametric Outputs:** Generates critical metrics like story drift, displacement, base shear, and energy dissipation ratios.

The integration of ETABS 22 ensures reliable, code-compliant results, making it an indispensable tool for this study.

1.4 Research Objectives

1. To evaluate the seismic performance of G+15 RCC buildings with varying horizontal irregularities — Rectangular, L-shaped, C-shaped, and H-shaped plans.
2. To compare the effectiveness of two lateral load-resisting systems: Conventional steel bracing (ISWB 600-1) and Star Seismic Buckling Restrained Braces (BRB_{26.5}).
3. To analyze and compare four bracing patterns (X, V, Inverted V, and Multistory-X) applied to each building plan.
4. To conduct seismic analysis using ETABS 22 based on IS 1893 (Part 1): 2016, utilizing both Equivalent Static and Response Spectrum Methods.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

5. To assess key response parameters like natural time period, storey drift, top-storey displacement, base shear, and lateral stiffness.
6. To determine the most suitable bracing type and configuration for improving the seismic behaviour of irregular RCC structures in high seismic zones.

1.5 Scope of the Project

1. The project is limited to analytical modeling and linear dynamic analysis of high-rise RCC buildings using ETABS 22 software.
2. Four different plan shapes — Rectangular, L-shaped, C-shaped, and H-shaped — are considered to simulate real-world irregularities.
3. Structural retrofitting is tested using two bracing systems and four configurations under both EQ and RS loading in X and Y directions.
4. The seismic loading and design considerations are strictly based on IS 1893:2016 for Zone V (Bhuj region).
5. The study assumes ideal boundary conditions, standard loading as per IS 875, and excludes cost or time-history-based assessments.
6. This study provides design-level guidance and comparative insights, especially useful for selecting bracing systems in irregular buildings.

II. LITERATURE REVIEW

Seismic retrofitting of reinforced concrete (RCC) structures with irregular geometries has drawn considerable attention due to their heightened vulnerability to torsional effects and uneven seismic force distribution. Traditional steel bracing systems, commonly used for lateral load resistance, often exhibit premature buckling and limited energy dissipation capacity under cyclic loading, which compromises their effectiveness during earthquakes. This limitation has led to the adoption and development of advanced buckling-restrained braces (BRBs). Originally conceptualized in Japan during the 1980s, BRBs feature a steel core encased within a concrete-filled tube, separated by an unbonding layer that allows symmetric yielding in both tension and compression, thus preventing buckling and enhancing ductility.

Several key studies have substantiated the superior performance of BRBs. **Niyonyungu et al. [1]** applied BRBs to reinforced concrete frames with weak first-story irregularities using elastic response spectrum and nonlinear time history analyses, reporting up to a 39% reduction in story drifts. Among various bracing patterns tested, inverted V and X layouts showed optimal seismic performance, maintaining structural integrity where conventional braces buckled. In a cost-benefit analysis, **Chavan et al. [3]** demonstrated that BRBs reduced steel consumption and construction costs by over 40%, while also decreasing displacements by nearly 40%, highlighting their economic and structural advantages over traditional braces. **Gottem et al. [4]** examined multiple BRB configurations in a high-rise RC building under seismic zones III and V, finding inverted V and X BRBs reduced drifts by as much as 103% compared to bare frames and enhanced stiffness by up to 49%. **Hossain and Mondal's [6]** nonlinear pushover analysis revealed that diagonal BRBs exhibited the highest lateral stiffness and base shear capacity among four tested patterns, with improved energy dissipation and delayed hinge formation, confirming the diagonal layout's effectiveness for seismic resilience.

Comparisons between BRBs and viscous dampers (VDs) by **Javaid and Verma [8]** showed VDs slightly outperformed BRBs in some cases, especially when optimally placed. Nonetheless, BRBs continue to provide stable hysteretic behavior and architectural flexibility. **Babu's [7]** evaluation of a 10-story BRB braced frame showed a 40% decrease in displacements and improved seismic performance indicators. Other studies by **Islam and Waseem [2]**, and **Rizwan and Hashmi [5]** reinforced the benefits of X and diagonal bracing layouts for controlling displacements and increasing stiffness in both regular and irregular frames.

Collectively, these studies confirm that BRBs outperform conventional steel bracing by significantly enhancing seismic performance—reducing drifts and displacements while increasing stiffness and energy dissipation—in diverse RCC structures. However, gaps remain in thoroughly analysing BRB patterns, especially Multistory-X, under Indian seismic



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

standards for high-rise irregular buildings. This study aims to bridge these gaps by evaluating multiple BRB configurations through advanced nonlinear dynamic and response spectrum analyses, thereby advancing the understanding and application of BRBs in seismic retrofitting.

Despite the substantial body of work on BRBs and conventional steel bracing, the following gaps remain:

- **Application in Irregular RCC Structures:** Limited research has been conducted on retrofitting irregular RCC buildings with BRBs, particularly for high-rise G+15 configurations.
- **Comparison of Multiple Bracing Patterns:** There is a lack of comparative studies evaluating the performance of various bracing patterns (X, V, Inverted V, Multistorey-X) within the same structural system.
- **Indian Seismic Context:** Most available research is based on international standards, with insufficient focus on seismic demands as defined by IS 1893:2016 for Zone V regions.
- **Advanced Simulation Techniques:** Overreliance on linear static analyses persists, whereas nonlinear dynamic or RSA methods provide a more realistic assessment of seismic behaviour.

In summary, this study is built on previous research in seismic retrofitting of RCC frames with buckling-restrained braces. While earlier work focused on performance improvements of individual BRB configurations, we focus on systematically evaluating multiple BRB patterns, including Multistorey-X, in G+15 irregular RCC structures under Indian seismic codes using advanced dynamic analysis methods.

III. METHODOLOGY

This chapter delineates the systematic approach adopted for evaluating the seismic performance of G+15 reinforced concrete (RCC) structures with plan irregularities in Seismic Zone V, as per IS 1893:2016. The methodology integrates finite element modeling using ETABS 22 software to conduct equivalent static and response spectrum analyses, facilitating a comparative assessment of conventional steel bracing and buckling-restrained braces (BRBs). The procedural framework encompasses structural configuration, material specifications, loading regimes, bracing typologies, and analytical techniques to derive critical response parameters, including natural periods, inter-story drifts, lateral displacements, base shear forces, and stiffness characteristics.

