

PERFORMANCE OF VARIOUS BRACING SYSTEMS IN RESISTING LATERAL LOADS: A LIMIT STATE DESIGN PERSPECTIVE

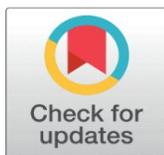
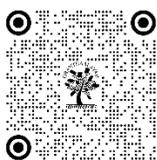
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ABSTRACT

This paper presents a comparative study on the effectiveness of various bracing systems in multi-story steel buildings, a critical aspect of structural design given the significant influence of lateral loads. While bracing systems are globally recognized as a superior solution for resisting lateral forces, their comparative performance across different configurations requires detailed investigation. The study models a **20-story steel building** with a uniform layout, incorporating four distinct bracing types: **knee, Z, X, and V bracings along with bare frame model**. Using the commercial software **Staad Pro V8i** for analysis, the comparison measures the crucial performance indicators such as **top story displacement**, and the **axial force, bending moment, and shear forces** experienced by columns. All structural sections are designed in accordance with **IS 800:2007**, integrating the **Limit State Design** philosophy. The findings aim to demonstrate the impact of these different bracing configurations on the structural response of multi-story steel buildings under lateral loads.

Keywords: Bracing System, Limit State Philosophy, Lateral Load, Steel Section

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1. INTRODUCTION

Bracing is the highly efficient and economical method of resisting horizontal forces in a frame structure. A braced bent consists of the usual columns and girders, whose primary purpose is to support the gravity loading, and diagonal bracing members that are connected so that the total set of members forms vertical cantilever truss to resist the horizontal loading. The braces and girders act as the web members of truss, while the column act as the chords. Bracing is efficient because the diagonals work in axial stress and therefore call for minimum member sizes in providing stiffness and strength against horizontal shear.

2. CONCENTRIC BRACING

Centrally braced frames are defined as those where the center lines of all intersecting members meet at a point as shown in Fig.1. This traditional form of bracing is, of course, widely used for all kinds of construction such as towers, bridges, and buildings, creating stiffness with great economy of materials in two-dimensional space frames.

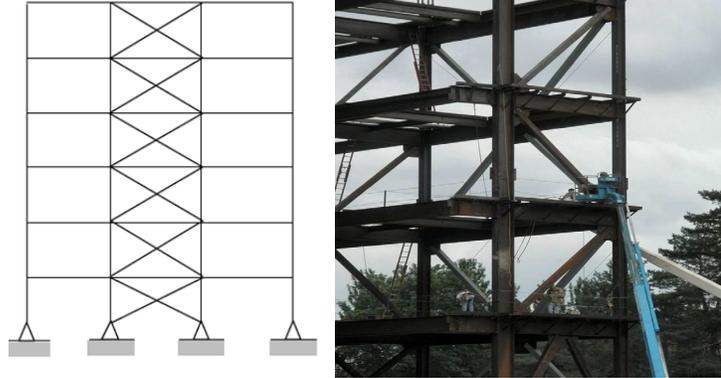


Fig.1 Concentric Brace Frame

3. ECCENTRIC BRACING

An eccentric bracing system attempts to combine the strength and stiffness of a braced frame with the inelastic behaviour and energy dissipation characteristics of a moment frame as shown in Fig.2. The system is called eccentric because deliberate eccentricities are inserted between beam to-column or beam-to-brace connections. The eccentric beam element acts as a fuse by limiting large forces from entering into and causing buckling of braces. The eccentric segment of the beam, called the link, undergoes flexural or shear yielding prior to formation of plastic hinges in other bending members and well before buckling of any compression members. Thus, the system maintains stability even under large inelastic deformations.



