Grenze International Journal of Engineering and Technology, June Issue

Seismic Performance Analysis of Industrial Steel Structures with Various Bracing Systems: A Comprehensive Review

Sanvidhan Kamble[1], N. H. Pitale[2] and Bhavesh Sahini[3]
[1-2]Structural Engineering, Department of Civil Engineering, G H Raisoni College of Engineering, Nagpur.
Email: sanvidhan.kamble.st@ghrce.raisoni.net, nikhil.pitale@raisoni.net
[3]Structural Engineer, Arun Uttarwar and Associates, Nagpur
Email: bhavesh.sahini26@gmail.com

***Abstract*— The essential infrastructure needs Industrial steel structures to function as its main component because their structural integrity and operational capability will withstand seismic activities. Industrial steel buildings exhibit different seismic response patterns than the standard multi-storey structures due to their extensive dimensions, also their capacity for supporting heavy equipment, and their unconventional architectural designs. The bracing systems function as vital components that control the lateral movements during earthquakes, protect against structural damage, and also to improve the energy absorption capacity. The review evaluates the earthquake performance of the industrial steel framework through recent research studies that examine various bracing systems using the analytical methods as well as performance evaluation criteria, while analysing the actual behavior patterns. The research team used experimental studies, numerical simulations, and analytical investigations to create a comprehensive assessment of concentrically braced frames, eccentrically braced frames, and buckling-restrained braced frames and emerging hybrid configurations. These review studies show that braced frames deliver two advantages because it provides initial stiffness as well as enable effective drift control during low to moderate seismic requirements. The performance of the system experiences two types of restrictions because brace buckling occurs and cyclic stiffness degradation takes place. Eccentrically braced frames demonstrate enhanced ductility, as well as stable energy dissipation while buckling-restrained braced frames exhibit the superior hysteretic stability, strength retention, and the reduced residual deformations. Hybrid bracing systems show the promising performance improvements, but introduce the additional design complexity. The review demonstrates how performance-based design methods and advanced code requirements together enhance the seismic resistance of industrial steel structures.**

***Index Terms*— Braced steel structures, Industrial steel buildings, Performance-based seismic design, Seismic analysis methods, Seismic performance evaluation, Structural ductility.**

I. INTRODUCTION

Steel structures in the industrial applications serve as essential components for the current infrastructure requirements of power plants as well as manufacturing facilities, and petrochemical plants, along with the logistics centers.

Grenze ID: 01.GIJET.12.2.312_22
© Grenze Scientific Society, 2026

The seismic performance assessment of structures requires testing procedures that produce the dependable outcomes as previous earthquakes have demonstrated that structural damage as well as operational downtime, and hazardous material release along with the economic losses would occur during such events [1][2]. The seismic response of the industrial steel buildings follows design regulations that establish their performance standards, which differ from the operational patterns of the residential as well as commercial buildings. The building design includes the extended floor areas together with the extensive roof systems, and tall building sections, along with the substantial equipment, which results in the extra seismic weight that complicates load distribution, which increases the inertial demands during the intense ground shaking events [3].

Industrial facilities show the geometric as well as stiffness irregularities due to their design includes the asymmetric layouts, and mezzanine floors along with the equipment platforms as well as nonuniform bay spacing between their structural elements. The construction projects achieve benefits from the steel framing as it has the high strength-to-weight ratio, but the projects encounter problems due to the lateral systems do not provide enough support, which results in the excessive building movement that disrupts crane operations while damaging sensitive equipment. Bracing systems which include concentrically eccentrically as well as buckling-restrained braced frames have become common because they improve the structural components through their ability to increase the stiffness as well as strength, and the energy dissipation capabilities. Research on the seismic behavior of the braced industrial steel structures exists in the limited quantities compared to residential buildings because scientists have studied crane activities as well as industrial equipment performance in the various buildings as shown in Figure 1 [10].

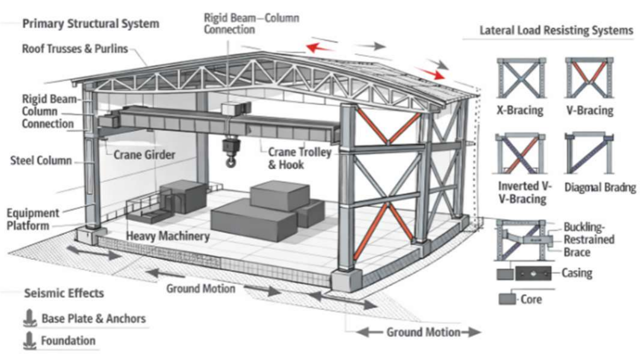

Figure 1. A schematic diagram of the industrial steel building which is demonstrated the seismic performance through its design that uses the extended framework systems, equipment weight requirements as well as the standard engineering bracing methods to enhance its resistance against the sideway forces.