3.1 Research Framework and Analytical Strategy

This study evaluates the seismic performance of G+15 reinforced concrete (RCC) buildings with horizontal plan irregularities, modelled for conditions representative of Bhuj, Gujarat, a high-risk region classified under Seismic Zone V with a peak ground acceleration (PGA) of 0.36g, as per IS 1893:2016. A total of four plan configurations—Rectangular, L-shape, C-shape, and H-shape—are assessed to understand the influence of geometric irregularity on structural response. The analytical framework compares two retrofitting strategies: Model A, incorporating Star Buckling Restrained Braces (BRBs), and Model B, employing Conventional Steel Bracing. Each model begins with an unbraced baseline and progresses to retrofitted versions featuring four bracing patterns: X, V, Inverted V, and Multistorey X. ETABS 22 is used for finite element modeling, with material properties and load cases defined according to Indian standards. Both Equivalent Static and Response Spectrum analyses are performed, with particular focus on linear dynamic behavior and modal contributions to account for torsional effects in irregular structures. The methodology emphasizes code compliance by evaluating inter-story drift, fundamental time periods, base shear, and lateral stiffness—providing a comparative basis for assessing the effectiveness of bracing systems in enhancing the seismic resilience of irregular high-rise buildings.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

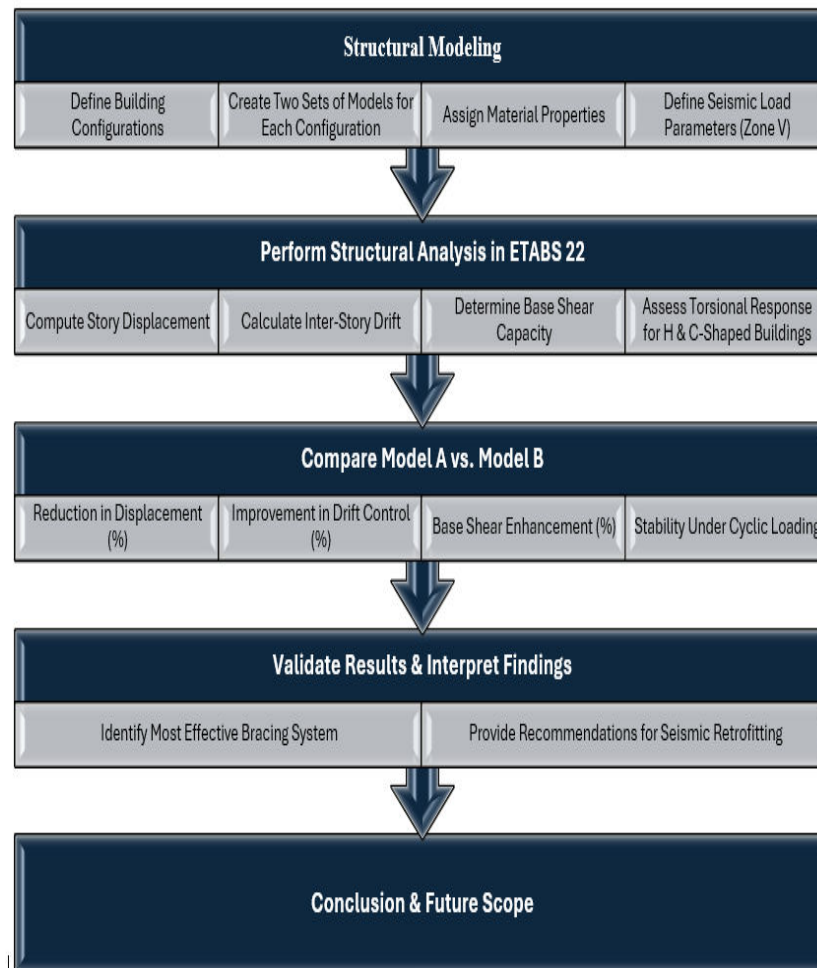


Figure 3: Research Methodology

3.2 Structural Configuration and Geometric Modeling

The study examines four distinct building typologies to capture the influence of plan irregularities on seismic response: a regular rectangular configuration as the baseline, and three irregular configurations—L-shaped, C-shaped, and H-shaped. Each model represents a G+15 structure, comprising 16 levels with a consistent story height of 3 meters, resulting in a total height of 50 meters, inclusive of a 2-meter foundation depth. The structural elements are dimensioned as follows: columns at 600 mm × 600 mm, beams at 300 mm × 600 mm, and slabs with a thickness of 150 mm. These dimensions reflect typical high-rise RCC construction practices in seismically active regions.

The modeling process was executed in ETABS 22, ensuring precise representation of geometric irregularities and member connectivity. Boundary conditions assumed fixed supports at the base to simulate rigid foundation interaction, while mass distribution incorporated dead loads and a fraction of live loads (25%) as per code stipulations for seismic analysis. Seismic loading was modelled for conditions representing Bhuj in Gujarat, situated in Seismic Zone V (as per IS 1893:2016), with a zone factor (Z) of 0.36. This setup enabled accurate simulation of dynamic behaviour under lateral forces, particularly for irregular plans prone to torsional effects.



International Journal of Multidisciplinary Research in
Science, Engineering and Technology (IJMRSET)
(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

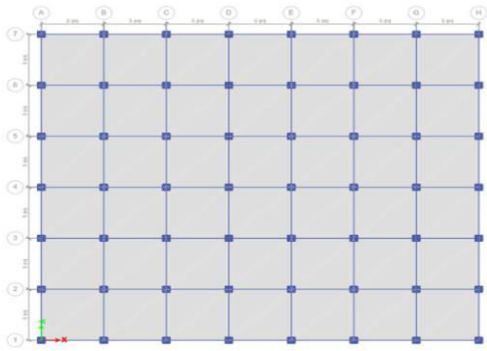


Figure 4: Regular Rectangular Building

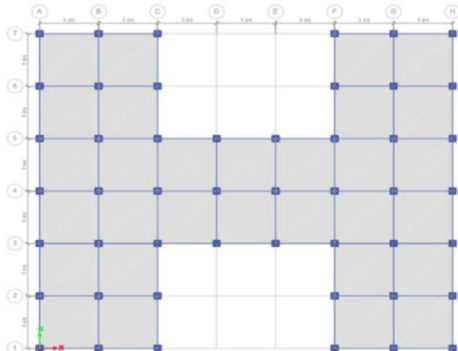


Figure 5: H - Shaped Building

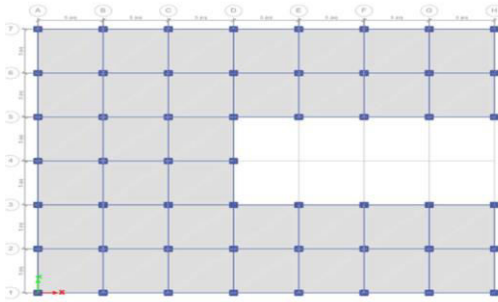


Figure 6: C - Shaped Building

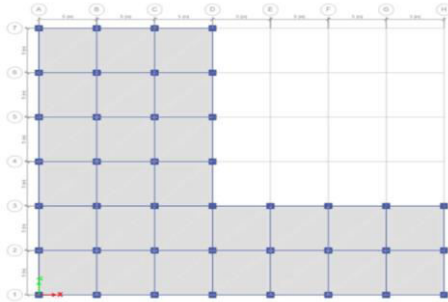


Figure 7: L - Shaped Building

Table 1: Section Details

Component	Dimensions/Specification
Columns	600 mm × 600 mm
Beams	300 mm × 600 mm
Slab Thickness	150 mm
Conventional Bracing	ISWB 600-1
Star BRB	Star Seismic BRB_26.5



