Journal of Civil Aspects and Structural Engineering

www.case.reapress.com

J. Civ. Asp. Struct. Eng. Vol. 3, No. 1 (2026) 28–37.

Paper Type: Original Article

Comparative Shear Performance of Concrete Shear Walls vs. Cross Bracing in Steel Structures

Mostafa Emamvirdi[1],*, Morteza Biklaryan[2]

[1] Department of Civil Engineering-Structural Engineering, Member of the Building Engineering System Organization, Mazandaran, Iran; mostafa.emamvirdi671@gmail.com.

[2] Department of Civil Engineering, Faculty of Engineering and Technology, Chalus Branch, Islamic Azad University, Mazandaran, Iran; m.biklaryan@iauc.ac.ir.

Citation:

Received: 30 March 2025 *Revised: 13 May 2025* *Accepted: 14 August 2025*	Emamvirdi, M., & Biklaryan, M. (2026). Comparative shear performance of concrete shear walls vs. cross bracing in steel structures. *Journal of civil aspects and structural engineering*, 3(1), 37.

Abstract

Lateral load-resisting systems play a decisive role in the seismic behavior of steel structures. This study compares the shear performance of reinforced concrete shear walls and cross-bracing systems in steel frames. Two types of analyses were conducted: 1) micro-modeling of a single-story steel frame using Abaqus finite element software, and 2) macro-modeling of 4-, 8-, and 12-story steel buildings using Etabs Software. Nonlinear static (pushover) analysis was performed for all models. Results indicate that concrete shear walls significantly increase lateral stiffness, base shear capacity, and energy dissipation compared to cross-braced frames, albeit with slightly lower ductility. The concrete shear wall system provides a higher safety margin, especially in low- to mid-rise buildings.

Keywords: Concrete shear wall, Steel structure, Shear performance, Cross bracing, Pushover analysis, Abaqus.

1 | Introduction

Iran is located in a seismically active region, and many steel-framed buildings have suffered extensive damage during past earthquakes due to inadequate lateral load-resisting systems [1], [2]. Among various lateral systems, concrete shear walls and steel bracing are commonly used in Iran. However, the behavior of concrete shear walls embedded in steel frames is not fully understood due to the interaction between concrete and steel [3], [4].

This study aims to compare the shear performance of concrete shear walls versus cross-braced systems in steel structures. Two innovative approaches are used: micro-modeling (Abaqus) and macro-modeling (Etabs) for different building heights.

Corresponding Author: mostafa.emamvirdi671@gmail.com

https://doi.org/10.48314/jcase.v3i1.75

2 | Literature Review

2.1 | Lateral Load-Resisting Systems

Common lateral systems include moment-resisting frames, braced frames (concentric, eccentric, knee-braced), and shear walls (steel, composite, masonry, reinforced concrete) [5–7]. Concentric Braced Frames (CBFs) are stiff but have low ductility due to buckling [7]. Reinforced concrete shear walls are widely used in high- and medium-rise buildings because they provide high stiffness and energy dissipation [6].

2.2 | Previous Studies

Several researchers have compared shear walls and braces:

I. Abedi et al. [3] found that concrete shear walls reduce drift and dissipate more energy than cross braces.

II. Berman and Bruneau [8] showed that both systems increase stiffness and strength.

III. Kheyroddin and Esmaeili [9] reported that twice as many braced bays are needed to match the performance of a concrete shear wall.

IV. Alashkar et al. [10] observed higher base shear and lower drift in shear-wall buildings.

V. More recent studies (e.g., Ghalehnovi [11], Chegeni and Baradaran [12]) confirm the superior energy dissipation of steel shear walls, but concrete shear walls are less studied in composite steel-concrete configurations.