II. Characteristics of Industrial Steel Structures under Seismic Loading

A. Structural Configurations Commonly Used in Industrial Facilities

Usually, the industrial steel plants are constructed by single level buildings which contain the expansive floor areas as well as the elongated structural frameworks. The common architectural configuration implies the portal frames, or the braced frames, as well as the hybrid moment braced systems [11]. The use of the variable bay spacing for the equipment setup as well as the access routes introduces the stiffness irregularities which influence the modal behavior, and the seismic demand distribution which necessitates the accurate 3D modelling for the structural analysis [12][13].

B. Effect of the Mass Distribution, Vertical Irregularities and the Crane Loadings

The weight distribution in the industrial steel structures is largely affected by the storage systems for the heavy machinery as well as the overhead cranes which remain integral to the industrial facility. The concentrated masses located at the elevated points within the structure increase the seismic inertia forces and alter the dynamic response of the building. The seismic base shear for the industrial facility may be expressed as [14]:

$$V = \sum_{i=1}^{n} m_i \, a_i \qquad (1)$$

where m_i denotes as the seismic mass for the level i which is represented by a_i which indicates the corresponding lateral acceleration. The presence of the concentrated masses from cranes as well as the equipment results in the specific areas experiencing the higher seismic demands.

Overhead cranes create dynamic loads through their moving masses which travel along with the nonstandard load paths. This movement shows results in the combined inertial, and gravity forces that impact both the crane girders, and also their supporting columns during the earthquakes. The actual seismic mass which represents the portion of the crane's total capacity determines how the modal participation as well as storey shear distribution will be affected. The presence of the vertical irregularities leads to the increase in both the higher-mode effects as well as deformation requirements [15][16].

$$\theta_i = \frac{\Delta_i - \Delta_{i-1}}{h_i} \quad (2)$$

where Δ_i, and Δ_{i-1} is the lateral displacements between adjacent levels which creates horizontal movements at each level which maintain the height of h_i. Industrial buildings experience operational problems when their crane levels exceed the permitted drift limits despite meeting the structural safety requirements.

C. Differential Response of Mid-Rise Buildings to Seismic Excitations as Compared to That of High-Rise Buildings

Industrial steel structures differ from the conventional buildings which is featuring localized bracing, significant mass as well as stiffness irregularities, and also performance goals including the operational continuity as well as equipment protection beyond the standard life-safety considerations [17][18]

The seismic design differences between the industrial steel structures as well as conventional multistorey buildings are presented in Table I as their main distinction.

TABLE I. COMPARISON BETWEEN INDUSTRIAL STEEL STRUCTURES AND CONVENTIONAL MULTISTOREY BUILDINGS

Aspect	Industrial Steel Structures	Conventional Multistorey Buildings
Typical height	Single-storey or low-rise	Medium to high-rise
Span length	Large spans	Moderate spans
Mass distribution	Highly nonuniform, equipment-driven	Relatively uniform
Lateral system	Discrete bracing bays	Distributed frames or walls
Performance objectives	Safety and operational continuity	Primarily life safety
Nonstructural sensitivity	High (cranes, machinery)	Moderate

D. Managing Failure Mechanisms in the Event of Severe Ground Motions

While excessive shifts in the eccentrically welded links can decrease the energy transfer if poorly detailed, steel used in the industrial structures may suffer critical failures under the strong earthquake excitation like compressive brace buckling as well as the tension fractures in concentrically welded frames, resulting in the stiffness degradation as well as lateral strength loss [19]. High axial loads also put the column bases, beam–column, as well as brace connections at the risk, and significant lateral displacements could cause the crane rails to misalign as well as interfere with the operations despite overall stability [20].

III. CLASSIFICATION OF BRACING SYSTEMS UTILIZED IN INDUSTRIAL STEEL STRUCTURES

A. Concentrically Braced Frames

Because of its high initial lateral rigidity as well as the geometric simplicity, concentrically frames with braces are frequently utilized in the industrial buildings. In order to reduce the secondary bending, braces connect at common joints. Common design includes X, V, $inverted - V$, K, even the single-diagonal configurations [21][22]:

$$K_b = \sum \frac{A_b E}{L_b} \cos^2 \theta \quad (3)$$

The brace's area A_b, length L_b, the steel modulus as well as the inclination θ which reduces the drifts by influencing lateral stiffness. Ductility is limited by the tension fracture, or buckling, while V, $inverted - V$, as well as K bracings require the careful design in the seismic regions [23].

B. Link Behavior with Eccentrically Braced Frames

For an eccentrically braced frame, the stiffness will come from the bracing system and the ductility will come from the frame's moment resisting capacity. The eccentrically connected link undergoes controlled inelastic deformation which researchers classify as shear- or flexure-dominated. The link system uses this method to dissipate seismic energy [24]:

$$V_p = 0.6 F_y A_w \quad (4)$$

where F_y is the strength, and A_w is the web area of the link. The proper linkage system elements demonstrate the stable hysteretic performance which improves their ductility as well as energy dissipation capabilities. The use of eccentrically braced frames in the industrial steel structures provides better seismic protection, but their implementation requires the higher manufacturing complexity as well as costs as more advanced construction techniques.

