

Comparative Analysis of Buckling Restrained Bracing Configurations in RC Buildings under Seismic Loading

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Abstract - The seismic performance of reinforced concrete (RC) structures can be significantly enhanced through the use of Buckling Restrained Braces (BRBs). However, the effectiveness of BRB systems largely depends on their configuration and placement within the structure. This study presents a comprehensive comparative analysis of different BRB configurations, namely Inverted V, X-pattern, zig-zag, and K-bracing systems, in a multi-storey RC building subjected to seismic loading.

A G+25 storey building is modeled and analyzed using ETABS 2022 software, and response spectrum analysis is carried out in accordance with IS 1893 (Part 1): 2016. Key response parameters including storey displacement, storey drift, storey shear, and overturning moment are evaluated for each bracing configuration.

The results indicate that all bracing configurations improve seismic performance compared to unbraced frames; however, the degree of improvement varies significantly. Among the configurations studied, X-pattern and inverted V bracing systems demonstrate superior performance in reducing displacement and drift, while zig-zag and K-bracing show moderate effectiveness. The study highlights the importance of selecting an optimal bracing configuration to achieve maximum structural efficiency and seismic resistance.

Key Words: Buckling Restrained Braces; Bracing Configuration; Seismic Performance; RC Building; Response Spectrum Analysis; ETABS

1. INTRODUCTION

The increasing vulnerability of high-rise structures under seismic loading has necessitated the development of efficient lateral load-resisting systems. Conventional RC moment-resisting frames often exhibit excessive lateral deformation due to limited stiffness and energy dissipation capacity. To overcome these limitations, bracing systems have been widely adopted as an effective means of enhancing seismic performance.

Among various bracing systems, Buckling Restrained Braces (BRBs) have gained prominence due to their ability to sustain large inelastic deformations without buckling. Unlike conventional braces, BRBs exhibit stable and symmetrical behavior under both tensile and compressive forces, making them highly suitable for earthquake-resistant design [1,2].

While numerous studies have established the effectiveness of BRBs in improving seismic response, the influence of bracing configuration remains a critical aspect that directly affects structural behavior. Different configurations such as inverted V, X-pattern, zig-zag, and K-bracing provide distinct load paths and stiffness distributions, leading to variations in seismic response.

Previous research has shown that X-bracing systems offer superior stiffness due to direct load transfer paths, whereas inverted V configurations provide balanced force distribution with architectural flexibility [3–5]. However, limited studies provide a comprehensive comparison of multiple configurations within a unified analytical framework, especially for high-rise RC buildings designed as per Indian seismic codes.

The present study addresses this gap by conducting a detailed comparative analysis of various BRB configurations using a consistent modeling approach. The structural responses are evaluated based on displacement, drift, shear, and overturning moment derived from response spectrum analysis.

The objective is to identify the most effective bracing configuration for enhancing seismic performance and to provide design insights for practical implementation in earthquake-prone regions.

2. LITERATURE REVIEW

The seismic performance of buildings is significantly influenced by the type and configuration of lateral load-resisting systems. Among various techniques, bracing systems have been widely studied due to their efficiency in improving stiffness, strength, and energy dissipation capacity. In recent years, Buckling Restrained Braces (BRBs) have gained considerable attention as an advanced bracing solution capable of overcoming the limitations of conventional systems.

Traditional bracing configurations such as diagonal, V-type, inverted V-type, X-pattern, and K-bracing have been extensively investigated for their influence on structural response. Studies indicate that the effectiveness of these configurations depends largely on their ability to provide efficient load paths and uniform distribution of seismic forces.

Research by Black et al. [1] and Sabelli et al. [2] established the fundamental behavior of BRBs, highlighting their stable hysteretic response and ability to resist both tensile and compressive forces without buckling. These characteristics make BRBs superior to conventional bracing systems, particularly under cyclic loading conditions.

Several analytical studies have compared different bracing configurations in multi-storey buildings. Patel and Patel (2025) examined various bracing patterns including forward diagonal, cross-diagonal, V-type, and inverted V-type systems. Their findings revealed that cross-diagonal (X-pattern) and inverted V configurations significantly reduce storey displacement and drift compared to other arrangements, with reductions exceeding 60% in certain cases.

