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Study on Seismic Performance of High-Rise Building Using Cross and Diagonal Bracings

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Abstract -

The growing demand for shelter in urban areas, driven by overpopulation, has led to a shortage of available land, necessitating more efficient use of space. High-rise buildings offer a viable solution to this issue; however, as building heights increase, they become more susceptible to deformation under lateral loads, such as wind and seismic forces. Bracing systems, such as diagonal or cross-bracing, are essential for enhancing the lateral strength and seismic performance of these structures. The analysis is conducted in different seismic zones, with design considerations based on Indian standards such as IS 13920:2016 and IS 875:2015 (Part 3). The focus is on high-rise structures and their response to lateral loads, specifically wind and earthquake forces. The study aims to assess the impact of bracing systems in reducing sway, improving stability, and dissipating energy during seismic events. Key seismic responses, including story drift, story shear, and displacement, will be evaluated in buildings located in Seismic Zones II and V. Ultimately, this research seeks to highlight the effectiveness of bracing systems in enhancing the seismic performance and safety of high-rise buildings.

Keywords- High-rise buildings, seismic performance, bracing systems, lateral load resistance, E-TABs software, earthquake zones, story drift, story shear, building displacement, diagonal bracing, cross bracing, structural stability.

1. INTRODUCTION-

In modern urban environments, high-rise or multistory buildings have become essential for accommodating the increasing population, preserving green spaces, and enhancing economic efficiency by integrating commercial, residential, and public amenities within a single structure. These tall structures, often referred to as high-rise buildings, play a key role in contemporary city planning.

Seismic performance refers to a building's ability to withstand the forces generated by an earthquake while maintaining its safety and structural integrity. Earthquakes are natural occurrences brought on by the abrupt release of energy from tectonic plate movement along crustal fault lines. Engineers must create structures that can withstand moderate seismic activity since earthquakes can happen at any time. These structures must possess sufficient strength and stiffness to limit deflection and prevent collapse during seismic events.

An effective earthquake-resistant design ensures that a building can both absorb energy and control its movements during seismic activity, transferring forces safely to the foundation. Braced frame systems offer a practical way to accomplish these goals. Their elastic qualities provide the strength and rigidity required to preserve the structure's usefulness, especially when it comes to the performance of non-structural components. When bracing systems are constructed correctly, they can absorb seismic energy and allow for extensive movement, increasing the overall resilience of the building.

1.1 Steel bracing :-

In reinforced concrete (RC) high-rise structures, the steel bracing system is one of the most effective ways to withstand horizontal stresses like those caused by wind and seismic activity. Bracing systems are a useful tool for strengthening or adapting existing structures to increase their resilience against seismic risks. Steel bracing reduces the deformation of RC multistory structures under lateral loads by increasing their strength and stiffness.

Steel braced frames serve as one of the key frameworks that counteract lateral loads in multistorey structures. These bracing elements stabilize the building by transferring horizontal forces, such as those generated by earthquakes or wind, to the foundation. Incorporating steel bracing members into RC multistorey buildings is not only cost-effective but also requires less space compared to other reinforcement methods. The addition of steel bracing increases the building's stiffness, base shear capacity, and torsional resistance.

There are several types of bracing systems, including X-bracing, V-bracing, inverted V-bracing, K-bracing, and diagonal bracing, each designed to enhance the structural performance of high-rise buildings.

Fig.1: Steel bracing in RC Structure

1.2 Diagonal Bracing -

Diagonal bracing is a structural element employed in construction to enhance the lateral stability and strength of buildings. These braces are positioned diagonally between two structural members, allowing them to resist both lateral and vertical forces effectively. Diagonal braces can be constructed from various materials, such as wood, steel strapping, or galvanized steel. Figure (a) illustrates the concept of diagonal bracing.

