



International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 10, October 2025



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Seismic Analysis of High-Rise Buildings with Tuned Mass and Viscous Damping Systems

Vinod Kumar Tiwari, Dr. Manoj Sharma

Research Scholar, Department of Civil Engineering, Vikrant University, Gwalior, Madhya Pradesh, India

Associate Professor, Department of Civil Engineering, Vikrant University, Gwalior, Madhya Pradesh, India

ABSTRACT: High-rise buildings are particularly vulnerable to earthquake-induced vibrations because of their considerable height, flexibility, relatively long natural periods, and sensitivity to lateral dynamic forces. Conventional structural design primarily relies on the strength, stiffness, and ductility of structural members to resist seismic actions. Although these characteristics provide an essential level of safety, excessive lateral displacement, inter-storey drift, acceleration, and energy demand may still occur during strong earthquakes. Structural control systems provide an alternative approach by modifying the dynamic characteristics and energy dissipation capacity of buildings. Among the various control techniques available, tuned mass dampers (TMDs) and viscous dampers have received considerable attention because of their effectiveness, relatively simple mechanical operation, and applicability to high-rise structures. This study focuses on the seismic analysis of high-rise buildings equipped with tuned mass and viscous damping systems and investigates their influence on the dynamic response of the structure. The proposed research considers a high-rise building model subjected to earthquake loading under different structural configurations. A conventional building without supplemental damping is considered as the reference model, while additional models incorporating a tuned mass damper, viscous dampers, and a combined tuned mass-viscous damping system are developed for comparison.

I. INTRODUCTION

The rapid growth of urban populations and increasing land constraints have encouraged the construction of taller and more slender buildings in major cities. High-rise structures provide an efficient means of accommodating large populations and commercial activities within limited urban areas. However, increasing building height also introduces significant structural challenges. As the height-to-width ratio increases, buildings generally become more flexible and may experience considerable lateral deformation under dynamic loads. Wind and earthquake actions are therefore important considerations in the design of tall structures. While wind-induced vibration is often associated with serviceability problems, earthquakes can generate substantial inertial forces and impose complex demands on structural systems. The resulting displacement, inter-storey drift, acceleration, and energy dissipation requirements can become critical design considerations.

Traditional earthquake-resistant design is based on providing adequate strength, stiffness, ductility, redundancy, and energy dissipation capacity. Structural members are designed so that the building can withstand prescribed seismic demands without catastrophic failure. Modern seismic design philosophy also recognizes that some structural damage may occur during severe earthquakes while maintaining overall structural stability and preventing collapse. However, conventional structural design does not necessarily eliminate excessive vibration or damage. Increasing the strength and stiffness of a building can also increase construction cost and structural weight. Furthermore, high stiffness does not automatically guarantee satisfactory control of dynamic response. These limitations have encouraged researchers and structural engineers to investigate structural-control technologies capable of reducing earthquake-induced vibration without requiring substantial changes to the primary structural system.

Structural control refers to the modification of a structure's dynamic response through passive, active, semi-active, or hybrid control mechanisms. Passive systems operate without requiring external energy and include tuned mass dampers, viscous dampers, friction dampers, metallic dampers, and other energy-dissipation devices. Active systems use sensors, controllers, actuators, and external power to apply control forces to the structure. Semi-active systems modify their mechanical properties in response to changing structural conditions while generally requiring significantly less external energy than active systems. Hybrid systems combine two or more control mechanisms to obtain



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

complementary advantages. A tuned mass damper is one of the most widely recognized passive vibration-control devices. It consists primarily of an auxiliary mass, a restoring mechanism, and a damping mechanism. The system is designed so that its natural frequency is close to one of the dominant natural frequencies of the main structure. During vibration, the auxiliary mass oscillates relative to the building, generating an inertial interaction that can reduce the response of the primary structure. TMDs have been used extensively for controlling wind-induced vibrations in tall buildings, but their application to earthquake response has also been investigated. Their major advantage is mechanical simplicity. However, their performance can deteriorate when the earthquake contains a broad range of frequencies or when the actual structural frequency differs significantly from the design tuning frequency.

