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ANALYTICAL STUDY OF BUCKLING RESTRAINED BRACED FRAMES IN DIFFERENT SEISMIC ZONE USING ETABS

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Abstract

Tall buildings have unique seismic challenges, particularly the P-delta effect. This can cause an increase in loads on certain parts of the structure, leading to potential instability or collapse. The solution is to use buckling restrained bracing (BRB) systems, which improve the lateral strength of the structure and control the P-delta effect. The present study aimed to determine the effectiveness of various brace configurations in reducing the seismic response of a 50-story reinforced concrete structure, with a focus on P-delta effects. To achieve this, linear dynamic analysis (response spectrum analysis) was conducted using E-TAB software. The selection of bracing configuration, however, depends upon the seismic zone. For this reason, five distinct configurations (X-pattern, inverted V, forward inclined, zig-zag, and bare frame) are considered for the analysis of buildings in different seismic zones. A building model was employed to study the behaviour of a structure with and without BRB to compare the parameters of storey drift, story displacement, diaphragm drift, story shear, story stiffness, and story acceleration using E-TAB software. Results showed that both Type-4 and Type-2 braces perform similarly in several aspects in seismic zones III and V. However, Type-2 braces perform slightly better in terms of storey stiffness-Y, with a lower difference of 39-40 % compared to Type-4 braces with a difference of 49 %.

Keywords:

BRBs;
Buckling restrained brace;
Seismic zone;
P-delta;
Linear dynamic.

1 Introduction

Structural engineering plays a crucial role in the design and construction of tall buildings, as their increased height presents unique challenges in ensuring safety and stability, particularly during seismic events like earthquakes. One of the key challenges engineers face is the P-delta effect. This phenomenon occurs when a structure is subjected to lateral loads, such as those caused by wind or earthquakes, which cause the structure to sway and bend, which in turn increases the forces on certain parts of the building, potentially leading to instability or collapse. This can result in a significant loss of human life and property. To overcome this challenge, a new type of brace called Buckling Restrained Braces (BRBs) was provided to resist or reduce the risk of the P-delta effect without affecting the stability and strength of the structure. The P-delta effect is a complex and multifaceted phenomenon resulting from the interaction of various factors such as geometry, material properties, and loading conditions. Therefore, it is of utmost importance for a structure to possess a balance of both strength to withstand vertical loads and flexibility to resist lateral forces in order to ensure stability and safety. A Buckling Restrained Brace (BRB) is a type of brace designed to prevent

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buckling under compression. It exhibits balanced behavior in both compression and tension, characterized by full hysteresis loops [1]. However, the selection of bracing configuration is based on the seismic zone, its intended function, and the estimated cost [2]. Several experiments were conducted to determine the stability of the structure with braces, the structure's inelastic behavior under severe earthquakes, and to establish the correlation between brace force and displacement [3].

Buildings' behavior under external loads is affected by the number of modes they exhibit, and as the number of modes decreases, the building is less likely to experience distortion. However, a building with a circular frequency of zero is in danger of collapsing, particularly under seismic forces [4]. Taller buildings require stronger and more robust structural systems to prevent collapse as their reaction to lateral loads increases with elevation [5]. Steel bracing is a beneficial concept for strengthening or retrofitting existing structures, as it reduces flexure and shear demands on beams and columns, transferring lateral loads through an axial load mechanism. Certain types of bracing systems, such as building frames with an X-bracing system, have the least bending moments compared to other systems [6].

To achieve the optimal yield stress that maximizes the equivalent damping ratio of a structure, two independent design parameters can be used: stiffness and strength. However, varying the cross-sectional area to control stiffness is the most feasible option for a structural engineer, as steel yield stress is only available in discrete values, and structural responses do not change monotonically with changes in yield stress. Increasing the stiffness of Buckling Restrained Braces (BRB) leads to a decrease in maximum displacement, making stiffness a useful design parameter for seismic design [7].

Lateral stiffness greatly affects the p-delta effect in square models, with an increase in lateral stiffness leading to a decrease in the p-delta effect on top storey deflection. However, as the H/B ratio decreases for a 30 m x 30 m model, the p-delta effect increases by 21.72 %. The same trend is observed for rectangular models, and the p-delta effect is more pronounced along the Z direction due to less lateral stiffness in that direction [8]. Increasing lateral stiffness reduces the p-delta effect on top storey deflection [9].

Altitude-dependent changes in seismic region also play a role in building design and seismic resistance [10]. In comparison, ordinary braces require a larger cross-sectional area than BRBs to achieve the same stiffness performance [11]. Additionally, buildings with BRBs have lower displacement values than those without BRBs [12]. Hence, in creating concrete's uniqueness in the construction industry, there is a need for sustainability, and efforts must be geared towards the effective utilization of industrial waste products, such as induction furnace slag and quarry dust in concrete production [16].

1.1 Concept of BRBs

Buckling restrained braces (BRBs) were first made by Nippon Steel in Japan in the late 1980s and called "Unbonded Brace". They were introduced in the US in 1999. Mover Star Seismic is a worldwide manufacture of Buckling Restrained Braces (BRBs), offering a comprehensive manual for its products. The company offers a variety of BRB sizes, from 25.4 mm^2 to 1320.8 mm^2, to accommodate different structures. Their advanced software streamlines the selection process by automatically choosing the most appropriate BRB based on factors such as load capacity, stiffness, and cost-efficiency. In this case, the software determined that a 420 mm^2 cross-section BRB was optimal, a process referred to as optimizing BRB. The BRB, or unbounded brace, has three key components as a steel core, a restrainer, and an unbonding material/gap shown in Fig. 1.

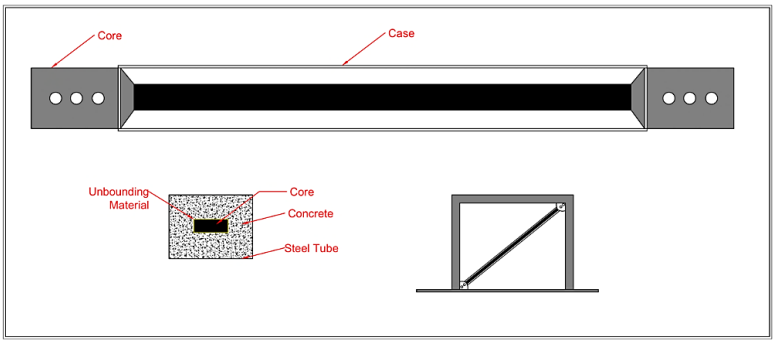


Fig. 1: Schematic representation of a buckling restrained brace.

Steel core is the primary component that resists axial load. **Restrainer's function** is to prevent the steel core from working in lower modes, and it is typically filled with high-strength mortar. **Unbonding material/gap** is crucial for avoiding poisoning effects in the steel core, as it allows the steel core to expand and contract independently of the restrainer.

1.2 Advantages of BRBs

1) Easy to adopt in seismic retrofitting through bolted or pinned connections to gusset plates
2) BRBs separate the stress-resisting and flexural-buckling resisting aspects of compression strength, leading to a more efficient design
3) Steel core in BRBs resists axial stresses, resulting in uniform axial strains and no formation of plastic hinges.
4) Inelastic demands are distributed over multiple stories and BRBs are not susceptible to fracture under seismic loading.
5) Post-earthquake damage is concentrated in a small area, making investigation and replacement relatively easy.

1.3 Behavior of the BRBs under both gravity and lateral loads

Under the weight of gravitational forces, columns in a structure exhibit axial contraction. The compression loads acting on the columns cause a decrease in length along their vertical axes. The diagonal members are impacted by this axial contraction through compression, while the beams experience tension from the transfer of compressive loads from columns to beams through the linking effect of the diagonal members. This collaboration between columns, diagonal members, and beams is depicted in Fig. 2.

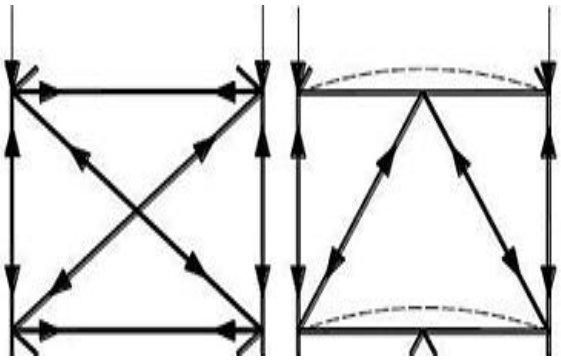


Fig. 2: Braces under gravitational loads.

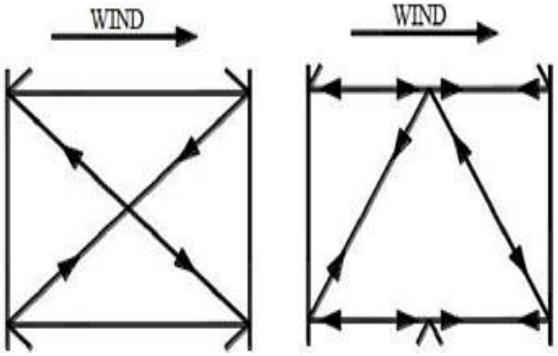


Fig. 3: Braces under lateral loads.

Tall building design is influenced by wind-generated lateral forces. Braced frames are deemed the most efficient for resisting these forces in either direction. The role of bracing is to withstand horizontal shear that results from lateral forces. The way bracing resists horizontal shear can be visualized by tracing its path through the frame, as shown in Fig. 3.

2 Objective

The current study aims to assess the impact of Buckling Restrained Bracings (BRBs) on building behavior during earthquakes, with the following objectives in mind.