C. Buckling-Restrained Braced Frames

Buckling-restrained braced frames work as the advanced bracing system which helps engineers to solve the basic limitations which impact concentrically braced frames during tests that involve multiple seismic load applications. The system functions through its steel yielding core which remains the safe due to the buckling restraining system that allows the brace to continuously yield for both the tension as well as compression needs [25].

D. Hybrid and Innovative Bracing Systems

The hybrid bracing systems which combine the conventional braces with the energy dissipating devices including the friction dampers, viscous dampers, as well as the shape memory alloy components which are recommended by the research conducted during the period.

By separating stiffness requirements from the energy dissipation requirements, the systems improve seismic performance. The adjustable bracing devices have been studied as well as suggested by the researchers which assist the industrial sites that must resume the operations following the earthquakes where the equipment must remain continuously operational.

E. Comparative Discussion

Table II given below shows the similarities between the various bracing techniques utilized in the industrial steel constructions.

TABLE II: BRACING SYSTEMS USE IN THE INDUSTRIAL STEEL STRUCTURES

Bracing system	Initial stiffness	Ductility	Energy dissipation	Constructability
Concentrically braced frame	High	Low to moderate	Limited	Simple
Eccentrically braced frame	Moderate	High	High	Moderate
Buckling-restrained braced frame	High	High	Very high	Moderate to complex
Hybrid bracing systems	Tunable	High	Very high	Complex

While the eccentrically braced systems provide the structures greater flexibility which also improve the energy absorption, the concentrically braced frames offer the structural rigidity together with the straightforward design. Because the hybrid systems involve the more complicated design requirements, designers encounter the additional challenges.

IV. LITERATURE REVIEW: SEISMIC ANALYSIS METHODS ADOPTED

A. Linear static and linear dynamic analysis approaches

Because of their computing efficiency, linear dynamic modal studies and linear static (equivalent horizontal force) techniques are frequently employed for preliminary design as well as code checks. For linear static techniques, the design base of shear is typically written as [31]:

$$V_b = S_D \cdot W \quad (6)$$

where S_D is the effective seismic weight, W is the design the spectral acceleration value. Modal superposition provides the overall response for the modal quadratic dynamic analysis [32]:

$$\mathrm{R}(t) = \sum_{k=1}^{m} \phi_k \, q_k(t) \quad (7)$$

where ϕ_k are the modal coordinates, $q_k\ (t)$ is the mode shapes. These linear approaches can quickly estimate the inertial demand, but they are unable to anticipate the inelastic energy dissipation as well as the post-yield stiffness degradation because they ignore the material as well as geometric nonlinearity. Linear techniques consistently underestimate the damage in situations where the brace buckling, connector yielding, or the link plasticity dominated the response, according to the number of comparative studies [31], [32].

B. Nonlinear static (pushover) approach for assessing performance evaluation

By applying the periodic lateral loads as well as idealizing the building as the SDoF system to facilitate the comparison to demand the spectra, nonlinear dynamic (pushover) analysis creates the global capacity curve (base shear vs. roof displacement). It is constrained by the static assumptions overall deformation shape approximations, but it detects the weak tales, plastic hinges, as well as overall capacity [31][33].

C. Realistic earthquake response assessment using nonlinear time-history analysis

Nonlinear time-history analytics (NTHA) integrates equations of the motion directly using the recorded, or artificial ground motions [34]:

$$\mathrm{M}\ddot{\mathrm{u}}(t) + \mathrm{C}\dot{\mathrm{u}}(t) + \mathrm{F}_{\mathrm{int}}(\mathrm{u}, \dot{\mathrm{u}}) = \mathrm{M1}\, a_g(t) \tag{8}$$

where $\mathrm{F}_{\mathrm{int}}$ represents the internal restoring forces that may be nonlinear, and $a_g(t)$ is the ground acceleration. The standard for the realistic collapse as well as performance prediction is the Nonlinear Times History Analysis (NTHA) which precisely represents the hysteresis sequencing, stress accumulation which is including the interaction effects [32], [34]. However, because the incorrect modelling of the brace buckling as well as connection behavior can result in the large inconsistencies with trials, it necessitates careful ground motion optimization, high computationally effort which is including the validated nonlinear models [35],[36].

D. Material nonlinearity, and the modeling assumptions

The seismic analysis demands the multiple modeling techniques which include two modeling approaches that use the simplified line element modeling with the plastic hinges to assess the structural performance as well as distributed flexibility finite element modeling. The investigation focuses on three essential factors which include the brace axial force bending interaction as well as buckling, and also the stress hardening along with the gusset connection slip which also have crane mass modeling. The NTHA analysis needs BRB excitation modeling as well as the EBF link behavior modeling according to the research papers 35 through 38 which require empirical calibration work [35][36][37][38].

