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Enhancing Building Stability and Seismic Resilience with Water-Added Tuned Mass Dampers

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Abstract
These days, the construction industry is increasingly producing buildings with extremely low damping values. Under structural vibrations caused by storms and earthquakes, structures can collapse easily. There are now several methods for reducing structural vibrations, and one of the methods currently employed is the Tuned Mass Damper (TMD). Research is being conducted to determine its performance and importance. The entire damper was tuned for various constructions. An eight-story model specifically designed for the structure was used in this study to observe the structure's response with and without TMD during shaking table experiments. Compared to passive control devices (PTMDs), Active Tuned Mass Dampers (ATMDs) are more efficient as they are active control devices powered externally. By maintaining the structure's frequency, damping, and stiffness constant, other variables such as the percentage reduction in structural capacity can effectively control structure vibrations. The findings and observations from TMD studies can be used to address challenges in earthquake structural control considering current technological limitations and energy demands. The results illustrate significant improvements with damping: the damped structure experienced a 21% increase in acceleration, a 17% increase in velocity, and a 79% reduction in displacement compared to the undamped structure. These findings underscore the effectiveness of damping in mitigating earthquake-induced vibrations.

Keywords: Tuned Mass Damper, Active Mass Damper, Building Stability, (TMD and ATMD), Enhancing Structural Performance, Water-Added Tuned Mass Dampers, Vibration, Earthquake Mitigation Strategies.

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1. Introduction

A structure's reaction to an earthquake's excitation. In areas where earthquakes are common, this is necessary for the Continuous structural analysis component called "earthquake" which deals with calculating structural design, structural evaluation, and retrofitting of the buildings [1]. To reduce the growing space issues in metropolitan regions, the number of tall structures is growing these days. These buildings are very adaptable and have extremely low damping values. When confronted with severe seismic motion, these structures should be built to deform beyond the elastic limit to counter dynamic forces by amix of strength, flexibility, and energy absorption [2], [3], and [4].

In the experiment, the model is linear taken into consideration. One way to study this is by taking a nonlinear model into account. In the upper part of the building, we placed the adjusting block on two iron strips that moved according to the sliding of the block during the earthquake., and a decrease in responsiveness was noted. Positioning the damper consists of using water as part of the damper mass, which leads to increasing its mass and thus increasing its efficiency in damping vibrations [5], [6], and [7].

The following is a summary of the studythat has been done on the issue and will assist us in making a decision. Numerous scholars have made significant contributions to the advancement of our comprehension of the Tuned Mass Damper

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experimental investigations [8]. To simulate the overall impact of the vehicle, a three-axis, and two-degree freedom system was used to reduce the structural vibration of a three-span box steel bridge [1], [9]. The kinematic equation was derived using the Bernoulli-Euler package, which takes the bridge surface roughness into account, ignoring the torsional DOF [10]. Effectively reduces free body vibration by using TMD effects on steel box bridges it is ineffective in lowering the maximum deflection. It demonstrates that the maximum static deflection cannot be controlled by the TMD, but only the dynamic amplitude [11], [12]. The mass at various frame structure floors, further research may be done by utilizing numerous tuned mass dampers (TMD) set at different levels and with different modal frequencies, the study may be expanded. The actuator on their suggested HMD was a PTMD that was fastened to the TMD mass. The authors found that the suggested HMD performs significantly better than a PTMD after doing this comparison [13].

In the work of Banerji et al. [14], the research examines the effectiveness of tuned liquid dampers (TLDs) in reducing the response of single-degree-of-freedom (SDOF) structures to earthquake ground motions. It concludes that a well-designed TLD can significantly mitigate the structural response. The TLD used is a rigid, rectangular tank with shallow water, tuned to match the structure's natural frequency. It proves more effective with higher ground excitation levels, dissipating energy through sloshing and wave breaking. The study challenges previous findings by suggesting a larger water-depth to tank-length ratio and a higher water-mass to structure-mass ratio for optimal performance under strong earthquakes. It highlights that the reduction in structural response remains consistent across different ground motion bandwidths but depends on the relative frequencies between the structure and ground motion. Finally, practical design recommendations are provided for implementing TLDs to control earthquake responses effectively.