1) To study G+50 reinforced concrete buildings with and without BRBs for different seismic zone using ETABS.
2) To investigate X, Zig - Zag, Inverted V, Forward inclined, and Bare frame systems.
3) To determine the response of different braced and unbraced buildings subjected to lateral loads.
4) To investigate the most suitable bracing system for a particular seismic zone.
5) To determine the optimal configuration, we will compare the results obtained from two different
6) Analyzing methods in different seismic zones.

3 Methodology

1) The building plan is initially selected and modeled in ETABS [17], with preliminary units, dimensions, and codes set according to Indian standards, especially those governing seismic design.
2) Preliminary sizes are then assigned for columns, beams, slabs, retaining walls, and BRBs.
3) Fixed supports are added as required for the building,
4) And diaphragms are included and assigned to each floor.
5) Loads, such as dead, live, wind, and earthquake loads, are calculated in accordance with IS 875-part 1, 2, 3, [15] and IS 1893 [13], respectively.
6) Load combinations are created according to IS 1893-2016 [13], IS 456-2000 and IS 16700-2017 [14].
7) Finally, dead and live loads are assigned to the frames, while wind and earthquake loads are assigned to the diaphragms as storey shear.

3.1 Building model

The seismic response of a building equipped with BRBs was analyzed through the G+50 RC structural design. The symmetrical plan was used to assess the differences in storey drift and displacement. The building boasts five bays in the *X*-direction and four in the *Y*-direction, with identical column and beam sizes throughout all stories. It was engineered to endure wind and earthquake loads in accordance with the Indian Standard Code. The model was generated using the industry-standard software ETABS v17.0.0 [17] and underwent linear dynamic and P-delta analysis in seismic zones III and V. Various loads, including dead, live, wind, and earthquake loads, were applied to the building during the evaluation.

The load calculations at each storey level are determined by various critical factors, which are listed in Table 1. This includes information such as the plan area, beam size, column size, slab thickness, and building height. To ensure earthquake resistance, the seismic parameters such as Seismic Zone, Zone factor, Importance factor, Response Reduction factor, and soil type are taken into account, as outlined in IS 1893-2016 [13]. The initial load analysis utilizes the P-delta load combination as specified in IS 16700:2017 [14]. Additionally, the wind load parameters including basic wind speed, design wind pressure, k1, k2, and k3, are considered to ensure wind resistance, as per IS 875(3)-2015 [15].

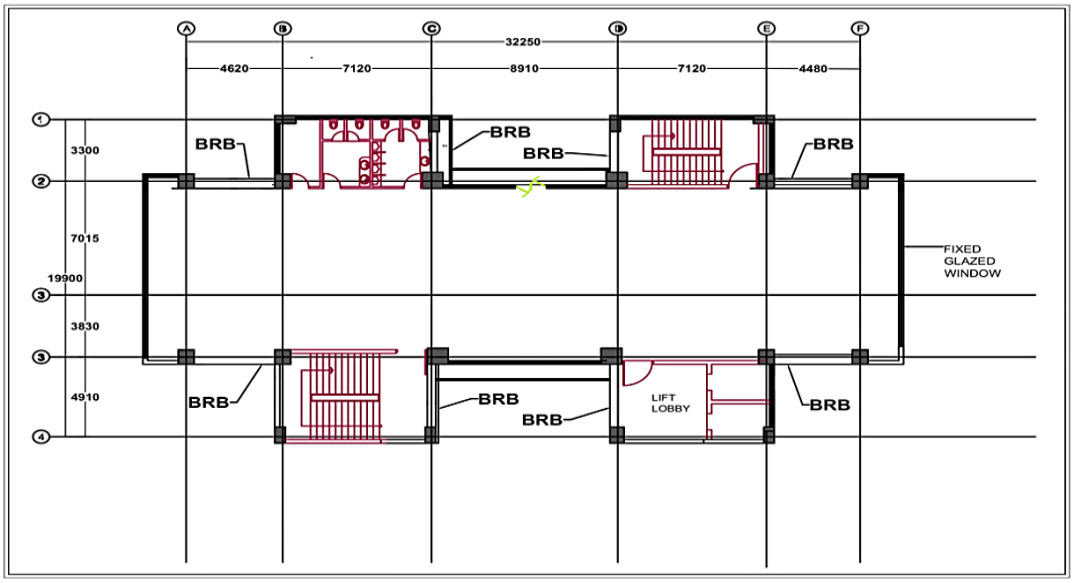


Fig. 4: Typical building plan.

The specifications of the building and its components are outlined as follows:

Table 1: Plan details.

Plan area	32.2 x 19.5 m
Size of main beams	450 mm x 900 mm
Size of peripheral beams	400 mm x 750 mm
Size of the columns	500 mm x 1000 mm
	1000 mm x 1000 mm
	750 mm x 900 mm
Thickness of structural walls	400 mm, 600 mm
Depth of slabs	225 mm
Utility of building	Office building
Height of building	188.6 m
Type of construction	RC framed structure
Grades of concrete	M35, M45, M50
Grades of rebar	Fe500
Zone factor for zone-III	0.16
Zone factor for zone-V	0.36
Importance factor	1
Response reduction factor	5
Soil type	Medium

The analysis considered five different configurations of BRB, which are shown in Fig. 5 and listed below:

1) Bare frame
2) Type-1: Forward-inclined
3) Type-2: Inverted V
4) Type-3: Zig - Zag
5) Type-4: X-patter.

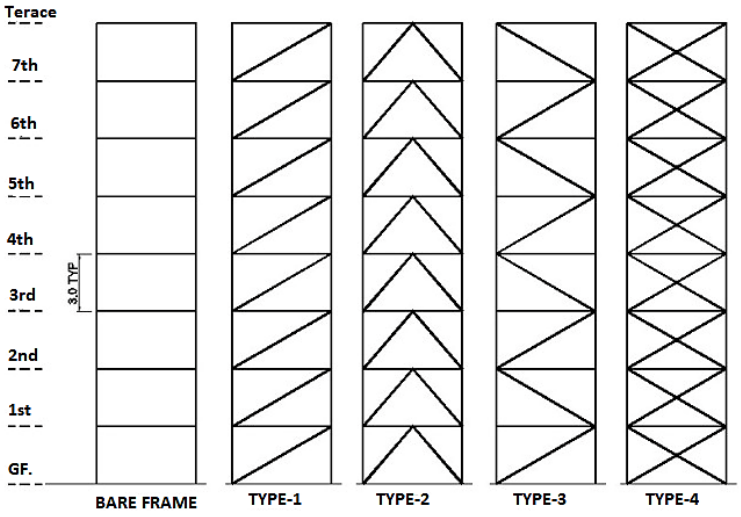


Fig. 5: Different configurations of BRB.

Fig. 6 displays a 3D view of the X and inverted V patterns analyzed using ETABS [17]. Bracing was provided on all four sides of the building, as shown in the building plan, and analyzed with different load combinations. The analysis indicates that X and inverted V patterns exhibit superior performance in different seismic zones when compared to other configurations.

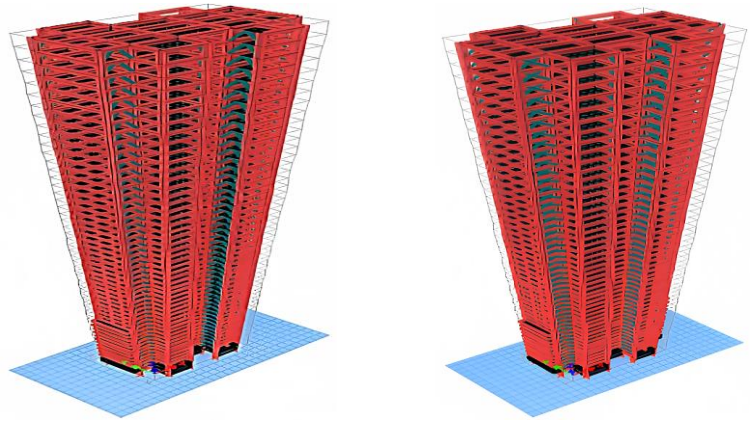


Fig. 6: 3D view of building with inverted V and X pattern bracing.

4 Results and discussions

The BRBs of the building were designed with various configurations, including Type-1, Type-2, Type-3, Type-4, and bare frame. A comparison was made between two analysis methods, the linear dynamic and P-delta methods, for seismic zones III and V. The linear dynamic method analyzes a structure's response to dynamic loads like earthquakes and wind, assuming a linear response. It determines natural frequencies and mode shapes, crucial for designing structures that can endure dynamic loads. While the P-delta method evaluates the stability of tall structures like high-rise buildings and bridges under gravity loads, accounting for second-order deformation caused by lateral displacement. This method ensures structural safety and durability by providing a more precise estimate of lateral stability. The aim was to identify the most appropriate configuration. To evaluate the advantages of the BRB system under lateral load conditions, a comparison was made, after thorough analysis, it has been ascertained that Type-2 and Type-4 exhibit exceptional performance in withstanding lateral loads, particularly those imposed by seismic forces. In contrast to the bare frame, the other configurations demonstrate a notably improved performance for these loads.

4.1 Linear dynamic results and discussions

A linear dynamic method was used to model the BRBs with various configurations for the building in seismic zone III and V as per IS 1893-2016 [13], and a comparison was conducted to recommend the optimal configuration. In Zone-III, Fig. 7a shows that a building without buckling-restrained braces (BRBs) experiences greater storey drift than those with various types of BRBs.BRBs of Type-2 and Type-4 demonstrated the lowest storey drift, whereas sudden spikes in storey drift took place on the 6th and 21st floors due to displacement variation. Fig. 7b, revealed that displacement was similar between Type-2 and Type-4, as well as between Type-1 and Type-3. The bare frame configuration exhibited the highest diaphragm drift in the x-direction Fig. 7c. Type-2 and Type-4 had the lowest levels of Y-direction drift Fig. 7d. The stiffness gradually increased with height for all BRBs in the X-direction Fig. 7e, whereas the bare frame had uniform stiffness except on the 6th and 21st floors. Type-2 and Type-4 showed the highest levels of stiffness in the y-direction Fig. 7f. Building equipped with BRBs had lower values of storey forces at the base than the bare frame in both x and y-directions Fig. 7g. Type-4 showed the lowest values of storey shear at the base Fig. 7h. Type-2 had the highest levels of storey accelerations in the X-direction Fig. 7i, and there was little difference in acceleration between different types of BRBs in the Y-direction Fig. 7j.