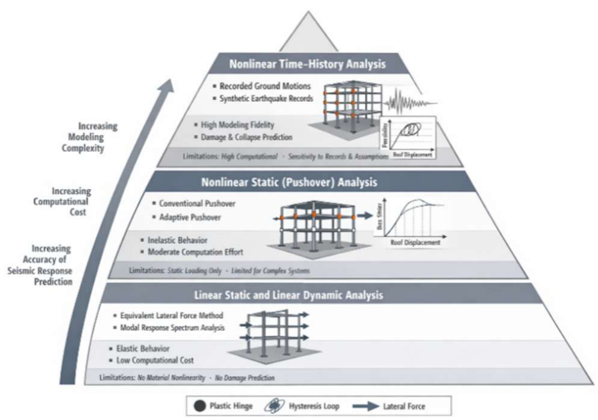

Figure 2. Hierarchical representation of seismic analysis methods for braced steel structures, ranging from linear static and dynamic screening procedures to nonlinear static pushover analysis and detailed nonlinear time-history verification, with increasing modeling fidelity and computational demand.

Figure 2 presents the hierarchical framework of the seismic analysis methods commonly adopted for the braced steel structures, illustrating the progression from simplified linear procedures to advance nonlinear time-history analysis, together with their associated modeling fidelity, application scope, and the inherent limitations.

E. Limitations of commonly adopted analytical approaches

Across the surveyed literature the following limitations are commonly reported: (i) linear methods fail to capture inelastic energy dissipation; (ii) pushover analysis may under- or over-estimate demand for structures with strong higher-mode effects or irregular mass/stiffness distribution [31], [33]; (iii) NTHA is sensitive to record selection, scaling, and imperfectly characterized element cyclic behavior [32], [34], [36]; and (iv) many studies adopt simplified connection models, which can misrepresent local failure modes and lead to nonconservative predictions. The reviews that have been conducted recently reach a unified conclusion which recommends hybrid approaches that combine three specific methods [31-34], [37-50].

TABLE III: LITERATURE REVIEW SUMMARY

Author (Year)	Method	Key Findings	Limitation / Research Gap
K. K. Kuria (2023) [31]	Review pushover methods	Identified strengths/limitations of NSPs; recommended multi-mode pushover improvements.	Need for unified guidelines for irregular structures.
P. C. Nguyen (2021) [32]	NTHA method development	Proposed fiber plastic hinge method for efficient NTHA of steel frames.	Limited validation on complex braced systems.
A. Y. Rahmani (2019) [33]	Adaptive pushover	Improved performance for tall buildings using adaptive procedures.	Application to industrial single-storey systems unclear.
M. A. Q. Al-Janabi (2021) [34]	NTHA / EBF assessment	Evaluated EBF performance under code provisions.	Limited component-level cyclic validation.
B. Mohebi (2023) [35]	BRB numerical/ experimental	Proposed double-stage BRBs with superior dissipation.	Fabrication complexity and field application issues.
X. Yan (2024) [36]	Life-cycle seismic assessment	Showed economic benefits of self-centering/hybrid bracing.	Life-cycle models need more real earthquake case studies.
K. Wu (2025) [37]	Experimental BRB tests	BRB length influences energy dissipation and hysteresis.	Limited to specific core materials and sections.
M. Wang (2024) [38]	Experimental BRB assemblies	LYBRBs show stable hysteresis; good fatigue performance.	Post-earthquake replaceability studies lacking.
R. Mata (2023) [39]	IDA / EBF links	Long-link behavior under Chilean records; soil influence noted.	Geographic record dependence noted.
V. Mazzotta (2017) [40]	Numerical modeling tall braced cores	Verified braced core strategies for tall steel frames.	Limited to high-rise typologies.
G. Cantisani (2021) [41]	Pushover and modeling issues	Discussed single-storey older steel buildings modeling.	Uncertainties in as-built connection details.
S. Semsar (2023) [42]	EBF enhancements	Tie elements improved EBF performance.	Implementation complexity.
V. Baca (2021) [43]	BRB-RC hybrid numerical	BRBs improve performance in RC frames.	Hybrid system integration concerns.
K. Ma (2022) [44]	Variable cross-section shear links	Improved shear link behavior for EBFs.	Need for broader cyclic tests.
S. Shi (2025) [45]	Retrofit with BRBs (case study)	BRB retrofit enhanced seismic compliance for a 24-storey building.	Scalability to industrial low-rise not discussed.
X. Yan (2024) [46]	Self-centering hybrid bracing economics	Hybrid systems reduce life-cycle losses.	Sensitivity to hazard scenario assumptions.
A. T. Alisawi (2021) [47]	Nonlinear analysis + post-fire	Post-earthquake fire effects on steel frames.	Coupled hazards need more study for braced systems.
B. Liu (2024) [48]	EBF form study	Different EBF geometries satisfy performance objectives.	Loss analysis and fragility studies limited.
S. Semsar (2023) [49]	Tie elements in EBFs	Enhanced resistance against progressive collapse.	Large-scale test validation needed.
Y. Mo (2024) [50]	Hybrid damper-brace systems	Tunable damping improves acceleration control.	There is room to increase the durability of air dampers.

