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A Systematic Review on Cross-Braced Steel Frames for Seismic Resistance in Multi-Storey Buildings

[1]Princy Bharti, [2]Rajeev Singh Parihar.

[1,2]Department of Structural Engineering, Lakshmi Narain College of Technology, Bhopal

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Abstract: *Seismic forces are one of the primary threats to the safety and stability of high-rise buildings under normal or seismic events in earthquake-prone areas. Steel frame structures have provided modern architecture with enormous strength, ductility, and flexibility features; although, they require lateral load-resisting systems to resist seismic forces efficiently. According to many experts, a building excited by a seismic force may not respond predictably using any one mathematical model. It is important to have more realistic modeling based on these facts for practical applications. Cross-braced systems generally make a couple of widely returning issues in structure. However, what is being done to overcome those issues? Thus, the perception of that research pathway should replace it. This paper investigates the significance of cross-braced steel frames as means to enhance the seismic performance of multi-storey buildings from an objective perspective, and the study investigates how different bracing configurations, namely x-bracing, concentric bracing, or eccentric bracing, affect lateral deformation, storey weed, and structural responses in the occurrence of a seismic activity. The study deals with the significance of the bracing location to improve the overall performance of such systems. Other possible research gaps were explored in the reviewed literature. Different kinds of analytical and numerical methods commonly encountered in the investigation of seismic behavior in various previous studies were introduced during the review. It also revisits and synthesizes some important results relating to lateral stiffness, energy dissipation capability, and economic sustainability of cross-braced systems. According to findings from the reviewed literature, designing cross-bracing properly is a surefire way to ensure a high standard of lateral stability and seismic resistance for steel systems. The paper concludes by identifying some research gaps to be filled in through future work, considering the optimization of bracing locations, working on advanced materials, or using computational techniques for enhanced seismic design. This paper assists researchers and structural engineers in assisting them develop very efficient and resilient steel frame buildings in the seismic region.*

Key Words: Seismic response, Steel frame structures, Cross-braced systems, multi-storey buildings, Lateral load resistance, Structural stability, Earthquake engineering.

1. INTRODUCTION

Among natural disasters, occurrences of earthquake are perhaps amongst the most severe in terms of direct effects on infrastructure and its adjacent surroundings. In cases of such violent earthquakes, the design of multi-storey buildings predominantly relies on resisting lateral forces which result from ground shaking. Steel frame structures are prominent in today's construction carrying an excellent strength-to-weight ratio, good ductility, ease of fabrication, and high level of stiffness. However, a bare steel frame system recognizes excessive deflections and a loss of stiffness, where strong seismic forces are applied onto it. For these reasons, structures featuring many different systems of lateral load resisting have been developed, with the one system including the X-bracing that is receiving attention from the structural community. The cross-bracing, frequently known as X-bracing, is commonly considered one of the most viable and cost-effective means to shake up a building of steel-to enhance its seismic performance [1]. This system involves each diagonal element being placed between the bay columns in the so-called "X" cross shape, thereby increasing structural stiffness and in turn strength. The braced framework utilises the tension and compression mechanisms where it rapidly transmits holding forces to the base, thus restraining lateral drift, amplifying load-carrying capacity, and bolstering the steadiness of the whole building. Cross-bracing is one of the best systems when it comes to multi-storey buildings [2].

In the recent past, a significant amount of work has been done on the seismic performance of steel frame buildings with various cross-bracing configurations, including cross bracing, chevron bracing, K-bracing, and V-bracing. Out of all these systems, the cross-bracing configuration showed the most optimum performance in terms of stiffness, energy dissipation capacity, and cost-effectiveness. Researchers have studied the effect of brace position, storey levels, structural geometry, and seismic zone on the overall performance of steel frame buildings. A detailed assessment of the advanced numerical modeling technique requiring finite element analysis and performance-based seismic design methodology supplements the work done by researchers towards understanding the effectiveness of the cross-bracing system under dynamic load effects [3].

However, it may well be useful to bring existing informative facts into coherence for an analytical knowledge on certain trends, pros, cons, and research gaps associated with cross-braced steel frames in multi-storey buildings. This literature review will help structural engineers, researchers, or designers understand the behavior of these systems, hence supporting the development of improved seismic-resistant design strategies. In view of this, the systematic review' goal is to examine and synthesize existing literature on cross-braced steel frame systems used for seismic performance in multistoried structures. The review, therefore, considers evaluating different bracing arrangements, structure performance under seismic loading, different analytical and experimental methods employed in various studies, and the influence of brace placement on storey locations [4]. By summarizing the present research findings, the study is going to also bring out the findings that can provide insights and directions for future research and practical implementation in seismic design of structures. Figure 1 illustrates a structural system in which diagonal steel members are installed within a frame to increase stiffness and enhance the building's resistance to lateral loads such as earthquakes and wind.

