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Experimental Study on Tuned Mass Damper in Controlling Vibration of Frame Structures- A Review

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Abstract: The rapid growth of urbanization and the increasing demand for tall, slender, and lightweight structures have significantly intensified vibration-related serviceability and safety concerns in civil engineering. Modern structures, designed with reduced mass and stiffness for economic and functional efficiency, inherently possess low damping characteristics, making them highly susceptible to excessive vibrations induced by wind, earthquakes, machinery, and human activities. Among various vibration mitigation techniques, tuned mass dampers (TMDs) have emerged as one of the most reliable and widely adopted passive control devices due to their simplicity, effectiveness, and ease of implementation. This review paper presents a comprehensive synthesis of experimental, numerical, and analytical research developments related to the application of tuned mass dampers and their advanced variants, including multiple TMDs, adaptive TMDs, variable stiffness TMDs, and tuned mass damper inerter (TMDI) systems. The paper critically examines the performance of these systems in controlling vibrations of frame structures, bridges, and floor systems under seismic, wind, and human-induced excitations. Furthermore, the review highlights the limitations of existing studies and identifies key research gaps that necessitate further investigation to enhance the robustness, adaptability, and real-world applicability of TMD-based vibration control systems.

Keywords: Tuned Mass Damper, Structural Vibration Control, Passive Control Systems, Frame Structures, Seismic Response, Human-Induced Vibrations

I. INTRODUCTION

The rapid advancement of construction technology, coupled with accelerated urbanization and the continuous demand for efficient land use, has led to the widespread development of tall, slender, and lightweight structures such as high-rise buildings, long-span bridges, pedestrian footbridges, and flexible floor systems. While these modern structural forms offer significant advantages in terms of architectural flexibility, material efficiency, and economic feasibility, they inherently possess low stiffness and low inherent damping, making them highly susceptible to excessive vibrations under various dynamic excitations. Structural vibrations induced by earthquakes, wind loads, traffic, machinery operations, and human activities such as walking, running, or jumping have emerged as a major concern in contemporary structural engineering practice. Excessive vibrations not only threaten the structural safety by inducing additional stresses and potential fatigue damage but also adversely affect serviceability, occupant comfort, and functional performance, which are increasingly emphasized in modern performance-based design philosophies. In particular, serviceability issues such as discomfort, loss of functionality, and damage to non-structural components often govern the design of flexible structures, even when strength and stability requirements are satisfied. Traditionally, structural vibration mitigation has been achieved through conventional design strategies, such as increasing member sizes, adding shear walls or bracing systems, modifying structural stiffness and mass distribution, or enhancing energy dissipation through ductile detailing.

However, these approaches often result in increased construction costs, architectural constraints, and additional self-weight, which may counteract the original objectives of lightweight and efficient design. Consequently, the focus of research and practice has gradually shifted toward the development and implementation of structural vibration control systems, which aim to reduce dynamic responses without significantly altering the primary load-resisting system. Structural control technologies are broadly classified into passive, active, semi-active, and hybrid control systems, depending on their energy requirements and operational mechanisms. Among these, passive control systems have gained widespread acceptance due to their simplicity, reliability, cost-effectiveness, and independence from external power sources, making them particularly suitable for large-scale civil engineering applications. Within the family of passive control devices, the tuned mass damper (TMD) has emerged as one of the most extensively researched and practically implemented solutions for vibration mitigation. A TMD typically consists of a secondary mass attached to the main structure through a spring and a damper, tuned to the dominant natural frequency of the structure. When the structure vibrates near its resonance frequency, the TMD oscillates out of phase with the primary structure, thereby transferring vibrational energy from the main system to the auxiliary mass and dissipating it through damping mechanisms. Since its early applications in tall buildings to control wind-induced vibrations, the TMD concept has been successfully extended to a wide range of civil engineering structures, including high-rise buildings, long-span bridges, chimneys, towers, industrial structures, and floor systems. The effectiveness of TMDs in reducing displacement, acceleration, and inter-storey drift responses has been demonstrated through numerous analytical, numerical, and experimental studies, establishing them as a reliable passive vibration control strategy. In this context, a comprehensive and critical review of existing research on tuned mass damper systems is essential to understand current capabilities, identify limitations, and define future research directions. This review paper aims to synthesize experimental, numerical, and analytical studies on the application of TMDs and their advanced variants for vibration control of framed structures, bridges, and floor systems. By examining the evolution of TMD technology, evaluating their performance under different dynamic loading scenarios, and highlighting unresolved challenges, the present study seeks to provide a consolidated knowledge base that supports the development of robust, adaptable, and practical vibration control strategies for modern civil engineering structures.