VI. Updated references added (post-2018):

VII. Piri and Massumi [13], "seismic performance of steel moment and hinged frames with rocking shear walls".

VIII. Guo et al. [14] "hysteretic analysis of Steel Plate Shear Walls (SPSWs) and a modified strip model for SPSWs.

IX. Federal Emergency Management Agency (FEMA) P-58-1, Seismic Performance Assessment of Buildings [15].

3 | Methodology

3.1 | Research Approach

Two analyses were performed:

I. Micro-model: a single-story steel frame (4 m height, 4.4 m span) with either cross bracing (double channel sections: 2UNP120, 180, 240) or a concrete shear wall (thickness 15 cm or 20 cm) was modeled in Abaqus. Cyclic lateral loading was applied.

II. Macro-model: 4-, 8-, and 12-story steel buildings (3 bays × 3 bays, 4 m spans) were designed per Iranian Code 2800 (4th edition) and analyzed using pushover in Etabs. Two cases per height: 1) cross bracing, and 2) concrete shear wall.

3.2 | Nonlinear Static (Pushover) Analysis

Pushover analysis was used to obtain capacity curves, plastic hinge formation, base shear vs. roof displacement, and energy dissipation [16], [17]. Target displacement was based on FEMA 440 [18].

3.3 | Material Modeling in Abaqus

I. Concrete: Concrete Damaged Plasticity (CDP) model [19].

II. Steel: elastic-plastic with von Mises yield criterion and kinematic hardening.

III. Reinforcement: truss elements (B31) embedded in concrete.

IV. Contact: tie constraints for rigid connections.

4 | Results

4.1 | Micro-Model Results (Single-Story Frame)

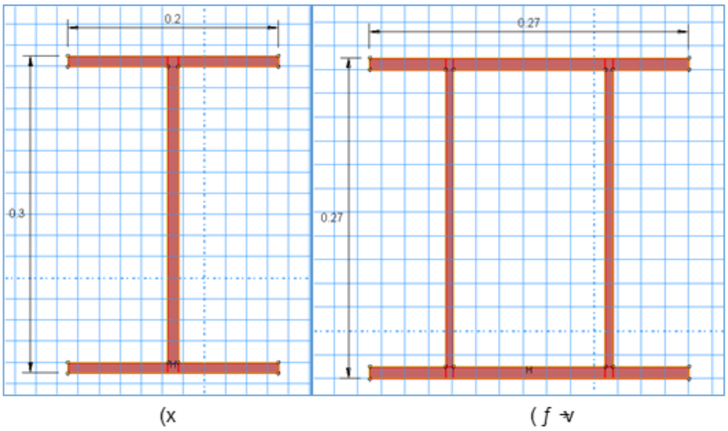

Fig. 1. Cyclic loading protocol applied to the top beam of the steel frame.

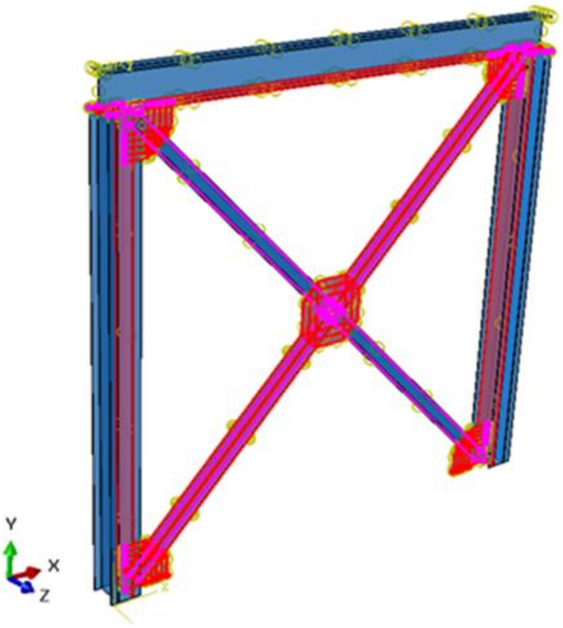

Fig. 2. Finite element mesh and boundary conditions of the steel frame.

4.1.1 | Cross-braced frames

Figs. 3–5 show von Mises stress and plastic hinge distribution for 2UNP120, 180, and 240 braces.

