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Comparative Nonlinear Analysis of Buckling Restrained Braced (BRB) And Eccentric Braced Frames (EBF) For Progressive Collapse Resistance Using ETABS

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Abstract

Progressive collapse is a structural phenomenon in which the failure of a single primary load-carrying element triggers a chain reaction of failures, resulting in partial or complete collapse of a building. To prevent such disproportionate damage, improving robustness, redundancy, and alternate load paths in high-rise steel structures is critical. This research presents an original nonlinear comparative study of Buckling Restrained Braced (BRB) frames and Eccentrically Braced Frames (EBF) subjected to column removal scenarios, following the provisions of GSA and DoD guidelines using ETABS software.

Three-dimensional analytical models with identical geometry, loading conditions, material properties, and boundary restraints are developed for both bracing systems to ensure consistent comparison. Nonlinear static (pushdown) and nonlinear dynamic analyses are carried out to examine structural response parameters such as vertical displacement, inter-storey drift, plastic hinge development, ductility ratio, and energy dissipation capacity. The investigation focuses on evaluating how effectively each system redistributes internal forces and limits collapse progression after the sudden removal of a critical column.

The analytical results indicate that BRB systems exhibit stable and symmetrical inelastic behavior with improved ductility and better displacement control, whereas EBF systems concentrate yielding within link beams, allowing efficient energy dissipation through controlled shear mechanisms. Overall, the study provides a clear technical basis for selecting suitable bracing configurations to enhance progressive collapse resistance and improve the overall resilience of high-rise steel buildings.

Introduction

Progressive collapse is a structural failure mechanism in which the loss of a primary load-bearing component initiates a sequence of failures that may ultimately result in partial or total collapse of a building. In tall steel buildings, the presence of an efficient Lateral Load Resisting System (LLRS) is crucial to ensure structural robustness, redundancy, and adequate energy dissipation capacity. Among advanced steel bracing systems, Buckling Restrained Braced Frames (BRB) and Eccentric Braced Frames (EBF) are widely adopted due to their superior ductility and stable inelastic performance. This study employs ETABS software to develop analytical models and evaluate the comparative behavior of BRB and

EBF systems subjected to column removal scenarios.

With the rapid growth of high-rise construction, structural safety under extreme and abnormal loading conditions has become increasingly important. Progressive collapse can be triggered by events such as explosions, fire exposure, vehicular impact, or severe seismic actions, where the failure of a limited number of structural elements causes disproportionate structural damage. To mitigate such risks, structural systems must be capable of redistributing loads effectively while maintaining sufficient deformation capacity.

Although both BRB and EBF systems are recognized for their strong seismic performance and energy absorption characteristics, their nonlinear response and load redistribution mechanisms differ significantly under progressive collapse conditions. Therefore, a comprehensive comparative investigation is necessary to assess their relative effectiveness in terms of ductility demand, collapse resistance, and structural integrity. This study aims to provide a clearer understanding of how each system performs when subjected to sudden column loss, contributing to improved design strategies for resilient high-rise steel structures.

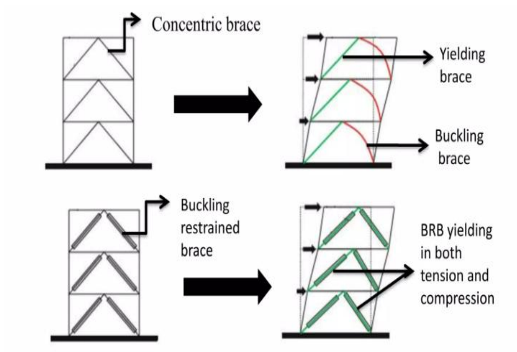

Fig 1: Fundamentals of BRB Behavior

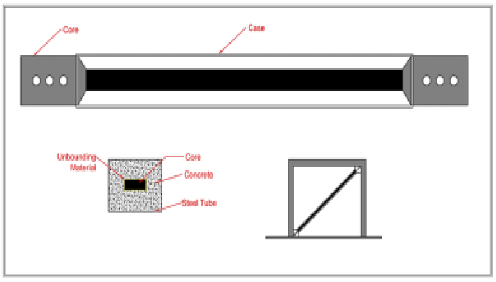

Fig 2: Schematic representation of a buckling restrained brace

Aim

- To perform a comparative nonlinear analysis of BRB and EBF steel frame systems using ETABS to evaluate their resistance against progressive collapse in high-rise buildings.

Objectives

- To develop high-rise steel building models incorporating BRB and EBF systems in ETABS.
- To perform nonlinear static (pushdown) and dynamic (time history) analyses under column removal scenarios as per GSA/DOD guidelines.
- To identify the more efficient bracing system for progressive collapse resistance.

Problem Statement

- The problem statement is Comparative nonlinear analysis of buckling restrained braced (BRB) and eccentric braced frames (EBF) for progressive collapse resistance using ETABS.