II. LITERATURE REVIEW

In 2025, Sijie Peng, Lianzhen Zhang, Yan Chen, and Xiaopeng Chai published an important experimental investigation titled *“Experimental study on the performance of tuned mass damper inerter in suppressing low-frequency vibrations of long-span bridges: Model experiments and full-scale field tests”* in the journal Structures. This study addresses one of the critical challenges in modern bridge engineering, namely the effective control of low-frequency vibrations in long-span bridges, where conventional tuned mass dampers (TMDs) often become impractical due to excessive mass and space requirements. The authors proposed a novel low-frequency tuned mass damper inerter (TMDI) based on a rack–pinion mechanism, capable of precise frequency tuning over a wide range, which is particularly suitable for targeting dominant low-order vibration modes of long-span bridges. Through detailed model-scale experiments, the study examined the dynamic characteristics and vibration control performance of the TMDI, revealing distinctive spiking behavior in acceleration responses caused by backlash effects in the rack–pinion inerter mechanism. Importantly, the results demonstrated that while these spiking responses have negligible influence on the natural frequency and overall vibration mitigation efficiency, they may raise concerns related to local fatigue damage, highlighting the need for careful mechanical detailing in practical applications. Furthermore, the study provided a critical comparison between idealized TMDI behavior and real mechanical systems, showing that Coulomb friction and mechanical nonlinearity significantly affect dynamic response characteristics, introducing amplitude dependency and stick–slip behavior at small vibration levels. However, the authors convincingly showed that when the TMDI is scaled to real bridge applications, the influence of friction becomes much less significant due to the large effective inertia of the inerter mass. This conclusion was validated through full-scale field testing, in which a 3-ton TMDI was installed on a long-span cable-stayed bridge to control its first-order vertical bending mode. Field measurements revealed a remarkable improvement in structural damping, with the damping ratio increasing from 0.198 % to 0.585 %, corresponding to nearly a threefold enhancement, despite an extremely small mass ratio of only 0.466 ‰. The findings of this study clearly establish the practical feasibility, high efficiency, and space-saving advantages of TMDI systems for real-world bridge applications, and demonstrate their strong potential as an advanced passive control technology for mitigating low-frequency vibrations in long-span bridges where traditional vibration control devices are insufficient.

In 2025, Aditya Ajay There and H B Dahake presented a comprehensive review titled *"Experimental Study of Vibration Control of Framed Structure Using Various Dampers: A Comprehensive Review"* in the International Journal for Research in Applied Science & Engineering Technology (IJRASET). This review paper addresses the growing challenges associated with the increasing adoption of tall and slender buildings in modern urban environments, where architectural demands for lightweight, cost-effective, and rapidly constructible structures often lead to reduced inherent damping and increased vulnerability to excessive vibrations. The authors systematically reviewed experimental and analytical studies related to passive energy dissipation systems used for vibration control in framed structures, emphasizing solutions that operate without external power sources and rely on structural motion to dissipate energy. The study critically examined the performance of commonly used passive damping devices, including metallic dampers, friction dampers, viscoelastic dampers, and fluid viscous dampers (FVDs), highlighting their working mechanisms, advantages, and limitations under dynamic loading conditions such as wind and seismic excitations. A key finding of the review is that among the various passive systems, fluid viscous dampers exhibit superior performance in controlling shock forces and reducing structural responses due to their ability to dissipate energy efficiently over a wide range of vibration frequencies. The authors emphasized that FVDs, by effectively combining stiffness and damping characteristics, significantly enhance the stability, safety, and robustness of framed structures subjected to severe dynamic loads. Furthermore, the review pointed out that passive damping systems, particularly FVDs, contribute to improved serviceability and reduced structural damage without altering the primary load-resisting system, making them highly suitable for both new construction and retrofitting of existing tall buildings. Overall, this comprehensive review reinforces the critical role of passive vibration control devices, especially fluid viscous dampers, as reliable and efficient solutions for mitigating dynamic responses in modern high-rise structures and provides a consolidated knowledge base for future experimental and design-oriented research in structural vibration control.

