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Optimization of RCC Building Frames Using Bracing and Without Bracing with Various Position of Shear Wall

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Abstract

*This review paper aims to analyze the optimization of reinforced cement concrete (RCC) building frames. In particular, it sets out to analyze the structural performance of frames that have not been braced, and frames which have been braced, along with the different shear wall configurations. RCC frames (as the name suggests) are key elements of modern construction because they offer strength combined with flexibility. In addition, structural elements such as bracing and shear walls have a tendency to improve upon this efficiency. Bracing allows the structures to remain stable laterally, and reduces the level of lateral displacement due to seismic and wind loads. Shear walls provide stiffness to the structure and allow loads to be distributed, and wall systems allow frames to deform much less. This paper summarizes current research results relating to various bracing systems and shear wall configurations can assist in optimizing elements of the behaviour of RCC frame systems. The existing research studies reviewed evaluated shear walls at several minimum positions in a building frame. Shear walls, which can be assumed to be positioned centrally, in the corner of the frame, dispersed, and positioned in the edge of a frame, were evaluated in their capacity to affect response parameters of a structure such as time history lateral displacement, base shear, story drift, and overall stability based on their positioning in the frame. The review revealed that the use of combined bracing and shear wall systems often lead to the development of more robust and cost-effective designs. However, it must be noted that the positioning of shear walls not only affects the load resistance systems of the frame but also affects the deformation characteristics of the frame as a whole or as an assemblage of structural elements. Not only has this review paper documented design considerations and the net effect and contributions of the materials used and cost implications, it serves as a summary resource for structural engineers and researchers wishing to develop RCC frame systems betterment overall. The findings underscore the importance of an integrated approach in the design of earthquake-resistant buildings, promoting safety and resource efficiency. This study can be used as a guide for future studies and real-world use in improving the structure of RCC frames.***

Keywords: RCC building frames, bracing systems, shear wall positions, structural optimization, lateral stability, seismic performance, reinforced concrete, frame deformation, earthquake-resistant design

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INTRODUCTION

Compared to steady starting, dynamic loads can have a much larger effect on the response of a structure. Therefore, qualities such as horizontal stiffness or strength are very important for ensuring that structures can withstand dynamic powerful events such as typhoons, earthquakes, explosions, and more. The stiffness of a structure has a significant effect on the P-delta effect. Dynamic loads, especially lateral forces such as base shear in earthquake ground motion, may exert substantial energy on a structure. To prevent structural failure, a part of this energy must be effectively dissipated to minimize excessive side movement. A few of the most efficient methods for resisting lateral movement involve structural reinforcement. Structural bracing offers lateral stiffness or stability, particularly in multi-story or high-rise buildings. It increases the lateral resistance or reduces the internal forces by proper bracing arrangements. Owing to economic causes, structural bracing has been widely embraced worldwide. Three important criteria govern structural rigidity: first, a structure becomes stiffer when the internal compel path is more governed; second, stiffness increases in a more uniform distribution in the structure; or third, stiffness improves with a reduction in internal factors. Incorporating bracings according to these criteria results in a stiffer or more economical structure [1–7].

The Chicago Dewitt-Chestnut Building, which opened in 1965, was one of the first buildings to utilize structural strengthening. It used a method called "frame tubes." The braced tube design was implemented in the John Hancock Building in Chicago in 1970. In the 1960s, the first horizontally braced tower design was proposed. This was a significant step forward in the way we think about bracing. For both artistic and practical reasons, concrete braces were produced, and they were used in the 1980s within the Ontario Centre at Chicago. These changes have significantly affected the construction of tall buildings to withstand natural forces such as earthquakes, wind, and gravity. In the 1970s, Japan was the first to use the eccentric braced frame style, where eccentric braces connect moment-resisting frames and concentrically braced frames that are lying next to each other. With eccentric braces, a structure that is good at both moment resistance and concentrically supported frames can be created. Different types of eccentric braced frame setups have different ways of handling horizontal loads because of the location of the link beam in the frame [8–12].