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Table 2: BRB Section Properties (StarBRB_26.5)

Parameter	Specification
Material of Yielding Core	Fe250
Total BRB Weight	25.54 kN
Overall Depth	406.4 mm
Overall Width	304.8 mm
Area of Yielding Core	171 cm ²
Length of Yielding Core	4.267 m
Length of Elastic Segment	2.271 m
Stiffness of Elastic Segment	4.33×10^6 kN/m
Effective Axial Stiffness	7.05×10^5 kN/m

3.3 Material Properties and Specifications

Material selection adhered to Indian standards to ensure relevance to local construction norms. Concrete of grade M30 was utilized, exhibiting a characteristic compressive strength of 30 MPa, while reinforcement bars were specified as Fe500 grade steel with a yield strength of 500 MPa. For lateral load-resisting systems, conventional steel bracing employed ISWB 600-1 sections, characterized by their standard wide-flange profiles. In contrast, buckling-restrained braces were modelled based on high-performance systems equivalent to Star Seismic BRB26.5, designed to prevent compressive buckling through a confined steel core encased in a mortar-filled tube with an unbonding interface.

3.4 Bracing Configurations

The following configurations are implemented in the ETABS models:

- X-Bracing: Diagonal cross-bracing pattern
- V-Bracing: Chevron-style configuration
- Inverted V-Bracing: Inverted chevron, suitable for upper stories
- Multi-story X-Bracing (MSX): Extending X-bracing over multiple floors for better lateral stiffness

For each configuration, two sets of models are created:

- Model A: Star BRB system
- Model B: Conventional steel bracing



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

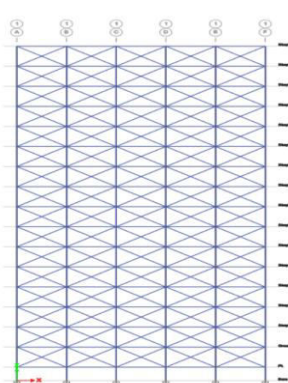


Figure 8: X-Bracing

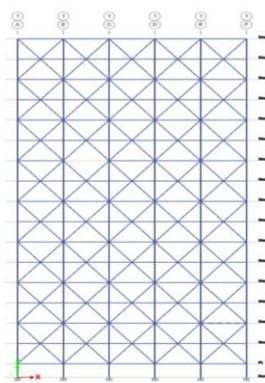


Figure 9: Multi-story
X-Bracing

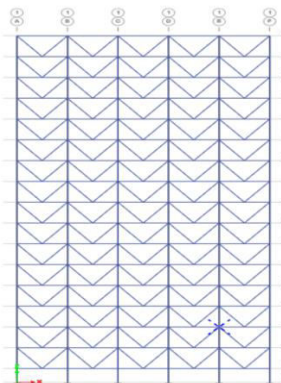


Figure 10: V-Bracing

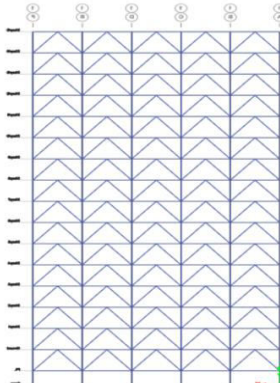


Figure 11:
Inverted V-Bracing

3.5 Loading and Seismic Parameters

Loading conditions were meticulously defined to reflect realistic gravitational and seismic demands as per Indian codes.

- Dead Load: Dead loads included the self-weight of structural components, wall loads at 11 kN/m (incorporating parapet loads of 2 kN/m), and floor finishing loads at 4.75 kN/m².
- Live Load: Live loads were assigned as 3 kN/m² for typical floors and 1.5 kN/m² for terrace levels, in compliance with IS 875 (Part 2).
- Seismic Load: Seismic loading targeted conditions representative of Bhuj, Gujarat, within Seismic Zone V, characterized by a zone factor of 0.36, an importance factor of 1.5, a response reduction factor of 5, and medium soil conditions (Type II) as per IS 1893:2016. Seismic forces were applied through two primary methods: equivalent static loads (EQ-X and EQ-Y) and response spectrum loads (RS-X and RS-Y), acting along the principal orthogonal axes to account for directional effects.
- Wind Load: The horizontal load caused by the wind is called as wind loads. It depends upon the velocity of wind and shape and size of the building. Complete details of calculating wind loads on structures are given in IS 875(part -3)-1987.
- Load Combinations: Load combinations were formulated to include 1.5 times the dead load plus seismic effects, ensuring conservative estimation of structural demands under critical scenarios. These parameters were integrated into the ETABS environment to simulate both static and dynamic responses accurately.

3.6 Analytical Techniques and Evaluation Criteria

The analytical process commenced with eigenvalue analysis to extract natural periods and mode shapes, ensuring that modal mass participation exceeded 90% in each principal direction as mandated by IS 1893:2016. This step validated the dynamic characteristics of the models prior to load application. The equivalent static method was employed to compute base shear based on seismic weight and height distribution, providing a preliminary assessment of lateral force demands.

For a more refined evaluation, response spectrum analysis (RSA) was conducted, utilizing the complete quadratic combination (CQC) method to aggregate modal responses, particularly critical for capturing higher-mode effects in tall and irregular structures. Key performance metrics included inter-story drifts (restricted to 0.004 times story height per code limits), lateral displacements at roof level, base shear capacities, and story-wise stiffness distributions. These outputs facilitated a direct comparison between unbraced, steel-braced, and BRB-retrofitted models across all geometries.

Additional checks focused on identifying soft-story formations and torsional irregularity factors, ensuring compliance with seismic design provisions. The analytical framework was designed to isolate the contributions of bracing systems to overall structural stability, providing a robust basis for recommending retrofitting strategies in high-seismic zones.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

IV. RESULTS AND DISCUSSIONS

This chapter presents the analytical outcomes of the seismic retrofitting study conducted using ETABS 22 on G+15 reinforced concrete buildings with various irregular plan configurations: rectangular, L-shaped, C-shaped, and H-shaped. The analysis was performed under seismic zone V as per IS 1893:2016, employing both Equivalent Static and Response Spectrum methods.

