Analysis of tuned mass damper effect on vibration control over tall building in seismic prone areas – A state-of-art review

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Abstract. Vibrations are one of the main environmental elements that influence buildings and mechanical structures, potentially shortening their lifespan. Taller, lighter, more flexible structures are required by current trends in the construction sector, yet they have relatively low damping values. This raises the likelihood of failure and causes issues with serviceability. If the frequency of excitation coincides with one of the inherent frequencies of the system, many building structures and bridges will collapse due to vibration. Today, a variety of techniques are available to reduce a structure's vibrations. One of these is the idea of using a tuned mass damper, which has become popular recently. In this paper a study has been investigated which is on the behaviour of tall building when it is equipped with Tuned Mass Damper. It is observed that buildings with Tuned Mass Damper are more resistant to seismic vibrations compared to the buildings without Tuned Mass Dampers.

1 Introduction

The increasing height of high-rise buildings offers substantial challenges for structural engineers and experts. One of the many intricate technical considerations associated with design is surely the effect of wind as well as earthquakes upon the structures. The most significant challenge is that both the serviceability and safety (strength) criteria must be carefully studied and met in the design. Modern structures get more flexible and thinner as they get taller. The serviceability of such structures is virtually always impacted by their sensitivity to wind excitations. Since that these constructions are usually always vulnerable to seismic excitations, serviceability becomes a crucial concern. Most of the time, a tall building's natural dampening is insufficient to meet the serviceability criteria. By changing rigidities, weights, damping, or shapes, as well as by applying passive or active counterforces, it is possible to manage structural vibrations brought on by earthquakes or winds. Due to internal strain, friction, cracking, plastic deformations, and other factors, all vibrating structures dissipate energy. The amplitudes of vibration are inversely proportional to the energy dissipation capacity. Certain structures endure enormous vibration amplitudes even during moderately powerful earthquakes because they have very poor damping of the order of 1% of critical damping.

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1.1 Tuned Mass Damper (TMD)

A mechanical vibration-dampening device placed in structures is known as a tuned mass damper (TMD), sometimes known as a harmonic absorber or seismic damper. It is made up of a mass that is supported by one or more damped springs. Its oscillation frequency is designed to be close to the resonance frequency of the object to which it is mounted, resulting in a reduction in its maximum amplitude while weighing far less than the item. TMDs can prevent annoyance, injury, or total structural breakdown. They are commonly found in motor vehicles, building projects, and power transmission.

1.2 Working principle of TMD

Harmonic vibrations result from a jerky motion, which TMD reduces. In order to reduce the system's worst-case vibrations, a comparatively light component to reduce the system's vibration. Practical systems are often tuned to either dampen a resonance which is expensive and hard to directly dampen or move the principal mode away from an undesirable excitation frequency. Instances of the latter include crankshaft torsional dampers. Mass dampers are frequently utilized with a frictional or hydraulic component, like an automotive shock absorber, that transforms mechanical kinetic energy into heat. motor with mass m1 vibrates while it runs, and the soft motor mounts serve as a parallel spring and damper, k1 and c1, when the motor is mounted to the ground through motor mounts. F0 is the force acting on the motor mounts. A smaller mass, m2, is coupled to m1 by a spring and a damper, k2 and c2, to minimize the maximum force on the motor mounts as it runs at various speeds. F1 is the force that the motor really experiences when it is operating

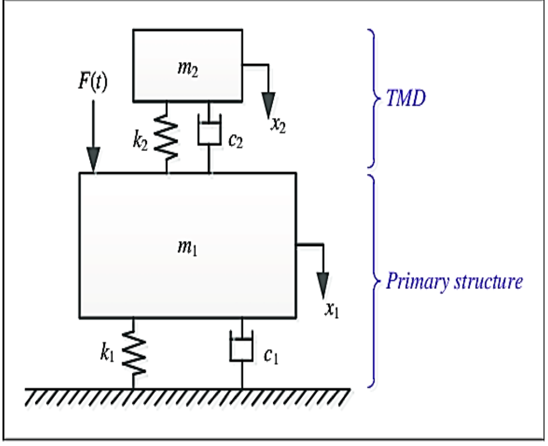

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Fig.1. Tuned Mass Damper (TMD)

1.2.1 TMD in Bridges

The TMD is a popular technique for adding dampening to bridges. The prevention of significant vibrations caused by resonance with pedestrian loads is one application for TMDs in bridges. A TMD increases the structure's damping, which lowers the vibration of the structure since the damping of the structure has an inverse relationship with the steady-state amplitude of the vibration.