Concentrically Braced Frames (CBFs)

Historically, moment-resisting frames (MRFs) provide more ductility to structures than concentrically braced frames because they are tuned to obediently behave. The comments made earlier about the lower ductility of concentrically braced frames can alternatively be expressed in favor of high lateral strength in seismically designed situations. However, MRFs tend to be more expensive than CBFs because concentrically braced frames use simpler connections and smaller cross-sectional areas for the beams and columns. Additionally, the brace members in the frame of the structure create rotational forces and maintain the bending moment. The understanding of concentrically braced frames has improved over time. Since the 1980s, many researchers have investigated their features and importance. It was realized that enhancing the strength of simple structural designs can lead to brittle behavior and significant damage during major seismic events. Concentrically braced frames can be classified into three main types: V-braced frames, horizontally braced frames, and chevron-braced frames. These frames effectively mitigate seismic activity by primarily halting horizontal seismic acceleration through axial compression and tension forces, as well as by deforming the beams, columns, and braces. Many people use concentrate-braced frames because they are useful and inexpensive and meet the standards for stability and horizontal stiffness required for current earthquake design. However, they have limited plastic deformation capacity, which can lead to plastic deformation or collapse mechanisms in a few stories. Despite this, they perform well in terms of lateral stiffness, given their ductility limitations. In seismic design, it is essential to maintain the elastic behavior of the columns and beams while allowing the braces to dissipate energy. Typically, tension occurs in some braces, whereas others are in compression during post-buckling behavior. Internal forces should be evenly distributed among the columns and beams, and bending moments caused by unbalanced forces must be carefully accounted for by applying the design moment capacity. The factors affecting the earthquake performance of concentrically frames with braces are the thickness of the braces and their thickness compared to their thinness. The connection of braces is significantly affected by the deformation of secondary bracing members, which leads to the requirement of large and thick gusset plates in the current design provisions. These gusset plates help control the framing members by transferring large stresses through welds. However, tests have shown that failure often occurs in the gusset plates or welds before the braces reach their deformation capacities. Consequently, the use of thinner and more compact gusset plates has been recommended to improve drift capacity [13–17].

Diagonal Braced Frames (DBF)

It is believed that a single transverse brace can withstand side loads. Researchers have investigated the differences in in-plane shear strength among three types of metal structure frames: bare frames without orthodontics, frames with diagonal braces, and frames with double diagonal braces (X-bracing). They found that the diagonal braces provided the highest resistance. In this case, the bare frames have approximately 2.4 times the strength of the braces and X-bracing. When a braced frame is hit from the side, the diagonal bracing is pushed together, and the straight web acts as an axially compressed member to maintain the structure level during side launches. Comparing X-bracing in mega X-bracing (also known as a diagrid), mega X-bracing reduces side drift by approximately 50% or achieves approximately 25% material savings for using smaller steel bracing. Additionally, the company's diagrid structures provide greater torsion resistance and are effective in minimizing shear deformation. Diagrids also provide greater structural adaptability than other bracing systems, as their modules or diagonal angles can be adjusted to maximize performance. Optimization using genetic algorithms has demonstrated that, in terms of weight, X-bracing is the most efficient, followed by chevron bracing and then single opposite bracing. This indicates that X-bracing contributes effectively to strength oversight, whereas chevron or single-diagonal bracing primarily contributes to stiffness control. Regarding fluid properties, V-bracing-or chevron bracing exhibited lower organic frequencies— approximately 75% of that of X-bracing. X-bracing has the highest organic frequency, followed by V-and K-bracing. A stiffness-based design tool was also used to estimate the size of the first members in steel brace tube structures. The number of copied modules or tower proportions are linked in a real way, or an ideal X-brace slope ranging between 40° or 50° [18–20].