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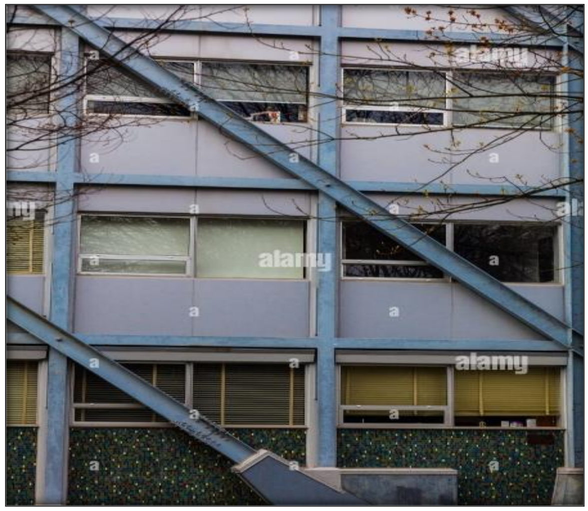

Fig.2: Diagonal bracing.

1.3 Cross Bracing (X)-

Cross bracing is a structural feature in buildings that utilizes two diagonal supports arranged in an X-shape to restrict lateral movement and minimize potential damage to building elements. This system enhances stability during wind loads or seismic events, such as earthquakes. Typically constructed from steel rods, angles, or tubes, cross bracing is often aligned with the building's columns. It can also be integrated within non-structural wall systems for a more streamlined appearance.

Fig.3: Cross bracing

2.OBJECTIVES-

- To reduce the sway and increase the stability of high rise buildings.
- To resist lateral loads, such as wind or earthquake loads, and helps in dissipate energy during horizontal movement of the building.

- To keep buildings stable when the wind blows during seismic events.
- To determine story drift, story shear, and displacement during seismic event.
- To find the best way to reduce sideways movement and make buildings stronger and more stable.
- The bracing at each floor (in horizontal planes) provides load paths for the transference of horizontal forces to the planes of vertical bracing.

3. LITERATURE REVIEW -

3.1) Sara Hadidi et al. (2024) investigated the use of an I-shaped shear link damper in their study. This innovative damper is designed for easy production and replacement after seismic events. Its primary function is to enhance the stiffness and ductility of the frame, allowing it to be more resistant to lateral forces. The concept is that the damper will absorb most of the seismic energy, thereby protecting the building's overall structure. However, the incorporation of the damper may reduce the frame's stiffness. To address this challenge, the study considers the application of low yield point (LYP) steel in the damper, which can enhance both the frame's stiffness and its energy absorption capacity during earthquakes. Additionally, the study notes that the thickness of the damper's flanges—flat sections of its I-shaped design—is also a critical factor in its performance.

3.2) Liang Zheng et al. (2024) used Abaqus finite element software to investigate various factors in order to assess the seismic performance of multistory X-braced steel frames and modified versions of these frames.

3.3) Yassin and Sadeghi et al. (2023) utilized nonlinear static analysis to assess the seismic behavior of various braced steel frames. They created and evaluated an 11-story model using ETABS, incorporating X-bracing, inverted V-bracing, and a version without bracing. A comprehensive analysis of seismic parameters was conducted, employing pushover analysis to evaluate maximum story drift, stiffness, and displacement. The results indicated that frames equipped with X-bracing exhibited superior performance during seismic events. The study also included braces positioned in the middle of two separate spans, revealing a marginal performance improvement when braces were installed across both spans.

3.4)Huijuan Jia et al. (2022) conducted a study on a 14-story office building in Nanjing, China, which features an irregular shape and varying heights. They utilized various analytical methods, including the Response Spectrum Method, Elastic Time History Analysis, and Elastic-Plastic Time History Analysis.

3.5) Mariem M. Abd-Alghany (2021) used the finite element approach to investigate the seismic performance of reinforced concrete (RC) buildings with a soft story. The study examined a number of variables, including the soft story's position, height, and any abnormalities in the building's plan proportions. The objective was to determine the soft story's ideal placement in order to reduce any negative consequences. Additionally, the study demonstrated how well shear walls work to increase stiffness and decrease displacements, pointing out that upgrading structure with a soft story with a bracing system improves their seismic performance.