V. PERFORMANCE PARAMETERS FOR SEISMIC EVALUATION

Seismic assessment of industrial steel structures evaluates strength and deformation along with damage progression and post-earthquake functionality assessment. The assessment of braced buildings requires three performance metrics which include combined force and deformation and energy-based metrics to ensure crane safety and operational continuity and control residual drift [51–53].

A. Global Response Parameters

The global response parameters provide an overall measure of the structural demand under the seismic loading. Base shear is commonly used as the indicator of global strength demand, and is directly related to the inertial forces developed in the structure. Many studies employ normalized base shear to compare different bracing systems under identical seismic input [51], [54]. Storey drift ratio is widely recognized as the most critical deformation-based parameter because it correlates strongly with both structural and nonstructural damage. It is defined as [55]:

$$\theta_i = \frac{\Delta_i - \Delta_{i-1}}{h_i} \quad (9)$$

where Δ_i, and Δ_{i-1} are the lateral displacements of adjacent levels, and h_i is the storey height. Roof displacement is also frequently reported as a global measure of flexibility and overall deformation capacity, particularly for low-rise industrial steel buildings with large spans [52], [55-59]

B. Code-based Acceptance Limits and Performance Objectives

Seismic design codes establish the acceptance thresholds for the essential parameters which include the storey drift as well as member ductility. The recent research shows that the code-based drift limits provide the life safety protection but they fail to safeguard the crane operations as well as delicate equipment [54][65]. Industrial steel buildings now focus on two performance objectives which require buildings to maintain operations while minimizing the damage.

TABLE IV: SELECTED NUMERICAL PERFORMANCE PARAMETERS REPORTED IN RECENT STUDIES

Author (Year)	Structural system	Peak storey drift (%)	Base shear (V/W)	Energy dissipation (relative)
Kuria (2023) [51]	CBF industrial frame	1.8	0.32	Low
Nguyen (2021) [52]	Steel braced frame	2.1	0.28	Moderate
Al-Janabi (2021) [53]	EBF	1.5	0.30	High
Rahmani (2019) [54]	Braced steel system	2.3	0.27	Moderate
Wu (2023) [55]	BRBF	1.2	0.35	Very high
Wang (2024) [56]	BRBF industrial bay	1.1	0.34	Very high
Ma (2022) [57]	EBF with shear links	1.4	0.31	High
Mohebi (2023) [58]	Advanced BRB	1.0	0.36	Very high
Liu (2024) [59]	Hybrid braced system	1.3	0.33	Very high
Shi (2025) [60]	BRB-retrofitted frame	1.2	0.34	High

VI. SEISMIC COMPARISON OF VARIOUS BRACING SYSTEMS

Different bracing systems determine the seismic performance of steel structures because each system demonstrates unique stiffness properties and different ways to reach ultimate strength and structural failure. Concentrically braced frames deliver excessive initial stiffness which successfully controls drift during moderate seismic events however their braces will buckle and their tensile parts will break leading to fast loss of stiffness and their ability to maintain weight at their original level [66]. Eccentrically braced frames provide a combination of strength and flexibility because they restrict permanent deformation to link elements which creates stable energy loss patterns and better control of remaining drift distances [67]. Buckling-restrained braced frames stop brace buckling which leads to even distribution of strength across braces while maintaining strength through sustained cycling performance although their post-yield stiffness maintains a high degree of reduction [68][69]. Hybrid bracing systems which use damper-assisted and self-cantering braces can deliver superior performance to BRBFs through their ability to control stiffness and energy loss and residual drift yet these systems require more intricate design work and higher expenses to implement (see Table V) [70–78].

TABLE V: COMPARATIVE PERFORMANCE (RECENT STUDIES)

Study (Author, Year)	System	Reported peak drift (approx.)	Noted advantage	Noted limitation
Qiu (2018) [66]	CBF (with BRB comparison)	1.5–3.0%	High initial stiffness	Brace buckling, stiffness loss
Miao (2022) [67]	EBF variants	0.8–1.8%	Stable link hysteresis	Fabrication cost
Kazemi (2023) [68]	BRBF	0.8–1.4%	Symmetric hysteresis, low residual drift	Lower post-yield stiffness
Lu (2023) [69]	BRB assemblies	0.7–1.2%	High energy dissipation	Field implementation issues
Titirla (2023) [71]	Damper-brace combos	0.7–1.5%	High damping, reduced accelerations	Maintenance of dampers
Alborzi (2019) [73]	Hybrid BRB	0.8–1.6%	Tunable performance	Life-cycle durability unknown
Jin (2023) [74]	Tied braced frames	1.0–1.8%	Uniform inelastic deformation	Additional members increase weight
Rezvan (2022) [76]	Self-centering EBF	0.6–1.5%	Low residual drift	Requires specialized devices

Stiffness-limited applications can effectively use the CBFs but the system fails when they experience buckling. EBFs serve as the required solution in situations which need both the ductility as well as controlled energy dissipation. The symmetric cyclic capacity of BRBFs together with their minimal residual drifts makes them the preferred solution for the high-seismic applications which require the critical infrastructure protection.