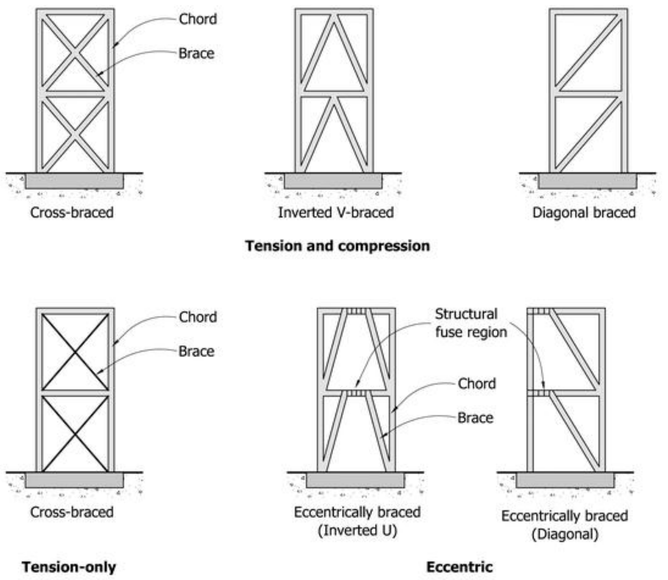

Fig. 1 Braced Frame

2. Seismic Behavior of Multi-Storey Steel Frame Buildings

The seismic performance of multi-storey steel frame buildings is a vital aspect of structural engineering, especially in earthquake-prone regions. During seismic events, buildings are subjected to lateral forces because of dynamic ground motions that vibrate, deform, and stress the structural components. The ability of the structure to withstand these forces without collapse depends on the structure's stiffness, strength, ductility, and ability to dissipate energy. Steel frame construction is extensively used in higher buildings up to high-rise and multi-storey buildings principally because of high strength-to-weight aspect, flexibility to lateral force, and said intrinsic nature of severe deformation forming energy during the event [5]. In high-rise buildings, earthquake forces work principally horizontally which causes a lateral movement and inter-storey drift. If structural members are not sufficiently stiff, deformation will be great in these buildings and may lead to structural damage and even collapse. For these reasons, seismic design can control some certain parameters in a building, such as storey displacement, base shear, and inter-storey drift. It has been concluded that the effectiveness of steel frame buildings in earthquake impacts significantly depends on the type of lateral load-resisting system adopted in the structure. Moment-resisting frames, shear walls, and braced frames are the common types of metal frames designed to counter these lateral forces [6]. Steel moment-resisting frames provide flexibility and ductility but may experience large lateral displacements under strong seismic excitations. And of course, concerning structures with a broad spectrum of behavior, braced systems (mechanical bracing) are usually employed to enhance lateral stiffness and stability. Actually, braced steel frames do give away a most efficient force path through diagonal members in order to absorb earthquake forces, thereby keeping the beams and columns with limited demands. Such systems also help in proper distribution of seismic loads and in restricting excessive structural deformation [7].

Design of multi-storied buildings steel building typically requires assessment in terms of dynamics using a number of response parameters - storey displacement, drift, base shear, floor acceleration and stiffness. Of these, the drift of the storey becomes so paramount a measure from which to judge the earthquake behavior of the structure that if it exceeds a certain acceptable limit bending deformation may initiate in the structure. Analytical methods such as nonlinear static analysis (pushover analysis) and nonlinear response history analysis are two of the most frequently used methods in the assessment of the response of a steel frame to earthquake loading [8]. The two methods allow engineers to understand the building behaviour of a steel frame under different seismic intensities and identify potential critical weaknesses. Research has shown that base bracing is a vital variable in the seismic behavior of steel buildings. Bracing indeed increases the lateral stiffness of buildings, decreases storey drift, and improves the overall stability of the frame system under earthquake levels. X-bracing, in particular, is such a great system in resisting horizontal forces by transferring loads through its members. That way, deformation is minimized (in a structural sense) and a fair load distribution achieved [9].

A fundamental parameter in influencing the seismic behavior of steel multi-story buildings is the height and shape of the building. With the number of storeys increasing, the building becomes more flexible, which may lead to huge lateral displacement and dynamic amplification effects during earthquakes. In general, irregularities in structural geometry, uneven mass distribution, or stiffening disparities between storeys can affect seismic performance. Hence, accordingly, a realistic structural design allowing for proper transfer of lateral loads becomes the most important and fundamental concept for the stability and safety of these buildings [10].