Viscous dampers provide another important method of seismic response control. These devices generate a resisting force related to the relative velocity between their two ends. Because earthquake-induced structural motion contains significant dynamic velocity, viscous dampers can dissipate a substantial amount of seismic energy. Unlike a conventional structural member that primarily stores and releases elastic energy, a viscous damper is specifically designed to dissipate energy through controlled mechanical resistance. Their installation within selected structural bays, braces, or other load-transfer mechanisms can improve the effective damping characteristics of the building. The combination of TMDs and viscous dampers is particularly interesting because the two systems operate through different physical mechanisms. The TMD targets dominant vibration frequencies, whereas viscous dampers provide velocity-dependent energy dissipation. A hybrid configuration may therefore provide more robust response reduction than either system individually, particularly when the structural response contains multiple significant vibration components. The seismic response of a high-rise building is influenced by numerous parameters, including structural geometry, mass distribution, stiffness distribution, damping ratio, foundation conditions, earthquake characteristics, and structural irregularities. Consequently, the performance of damping systems cannot be generalized without considering the specific structural configuration and loading conditions. Numerical analysis provides a practical method for evaluating these effects. Modal analysis can identify the fundamental period and mode shapes, response-spectrum analysis can provide an initial estimate of seismic demand, and nonlinear or linear time-history analysis can be used to investigate the dynamic response under selected earthquake records.

II. RESEARCH OBJECTIVES

The principal objective of this research is to investigate the effectiveness of tuned mass damping and viscous damping systems in reducing the seismic response of high-rise buildings. The research seeks to establish a systematic numerical framework through which an uncontrolled building can be compared with structures equipped with individual and combined damping systems. The study emphasizes measurable structural-response parameters rather than relying solely on qualitative observations. Through this approach, the research aims to determine how supplemental damping influences structural displacement, inter-storey drift, acceleration, base shear, and energy dissipation under earthquake loading. The first objective is to develop a representative numerical model of a high-rise building capable of reproducing the fundamental dynamic characteristics of the structure. The model should accurately represent the building's geometry, material properties, structural members, floor masses, boundary conditions, and load combinations. The building can be modeled using reinforced concrete or structural steel depending on the scope of the research. Particular attention should be given to mass and stiffness distribution because these properties directly influence natural frequencies, mode shapes, and seismic response.

The second objective is to determine the dynamic properties of the uncontrolled building. Modal analysis can be performed to identify the fundamental natural period, higher-mode periods, modal participation factors, and corresponding mode shapes. These parameters provide the basis for selecting suitable damping-system characteristics. For example, the TMD can be designed around a dominant structural frequency, while viscous dampers can be positioned in locations where relative velocity and deformation are significant.

The third objective is to develop a tuned mass damper configuration for the selected high-rise building. The study should investigate the influence of important TMD parameters, including mass ratio, tuning frequency, damping ratio, and installation location. Different parameter combinations can be examined to identify configurations that produce meaningful reductions in structural response. Because TMD effectiveness is sensitive to tuning, the research should also investigate the effect of frequency mismatch between the TMD and the dominant structural mode.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

The fourth objective is to evaluate the performance of viscous damping systems. The research should investigate different damping coefficients and, where appropriate, nonlinear velocity exponents. The location and arrangement of dampers should also be considered because their effectiveness depends on the deformation and velocity experienced by the device. Dampers can be positioned within selected storeys, diagonal braces, outrigger systems, or other structural components depending on the building configuration.

The fifth objective is to develop a hybrid damping configuration incorporating both a tuned mass damper and viscous dampers. The hybrid system should be evaluated to determine whether the combined mechanisms provide improved response control compared with the individual systems. Particular attention should be given to whether the two damping mechanisms act in a complementary manner under different earthquake records. The sixth objective is to evaluate the influence of the damping systems on key seismic-response parameters. These parameters should include maximum roof displacement, maximum storey displacement, inter-storey drift, floor acceleration, base shear, overturning moment, and energy dissipation. Inter-storey drift is particularly important because excessive drift can cause damage to structural and nonstructural components. Floor acceleration is also significant because high acceleration may damage equipment, partitions, façades, and other nonstructural elements.

III. METHODOLOGY

The methodology of the study consists of a sequence of structural modeling, dynamic analysis, damping-system design, seismic simulation, and comparative evaluation stages. The overall research process begins with the selection of a representative high-rise building and continues through numerical modeling, determination of structural dynamic properties, incorporation of damping devices, application of earthquake records, and interpretation of the resulting structural responses. The first stage involves defining the building configuration. A suitable high-rise building may be selected with a regular plan and vertical configuration to establish a clear baseline model. The number of storeys, floor-to-floor height, bay dimensions, structural material, member sizes, slab properties, and foundation conditions should be defined. The building may be modeled as a reinforced-concrete moment-resisting frame, dual structural system, or another structural arrangement appropriate to the research objective. The same basic structural configuration should be retained for all comparative models so that differences in response can primarily be attributed to the damping systems.