Similarly, Gottem et al. (2023) conducted a comparative study on different bracing configurations in high-rise buildings under multiple seismic zones. The results indicated that X-bracing provides maximum stiffness due to its direct load transfer mechanism, while inverted V-bracing offers a balanced

distribution of forces with improved ductility. Zig-zag and K-bracing configurations showed comparatively lower efficiency in controlling lateral displacement but still contributed to performance enhancement over unbraced frames.

The influence of bracing geometry on structural performance has also been investigated by Kumar et al. [3], who reported that X-bracing systems are highly effective in reducing storey drift due to their triangulated configuration, which minimizes deformation. In contrast, K-bracing systems were found to introduce additional bending in columns, reducing their effectiveness under seismic loading.

Studies focusing on zig-zag bracing configurations suggest that while they provide improved load redistribution and architectural flexibility, their performance is generally inferior to X and V-type systems in terms of stiffness and displacement control [4]. However, they may still be preferred in cases where architectural constraints limit the use of more rigid configurations.

In addition to configuration type, the interaction between bracing systems and RC frames plays a crucial role in determining overall seismic performance. Research by Ravi Kant et al. [5] demonstrated that BRBs enhance the global stiffness of the structure while concentrating inelastic deformation within the brace elements, thereby protecting primary structural components such as beams and columns.

Recent advancements in performance-based seismic design have further emphasized the importance of selecting optimal bracing configurations. Catalan et al. (2025) highlighted that the efficiency of BRB systems depends not only on their material properties but also on their geometric arrangement within the structure, which directly influences modal response and energy dissipation characteristics.

Research Gap

Despite extensive research on bracing systems, the following gaps are identified:

1. Most studies evaluate individual configurations separately, lacking a unified comparison of multiple BRB configurations under identical conditions.
2. Limited research is available on direct comparison of four or more configurations (Inverted V, X, zig-zag, K) within a single analytical framework.
3. The combined effect of configuration on multiple response parameters (displacement, drift, shear, overturning moment) is not comprehensively addressed.
4. There is insufficient work based on high-rise RC buildings designed using IS 1893:2016, particularly for Indian seismic conditions.
5. The influence of configuration on global vs local behavior simultaneously is rarely discussed in detail.

Objective of Present Study

The objectives of the present study are as follows:

1. To perform a comparative seismic analysis of different Buckling Restrained Bracing (BRB) configurations, namely Inverted V, X-pattern, zig-zag, and K-bracing systems in a multi-storey RC building.
2. To evaluate the structural response of each configuration based on key performance parameters such as storey displacement, storey drift, storey shear, and overturning moment.
3. To investigate the influence of bracing configuration on the overall stiffness, stability, and seismic behavior of the structure.

4. To identify the most effective BRB configuration for minimizing lateral deformation and enhancing seismic resistance.

5. To provide practical design insights for the optimal selection of bracing systems in high-rise RC buildings subjected to earthquake loading.

3. METHODOLOGY

3.1 Analytical Framework

The present study adopts a comparative analytical approach to evaluate the seismic performance of a multi-storey reinforced concrete (RC) building incorporating different Buckling Restrained Bracing (BRB) configurations. The analysis is performed using ETABS 2022, ensuring uniform modeling conditions for all structural cases. In order to isolate the effect of bracing configuration, all other parameters such as geometry, material properties, loading conditions, and boundary conditions are kept constant throughout the study. The structural system is analyzed under five different conditions, namely a bare frame without bracing and four braced configurations consisting of Inverted V, X-pattern, zig-zag, and K-bracing systems. This approach enables a direct and unbiased comparison of seismic performance among different configurations.

3.2 Seismic Analysis Method

The seismic response of the structure is evaluated using the response spectrum method, which is widely accepted for analyzing multi-storey buildings where higher mode effects are significant. The response spectrum is defined in accordance with IS 1893 (Part 1): 2016, considering appropriate seismic parameters such as zone factor, importance factor, response reduction factor, and soil type. A damping ratio of 5% is assumed for all cases. The method involves determining the natural modes of vibration of the structure, computing modal responses for each mode, and combining these responses using suitable modal combination rules. This ensures an accurate estimation of peak structural response under seismic excitation.