In 2023, Liangkun Wang, Satish Nagarajaiah, Ying Zhou, and Weixing Shi published an influential experimental study titled *"Experimental study on adaptive-passive tuned mass damper with variable stiffness for vertical human-induced vibration control"* in the journal Engineering Structures. This research addresses a critical serviceability issue associated with lightweight and slender pedestrian bridges, which typically exhibit low inherent damping and natural frequencies that fall within the range of human-induced excitation frequencies, making them highly susceptible to uncomfortable or unsafe vibration levels during walking or running activities. While conventional passive tuned mass dampers (TMDs) are widely used for vibration mitigation, their effectiveness is highly sensitive to frequency mistuning, which can occur due to modeling uncertainties, environmental changes, or structural aging. To overcome this limitation, the authors proposed a novel adaptive-passive variable stiffness tuned mass damper (APVS-TMD) capable of retuning its stiffness and frequency in situ without requiring active control input. In the proposed system, the stiffness and target frequency of the TMD are adjusted by modifying the free length of a cantilever beam, while the damping level is regulated through magnetic eddy-current damping by altering the air gap between conductor plates and magnets. A key contribution of the study is the development of an innovative structural natural frequency identification method, in which the first two modal frequencies of the coupled TMD–structure system are identified under ambient excitation, and the decoupled structural natural frequency is subsequently derived using an undamped two-degree-of-freedom (2-DOF) modal analysis framework. The accuracy of this identification strategy was first verified numerically using a single-degree-of-freedom lumped-mass system and an ideal simply supported beam model, demonstrating reliable frequency extraction even under coupled conditions. The methodology was then experimentally validated through a scaled footbridge model, where the APVS-TMD was installed and retuned based on the identified structural frequency. Comparative experimental results under walking- and running-induced vibrations showed that the APVS-TMD significantly outperformed a mistuned conventional TMD, achieving substantial reductions in vibration amplitudes and improving overall serviceability performance. The study conclusively demonstrated that the proposed APVS-TMD can accurately identify the structural natural frequency from a coupled system and effectively suppress human-induced vibrations through adaptive stiffness retuning. Overall, this work represents a significant advancement in adaptive passive vibration control, offering a practical and energy-efficient solution for mitigating serviceability problems in slender footbridges and other flexible structures where frequency variability poses a major challenge to conventional passive control devices.

In 2021, Ishtiak Anwar Shaikh, along with R R Kulkarni and B B Kedar, published a study titled *"Application of Tuned Mass Damper for Vibration Control of Frame Structures under Seismic Excitations"* in the International Journal of Creative Research Thoughts (IJCRT). This research was motivated by the growing trend in the construction industry toward taller, lighter, and more flexible structures, which inherently possess low inherent damping and are therefore more susceptible to excessive vibrations and serviceability problems during seismic events. The authors focused on the tuned mass damper (TMD) as an effective passive vibration control device and examined its applicability for mitigating seismic-induced vibrations in frame structures. Initially, a numerical algorithm was developed to analyze the dynamic response of a shear building model equipped with a TMD, followed by the formulation of another numerical model for a two-dimensional frame structure integrated with a TMD system. To realistically assess the performance of the TMD under seismic conditions, the structures were subjected to three distinct base excitation scenarios, namely sinusoidal loading, a compatible time-history generated as per IS 1893 (Part 1):2002 response spectrum for 5% damping on rocky soil with a peak ground acceleration (PGA) of 1g, and the historical 1940 El Centro earthquake record with a PGA of 0.313g. The numerical results clearly demonstrated that the inclusion of a TMD significantly reduced the displacement response of the structure under all loading conditions, confirming the effectiveness of TMDs in seismic vibration control. The study further revealed that the performance of the TMD is strongly influenced by the structural damping ratio, with greater effectiveness observed in structures having lower inherent damping. Additionally, a parametric investigation showed that increasing the mass ratio of the TMD leads to a progressive reduction in structural displacement, highlighting the importance of optimal mass tuning in achieving efficient vibration mitigation. Overall, this study provided valuable numerical evidence supporting the use of TMDs as a reliable and efficient passive control strategy for improving the seismic performance and serviceability of frame structures, particularly in low-damping structural systems.