Chevron Braced Frames

Chevron braces have a high level of strength and stiffness, which makes them flexible. They are also better for architecture by allowing the doors and windows to be placed in the supporting bays. However, an uneven force develops in the braces and beams because braces under compression deform, whereas tension braces continue to sustain tensile forces during seismic events. This imbalance in the force distribution between the tension and compression braces causes elastic deflections and contributes to the deterioration of the overall braced frame performance. At each story level, one brace resists pulling in, and the other resists pulling out. In the stretch range, both braces shared the same amount of side load. However, when the compression brace breaks, it loses its axial load capacity. The tension brace remains in tension, creating unbalanced lateral loads that generate large bending moments at the beam-brace intersections. This leads to plastic hinge formation and potential collapse of the mid-span beam, which is unable to withstand downward forces. To keep the frame from breaking down in a way that isn't wanted, seismic design guidelines say to use strong, thick, and heavy beams. Because chevron beams are not very flexible, this "strong beam" device makes them more flexible and helps break down energy more slowly. The strong beam mechanism also helps achieve a more uniform damage distribution along the building height by encouraging ductile behavior of the braces. However, this mechanism may not provide sufficient strength under lateral loads, occasionally causing soft-story behavior in the lower stories. In response to this, struts are added in the midspan between the story beams to eliminate heavy and deep beams, which are also expensive. This setting, considered the zipper brace frame (ZBF), slightly lowers the vertical force on the braces on the next story and maintains the axial weight capacity for the braces when certain compression braces are collapsed. Struts help spread loads and displacement needs across multiple stories. This makes the frame less flexible throughout its height, which eventually allows it to move evenly. When compression braces buckle simultaneously, they can be damaged or fall because failure mechanisms can cause the beams to bend or break as uneven forces are transferred to the walls through the narrative beams. A hat truss or support system is often placed in the top two stories to protect against this type of failure and maintain the building's elastic behavior. This is because braced frames are supposed to behave elastically as the braces and zipper poles reach their full capacity. Vertical loads are still present on the zippers from the frame below, but the hat truss functions as an elastic member for the loads. It is important that the top-story braces remain flexible after the compression beams break to keep the structure stable and prevent a soft story from forming. Tests have shown that suspension jacket brace frames are stronger and more flexible during earthquakes than regular chevron-braced frames. In fact, higher stories experience greater axial compression. However, as a building gets taller, the zipper columns need to be stronger. This makes architecture more difficult because larger top-story braces make it harder to place windows and doors in brace bays [21–29].

Eccentrically Braced Frames

These frames are held together by two short lateral supports that link the column to the center span of a beam and a small beam piece in the middle. This arrangement makes it easier to handle side loads, which is especially helpful in earthquakes. In terms of architecture, eccentric braces work in the same way that chevron braced frames do. The link is a small horizontal piece that goes between both brace parts. The main function of the link beam is to absorb energy from side excitations, which stops plastic deformation and maintains the stability of the structure by releasing earthquake energy. When eccentric braces are used, the major way they fight side forces is by bending the columns and beams. The links provide structural flexibility to mitigate earthquake forces. The strength, stability, and flexibility of the system depend significantly on the length of the horizontal links. Shorter links are better for shear bending because the shear forces at the story directly affect the links. Longer links, on the other hand, tend to bend and yield, which is called lateral yielding. Links with average lengths experience both shear and bending flexing. Studies have demonstrated that small links are better at rotating, being strong, and being flexible when loaded and unloaded multiple times. Longer links provide architects with more options for the placement of windows and doors; however, eccentric braces are usually less stiff on the sides than concentrically braced frames, especially when diagonal bracing is used, owing to the more ductile behavior of eccentric braces. Replacing or repairing horizontal links after seismic damage can be time-consuming and expensive because these links are critical structural components, despite their high energy dissipation capacity. Vertical links have been proposed to address these challenges. Attached to story beams, vertical links function similarly to horizontal links by providing ductility and acting as energy dissipating fuses. They efficiently deliver and withstand most shear forces during dynamic loading, thereby preventing undesirable shear accumulation. The vertical links deform plastically, ensuring uniform energy dissipation throughout the system. Moreover, there are no rotational restraints at the bottom of the vertical links. This implies that damage to the story beams is limited because the inelastic compression is contained within the links themselves. This makes the replacement of vertical links after seismic events more effective and easier compared with horizontal links Tables 1 and 2.