3.3 Structural Modeling Strategy

A three-dimensional analytical model of a G+25 RC building is developed using ETABS software. The structure is assumed to be fixed at the base, and floor slabs are modeled as rigid diaphragms to ensure uniform lateral displacement at each storey level. The mass of the structure is lumped at the floor levels, and linear elastic material behavior is considered for all structural components. Gravity loads and seismic loads are applied as per relevant code provisions. The modeling strategy is designed to maintain consistency across all cases, with variations introduced only in the bracing configuration. The BRB elements are modeled as axial members capable of resisting both tensile and compressive forces without buckling, thereby simulating their actual behavior under cyclic loading.

3.4 Bracing Configurations

Four different BRB configurations are considered in this study, namely Inverted V, X-pattern, zig-zag, and K-bracing systems. In the Inverted V configuration, the braces converge at the beam midpoint, resulting in a balanced distribution of forces. The X-pattern configuration consists of intersecting diagonal members forming a triangulated system that enhances structural stiffness. The zig-zag configuration involves alternating diagonal members, which facilitate load redistribution along the height of the structure. In the K-

bracing system, braces are connected between beams and columns, influencing both axial and flexural behavior of the frame. Each configuration is applied consistently over the height of the building to ensure comparability of results.

3.5 Performance Evaluation Parameters

The seismic performance of each structural configuration is evaluated based on key response parameters including storey displacement, storey drift, storey shear, overturning moment, and dynamic characteristics such as time period and frequency. Storey displacement provides an indication of overall lateral movement, while storey drift reflects inter-storey deformation and potential structural damage. Storey shear represents the distribution of lateral forces along the height, and overturning moment indicates the global stability of the structure. The time period and frequency define the dynamic response characteristics and are directly influenced by structural stiffness. These parameters collectively provide a comprehensive assessment of structural behavior under seismic loading.

3.6 Comparative Assessment

The results obtained from each bracing configuration are systematically compared to evaluate their effectiveness in improving seismic performance. The comparison is based on the reduction in displacement and drift, improvement in stiffness and stability, and efficiency in force distribution. This comparative approach enables the identification of the most effective bracing configuration for enhancing seismic resistance in high-rise RC buildings.

4. RESULTS AND DISCUSSION

4.1 General Comparison of Bracing Configurations

The seismic performance of the RC building is evaluated for four different BRB configurations, namely Inverted V, X-pattern, zig-zag, and K-bracing systems. The results are compared with the bare frame structure to assess the effectiveness of each configuration under identical loading conditions. It is observed that the inclusion of BRBs significantly improves the seismic response of the structure; however, the extent of improvement varies depending on the configuration adopted.

Configurations that provide direct load transfer mechanisms and enhanced geometric stability exhibit better performance due to increased lateral stiffness and efficient force redistribution.

4.2 Storey Displacement

Storey displacement is a primary indicator of structural flexibility and overall lateral response. The results indicate that all bracing configurations reduce displacement compared to the unbraced frame. Among the configurations studied, the X-pattern bracing system shows the minimum displacement values across all storeys, followed by the inverted V configuration. The zig-zag and K-bracing systems also reduce displacement but to a lesser extent.

The superior performance of the X-pattern configuration is attributed to its fully triangulated geometry, which enables direct axial load transfer and minimizes lateral deformation. The inverted V configuration also provides effective load distribution; however, interaction between braces and beams slightly reduces its efficiency. In contrast, zig-zag and K-

bracing configurations introduce indirect load paths, resulting in comparatively higher displacement values.

4.3 Storey Drift

Storey drift is a critical parameter for evaluating structural safety and serviceability under seismic loading. The results show that maximum drift occurs at intermediate storey levels for all configurations. The X-pattern bracing system exhibits the lowest drift values, indicating superior stiffness and deformation control. The inverted V configuration also performs effectively in reducing drift, while zig-zag and K-bracing configurations show relatively higher drift values.

The improved drift control in X-bracing is due to its ability to resist lateral forces through axial action, thereby minimizing inter-storey deformation. Inverted V bracing provides balanced force distribution but introduces additional bending effects in beams, which slightly reduces its efficiency. Zig-zag and K-bracing configurations, although beneficial, are less effective in controlling drift due to their less efficient load transfer mechanisms.