One of the important topics in structural engineering is dynamic loads such as earthquakes, strong winds, and similar matters [1], [9]. neuro central algorithm (v) based on modal-energy for the management of civil constructions during seismic tremors. The controller employed the control signal and the modal energy to minimize the structure's modal energy, which served as an objective function for the controller training. An AMD-equipped three-story nonlinear structure was utilized by the writers. The method was shown to be effective in lowering the modal energy and structural reactions. Finally, nonlinear hysteretic behaviors were seen in the uncontrolled situation but nearly vanished in the MEBNC-regulated instance.

In the work of Kayabekir et al. [15] adjusted a harmony search method using a musical theme for an ATMD's and a PID controller's settings. the authors used a ten-story sheer skyscraper to show how successful their plan was. It was discovered that the ATMD performed 22.51% better than a PTMD and could minimize the structure's maximum displacement by 53.71%. In the study of [16], Experimental tests were conducted to evaluate the efficiency and effectiveness of water-damped tuned mass dampers in seismic vibration control. Prototype models incorporating water-filled dampers were designed, and subjected to simulated earthquake vibrations of varying intensities. The results of the experiments demonstrated that utilizing water in tuned mass dampers can enhance their ability to dampen seismic vibrations compared to traditional dampers. Water's effectiveness lies in increasing the overall mass of the damper, thereby reducing disruptive vibrations in the building.

This study underscores the importance of using damping materials like water in tuned mass damper technologies to bolster building stability and improve earthquake resistance. It provides experimental evidence supporting the effectiveness of such technologies in mitigating seismic vibration [17], The study focused on the optimal design of earthquake-resistant containment for FPS-isolated nuclear power plants using electromagnetic-tuned liquid column dampers. Published in the Journal of Mechanical Science and Technology, it aimed to enhance the seismic performance of nuclear systems through advanced damper technologies [18]. This paper presents an experimental assessment conducted on one of two identical high-rise towers of the

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European Court of Justice in Luxembourg. The assessment focuses on the dynamic characteristics before and after the activation of tuned liquid dampers (TLDs), specifically tuned to the frequency of the first mode of the structure.

The primary objective was to evaluate structural damping and the impact of TLD activation. Two full-scale test methods were employed: operational modal analysis using ambient vibrations, and harmonic forced vibration tests using centrifugal mass exciters. These tests targeted three modes with natural frequencies around 0.44 Hz, 0.57 Hz, and 0.82 Hz. The assessment revealed a significant increase in damping after activating the TLDs. Specifically, the damping ratio for the first mode increased from 0.8% to 3.8%, indicating a more than five-fold increase. The second mode also showed increased damping, although to a lesser extent, from about 0.8% to 1%. The third torsional mode, with approximately 0.6% damping, remained unaffected by the TLD activation. The study suggests the nonlinear behavior of the TLDs, with higher damping observed at higher vibration levels. Overall, the results demonstrate the effectiveness of TLDs in enhancing damping ratios, particularly in mitigating vibrations associated with the first and second modes of tall buildings.

In the work of Gur et al. [19], the authors evaluate the efficiency of the tuned liquid column ball damper (TLCBD) as a passive vibration control device for structures, particularly under random earthquake events. Compared to the traditional tuned liquid column damper (TLCD), the TLCBD is introduced for enhanced performance. The study employs stochastic analysis to assess the response of a single-degree-of-freedom system equipped with TLCBD and compares it with TLCD. Results indicate that TLCBD significantly improves the structure's response reduction and enhances control over the liquid column itself. Key factors influencing TLCBD's performance include the optimal tuning ratio and the ratio between the ball and tube diameters, which are proposed and analyzed in the paper. Parametric studies confirm the robustness of TLCBD's performance under various loading conditions and parameter variations. Additionally, the study validates the accuracy of optimal stochastic responses through deterministic analysis using recorded seismic motions. This research contributes to advancing the understanding and application of TLCBD for effective seismic vibration control in structures [19].

2. Experimental work

Many tall buildings and towers across the world employ tuned mass dampers, a low-cost seismic safety method that does not interfere with building operations. Consequently, until to this point, several studies have been carried out to determine how TMD might lessen the structure's numerical seismic shaking. There is, however, adearth of experimental research in this area. In addition to determining the effect of various factors such as tuning ratio, mass ratio, frequency ratio, etc., the aim of this study is to add a mass of water over the surface of the entire model under Si-Lucy loading to reduce the response.