Understanding the seismic performance of the multi-storey steel frame buildings is a basic input for the design of safe buildings that are stable enough to withstand earthquakes. Using lateral load-resisting systems such as bracing, the engineers can greatly enhance earthquake resistance and, at the same time, reduce the seismic damage of the structure. Research and improved analytical methods have also played an important role in improving seismic design strategies for modern steel structures. Table 1 presents a comparative summary of previous studies highlighting how different steel bracing configurations improve the seismic performance, stability, and energy dissipation capacity of multi-storey buildings.

Table -1: Seismic Resistance of Multi-Storey Buildings Using Steel Bracing Systems

Ref	Study Focus	Method / Approach	Key Findings
[1]	Wind analysis of high-rise buildings with irregularities using lateral resisting systems	Review of different lateral systems	Different lateral resisting systems significantly improve wind performance and stability of irregular tall buildings.
[2]	Seismic response of steel frame buildings with cross bracing	Comparative structural analysis	Cross bracing placed at different building locations improves seismic resistance and reduces lateral displacement.
[3]	Effectiveness of steel bracing configurations in mitigating soft storey effect	Comparative structural study	Different bracing configurations significantly reduce soft storey failure in multi-storey buildings.
[4]	Soil-structure interaction effects on buckling behaviour of braced steel frames	Numerical analysis	Soil properties strongly influence the buckling performance of braced multi-storey steel frames.
[6]	Effect of outrigger systems on semi-rigid high-rise structures	Optimization approach	Outrigger systems significantly reduce structural drift and increase stiffness in tall buildings.
[7]	Radially perforated plate damper in steel beam-column connections	Experimental and parametric study	The proposed damper improves energy dissipation capacity and structural resilience.
[8]	Seismic response of multitiered concentrically braced frames	Design and response evaluation	Multitiered braced frames provide improved seismic resistance when properly designed.
[10]	Performance of grooved gusset plate dampers for cross-braced frames	Numerical and experimental study	Stiffener configuration significantly affects damper performance and energy absorption.
[11]	Review on slit steel shear walls	Literature review	Slit shear walls show improved seismic resistance and energy dissipation capabilities.
[17]	Seismic analysis of slit reinforced concrete shafts in water tanks	Structural analysis	Slit RC shafts improve seismic stability of elevated water tank structures.
[18]	Digital modelling of seismic impact with outrigger systems	Computational modelling	Outrigger systems reduce displacement and improve seismic resistance.
[20]	Seismic response of buildings with and without base isolators	Comparative analysis	Base isolation significantly reduces seismic forces and structural damage.
[21]	Racking behaviour of timber-framed buildings	Numerical analysis	Double-skin façade elements contribute to structural load resistance.
[22]	Cost-benefit analysis of earthquake-resistant technologies	Economic and structural evaluation	Advanced seismic technologies improve safety but must be balanced with cost efficiency.
[24]	Construction technology parameters for multi-storey wooden structures	Construction analysis	Wooden structures can be efficient for multi-storey construction under certain conditions.
[25]	Timber structures for high-rise buildings in seismic regions	Structural feasibility study	Timber structures show potential for sustainable high-rise construction in seismic areas.
[26]	Pushover analysis of multi-storey concrete structures	Nonlinear structural analysis	Pushover analysis effectively evaluates structural performance under seismic loads.

3. Cross-Braced Steel Frame Systems

Structural steel X-bracing systems are used as a viable option to increase the rigid capacities of multi storied buildings with respect to seismic requirements. These systems are made up of diagonal members placed within the bays of the steel frame with an "X" pattern. These braces tie the beam-column joints diagonally, thus forming a cross pattern capable of resisting lateral thrusts generated by wind and seismic loads. Owing to extensive benefits in terms of simplicity, cost-effectiveness, high efficiency in bracing horizontal forces, cross-bracing is the most preferred choice for steel structures, especially in seismic areas. Cross-bracing serves a predominant purpose in effecting the lateral stiffness and strength of the framework. Wherever the ground motion creates horizontal forces-"building sways" during an earthquake, they are a result of these horizontal forces. In a typical moment-resisting frame, the beams and columns just resist those lateral loads, leading to excessive displacements and structural stress. By incorporating cross-braces, tension and compression members from the diagonal elements act as means of efficiently transferring the excess seismic force to the foundation. Only at a very lesser degree does this sway regularize lateral displacement and inter-story drift [11].