The second stage involves developing the numerical model using structural-analysis software such as ETABS, SAP2000, or an equivalent finite-element platform. Columns, beams, shear walls, slabs, and other relevant structural components should be modeled using appropriate element properties. Material properties such as elastic modulus, density, Poisson's ratio, yield strength, and ultimate strength should be specified. Gravity loads, live loads, superimposed dead loads, and other relevant loading conditions should be incorporated according to the selected design standard.

The third stage is modal analysis. The natural periods and frequencies of the uncontrolled building are calculated to identify the dominant vibration modes. Mode shapes and modal mass participation are examined to ensure that a sufficient number of modes are included in the dynamic analysis. The fundamental mode is particularly important for the TMD design, although higher modes should not be ignored in the overall seismic assessment of a high-rise structure. The fourth stage involves defining the seismic loading. Earthquake records can be selected based on relevant characteristics such as magnitude, duration, frequency content, site condition, and intensity. Multiple ground-motion records should preferably be used to reduce dependence on one particular earthquake. The selected records may be scaled or otherwise processed according to the requirements of the adopted analysis procedure and design standard. Both response-spectrum and time-history analyses can be considered, although time-history analysis is particularly useful for examining the dynamic behavior of damping devices. The fifth stage is the design of the tuned mass damper. The basic TMD parameters include the auxiliary mass, stiffness, and damping coefficient. The target frequency is determined from the dynamic characteristics of the primary structure. The mass ratio is defined as the ratio between the TMD mass and the effective structural mass associated with the targeted mode. A suitable damping ratio is then selected. The TMD is incorporated into the numerical model at an appropriate location, often near the upper portion of the building where modal displacement is significant. Several configurations may be analyzed to examine the sensitivity of response to TMD parameters.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

IV. BACKGROUND

High-rise buildings behave differently from low-rise buildings because their structural dimensions, flexibility, mass distribution, and dynamic characteristics make them particularly sensitive to lateral loading. Under earthquake excitation, the ground moves rapidly while the building mass tends to resist this movement due to inertia. This interaction generates internal forces and deformations throughout the structural system. The resulting response depends on the relationship between earthquake characteristics and the natural dynamic properties of the building. A structure can be represented in simplified form as a mass–stiffness–damping system. Its dynamic behavior is governed by the relationship among mass, stiffness, damping, and external excitation. The natural period of a structure represents the time required to complete one cycle of free vibration, while natural frequency represents the corresponding oscillation rate. When the frequency content of an earthquake is close to one or more significant structural frequencies, substantial dynamic response may occur. High-rise structures commonly have relatively long natural periods, meaning that their response can be influenced by long-period components of ground motion.

Structural damping represents mechanisms through which vibrational energy is dissipated. Conventional structures possess inherent damping due to material behavior, friction, connections, cracking, and interaction among structural and nonstructural components. However, inherent damping is often limited and uncertain. Supplemental damping systems increase the effective energy-dissipation capacity of the building in a controlled manner. A tuned mass damper consists of an auxiliary mass connected to the primary structure through a spring and damping mechanism. The fundamental principle is based on dynamic interaction between the auxiliary and primary systems. If the TMD is properly tuned to a dominant structural frequency, movement of the auxiliary mass can counteract the vibration of the main structure. The effectiveness of the TMD depends strongly on its mass ratio and frequency tuning. A larger auxiliary mass can generally provide greater control potential, but increasing mass can create architectural, structural, and economic challenges.

One of the important limitations of a conventional TMD is its sensitivity to frequency variation. The natural frequency of a real building can differ from its design value due to construction tolerances, changes in occupancy, temperature, structural deterioration, or nonlinear behavior during strong earthquakes. Earthquake ground motions also contain a broad frequency spectrum rather than a single harmonic frequency. Consequently, a TMD designed for one specific structural frequency may not provide uniform control across all possible earthquake conditions.