The mass ratio of the dampers is about 20% of the weight of the total model, and the frequency ratio is the propagation frequency you perform is divided by the fundamental frequency of the structure, and the adjustment ratio is the dune aeration frequency divided by the structural frequency.

The purpose of this experiment is to investigate the dynamic behavior under sinusoidal ground motion, both with and without TMD, using a shaking table test. The platform of the shaking table is firmly fixed to the structure. It is possible to think of the structure's weight as It is located on the roof of the building. A sinusoidal motion will offer a more comprehensive comprehension of the structure system's behavior, as it comprises just one frequency. Through free vibration analysis, the structure's fundamental frequency is found.

3. Tuned Mass Damper Structure Model

An eight-story building the model has been made to scale down with a height of 136 cm and a foundation width of 35 cm, according to the following dimensions: First, the height of one floor is 15 cm. The thickness of the roof is 15 cm. The other dimension of the building is 30 cm. The use of a mass damper consisting of a mass of water 20% of

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the weight of the entire building is an inexpensive control that doesnot require external energy sources compared to other applications, a building has been prepared with the same dimensions mentioned without estimation technology, and to record the acceleration. To do force vibration analysis, the frame is excited at different frequencies, and the response is noted. Typically, signal analysis is broken down into the time and frequency domains; each domain provides a unique perspective and understanding ofthe vibration's nature. The first step in time domain analysis is to examine the signal as a function of time. The signal can be developed using a signal analyzer. Plots from the time history analysis provide details that aid in explaining how the structure behaves. The highest vibration level can be used to describe its behavior.

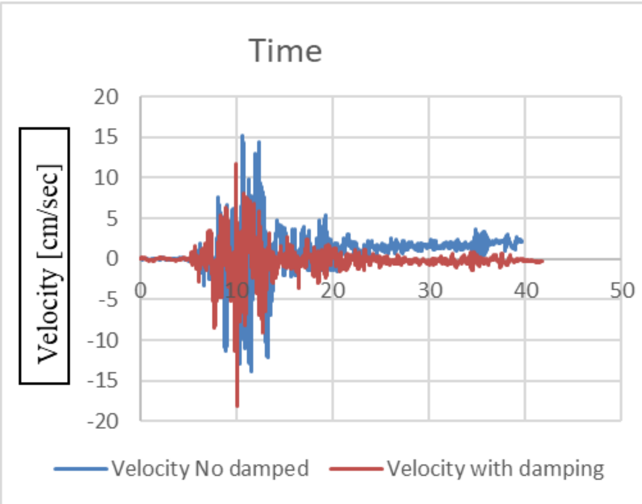
In addition, frequency analysis offers insightful data on structural vibration. Any signal with a temporal history can be converted to a frequency domain. For converting temporal signals into the frequency domain, theFourier Transform is the most widely used mathematical method. According to FourierTransform theory, a sequence of pure sine tones may be used to represent any periodic signal. Time waveforms in the structural analysis are sometimes measured and the resulting Fourier transforms are given. The Fourier Transform has beencomputationally enhanced to create the Fast Fourier Transform (FFT). Test experience can help one learn how to analyze frequency data to comprehend structural vibration.

4. Test Methods

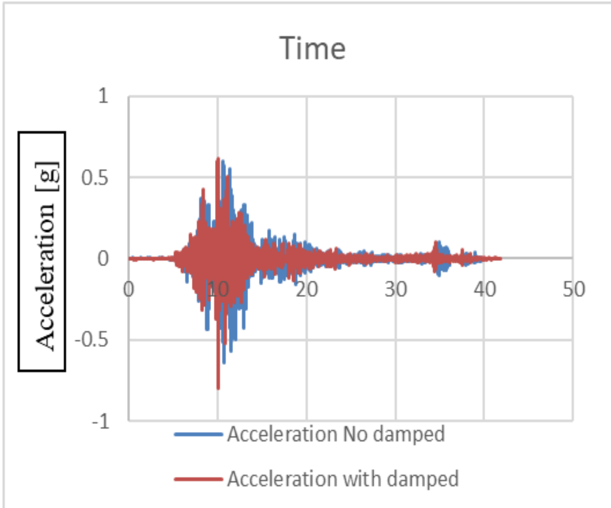
Weight of water mass=4Kg, wall thickness= 2 135cm building's =cm, building height fundamental frequency (f) is 1.90 Hz (found by free vibration study), amplitude of displacement (x0) = 2 cm, the stiffness of building (k)=3140 N/m, the stiffness of each column=k/4=785 N/m.