In cross-bracing systems, a seismic load induces compressive forces on one of the edges, with the other edge that is really stretched retaining the resistance filled with a lot more tensile force. The steel construction of the brace becomes very much suitable as the material properties permit high tensile strength and ductility. The tensile brace-in this case-gets to carry the loading forwards, whereas the compressed brace just fails to carry the extra loading that may become quite intense, depending on their slenderness and loading intensity. Consequently, the forbidding brace continues resisting, even while one side braces buckles, guaranteeing the stability of the structural frame [12]. The simultaneous engagement of both braces in stabilizing the structure succeeds in transmitting the loads effectively during the seismic loading such that the scheme becomes very dependable and robust. Cross-braced steel frame systems have an essential quality of enabling efficient energy dissipation during seismic events via extensive applications of second-order energy-absorbing mechanisms. Being a much stiffer element, the X-braces accept the energy input through seismic ground shaking from other members such as beams and columns, and in this way, a certain amount of damage may be avoided by minimizing the stress intrusion. This leads to better ductility and structural performance. Another positive effect of bracing to the building structure is the elevation of its fundamental stiffness, which helps to regulate sway and vibration.

The construction and economic advantages from mostly cross-braced systems must not be undermined. The design and placement of diagonal braces are simplistic vis-à-vis other lateral load structures. The braces can be nestled in the structure with little to no impact on construction schedule or cost. Further, cross-bracing necessitates less material than bulky shear walls-in short, a cheaper solution to increase seismic resistance. Contradictorily, cross-braced systems come with their limitations as well: For example, braces or compression under buckling may obstruct architectural openings such as doors, windows, or passages within the building frame; besides, if one of the braces buckles, that will drop the stiffness of the whole system. Therefore, most often, designers decided to supplement cross-bracing with other structural systems or to use advanced bracing types like buckling-restrained bracing [13].

Cross-braced steel frame systems continue to be one of the most effective methods used to enhance the seismic resistance of multi-story buildings. Their ability to increase the structural stiffness-to reduce lateral displacement, while also very efficiently transferring seismic forces-makes them a critical part of modern earthquake-resistive structural design. Continuous research and enhancements in structural analysis further contribute to improving the performance and reliability of cross-braced steel frame systems in seismic applications.

3.1. Types of Cross-Bracing Configurations

Steel-frame structures are braced by different bracing configurations to enhance the lateral stiffness and the seismic resistance. The arrangements of braces exert their impact on how the seismic forces are transmitted into the structure, how lateral displacements and storey drifts are controlled, and which bracing configurations should be applied, corresponding to structural requirements, architectural constraints, and load magnitudes. Commonly used bracing configurations in practice are listed in the table 2 below.

Table -2 Types of Cross-Bracing Configurations

Type of Bracing Configuration	Description	Key Characteristics	Common Applications
X-Bracing (Cross Bracing)	Two diagonal members intersect in the middle of the frame forming an "X" shape.	High stiffness, efficient lateral load transfer, reduces storey drift.	Multi-storey steel frame buildings, seismic zones.
Diagonal Bracing	A single diagonal member connects opposite corners of the frame.	Simple design, economical, moderate stiffness.	Low to medium height structures.
V-Bracing (Chevron Bracing)	Two braces meet at the center of a beam forming a "V" shape.	Distributes loads to beam center, allows space for openings.	Industrial buildings and commercial structures.
Inverted V-Bracing	Two braces connect from beam ends to a common point at the center of the column below.	Balanced load distribution, good lateral resistance.	Mid-rise steel structures.
K-Bracing	Diagonal braces connect from the column midpoint to the beam-column joints forming a "K".	Provides architectural space but may induce column stresses.	Buildings with large openings.
Eccentric Bracing (EBF)	Braces are connected eccentrically to beams, creating a short link beam for energy dissipation.	High ductility, good energy absorption during earthquakes.	High seismic risk buildings.
Z-Bracing	Braces arranged in a zig-zag or "Z" pattern across storeys.	Provides continuous load path and moderate stiffness.	Tall buildings and industrial frames.
Double X-Bracing	Two sets of cross braces are placed in the same bay or across multiple storeys.	Very high stiffness and strength, strong seismic resistance.	High-rise or heavily loaded structures.