4.1 Fundamental Period Analysis

Fundamental time periods reduced significantly with the addition of bracing systems, especially with buckling-restrained braces (BRBs). The Multistory-X configuration exhibited the greatest reduction in fundamental period, indicating enhanced structural stiffness. The time period reductions reached up to 40% for retrofitted irregular buildings compared to their unbraced counterparts.

Table 3: Comparison of Maximum Time Periods for Different Building Shapes and Bracing Configurations

Type Of bracing	Timeperiods Of different shapes of building (Sec)			
	Rectangular	H - shape	C-Shape	L- Shape
Without Braces	2.397	2.401	2.459	2.405
BRB X-Bracing	1	0.909	1.072	0.978
Steel X-Bracing	1.054	0.947	1.112	1.004
BRB Multistory-X	1.031	0.945	1.1	0.987
Steel Multistory-X	1.09	0.984	1.14	1.107
BRB V-Bracing	1.076	1.033	1.157	1.095
Steel V-Bracing	1.127	1.056	1.188	1.107
BRB Inverted V -Bracing	1.045	0.997	1.115	1.044
Steel Inverted V -Bracing	1.099	1.023	1.149	1.061

4.2 Inter-Story Drift Performance

Inter-story drift analysis confirmed that irregular plan geometries, particularly L- and C-shaped buildings, governed the seismic demand due to torsional amplification and discontinuous stiffness and mass distribution. The inclusion of bracing systems—especially Buckling Restrained Braces (BRBs) in Multistory-X (MSX) or X configurations—significantly reduced drifts, maintaining them well within the IS 1893:2016 limit of 0.004h (approximately 12 mm for 3 m storey height) under both Equivalent Static and Response Spectrum analyses. In the EQ-X direction, drift decreased from 0.002091 to 0.001341 for the C-shaped frame and from 0.002280 to 0.001309 for the L-shaped frame with BRB-MS-X, while comparable steel MSX values were marginally lower at 0.001222 and 0.001199. Similar improvements were observed under RS-X and RS-Y conditions, where the unbraced L-shaped frame reduced from 0.002224 to 0.001629 and the C-shaped frame from 0.002270 to 0.001249 with BRB-MS-X, confirming effective torsional control. The H-shaped and rectangular frames showed moderate drift values, with BRB-MS-X reducing them by nearly half (for example, H: 0.002137 to 0.001244; Rectangular: 0.002218 to 0.001229). Although steel braces yielded 5–10% lower peak drifts due to higher initial stiffness, BRBs provided superior reliability under inelastic demands by ensuring symmetric tension–compression yielding and preventing local buckling. Overall, the BRB-MS-X and X configurations demonstrated the most effective drift suppression and torsional stability, making them the preferred choice for enhancing the seismic resilience of irregular high-rise RCC buildings in Zone V.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