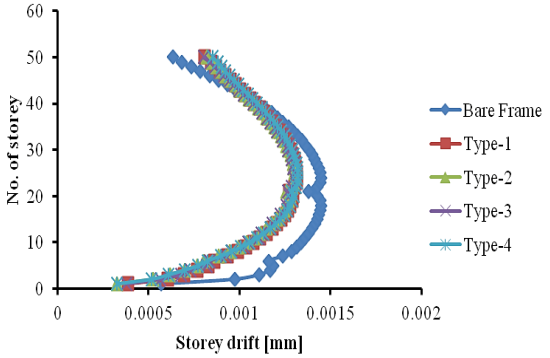


Fig. 7a: Storey drift in zone-III.

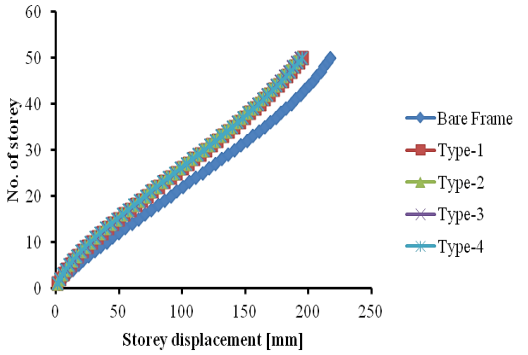


Fig. 7b: Storey displacement in zone-III.

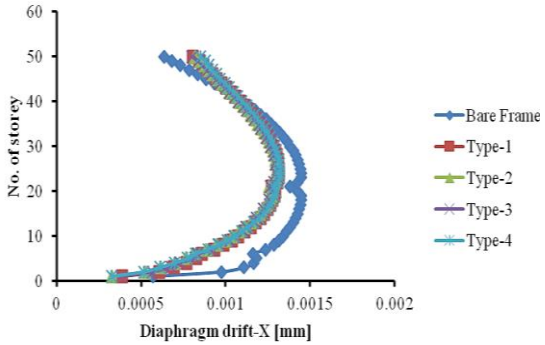


Fig. 7c: Diaphragm drift-X in zone-III.

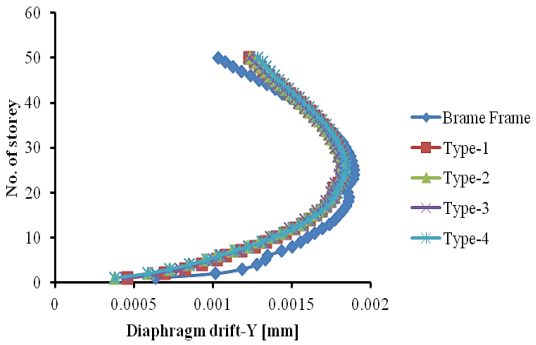


Fig. 7d: Diaphragm drift-Y in zone-III.

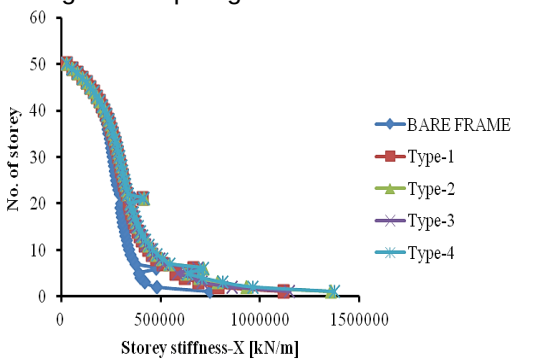


Fig. 7e: Storey stiffness-X in zone-III.

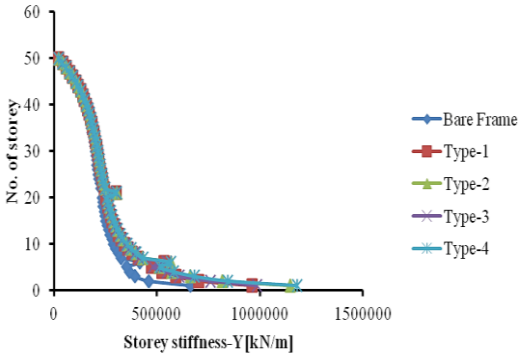


Fig. 7f: Storey stiffness-Y in zone-III.

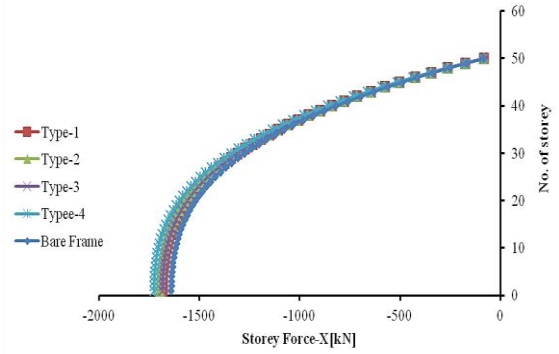


Fig. 7g: Storey forces-X in zone-III.

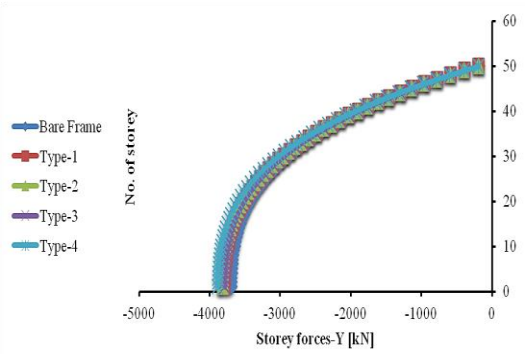


Fig. 7h: Storey forces-Y in zone-III.

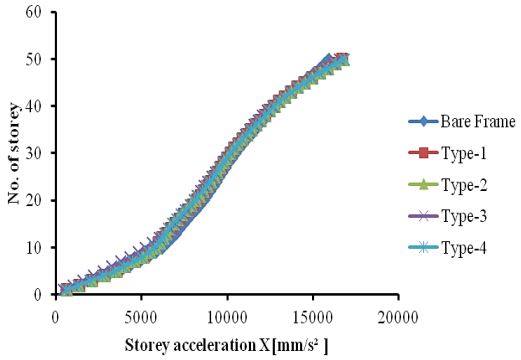


Fig. 7i: Storey acceleration-X in zone-III.

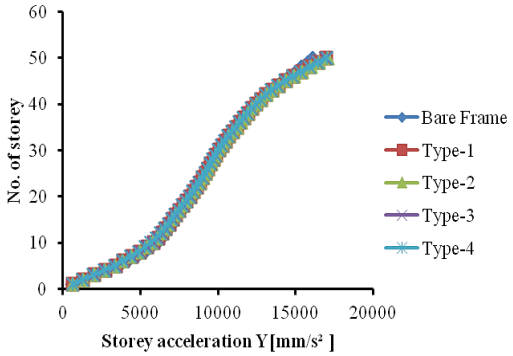


Fig. 7j: Storey acceleration-Y in zone-III.

In zone-V Fig. 8a, illustrates BRBs configurations resulted in higher degree of storey drift, with Type-2 and Type-4 showing the least amount of drift. Fig. 8b, shows no significant difference in displacement between the different types of BRBs.In Figs. 8c and 8d provide visual evidence indicating that the unbraced frame experienced significant drift along the X-direction, while exhibiting notable improvement in the Y-direction. Of note, Type-2 frame demonstrated the most favorable outcome with the lowest diaphragm drift value among the frames analyzed. Among the various BRBs configurations, Type-4 exhibited the highest storey stiffness in both X- and Y-directions in Figs. 8e and 8f. Building equipped with BRBs had lower values of storey forces at the base than the bare frame in both X and Y-directions. Type-4 showed the lowest values of storey shear at the base Figs. 7g and 7h. Type-2 had the highest X-direction storey acceleration Fig. 8i, while there was limited differentiation in acceleration among the various BRBs types in the Y-direction Fig. 8j.

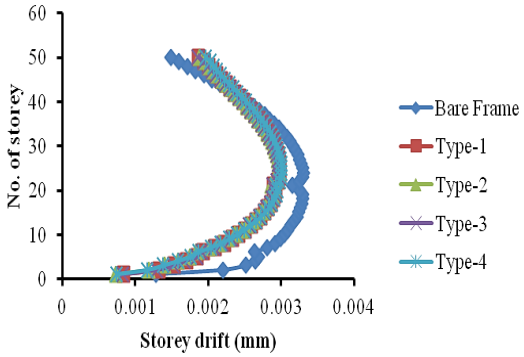


Fig. 8a: Storey drift in zone-V.

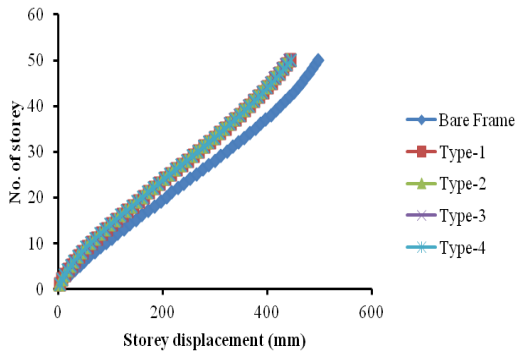


Fig. 8b: Storey displacement in zone-V.