1.2.2 TMD in Spacecraft

A design strategy to reduce peak loads on NASA's Ares solid fuel booster from 6g to 0.25g called for the use of 16 tuned mass dampers (TMDs), with the conventional vibration isolators among the upper stages then the booster handling the remaining reduction from 1g to 0.25g. At frequencies, nutation development occurs in spin stabilized satellites. Spin-stabilized satellites have been equipped with eddy current nutation dampers to control and stabilize nutation.

1.2.3 TMD in Transmission lines

Small barbell-shaped Stockbridge dampers are frequently suspended from the wires of high-tension lines to mitigate the high-frequency, low-amplitude oscillation commonly referred to as flutter.

1.2.4 TMD in Wind Turbines

Employing springs and dashpot parts, the primary structure of a TMD of wind turbines relates to an auxiliary mass. This dashpot damping ratio and the TMD's spring constant basically determine the natural frequency of the device. Utilising the tuned parameter of the TMD, the auxiliary mass may oscillate with a phase shift relative to the motion of the structure. A wind turbine's auxiliary mass is frequently positioned beneath the nacelle and is supported by friction plates or dampers.

1.2.5 TMD in Buildings

The huge concrete blocks or steel bodies used to construct skyscrapers or other structures function as dampers. Using springs, fluid, or pendulums, these bodies oscillate at a different frequency than the structure's resonance frequency.

2 Review of Literature

A significant amount of research work has been done on studying the seismic behavior of a tall building with and without Tuned Mass Damper by many investigators using different computer software's such as,

Tejas [1] revealed the behavior of an RCC structure that is susceptible to seismic activity for water tanks modelled in this construction as passive tuned dampers on the upper storyWith the use of IS 1893:2016 Part-1, dynamic studies such as Response Spectrum (RS) and El-Centro time history (TH) analysis were carried out. A square RCC building has a 1.63 H/D ratio with TMDs modelled with total mass ratios of 2.5, 5 , 7.5, and 10% of the first mode, a mass source of (1DL+0.25LL), a dampening ratio of 5%, and vertical irregularity through the inclusion of soft storey at the building's bottom, middle, along top storeys. Ishtiak [2] evaluate TMD's effectiveness in reducing structural vibration. A numerical algorithm was developed to first investigate the response of a shear building fitted with a TMD. At the base of the construction, three loading models were utilised. The first represented a sinusoidal loading, the second fitted an adequate temporal history, and the final one was the measurement of the 1940 El Centro Earthquake with (PGA = 0.313g), corresponding to the spectra of IS-1893 (Part -1):2002 for 5% damping at hard soil with (PGA = 1g). The examination shows that TMD can be effectively utilised for controlling structural vibration. TMD performed better when the damping ratio of the structure was smaller. As the mass ratio of the TMD increases, the structure's response to displacement steadily diminishes. *Admane* [3] evaluated how effective TMD is at reducing structural vibration. The structure is examined using numerical stimulations both with and without TMD. SAP2000 is used for G+11, rectangular structure and a direct integration approach for analysis. TMDs with percentage masses of 2%, 3%, 4%, and 5% are obtained using three different independently validated time histories of previous EQ. The top building deflection is decreased by a soft storey by 20% to 61%. The following occurrence of time history becoming compatible is the top building deflection, which is reduced by a soft storey in the Northridge EQ by roughly 6% to 15%. In the Taft EQ, a soft storey at the top of the building reduces top building displacement by around 38% to 67%, making this the third occasion when the TH is compatible. Among 2% to 5% TMDs, 5% TMD is found to be more effective at reducing displacement than 2%, 3%, and 4% TMDs. *Ashish* [4] investigated the seismic behaviour of buildings with tuned mass dampers and those without were examined for buildings with 10, 12, 14, 16, 18, and 21 stories. For the typical building construction, it is found that 5% TMD effectively lowers top floor displacement. building's eleventh story was lowered. For the typical building construction, it is found that 5% TMD effectively lowers top-floor displacement. The base shear (BS) is decreased by about 2%, the BS is minimised by 38.13 for the 10th storey, 36.36 for the 12th top storey building, 35.16 for the 14th storey , 33.34 for the 16th storey, 31.96 for the 18th storey, and 30.46 for the 21st storey.

