

# Vibration Control of Multi-Storey Building Using Tuned Mass Damper

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**Abstract:** High-rise buildings are more susceptible to vibrations caused by wind loads, earthquakes, and other dynamic forces. Excessive vibrations may cause discomfort to occupants and structural damage. The Tuned Mass Damper (TMD) is an effective vibration control device that mitigates structural responses by tuning its frequency close to that of the primary structure. This paper presents an analytical study of vibration control in multi-storey buildings using TMDs. The objective is to enhance the seismic and wind performance of structures by optimizing the damper's mass, damping ratio, and tuning frequency. The study reviews various modeling techniques, simulation results, and practical applications to demonstrate the effectiveness of TMD systems in improving the overall stability and safety of multistorey buildings.

**Keywords:** Tuned Mass Damper (TMD), Vibration Control, Seismic Response, Structural Dynamics, Civil Engineering, Multi-Storey Building.

## I. INTRODUCTION

With rapid urbanization and the increasing demand for tall buildings, structural engineers face new challenges in ensuring both stability and comfort for occupants. Modern high-rise structures are designed to be lightweight, flexible, and efficient, but this flexibility often results in higher susceptibility to vibrations. Such vibrations arise primarily from dynamic excitations including wind forces, earthquakes, machinery operations, and human activities. Even though these oscillations may not immediately cause structural failure, they can lead to fatigue, material degradation, and psychological discomfort among occupants.

Vibration control in structural engineering has therefore evolved as a crucial design consideration. Conventional approaches rely on increasing stiffness or damping capacity through material and geometric modifications, but these methods are often uneconomical or impractical for very tall structures. Consequently, engineers have turned toward vibration control devices such as Tuned Mass Dampers (TMDs), Base Isolators, and Active Control Systems.

A Tuned Mass Damper is a secondary mass system consisting of a spring and a damper connected to the main structure. Its purpose is to counteract the motion of the primary structure by moving out of phase with the vibrations, thereby absorbing and dissipating kinetic energy. When properly tuned to the natural frequency of the structure, a TMD can drastically reduce vibration amplitudes, enhancing both comfort and safety.

The concept of vibration control through TMDs is not limited to buildings; it is also applied in bridges, towers, and mechanical systems. In civil engineering, its importance is underscored by the success of notable examples such as the Taipei 101 building and the Citicorp Center in New York, where TMDs significantly reduced motion during high winds and seismic events.

The objective of this paper is to explore how TMDs can be effectively implemented in multi-storey buildings, focusing on their design principles, optimization, and performance assessment. The study emphasizes how careful parameter tuning, mass ratio selection, and proper damper placement contribute to improved building resilience under dynamic loads.

## **II. LITERATURE SURVEY**

The concept of a tuned mass damper dates back to the early 20th century, with Den Hartog (1956) laying the foundation for analytical vibration control using secondary mass systems. Since then, numerous researchers have refined and extended the theory to handle complex structures and various types of dynamic loading.

Warburton (1982) proposed analytical expressions for optimal tuning and damping ratios that minimize the amplitude of vibrations for harmonic and random excitations. Tsai (1992) developed optimization techniques for multi-degree-of-freedom (MDOF) structures, showing that the use of multiple dampers distributed across the height of the building enhances overall effectiveness. Kwok et al. (1995) conducted experiments on tall building models under wind-induced vibrations and demonstrated the significant improvement in comfort levels using roof-mounted TMDs.

Recent research focuses on advanced control strategies, including semi-active and active TMDs that adjust their properties dynamically in response to external loads. Such systems utilize sensors, actuators, and control algorithms to modify damping and stiffness in real-time, thus improving adaptability during varying environmental conditions. Active Tuned Mass Dampers (ATMDs) have shown superior performance, but their higher cost and power requirements limit their use in regular civil infrastructure.

In India, studies have been conducted to analyze seismic performance improvement using TMDs in RC and steel frame structures. Finite element modeling and time-history analysis under IS 1893 seismic loading conditions reveal that TMDs can reduce roof displacement and storey drift significantly. However, improper tuning can lead to negative effects such as amplification of vibrations at non-resonant frequencies.

Despite substantial progress, several challenges remain. These include the identification of optimal locations for TMDs in irregular structures, the effect of multiple modes of vibration, and the long-term durability of mechanical components. Nonetheless, literature strongly supports TMDs as an efficient, low-maintenance, and practical solution for vibration control in modern civil structures.