Fig 2. Eccentric Brace Frame

4. LITERATURE REVIEW

- **Dhokane et al. (2016) [1]** focused on soft-storey steel buildings, which are particularly vulnerable during seismic events. Using STAAD Pro modelling, they assessed the effectiveness of various bracing systems in reducing lateral displacements and improving overall structural performance. The study highlighted the benefits of diagonal and X-bracing systems in soft-storey mitigation
- **Nezamisavojbolaghi, K. (2020) [2]** A study on chevron braced frames examined two seismic design approaches in low- and medium-rise buildings, focusing on beam strength requirements before and after brace buckling

- **Chen et al. (2022) [2]** applied catastrophe theory to assess and manage safety risks associated with steel bracing systems. Their study offered a novel theoretical framework to quantify and mitigate structural vulnerabilities during failure events.
- **Patel and Joshi (2022) [4]** evaluated the effectiveness of chevron bracing in mitigating progressive collapse in multi-storey steel frames. Using case studies and simulations, they demonstrated how well-placed bracing reduces disproportionate structural failure after local member loss.
- **Hassan and Shrestha (2023) [5]** provided a comprehensive review of concentrically braced steel frames, covering traditional, buckling-restrained, and yielding brace systems. The paper highlights recent advances in design and identifies gaps in performance evaluation under extreme loading.
- **Singh et al. (2023) [6]** conducted a reliability-based performance analysis of steel structures incorporating chevron bracing systems. Their research applied a performance-based seismic design approach, accounting for uncertainties in loading and material properties. The results confirmed that chevron bracing offers efficient energy dissipation and enhances structural reliability under seismic conditions.
- **Acosta et al. (2024) [7]** focused on eccentrically braced frames (EBFs) and analysed the seismic performance of different bracing configurations. Their simulations revealed that the choice of bracing geometry significantly affects lateral stiffness and energy absorption.

5. ANALYSIS OF BUILDING

Following building plan is selected for the analysis and comparison of results.

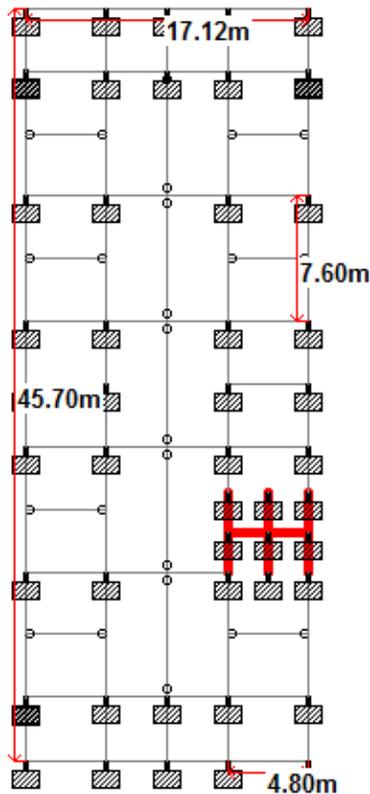


Fig 3 Plan of Building Model

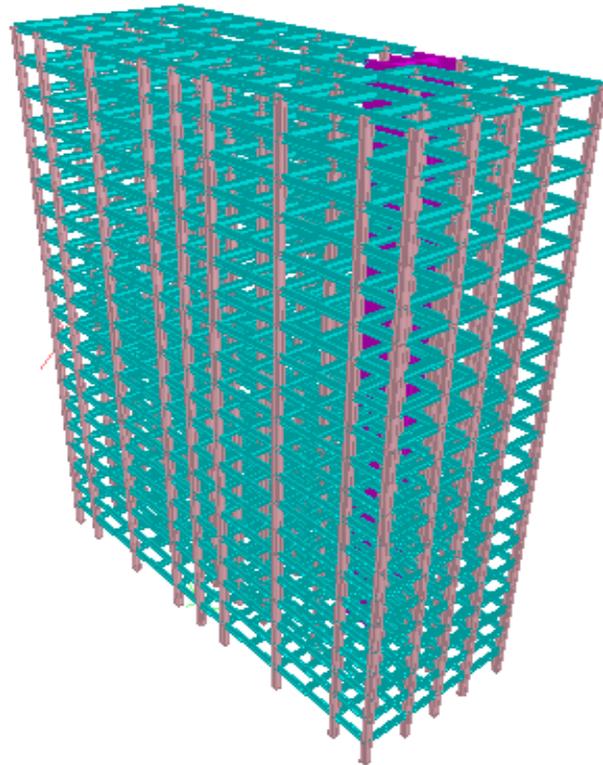


Fig 4 3D Model of Building

Staad Pro V8i software is used for analysis and design of members. The seismic and wind loads are applied as per IS1893 and IS875-III.

