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Literature Review On Seismic Response Of A High-Rise Building With Fluid Viscous Damper And Determination Of Optimum Location And Height Of Dampers

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Abstract: The literature on structural control systems, particularly in seismic and wind-prone environments, has advanced significantly. Various studies have explored the performance of high-rise buildings equipped with damping devices and other seismic control systems. Research has demonstrated that integrating viscous dampers, tuned mass dampers (TMDs), and other control mechanisms can improve structural resilience, reduce vibrations, and enhance occupant comfort. Wind tunnel experiments and computational methods have been effective in analyzing wind-induced responses in tall buildings, offering cost-effective solutions for urban high-rise designs. Moreover, seismic studies on buildings with irregular configurations highlight the efficiency of base isolators, viscous dampers, and hybrid systems in mitigating seismic damage, especially during mainshock-aftershock sequences. Optimization techniques, including metaheuristic algorithms and energy-based methods, have been successfully applied to enhance damper placement and performance in both regular and irregular structures. Furthermore, simplified design methodologies for integrating damping devices into reinforced concrete structures have proven effective in retrofitting older buildings and achieving compliance with modern seismic codes. Comparative studies on different damping systems, such as fluid viscous dampers and buckling-restrained braces (BRBs), emphasize the importance of selecting the right system based on the building’s dynamic requirements. Life-cycle cost analysis (LCCA) has been used to evaluate the economic viability of control systems, showing that despite higher initial costs, devices like TMDs provide long-term savings through reduced repair and maintenance costs. Overall, these findings are based on a thorough review of 27 research papers, underlining the importance of innovative seismic and wind control systems in enhancing the structural integrity and safety of high-rise buildings in seismic and wind-prone areas.

Index Terms **-** Structural control systems, Seismic performance, Wind-induced vibrations, Fluid viscous dampers (FVDs), Tuned mass dampers (TMDs)

I. Introduction

In recent years, there has been a significant surge of interest in structural control systems, particularly for high-rise buildings in seismic and wind-prone environments. With the advancement in technology and research, engineers and architects are now able to integrate various damping devices and control systems to enhance the structural performance of these buildings. Damping systems such as fluid viscous dampers (FVDs), tuned mass dampers (TMDs), and hybrid control systems are proving to be critical in improving the resilience of buildings to external forces, minimizing vibrations, and enhancing occupant comfort.

To understand the efficacy and optimization of these control systems, a comprehensive literature review was conducted, referring to 27 research papers. These studies explored various aspects of structural control systems, including wind load effects on high-rise buildings, seismic performance in irregular structures, and the application of metaheuristic algorithms for optimal damper placement. Researchers have developed simplified design methodologies for retrofitting existing buildings with damping devices and compared different types of dampers such as fluid viscous dampers, buckling-restrained braces (BRBs), and tuned mass dampers.

The findings from these studies suggest that integrating innovative damping solutions can significantly reduce vibrations, control displacements, and ensure the structural integrity of buildings. Additionally, the use of life-cycle cost analysis (LCCA) has demonstrated that while the initial installation costs of these systems may be high, the long-term savings in maintenance and repairs make them a viable and cost-effective option for enhancing structural safety. This introduction sets the foundation for a detailed analysis of the latest advancements in structural control systems and their application in modern high-rise construction.

FLUID VISCOUS DAMPER

High-rise buildings are particularly vulnerable to dynamic forces such as wind, seismic activity, and mechanical vibrations, which can result in structural damage and compromise safety if not adequately controlled. To address these challenges, engineers and researchers have developed advanced damping systems, among which fluid viscous dampers (FVDs) have emerged as an effective and reliable solution. Their exceptional energy dissipation capabilities make them a critical component in the seismic design of high-rise structures.

Fluid viscous dampers operate by utilizing the relative motion between structural elements to convert kinetic energy into heat through the movement of a viscous fluid, such as silicone oil, within a sealed chamber. This mechanism enables consistent damping performance over a broad spectrum of frequencies and amplitudes, effectively reducing seismic and vibrational responses. Furthermore, FVDs function independently of a building's stiffness, making them highly adaptable for retrofitting applications and the optimization of damper placement in new constructions.