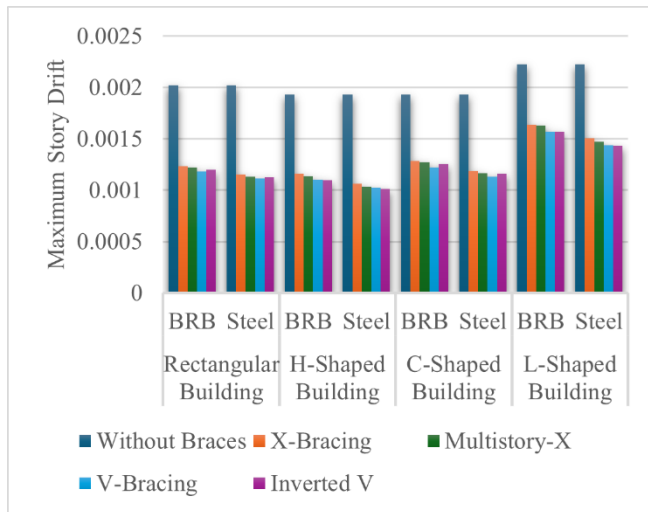


Figure 12: Maximum Inter-Story Drift Under EQ-X

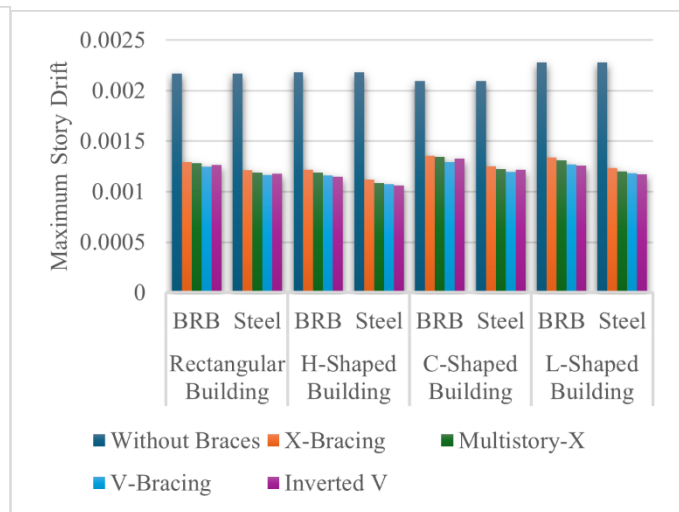


Figure 13: Maximum Inter-Story Drift Under RS-X

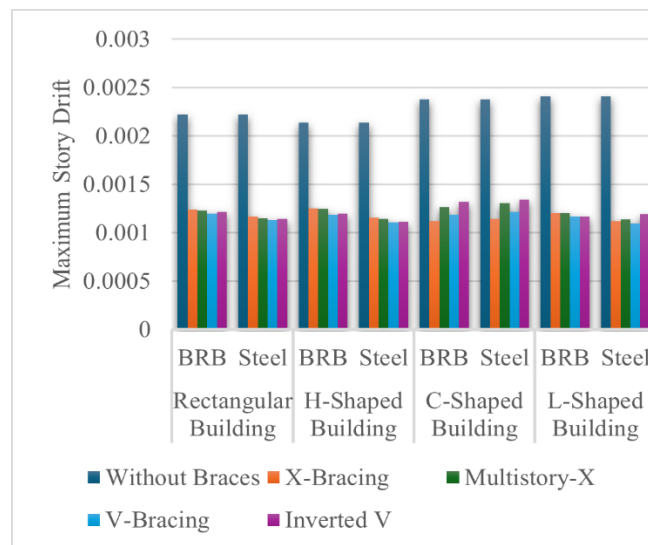


Figure 14: Maximum Inter-Story Drift Under EQ-Y

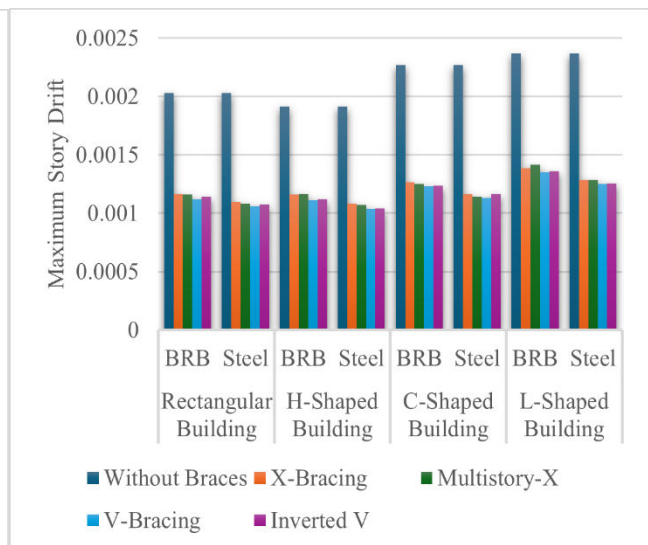


Figure 15: Maximum Inter-Story Drift Under RS-Y

4.3 Lateral Displacement Analysis

Across all four load cases, lateral roof displacements fell sharply with bracing, with the largest gains from BRB Multistory-X in torsion-sensitive plans: under EQ-X, unbraced peaks of 89.94 mm (L) and 80.19 mm (C) dropped to 37.99 mm and 29.67 mm, respectively, slightly outperforming steel MSX in the same geometries; under RS-X, unbraced 74.83 mm (L) and 60.82 mm (C) reduced to 35.36 mm and 23.77 mm with BRB MSX, typically 3–5% lower than steel; under EQ-Y, the highest unbraced values in C and L (96.08–96.56 mm) halved to 48.48 mm (C) and 41.99 mm (L) with BRB MSX; and under RS-Y, unbraced 80.14 mm (C) and 82.18 mm (L) reduced to 41.22 mm and 36.54 mm using BRB MSX—consistently achieving ~55–60% reductions from unbraced and a modest edge over steel due to superior energy dissipation and buckling restraint, while rectangular and H-shapes also benefited with smaller but meaningful cuts across EQX/EQY/RSX/RSY.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

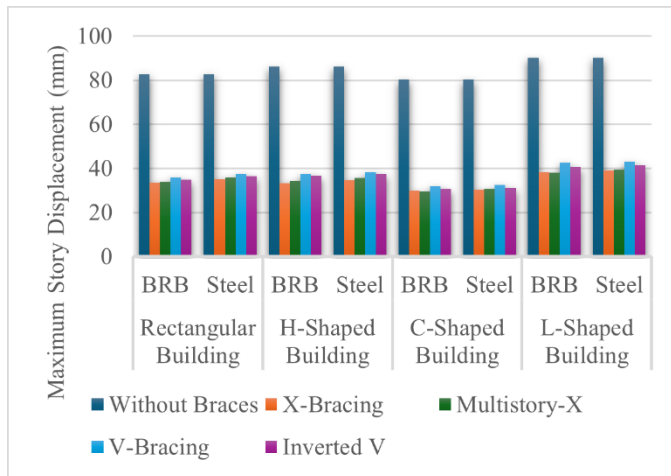


Figure 16: Lateral Displacement Under EQ-X

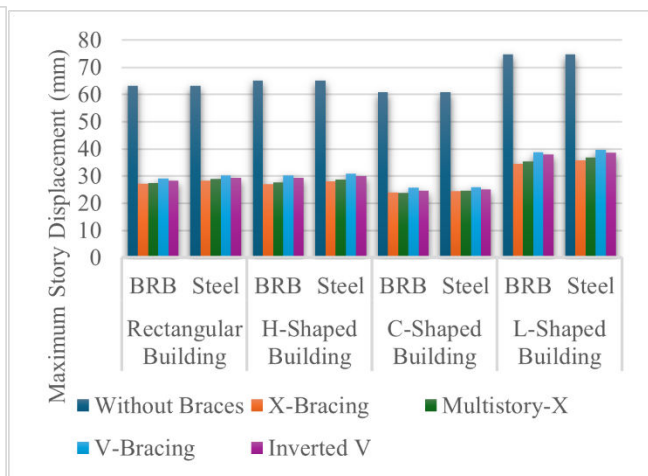


Figure 17: Lateral Displacement Under RS-X

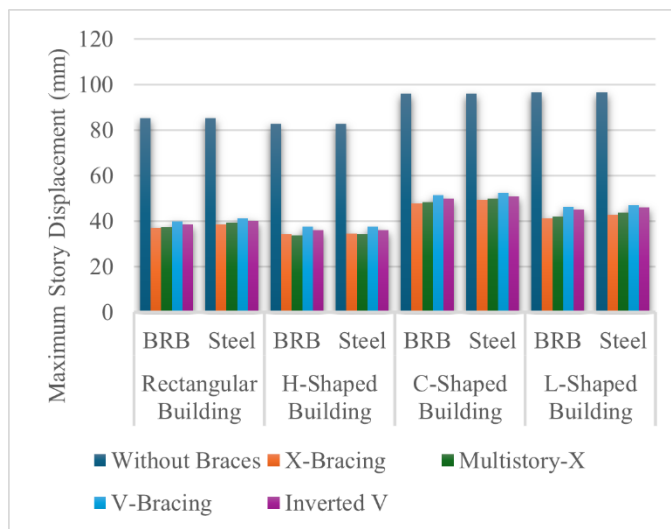


Figure 18: Lateral Displacement Under EQ-Y

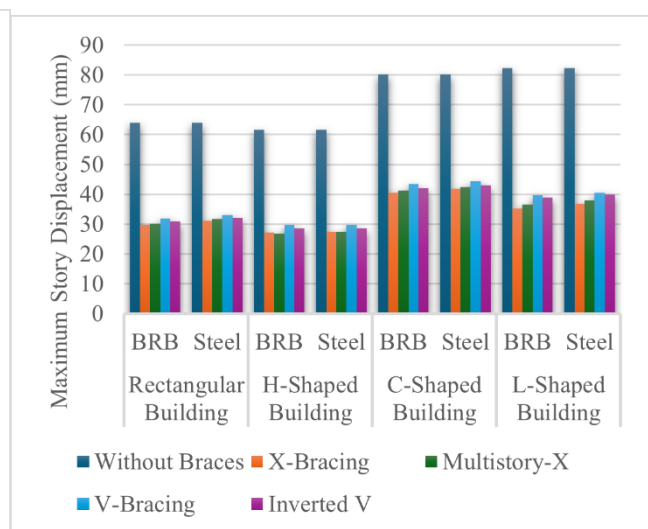


Figure 19: Lateral Displacement Under RS-Y

4.4 Base Shear Capacity Enhancement

Across all four load cases, base shear capacities increased dramatically with bracing, with BRB X-bracing yielding the highest enhancements, particularly in irregular geometries: under EQ-X, unbraced values of 6324.58 kN (L) and 8515.65 kN (C) surged to 18699.62 kN and 26366.09 kN, respectively, outperforming steel by 10–15% and achieving up to 164% gains.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