In 2020, Abdul Bari Sayyed, Ganesh Sonar, Kunal Suryawanshi, Mohammad Gaus Shaikh, and Satyam Taware published a study titled *"Design and Analysis of Tuned Mass Damper System"* in the International Journal of Engineering Research & Technology (IJERT). This research was motivated by the growing concern over vibration-induced performance degradation in modern structures, particularly in the context of contemporary construction trends that favor taller, lighter, and more flexible buildings with inherently low damping capacity. The authors emphasized that excessive vibrations not only reduce the service life of buildings and mechanical structures but may also lead to serviceability issues and structural failure, especially when the excitation frequency coincides with the natural frequency of the system, resulting in resonance. The study focused on evaluating the effectiveness of a tuned mass damper (TMD) as a passive vibration control device through both analytical comparison and experimental validation. A comparative analysis was carried out between an undamped single-degree-of-freedom (SDOF) structural frame and the same system equipped with a passive TMD, subjected to external dynamic excitation. To capture real-time vibration responses, the authors developed an experimental working model, incorporating an accelerometer integrated with an Arduino Uno R2 microcontroller, which enabled accurate measurement and processing of vibration data in the form of acceleration–time histories. The experimental setup allowed direct observation of vibration reduction due to the presence of the TMD, thereby bridging the gap between theoretical concepts and practical implementation. The results obtained from the experimental model clearly demonstrated that the inclusion of a tuned mass damper significantly reduces vibration amplitudes when compared to the undamped system, confirming the effectiveness of TMDs in mitigating structural vibrations. Furthermore, the study highlighted the simplicity, cost-effectiveness, and practical feasibility of passive TMD systems, particularly for low-rise and simplified structural models, making them attractive for educational, experimental, and preliminary design purposes. By combining analytical reasoning with hands-on experimentation, this research contributed valuable insights into the design principles, performance characteristics, and real-time monitoring of tuned mass damper systems, reinforcing their relevance as a reliable passive vibration control solution for modern civil engineering structures.

In 2020, Fatemeh Rahimi, Reza Aghayari, and Bijan Samali published a state-of-the-art review entitled *"Application of Tuned Mass Dampers for Structural Vibration Control: A State-of-the-art Review"*. This influential review article systematically examined the role of tuned mass dampers (TMDs) in mitigating structural vibrations induced by earthquakes, wind loads, and other dynamic excitations, in response to the rapidly increasing construction of high-rise and complex structural systems worldwide. The authors began by classifying vibration control technologies into passive, active, semi-active, and hybrid control systems, and provided a detailed theoretical overview of the fundamental principles governing each category. Emphasis was placed on TMD-based systems due to their simplicity, reliability, ease of optimization, and proven success in real-world applications, which have made them one of the most widely adopted vibration control devices in modern structural engineering practice. The review critically analyzed a broad spectrum of previous studies addressing passive, active, semi-active, and hybrid TMD configurations, and compared their effectiveness in reducing structural response, limiting damage, and enhancing overall structural performance. Unlike earlier review papers that focused only on either passive or active TMDs, this study offered a holistic and unified framework, covering the analytical formulations, structural configurations, practical implementation issues, and economic considerations associated with all major TMD types. A key contribution of this work lies in its identification of critical research gaps in existing literature. The authors highlighted that current engineering practices for determining the optimal tuning frequency of TMDs are often oversimplified and may not adequately represent the true dynamic behavior of real structures. Furthermore, the review emphasized the growing necessity for advanced analytical and numerical models that explicitly account for the nonlinear behavior of both structures and TMD systems, as linear assumptions can lead to inaccurate prediction of structural response and suboptimal damper performance. The authors argued that incorporating nonlinear effects into analysis and design procedures could significantly improve the accuracy of response prediction and the efficiency of TMD optimization. Overall, this state-of-the-art review serves as a foundational reference in the field of structural vibration control, offering a comprehensive synthesis of existing knowledge while clearly outlining future research directions aimed at improving the design, analysis, and practical deployment of TMD systems for enhanced resilience of structures subjected to dynamic loading.

In 2017, Said Elias and Vasant Matsagar published a comprehensive state-of-the-art review titled *"Research developments in vibration control of structures using passive tuned mass dampers"* in the journal Annual Reviews in Control. This review paper systematically synthesizes more than two decades of research on passive tuned mass damper (TMD)–based vibration control systems, with a primary focus on mitigating wind- and earthquake-induced responses of civil engineering structures. The authors began by placing TMDs within the broader framework of structural response control technologies, providing a qualitative comparison between passive, active, semi-active, and hybrid control systems, and emphasizing the robustness, simplicity, and reliability of passive systems, which operate without external power or real-time feedback. The review highlighted that among various passive devices—such as friction dampers, fluid viscous dampers, base isolation systems, tuned liquid dampers, and TMDs—the tuned mass damper remains one of the most extensively researched and practically implemented solutions due to its effectiveness and ease of optimization. A detailed and structured review of both theoretical formulations and experimental investigations related to TMDs was presented, covering fundamental concepts such as tuning frequency, mass ratio, damping optimization, and modal participation. Special emphasis was placed on the evolution of TMD configurations, including single tuned mass dampers (STMDs), multiple tuned mass dampers (MTMDs), and spatially distributed multiple tuned mass dampers (d-MTMDs), all of which have been analytically developed and experimentally validated through component-level testing and scaled structural models. The authors demonstrated that while STMDs are effective for dominant mode control, MTMDs and d-MTMDs offer superior robustness and reliability, particularly under uncertainties in structural properties and excitation characteristics. The review also documented successful real-world applications of TMDs in buildings, bridges, and industrial structures, highlighting their role in improving structural safety, performance, and occupant comfort, especially in tall and flexible structures subjected to ambient dynamic forces. Importantly, the paper identified critical future research needs, including the development of advanced time-domain and frequency-domain analysis methods for structures equipped with distributed MTMD systems, explicit consideration of uncertainties in structural parameters and loading characteristics, and the incorporation of material and geometric nonlinearities in both structures and TMD systems. The authors emphasized that addressing these gaps is essential for more accurate prediction of structural response and for enhancing the effectiveness of TMD-based vibration control strategies. Overall, this review serves as a foundational reference in the field of passive structural vibration control, consolidating existing knowledge while clearly outlining future research directions for improving the design, analysis, and application of STMDs, MTMDs, and d-MTMD systems in wind- and seismic-resistant structures.