In recent years, advancements in FVD technology have improved their efficiency, durability, and cost-effectiveness, further expanding their use in high-rise structures. Optimizing the placement and height of FVDs within a building is crucial to maximize their effectiveness in controlling seismic responses. This study reviews the behavior of fluid viscous dampers in high-rise buildings under seismic loading and explores methodologies for determining their optimal location and distribution, emphasizing their role in enhancing structural stability and safety.

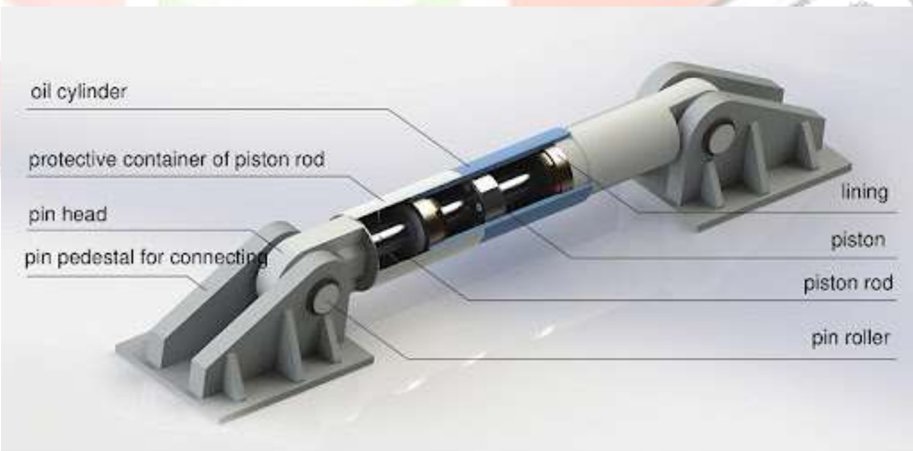

Fig 1: Fluid Viscous Damper Structure

TUNED MASS DAMPERS

Tuned Mass Dampers (TMDs) are another widely used vibration control system that has proven effective in minimizing dynamic responses in tall and flexible structures. TMDs consist of a secondary mass connected to the primary structure through a system of springs and dampers. By oscillating out of phase with the building's vibrations, TMDs effectively counteract resonant frequencies, reducing motion and protecting the structure from excessive deflections. The core concept of TMDs lies in tuning their natural frequency to align with the building's dominant vibration modes. This allows them to efficiently dissipate vibrational energy caused by seismic or wind-induced forces. High-rise buildings, which are more prone to these dynamic effects, benefit significantly from TMDs, as they improve occupant comfort and structural safety. While TMDs are highly effective for controlling wind-induced oscillations, they are generally less flexible compared to FVDs in handling multi-directional seismic loads.

In the context of high-rise buildings, this paper focuses on fluid viscous dampers due to their superior adaptability and efficiency in seismic applications. The study explores the integration of FVDs to enhance seismic performance and investigates optimal locations and height distributions to maximize their damping efficiency. This approach not only improves the safety of high-rise buildings under seismic loading but also underscores the importance of effective damper placement strategies in modern structural design.

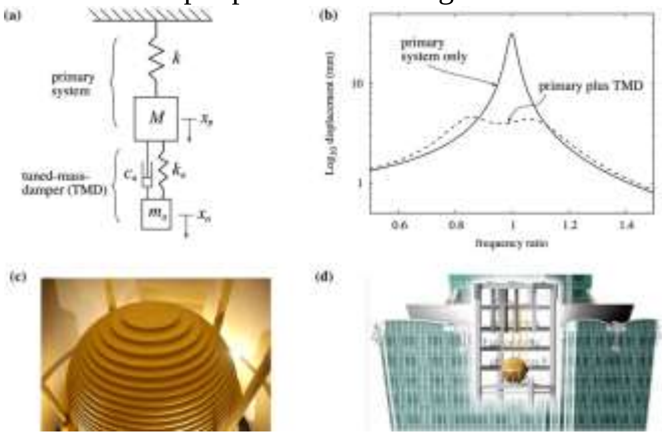

Fig 2: Tuned Mass Damper

II. Literature Review

Avini et al. (2018) conducted a study focusing on wind load effects on high-rise buildings, emphasizing the importance of surrounding structures and wind direction on the overall structural response. Using computational wind tunnel tests, they demonstrated how these factors could influence occupant comfort, particularly at the top floors of buildings. Their findings indicate that computational methods provide valuable, cost-effective alternatives to traditional wind tunnel experiments for high-rise urban design