3.6) Mustafa Hussini et al. (2020) used STAAD Pro and ETABS software to analyze several methodologies in their research on lateral load-resisting systems. They discovered that outrigger and diagrid systems outperformed conventional bracing systems. Buildings up to 30 to 35 stories can benefit from bracing, but the diagrid system greatly increases lateral strength and stiffness. For buildings that are high-rise or ultra-high-rise, the outrigger system proved to be especially effective.

3.7) The possible adverse effects of retrofitting steel X braces into existing RC frames on the overall response of the frame and its constituent parts (beams and joints) were examined by **A. Rahimi, Mahmoud R. Maheri, et al. (2020).** They discovered that retrofitting with steel X bracing decreased maximum lateral displacements across all frames, albeit to differing degrees, with the most notable reductions seen after doing thorough time history analyses of three test frames.

3.8) H. Eramma et al. (2015) used the Equivalent Static Method, Response Spectrum Method, and Pushover Analysis to examine structures of 6, 11, and 16 stories. According to the Indian standard IS 1893:2002, all studies were conducted in Zone IV, a high seismic risk location, using ETABS software (version 9.7.4). According to the results, buildings with friction dampers were more stable during seismic events because they had shorter durations, fewer story displacements, and fewer story drifts.

3.9) The performance of 6- and 12-story X-braced steel frames with strong and weak support beams under seismic stresses was investigated by **shen et al. (2014)**.Their study concentrated on how earthquake response is impacted by beam strength and deformation. They found that two-story X-braced frames with braced beams that were constructed with the bare minimum of strength permitted by present requirements saw significant vertical inelastic deformation. Additionally, the ductility requirements on braces and beam-to-column connections were greatly increased by inelastic deformation in the middle spans of these beams.

3.10) Alnajjar et al. (2023) explored the impact of adding seismic bracing to buildings, particularly in earthquake-prone regions like Istanbul, Turkiye. Their case study focused on a 40-year-old apartment building, consisting of three above-ground floors and two floors of basement levels, measuring approximately 19 meters long, 14 meters wide, and 11 meters tall. The study concluded that incorporating various seismic bracing designs significantly enhances both the safety and aesthetic appeal of buildings in seismically active areas.

3.11) Sugimoto (2012) conducted experiments that included Shaking Table Tests and Static Loading Tests. The results demonstrated that increasing the reinforcement ratio improved the strength and ductility of the frame, while variations in loading patterns did not significantly affect the overall load-displacement behavior.

3.12) Aparna Nishtala et al. (2024) in this paper, author analyzed the effect of bracing system and shear walls. When buildings have irregular or asymmetrical designs, they can be more vulnerable during earthquakes. It examines how steel braces can improve the performance of tall buildings when facing both wind and seismic forces. By testing different configurations of these braces, the study aims to find the best way to reduce sideways movement and make buildings stronger and more stable. The goal is to provide useful information to help design safer and more cost-effective buildings that can better withstand earthquakes and strong winds.

3.14) Nikhil Dixit et al. (2024) this paper reviews how reinforced concrete (RC) buildings with re-entrant (inward notches or corners) respond to seismic forces. These corners can create weak points in the building, leading to uneven force distribution. The paper also looks at how different types of bracing systems, such as diagonal, chevron, V, and X-bracing, can help improve the building's ability to withstand earthquakes. While bracing generally reduces how much the building moves, the type of bracing used can impact other factors, like the forces at the base and in the columns. X-bracing is particularly effective at controlling movement but increases the forces on the building's base and columns.

3.15) Mr. Kiran Chikane et al. (2023) in this paper, author focuses on analyzing how high-rise buildings respond to earthquake and wind force using a Response Spectrum Analysis. In which Different structural models are tested in the software Staad-Pro, including bare frames, braced frames, and shear wall frames. The building's natural time period, stiffness, base shear, storey drifts, and top-storey deflection to determine which design performs best under seismic conditions.