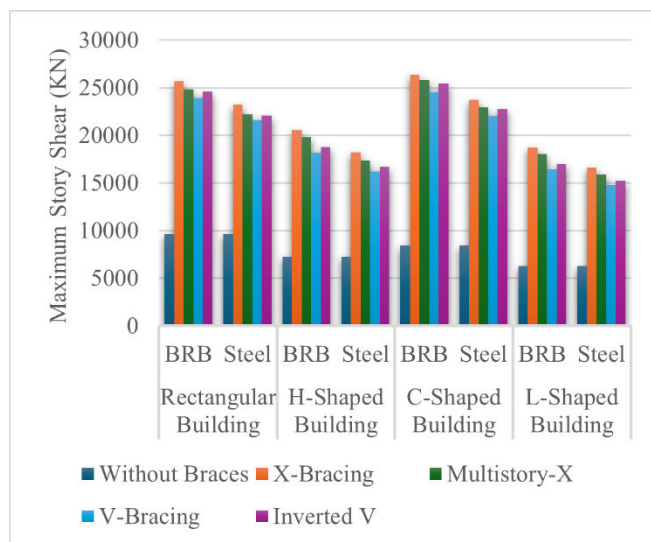


Figure 20: Base Shear Under EQ-X

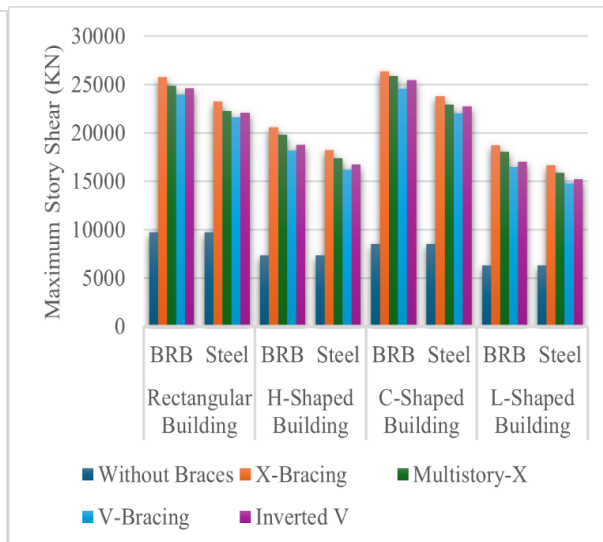


Figure 21: Base Shear Under RS-X

under RS-X, unbraced 6264.83 kN (L) and 8441.14 kN (C) rose to 18678.44 kN and 26344.95 kN with BRB X-bracing, maintaining a similar edge over steel; under EQ-Y, the lowest unbraced capacities in L and C (6204.29–7952.13 kN) improved to 16152.92 kN and 19303.79 kN using BRB X-bracing; and under RS-Y, unbraced 6142.08 kN (L) and 7865.64 kN (C) reached 16133.10 kN and 19272.51 kN with BRB X-bracing—consistently delivering 180–210% enhancements from unbraced states and 10–15% superiority over steel due to enhanced energy dissipation and buckling resistance, while rectangular and H-shapes also saw substantial but less pronounced boosts across EQX/EQY/RSX/RSY.