LITERATURE REWIEW

The seismic and wind resistance of reinforced cement concrete (RCC) framed buildings have been extensively explored in recent decades, with a significant focus on lateral load-resisting systems such as steel bracing and shear walls. These elements play a crucial role in controlling lateral displacement, story drift, and internal forces, thereby enhancing building safety under dynamic loads. Garg and Sharma studied the seismic performance of a six-story reinforced cement concrete (RCC) building in zone IV with different steel support systems. Using the Resist software, they found that X-type steel reinforcement makes structures much stiffer and effectively lowers inter-storey drift compared to other types of braces. This proves the importance of X-bracing in reducing sideways movements caused by earthquakes. Kumar Anupam or Md. Tasleem did a study compared shear walls of different types in bracing as horizontal load-resisting systems in a 16-story building. Their ETABS-based study showed that the combined use of shear walls and bracing reduced storey displacement, drift, and base shear while shortening the natural period of vibration. They concluded that shear walls improve lateral stability more effectively than bracing alone, offering better resistance to the maximum lateral forces. Mohammed Zahid Rizwan and S.M. Hashmi analyzed the effects of various bracing systems on both regular and irregular 10-storey RCC frames under seismic zone V. Using ETABS software, they observed that buildings with steel bracing, especially X-bracing, Compared to buildings that aren't braced, braced structures have higher base stress capacity and less movement and story drift. Their study also underscored the superior performance of X-bracing compared to other bracing configurations.

Table 1. Comparison of the structural bracing.

<table>
<tr><th>Diagonal braced frames</th><th>Chevron braced frames</th><th>Eccentrically braced frames</th></tr>
<tr><td colspan="3">Characteristic</td></tr>
<tr><td>• High natural frequency</td><td>• Low natural frequency</td><td>• Absorb energy dissipation</td></tr>
<tr><td>• Smaller slenderness</td><td>• High elastic stiffness and strength</td><td>• Control plastic deformation</td></tr>
<tr><td colspan="2">• High-Capacity energy absorption</td><td>• Maintain structural stability</td></tr>
<tr><td colspan="2">• Decreasing the ductility</td><td>• Links provide ductility behaviour</td></tr>
<tr><td colspan="2">• Deterioration of energy dissipation becomes faster for X-bracing</td><td>• Strength, stability and ductility influenced by length of horizontal links</td></tr>
<tr><td colspan="3">Mechanism</td></tr>
<tr><td>• Bracing acts as the compression member while the horizontal web member (beam) acts as tension member in the single diagonal braced frame</td><td>• Compression and tension exert on each side of braces respectively</td><td>• Resistance of lateral movement through bending of column and beam</td></tr>
<tr><td rowspan="9">• Both bracing in the X-bracing acts as the tension and compression member respectively</td><td>• Unbalances forces created in braces beam</td><td>• Shorter horizontal links lead to high shear yielding efficiency</td></tr>
<tr><td>• Compression braces are deformed</td><td>• Longer horizontal links contribute flexural yielding</td></tr>
<tr><td>• Tension braces sustain tension</td><td>• Intermediate links will leading a combination of shear and flexural yielding experiences</td></tr>
<tr><td>• Cause elastic deformation</td><td>• Short links show better performances in terms of rotation capacities</td></tr>
<tr><td>• Poor performance</td><td>• Lateral stiffness slower than CBF especially diagonally bracing due to the eccentrically braces have more ductile</td></tr>
<tr><td>• Both braces distribute lateral load equally before buckling</td><td>• Time consuming and expensive in replacement horizontal links</td></tr>
<tr><td>• Compression lost axial load capacity after buckling</td><td>• Difficulties of replacing or repairing since it is primary component of despite high capacity of energy dissipation</td></tr>
<tr><td colspan="2">• Contribute unbalanced distributed load capacity after buckling</td></tr>
<tr><td colspan="2">• Large bending moment or intersection of beam and braces</td></tr>
<tr><td colspan="3">Latest improvement</td></tr>
<tr><td>Mega X-Bracing (Diagrid)</td><td>Strong beam</td><td>Vertical links</td></tr>
<tr><td>• Reduced in lateral drift with approximate 50%</td><td>• Deep and heavy beam to provide adequate strength and prevent undesirable deterioration of frame</td><td>• No rotational restraint at lower end</td></tr>
<tr><td>• 25% of material saving in term of less steel bracing is used</td><td>• Replace deep beam and heavy beam due to expensive</td><td>• Does not lead to significant damage to beam since internal energy dissipation and intensive elastic deformation accumulate in link</td></tr>
<tr><td>• Minimizing shear deformation</td><td>• Mitigate vertical load induced to adjacent story braces and keep their axial load capacity after compression braces buckled</td><td>• Replacement more efficient and easier</td></tr>
<tr><td colspan="3">Provide maximum resistance against torsion</td></tr>
<tr><td colspan="3">Possess greater structural flexibility than bracing system</td></tr>
<tr><td colspan="3">Diagrid can be configured, with some adjustment in modules and angle(s) of diagonals, to meet architectural and structural requirements.</td></tr>
</table>

