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Review on Analysis of Multistory Building With and Without Tuned Mass Damper

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ABSTRACT: Urbanization and limited land availability have driven the development of tall buildings, which are highly susceptible to lateral forces induced by seismic activity and wind. Traditional structural designs may not always effectively mitigate these dynamic forces without substantial costs. This review paper examines the application of Tuned Mass Dampers (TMDs)-passive control devices that significantly enhance seismic resistance. The effectiveness of various TMD configurations and their comparative performance with other vibration mitigation systems are explored. A comprehensive literature review supports the utility of TMDs in improving structural resilience, especially in high-rise buildings.

I. INTRODUCTION

Seismic activity remains one of the most unpredictable and destructive natural hazards, posing significant challenges to structural engineers. Buildings must be designed not only for vertical loads but also to withstand the complex dynamics of ground shaking. The Tuned Mass Damper (TMD) is one such innovation that helps mitigate lateral vibrations by absorbing dynamic energy through a secondary mass-spring-damper mechanism.

TMDs are especially relevant in seismic zones and in flexible high-rise structures where conventional strengthening may prove either inefficient or uneconomical.

1. Tuned Mass Damper (TMD) Technologies

1.1 Types of TMDs

- Simple TMD (STMD)
- Viscoelastic TMD (VETMD)
- Pendulum TMD (PTMD)
- Frictional TMD (FTMD)
- Hybrid TMD
- Viscous TMD (VTMD)

1.2 Placement and Design Considerations

- Typically installed at the top floor for maximum displacement capture.
- Mass ratio ranges from 3% to 5% of the total structural mass.
- Proper tuning is essential for effectiveness.

2. Modern Seismic Control Alternatives

- Base Isolation Systems
- Shear Walls
- Moment-Resisting Frames
- Cross-Bracing and Mat Foundations

II. LITERATURE REVIEW

The application of Tuned Mass Dampers (TMDs) in vibration mitigation for multistory buildings has been the subject of numerous studies over the past decade. Researchers have explored a variety of configurations, mass ratios,

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installation strategies, and comparative technologies to assess the effectiveness of TMDs in both seismic and wind-induced dynamic scenarios. This section provides a comprehensive and clarified synthesis of key studies:

2.1 Design and Effectiveness of TMDs

- Prashanthi (2024) [21] Conducted parametric analysis using ETABS to study Pendulum Tuned Mass Dampers (PTMDs). The study found that the effectiveness of PTMDs increases with mass ratio up to a certain point, after which performance diminishes. The tuning of mass and frequency ratio was identified as critical to minimizing displacement and enhancing performance.
- Fouad Y. Alhamashi and Waleed K. Al-Ashtrai (2022) [20] Introduced a Friction Tuned Mass Damper (FTMD) system that integrates movable hose clamp ball bearings with fixed shafts. The combined frictional and mass damping mechanism successfully reduced seismic response in a two-story model.
- Mirza Aamir Baig (2020) [9] Studied a 15-storey building and demonstrated that increasing TMD mass ratios (0.01 to 0.04) significantly reduced building displacement (up to 29.1%) and improved damping efficiency (up to 11.09%).
- Ishtiak Anwar Shaikh et al. (2021) [10] Modeled a multi-degree-of-freedom frame structure and observed that TMDs are effective in reducing vibrations but become less efficient when the structure has a high damping ratio (e.g., 5%).
- Anupama Sanan and Kiran Jacob (2020) [32] Evaluated various structural geometries using ETABS and concluded that a 3% mass ratio was most effective for I- and T-shaped buildings, while 2% was ideal for L-shaped structures. Displacements and shear forces were reduced by up to 25%.

2.2 Seismic Performance and Comparative Technologies

- Fadhil A. Jasim (2024) [15] Compared base isolation systems, TMDs, and multi-level seismic strategies in RC buildings. Found that base isolation increased the fundamental period of buildings by over 37% and effectively reduced base shear, though it could increase displacement at the isolation level. TMDs complemented isolation strategies well.
- Samina M. Kazi and Digvijay (2024) [16] Investigated liquid TMDs and base isolation in high-rise buildings. Highlighted how these technologies transform structural performance in seismic zones, particularly when integrated with various architectural layouts (e.g., L and T shapes).
- Davide Forcellini (2023) [22] Proposed inter-story seismic isolation as an effective alternative to base isolation. By strategically placing isolation layers in a 20-storey building, reductions in shear force, acceleration, and lateral drift were achieved.
- Min Ho Chey (2014) [14] Suggested using upper stories as semi-active TMD systems. Results showed enhanced isolation and control due to the use of resettable devices that respond dynamically to seismic excitation.