3.16) Vaneeta Devi et al. (2023) tested five versions of a 10-story irregular building with varying steel bracing placements are analyzed using ETABS software and Response Spectrum Analysis, which is conducted in accordance with the guidelines of the Indian standard IS: 1893 (Part1)-2016. The results indicate that adding steel bracing increases the building's stiffness, base shear, and torsion, but also decreases the building's sways (storey drift), making it more stable.

3.17) Dhiraj Naxine et al. (2023) The study introduces Braces with Intentional Eccentricity (BIE) as an improvement over conventional buckling braces (CBBs) to increase seismic performance. They compare the seismic performance of a 20-story building designed with both an eccentric brace frame (EBF) and a BIE system under the ETABAS software. Then, a 25-story irregular structure using the BIE system is evaluated. The findings indicate that while BIEs demonstrate desirable performance and energy dissipation capabilities, they can also result in significant out-of-plane deformations in some instances.

3.18) Ahmed Mohammed Mudabbir et al. (2022) on a 30-story structure in Zone V, this Special Moment Resisting Frame with shear wall, Outrigger Core Belt Truss, and Braced Frame are utilized. Building sway, base shear, and overall stability are among the characteristics they compare using ETABS 2018 software. According to the analysis, the Outrigger Core Belt Truss system in the building outperformed the other two systems in terms of lateral force resistance.

3.19) Kishan pandey al. (2021) In this review paper, reinforced cement concrete (RCC) structures or frames that use different types of steel bracing systems, such as X, V, and K shapes. These bracing systems are added to withstand buildings during the effects of earthquakes and strong winds, making the structures safe.

3.20) Masood Ahmed Shariff et al. (2019) renewed the older buildings by using retrofitting and also other methods for strengthening these buildings is by adding steel bracing. By using bracing, the building becomes stronger, more stable, and provides less damage during an earthquake. In the study mentioned, an H-shaped building with a size of 36 meters by 36 meters was analyzed using ETABS software. They compared the performance of a building without bracing with X-shaped steel bracing. They evaluated lateral displacement and the force at its base during an earthquake.

3.21) Dadi Rama Prasad et al (2019) performed a seismic analysis of steel structures with and without bracings in different seismic zones. In this study, four G+5 steel structures without bracings and with bracing X, V bracings and diagonal bracings are analyzed. The buildings were designed in STAAD. Pro software by considering various load and load combinations as per IS: 1893-2002. Analysis was done for buildings in seismic zones 2, 3, 4, and 5. According to the investigation, X-type bracings had lower bending moments, shear forces, and lateral displacements than both X and V-type bracings. Thus, it was determined that in high seismic zones, X-type steel bracing is better.

3.22) The study "Comparative Study of Seismic characteristic of Diagrid Structural System in high-rise construction" was carried out by **Trupti A. Kinjawadekar and Amit C. Kinjawadekar (2018)**. Using the software SAP-2016, the study's objective is to investigate the relationship between diagrid structures and high-rise buildings. It found that storey drift and storey shear results are significantly lower in the diagrid angle region compared to the traditional construction system numerical models and seismic characteristics of diagrid members.

3.23) According to an analysis by **Patel and Solanki et al. (2017),** the top storey displacement, base shear, and storey drift values in the x and y directions are all the same. Off-diagonal bracing systems have a beneficial effect on concrete buildings up to ten stories, but they have little influence on taller structures. Off-diagonal bracing systems are not appropriate for reinforced concrete frames with more than one floor, and they may have unintended consequences.

3.24) Rishi Mishra et al (2014) Analysis of RC Building frames for seismic loading utilizing diverse sorts of Bracing frameworks in this investigation examination of skyscraper RC building outlines have been done with g+10 floors in STAAD programming and the aftereffects of various kinds of supporting framework (x, v, k & upset v) are contrasted and uncovered casing and expressed that inverted v have been more productive and practical.