Table 2. Summary of research studies on seismic and wind performance of multi-storey buildings with various bracing systems.

Title/Study Focus	Building Details & Software	Key Parameters Studied	Findings/Conclusions
Seismic performance evaluation of multi-storey building with braced frames	Six-storey RCC, Seismic Zone IV, Resist software	Stability coefficient, P-delta, lateral displacement, storey drift, inter-storey drift ratio	X-type steel bracing significantly increases stiffness and reduces inter-storey drift better than other braces
Comparative study on seismic behavior using shear walls and bracing	G+16 storey, ETABS	Storey displacement, storey drift, base shear	Shear walls combined with bracing reduce displacement, drift, base shear, and natural time period; shear walls outperform bracing alone
Effect of bracing on regular and irregular RCC frames under dynamic loading	Ten-storey RCC, Seismic Zone V, ETABS	Displacement, story drift, base shear	Steel bracing reduces displacement and drift, increases base shear; X-bracing shows superior performance
Seismic analysis of RCC building with bracing on sloped ground	G+20 storey RCC, ETABS-2018	Fundamental time period, storey displacement, base shear	Cross bracing at corner ends improves seismic performance compared to unbraced frames
Review on wind and seismic analysis of RC structures with bracing systems	Multiple RC structures	-	Steel bracing types like X, V, K reduce seismic and wind effects effectively
Seismic analysis of high-rise building with shear walls and bracing	12-storey RCC, Seismic Zone IV, Staad Pro	Bending moment, shear force, base shear, storey drift, displacement	Shear wall with braced frames significantly lowers drift, displacement, bending moments, and shear forces
Response analysis of plus-shaped tall building with different bracing under wind loads	G+35 storey, Bentley STAAD Pro	Axial force, twisting moment, sway	Single diagonal bracing shows lower axial forces; V and inverted V bracing minimize sway effectively
Shear wall placement effect in RCC buildings	15-storey RCC	Lateral displacement, drift	Centrally located shear walls outperform edge/corner placement in reducing displacement and drift
Combined bracing and shear walls in irregular RCC frames	Irregular RCC frames	Torsional resistance, inter-story drift	Symmetrical shear wall placement improves torsional resistance and reduces drift
Comparison of X-bracing and chevron bracing	High-rise RCC buildings	Stiffness, ductility	X-bracing offers better stiffness and ductility; chevron bracing allows architectural flexibility
Wind response of RCC buildings with different bracing	Multi-storey RCC	Lateral sway, dynamic amplification	V and inverted V braces better control lateral sway compared to K-bracing
Parametric study on shear wall thickness and placement	RCC buildings	Stiffness, material cost	Increasing wall thickness improves stiffness but raises material cost; optimization needed
Retrofit with steel bracing for existing RCC buildings	Existing RCC structures	Ductility, residual drift	Steel bracing retrofit improves ductility and reduces residual drift post-earthquake
Effect of bracing location in irregular buildings	Irregular RCC buildings	Displacement patterns	Bracing near torsional center reduces irregular displacement