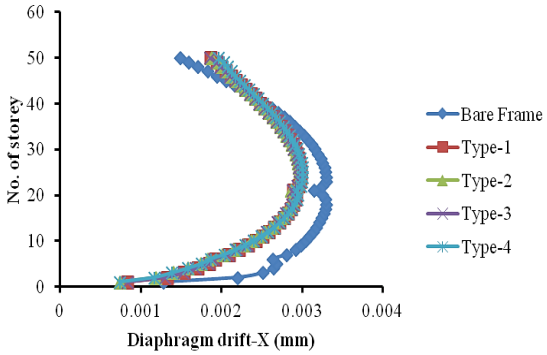


Fig. 8c: Diaphragm drift-X in zone-V.

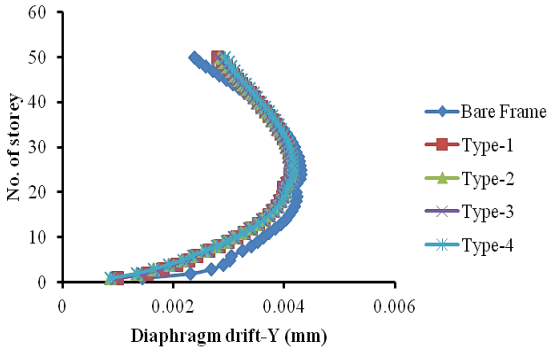


Fig. 8d: Diaphragm drift-Y in zone-V.

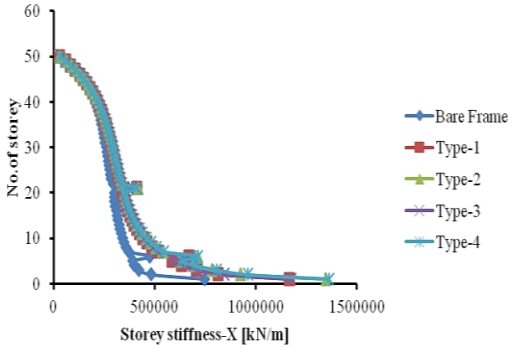


Fig. 8e: Storey stiffness-X in zone-V.

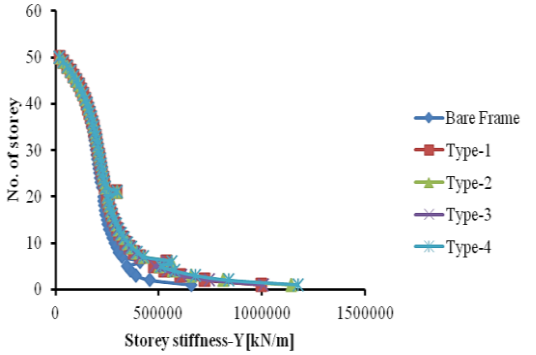


Fig. 8f: Storey stiffness-Y in zone-V.

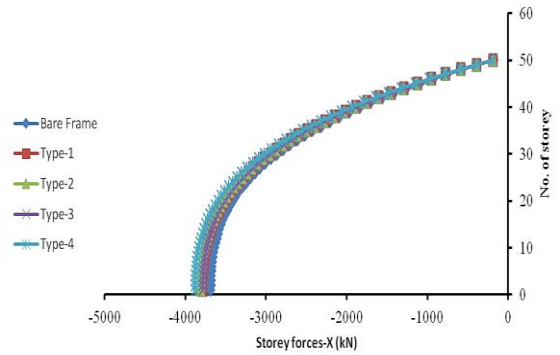


Fig. 8g: Storey forces-X in zone-V.

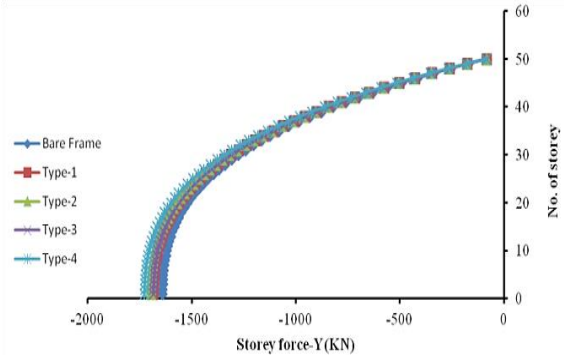


Fig. 8h: Storey forces-Y in zone-V.

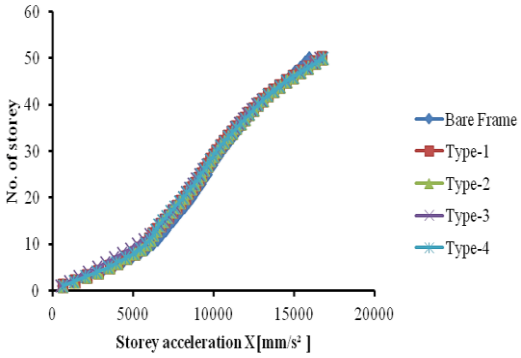


Fig. 8i: Storey acceleration-X in zone-V.

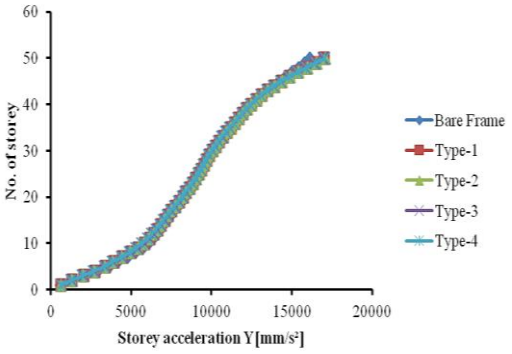


Fig. j: Storey acceleration-Y in zone-V.

4.2 P-delta effect results and discussions

A P-delta method was used to model the BRBs with various configurations for the building in seismic zone III and V as per IS 16700-2017 [14], and a comparison was conducted to recommend the optimal configuration. In zone-III, Fig. 9a, shows the difference in storey drift between buildings with and without buckling-restrained braces (BRBs). The building lacking BRBs had more significant storey drift, while the Type 2 of BRB is showing the lowest drift. Fig. 9b, results Type-1 and Type-3 exhibited comparable displacement, while Type-2 had lower levels. Figs. 9c and 9d show X and Y-direction diaphragm drift, with the unbraced frame having the most significant X-direction drift and Type-2 having the lowest Y-direction drift. Figs. 9e and 9f, shows increasing stiffness from the second to the top storey for BRBs, A bare frame appears to have uniform stiffness across all floors. In Fig. 9g and 9h, it is evident that buckling-restrained braces (BRBs) registered lower force values at the base compared to the unbraced frame, with Type-4 showcasing the most minimal force values. Type-2 had the highest acceleration levels in the X-direction Fig. 9i. There was not a significant difference in acceleration between the various types of BRBs in the Y-direction Fig. 9j.

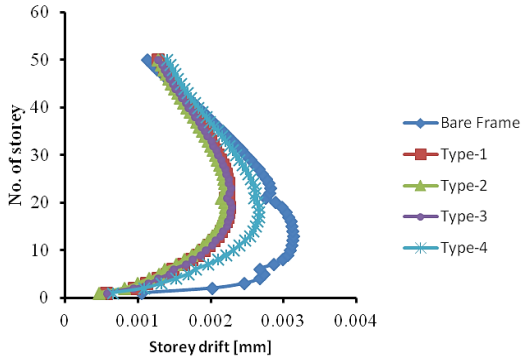


Fig. 9a: Storey drift in zone-III.

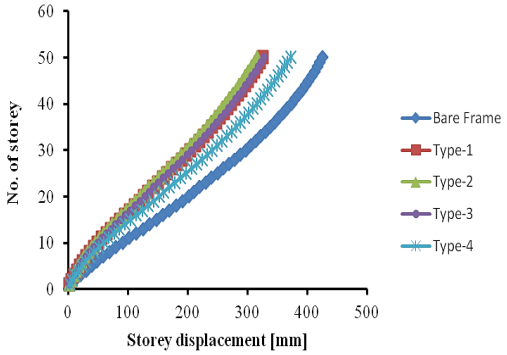


Fig. 9b: Storey displacement in zone-III.

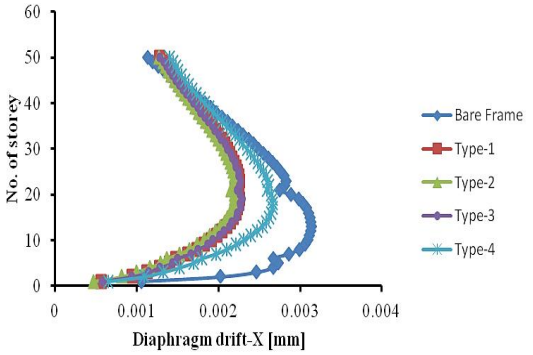


Fig. 9c: Diaphragm drift-X in zone-III.

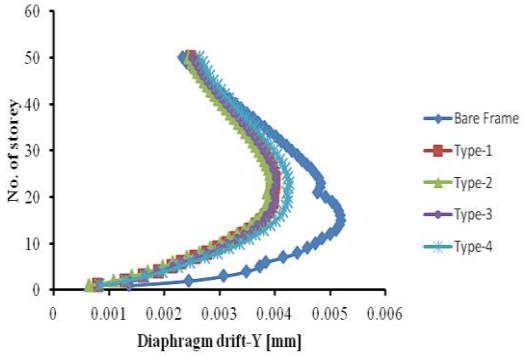


Fig. 9d: Diaphragm drift-Y in zone-III.