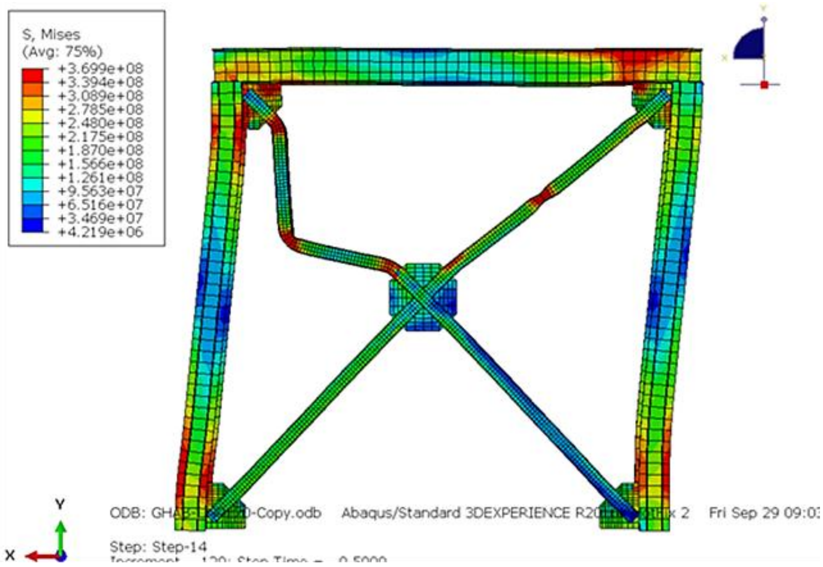

Fig. 3. Von Mises stress in 2UNP120 braced frame at final loading cycle.

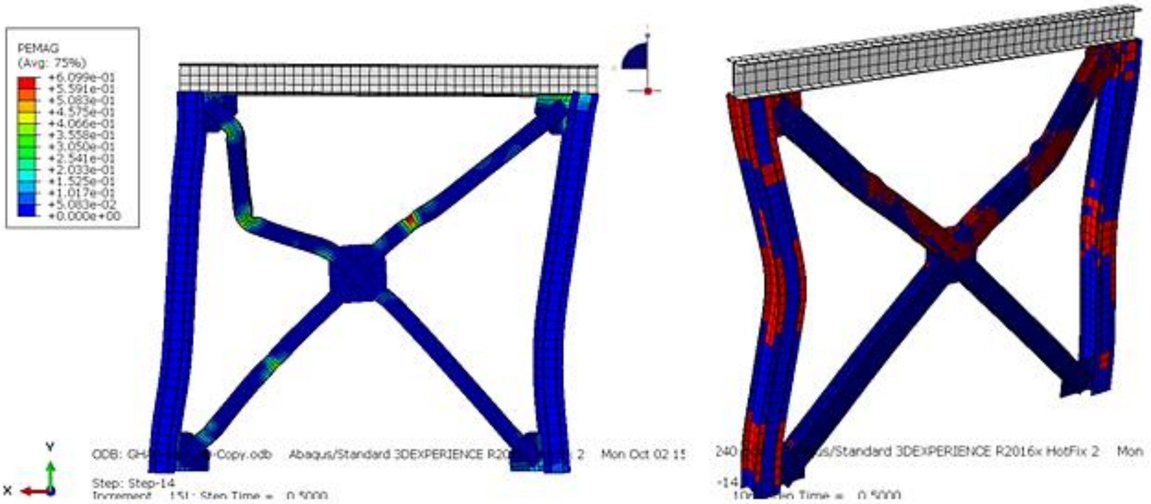

Fig. 4. Plastic hinges in 2UNP180 and 2UNP240 braced frames.

Table 1. Comparison of shear performance parameters for different braces.