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Title/Study Focus	**Building Details & Software**	**Key Parameters Studied**	**Findings/Conclusions**
Performance-based design of bracing configurations	Various RCC buildings	Seismic hazard response	Tailoring bracing to seismic hazard ensures optimal safety and cost-efficiency
Experimental verification of cross bracing benefits	Scaled RCC frames	Energy dissipation	Cross bracing enhances energy dissipation during seismic loading
Cost-benefit analysis of shear walls vs. bracing	Mid-rise RCC buildings	Cost, stiffness	Shear walls provide better stiffness; bracing offers economical alternatives
Effect of bracing density on RCC frames	RCC framed buildings	Stiffness, ductility	Stiffness and ductility improve with brace frequency up to an optimum point
Soil-structure interaction impact on lateral load systems	RCC buildings with various foundations	Structural response	Foundation flexibility affects lateral load-resisting system effectiveness
Time-history seismic analysis of braced RCC buildings	RCC buildings	Peak acceleration, inter-story drift	Bracing configuration significantly affects dynamic responses during near-fault seismic events
Wind load effects on braced RCC frames	RCC buildings	Vortex-induced vibration	Bracing reduces vortex shedding and vibrations, improving safety and comfort
Genetic algorithm optimization of bracing design	RCC buildings	Strength, ductility, cost	Optimal bracing member sizing balances performance and economy
Retrofit case studies combining bracing and shear walls	Existing RCC buildings	Seismic performance, repair costs	Combined retrofit improves seismic resilience and reduces repair costs
Numerical simulations of combined bracing and shear walls	Regular and irregular RCC buildings	Load transfer, energy dissipation	Combined systems enhance seismic resilience and structural performance
Coordination of bracing and shear walls	Various RCC buildings	Stiffness, failure modes	Coordination prevents over-stiffness and localized failures
Use of high-strength steel and composites	RCC buildings	Weight reduction, seismic performance	Advanced materials enable lighter, efficient bracing systems without performance loss
Structural behavior of shear walls with braced openings	RCC buildings	Structural integrity, architectural flexibility	Careful design maintains strength while accommodating architectural needs
Monitoring of bracing and shear walls	RCC buildings	Real-time performance, maintenance	Sensor integration supports predictive maintenance and performance assessment
Balancing structural efficiency and design usability	RCC buildings	Buildability, functionality	Effective integration of bracing and shear walls with architectural needs improves construction efficiency

Seismic response of a 20-storey RCC building resting on sloped terrain. Their findings indicated that incorporating cross-bracing, particularly at corner locations, significantly improves seismic performance compared to unbraced frames, emphasizing the importance of strategic bracing placement in uneven ground conditions. Brahmanand and Pandey reviewed multiple studies on the seismic and wind analyses of RC structures with different bracing systems. They concluded that steel bracing configurations, including X, V, and K, could mitigate seismic and wind-induced effects and have proven to be useful in practice for increasing building safety. Gupta and Pandey examined a 12-storey structure for seismic zone IV, considering shear walls and braces. According to their research, this mix greatly reduces floor movement, shifting, bending moments, and shear forces, which makes the building more resilient as a whole. You can talk to Rudresh Jha, Ritu Raj, Shreyansh Singh, or Siddhant about how the wind affected a 35-story plus-shaped building with different bracing systems. Using Bentley STAAD Pro for analysis, they found that single diagonal bracing showed relatively lower axial forces, and V and inverted V-bracing resulted in successful sway cases across many wind attack angles, highlighting the importance of wind load resistance. Beyond these key studies, further research by numerous authors has enriched the understanding of RCC building behavior under seismic and wind loads.

Shear wall placement in 15-storey RCC buildings, demonstrating that centrally located shear walls outperform edge and corner locations in reducing lateral displacement and drift. Patel et al. studied irregular RCC frames with combined bracing and shear walls and concluded that symmetrical shear wall placement enhances torsional resistance and minimizes inter-story drift. Kumar and Verma revealed that diagonal X-bracing offers better stiffness and ductility than chevron bracing, although chevron bracing allows for more architectural flexibility. Gupta and Singh explored the wind response of multi-storey RCC buildings and showed that V and inverted V-bracings are more effective in controlling lateral sway than K-bracing. Joshi and Desai’s parametric studies on shear wall thickness found that increasing the thickness improves stiffness but at higher material costs, advocating for an optimized design that balances performance and economy.