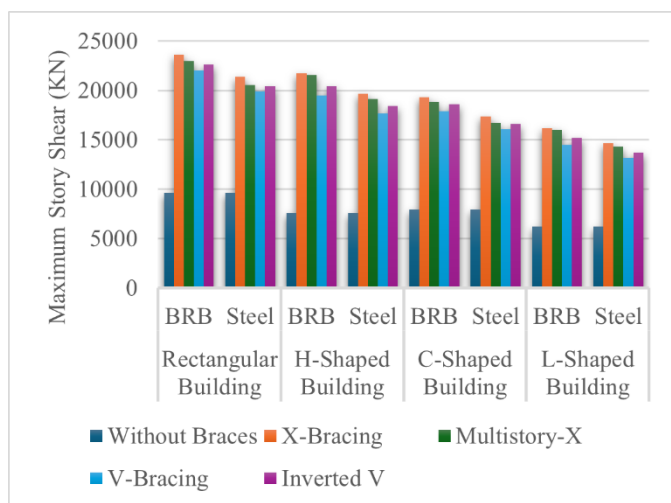


Figure 22: Base Shear Under EQ-Y

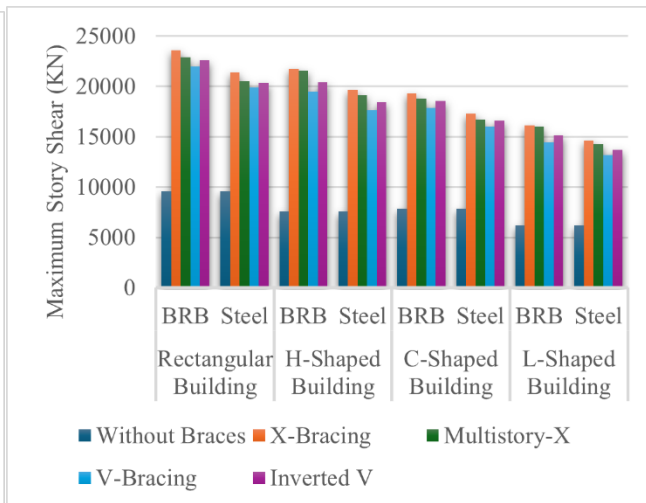


Figure 23: Base Shear Under RS-Y



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

4.5 Story Stiffness Enhancement

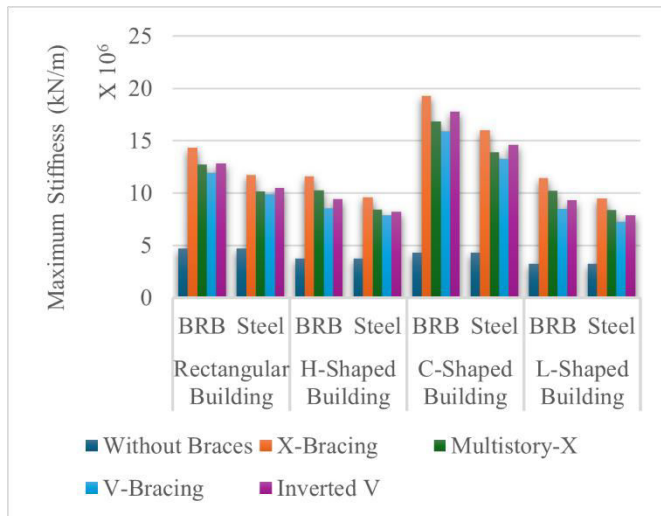


Figure 24: Global Stiffness Under EQ-X

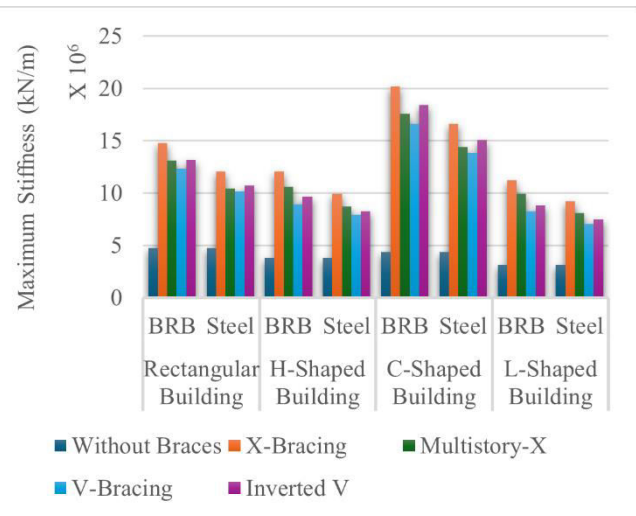


Figure 25: Global Stiffness Under RS-X

Story stiffness was markedly enhanced by bracing across all geometries and analysis directions, with Buckling-Restrained Braces delivering the most pronounced improvements: in EQ-X and RS-X, BRB X and Multistory-X configurations raised stiffness from baseline values on the order of $3.1\text{--}4.3 \times 10^6$ kN/m in irregular plans to approximately $11\text{--}20 \times 10^6$ kN/m (e.g., L-shape $\sim 11.4 \times 10^6$; C-shape $\sim 19.3\text{--}20.2 \times 10^6$), consistently exceeding steel bracing by roughly 10–25% for the same layouts; analogous gains were observed in EQ-Y and RS-Y, where BRB X-bracing elevated L-shape from $\sim 3.0\text{--}3.2 \times 10^6$ to $\sim 9.3\text{--}9.5 \times 10^6$ kN/m and H-shape to $\sim 15.9 \times 10^6$ kN/m, again outpacing steel; overall, stiffness improvements versus unbraced frames were on the order of 200–350%, with the most substantial benefits realized in irregular C and L plans and under dynamic (RS) conditions, thereby substantiating BRB X/MSX as the preferred configurations for stiffness enhancement in Zone-V design per the study's ETABS results.

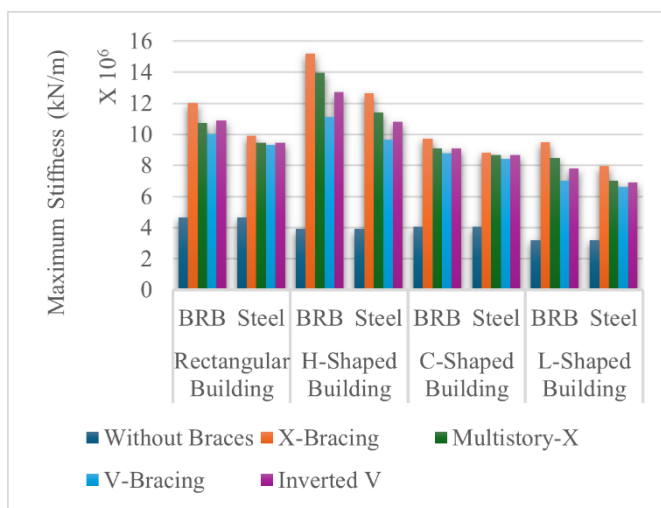


Figure 26: Global Stiffness Under EQ-Y

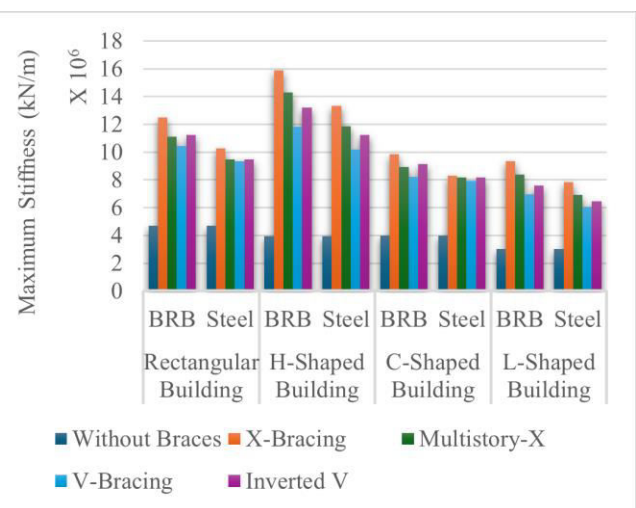
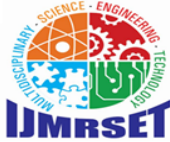


Figure 27: Global Stiffness Under RS-Y



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Overall, the study demonstrates that retrofitting G+15 RCC buildings—especially irregular L, C, and H plans—in Zone V with Buckling-Restrained Braces yields superior seismic performance to conventional steel bracing across all metrics: fundamental periods drop by roughly 35–40%, inter-story drifts and roof displacements reduce by about 50–60%, and base-shear mobilization increases by approximately 180–210% relative to unbraced frames, while story stiffness improves by about 200–350%; BRBs also provide a consistent 10–25% advantage in stiffness and 8–15% in base shear over steel for the same configuration, with the X and Multistory-X layouts performing best under both EQ and RS analyses in X/Y directions, thereby effectively mitigating torsion and rendering irregular frames comparable to—or better than—regular rectangular systems per the ETABS results aligned to IS 1893:2016.

V. CONCLUSION

5.1 Conclusion

This study has examined the seismic response of G+15 RCC buildings retrofitted with Buckling-Restrained Braces (BRBs), benchmarked against unbraced baselines and conventional steel bracing systems, using linear Equivalent Static (EQ) and Response Spectrum (RS) analyses in compliance with IS 1893:2016 for Zone V. The findings provide clear and consistent evidence of the superior performance of BRBs, especially in irregular plan geometries.