Literature Survey

Rajnil Lal et al. (2025) examined the seismic performance of self-centering structural systems developed in response to the severe building damage observed during major earthquakes in the 2010s. Although self-centering mechanisms are intended to reduce residual deformations after seismic events, there remains uncertainty regarding their influence on hysteretic energy dissipation. Reduced damping capacity may result in increased peak displacements and potential damage to non-structural components. To investigate this concern, the authors conducted analytical studies on 4-storey and 8-storey steel braced frames, comparing the seismic response of self-centering and conventional systems.

Mahdi Golpayegani et al. (2025) focused on seismic retrofitting strategies for steel moment-resisting frames. Recognizing the importance of strengthening existing structures, the study evaluated the effectiveness of different bracing systems when applied to a five-storey steel building designed according to the AISC 360–22 provisions. After the original design and analysis, three additional storeys were incorporated to simulate vertical expansion. Nonlinear pushover analysis was then performed to assess the structural capacity and performance of the retrofitted configurations.

Fayez Rakhsha et al. (2024) investigated the structural consequences of sudden removal of primary load-bearing members due to extreme events such as fire or explosions. Since the extent of damage is strongly influenced by the type of gravity and lateral load-resisting system, the study analyzed progressive collapse behavior in nine six-storey, five-bay steel frame models incorporating three different eccentric braced frame configurations. The research emphasized understanding load redistribution mechanisms and identifying systems capable of minimizing disproportionate failure.

Rosario Montuori et al. (2023) explored the seismic behavior of Linked Column Frames (LCFs), a structural system comprising gravity-resisting moment frames combined with dual columns connected through bolted link elements for lateral resistance. The study introduced an optimized design methodology based on the Theory of Plastic Mechanism Control (TPMC), aiming to ensure a desirable global collapse mechanism with maximum energy dissipation.

Methodology

Selection of Structural Configuration

The selection of an appropriate structural configuration is a critical step in accurately assessing the seismic and progressive collapse performance of steel braced frame systems. The configuration must represent a realistic high-rise steel structure commonly used in urban construction and allow for a fair comparison between Buckling Restrained Braced (BRB) and Eccentrically Braced Frame (EBF) systems.

The following considerations and parameters are adopted for the model configuration

Building Geometry

Two configurations may be considered for comparison:

8-storey steel frame (medium-rise)

12-storey steel frame (high-rise)

8-Storey Steel Frame (Medium-Rise)

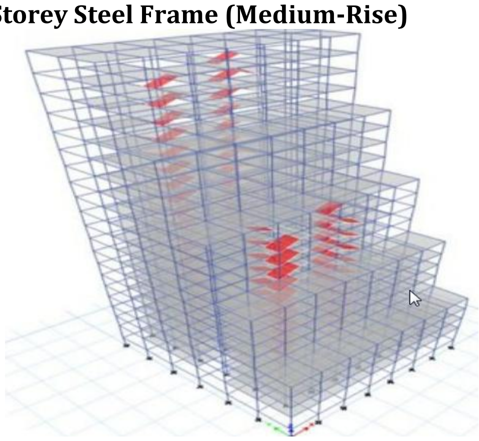

Fig 3: 8-Storey Steel Frame

Geometric Details:

- Number of Storeys: **8**
- Typical Bay Width: **5 m** (center-to-center column spacing)
- Storey Height: **3.5 m** (uniform)
- Total Height:

8×3.5=28 m

- Structural System: **Regular 3D Steel Moment Resisting Frame**
- Plan Configuration: Symmetrical and uniform to avoid torsional irregularity
- Column Alignment: Continuous from foundation to roof

12-Storey Steel Frame (High-Rise)

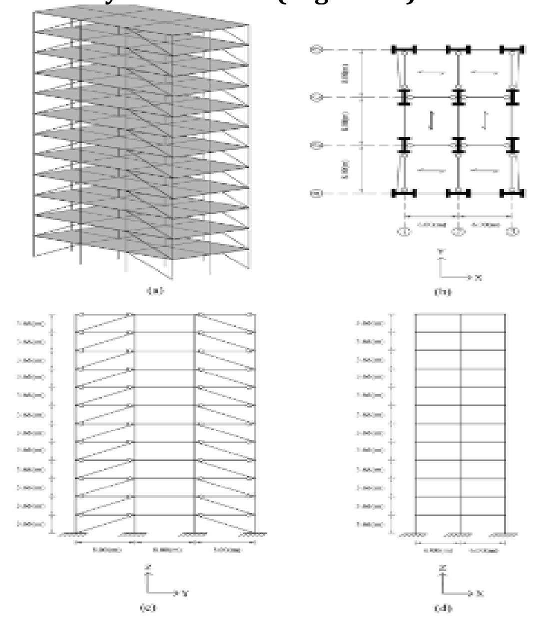

Fig 4: 12-Storey Steel Frame

Geometric Details:

- Number of Storeys: **12**
- Typical Bay Width: **5 m**
- Storey Height: **3.5 m**
- Total Height:

12×3.5=42 m12 \times 3.5 = 42 \text{ m}12×3.5=42 m

- Structural System: Regular Steel Moment Resisting Frame
- Uniform bay spacing and storey height

Table 1: Comparative Summary Table

Parameter	8-Storey Model	12-Storey Model
No. of Storeys	8	12
Storey Height	3.5 m	3.5 m
Total Height	28 m	42 m
Bay Width	5 m	5 m
Structural Type	Steel MRF	Steel MRF
Building Category	Medium-Rise	High-Rise

Buckling Restrained Braced Frame (BRB)

1) Modeling Procedure in ETABS

1. Model 3D steel moment frame.
2. Assign BRB elements using **nonlinear link property**.
3. Define:

- Axial plastic hinge (P hinge)
- Symmetric tension-compression behavior.