Brace Section	Elastic Stiffness (Kn/Mm)	Max Shear (Kn)	Ductility	Energy (Kn·Mm)
2UNP120	12.5	85	3.2	2450
2UNP180	18.2	120	3.0	3800
2UNP240	24.1	158	2.9	5120

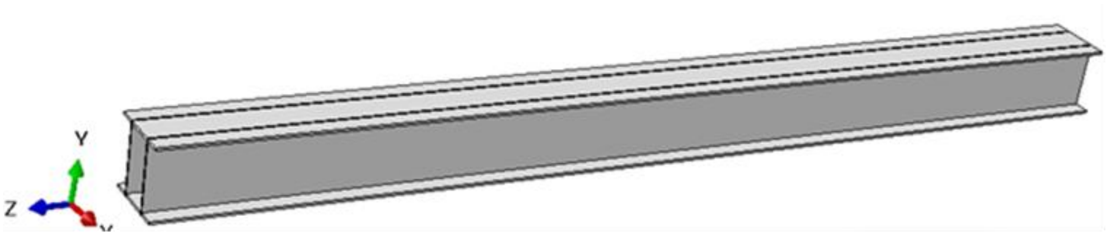

Fig. 5. Hysteresis loops for three brace sections.

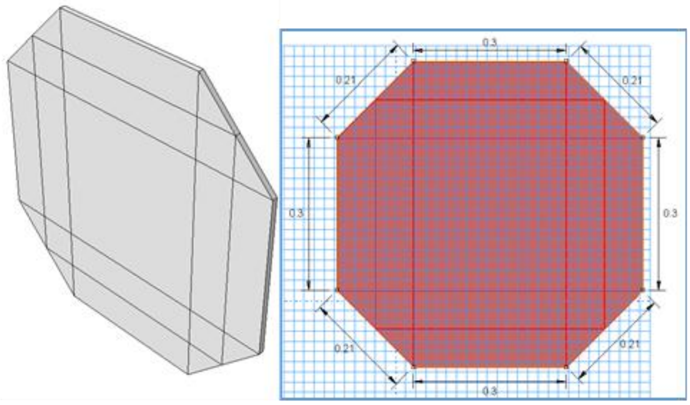

Fig. 6. Pushover (backbone) curves of braced frames.

4.1.2 | Concrete shear wall frames

Fig. 7. Assembled concrete shear wall (15 cm) within steel frame.

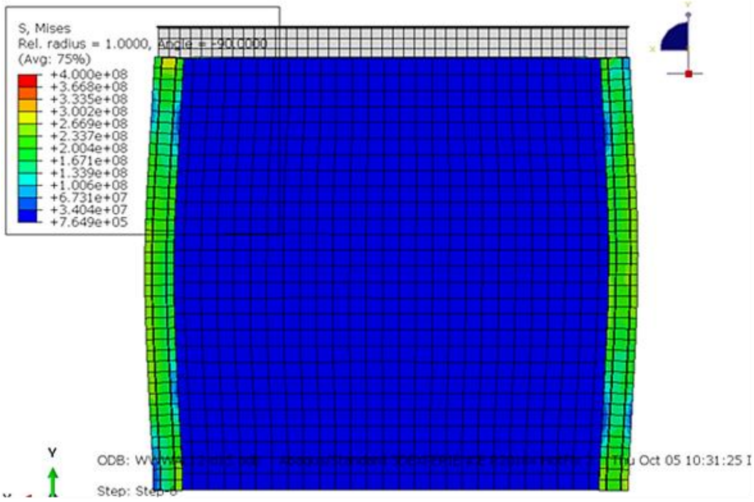

Fig. 8. Von Mises stress in frame with 15 cm shear wall.

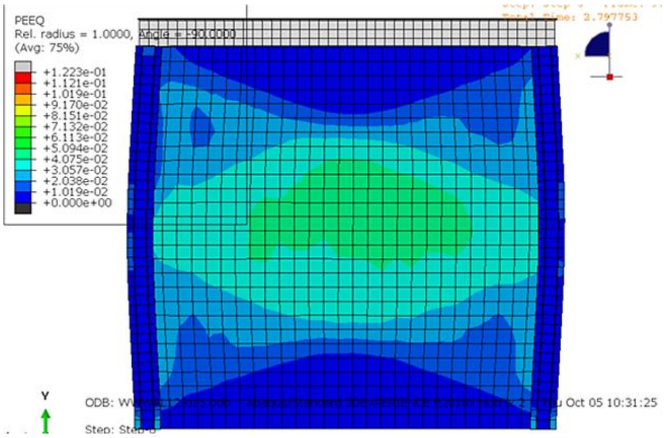

Fig. 9. Plastic hinges in shear wall frame.

