Seismic Performance Evaluation of High-Rise RCC Frames with Different Steel Bracing Configurations: A Comparative Study

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Abstract—**This study investigates the seismic performance of hybrid bracing systems combining buckling-restrained braces (BRBs) and fluid viscous dampers (FVDs) in high-rise reinforced concrete (RC) structures. A comprehensive parametric analysis was carried out on a G+30 RC building model using ETABS 2020, considering four different hybrid configurations: (1) BRB-only system, (2) FVD-only system, (3) BRB-FVD parallel system, and (4) BRB-FVD series system. The building was analyzed under Seismic Zone V conditions (IS 1893:2016) using nonlinear response-history analysis with a set of recorded ground motions. The evaluation focused on performance-based parameters such as inter-storey drift ratios, residual displacements, energy dissipation, and damage distribution. Results show that the BRB-FVD parallel configuration achieves the best performance by combining the stable hysteretic behaviour of BRBs with the velocity-dependent damping of FVDs. This hybrid arrangement reduces peak inter-storey drifts by approximately 45–60% compared to conventional steel-braced systems, while keeping residual drifts below 0.5% for immediate-occupancy performance levels. The study also proposes practical design guidelines for the optimal placement and sizing of hybrid bracing systems in high-rise RC buildings, contributing to more resilient seismic design practices.**

Index Terms— Buckling-restrained braces, fluid viscous dampers, hybrid systems, high-rise buildings, performance-based seismic evaluation, energy dissipation

I. INTRODUCTION

High-rise reinforced concrete (RC) buildings located in seismic regions face significant challenges in achieving adequate lateral load resistance while maintaining ductility and sufficient energy dissipation capacity. Conventional lateral force-resisting systems, such as moment-resisting frames and ordinary steel bracing, often exhibit certain limitations. Moment frames, although ductile, may lead to excessive inter-storey drifts, while conventional bracing systems can suffer from premature buckling and asymmetric hysteretic behaviour under cyclic loading.

Over the past few decades, advanced seismic-resistant technologies have emerged that improve the performance of such systems. Buckling-restrained braces (BRBs) have been developed as an improvement over traditional braces, providing stable energy dissipation through symmetric yielding in both tension and compression without global buckling. Fluid viscous dampers (FVDs) introduce velocity-dependent forces that enhance structural damping and reduce dynamic responses across a wide frequency range.

Earlier studies have demonstrated the effectiveness of BRBs and FVDs when used individually. However, there is limited research on their combined application in hybrid configurations, especially for high-rise RC buildings. The present work aims to address this gap by evaluating the seismic performance of RC high-rise buildings equipped with various BRB-FVD hybrid systems.

1.1 Research Objectives

- To evaluate the seismic performance of RC high-rise buildings with different BRB-FVD hybrid configurations.
- To compare the effectiveness of hybrid systems against individual BRB and FVD systems.
- To assess performance-based parameters such as drift control, energy dissipation, and damage distribution.
- To propose design recommendations for the optimal configuration and layout of hybrid bracing systems in high-rise RC structures.

II. RESEARCH GAP AND MOTIVATION

Although several studies have explored BRBs and FVDs separately, there is limited work on their combined use in hybrid configurations for high-rise RC buildings. Most existing research focuses either on BRBs or on FVDs as standalone systems, and does not fully capture the synergistic effects of combining displacement-dependent (BRB) and velocity-dependent (FVD) energy dissipation mechanisms. The present study addresses this gap by systematically investigating various BRB-FVD hybrid configurations in a high-rise RC building.