4. Influence of Bracing Location in Multi-Storey Buildings

The bracing configuration of multi-storey steel frames are key in determining the earthquake performance of the structure. In particular, where you put the bracing can significantly increase resistance to earthquake input. The distribution of lateral loads primarily in steel frame systems like a well-proportioned cantilever wall system is dependent upon strong bracing provided. Once this bracing of lateral loads is gone, chances are high that the whole building will vibrate in several different directions during the earthquake. Thus, location of the bracing system is important in years to have one put high grade shear-wall braces enhancing the basic strength-rerective congestion of the wall as the one from combined moment resistive to improve in-plane and out-of-plane behavior. At the same time, with more enhanced shear forces extruded at their ends, experts have started investigating under-seismic prone areas if some form of inertial loads is greater than expected [14].

4.1. Effect of Bracing Placement on Structural Stability

Where and how bracing is placed in each storey and bay primarily affects how seismic forces are transferred to the entire structure. Bracing running in outer perimeter frames of the building allows for a better resistance to lateral loads as the braces' longer reach counteracts the overturning effects. This provides higher stiffness for the building, with a reduced lateral displacement under seismic activity [15]. Conversely, if bracing were placed solely in interior bays, the structure would have disturbed load paths, creating undue stress in some members.

Structural designers generally equally distribute cross-bracing according to their building's floor plan to maintain balance and steering off torsional configurations. Torque occurs when the construction's center of stiffness does not coincide with its center of mass, causing twisting during earthquakes. Correct bracing, thus, allows for the required symmetry among the structural members, and evenly loads seismic forces of all floors. Studies show that if one place bracing strategically at the other ends of the building, their capacity to resist an earthquake will improve significantly and school forces of deformation would ease.

4.2. Influence of Bracing Location Along Building Height

An additional aspect affecting the seismic performance of any multistory building is the verticalization of bracing. It tends to be stiffer when bracing is placed on the lower stories, owing to the greater shear forces at these levels present during seismic action. The concentration of braces rather low in this case has the effect of making efficient force transfer to the foundation while also diminishing any lateral drift in the overall structure. Provided though, in this particular case, were, typically, only in such a situation would all seismic effects efficiently be carried down through the given configuration to a foundation that would ultimately minimize the lateral drift of the entire building. If bracing again is on the lower storeys only, upper floors might see excessive movement [16]. There are vast varieties to balance and validate the structural performance. It is conceivable to distribute bracing throughout the height so as to enforce structurally adequate behavior throughout. Occasionally, a brace may be attached to almost every level from the basement or ground floor to the highest storey, thus forming vertical braced frames that provide extra stability advantage. An alternate technique is to selectively locate bracing at points along the accommodating elevation, e.g. midheight or top stories, to control the patterns of deformation and to decrease the dynamic amplification. Studies of the Fundamental Behavior of Earthquake-Damaged Structures indicate that the uniform distribution of bracing to cross many stories has a strong probability to control storey drift. And thus, such a design approach is of more functional use to improve overall response with regard to seismic code level excitations into the structure [17]. The location of bracing mostly governs the design of earthquake-resistant steel frame buildings. Wherever bracing is placed, both horizontal and vertical placement is needed to improve stiffness, reduce displacement, and create a uniform distribution of seismic forces. By analysing the various bracing locations through structural modeling and simulation, engineers can make major contributions to safety and resilience of multi-storey buildings subjected to seismic loading.

5. Seismic Analysis Methods Used in Previous Studies

Seismic analysis is one of critical importance in estimating building behavior in multi-level steel frame structures under earthquake forces. Researchers and structural engineers put forward various techniques over the years to see how structures react to seismic loads: these methods come in handy in better understanding structural behavior, pinpointing weak points, and enhancing the design of structures resistant to earthquakes. In previous studies of cross braced steel frame systems, a wide range of seismic analysis techniques are so often used indeed: linear static analysis, response spectrum analysis, push-over analysis, and nonlinear time history analysis among others. Each method varies in accuracy and understanding insights into the dynamic response of a building under seismic conditions [18]].

5.1. Linear Static Analysis (Equivalent Static Method)

The Equivalent Static Analysis method, also known as linear-static analysis, is one of the simplest and most widely used indemnity-loss approaches in seismic analyzes. As such, for this method, seismic forces are simplified as equal static lateral loads financially injuring the structure. These loads are found from the overall building mass, building height, soil conditions, seismic zone, and structural element characteristics. The base shear is determined with the building's mass, and then it is distributed within the height of the building as per the guidelines of codes. This method assumes an elastic structure that can be approximated to dynamic earthquake effects of static forces. Linear static analysis is generally suitable for low-rise and regular buildings where the structural configuration is symmetrical and the height is limited. Several prior studies have used this method to evaluate the structural parameters of steel frame buildings, such as storey displacement, base shear, and storey drift. However, in the case of complex or tall structures, the method may not predict the true dynamic behavior of the building.