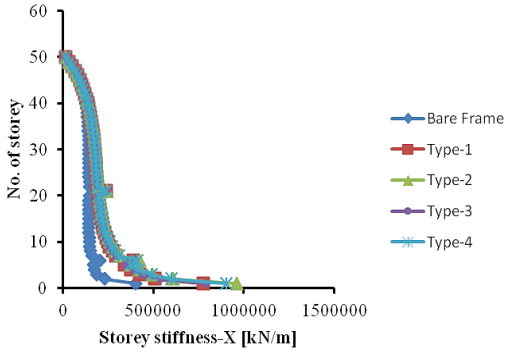


Fig. 9e: Storey stiffness-X in zone-III.

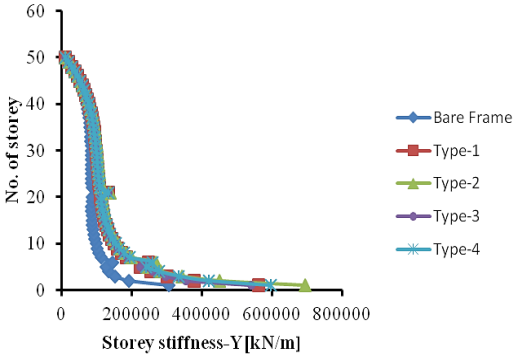


Fig. 9f: Storey stiffness-Y in zone-III.

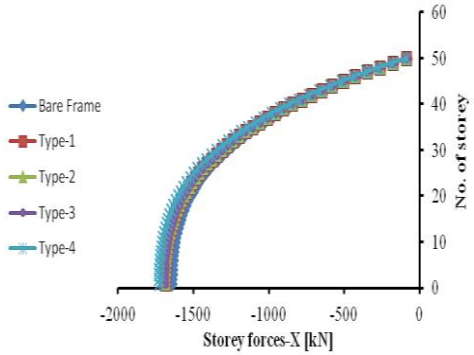


Fig. 9g: Storey forces-X in zone-III.

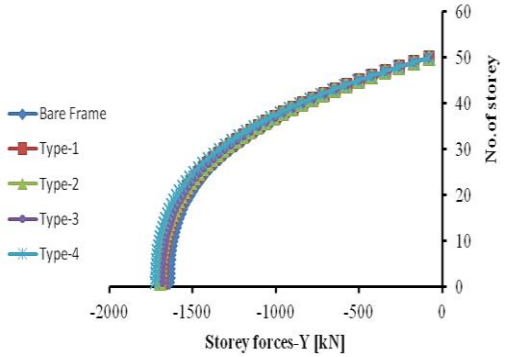


Fig. 9h: Storey forces-Y in zone-III.

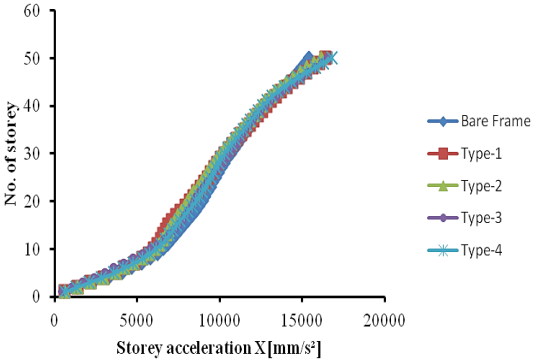


Fig. 9i: Storey acceleration-X in zone-III.

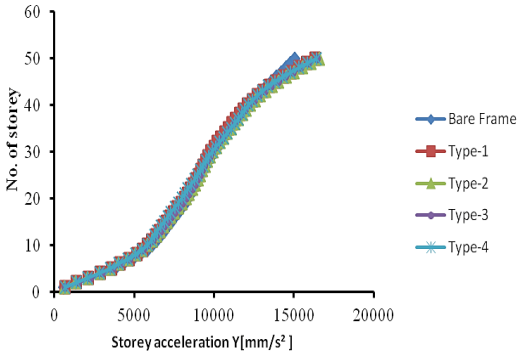


Fig. 9j: Storey acceleration-Y in zone-III.

In zone-V Fig. 10a, shows the storey drift comparison between a building with and without buckling-restrained braces (BRBs), where Type-2 displayed the lowest storey drift among the four types analyzed. Displacement variability was notably higher at the 6th and 21st floors. Fig. 10b, indicated that BRBs led to decreased displacement levels compared to an unbraced frame, with Type-2 showing the lowest displacement levels. Fig. 10c and 10d showed the unbraced frame had significant X-direction drift but improved performance in the Y-direction. Type-2 had the lowest diaphragm drift value. Fig. 10e and 10f demonstrated stiffness gradually increased from the second to the top storey, while Type-4 had the highest stiffness levels. Figs. 10g and 10h displayed lower force values at the base with the incorporation of BRBs, with Type-4 exhibiting the lowest force values. Type-2 had the highest acceleration levels in the X-direction in Fig. 10i, while Fig. 10j, showed little differentiation in acceleration among the different types of BRBs in the Y-direction.

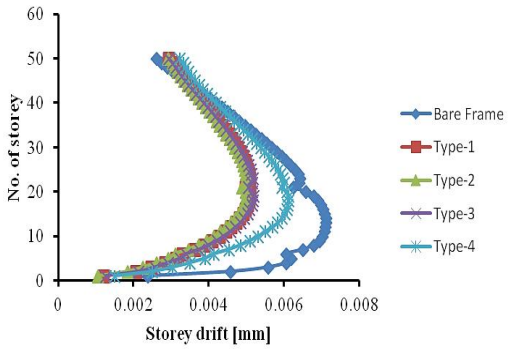


Fig. 10a: Storey drift in zone-V.

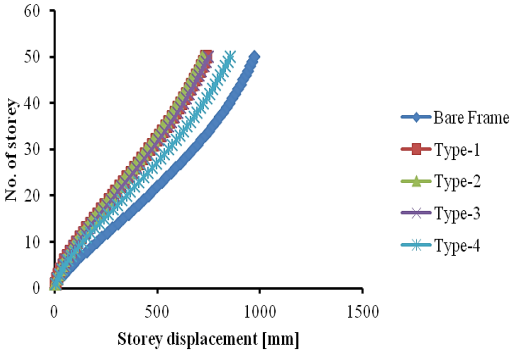


Fig. 10b: Storey displacement in zone-V.

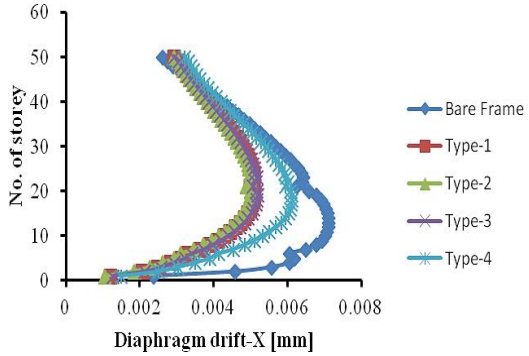


Fig. 10c: Diaphragm drift-X in zone-V.

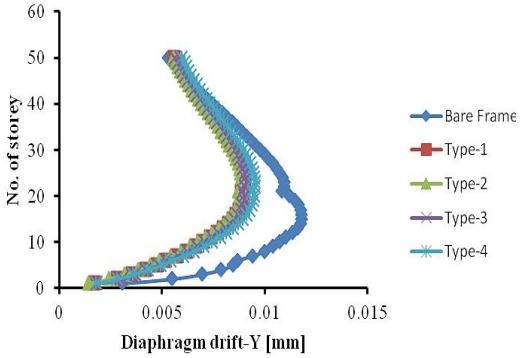


Fig. 10d: Diaphragm drift-Y in zone-V.

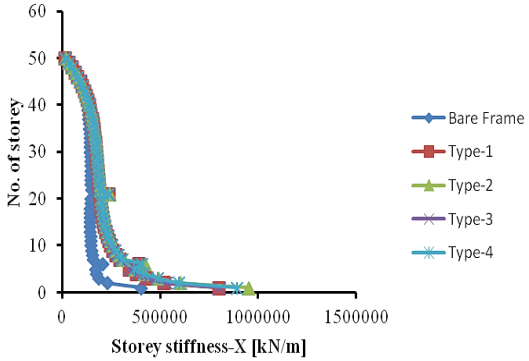


Fig. 10e: Storey stiffness-X in zone-V.

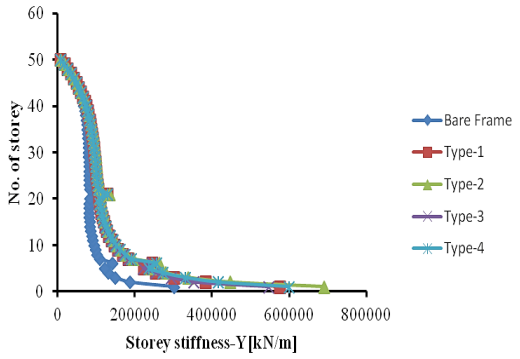


Fig. 10f: Storey stiffness-Y in zone-V.

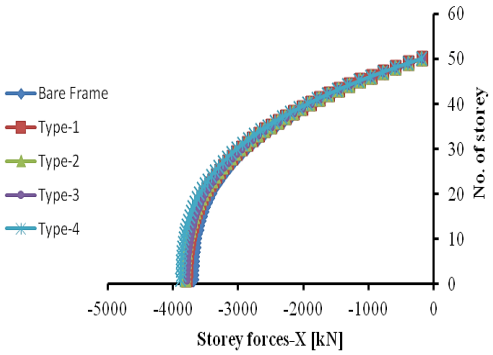


Fig. 10g: Storey forces-X in zone-V.