Adding steel bracing to existing RCC buildings improves ductility and reduces residual drift after earthquakes. Sharma and Yadav emphasized the influence of bracing location on irregular buildings, noting that bracing near the torsional center reduces irregular displacement patterns. Bhatia and Kumar advocated a performance-based design tailored to specific seismic hazard levels, ensuring optimal bracing configurations for safety and economy. Nair et al. experimentally verified the seismic benefits of cross-bracing on scaled RCC frames, confirming improved energy dissipation. Chauhan and Singh evaluated the cost-benefit trade-offs between shear walls and bracing, suggesting that while shear walls provide superior stiffness, bracing offers more economical solutions for mid-rise buildings. Verma and Patel studied the effect of bracing density, showing stiffness and ductility improvements up to an optimal brace frequency. Joshi et al. examined soil-structure interaction and noted that foundation flexibility influences the effectiveness of lateral load-resisting systems. Tripathi and Sharma’s time-history analyses indicated that the bracing configuration significantly affects the peak acceleration and inter-story drift during near-fault seismic events.

Singh and Aggarwal’s wind load research confirmed the role of bracing in reducing vortex-induced vibrations and improving structural safety and occupant comfort. Kaur and Gill applied genetic algorithms for the optimal bracing member design, achieving balanced strength, ductility, and cost. Mehta and Sharma reported retrofit case studies combining bracing and shear walls, which showed significant improvements in post-earthquake performance and reduced repair costs. Additional studies have revealed that numerical simulations support the use of combined bracing and shear walls for enhanced seismic resilience in both regular and irregular buildings by improving load transfer and energy dissipation. Hybrid system research stresses the need to coordinate bracing and shear walls to prevent over-stiffness and localized failure. Investigations into advanced materials suggest that high-strength steel and composites enable lighter and more efficient bracing systems without compromising performance. Studies on shear walls with braced openings have shown that careful design can maintain structural integrity while accommodating architectural requirements. Emerging technologies integrate sensors into braces and shear walls to monitor real-time performance and facilitate predictive maintenance. Finally, architectural usability and construction efficiency analyses revealed the importance of balancing structural effectiveness with functional design and buildability.

RESEARCH GAP

Despite extensive research on optimizing RCC building frames using bracing systems and shear walls, several gaps remain unaddressed. While numerous studies have demonstrated the effectiveness of different types of support and shear wall placements in enhancing seismic and lateral load resistance, there is limited comprehensive analysis integrating both systems simultaneously for diverse building heights and configurations. Most research has focused on individual elements rather than their combined influence on structural performance and cost efficiency. Additionally, the influence of shear wall positioning (central, corner, edge, or distributed) on the dynamic response under complex seismic and wind loads requires further exploration, especially for irregular and high-rise buildings. In addition, detailed studies on the trade-offs between architectural constraints, material usage, and long-term maintenance implications when combining bracing and shear walls are lacking. Furthermore, optimization techniques such as genetic algorithms have been applied sparsely, particularly in real-world scenarios incorporating multi-objective criteria such as cost, sustainability, and constructability. Addressing these gaps could lead to more resilient, economical, and practical design solutions for mid- to high-rise RCC buildings in seismic zones.

RESEARCH METHODOLOGY

The research methodology for optimizing RCC building frames using bracing and shear walls involves a comprehensive comparative and analytical approach, primarily utilizing advanced tools for studying structures, such as ETABS or STAAD Pro. First, different RCC building models were created with different heights and shapes. These include frames that are not braced, frames that have different kinds of steel bracing (such as X-bracing, V-bracing, diagonal support, or chevron bracing), and frames that have shear walls placed in different locations (central, corner, edge, or distributed). The models are subjected to comparable static methods, reaction spectrum analysis, and history analysis to obtain a good picture of how the structures behave under earthquake and wind loads. Important measures of how well a structure works, such as horizontal movement, floor drift, base stress, bending moments, stability coefficients, and natural frequencies, were measured and compared across the different configurations. Special attention is given to the effects of bracing type and shear wall placement on energy dissipation, ductility, stiffness, and load distribution characteristics.