5.2. Response Spectrum Analysis

During earthquake situations, response spectrum analysis is a sophisticated way of scrutinizing the dynamic response of measurements under seismic loads. Unlike the equivalent static method, this technique focuses greatly on the natural vibration characteristics of the structure, which include, but are not limited to, natural frequency, mode shape, etc. A response spectrum represents the peak responses of a structure corresponding to varying vibration periods in the course of an earthquake. In this particular method the building was analyzed for several vibration modes and their responses were combined via statistical techniques such as Square Root of the Sum of Squares (SRSS) or Complete Quadratic Combination (CQC). Response spectrum analysis in the design of high-rising structures is particularly popular in seismic design of the structures because it can yield much more accurate results than static methods. The response spectrum analysis had been used in the past research for cross-braced steel frames in order to understand how different configurations of bracing affect the structural response to lateral displacement, base shear, and inter-storey drift [19]-[20].

5.3. Nonlinear Static Analysis (Pushover Analysis)

Nonlinear static analysis, commonly known as pushover analysis, is used to assess the inelastic behavior and collapse capacity for structures subjected to strong earthquakes. In this procedure, the structure is subjected to increasing lateral load until the desired displacement (displacement control) or failure condition (force control) is reached. The analysis generates a load-deformation or capacity curve representing the relationship between the base shear and roof displacement at a building level. Pushover analysis is useful in assisting building designers in understanding the behavior of their structures beyond just its elastic region for discussing ductility, energy dissipation, and different modes of failure as possible. Pushover and other advanced analysis methods have been extensively used in the past to assess the effectiveness of bracing systems in improving the stability of steel cross-braced frames. Indeed, the results show the bracing system has generally increased the strength and stiffness of buildings to withstand significant seismic deformations.

5.4. Nonlinear Time-History Analysis

Time-history analysis nonlinear. Sometimes considered to be one of the most accurate and comprehensive methods of seismic evaluation, in it, time-histories of earthquake ground motion real or intermediate model reordered over supporting structure and analyzed for structural response. This system of time-history analysis is seemed not static in nature, instead, it includes dynamic environment effects of earthquakes consisting of varying accelerations, velocities, and the consequent structural displacements. Time-history analysis permits researchers to examine in detail different characteristics of the behaviors of structures under true earthquakes such as material non-linearity, geometric effects, and the interaction between the structural components. These methods of analysis could help evaluate complex structures, tall buildings, and advanced bracing systems [21]. In several most recent studies, this method has been used to compare seismic response caused by different bracing configurations based on concerned parameters such as peak displacements, acceleration response, and structural energy dissipation.

6. Comparative Use of Multiple Analysis Methods

Various research works have combined many different methods of seismic analysis to obtain thorough results. For instances, the initial checks of linear static are carried out, and then comes response spectrum and pushover analyses to give a deeper understanding of the structural behavior [22]. Time-history analysis is typically seen to support explanations and computer simulation of real seismic force conditions in the study. With multiple approaches, the engineers can acquire first-hand experience of the strengths and shortcomings of individual techniques hence improving the confidence in attributing the relative performance of shear wall systems with the respect to steel-braced moment frames. Half a century of progress in software tools and computing brought with it sophisticated computer-aided analysis and modeling- oth actively pursued in various combinations in order to fortify the efficiency, competence, and degree of uncertainty in seismic design and seismic performance evaluation of multistory buildings [23].

7. Comparative Review of Cross-Braced and Other Bracing Systems

Cross-braced steel frame systems are commonly used in multi-storey buildings for enhancing seismic resistance and overall structural stability. Diagonal members that effectively transfer lateral loads are used to stiffen and strengthen the structure sometimes necessary to stiffen and strengthen the frame. Nevertheless, just like any other structural system, cross-bracing has its own constraints, mainly having to do with architectural flexibility, buckling of the members, and structural designing. In the table 3 stated below, major advantages and limitations of cross-braced systems are statistically compared.