In 2015, Bibin Mathew and Anu A. presented a research study titled *"Vibration Control of High Rise Structures by Using Tuned Mass Dampers"* under the NCRACE – 2015 conference series, later published by the International Journal of Engineering Research & Technology (IJERT). The study was motivated by the rapid global increase in the construction of tall and slender buildings, which are typically designed to be lightweight to reduce seismic forces but consequently possess low inherent damping, making them highly susceptible to excessive vibrations under wind and earthquake loading. The authors emphasized that such vibrations not only compromise serviceability requirements but also reduce structural integrity, potentially leading to long-term damage or failure. While shear walls are a well-established and commonly adopted solution for lateral load resistance, the study explored the emerging application of passive tuned mass dampers (TMDs) for controlling earthquake-induced vibrations, a domain traditionally dominated by wind-response mitigation. A detailed finite element analysis was carried out using SAP2000, where a 30-storey symmetrical three-dimensional moment-resisting frame (MRF) building was modeled and subjected to seismic loading. The structural response was evaluated under different configurations, including the introduction of shear walls and TMDs applied alternatively, allowing a direct comparison of their vibration control efficiency. Furthermore, multiple TMD placement arrangements were investigated to identify the most effective configuration in reducing lateral displacement and dynamic response. Based on the results obtained from the 30-storey model, the optimum TMD arrangement was subsequently implemented in a 50-storey building, and its performance was evaluated using time-history analysis with the 1940 El Centro earthquake record. The findings demonstrated that appropriately designed and strategically placed TMDs significantly reduce seismic-induced vibrations and lateral displacements in high-rise buildings, thereby enhancing serviceability and seismic performance. The study concluded that while shear walls remain effective structural elements, TMDs offer a flexible and efficient supplementary vibration control solution, particularly when optimal tuning and placement are achieved. Overall, this research contributed valuable insights into the comparative effectiveness of shear walls and tuned mass dampers, and reinforced the potential of TMDs as a viable passive control device for improving the seismic response of high-rise structures.

In 2012, Bablu Bhattacharjee published a seminal work titled *"An Experimental Study of Tuned Mass Damper to Control the Vibration of Concrete Floors: Innovative Techniques for Vibration Control in Tall and Flexible Structures"* in the Journal of Advances in Science and Technology, published by Ignited Minds Journals. This study addressed the growing concern associated with modern construction practices, where the demand for taller, lighter, and more flexible structures has led to significantly lower inherent damping, thereby increasing the susceptibility of structures to excessive vibrations and serviceability-related issues. The research primarily focused on evaluating the effectiveness of tuned mass dampers (TMDs) as passive vibration control devices for mitigating vibrations in concrete floors and framed structural systems. Initially, the author developed numerical algorithms to study the dynamic response of a shear building model equipped with a TMD, followed by a detailed numerical investigation of a two-dimensional frame structure integrated with a TMD system. To ensure realistic assessment under dynamic conditions, three different base excitation scenarios were considered, namely sinusoidal loading, a spectrum-compatible time history based on IS 1893 (Part 1):2002 for 5% damping on rocky soil with a peak ground acceleration (PGA) of 1g, and the historical 1940 El Centro earthquake record with a PGA of 0.313g. The numerical findings clearly demonstrated that TMDs are highly effective in reducing structural displacement responses under all loading conditions, with enhanced performance observed in structures possessing lower inherent damping ratios. Furthermore, the study revealed that a gradual increase in the mass ratio of the TMD leads to a corresponding reduction in vibration amplitudes, highlighting the importance of optimal mass tuning in vibration mitigation. Beyond conventional TMD applications, the paper also addressed the optimum design of TMDs for machine-induced vertical vibrations, emphasizing that while ideal tuning without damping yields maximum control efficiency, zero damping is impractical in real systems. To overcome this limitation, a field-based design methodology and an innovative vertically moving tuned mass damper (VTMD) were proposed, incorporating adjustable mass blocks and variable stiffness springs to allow precise tuning. A prototype VTMD was fabricated and experimentally tested on both a simply supported beam and a reinforced concrete floor of a school building, where experimental results confirmed its significant vibration reduction capability and practical usefulness. Additionally, the study highlighted the prevalence of unwanted floor vibrations in light and long-span floor systems caused by human activities such as walking and jumping, which often result in occupant discomfort. To address this serviceability issue, the research introduced a novel passive viscoelastic four-arms damper, specifically designed to reduce floor vibration amplitudes. Overall, this comprehensive study provided valuable numerical, experimental, and practical insights into the design, optimization, and implementation of passive vibration control devices, establishing TMDs, VTMDs, and viscoelastic dampers as effective solutions for improving the dynamic performance and serviceability of concrete floors and flexible structural systems.