Following data is used for the analysis and design of building in software.

TABLE I: General data for Analysis

Type	Hotel Building (20 storey)
Plan Dimension	17.12 m X 45.70m
Height of Storey	3.0 m
Earthquake Zone	III
Soil Type	Medium
Location	Ahmedabad
Basic Wind Speed	39m/s

6. TYPES OF MODELS

There are five types of different models are used for the analysis

- 1) Without brace model
- 2) X brace model
- 3) Z brace model
- 4) Knee brace model
- 5) V brace model

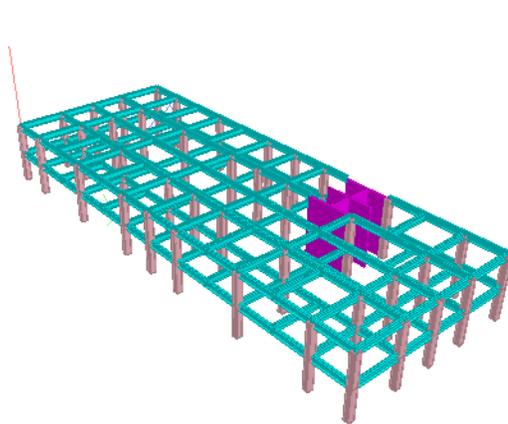


Fig 5 without brace model

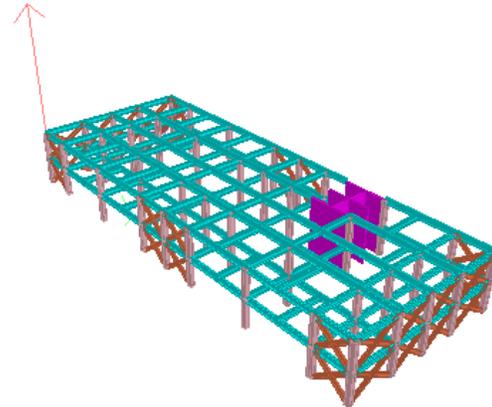


Fig 6 X brace model

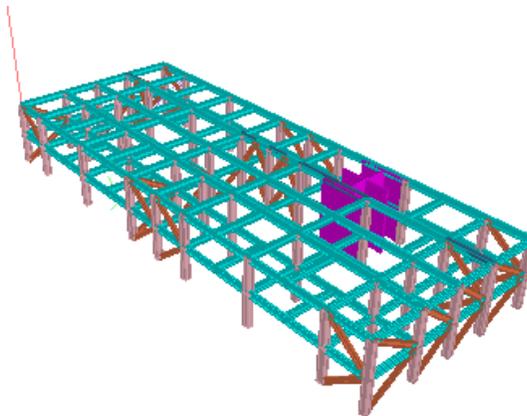


Fig 7 Z brace model

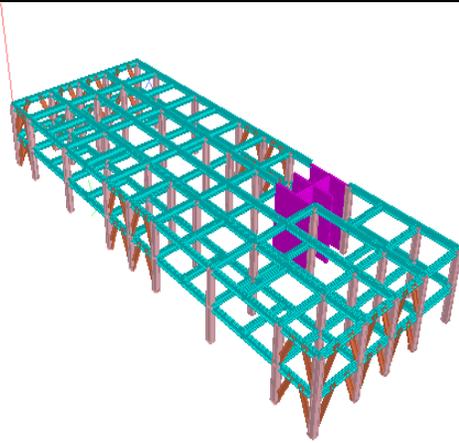


Fig 8 Knee brace model

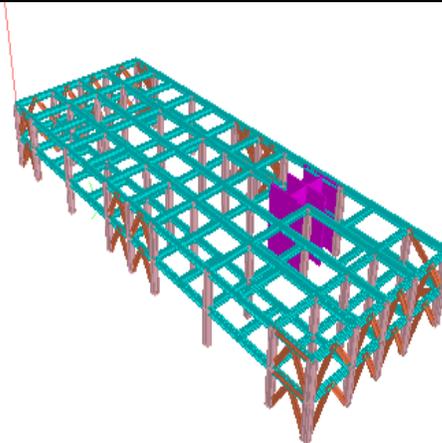


Fig 9 V brace model

The property for the given models is used as per SP 6 and IS 800:2007. For columns box section 500mm x 500mm with 50 mm thickness in without brace and for X brace and knee brace model 450mm x 450mm with 55mm thickness box sections are used. Beam sections for without brace model are built up member of wide flange beams of 300mm wide flange of ISWB 600 and for other models ISWB 600A sections are used and for lift core 150mm thick concrete walls are used for all models. The bracing systems are used as per the requirements and they take as double Channel sections back-to-back. For X brace, Z brace and knee brace models ISMC 400 D and for V brace model ISMC 300 D sections are used.

7. LOAD CALCULATIONS

Loads and Load combinations are given as per Indian standards (IS 875, IS 1893 and IS 800:2007)