Table-3 Advantages and Limitations of Cross-Braced Systems [24]-[25]

Advantages of Cross-Braced Systems	Explanation	Limitations of Cross-Braced Systems	Explanation
High Lateral Stiffness	Cross-bracing significantly increases the lateral stiffness of the building, helping it resist horizontal forces generated by earthquakes and wind loads.	**Obstruction of Architectural Space**	Diagonal braces may block openings such as doors, windows, corridors, or façade designs, limiting architectural flexibility.
Improved Seismic Performance	The braces efficiently transfer seismic forces to the foundation, reducing storey displacement and inter-storey drift.	**Buckling of Compression Braces**	During seismic loading, braces under compression may buckle, which can reduce structural stiffness and load-carrying capacity.
Cost-Effective Solution	Compared to shear walls and other complex lateral load-resisting systems, cross-bracing requires less material and is relatively economical to install.	**Uneven Load Distribution**	Improper placement of braces may lead to uneven force distribution and potential stress concentration in certain structural members.
Simple Design and Construction	The structural configuration of cross-bracing is simple, making it easier to design, fabricate, and install during construction.	**Reduced Aesthetic Appeal**	Visible diagonal braces may affect the visual appearance of the building façade, which may not be desirable in architectural designs.
Enhanced Structural Stability	Cross-braced systems provide additional support to beams and columns, improving the overall stability of multi-storey structures.	**Maintenance Challenges**	Bracing members may require periodic inspection and maintenance, especially in corrosive environments.

Efficient Load Transfer Mechanism	Diagonal braces act as tension and compression members that create a direct load path for transferring seismic forces to the foundation.	**Design Complexity in Tall Buildings**	In very tall structures, bracing systems may require advanced analysis and careful design to ensure adequate performance.
Reduced Structural Weight	Steel braces are relatively lightweight compared to reinforced concrete shear walls, reducing the overall weight of the structure.	**Limited Flexibility for Future Modifications**	Structural modifications or changes in building layout can be difficult because braces form an integral part of the load-resisting system.
Improved Energy Dissipation	Cross-bracing helps absorb and dissipate seismic energy during earthquakes, reducing damage to primary structural components.	**Potential Connection Failures**	If brace connections are not properly designed or constructed, they may experience failure under severe seismic loading.

8. CONCLUSION AND FUTURE WORK

The study shows how different cross-bracing configurations, such as X-bracing, V-bracing, inverted V-bracing, K-bracing and diagonal bracing, are more significant in the behavior of steel frames. Among these configuration, X-bracing is known for its higher stiffness carrying capacity and efficient load distribution. Placement of bracing within a multistorey building plays a key role in the control of the overall structural deformation and storey deflection, as well as in maintaining the general stability. The correct positioning of braces in a horizontal and vertical arrangement ensures symmetry and consequent reduction of torsional effects within the structure, and the potential trigger of improved responses during seismic conditions. Techniques like linear static analysis, response spectrum analysis, pushover analysis, and nonlinear time-history analysis are beneficial for looking into the dynamic behavior of structures under earthquake loading. Such techniques give the engineer valuable input into parameters such as base shear, displacement, and energy dissipation.

Overall x-braced steel frame systems are seen as affording various advantages, including affordability, ease of construction, and superior seismic behavior. However, some disadvantages, such as architectural constraints, and the tendency for brace buckling, have to be addressed in the design. Future research should focus on the optimization of bracing configurations, better analytical methods, and the introduction of state-of-the-art materials within the frame-work of multi-story steel frame buildings for enhanced seismic resistance.

REFERENCES

[1] Kaif, Md, and Babita Saini. "A Review on Wind Analysis of High-Rise Buildings with Irregularities Using Different Lateral Resisting Systems." International Conference on Sustainable Planning, Architecture and Civil Engineering (SPACE 2026). Allied Publishers, 2026.

[2] Kumar, Vivek, et al. "Seismic response assessment of steel frame building with cross braced systems in different locations of multi-storey building." Procedia Structural Integrity 70 (2025): 97-104.

[3] Mahmud, Mostafa, Md Faiyaz Shahriar, and Md Saifur Rahman Ruman. "Comparative Study On The Effectiveness Of Various Steel Bracing Configurations In Mitigating The Soft Story Effect In Multi-Story Buildings."

[4] Ubani, Obinna Uzodimma, and Chidozie Maduabuchukwu Nwakaire. "Soil-Structure Interaction Effects on the Buckling Behaviour of Braced Multi-Storey Steel Frames." UNIZIK Journal of Engineering and Applied Sciences 5.4 (2025): 2972-2986.

[5] Noor, Khaleel Ibrahim, et al. "Structural responses of single diagonally braced frames having cross-strip damper." Alexandria Engineering Journal 121 (2025): 271-282.

[6] Üstüner, Betül, and Erkan Doğan. "Effect of Outrigger on Semi-Rigid High-Rise Structures: An Optimization Approach." Available at SSRN 5202138.

[7] Almohammad-albakkar, M., and Zaid A. Al-Sadoon. "Experimental testing and numerical parametric study of radially perforated plate damper in steel beam-column connections." Archives of Civil and Mechanical Engineering 25.7 (2025): 305.