3.25) A. Wasnik (2024) in this study, tall buildings with 16 floors can handle earthquakes by comparing different building designs are analyzed. Using a software called STAAD Pro, they tested buildings with different structural elements and materials that react to seismic forces. The aim is to find out which designs are the safest, most efficient, and cost-effective. The buildings were tested under earthquake conditions, and important factors like how much the building sways, the forces at the base, and how much the floors shift during an earthquake were measured and compared.

3.26) A. Abdulhameed (2023) this study used the ETABS v16 software to design a multi-story building, nine different types of bracing systems were added in both the X and Y directions, using various brace types like mega-braced frames (MBFs), inverted V-braces, and X-braces placed in different locations and patterns. The goal was to improve the building's strength by measuring factors like roof displacement, base shear, base moments, and drift ratio. The results showed that Model 9 was the best. It significantly reduced the roof's movement and the building's drift by around 46.1% and 41%, respectively. In terms of base shear, a measure of earthquake forces on the base of the building), Model 9 also performed better than the other models.

3.27) B. Patel (2017) this study investigates the impact of different bracing systems on high-rise buildings. It compares Moment Resisting Frames (MRFs), X-Braced Frames (XBFs), and V-Braced Frames (VBFs) for an 11-story (G+10) building. The primary objective is to evaluate the efficiency of each bracing system also focus on base shear and story displacement. The analysis, conducted using STADD. Pro V8i and ETABs software, The results of the study indicate that X-braced frames perform better during seismic events, offering greater safety and efficiency than MRFs and VBFs.

3.28) D. Patil (2016) this paper investigates the seismic behavior of outrigger-braced high-rise steel buildings to determine the optimal outrigger location. A nonlinear static pushover analysis was conducted on buildings with 20, 25, 30, and 35 stories, with the outrigger position varying from the first to the top story. The study reveals that the position of outriggers, along with lateral load patterns and building height. Outriggers increase strength and stiffness, as indicated by factors such as base shear, story displacement, inter-story drift ratio, and the performance point.

3.29) Jadhav Nachiket S. (2020) this research focuses on analyzing how well a building can withstand by studying dampers, base isolators, cross bracing, and shear walls. The study compares heights (G+9, G+15, and G+20 stories) to understand which system and placement are most effective in reducing structural damage during an earthquake. The analysis uses data from past earthquakes (from the PEER Ground Motion Database) to calculate how much force (storey shear) and overturning moment the building experiences. By comparing these values, the study identifies the best structural model for earthquake resistance.

3.30) K.K. Sangle This paper focuses on how different bracing systems affect the seismic performance of high-rise steel buildings. The study uses linear time history analysis to examine a high-rise steel building with different bracing patterns under the Northridge earthquake. Natural frequencies, fundamental time periods, mode shapes, inter-story drift, and base shear for each bracing pattern are also analyzed. The research also includes an optimization study to identify the most suitable bracing pattern, ensuring that the inter-story drift , total lateral displacement.

3.31) K. Kanchan (2024) this research focuses on comparing different bracing systems for a 15-story RC building. The study looked at factors like maximum story displacement, story shear, story drift, and the building's ability to resist lateral loads. Using ETAB software, the analysis was conducted in a seismic zone VI setting with medium soil conditions, based on the Indian Standard 1893: 2002. Different bracing systems (X, V, inverted V, and corner X) were compared to a bare frame model without bracing. Results showed that all bracing systems reduced lateral movement and story drift, improving the building's ability to resist seismic forces. Among them, the X-bracing system was the most effective in minimizing lateral displacement.

3.32) Kibriya Banu et al. [2022] this study analyzed a 15-story building including shear walls, bracing systems, and friction dampers, with ETABS 2017 software. They studied story displacement, story drift, and base shear. Results showed that buildings in seismic Zone V experienced 2% more lateral displacement compared to Zone II. The presence of shear walls significantly reduced this displacement, with a 50% reduction when placed at the core and 25% when placed at the corners of the structure. Using X-bracing reduced lateral displacement by 30% in Zone II and 50% in Zone V.