Key outcomes:

- Across the 36-model framework, bracing systems achieved notable reductions in inter-storey drift (up to 50%) and roof displacement (up to 60%), accompanied by marked increases in global response parameters. Base shear capacities improved by about 180–210%, while global story stiffness rise dramatically in the range of 200–350%, with the largest gains observed in torsionally irregular L- and C-shaped plans. These outcomes underscore the dual role of BRBs in controlling lateral deformation and mobilizing structural resistance.
- Although conventional steel bracing occasionally delivered marginally lower peak drift values (5–10%) due to its higher initial stiffness, BRBs consistently outperformed steel alternatives in terms of base shear (8–15% higher) and stiffness (10–25% higher) in RS combinations. This makes BRBs the more suitable choice for performance-based design objectives, where cyclic stability and energy dissipation capacity govern long-term reliability.
- The choice of bracing pattern further influenced performance. Multistory-X (MSX) and X configurations provided the most balanced outcomes, outperforming V and Inverted-V systems. Rectangular frames showed robust improvement under all bracing types; however, irregular L and C plans benefitted most strongly from BRB-MSX and BRB-X layouts, which demonstrated superior torsional control, particularly under RS-Y excitations. In H-shaped frames, BRB-MSX and BRB-X reduced drifts by nearly 50% and boosted stiffness by 200–350%, again emphasizing the comparative advantages of BRBs over steel bracing.
- From a practical standpoint, BRB-MSX may be recommended as the default retrofitting scheme for high-rise RCC buildings in severe seismic zones, with BRB-X as a viable alternative where full-storey MSX installation is impractical. V and Inverted-V remain acceptable under architectural or functional constraints, albeit with measurable trade-offs in efficiency. Importantly, all braced configurations satisfied the IS 1893 drift limitation of 0.004h, ensuring compliance with code-mandated deformation control.

In summary, this study establishes that the retrofitting and design of irregular RCC buildings using BRBs (and, to a significant extent, optimally placed steel bracing) provide robust solutions for seismic resilience. The selection of the suitable bracing configuration—tailored to building geometry and functional constraints—is critical to achieving the highest standards of safety and performance in earthquake-prone regions. The findings advocate for the broader adoption of BRBs and careful configuration selection as key strategies for modern seismic retrofitting and design.

5.2 Future Scope

- **Nonlinear Analyses:** Incorporate time-history analysis to capture inelastic behavior and energy dissipation.
- **Experimental Validation:** Conduct full-scale or shake-table testing for irregular BRB-retrofitted frames.
- **Optimization Studies:** Apply algorithms for optimal sizing and placement of braces.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

- **Hybrid Systems:** Explore BRBs in combination with other dampers (e.g., viscous, friction) for enhanced resilience.

REFERENCES

- [1] Niyonyungu F., Zhao J., Yang Q., Wang G., Xu J. "Research on Application of Buckling Restrained Braces in Strengthening of Concrete Frame Structures." *Civil Engineering Journal*, Vol. 6, No. 2, pp. 344–360, 2020. <https://doi.org/10.28991/cej-2020-03091468>.
- [2] Islam S.U., Waseem S.A. "Comparative study on seismic behaviour of different types of reinforced cement concrete bracing system in high rise reinforced concrete structures." *Conference Paper*, 2020.
- [3] Chavan H., Mane N., Mali T. "Analytical Comparison of Unbraced, Braced and Buckling Restrained Braced Structures with Cost Comparison of Conventional Bracing and Buckling Restrained Bracing Systems." *International Journal of Advanced Technology in Engineering and Science*, Vol. 4, No. Special Issue 01, pp. 334–343, 2016.
- [4] Gottem A.S., Lingeshwaran N., Himath Kumar Y., Chowdary C.M., Pratheba S., Perumal K. "Analytical Study of Buckling Restrained Braced Frames in Different Seismic Zone Using ET ABS." *Civil and Environmental Engineering*, Vol. 19, No. 1, pp. 426–443, 2023. <https://doi.org/10.2478/cee-2023-0038>
- [5] Rizwan M.Z., Hashmi S.M. "Effect of Bracing on Regular and Irregular RCC (G+10) Frame Structure with Different Types of Bracings under Dynamic Loading." *International Journal for Research in Applied Science & Engineering Technology*, Vol. 8, No. 12, pp. 317–327, 2020. <https://doi.org/10.22214/ijraset.2020.32498>
- [6] Hossain M.S., Mondal S. "Pushover Analysis Between Different Shapes of BRB for Seismic Analysis in RCC Structure with IS 18993:2016." *International Journal for Multidisciplinary Research*, Vol. 5, No. 6, pp. 1–9, 2023.
- [7] Babu M.G. "Reliability Index for Buckling Restrained Braced Frame." *International Journal of Advances in Engineering and Management*, Vol. 3, No. 7, pp. 49–57, 2021.
- [8] Javaid K., Verma N. "Vibration control of seismic forces using viscous dampers and buckling restrained braces in irregular composite buildings." *IOP Conference Series: Earth and Environmental Science*, Vol. 1110, pp. 012052, 2023. <https://doi.org/10.1088/1755-1315/1110/1/012052>
- [9] Black C.J., Makris N., Aiken I.D. "Component Testing, Seismic Evaluation, and Characterization of Buckling-Restrained Braces." *Journal of Structural Engineering*, Vol. 130, No. 6, pp. 880–894, 2004. [https://doi.org/10.1061/\(ASCE\)0733-9445\(2004\)130:6\(880\)](https://doi.org/10.1061/(ASCE)0733-9445(2004)130:6(880))
- [10] Chopra A.K. *Dynamics of Structures: Theory and Applications to Earthquake Engineering* (5th ed.). Pearson Education India, 2017.
- [11] Computers and Structures Inc. "ETABS: Integrated Building Design Software." Berkeley, California, USA, 2023. Available at: <https://www.csiamerica.com/products/etabs>
- [12] Bureau of Indian Standards (BIS). (1987). IS 875 (Part 1 & 2): Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures – Part 1: Dead Loads, Part 2: Imposed Loads. Manak Bhavan, New Delhi, India.
- [13] Bureau of Indian Standards (BIS), IS 456-2000: Code of Practice for Plain and Reinforced Concrete, Manak Bhavan, New Delhi, 110002, India.
- [14] Bureau of Indian Standards (BIS), IS 875 (Part 3) - 2015: Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures - Wind Loads, Manak Bhavan, New Delhi, 110002, India.
- [15] Bureau of Indian Standards (BIS), IS 1893 (Part 1): 2016: Criteria for Earthquake Resistant Design of Structures - Part 1: General Provisions and Buildings, Manak Bhavan, New Delhi, 110002, India.
- [16] Bureau of Indian Standards (BIS), IS 13920: 2016: Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice, Manak Bhavan, New Delhi, 110002, India.
- [17] Bureau of Indian Standards. (BIS). IS 800:2007: General Construction in Steel – Code of Practice. New Delhi.



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com