[8] Imanpour, Ali. "Seismic response and design of steel multitiered concentrically braced frames not specifically detailed for seismic resistance." Journal of Structural Engineering 150.3 (2024): 04023232.

[9] Al-Sadoon, Zaid A., and M. Almohammad-Albakkar. "Seismic resilience of steel-braced frames incorporating steel slit dampers: a review and comparative numerical analysis." Civil Engineering Journal 10.4 (2024): 1310-1335.

[10] Almohammad-albakkar, Mohammad, and Farhad Behnamfar. "Effects of stiffener characteristics on the performance of the novel grooved gusset plate damper for cross-braced frames: numerical and experimental study." International Journal of Steel Structures 24.5 (2024): 1051-1064.

[11] Almohammad-Albakkar, M., and Hayder AO Al-Deewan. "Al-Wadi. A Review on Slit Steel Shear Walls:

Development, Implementation, and Performance." Sch J Eng Tech 4 (2024): 133-145.

[12] Swetha, Ramya, Venu Malagavelli, and J. Cici Jennifer Raj. "Pseudo-Static Loading Investigation on the Performance of Steel Frame with and without STRP Bearings as the Base Isolation Material." International Journal of Civil Engineering 11 (2024): 34-40.

[13] Tedesco, Gabriele. "Earthquake-Resistant Timber Frame Techniques in the Calabrian Valleys of Gallico and Catona After the 1908 Messina Earthquake: Analysis and Typological Classification." International Conference of Ar. Tec.(Scientific Society of Architectural Engineering). Cham: Springer Nature Switzerland, 2024.

[14] Patil, Jagruti, Shashank Dhagdhage, and Pravin Minde. "Enhancing earthquake resilience in L-and T-shaped buildings using post-tensioned rocking shear walls." Innovative Infrastructure Solutions 9.9 (2024): 352.

[15] De'nan, Fatimah, et al. "Stability consideration in design of steel structures: a review." Electronic Journal of Structural Engineering 23.2 (2023): 27-32.

[16] Roberts, Michael J. Modelling structure cladding interaction in large single-storey steel-framed buildings. Diss. The University of Manchester (United Kingdom), 2023.

[17] Gurkalo, Filip. An investigation into the analysis of innovative slit reinforced concrete shafts design in elevated water tanks in seismic regions. Diss. Anglia Ruskin Research Online (ARRO), 2023.

[18] Agakhanov, Elifkhan, et al. "Digital modeling of seismic impact on the frame of multi-storey buildings with outrigger systems." E3S Web of Conferences. Vol. 381. EDP Sciences, 2023.

[19] Ding, X., M. Liapopoulou, and A. Y. Elghazouli. "Seismic response prediction for non-structural components in multi-storey structures." Proceedings of the Society for Earthquake and Civil Engineering Dynamics (SECED) 2023 Conference, London, UK. 2023.

[20] Qambrani, Maliha Mehar, Fizza Mirza, and Muhammad Habib. "Comparative seismic response analysis of a multi-storey building with and without base isolators under high magnitude earthquake." Engineering Proceedings 44.1 (2023): 6.

[21] Premrov, Miroslav, and Erika Kozem Šilih. "Numerical analysis of the racking behaviour of multi-storey timber-framed buildings considering load-bearing function of double-skin façade elements." Sustainability 15.8 (2023): 6379.

[22] Ciurlanti, Jonathan, Simona Bianchi, and Stefano Pampanin. "Raising the bar in seismic design: cost–benefit analysis of alternative design methodologies and earthquake-resistant technologies." Bulletin of Earthquake Engineering 21.5 (2023): 2723-2757.

[23] Di Trapani, Fabio, et al. "Dynamic progressive collapse response of multi-storey frame structures with masonry infills." Structures. Vol. 54. Elsevier, 2023.

[24] Guyduk, I. V., and E. E. Sushkova. "Analysis Of Technological Parameters Of The Construction Of Objects Of Multi-Storey Building Using Wooden Structures." Priority Directions Of Scientific Research. Analysis (2023): 66.

[25] Aleksandr, Chernykh, et al. "On the possibility of using timber structures in the construction of high-rise buildings in seismic areas." Architecture and Engineering 8.1 (2023): 60-70.

[26] Zihni, Muhamad, Riza Suwondo, and Made Suangga. "Pushover analysis of multi-storey concrete structures." IOP Conference Series: Earth and Environmental Science. Vol. 1169. No. 1. IOP Publishing, 2023.