3.33) K.G. Vishwanath (2010) used STAAD Pro software to analyze a four-story structure that was situated in seismic Zone IV in accordance with IS 1893:2002. By assessing its performance in terms of story and global drift, the study concentrated on how well steel bracing worked to restore the four-story building. The research was then expanded to measure the lateral displacement of each level in structures that were eight, twelve, and sixteen stories tall. The results showed that the most effective bracing method was X-bracing.

4. CONCLUSION OF LITERATURE REVIEW -

The comprehensive literature review on the seismic performance of high-rise buildings using various bracing systems underscores the critical role these systems play in enhancing structural integrity during seismic events. Various studies highlight that different bracing configurations such as X, V, and diagonal bracing effectively improve stiffness, reduce lateral displacement, and minimize story drift, significantly contributing to overall building stability.

Innovative techniques, such as the incorporation of I-shaped shear link dampers and low yield point (LYP) steel, have demonstrated their efficacy in augmenting both energy absorption and the frame's ductility. Research findings consistently indicate that X-bracing outperforms other bracing types in terms of lateral strength and stability, particularly in high seismic zones. Moreover, studies utilizing advanced simulation software facilitate detailed analyses of various structural configurations, leading to improved design strategies. The investigations into bracing systems' impact on buildings with irregular geometries also reveal that thoughtful design and placement of braces, along with the use of shear walls and damping systems, can further enhance seismic performance. Overall, this body of work emphasizes the importance of selecting appropriate bracing systems tailored to specific building designs and seismic conditions, paving the way for safer and more resilient high-rise structures in earthquake-prone regions.

4. METHODOLOGY TO BE USED-

After reviewing different literature, we structured a methodology for analyzing the seismic behavior of high-rise structures. The methodology for evaluating the seismic performance of high-rise buildings utilizing cross and diagonal bracing systems involves several systematic steps. First, a representative high-rise building model, such as a 15-story or 20-story structure, will be selected, incorporating both regular and irregular geometries to assess variations in seismic performance. Structural modelling will be performed using simulation software, implementing various bracing configurations, including cross bracing (X-bracing) and diagonal bracing (standard diagonal, inverted V-bracing, and chevron bracing). Material properties will be defined based on relevant codes, incorporating innovative materials like Low Yield Point (LYP) steel to enhance ductility and energy absorption.

The analysis will encompass both static and dynamic procedures, starting with linear static analysis (equivalent lateral force method) to determine base shear and lateral forces, followed by nonlinear static analysis (pushover analysis) to evaluate structural capacity under incremental lateral loading. Dynamic time history analysis will simulate earthquake effects using realistic ground motion data, while response spectrum analysis will capture the dynamic response of the structure under various seismic scenarios. Key performance parameters, including maximum story drift, lateral displacement, base shear, structural stiffness, and ductility, will be analyzed to quantify the effectiveness of cross and diagonal bracing in comparison to un-braced models.

Furthermore, a sensitivity analysis will be conducted to assess how variations in bracing configuration and material properties impact overall seismic performance. Validation of results will be performed by comparing simulation findings with empirical data from existing studies, and discussing any discrepancies and necessary adjustments. Finally, the findings will be documented in a comprehensive report, including visual representations of results to facilitate understanding, alongside recommendations for practical applications in high-rise building design based on the analysis outcomes. This methodology aims to enhance understanding of structural behavior during seismic events and contribute to developing safer building designs.

5. CONCLUSION -

In summary, the literature review highlights the significant impact of cross and diagonal bracing systems on enhancing the seismic performance of high-rise buildings. Studies consistently show that X-bracing provides superior stiffness, reduces lateral displacements and story drifts, and improves overall structural resilience, particularly in high seismic zones. The methodologies utilized in these studies, including advanced structural analysis software and both static and dynamic analyses, offer valuable insights for future research and practical applications in architectural design.

As urbanization continues and seismic risks remain, these findings underscore the importance of optimizing bracing configurations to enhance building safety and longevity. Continued exploration in this area will help inform building codes and contribute to the development of more resilient structures, ultimately safeguarding lives and property in earthquake-prone regions.

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