Balakrishna [5] improved the seismic response of buildings in earthquake-prone areas, they talked of adopting passive energy absorbing devices. Here, a 6-story conventional building is examined using SAP2000 v14 both with and without a TMD and a viscous damper (VFD). With varying mass ratios of 2%, 3%, and 5%, TMDs were employed. According to a study analysing the Bhuj earthquake's non-linear time history, conventional framed buildings may effectively decrease base shear by roughly 10–35% and top storey displacement by about 10–25% with 3% TMD. *Alex Y. Tuan* [6] analysed structural dynamics of the Taipei 101 Tower were examined in relation to a TMD. A comprehensive dynamic analysis is used to evaluate the performance of the structure-TMD system, and the findings show that the TMD for this building greatly reduces wind-induced vibrations. TMD is typically close to the top of a tall building. When the frequency of the TMD is tuned in accordance with the dominant vibration frequency of the primary structure, the acceleration responses in the along-wind, as well as across-wind directions, are drastically decreased by 31.7% & 33.8%, respectively. A remote EQ event's overall acceleration is reduced by 13%.

Thakur [7] clarified how TMD is used as a soft story that is added on top of the framework. The direct integration method is used by the FE programme SAP 2000 to analyze a rectangular, six-story building. The percentage masses of the TMDs in this area are 2% and 3%. Three different reported time histories of prior earthquakes are used in the investigation. Structures that contain and do not include TMD are compared using comparative analysis. Often, a soft story at the top of a structure lessens the building's top's deflection by 10% to 50%. When it comes to axial force, bending moment, and displacement reduction, the 3% TMD outperforms the 2% and 3% TMDs. *Waseem Khan* [8] investigated into the seismic behaviour of a structure with and without a damper at various earthquake acceleration frequencies. The dampers that are needed for the suggested system are installed on the 5th and 9th floors of a nine-story building frame, and the outcomes are analysed to determine which shape functions best. According to IS-1893 2002 non-linear TH investigations of body shape, dampers installed in building bodies from the base assist to the 5th level and the base guide to the 9th floor effectively decrease maximum displacement and BS, and maximum acceleration.

Vyacheslav [9] studied substantial acceleration as well as amplitude of vibrations of the upper floors under dynamic wind impacts, they investigated the use of TMD in high-rise building construction. Analysis takes place on people's vulnerability to acceleration in tall buildings and potential solutions for lowering wind-induced oscillations in structures. The data of TMD use in high-rise building around the globe were displayed. *Martin* [10] talked about the energy from the protected structure is transferred to the control device using TMDs, which are devices that can lessen structural vibration. This study examines how seismic recordings from close to a fault affect structures that include TMDs. There are limited pulses of high amplitude and low frequency in this seismic record type's short substantial duration. Since the TMD has a very short time to transfer the energy from the main structure, these qualities create concerns about how well it will function over this type of seismic event. *Bari Sayyed* [11] investigated the efficacy of TMD in reducing structural vibration. On single degree of freedom structural frames that are sensitive to external excitation, the article provides a comparison analysis of passive vibration control systems with un-damped systems. To quantify vibrations and analyse the data into an acceleration vs. time graph, an accelerometer and Arduino Uno R2 combined unit is used. Based on the initial findings, we can draw a conclusion. To conduct the experiment for studying the TMD, a practical replica was created and produced. *Gutierrez* [12] investigated 8 distinct sets of equations for adjusting the TMD's parameters have been investigated in this research employing a 5-story building with irregular plan and elevation, as well as a 15-story and a 20-story building having irregular plan that has been being subjected to seismic loading. For structures having a fundamental period of vibrations higher than one second, suitable formulae are advised. The performance of the BTMD in lowering vibration responses is found to be influenced by the rigidity of the structure by looking at the displacement, acceleration, and base shear data; it is more efficient for higher and more flexible structures.

3 Conclusions

In India, the construction of tall structures has increased significantly, posing new problems that call for engineering judgement. It can be quite challenging to choose the right structural plan for a tall building that will be vulnerable to seismic loads. To reduce horizontal displacement and storey drift, a very effective and efficient structural technology has been used: the tuned mass damper system. Yet, as a structure's height increases, it lacks the necessary rigidity to keep the storey drift within acceptable bounds. A structural mechanism called TMD (tuned mass damper) was developed for such tall constructions. This technology assists in minimizing structural movement, storey drift, and lateral displacement. Although many analyses have been conducted over the years, the improvements in technology and structural analysis techniques have led to more accurate results. Consequently, using some cutting-edge technologies to do structural analysis is necessary. The ETABS programme is proposed in the later study to analyse and examine the many aspects of structural performance. In earlier research, scientists merely considered the regular geometry of the structure, placing TMDs (tuned mass dampers) at various story levels under seismic strain to determine the structure's ideal position.

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