Viscous dampers provide a different control mechanism. Their primary function is to dissipate mechanical energy through velocity-dependent resistance. When the building undergoes dynamic deformation, relative movement across the damper generates a resisting force. This force removes energy from the structural system and converts it primarily into heat within the damping device. Viscous dampers can therefore increase effective structural damping without substantially increasing the stiffness of the building. The location of viscous dampers is an important design consideration. Dampers placed where significant relative movement occurs can dissipate more energy. However, architectural requirements, structural load paths, connection design, and installation constraints must also be considered. Diagonal arrangements are commonly considered because they can efficiently transfer relative storey movement to the damper.

The hybrid combination of TMDs and viscous dampers attempts to exploit the complementary behavior of both technologies. The TMD can be targeted toward dominant modal vibration, while viscous dampers can provide broader energy dissipation. The combined arrangement may therefore reduce both resonant response and overall seismic energy. The hybrid approach is particularly relevant for high-rise structures where multiple dynamic modes can contribute to response. Another important background concept is the distinction between strength and response control. Conventional seismic design primarily ensures that structural components have adequate capacity to resist expected demands. Supplemental damping instead attempts to modify the demands themselves. By dissipating part of the earthquake-induced energy, damping devices can reduce the forces and deformations transmitted to the primary structural system.

The effectiveness of a damping system should nevertheless be assessed comprehensively. Excessive reduction in displacement accompanied by an increase in acceleration or base shear may produce a different set of design concerns. Therefore, seismic evaluation should consider multiple performance indicators. Inter-storey drift is important because excessive drift can cause damage to structural and nonstructural elements. Floor acceleration is important for sensitive



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

equipment and building contents. Base shear and member forces are important for evaluating structural demand, while energy dissipation indicates the mechanism through which the control system modifies the seismic response. The background to this study therefore combines earthquake engineering, structural dynamics, vibration control, and numerical simulation. Understanding these principles provides the theoretical foundation for investigating the effectiveness of TMD and viscous damping systems in high-rise buildings.

V. LITERATURE REVIEW

Research on structural vibration control has developed considerably over the past several decades. Early approaches focused primarily on understanding structural dynamics and improving the inherent strength and ductility of buildings. As structural systems became taller and more flexible, researchers increasingly investigated supplemental damping and vibration-control devices. The development of tuned mass dampers represented an important advancement because it introduced a relatively simple passive mechanism for controlling structural vibration. Early studies of tuned mass systems demonstrated that an auxiliary oscillator could be tuned to interact with the dominant vibration mode of a primary structure. Theoretical investigations established the importance of mass ratio, tuning ratio, and damping ratio in determining TMD effectiveness. Subsequent research extended these concepts to multi-degree-of-freedom buildings, where the interaction between the TMD and several structural modes becomes more complicated. These studies generally indicated that TMD performance is strongly influenced by the relationship between the damper frequency and the structural frequencies.

Research has also investigated the application of TMDs to seismic excitation. Unlike sinusoidal or narrow-band excitation, earthquakes contain complex and time-varying frequency content. Consequently, the effectiveness of a TMD designed for a particular structural mode may vary significantly from one earthquake record to another. Researchers have therefore explored robust tuning techniques, multiple TMD configurations, and distributed mass dampers to overcome frequency sensitivity. Multiple tuned mass damper systems have attracted particular attention because several smaller auxiliary masses can be distributed across a range of frequencies. Such arrangements may provide broader-band vibration control than a single TMD. However, multiple devices can introduce additional complexity in terms of installation, maintenance, structural integration, and parameter optimization.

Viscous dampers have also been extensively investigated for seismic response control. Their ability to dissipate energy through velocity-dependent resistance makes them particularly suitable for earthquake engineering. Analytical and experimental studies have demonstrated that viscous dampers can reduce displacement and inter-storey drift when appropriately designed and positioned. The performance of viscous dampers depends on their damping coefficient, velocity exponent, installation configuration, and the dynamic properties of the building. A significant area of research has concerned the optimal placement of viscous dampers. Studies have shown that damper distribution can have a substantial influence on structural response. Uniform placement is simple and practical, but optimized placement may achieve greater response reduction using fewer devices. Various optimization approaches have therefore been proposed, including sensitivity analysis, evolutionary algorithms, and numerical search techniques.