VIII. CONCLUSIONS

The literature that we have analysed demonstrates that the concentrically braced frames maintain high initial stiffness while they effectively manage lateral movement during the moderate seismic events, but brace buckling and multiple loading cycles cause their performance limitations. Eccentrically braced frames achieve improved ductility together with constant energy dissipation because their inelastic behaviour remains restricted to specific link components. Buckling-restrained braced frames show better hysteretic behaviour than conventional systems because they maintain structural strength while showing minimal permanent deformation, which makes them suitable for industrial facilities located in high seismic areas and facilities that require stringent performance criteria. The evaluation results demonstrate that operational requirements and allowed structural movement together with building construction restrictions determine optimal seismic performance for the different bracing systems. Engineers who practice their profession should select bracing systems according to their established performance objectives rather than using the initial stiffness measurement. The results demonstrate to researchers and code developers that they require better modeling guidance and operational performance acceptance criteria and unified design standards to develop advanced and hybrid bracing systems. The industrial steel facilities will achieve better resilience and reliability through the ongoing integration of experimental proof with performance-based seismic design methodologies.

REFERENCES

[1] Abhishek Kuralkar, Isha Khedikar; Kuldeep Dabhekar, "Comparative analysis and design of pre-engineered buildings and conventional steel frames" AIP Conf. Proc. 3255, 040003, 2025.
[2] Tushar Mahurkar, Kuldeep Dabhekar, "Design and analysis of a multi-storey steel building (G+8) by response spectrum analysis," AIP Conf. Proc. 3139, 110003, 2024.
[3] Tushar Mahurkar, Kuldeep Dabhekar, " Comparative Analysis and Costing of a Multi-story Steel Building," Indian Society for Technical Education, Vol. 46 Special Issue, September, 2023.
[4] Md Aashim Khan, Subodh Tembhekar, Deepak Otwani, Ashutosh Jaiswal, Kuldeep Dabhekar, Isha Khedikar, Neha Pawar, " Review on "Effect of various concentric bracing in building," J. Phys.: Conf. Ser., vol. 1913, no. 1, p. 012148, 2021, AIP Conf. Proc. 2759, 050027, 2023.
[5] Akshita Janbandhu, Piyush Singh, K R Dabhekar, I Khedikar and Janmejay V Shukla, " Effect of Various Concentric Bracing in Building," IOP Conf. Series: Earth and Environmental Science, 2023, 1193, 01201.
[6] Mohammed Sadeq Al-sabaeei, K.R. Dabhekar, I. Khedikar "State of art on seismic comparison of different types (V, diagonal and X) of bracings on different shapes of buildings (L, H, T and rectangular) with response spectrum method," Materials Today: Proceedings, 2023.
[7] Gaurav Shinde, Nikhil Pitale, "Study of Various Types of Roof Trusses for Same Span," International Research Journal of Engineering and Technology, Volume: 06 Issue: 04, Apr 2019.
[8] Sumit Gawande, Uday Amte, Siddharth Agrawal, Abhishek Saonerkar, Kuldeep R Dabhekar, Isha P Khedikar, Rahul Agrawal, "Seismic Analysis of Tall Structures," IOP Conference Series: Earth and Environmental Science, 2021.
[9] S. Gawande, U. Amte, S. Agrwal, A. Saonerkar, K. Dabhekar, I. Khedikar, and R. Agrwal, "Seismic analysis of tall structures," IOP Conf. Ser.: Earth Environ. Sci., vol. 822, 2021, International Conference on Contemporary and Sustainable Infrastructure, Bangalore, India, May 21-22, 2021.
[10] Abhishek K Patil, Adarsh P Solanke, Kuldeep R Dabhekar, Isha P Khedikar, Rahul Agrawal, Pratik P Rajput, Pranav V Chavan, "Comparative analysis of structure with and without seismic load," IOP Conference Series: Materials Science and Engineering, 2021.
[11] Syed Mudassir, Kuldeep Dabhekar, Mohd Faizuddin, Isha P Khedikar, "Wind Analysis of Tall Buildings for Vertical Irregularity: A Review," International Journal of Scientific Research in Science and Technology (IJSRST), 2020.
[12] Nikunj D Banugariya, SS Solanke, "Analysis of Multi-storey Structures with Respect to Sequential Analysis," Smart Technologies for Energy, Environment and Sustainable Development, 2019.
[13] Seki, A., Inoue, K., Okazaki, T., Hashioka, S., & Asada, H. (2022). Seismic performance of steel chevron braced frames designed according to Japanese practice. Journal of Constructional Steel Research, 189, 107066.
[14] Ashrafi, A., & Imanpour, A. (2021). Seismic response of steel multi-tiered eccentrically braced frames. Journal of Constructional Steel Research, 181, 106600.
[15] Bani, M., & Imanpour, A. (2024). Seismic performance assessment of multitiered steel buckling-restrained braced frames designed to 2010 and 2022 AISC seismic provisions. Journal of Structural Engineering, 150(9), 04024113.
[16] Gamal, Y. A. (2022). Using bracing systems to improve the seismic performance of moment resisting frame. JES. Journal of Engineering Sciences, 50(4), 205-226.
[17] Qiao, X., Cui, J., & Jin, M. (2025). Seismic Performance Analysis Of Complex High-Rise Braced Frame Structure Of Coal Gasification Plant. ce/papers, 8(2), 737-748.
[18] Li, J., Wang, W., & Li, P. (2021). Development, testing and performance evaluation of steel beam-through framed connections with curved knee braces for improving seismic performance. Journal of Constructional Steel Research, 179, 106552.