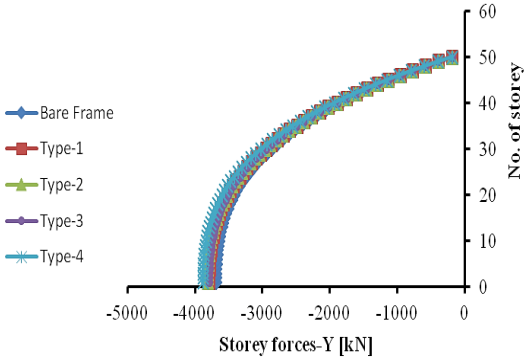


Fig. 10h: Storey forces-Y in zone-V.

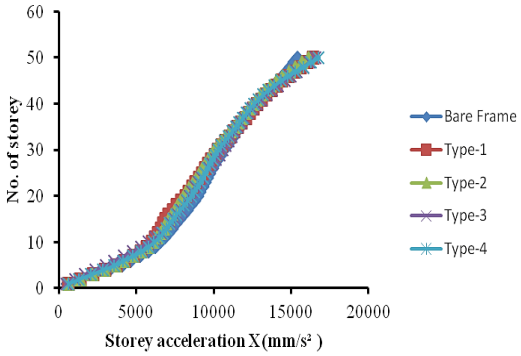


Fig. 10i: Storey acceleration-X in zone-V.

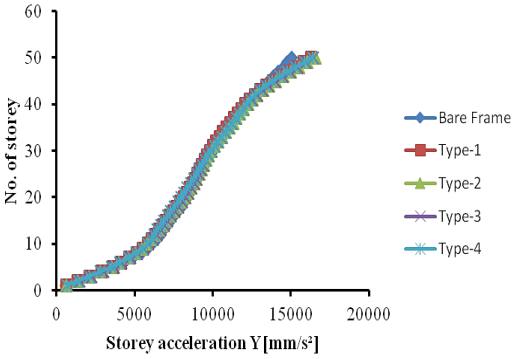


Fig. 10j: Storey acceleration-Yin zone-V.

5 Comparison of results

The results indicate that for Type-4 buildings in zone III, the peak storey drift value obtained by P-Delta method 0.00226 mm was 71 % more than that obtained by linear dynamic method 0.00132 mm. Similarly, for Type-2 buildings in zone III, the peak storey drift value obtained by P-Delta method 0.0022 mm was 69 % more than that obtained by linear dynamic method 0.0013 mm. For Type-4 buildings in zone V, the peak storey drift value obtained by P-Delta method 0.00612 mm was 103 % more than that obtained by linear dynamic method 0.00301mm. Similarly, for Type-2 buildings in zone V, the peak storey drift value obtained by P-Delta method 0.00501 mm was 69 % more than that obtained by linear dynamic method 0.00297 mm. Fig. 11, displays the peak storey drift values obtained by both methods in seismic zones III and V.

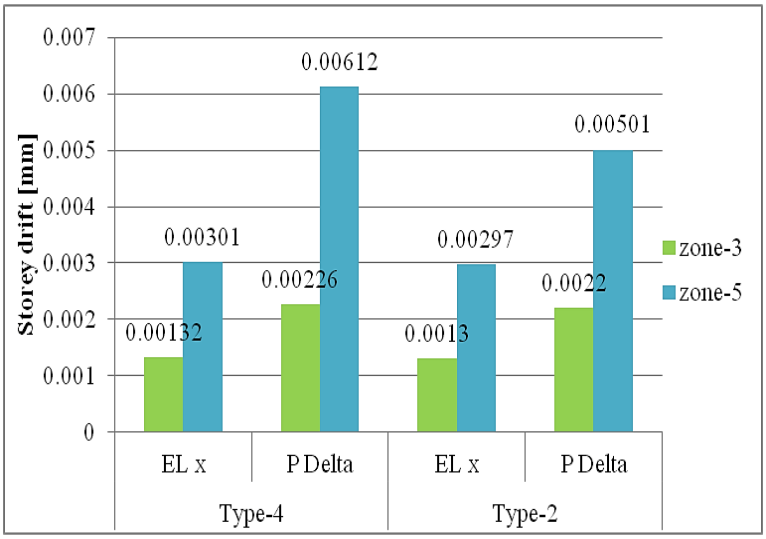


Fig. 11: Comparison of peak storey drift.

The results indicate that for Type-4 buildings in zone III, the peak storey displacement value obtained by P-Delta method 372.544 mm was 91 % more than that obtained by linear dynamic method 195.279 mm. Similarly, for Type-2 buildings in zone III, the peak storey displacement value obtained by P-Delta method 315.822 mm was 64 % more than that obtained by linear dynamic method 192.084 mm. For Type-4 buildings in zone V, the peak storey displacement value obtained by P-Delta method 856.289 mm was 92 % more than that obtained by linear dynamic method 445.695 mm. Similarly, for Type-2 buildings in zone V, the peak storey displacement value obtained by P-Delta method 721.092 mm was 64 % more than that obtained by linear dynamic method 438.836 mm. Fig. 12, displays the peak storey displacement values obtained by both methods in seismic zones III and V.

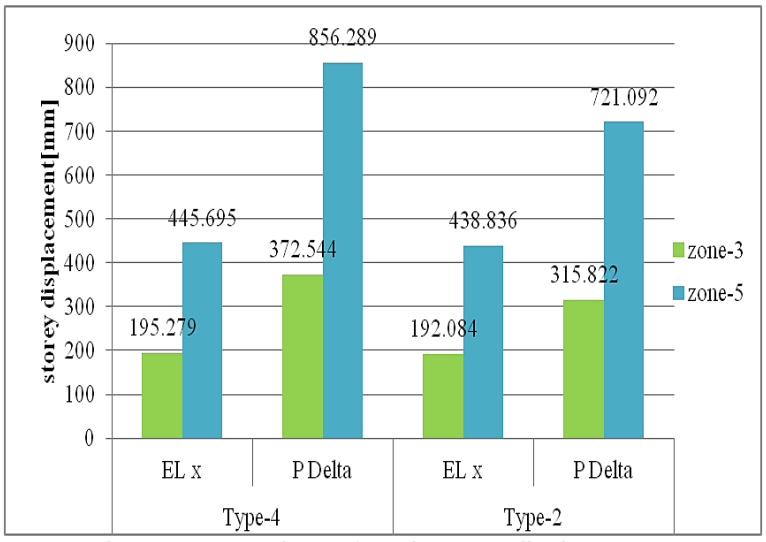


Fig. 12: Comparison of peak storey displacement.

The results indicate that for Type-4 buildings in zone III, the peak diaphragm drift-X value obtained by P-Delta method 0.002664 mm was 102 % more than that obtained by linear dynamic method 0.001321 mm. Similarly, for Type-2 buildings in zone III, the peak diaphragm drift-X value obtained by P-Delta method 0.002198 mm was 69 % more than that obtained by linear dynamic method 0.001302 mm. For Type-4 buildings in zone V, the peak diaphragm drift-X value obtained by P-Delta method 0.006123 mm was 103 % more than that obtained by linear dynamic method 0.003009 mm. Similarly, for Type-2 buildings in zone V, the peak diaphragm drift-X value obtained by P-Delta method 0.005009 mm was 69 % more than that obtained by linear dynamic method 0.002968.

Fig. 13, displays the peak diaphragm drift-x values obtained by both methods in seismic zones III and V.

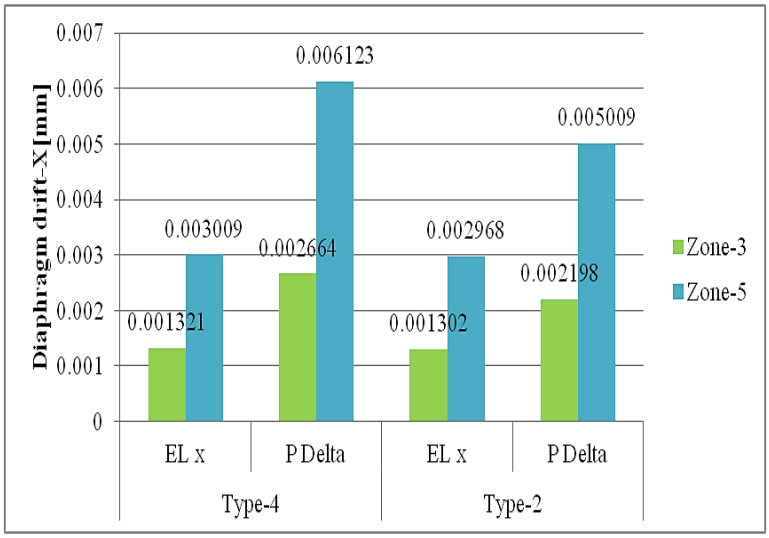


Fig. 13: Comparison of peak diaphragm drift-X.

The results indicate that for Type-4 buildings in zone III, the peak diaphragm drift-y value obtained by P-Delta method 0.00425 mm was 130 % more than that obtained by linear dynamic method 0.001849 mm. Similarly, for Type-2 buildings in zone III, the peak diaphragm drift-Y value obtained by P-Delta method 0.003924 mm was 116 % more than that obtained by linear dynamic method 0.001814 mm. For Type-4 buildings in zone V, the peak diaphragm drift-Y value obtained by P-Delta method 0.00953 mm was 129 % more than that obtained by linear dynamic method 0.00416 mm. Similarly, for Type-2 buildings in zone V, the peak diaphragm drift-y value obtained by P-Delta method 0.008885 mm was 116 % more than that obtained by linear dynamic method 0.00411 mm. Fig. 14, displays the peak diaphragm drift-Y values obtained by both methods in seismic zones III and V.