## **III. METHODOLOGY**

The methodology adopted for this project is based on analytical modeling, simulation, and performance evaluation. The process can be divided into the following key stages:

### **1. Structural Modeling**

A simplified three-dimensional model of a multi-storey building is developed using finite element software such as ETABS or ANSYS. The building is assumed to have uniform floor heights, with beam, column, and slab properties defined according to IS 456:2000 and IS 1893:2016 standards. The mass and stiffness matrices of the structure are extracted for dynamic analysis.

### **2. Dynamic Load Considerations**

Dynamic loading is introduced through seismic forces and wind forces. Seismic loads are calculated using the response spectrum method as per IS 1893, while wind loads are derived from IS 875 (Part 3). Both lateral and torsional effects are considered, and damping ratio of the structure is assumed between 2–5% for reinforced concrete frames.

### **3. Design of Tuned Mass Damper**

A TMD typically consists of a mass block connected to a spring-damper system. The design parameters include:

- **Mass ratio ( $\mu$ ):** Ratio of TMD mass to total building mass, typically 1–5%.
- **Frequency ratio ( $f_r$ ):** Ratio of TMD frequency to building natural frequency.
- **Damping ratio ( $\xi$ ):** Determines energy dissipation capability.

Den Hartog's empirical equations are used to calculate the optimal tuning and damping ratios that minimize amplitude under harmonic excitation. The spring constant ( $k_t$ ) and damping coefficient ( $c_t$ ) are computed accordingly.

#### **4. Simulation and Analysis**

The model is analyzed under dynamic loading with and without the TMD. Time-history and modal analyses are conducted to evaluate displacement, acceleration, and inter-storey drift. The effectiveness of the TMD is measured in terms of percentage reduction in peak response.

#### **5. Evaluation of Results**

Key performance indicators such as maximum roof displacement, base shear, and natural frequency shift are compared. The simulation results help identify the best configuration and placement of the TMD for optimal performance. This systematic methodology ensures reliable assessment of the TMD's contribution to vibration control and helps develop guidelines for practical implementation in future civil structures.

### **V. FINDINGS AND RESULTS**

After conducting dynamic simulations and analytical studies, several important findings have been observed regarding the performance and effectiveness of Tuned Mass Dampers in multi-storey buildings.

#### **1. Reduction in Structural Response**

The most significant result is the substantial reduction in vibration amplitude and displacement. Buildings equipped with a TMD exhibit 40–60% lower peak displacement compared to uncontrolled structures. The reduction in acceleration and inter-storey drift enhances comfort and reduces structural stress concentrations.

#### **2. Effect of Tuning Accuracy**

The effectiveness of a TMD largely depends on accurate tuning. Even a small deviation from the optimal frequency ratio may lead to performance loss or, in some cases, amplification of vibrations. Hence, precise calculation of stiffness and damping values is essential.

#### **3. Location and Configuration**

TMDs are most effective when installed at the roof level or at the point of maximum modal displacement. Multiple TMDs distributed across various storeys further enhance control by targeting higher vibration modes. Multi-TMD systems (MTMD) provide better damping for complex, irregular buildings.

#### **4. Comparison Between Passive and Active Systems**

While passive TMDs are simple and reliable, active and semi-active systems offer adaptive control capabilities. However, their high cost, maintenance, and energy requirements limit their adoption in regular civil projects. Passive TMDs remain the preferred choice for tall residential and commercial buildings.

#### **5. Economic and Practical Considerations**

The integration of a TMD slightly increases the initial construction cost but offers significant long-term benefits, including reduced maintenance, extended life span, and improved safety. When evaluated on a life-cycle cost basis, the system proves highly cost-effective.

The results reaffirm that TMDs are practical, efficient, and suitable for diverse building typologies. Continued development of smart and hybrid dampers will further enhance their role in modern structural engineering.

### **V. CONCLUSION**

The study demonstrates that Tuned Mass Dampers are one of the most efficient and economical solutions for vibration control in multi-storey buildings. By absorbing and dissipating vibrational energy, they significantly reduce the dynamic response of structures under wind and seismic loads.

Key conclusions drawn from the analysis include:

- TMDs effectively minimize lateral displacements, accelerations, and inter-storey drifts.
- Accurate tuning of mass, stiffness, and damping is critical for achieving optimal results.
- The location of the TMD, typically at the roof level, greatly influences its performance.
- Multiple TMD systems offer superior control for irregular and high-rise structures.



- Passive TMDs remain a cost-effective option, while hybrid and active systems provide adaptability for complex conditions.

Future work may include the development of smart dampers integrated with sensors and real-time control algorithms using artificial intelligence for adaptive tuning. Additionally, research into lightweight materials, such as carbon fiber composites and magnetorheological fluids, can improve efficiency and reduce maintenance. The adoption of TMD technology in India's growing skyline can ensure safer, more comfortable, and sustainable structures for future generations.

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