[19] Lee, V. Z. T., & Taip, A. (2024). Seismic performance comparison of reinforced concrete and steel frames with various bracing configurations. GeoStruct. Innov, 2(3), 161-171.
[20] Landolfo, R., Campiche, A., Iuorio, O., & Fiorino, L. (2021, October). Seismic performance evaluation of CFS strap-braced buildings through experimental tests. In Structures (Vol. 33, pp. 3040-3054). Elsevier.
[21] Mahdavi, M., & Aghababaei Mornani, B. (2024). Evaluation and Comparison of the Seismic Performance of Modern Concentrically Braces in the Near-Fault Zone. Advance Researches in Civil Engineering, 6(1), 1-17.
[22] Dal Lago, B., Naveed, M., & Lamperti Tornaghi, M. (2021). Tension-only ideal dissipative bracing for the seismic retrofit of precast industrial buildings. Bulletin of Earthquake Engineering, 19(11), 4503-4532.
[23] BACIU, C., & LUPOAE, M. (2022). Effect of Different Bracing Systems on the Performance of Metallic Tower. Journal of Military Technology Vol, 5(1).
[24] Khan, M. S., & Alluqmani, A. E. (2023). Seismic performance evaluation of RC frames strengthened with eccentric steel braces and column jackets. Innovative Infrastructure Solutions, 8(3), 92.
[25] Yakubu, A. S., & Mishra, N. B. (2024, May). Assessment and Analysis of Seismic Retrofitting Techniques for Performance-based Design of Steel Framed Building in Earthquake-prone Region. In 2024 International Conference on Communication, Computer Sciences and Engineering (IC3SE) (pp. 791-797). IEEE.
[26] Zhang, G., Xu, L. H., & Li, Z. X. (2022). Experimental evaluation on seismic performance of a novel plug-in modular steel structure connection system. Engineering Structures, 273, 115099.
[27] Behnamfar, F., & Almohammad-Albakkar, M. (2023). Development of steel yielding seismic dampers used to improve seismic performance of structures: A comprehensive review. International Journal of Engineering, 36(4), 746-775.
[28] Bharmal, P. P., Kumbhar, P. D., & Gumaste, K. S. (2024). Structural behavior of pre-engineered industrial buildings provided with different types of bracings in various seismic zones. Asian Journal of Civil Engineering, 25(2), 1531-1538.
[29] Mokhtari, M., Islam, A., & Imanpour, A. (2022). Development, seismic performance and collapse evaluation of steel moment-resisting knee braced frame. Journal of Constructional Steel Research, 193, 107262.
[30] Bosco, M. (2023). Influence of uncertainties on the seismic performance assessment of chevron braced frames. Engineering Structures, 294, 116594.
[31] K. K. Kuria, “Pushover analysis in seismic engineering: a detailed review,” Appl. Sci., vol. 14, no. 1, 2023.
[32] P. C. Nguyen, “Nonlinear time-history earthquake analysis for steel frames,” J. Eng. Mech., 2021.
[33] A. Y. Rahmani, “Adaptive upper-bound pushover analysis for high-rise structures,” Struct. Eng. Mech., 2019.
[34] M. A. Q. Al-Janabi, “Seismic performance of eccentrically braced frames,” Eng. Structs., 2021.
[35] B. Mohebi, “Enhancing seismic performance of buckling-restrained braces,” SN Appl. Sci., 2023.
[36] X. Yan, “Seismic life-cycle cost evaluation of steel-braced frames,” Eng. Structs., 2024.
[37] K. Wu et al., “Experimental study on seismic performance of buckling-restrained braces with different lengths,” Buildings, vol. 15, 2025.
[38] M. Wang et al., “Experimental study on assembled buckling-restrained braces,” Eng. Structs., 2024.
[39] R. Mata, “Seismic performance of EBFs with long links: an IDA-based study,” Structures, 2023.
[40] V. Mazzotta, “Numerical modeling and seismic analysis of tall steel frames,” Period. Polytech. Civ. Eng., 2017.
[41] G. Cantisani, “Modelling issues and pushover response of single-storey steel buildings,” Constr. Eng. Mech. Anal., 2021.
[42] S. Semsar, “Improving the seismic performance of eccentrically braced frames,” Int. J. Steel Struct., 2023.
[43] V. Baca, “Enhanced seismic structural reliability with BRBs,” Math. Probl. Eng., 2021.
[44] K. Ma, “Variable-cross-section shear links for EBFs,” J. Constr. Steel Res., 2022.
[45] S. Shi, “Seismic retrofit of high-rise buildings using buckling-restrained braces,” Sci. Rep., 2025.
[46] X. Yan, “Life-cycle economic benefits of self-centering/hybrid bracing,” Eng. Structs., 2024.
[47] A. T. Alisawi, “Nonlinear analysis of steel frames under post-earthquake fire,” Fire Sci., 2021.
[48] B. Liu, “Study on seismic behavior of different EBF forms,” Buildings, 2024.
[49] S. Semsar, “Tie elements for progressive collapse resistance in EBFs,” World Sci., 2023.
[50] Y. Mo, “Hybrid damper-brace systems for acceleration control,” Struct. Control Health Monit., 2024.
[51] K. K. Kuria, “Performance indicators in seismic evaluation of steel structures,” Applied Sciences, vol. 13, 2023.
[52] P. C. Nguyen, “Global and local seismic response of steel braced frames,” Journal of Engineering Mechanics, 2021.
[53] M. A. Q. Al-Janabi, “Performance-based assessment of eccentrically braced frames,” Engineering Structures, 2021.
[54] A. Y. Rahmani, “Seismic demand parameters for braced steel systems,” Structural Engineering and Mechanics, 2019.
[55] G. Cantisani, “Drift-based evaluation of single-storey steel buildings,” Construction Engineering Mechanics and Analysis, 2021.
[56] K. Wu et al., “Seismic performance of buckling-restrained braced frames,” Buildings, 2023.
[57] M. Wang et al., “Cyclic behavior and energy dissipation of BRBs,” Engineering Structures, 2024.
[58] K. Ma et al., “Seismic behavior of eccentrically braced frames with shear links,” Journal of Constructional Steel Research, 2022.
[59] S. Semsar, “Connection behavior and local damage in steel braced frames,” International Journal of Steel Structures, 2023.
[60] B. Mohebi, “Energy dissipation characteristics of advanced buckling-restrained braces,” SN Applied Sciences, 2023.
[61] R. Mata, “Hysteretic performance of EBF systems under strong ground motion,” Structures, 2023.