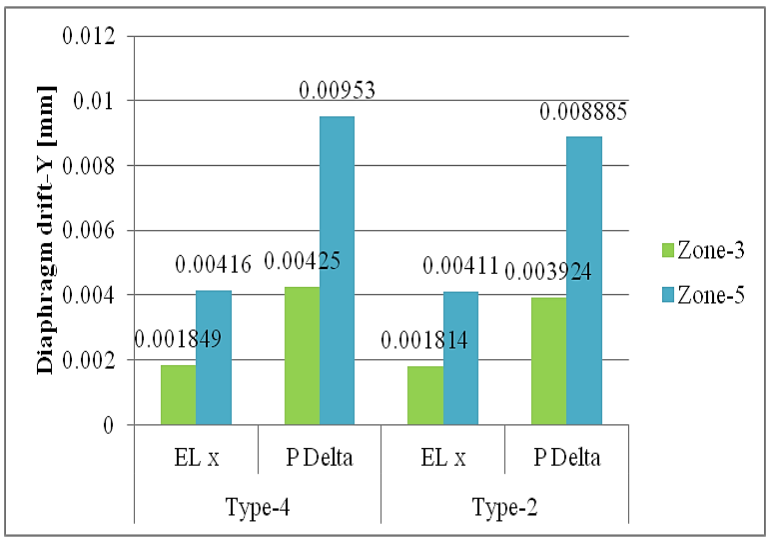


Fig. 14: Comparison of peak diaphragm drift-Y.

The results indicate that for Type-4 buildings in zone III, the peak storey stiffness-X value obtained by P-Delta method 903912.08 kN/m was 34 % less than that obtained by linear dynamic method 1374095.35 kN/m2. Similarly, for Type-2 buildings in zone III, the peak storey stiffness-X value obtained by P-Delta method 962022.599 kN/m was 29 % less than that obtained by linear dynamic method 1357899.727 kN/m. For Type-4 buildings in zone V, the peak storey stiffness-X value obtained by P-Delta method 895538.874 kN/m was 34 % less than that obtained by linear dynamic method 1364130.991 kN/m. Similarly, for Type-2 buildings in zone V, the peak storey stiffness-X value

obtained by P-Delta method 954301.816 kN/m was 29 % less than that obtained by linear dynamic method 962022.599 kN/m2. Fig. 15, displays the peak storey stiffness-X values obtained by both methods in seismic zones III and V.

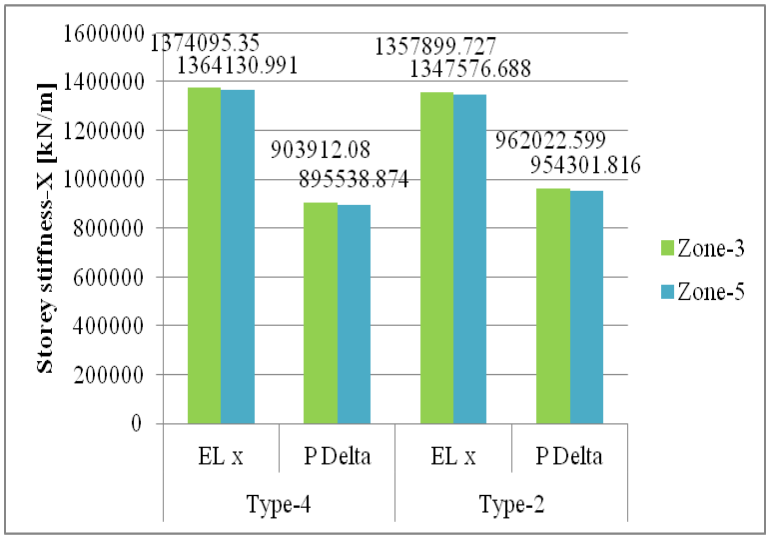


Fig. 15: Comparison of peak storey stiffness-X.

The results indicate that for Type-4 buildings in zone III, the peak storey stiffness-y value obtained by P-Delta method 595476.504 kN/m2 was 49 % less than that obtained by linear dynamic method 179107.404 kN/m2. Similarly, for Type-2 buildings in zone III, the peak storey stiffness-Y value obtained by P-Delta method 692699.75 kN/m2 was 39 % less than that obtained by linear dynamic method 1144702.805 kN/m2. For Type-4 buildings in zone V, the peak storey stiffness-Y value obtained by P-Delta method 600395.873 kN/m2 was 49 % less than that obtained by linear dynamic method 1177097.96 kN/m2. Similarly, for Type-2 buildings in zone V, the peak storey stiffness-Y value obtained by P-Delta method 690467.605 kN/m2 was 40 % less than that obtained by linear dynamic method 1143425.707 kN/m2. Fig. 16, displays the peak storey stiffness-Y values obtained by both methods in seismic zones III and V.

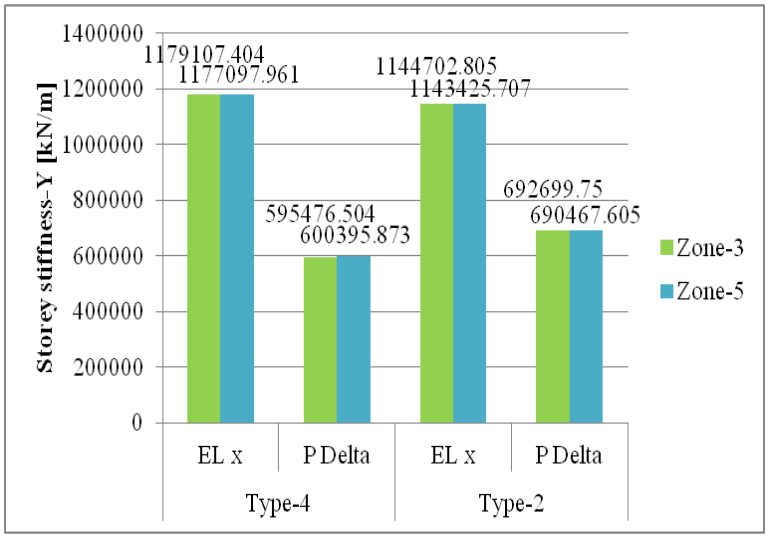


Fig. 16: Comparison of peak storey stiffness-Y.

For Type-4 buildings in Zone III, the peak storey force-x value was found to be -84.2811 kN using both methods. Similarly, for Type-2 buildings in the same zone, the peak storey force-X value was -83.1891 kN. Likewise, for Type-4 buildings in Zone V, the peak storey force-x value was found to be -189.633 kN using both methods. For Type-2 buildings in the same zone, the peak storey force-X

value was -187.176 kN using both methods. Fig. 17, displays the peak storey force-X values obtained by both methods in seismic zones III and V.

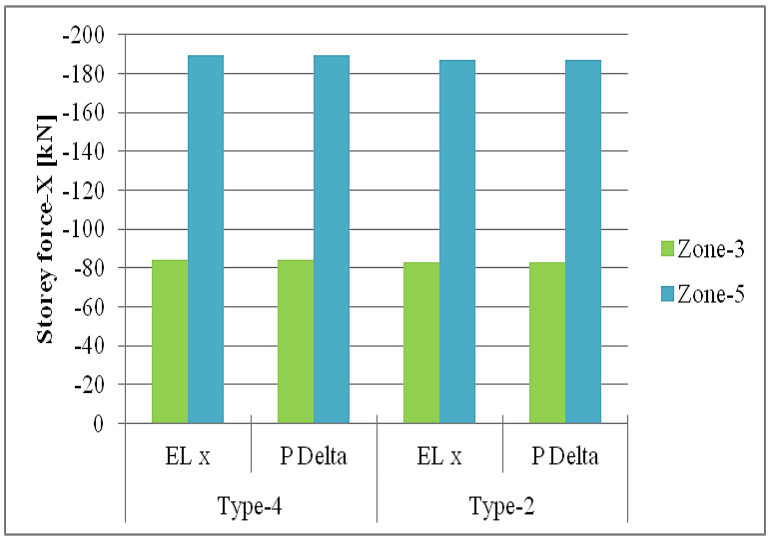


Fig. 17: Comparison of peak storey force-X.

For Type-4 buildings in Zone III, the peak storey force-X value was found to be -84.2811 kN using both methods. Similarly, for Type-2 buildings in the same zone, the peak storey force-X value was -83.1891 kN. Likewise, for Type-4 buildings in Zone V, the peak storey force-X value was found to be -189.633 kN using both methods. For Type-2 buildings in the same zone, the peak storey force-X value was -187.176 kN using both methods. Fig. 18, displays the peak storey force-X values obtained by both methods in seismic zones III and V.

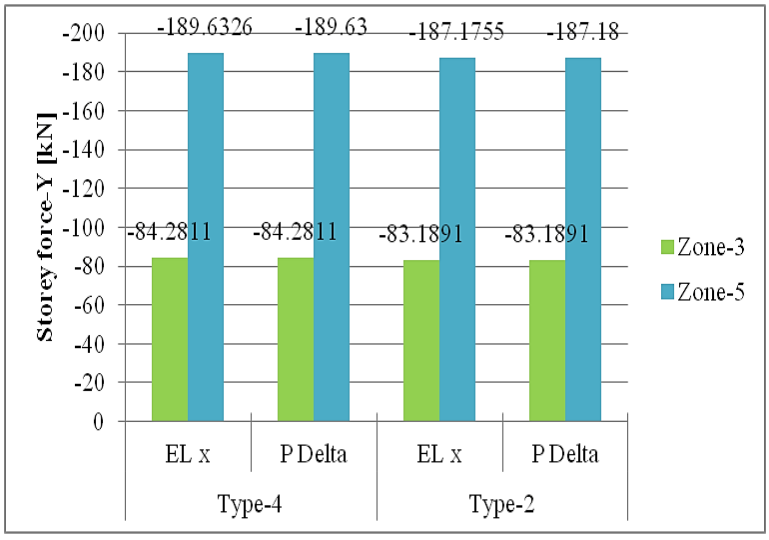


Fig. 18: Comparison of peak storey force-*Y*.