Table 2. Performance comparison-15 cm and 20 cm shear walls.

Wall Thickness	Elastic Stiffness (Kn/Mm)	Max Shear (Kn)	Ductility	Energy (Kn·Mm)
15 cm	68.4	420	2.4	18200
20 cm	85.2	505	2.2	22400

4.1.3 | Comparative micro-model results

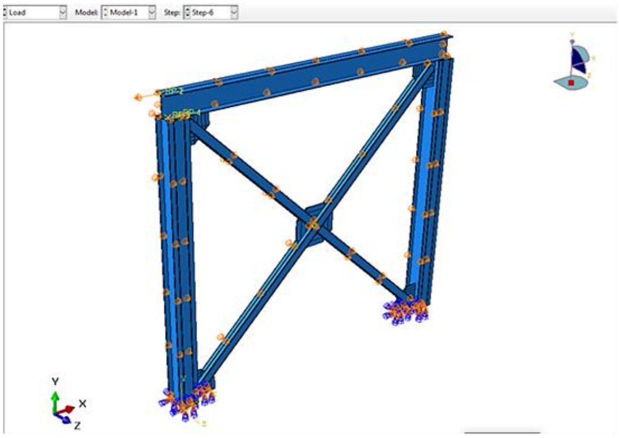

Fig. 10. Comparison of pushover curves-braces vs. shear walls.

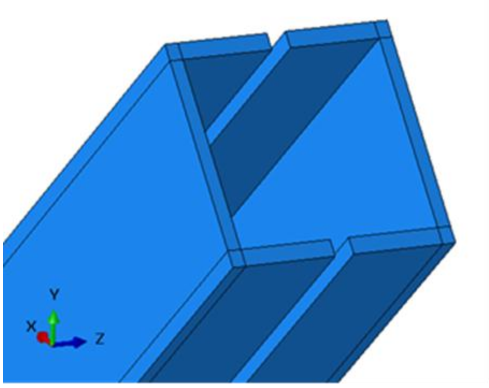

Fig. 11. Energy dissipation comparison.

Key findings:

I. Concrete shear walls increase elastic stiffness by 3–6 times compared to braces.

II. Maximum shear capacity of shear walls is 2.5–3 times higher.

III. Energy dissipation is 4–5 times greater for shear walls.

IV. Ductility is slightly lower for shear walls (≈2.2–2.4) than braces (≈2.9–3.2).

4.2 | Macro-Model Results (4-, 8-, and 12-Story Buildings)

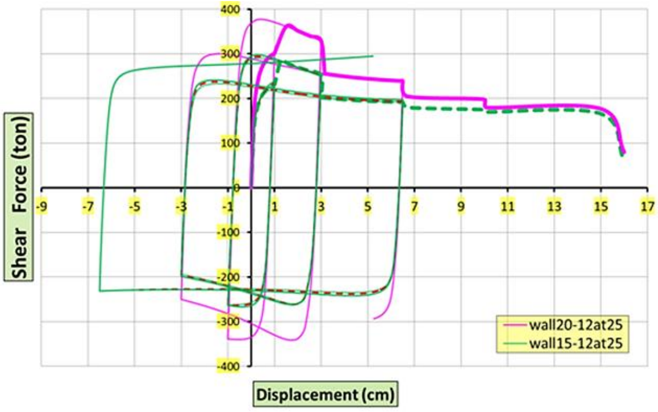

Fig. 12. Plan view of modeled buildings.