5. Results

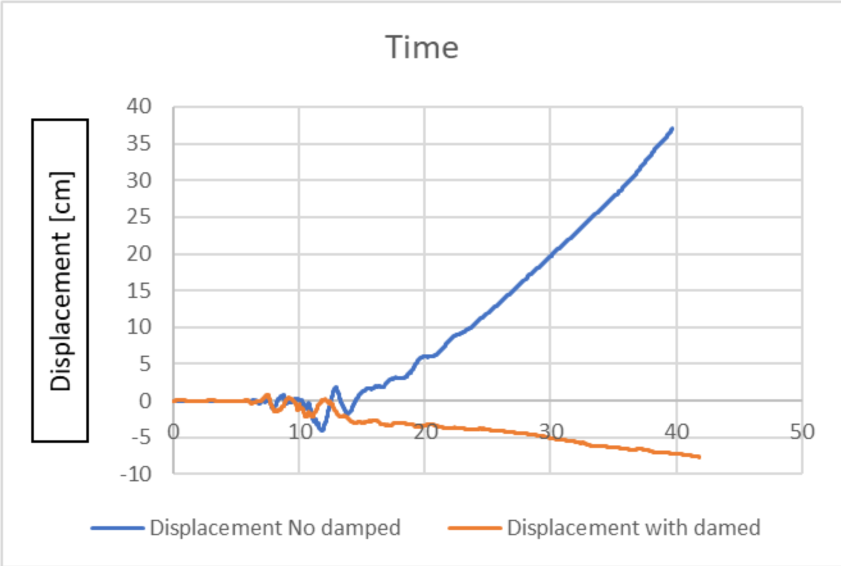
In Figs. 1 and 2 the difference between an undamped and a damped structure through acceleration, velocity, and displacement have been displayed.



(A) Velocity of damped and undamped structures



(B) Acceleration of damped and undamped structures



(C) Displacement of the damped and undamped structure

Fig. 1 Comparing the results in terms of acceleration, velocity, and displacement between the two structures.

		
1-With TMD	2-With out TMD	3- Together

Fig. 2 (1, 2, and 3) The model of structural.

1. The applications

1- High-rise multi-story buildings.

2- It can be implemented in residential complexes, including buildings, schools, hospitals, malls, and airports.

3- It can be implemented in universities, meeting rooms, gyms, hotels, restaurants, and indoor gymnasiums. Adjusted collective dampers may be designed during the work or installed later

2. Conclusion

An updated review of the literature was conducted related to studies dealing with mass inhibitor technology and included some of these studies that investigated passive, active, semi-, and semi-active control. We conclude from this experience the possibility of developing it to become suitable for all other structures, but with different methods in designs, mitigating the severity of

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earthquakes and winds, and the possibility of applying it not only on high-rise buildings, but also on low- and medium-rise buildings, and this would help reduce displacement. It is clear from all research that proper implementation in any high-rise buildings orany other buildings in terms of height in areas prone to earthquakes is necessary. We notice from the results that the un-damped structure reaches a maximum acceleration of 0.6m/s^2, while the acceleration in the damped structure is 0.76 m/s^2, and the speed in the non-damped structure is 14 m/s, while the speed in the damped structure is 17.01 m/s, and the displacement in the non-damped structure is 35.7mm/s, while in the damped structure it is 7.4mm/s, meaning the displacement decreased by 28.3mm/s.

The results show that the acceleration of the damped structure increased by 21% over that of the non-damped structure, and that the speed of the damped structure increased by 17% over that of the unfrozen structure, while the displacement of the damped structure was reduced by 79% compared to the displacement of the un damped structure, and in this percentage we find that the damping in this way useful in reducing vibrations resulting from earthquakes This last result is the effectiveness of the damping method.

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