Wasey et al. (2022) explored the seismic performance of vertically irregular buildings, employing non-linear time history analysis to evaluate several seismic control systems, including base isolators, fluid viscous dampers, and shear walls. They discovered that the combination of base isolators and dampers greatly improved seismic resistance in buildings of various heights, making these systems effective in reducing earthquake-induced displacements

De Domenico and Ricciardi (2018) advanced the understanding of seismic protection for structures by focusing on nonlinear fluid viscous dampers. They incorporated the dampers' nonlinear behavior early in the design optimization process and demonstrated that this approach significantly improved the system's energy dissipation capacity, leading to more effective seismic response control compared to conventional linear models

Zhu et al. (2011) investigated the optimal use of dampers connecting adjacent structures to minimize seismic vibrations. By analyzing viscoelastic and viscous fluid dampers, their study revealed that proper damper selection and placement significantly reduce the vibrational energy in both structures, thus enhancing overall seismic performance

Çerçevik et al. (2021) applied metaheuristic algorithms to optimize the placement of viscous wall dampers in reinforced concrete moment-resisting frames. The study found that optimal damper placement reduced inter-story drifts and improved the seismic resilience of the frames, highlighting the efficiency of metaheuristic search methods for structural optimization

Zhou et al. (2012) proposed a practical design methodology for integrating viscous dampers into reinforced concrete structures, particularly in the context of retrofitting buildings following seismic events. Their approach demonstrated how dampers could significantly enhance the structural integrity and seismic resistance of buildings, offering an effective solution for retrofitting older structures to meet modern seismic codes

Lin et al. (2024) introduced a friction-type multiple tuned mass damper (FT-MTMD) system designed to mitigate seismic vibrations in high-rise buildings. Their experimental work, including shaking table tests, confirmed the system's effectiveness in reducing building vibrations under seismic loading. Additionally, they incorporated a fail-safe mechanism to prevent damper overloading during extreme events, ensuring continued structural protection

Wang et al. (2021) developed a multi-tuned liquid column damper-inerter (MTLCDI) system, specifically for controlling seismic responses in adjacent high-rise buildings. By employing optimization techniques, they demonstrated the system's superior ability to reduce both inter-story drift and acceleration when compared to traditional dampers. This research contributes to enhancing seismic performance in densely constructed urban environments

Sharma et al. (2023) focused on the application of fluid viscous dampers in tall buildings, assessing their placement strategies to improve structural resilience to seismic forces. Their study concluded that installing dampers on every floor provided the most effective reduction in displacement and drift, offering practical guidance for designing earthquake-resistant tall structures

Mehmandousti et al. (2023) analyzed the seismic response of mid-rise steel frames fitted with fluid viscous dampers under seismic sequences. The study found that these dampers significantly reduce displacements and other structural responses, with aftershocks causing more damage than main shocks. Near-field seismic records showed higher structural demands than far-field records, emphasizing the critical role of aftershocks in increasing seismic damage

Soureshjani and Lavassani (2023) studied the performance of a hybrid seismic control system consisting of a Tuned Particle Impact Damper (TPID) and a Tuned Mass Damper (TMD) under mainshock-aftershock sequences. The results showed that both TPID and TMD systems efficiently reduced seismic responses. However, the TPID system demonstrated better performance than TMD in reducing displacement and structural damage

Sun et al. (2021) investigated wind-induced responses in a 1040-meter skyscraper using mass and viscous dampers. Their analysis revealed that hybrid control methods combining both types of dampers provided optimal vibration control, significantly improving structural stability and occupant comfort. The study demonstrated that using multiple control schemes, including mass and viscous dampers, is an effective approach for managing wind-induced vibrations in super-tall buildings(1-s2.0-S235271022100409…).