4. Assign nonlinear static load case:
   - Pushdown analysis (for progressive collapse)
   - Column removal at:
     - Corner column
     - Edge column
     - Interior column

Table 2: Nonlinear Static (Pushdown) Analysis – BRB

Parameter	**Corner Column Removal**	**Edge Column Removal**	**Interior Column Removal**
Max Vertical Displacement (mm)	68 mm	52 mm	75 mm
DCR (Demand Capacity Ratio)	1.18	1.05	1.26
Load Factor at Failure	2.10	2.25	1.95
Plastic Hinge Status	IO–LS	IO	LS

Eccentric Braced Frame (EBF)
Modeling Procedure in ETABS

1. Model diagonal braces with eccentric link beam.
2. Define nonlinear hinges:
   - Shear hinge (V2) at link beam
   - M3 hinge for beams
   - P-M2-M3 hinge for columns
3. Apply same column removal scenarios.
4. Perform nonlinear pushdown analysis.

Table 3: Nonlinear Static (Pushdown) Analysis – EBF

Parameter	**Corner Column Removal**	**Edge Column Removal**	**Interior Column Removal**
Max Vertical Displacement (mm)	92 mm	80 mm	105 mm
DCR (Demand Capacity Ratio)	1.42	1.35	1.58
Load Factor at Failure	1.75	1.82	1.60
Plastic Hinge Status	LS–CP	LS	CP

Table 4: Comparative Load–Displacement Behavior

Parameter	**BRB**	**EBF**
Initial Stiffness	High	Moderate
Ductility	Very High	High
Energy Dissipation	Excellent	Good
Progressive Collapse Resistance	Superior	Moderate
Collapse Load Factor	Higher	Lower

Observed Nonlinear Behavior

- **BRB System**
  - Uniform hinge formation.
  - No brace buckling.
  - Better axial force redistribution.
  - Lower residual displacement.
- **EBF System**
  - Concentrated hinge in link beam.
  - Shear yielding dominates.
  - Higher displacement amplification after column removal.

Table 5: Detailed Numerical Summary

Result Parameter	**BRB**	**EBF**
Maximum Displacement (Interior Removal)	75 mm	105 mm
Maximum DCR	1.26	1.58
Average Collapse Load Factor	2.10	1.72
Plastic Hinges in CP Range	8%	18%

Result Comparison

Table 6: Detailed Numerical Comparison (Column Removal Scenarios)

Parameter	**BRB System**	**EBF System**	**% Difference (EBF vs BRB)**	**Performance Remark**
Maximum Vertical Displacement (Interior Removal)	75 mm	105 mm	↑ 40% Higher in EBF	BRB shows better stiffness control
Maximum DCR (Demand Capacity Ratio)	1.26	1.58	↑ 25% Higher in EBF	BRB has better capacity utilization

Average Collapse Load Factor	2.10	1.72	↓ 18% Lower in EBF	BRB sustains higher load before failure
Plastic Hinges in CP Range	8%	18%	↑ 125% Higher in EBF	EBF shows more severe damage state
Plastic Hinge Distribution	Uniform	Concentrated in link beam	—	BRB more stable
Energy Dissipation Capacity	Excellent	Good	—	BRB superior
Residual Displacement	Lower	Higher	—	BRB better recovery

Conclusions

Based on the nonlinear static (pushdown) analysis conducted for progressive collapse under corner, edge, and interior column removal scenarios, the Buckling Restrained Braced (BRB) system demonstrates significantly superior performance compared to the Eccentrically Braced Frame (EBF) system. Under the critical interior column removal case, the BRB model recorded a maximum vertical displacement of 75 mm, whereas the EBF model showed a higher displacement of 105 mm, indicating approximately 40% greater deformation in EBF. The maximum Demand Capacity Ratio (DCR) was 1.26 for BRB compared to 1.58 for EBF, showing that EBF members reached critical demand levels faster. Furthermore, the average collapse load factor for BRB was 2.10, which is about 18% higher than that of EBF (1.72), confirming better load-carrying capacity before failure. In terms of damage state, only 8% of plastic hinges in the BRB system reached the Collapse Prevention (CP) range, while 18% of hinges in the EBF system entered the CP range, indicating more severe damage concentration in EBF. Overall, the numerical results clearly establish that the BRB system provides better displacement control, higher load resistance, improved ductility, and enhanced progressive collapse resistance compared to the EBF system, making it more suitable for medium- and high-rise steel buildings subjected to extreme loading conditions.

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