- 1) Gravity Loading: - Floor load and member weight are calculated as per general considerations as per IS 875 part1. Live load is taken for hotel building as 3kN/m² and at top floor live load is taken 1.5kN/m² as per IS 875 part 2.
- 2) Seismic Loading: - Seismic load is given as per IS 1893. Following assumptions are used for the calculation.
 - Zone factor – 0.16
 - Soil type – 2 (medium Soil)
 - Importance Factor – 1.5
 - Damping co-efficient – 2%
 - Response reduction – 4 (for concentric brace)
 - 5 (for eccentric brace)
- 3) Wind loading: - Static wind load is given as per IS 875-III. Following assumptions are used for calculation.
 - Location – Ahmadabad
 - Wind speed – 39m/s
 - Terrain category – 3
 - Class – C
 - K1 – 1.06 (life- 100 years)
 - K2 – depending upon the variation of height
 - K3 – 1.00 (flat topography)

Dynamic wind load also calculated by using gust factor approach.

8. RESULTS

All loads and load combinations are considered for the results but values are presented for the maximum load case which is 0.9 DL + 1.5 EQ. Rigid diaphragm action is given to all floor level to get same displacement at all floor level.

1) Lateral Displacement:

TABLE II: Comparison of top storey displacement

Model	Top Storey Displacement (mm)	% decrease
Without Brace	101.92	-
X Brace	44.78	56.06
Z Brace	58.33	42.76
V Brace	51.68	49.29
Knee Brace	59.08	42.03

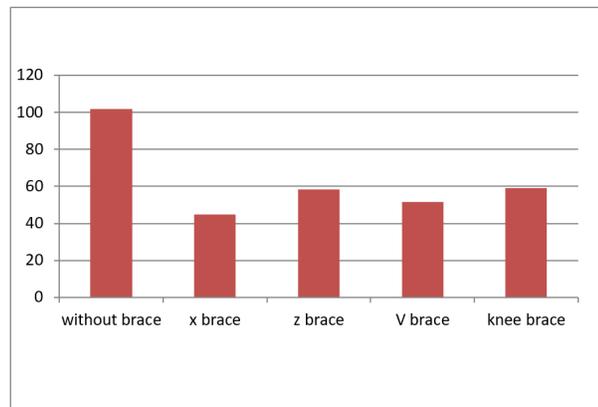


Chart 1 Lateral displacement

2) Axial force in column

TABLE III: Comparison of Axial force in Column

Model	Axial force in column kN
Without brace	7678
X Brace	13028
Z Brace	8940
V Brace	9311
Knee Brace	8362