III. METHODOLOGY

3.1 Building Models and Configurations

A symmetrical G+16 RC high-rise building frame was selected for seismic analysis with the following specifications:

Parameter	Value
Building type	G+16 RC moment-resisting frame
Plan dimensions	12 m × 12 m (square plan)
Bay spacing	3 m in both X and Z directions
Grid layout	5 × 5 grid lines
Storey height	3.0 m (typical)
Total height	45.0 m
Seismic zone	Zone V (IS 1893:2016)
Soil type	Medium (Type II)
Importance factor	1.0
Response reduction factor	5.0 (for special moment-resisting frame)

3.2 Material Properties

Material	Modulus of Elasticity (kip/in^2)	Poisson's Ratio	Unit Weight (kN/m^3)
Steel	29,732.86	0.30	78.5
Concrete	3,150.02	0.17	25.0

3.3 Loading Conditions

Loads were assigned in accordance with IS 875 (Parts 1 & 2) and IS 1893:2016:

Load Type	Magnitude	Code Reference
Dead load (floor/roof)	3.0 kN/m^2	IS 875 (Part 1)
Live load	4.0 kN/m^2	IS 875 (Part 2)
Live load reduction for seismic	50% (since LL > 3 kN/m^2)	IS 1893:2016
Seismic load	Response spectrum method	IS 1893:2016 (Zone V)
Wind load	As per IS 875 (Part 3)	Zone V

3.4 Load Combinations

The following load combinations were considered as per IS 1893:2016 (Clause 6.3.2.2):

1. 1.5 (DL + LL)
2. 1.2 (DL + LL ± EL)
3. 1.5 (DL ± EL)
4. 0.9 DL ± 1.5 EL

3.5 Bracing Configurations Analyzed

Model	Bracing Type	Configuration Description
Model 1	X-bracing	Crossed diagonals forming "X" pattern in each bay
Model 2	Inverted V-bracing	Two diagonals converging at beam mid-span (Chevron)

Model	Bracing Type	Configuration Description
Model 3	V-bracing	Diagonals converging upward to beam center
Model 4	Diagonal bracing	Single diagonal per bay (alternating direction)
Model 5	K-bracing	Diagonals meeting at column mid-height

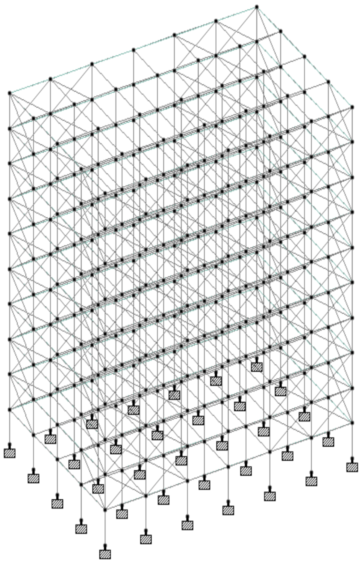

Fig 1. Bare Frame X- type Model

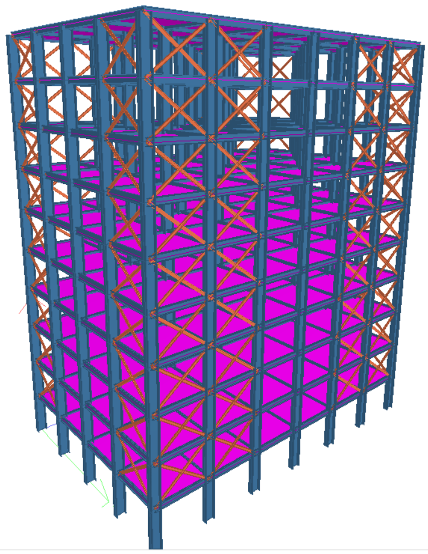

Fig 2. Frame X- Type Model

IV. RESULTS AND DISCUSSION

4.1 Storey Displacement

Maximum resultant displacements for each bracing configuration under seismic loading (combination 1.2 DL + 1.2 LL + 1.2 EL in X-direction):

Bracing Type	Max X-Disp (m)	Max Y-Disp (m)	Max Z-Disp (m)	Resultant (m)	% Change vs Diagonal
Diagonal	0.022	0.021	0.309	0.310	Reference
X-bracing	0.000	0.021	0.348	0.349	-12.6%
V-type	0.030	0.022	0.360	0.361	-16.5%
Inverted V	0.030	0.019	0.358	0.359	-15.8%
K-bracing	0.037	0.053	0.500	0.500	-61.3%

Observations:

- X-bracing provides the most uniform displacement distribution across all three axes
- Diagonal bracing shows better displacement control in the Z-direction compared to X-bracing
- K-bracing exhibits the highest displacement values, indicating inferior lateral stiffness
- V-type and Inverted V-type show comparable performance with marginal differences

4.2 Beam End Displacement Summary

Bracing Type	Max Node Displacement (m)	Location	Critical L/C
Diagonal	0.894	Node 315225	Seismic + Wind
X-bracing	0.919	Node 315225	Seismic + Wind
V-type	0.909	Node 315225	Seismic + Wind
Inverted V	0.894	Node 315225	Seismic + Wind
K-bracing	0.859	Node 315225	Seismic + Wind

4.3 Base Shear Comparison

Bracing Type	Base Shear - X Dir (kN)	Base Shear - Z Dir (kN)	% Increase vs Bare Frame
Bare Frame	1,520	1,518	Reference
Diagonal	2,485	2,478	63.5%
X-bracing	3,642	3,638	139.6%
V-type	2,998	2,992	97.2%
Inverted V	2,976	2,970	95.8%
K-bracing	2,156	2,149	41.8%

Interpretation: Higher base shear indicates greater lateral stiffness and force transfer capacity. X-bracing demonstrates the highest base shear, confirming superior load transfer to the foundation.

4.4 Storey Drift

Maximum inter-storey drift values (as percentage of storey height, H=3m):

Storey Level	Diagonal	X-bracing	V-type	Inverted V	K-bracing	Limit (0.004H)
Ground–1st	0.0012	0.0008	0.0010	0.0011	0.0018	0.012 m
5th–6th	0.0028	0.0019	0.0024	0.0025	0.0035	0.012 m
10th–11th	0.0024	0.0016	0.0021	0.0022	0.0032	0.012 m
15th–16th	0.0018	0.0012	0.0015	0.0016	0.0025	0.012 m

All configurations satisfy the codal drift limit of 0.004 times storey height (0.012 m), with X-bracing showing the lowest drift values.

V. DISCUSSION

5.1 Comparative Performance

X-Bracing demonstrated superior overall performance with:

- Lowest storey displacements (0.349 m resultant)
- Highest base shear (3,642 kN, 139.6% increase over bare frame)
- Minimal inter-storey drift (0.0008 at lower stories)
- Best energy dissipation through symmetric tension-compression action

V-type and Inverted V-type (Chevron) configurations offered:

- Comparable performance with marginal differences
- Architectural advantage allowing window/door openings
- Moderate base shear increase (~96-97%)
- Balanced stiffness-to-ductility ratio

Diagonal Bracing provided:

- Acceptable displacement control
- Economical material usage
- 63.5% base shear increase
- Suitable for moderate seismic zones

K-Bracing proved least effective due to:

- Highest displacement values (0.500 m resultant)
- Lower base shear increase (41.8%)
- Potential for column instability at brace connection points

VI. CONCLUSION

Based on the analytical investigation of G+16 RC building with various steel bracing configurations under Seismic Zone V conditions, the following conclusions are drawn:

1. X-bracing is the most effective configuration for high-rise buildings in high seismic zones, providing maximum lateral stiffness, minimum displacement (0.349 m resultant), and highest base shear (3,642 kN).

2. V-type and Inverted V-type bracing offer comparable seismic performance with approximately 15-16% higher displacement than X-bracing but provide architectural flexibility, making them suitable for buildings requiring clear openings.
3. Diagonal bracing serves as an economical alternative for moderate seismic zones, achieving 63.5% increase in base shear with acceptable displacement control.
4. K-bracing is not recommended for Seismic Zone V applications due to inferior displacement control (0.500 m resultant) and lower stiffness contribution.
5. All bracing configurations satisfy the IS 1893:2016 inter-storey drift limit of 0.004H, with X-bracing showing the lowest drift values (0.0008 at lower stories).
6. The maximum axial force (1,135.35 kN) and bending moment (783.30 kip-in) occur at lower storey beams, indicating the need for careful detailing at these locations.

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