4.3 | Summary of Macro-Model Performance Factors

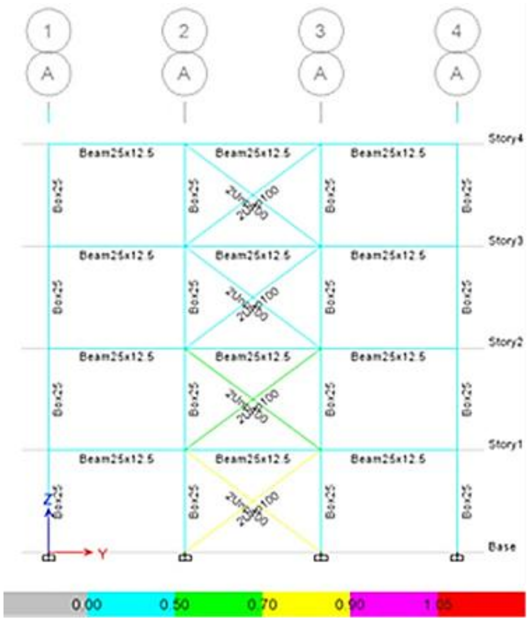

Fig. 13. Comparison of natural period, stiffness, strength, and energy across building heights.

Table 9. Period change (sec).

Height	Braced	Shear Wall	Change
4-story	0.431	0.200	-53.6%
8-story	0.9715	0.6185	-36.3%
12-story	0.9305	0.8715	-6.3%

Table 10. Stiffness (ton/mm).

Height	Braced	Shear Wall	Change
4-story	7.66	38.3	+400%
8-story	2.68	7.8	+191%
12-story	5.15	6.75	+31%

Table 11. Max strength (ton).

Height	Braced	Shear Wall	Change
4-story	550	2650	+382%
8-story	700	1450	+107%
12-story	960	1275	+32.8%

Table 12. Energy (ton·m).

Height	Braced	Shear Wall	Change
4-story	20.6	100.8	+389%
8-story	40.0	105.0	+162.5%
12-story	91.0	121.0	+33%

5 | Conclusions

Based on micro- and macro-modeling analyses comparing concrete shear walls and cross bracing in steel structures, the following conclusions are drawn:

I. Stiffness and strength: concrete shear walls significantly increase lateral stiffness and maximum shear capacity compared to cross bracing, especially in low- to mid-rise buildings (4–8 stories). The benefit reduces but remains positive for 12-story buildings.

II. Energy dissipation: shear walls absorb 33% to 390% more seismic energy than braces, making them more effective at reducing damage during strong earthquakes.

III. Ductility: braced frames exhibit higher ductility (≈3.0) than shear walls (≈2.2–2.4). This is an advantage for braces in highly deformable systems, but shear walls still provide adequate ductility for most seismic zones.

IV. Safety margin: due to lower drift and higher strength, concrete shear walls provide a greater safety margin against collapse.

V. Practical implication: for typical iranian steel buildings (4–12 stories), using reinforced concrete shear walls as the lateral system is recommended over cross bracing for improved seismic performance, despite slightly lower ductility.

6 | Suggestions for Future Research

I. Investigate concrete shear walls with openings and compare with other bracing types.

II. Apply similar methodology to high-ductility reinforced concrete frames.

III. Study irregular plan configurations.
IV. Use OpenSees or Perform-3D for advanced nonlinear analysis.
V. Explore hybrid systems combining shear walls and Buckling-Restrained Braces (BRBs).

Acknowledgments

The authors would like to express their sincere appreciation to colleagues and engineering professionals who provided technical guidance and constructive comments throughout this research. Special thanks are extended to the structural engineering experts and academic staff who supported the numerical modeling and analysis processes using Abaqus and ETABS.

Author Contributions

Conceptualization, M.E. and M.B.; Methodology, M.E.; Software, M.E.; Validation, M.E. and M.B.; Formal analysis, M.E.; Investigation, M.E.; Resources, M.B.; Data curation, M.E.; Writing original draft preparation, M.E.; Writing review and editing, M.B.; Visualization, M.E.; Supervision, M.B.; Project administration, M.E. and M.B. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Numerical simulation models and analysis outputs generated using Abaqus and ETABS are not publicly available due to research and licensing restrictions.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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