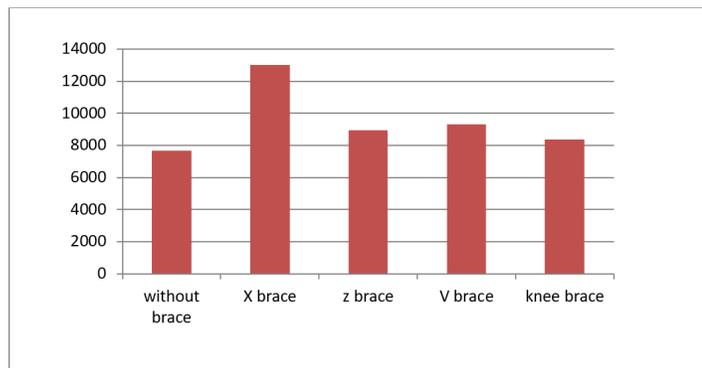


Chart 2 Axial force in column

3) Bending moment in column

TABLE IV: Comparison Bending Moment in Column

Model	Bending moment in column kNm
Without brace	486.96
X Brace	121.31
Z Brace	267.35
V Brace	131.31
Knee Brace	122.32

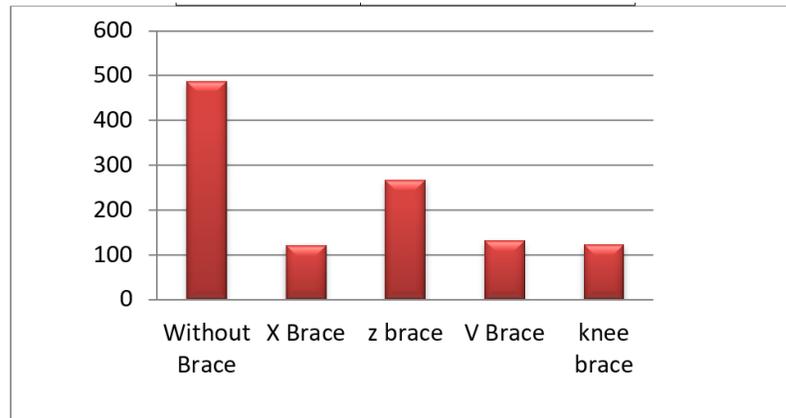


Chart 3 Bending moment in column

4) Shear force in column

TABLE V: Comparison of Shear Force in Column

Model	Shear force in column kN
Without brace	175.8
X Brace	34.87
Z Brace	98.05
V Brace	40.68
Knee Brace	80.22

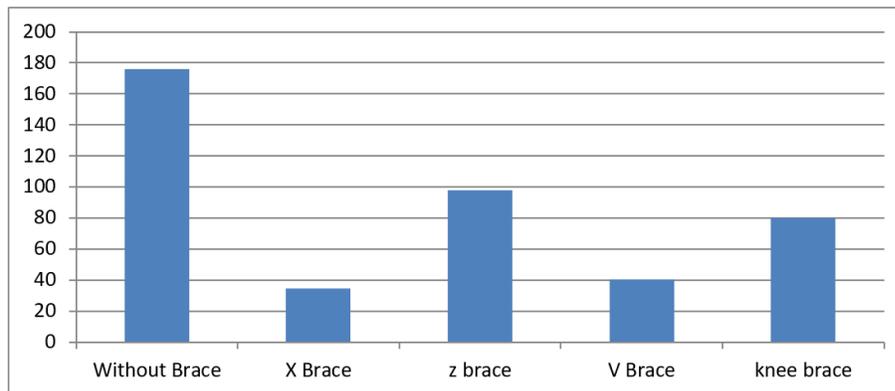


Chart 4 shear force in column

9. CONCLUSION

Different parameters are compared for five models as shown above and it is found that as per the displacement criteria bracings are good to reduce the lateral displacement that can be seen from above results and max reduction found in X braced model 56.06% as compare to without brace model.

Bracings absorb the horizontal shear and convert it into vertical axial force so it can be seen from above results that axial force produced in column is more in the braced models than the model without brace.

The Bending moment and Shear force in columns are also reduced in braced models from which it can found that these are less in X brace model compare to other models.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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