4.4 Storey Shear

The distribution of storey shear along the height of the building follows a typical pattern, with values increasing from the top to the base. The introduction of BRBs results in improved distribution of lateral forces across the structure. Among the configurations, X-pattern and inverted V bracing systems demonstrate better performance in terms of uniform shear distribution, reducing stress concentration in structural elements.

The enhanced performance of these configurations is due to their ability to provide continuous and direct load paths. Zig-zag and K-bracing configurations show less efficient force redistribution, which may lead to localized stress concentrations and comparatively higher demand on structural members.

4.5 Overturning Moment

Overturning moment is an important parameter for assessing the global stability of the structure. The results indicate that all bracing configurations reduce overturning moment compared to the bare frame structure. The X-pattern configuration shows the maximum reduction, followed by the inverted V configuration. Zig-zag and K-bracing systems also contribute to stability improvement but are less effective.

The reduction in overturning moment is directly related to increased lateral stiffness and reduced displacement. X-bracing provides efficient resistance to lateral forces, thereby minimizing rotational effects at the base. Inverted V bracing also enhances stability, although its effectiveness is slightly reduced due to beam interaction effects.

4.6 Comparative Performance Evaluation

A comparative assessment of all configurations indicates that the X-pattern bracing system consistently outperforms other configurations in terms of displacement control, drift reduction, shear distribution, and stability enhancement. The inverted V configuration demonstrates very good performance and can be considered an effective alternative where architectural constraints exist. Zig-zag and K-bracing configurations provide moderate improvement but are less efficient in controlling seismic response.

Based on overall performance, the configurations can be ranked in descending order of effectiveness as follows: X-pattern, inverted V, zig-zag, and K-bracing.

The study clearly demonstrates that the effectiveness of BRB systems is highly dependent on configuration geometry. Configurations that ensure direct axial load transfer and provide a triangulated structural system exhibit superior seismic performance. The X-pattern configuration satisfies these conditions, resulting in maximum stiffness and minimum deformation. In contrast, configurations that introduce indirect load paths or additional bending effects, such as K-bracing, show comparatively lower efficiency.

5. CONCLUSION

The present study investigated the influence of different Buckling Restrained Bracing (BRB) configurations on the seismic performance of a multi-storey reinforced concrete (RC) building using response spectrum analysis as per IS 1893 (Part 1): 2016. Four bracing configurations, namely Inverted V, X-pattern, zig-zag, and K-bracing systems, were analyzed and compared based on key structural response parameters.

The results clearly demonstrate that the incorporation of BRBs significantly enhances the seismic performance of RC structures; however, the degree of improvement is highly dependent on the bracing configuration. Among all configurations studied, the X-pattern bracing system exhibited the best overall performance, showing the maximum reduction in storey displacement and inter-storey drift, along with improved distribution of storey shear and reduced overturning moment. This superior performance is attributed to its fully triangulated geometry, which enables direct axial load transfer and maximizes structural stiffness.

The inverted V configuration also demonstrated strong performance, providing effective reduction in displacement and drift while maintaining a balanced distribution of forces. However, its efficiency is slightly reduced due to the interaction between braces and beams, which introduces additional bending effects. Nevertheless, it remains a practical and efficient alternative, especially in cases where architectural constraints limit the use of X-bracing.

The zig-zag and K-bracing configurations showed moderate improvement in seismic performance compared to the unbraced structure. Although these configurations contribute to stiffness enhancement and load redistribution, their effectiveness is limited due to indirect load paths and less efficient force transfer mechanisms. In particular, K-bracing introduces additional bending forces in columns, which may reduce its efficiency under seismic loading.

Overall, the study highlights that the selection of an appropriate bracing configuration is crucial for optimizing seismic performance. Configurations that ensure direct load paths and minimize bending interactions provide superior results. The findings of this study can assist structural engineers in selecting suitable BRB configurations for high-rise buildings in seismic regions.

Future Scope

Further research can be extended to nonlinear time history analysis to capture the inelastic behavior of different bracing configurations under real earthquake records. In addition, performance-based design approaches can be adopted to evaluate damage levels and structural performance objectives. The effect of bracing location, irregular building geometries, and soil-structure interaction can also be investigated. Experimental validation and hybrid systems combining BRBs

with advanced materials such as Shape Memory Alloys (SMA) may provide further improvements in seismic resilience.

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