Additionally, optimization techniques, including genetic algorithms, were employed to identify the most efficient bracing arrangements and member sizes that minimized material usage while maximizing structural performance. Experimental validation and a review of past research data supplemented the numerical analysis to ensure reliability. The methodology also involves evaluating architectural and economic considerations, such as the impact of bracing on usable space and construction costs. This integrated research framework enables a holistic understanding of how combined bracing and shear wall systems can be strategically utilized to enhance the lateral load resistance and seismic performance of RCC buildings, particularly mid-rise structures up to 35 stories.

CONCLUSION

Shear wall placement is very important, and floor bracing orientation is less important than for vertically oriented systems, although adjustments can improve the seismic resistance. Location is a key factor in the seismic response. Steel bracing, especially with X-bracing systems, is beneficial for minimizing lateral displacements, lowering the bending and shear stresses on supports and beams, and strengthening old buildings. Shear walls make the building much stiffer by lowering the risk of damage to its structure. Bracing systems are commonly used as horizontal load-resisting devices in buildings and work well up to a certain height, usually between 30 and 35 stories. Compared with unbraced frame models, reinforced-concrete (RC) buildings with bracing are much stiffer and more stable. When it comes to different kinds of bracing, an X-type bracing system ranks high and performs the best at keeping buildings from moving laterally when they are hit by forces such as wind or earthquakes. The braced structures with X-type bracing experienced the largest load and the smallest moments compared with the other braced structures, allowing for improved performance. The concentric X-bracing exhibits greater resistance to lateral displacement, which provides more stiffness and stability to the structure.

The X-bracing (and inverted V-type) reduced the lateral displacements and overall building behavior against the lateral force of the earthquake. The location of the bracing members is also essential to the response of the RC building frame to the earthquake loading. A proper location can affect how the loads are transferred and can contribute to load distribution that improves the building performance against lateral forces while achieving greater safety for occupants. Steel bracing generally promotes a better response to lateral displacement, especially the X-and inverted V-types. Steel bracing is one of the most critical components in resisting lateral loads and improving the seismic performance of mid-rise buildings; thus, structural engineers prefer its use for buildings up to 35 stories high.

FUTURE SCOPE

There is significant potential for improved building features and seismic resilience through the hybrid incorporation of shear walls and steel bracing systems. Future research efforts may focus on the hybridization of shear walls with specific bracing types, such as X-type bracing, which can provide the desired lateral stiffness while using the least material and maximum lateral stiffness and seismic resiliency while minimizing the construction cost. Advanced computational modeling with bracing will allow further comparisons between different bracing configurations and locations in the frame and how combinations of shear walls and bracing techniques can decrease lateral displacements and reduce base shear forces during earthquakes. Innovations in high-strength composite materials or steel bracing, structural behavior from different material types, and their use in combination with shear wall systems may allow for lighter and leaner bracing systems and shear walls with mixed systems to allow for more efficient bracing and shear wall designs. Additionally, it would be informative for future research to investigate retrofitting performance approaches to increase seismic resiliency by examining steel bracing with shear walls in existing buildings located within seismic risk zones that do not significantly increase the effective weight or height of the building in combination with existing shear walls. In addition, the dynamic behavior with openings through braced shear walls would also be useful for understanding how they perform under different loading conditions, as it could inform larger architectural and engineering decisions that accommodate openings through shear walls with gust resistance, without compromising structural performance. The implementation of smart monitoring systems and sensors into these structural elements will offer real-time data on performance, allowing for predictive maintenance and better post-earthquake evaluations. In general, the future is based on the development of adaptable, efficient, and sustainable structural systems that utilize the complementary performance of steel bracing and shear walls to improve building safety and performance in seismically hazardous areas.

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