Wasey et al. (2022) explored seismic control systems, such as fluid viscous dampers, base isolators, and shear walls, for vertically irregular buildings. They found that base isolators and fluid viscous dampers provided the best performance in reducing seismic displacements, while shear walls effectively controlled maximum story drifts. The study highlighted the importance of selecting the right control system based on the specific irregularities present in the structure

Tiwary et al. (2022) analyzed the effects of viscous dampers and base isolation techniques on the dynamic response of a G+10 story reinforced concrete composite structure. The combination of viscous dampers and base isolation showed significant reductions in story displacement and drift, providing better control of the structure's seismic response. However, viscous dampers increased base shear, a limitation that was mitigated when combined with base isolation

Javaid and Verma (2023) performed a comparative study of Buckling Restrained Braces (BRBs) and viscous dampers in a 15-story steel-concrete composite building. Their analysis showed that both BRBs and viscous dampers effectively reduced seismic responses, but viscous dampers provided better results in reducing the time period and base shear, while BRBs were more effective in reducing overturning moments

Faruk et al. (2023) compared the performance of BRBs and fluid viscous dampers in a reinforced concrete structure following pushover analysis. They found that BRBs were more effective in increasing the stiffness of the structure, while viscous dampers performed better at larger displacements. The study concluded that the selection of energy dissipators should consider both the stiffness and displacement requirements of the structure

Feng et al. (2021) proposed a multi-toggle brace damper (MTBD) system to enhance energy dissipation and control vibrations in structures under seismic excitation. The MTBD system showed better performance than traditional toggle brace dampers, reducing roof displacement by an average of 41.1%. The study demonstrated that the MTBD system is an effective solution for improving structural resilience during dynamic loading

Zhou et al. (2021) developed a novel energy dissipation system using multi-toggle braces to enhance the seismic performance of structures. By comparing the system to traditional solutions, they demonstrated that the multi-toggle brace system could significantly reduce dynamic responses, offering a more efficient solution for structures facing seismic excitations.

Kumari et al. (2021) explored the seismic performance of multi-story residential buildings using equivalent static and response spectrum analyses. Their study analyzed a G+8 building located in seismic zones 2 and 4 using STAAD Pro software, comparing ordinary moment resisting frames with special moment resisting frames. The study concluded that special moment resisting frames provide better seismic performance by reducing story drifts and base shear

Landi et al. (2015) examined the effectiveness of various distributions of viscous damping coefficients for the seismic retrofitting of regular and irregular reinforced concrete (RC) frames. The study employed different methods, such as energy-based and simplified search algorithms, to optimize damper placement. The results revealed that energy methods were efficient and reduced costs while improving structural performance in terms of interstory drifts and peak floor accelerations

Lewandowski and Pawlak (2018) extended the response spectrum method to buildings equipped with viscoelastic dampers, modeled using fractional derivatives. The authors developed a solution in the frequency domain to account for non-proportional damping matrices. Their findings demonstrated that the fractional derivative models provided better representation of viscoelastic materials' behavior across a wide frequency range, making this approach suitable for buildings subjected to seismic loads

Ijmulwar and Patro (2024) proposed a simplified performance-based seismic design for reinforced concrete buildings equipped with fluid viscous dampers (FVDs). Their method focused on achieving maximum energy dissipation and uniform damage distribution by optimizing the placement of dampers. The study confirmed that using FVDs effectively reduced seismic responses and improved building resilience to earthquakes

Shivarani and Reddy (2021) performed a comparative analysis of RC buildings with and without dampers at varying heights using ETABS software. The study evaluated base shear, story drifts, and stiffness in structures of 10m, 20m, and 30m. The results indicated that incorporating dampers significantly improved structural performance by reducing vibrations and seismic damage, especially in taller buildings

Arya et al. (2023) reviewed various types of dampers, including viscous, friction, and tuned mass dampers, in controlling structural vibrations during seismic events. The study concluded that viscous dampers, due to their adaptability and energy dissipation capacity, are the most effective for retrofitting and designing new structures to reduce earthquake-induced damage

Elias and Matsagar (2018) investigated wind-induced responses in tall buildings equipped with a single tuned mass damper (TMD). By placing the TMD at different floors, the study revealed that tuning the TMD to the building's dominant modal frequency significantly reduced vibrations and enhanced structural stability during wind forces

Forberger (2015) explored the dissipation in fluid dampers using non-Newtonian fluid models. The study compared different fluid models, including Maxwell and Oldroyd-B, to calculate energy dissipation in high shear-rate scenarios. The findings suggested that non-Newtonian fluids exhibit lower dissipation compared to Newtonian fluids, making them more efficient for use in damping systems