In 2012, Zoran T. Rakicevic, Aleksandra Bogdanovic, Dimitar Jurukovski, and Peter Nawrotzki published a significant experimental research paper titled *"Effectiveness of Tuned Mass Damper in the Reduction of the Seismic Response of the Structure"* in the Bulletin of Earthquake Engineering. This study represents one of the early large-scale shaking table experimental investigations focused on evaluating the seismic performance of tuned mass dampers (TMDs) in real structural systems. The authors conducted extensive experimental testing on a 16.6-ton, five-storey steel frame structure, equipped with a TMD installed at the roof level, referred to as a Tuned Mass Control System (TMCS). The experiments were carried out at the Institute of Earthquake Engineering and Engineering Seismology (IZIIS), Skopje, using a shaking table to simulate a wide range of earthquake ground motion records. By subjecting the structure to multiple seismic time histories both with and without the TMCS, the study quantitatively demonstrated the effectiveness of the TMD in mitigating seismic responses. The experimental results showed that the TMCS was capable of reducing structural responses by approximately 10% to over 50%, depending on the frequency content of the earthquake excitation and the dynamic characteristics of the structure. In addition to experimental testing, the authors developed a high-fidelity analytical model of the structure–TMD system, which was used to perform extensive parametric and variant analyses. These analyses examined the influence of key design parameters such as TMD tuning frequency, mass, damping, and installation location on the overall vibration control efficiency. A particular emphasis was placed on studying the effect of TMD placement at different storey levels, revealing that roof-level installation generally provides superior vibration mitigation due to higher modal participation. Furthermore, a comparative evaluation between an optimally tuned TMCS and a TMCS with mechanical properties identical to the tested specimen demonstrated that optimal tuning significantly enhances seismic performance, especially when the dominant earthquake frequency content aligns closely with the structural natural frequencies. The study conclusively established that the effectiveness of TMD systems is highly dependent on accurate tuning and proper placement, and that well-designed TMDs can serve as a powerful passive seismic control strategy. Overall, this research provided strong experimental and analytical evidence supporting the use of tuned mass dampers for seismic response reduction and laid an important foundation for subsequent developments in advanced passive and adaptive vibration control systems.