The results indicate that for Type-4 buildings in zone III, the peak storey acceleration-X value obtained by P-Delta method 16810 mm/s2 was 0 % more than that obtained by linear dynamic method 16810 mm/s2. Similarly, for Type-2 buildings in zone III, the peak storey acceleration-X value obtained by P-Delta method 16140 mm/s2 was 4 % more than that obtained by linear dynamic method 16810 mm/s2. For Type-4 buildings in zone V, the peak storey acceleration-X value obtained by P-Delta method 16810 mm/s2 was 0 % more than that obtained by linear dynamic method 16810 mm/s2. Similarly, for Type-2 buildings in zone V, the peak storey acceleration-X value obtained by P-Delta method 16140 mm/s2 was 4 % more than that obtained by linear dynamic method 16800 mm/s2. Fig. 19, displays the peak storey acceleration-X values obtained by both methods in seismic zones III and V.

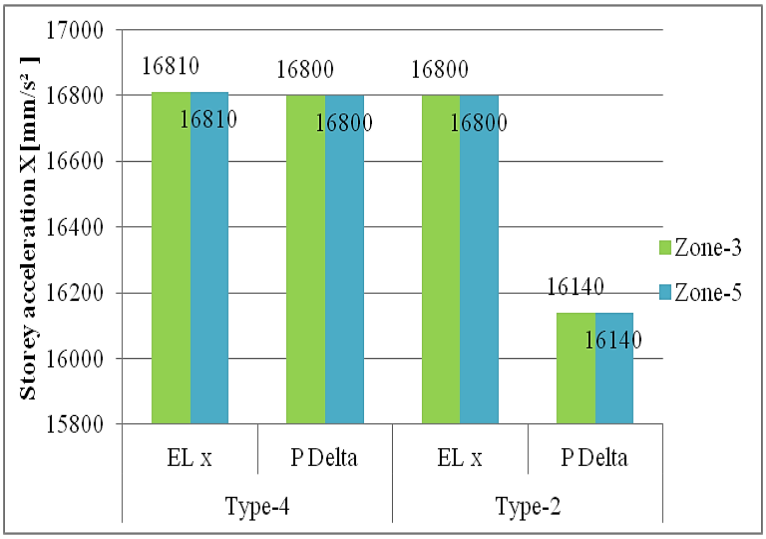


Fig. 19: Comparison of peak storey acceleration-*X*.

The results indicate that for Type-4 buildings in zone III, the peak storey acceleration-Y value obtained by P-Delta method 16810 mm/s2 was 0 % more than that obtained by linear dynamic method 16810 mm/s2. Similarly, for Type-2 buildings in zone III, the peak storey acceleration-X value obtained by P-Delta method 16140 mm/s2 was 4 % more than that obtained by linear dynamic method 16810 mm/s2. For Type-4 buildings in zone V, the peak storey acceleration-Y value obtained by P-Delta method 16810 mm/s2 was 0 % more than that obtained by linear dynamic method 16810 mm/s2. Similarly, for Type-2 buildings in zone V, the peak storey acceleration-X value obtained by P-Delta method 16140 mm/s2 was 4 % more than that obtained by linear dynamic method 16800 mm/s2. Fig. 20, displays the peak storey acceleration-Y values obtained by both methods in seismic zones III and V.

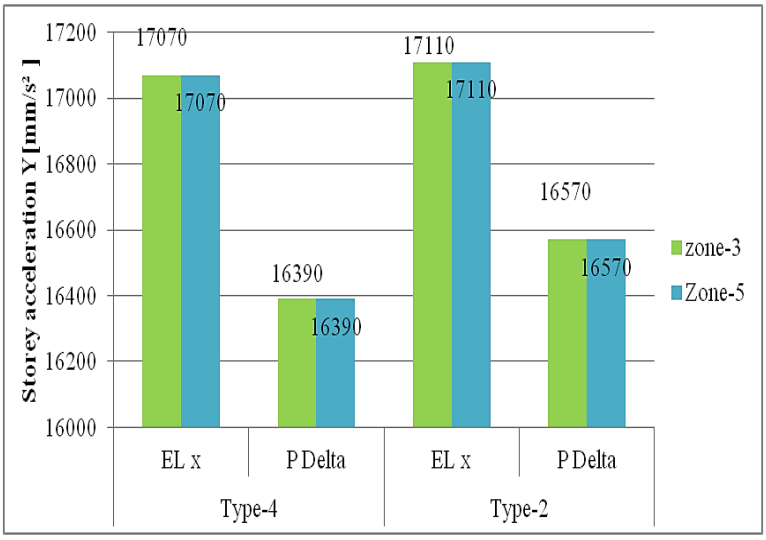


Fig. 20: Comparison of peak storey acceleration-*Y*.

6 Conclusion

Based on this analytical study, it has been determined that Type-2 and Type-4 demonstrate exceptional performance in withstanding lateral loads, especially those imposed by seismic forces. In comparison to the bare frame, the other configurations exhibit notably improved performance under these loads. It appears that both Type-2 and Type-4 braces provide similar resistance to lateral loads in seismic zones III and V. However, Type-2 braces exhibit slightly better in terms of storey stiffness, with a lower difference of 39-40 % compared to Type-4 braces which have a difference of 49 %. For diaphragm drift, the linear dynamic method is recommended over the P-Delta Method to ensure better

seismic performance. Ultimately, the selection of brace type and method should be based on the specific requirements and conditions of the building structure and design.

The use of BRBs typically reduces storey drift and displacements, with Type-2, Type-3, and Type-4 showing better performance in seismic zone-III and V compared to bare frames.

The utilization of BRBs with the linear dynamic method has been found to decrease diaphragm drift in various seismic regions when compared to the P-delta method under equivalent loads.

The increase in seismic zone resulted in an improvement of storey stiffness with an increase in both the number and configuration of BRBs.

The resistance offered by BRBs towards storey shear increases with an increase in the seismic zone.

References

[1] TALEBI, E. - ZHAMATKESH, F.: Performance of BRBF System and Comparing it with the OCBF. Int. J. Civil, Environ. Struct. Constr. Archit. Eng., Vol. 4, No. 8, 2010, pp. 863–870.

[2] LAXMI GOLI, B. - KUMAR YERRAAMASETTY, H. - Nagarathinam, L. - Nandam, S.: Analytical Study of Buckling Restrained Braced Frames Under Lateral Loads Using Etabs. Int. J. Pure Appl. Math., Vol. 115, No. 8, 2017, pp. 431–436.

[3] BLACK, C. J. - MAKIRS, N. - I. D. AIKEN, D.: Component Testing, Seismic Evaluation and Characterization of Buckling-Restrained Braces. J. Struct. Eng., Vol. 130, No. 6, 2004, pp. 880–894.

[4] Babu, M. G.: Reliability Analysis for Buckling Restrained Braced Frame (BRBF). Int. J. Eng. reseach Technol., Vol. 10, No. 06, 2021, pp. 512–516.

[5] D. K. S. - S. C. G.: Significance of P-Delta Effects in High Rise RC Structure in Various Seismic Zones. 2021.

[6] VISWANATH, K. - PRAKASH, K. B. - Anant, D.: Seismic Analysis of Steel Braced Reinforced Concrete Frames. Int. J. Civ. Struct. Eng., Vol. 1, No. 1, 2010, pp. 114–122.

[7] KIM, J. - CHOI, H.: Behavior and design of structures with buckling-restrained braces. Eng. Struct., Vol. 26, No. 6, May 2004, pp. 693–706.

[8] SAHOO, D. R. - CHAO, S. H.: Performance-based plastic design method for buckling-restrained braced frames. Eng. Struct., Vol. 32, No. 9, Sep. 2010, pp. 2950–2958.

[9] AVINASH, T. - AUGUSTINE MANIRAJ PANDIAN, G.: Investigation of the effects of P-delta on tubular tall buildings. Int. J. Civ. Eng. Technol., Vol. 8, No. 2, 2017, pp. 487–495.

[10] SOMASE, A. N. - SAYYED, S. - GAWAI, A. G. - GAIKWAD, S. S.: Seismic Analysis of RCC Structure with Various Types of Bracing System Using ETABS for Different Seismic Zone. 2021.

[11] FERDINAND, N. - JIANCHANG, Z. - QIANGQIANG, Y. - WANG, G. - JUNJIE, X.: Research on application of buckling restrained braces in strengthening of concrete frame structures. Civ. Eng. J., Vol. 6, No. 2, Feb. 2020, pp. 344–362.

[12] SURENDRAN, N. - SUBHA, K.: Seismic Evaluation of Building With Buckling Restrained Braces (Brb). Int. J. Sci. Eng. Research, Vol. 8, No. 11, 2017, pp. 80–86.

[13] IS-1893-PART-1-2016: Criteria for Earthquake resistant design of structures, Part 1: General Provisions and buildings. Bur. Indian Stand. New Delhi, Vol. 1893, No. December 2016, pp. 1–44.

[14] IS 16700 , 2017: Indian Standard Criteria for Structural Safety of Tall Concrete Buildings. Bureau of Indian Standards, New Delhi, No. Reaffirmed 0, 2017, p. 32.

[15] IS: 875, 2015: Indian Standard design loads (other than earthquake) for buildings and structures-code of practice,part 3 (wind loads). Bureau of Indian Standards, New Delhi, 2015, p. 51.

[16] O. MARK - A. EDE - Ch. ARUM - P. AWOYERA: Strength and Durability Assessments of Induction Furnace Slag - Quarry Dust - Based High Performance Self - Compacting Concrete. Civil and Environmental Engineering, Vol. 18, Iss. 1, 2022, p. 1-16, doi: https://doi.org/10.2478/cee-2022-0001.

[17] P. SIYANI - S. TANK - P. V PATEL: Learning of etabs software - Design, 2009, pp. 1–50.