Ierimonti et al. (2018) conducted a life-cycle cost analysis (LCCA) for tall buildings equipped with tuned mass dampers (TMDs). The study emphasized that, although TMDs have high initial costs, they reduce long-term maintenance and repair costs by minimizing wind-induced structural damage. The LCCA approach provided a comprehensive assessment of the cost-benefit ratio for adopting TMDs in high-rise buildings

III. Research Gap from Literature Review

Despite significant advancements in structural control systems for high-rise buildings, several critical areas remain underexplored. The current body of research has primarily focused on integrating damping devices such as fluid viscous dampers (FVDs), tuned mass dampers (TMDs), and hybrid systems to enhance the seismic and wind-induced performance of buildings. While these studies have proven the effectiveness of such systems in reducing vibrations and improving structural stability, there is a noticeable gap in the comprehensive assessment of these devices across varying building configurations, particularly irregular or complex geometries.

Most existing studies focus on optimizing damper placement and performance in regular structures, leaving a gap in understanding how these systems behave in buildings with unusual layouts or in cases where the dynamic load distribution is irregular. Additionally, while computational wind tunnel tests and metaheuristic optimization algorithms have shown promising results in specific scenarios, there is insufficient research on how these methods perform under real-world, multi-hazard conditions—such as simultaneous seismic and wind loads, or during extreme events like hurricanes and earthquakes.

Another significant gap lies in the assessment of energy dissipation and long-term performance of these systems under different environmental stresses, such as temperature variations and long-term material degradation. Furthermore, while life-cycle cost analysis (LCCA) has been used to demonstrate the financial benefits of damping systems, the literature lacks detailed comparative studies that examine the trade-offs between different types of dampers, focusing on both short-term performance and long-term maintenance requirements across different types of structures and environments.

Finally, many studies have focused on passive damping systems, but there is limited exploration of integrating active and semi-active control systems, which can adapt to changing loads in real-time. There is also a need for research on how the combination of passive and active systems can provide more resilient solutions, particularly in buildings located in high-risk seismic or wind-prone areas. Addressing these gaps will contribute to a more robust understanding of how innovative control systems can be optimized for a wide range of building types and environmental conditions, ultimately improving the safety and resilience of urban infrastructure.

This gap in the literature underscores the necessity for future research to expand the focus beyond conventional seismic and wind performance evaluations, incorporating a broader spectrum of load conditions, building types, and environmental factors.

IV. CONCLUSION

The advancement of structural control systems, particularly for high-rise buildings in seismic and wind-prone environments, has shown great potential in enhancing structural resilience and occupant safety. Various damping devices, including fluid viscous dampers (FVDs) and tuned mass dampers (TMDs), have proven effective in reducing vibrations, improving seismic resistance, and enhancing the overall stability of tall buildings. Wind tunnel experiments and computational methods have been essential in understanding the behavior of these structures under dynamic loading conditions, offering cost-effective solutions for urban high-rise designs.

However, despite these advancements, there remain gaps in the research that need to be addressed. Current studies have largely focused on regular building configurations, leaving the performance of damping systems in irregular and complex geometries underexplored. Furthermore, while optimization techniques and energy-based methods have shown success in damper placement and performance, more research is needed on how these systems perform under real-world, multi-hazard conditions, such as simultaneous seismic and wind loads or during extreme events like hurricanes.

Additionally, the integration of active and semi-active control systems alongside passive damping systems presents an opportunity for more adaptive and resilient structures. These systems could further improve the safety of buildings, especially in high-risk areas prone to seismic and wind activity. While life-cycle cost analysis (LCCA) has demonstrated the economic viability of these systems in the long term, future research should explore the balance between initial investment, maintenance, and performance, ensuring optimal outcomes for a wider variety of building types.

Ultimately, addressing these research gaps will contribute to a more comprehensive understanding of how innovative damping solutions can be optimized to enhance the structural integrity, safety, and economic efficiency of high-rise buildings, particularly in challenging environmental conditions. This work will pave the way for future advancements in urban infrastructure, ensuring that modern buildings are not only safe but also economically and environmentally sustainable.

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