III. RESEARCH GAP

A critical synthesis of the ten reviewed studies on vibration control of structures using tuned mass dampers (TMDs) and their advanced variants reveals significant progress in both theoretical development and experimental validation; however, several important research gaps still persist. Although extensive experimental and numerical investigations have confirmed the effectiveness of conventional passive TMDs in reducing wind-, seismic-, and human-induced vibrations in buildings, bridges, and floors, the majority of existing studies focus on single-mode control and idealized linear behavior of structural systems. The performance of TMDs under multi-modal excitation, especially in tall, irregular, and flexible structures, remains insufficiently explored. Furthermore, while recent advancements such as multiple tuned mass dampers (MTMDs), distributed MTMDs, adaptive TMDs, variable stiffness TMDs, and tuned mass damper inerter (TMDI) systems have demonstrated enhanced robustness and efficiency, their comparative performance under identical structural and loading conditions has not been systematically evaluated, limiting the ability to identify optimal damper configurations for practical applications.
Another major gap identified is the sensitivity of passive TMDs to mistuning, which arises due to uncertainties in structural properties, environmental variations, aging, and construction tolerances. Although adaptive and semi-active TMD systems have been proposed to address this issue, most studies remain limited to laboratory-scale experiments or numerical simulations, with very few full-scale implementations or long-term performance assessments under real operational conditions. Additionally, existing frequency identification and retuning strategies often assume simplified system behavior and do not adequately account for nonlinearities introduced by friction, backlash, material yielding, and large-amplitude vibrations, which can significantly influence damper effectiveness. The reviewed literature also indicates a lack of comprehensive studies addressing the combined effects of seismic, wind, and human-induced excitations, despite the fact that real structures are frequently subjected to multiple dynamic loading sources throughout their service life. Most studies treat these excitations independently, thereby limiting the generalizability of their conclusions. Moreover, while experimental studies have demonstrated notable reductions in displacement, acceleration, and damping ratios, there is limited focus on fatigue performance, durability, maintenance requirements, and life-cycle cost analysis of TMD and advanced damper systems, which are critical for large-scale implementation in infrastructure projects. From a modeling and analysis perspective, many investigations rely on linear time-history or frequency-domain analyses, with limited incorporation of material nonlinearity, geometric nonlinearity, and uncertainty-based probabilistic frameworks. This restricts the accuracy of response prediction and may lead to suboptimal damper design, particularly for high-rise buildings and long-span bridges subjected to extreme loading scenarios. Additionally, the optimal placement, number, and distribution of dampers in complex three-dimensional structures remain open research questions, as most studies focus on roof-level or single-location installations.

Finally, despite the growing emphasis on performance-based design and sustainability, there is a noticeable lack of research integrating TMD-based vibration control systems with modern design codes, smart sensing technologies, and low-energy adaptive mechanisms. The potential of combining passive robustness with adaptive intelligence, while ensuring economic feasibility and ease of implementation, has not been fully realized. Therefore, there exists a clear research gap in developing a comprehensive, robust, and scalable vibration control framework that integrates advanced TMD configurations, nonlinear and uncertainty-aware analysis, multi-hazard loading scenarios, and practical design considerations. Addressing these gaps is essential to enhance the reliability, adaptability, and real-world applicability of tuned mass damper systems in modern civil engineering structures.

CONCLUSION

This review paper has presented a comprehensive synthesis of experimental, numerical, and analytical research on the application of tuned mass dampers (TMDs) and their advanced variants for vibration control in modern civil engineering structures. The reviewed literature clearly demonstrates that TMD-based systems are highly effective in mitigating structural vibrations induced by seismic events, wind loads, human activities, and machine operations, particularly in tall, slender, and lightweight structures that inherently possess low damping characteristics. Conventional passive TMDs have been shown to significantly reduce displacement, acceleration, and inter-storey drift responses, thereby improving both structural safety and serviceability performance. However, their effectiveness is strongly influenced by tuning accuracy, mass ratio, damping characteristics, and placement within the structure, making careful design and optimization essential. Recent advancements in vibration control technology, such as multiple tuned mass dampers (MTMDs), distributed MTMDs, adaptive and variable stiffness TMDs, and tuned mass damper inerter (TMDI) systems, have addressed several limitations associated with traditional single TMD configurations. These advanced systems exhibit enhanced robustness against frequency mistuning, improved efficiency in multimodal vibration control, and greater adaptability to uncertainties in structural properties and loading conditions. Experimental studies, including laboratory-scale tests and full-scale field implementations, have validated the practical feasibility and superior performance of these advanced TMD configurations, particularly in controlling low-frequency vibrations in long-span bridges and serviceability-related vibrations in pedestrian bridges and floor systems. Despite these significant developments, the review highlights that further research is required to fully exploit the potential of TMD-based vibration control systems. Key areas requiring attention include the incorporation of nonlinear structural behavior, uncertainty-based and probabilistic analysis frameworks, multi-hazard loading scenarios, and long-term performance evaluation considering durability, fatigue, and maintenance aspects. In addition, the integration of TMD systems with modern sensing technologies, adaptive mechanisms, and performance-based design approaches remains an open and promising area of research. Overall, the findings of this review confirm that tuned mass dampers and their advanced variants represent a reliable, efficient, and scalable solution for structural vibration control, and continued research in this field will play a vital role in enhancing the resilience, comfort, and sustainability of future civil engineering infrastructure.