2.3 Optimization and Advanced Applications

- Fan Yang et al. (2021) [3] Provided a review of TMD design methodologies, focusing on modeling, optimization, and practical implementation. Emphasized future research directions involving hybrid and friction-integrated control models.
- Niraj Maharjan and Gokarna Bahadur Motra (2022) [23] Modeled high-rise buildings using ETABS with various TLD mass ratios (2%–5%) and concluded that a 3% ratio is optimal for minimizing displacement.
- M. Venkatesh Reddy and V. Rajendra Kumar (2020) [31] Explored the use of water tanks as TMDs. The best performance was observed when water levels were maintained between 1/2 and 3/4 of tank height, effectively reducing seismic response.
- R. K. Sharma (2019) [19] Applied TMDs to an offshore platform and recorded a 53–58% reduction in response under El Centro and Kobe earthquake conditions, demonstrating TMD versatility.
- Fahimeh Hosein Zadeh and D. Rupesh Kumar (2015) [17] Conducted large-scale ETABS simulations with 63 irregular RCC buildings and confirmed that assigning 3% of floor weight as damper mass yielded substantial vibration reduction.

2.4 Parametric Studies and Vibration Analysis

- Eswara Rao K. and Vamsi Krishna (2019) [8] Analyzed a 10-storey building using SAP2000. Found that increasing TMD mass ratios (3%, 6%, 9%) correspondingly reduced displacement from 28 mm to 7 mm.
- V. R. Sindhu Priya and Dr. Gopi Siddappa (2018) [29] Compared single TMDs and MTMDs (Multiple TMDs) and found that MTMDs with uniform mass distribution were more effective in reducing vibrations.

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- Chaitanya Halmare and Laxmikant Wairagade (2017) [33] Found that a 2% damping ratio was more effective than 5% for reducing displacement under earthquake loading. Increased mass ratios correlated with improved column performance.
- Hossein Shad and Azlan Adnan (2013) [11] Studied harmonic loading and observed that higher TMD mass ratios increased the structural reactance, reinforcing the value of precise tuning.

2.5 Software-Based Structural Analysis

- M. S. Landge (2017) [4] Performed comparative analysis of various dampers using the response spectrum method on a G+7 RCC structure. Validated TMD effectiveness in reducing displacement and acceleration.
- Khemraj S. Deore (2017) [5] Emphasized top-floor placement for TMDs, which showed maximum vibration reduction. Observed consistent decline in displacement and fundamental frequency.
- Ashish A. Mohite and Prof. G.R. Patil (2015) [24] Analyzed buildings ranging from 10 to 21 storeys. Found 5% mass ratio TMDs significantly effective in reducing top-story acceleration and displacement.
- Raveesh R. M. and Sahana T. S. (2014) [18] Modeled buildings with height-to-breadth ratios of 1 to 3 and found higher TMD mass ratios (0.25–0.75) improved vibration control, especially in zone-V seismic regions.

III. DISCUSSION

The extensive body of literature analyzed confirms the significant potential of Tuned Mass Dampers (TMDs) as a cost-effective, passive control mechanism to mitigate structural responses to dynamic loads, particularly in high-rise buildings located in seismically active or wind-prone regions.

A central theme across studies is the importance of mass ratio and tuning parameters. Most research agrees that mass ratios between 3% and 5% of the total building mass tend to yield the best results, although the exact optimal ratio varies depending on building height, shape, stiffness, and damping characteristics. For example, PTMDs and TLDs demonstrate a non-linear relationship with performance — beyond certain thresholds, increased mass can reduce effectiveness due to over-damping or structural incompatibility.

The placement of the TMD — typically at the topmost floor — continues to be emphasized for maximizing its dynamic response to displacement. However, recent innovations such as inter-story isolation, semi-active TMDs, and multi-level damping systems demonstrate promising avenues for even greater vibration control and structural adaptability.

The studies also reflect a growing shift toward hybrid systems, combining TMDs with base isolation, liquid damping, or semi-active control devices. These integrated systems can cater to a broader frequency range and adapt to varying seismic intensities, offering superior performance in complex or irregular building geometries.

It is also evident that the geometry of the building (L-shaped, T-shaped, I-shaped) influences the efficiency of TMDs. Optimized mass distribution and tuning for specific geometries are crucial. Additionally, multiple TMD configurations (MTMDs) have shown better performance compared to single dampers in distributing control forces and avoiding localized over-stressing.

Despite their effectiveness, TMDs come with limitations. Their requirement for significant space, added structural mass, and precision tuning pose challenges in both new constructions and retrofitting. In extreme loading conditions, large relative displacements and potential collisions must be accounted for in design.

IV. CONCLUSION

This review has underscored the pivotal role of Tuned Mass Dampers in the structural resilience of multistory buildings. Key takeaways include:

- TMDs are a proven passive solution for reducing seismic and wind-induced vibrations, particularly in tall, symmetrical, and flexible structures.
- Mass ratio, frequency tuning, and installation height are the most critical parameters influencing damper effectiveness.

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- Hybrid and adaptive TMD systems, combining passive and active elements, offer promising advancements in structural control.
- Proper structural modeling and software-based simulations (e.g., ETABS, SAP2000) are essential tools in optimizing damper configurations during the design phase.
- While TMDs have certain limitations, including spatial and structural integration concerns, these are often outweighed by the benefits in improved safety and serviceability.

Future research and practical implementations should focus on the integration of smart materials, real-time tuning mechanisms, and cost-effective manufacturing to broaden the applicability of TMDs in diverse building types and regions. With continued innovation, TMDs will remain a cornerstone of resilient, high-performance structural engineering.

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