[62] B. Liu, "Hybrid bracing systems for improved seismic energy dissipation," Buildings, 2024.
[63] X. Yan, "Performance-based seismic assessment of steel structures," Engineering Structures, 2024.
[64] A. T. Alisawi, "Damage indices for steel frames under seismic loading," Fire Safety Journal, 2021.
[65] S. Shi, "Evaluation of code drift limits for BRB-retrofitted steel buildings," Scientific Reports, 2025.
[66] C. Qiu, "Seismic performance of concentrically braced frames with and without brace buckling," Eng. Structs., 2018..
[67] F. Miao, "Seismic performance of eccentrically braced frames with vertical shear link," Buildings, 2022.
[68] F. Kazemi, "Seismic performance evaluation of buckling-restrained braced frames," Eng. Structs., 2023.
[69] J. Lu, "Numerical study on seismic performance of buckling-restrained braces," Appl. Sci., 2023.
[70] R. Lal, "Comparative seismic performance of self-centering and non-self-centering systems," J. Earthquake Eng., 2025.
[71] M. D. Titirla, "State-of-the-art review of passive energy dissipation devices for steel braces," Buildings, 2023.
[72] H. Asada, "Seismic performance of chevron-configured special concentrically braced frames," Conf. Proc., 2020.
[73] M. Alborzi, "Numerical comparison on efficiency of conventional and buckling-restrained braces," Int. J. Steel Struct., 2019.
[74] T. Jin, "Design and seismic performance of tied braced frames," Buildings, 2023.
[75] Bo Yang et al., "Seismic behavior of buckling-restrained brace with full-length restraint," Advanced Steel Constr., 2023.
[76] Y. Rezvan, "Nonlinear performance of D-type self-centering EBF," Earthq. Eng. Struct. Dyn., 2022.