REFERENCES

1. Peng, S., Zhang, L., Chen, Y., & Chai, X. (2025). Experimental study on the performance of tuned mass damper inerter in suppressing low-frequency vibrations of long-span bridges: Model experiments and full-scale field tests. *Structures*, 73, 108357. https://doi.org/10.1016/j.istruc.2025.108357
2. Shaikh, I. A., Kulkarni, R. R., & Kedar, B. B. (2021). Application of tuned mass damper for vibration control of frame structures under seismic excitations. *International Journal of Creative Research Thoughts (IJCRT)*, 9(7), 352–358. ISSN: 2320-2882.
3. There, A. A., & Dahake, H. B. (2025). Experimental study of vibration control of framed structure using various dampers: A comprehensive review. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, 13(4), 857–864. ISSN: 2321-9653.
4. Bhattacharjee, B. (2012). An experimental study of tuned mass damper to control the vibration of concrete floors: Innovative techniques for vibration control in tall and flexible structures. *Journal of Advances in Science and Technology*, 4(7). E-ISSN: 2230-9659.
5. Rahimi, F., Aghayari, R., & Samali, B. (2020). Application of tuned mass dampers for structural vibration control: A state-of-the-art review. *Civil Engineering Journal*, 6(8). https://doi.org/10.28991/cej-2020-03091571
6. Mathew, B., & Anu, A. (2015). Vibration control of high rise structures by using tuned mass dampers. In *Proceedings of NCRACE–2015*, *International Journal of Engineering Research & Technology (IJERT)*, 3(29). https://doi.org/10.17577/IJERTCONV3IS29058
7. Wang, L., Nagarajaiah, S., Zhou, Y., & Shi, W. (2023). Experimental study on adaptive-passive tuned mass damper with variable stiffness for vertical human-induced vibration control. *Engineering Structures*, 280, 115714. https://doi.org/10.1016/j.engstruct.2023.115714
8. Rakicevic, Z. T., Bogdanovic, A., Jurukovski, D., & Nawrotzki, P. (2012). Effectiveness of tuned mass damper in the reduction of the seismic response of the structure. *Bulletin of Earthquake Engineering*, 10, 1049–1073. https://doi.org/10.1007/s10518-012-9342-5
9. Sayyed, A. B., Sonar, G., Suryawanshi, K., Shaikh, M. G., & Taware, S. (2020). Design and analysis of tuned mass damper system. *International Journal of Engineering Research & Technology (IJERT)*, 9(10). https://doi.org/10.17577/IJERTV9IS100244

10. Elias, S., & Matsagar, V. (2017). Research developments in vibration control of structures using passive tuned mass dampers. *Annual Reviews in Control*, 44, 129–156. https://doi.org/10.1016/j.arcontrol.2017.09.015
11. Chi-Chang Lin In, 'Vibration Control Of Civil Structures Using Tuned Mass Dampers With Adjustable Stiffness ' San Francisco, California, USA,pp. 18-23,August 2013.
12. S Pani , S.K Senapati , K.C Patra ,P Nath In "Review Of An Effective Dynamic Vibration Absorber For A Simply Supported Beam And Parametric Optimization To Reduce Vibration Amplitude" Int. Journal Of Engineering Research And Application Vol. 7, Issue 7, (Part -3), Pp.49-77,July 2017.
13. O R Jaiswal In "Simple Tuned Mass Damper To Control Seismic Response Of Elevated Tanks",13th World Conference On Earthquake Engineering Vancouver, B. C., Canada, Pp 2923, August 2004
14. Mr. Ashish A. Mohite, Prof. G.R. Patil In "Earthquake Analysis of Tall Building with Tuned Mass Damper " IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) PP 113-122
15. D. Rupesh Kumar and Fahimeh Hoseinzadeh In 'A Study on Effect of Water Tanks Modeled As Tuned Mass Dampers on Dynamic Properties of Structures' International Journal of Research In Engineering and Technology.
16. IS: 875 (Part 1) – 1987; "Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures – Dead Loads"; Bureau of Indian Standards, New Delhi.
17. IS: 875 (Part 2) – 1987; "Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures – Imposed Loads"; Bureau of Indian Standards, New Delhi.
18. IS: 875 (Part 3)– 1987; "Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures – Wind Loads"; Bureau of Indian Standards, New Delhi.
19. IS: 1893 (Part 1) – 2002; "Criteria for Earthquake Resistant Design of Structures – general provisions and buildings"; Bureau of Indian Standards, New Delhi.
20. Abe M and Igusa T. (1995). "Tuned mass dampers for structures with closely spaced natural frequencies." Earthquake Eng. and Struct. Dyn., Vol. 24, 247–261.
21. Agarwal P and Shrikhande M (2008) "Earthquake resistance design of structures", New Delhi, PHI Learning
22. Bandivadekar T.P and Jangid R.S (2012). "Mass distribution of multiple tuned mass dampers for vibration control of structures ". International Journal of Civil and Structural Engineering , Volume 3 ISSN 0976-4399.