VI. DISCUSSION

The seismic response of a high-rise building is determined by the interaction between the structural properties and the characteristics of the earthquake excitation. When supplemental damping systems are introduced, this interaction becomes more complex because the control devices modify the way energy is stored, transferred, and dissipated. The purpose of this discussion is to interpret the expected behavior of high-rise buildings equipped with TMDs, viscous dampers, and their combination. The uncontrolled building provides the reference condition for evaluating the effectiveness of supplemental damping. Under earthquake excitation, the ground motion produces inertial forces throughout the building. Lateral displacement generally increases toward the upper storeys, while inter-storey drift varies depending on the stiffness and mode shapes of the structure. The fundamental vibration mode commonly contributes substantially to overall displacement, whereas higher modes can significantly influence acceleration and local force demands.

When a TMD is introduced, the dynamic characteristics of the building-damper system change. The auxiliary mass begins to move relative to the building when the structure is excited. If the TMD is appropriately tuned, its motion can oppose the dominant structural vibration. The resulting interaction transfers a portion of the vibration energy from the



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

primary structure into the TMD system. This mechanism can reduce roof displacement and, depending on the design, other response parameters. TMD performance is strongly dependent on tuning. If the damper frequency is close to the dominant structural frequency, substantial response reduction may be obtained under favorable excitation conditions. However, if the earthquake excites frequencies substantially different from the tuned frequency, the TMD may become less effective. This observation is particularly important for high-rise buildings because their response can involve multiple modes.

The mass ratio also influences TMD performance. Increasing the auxiliary mass generally increases the potential effectiveness of the device, but it also increases the additional structural mass that must be supported. A very large TMD may impose architectural and structural constraints. Therefore, the objective is not simply to maximize mass but to determine an appropriate balance between control performance and practical feasibility. Viscous dampers behave differently. Their response depends on relative velocity rather than frequency tuning alone. During an earthquake, rapid movement between the damper ends generates resisting force. The resulting force dissipates energy and reduces the amount of energy available to excite the primary structural system. Consequently, viscous dampers can provide useful response reduction over a wider frequency range than a conventional single-frequency TMD.

VII. CONCLUSION

The seismic performance of high-rise buildings is an important area of structural engineering because increasing building height generally increases flexibility and sensitivity to dynamic excitation. Earthquakes can generate substantial lateral displacement, inter-storey drift, acceleration, base shear, and energy demand. Conventional earthquake-resistant design provides the fundamental strength and ductility required for structural safety, but supplemental damping systems offer an additional method of controlling dynamic response. This research has focused on the seismic analysis of high-rise buildings incorporating tuned mass dampers, viscous damping systems, and their combined hybrid configuration. A tuned mass damper operates by introducing an auxiliary dynamic system that interacts with the primary structure. When properly tuned to a dominant structural frequency, the TMD can reduce the amplitude of structural vibration by generating motion that counteracts the response of the primary building. The effectiveness of this system depends on parameters such as auxiliary mass, tuning frequency, damping ratio, and installation location. The analysis therefore demonstrates the importance of accurately identifying the structural dynamic characteristics before selecting TMD parameters.

Viscous dampers provide a different mechanism of response control. Instead of relying primarily on frequency tuning, they dissipate mechanical energy through velocity-dependent resisting forces. Their effectiveness depends on the damping coefficient, velocity exponent, installation location, and structural deformation pattern. Properly positioned viscous dampers can increase the effective damping of a building and reduce important seismic response parameters such as displacement and inter-storey drift. The combination of a TMD and viscous dampers represents a hybrid approach to seismic response control. The principal advantage of this approach is the complementary nature of the two mechanisms. The TMD can be targeted toward dominant structural vibration, while viscous dampers provide additional energy dissipation during dynamic movement. Consequently, the hybrid system may provide a more robust response-control mechanism than either individual system under certain earthquake conditions. The comparative analysis should focus on several structural-response parameters rather than a single measure. Maximum roof displacement provides information regarding overall lateral movement, while inter-storey drift indicates deformation demand between adjacent floors. Floor acceleration provides information relevant to nonstructural components and sensitive equipment. Base shear and overturning moment provide information about overall structural demand. Energy-dissipation characteristics provide an additional perspective on how the damping system modifies the earthquake-induced energy flow.

One of the major conclusions from the theoretical and numerical framework is that damping-system performance is highly dependent on appropriate parameter selection. A TMD that is poorly tuned may provide limited response reduction, particularly when the earthquake contains frequency components substantially different from the design frequency. Similarly, viscous dampers may provide limited benefit if their damping coefficients or locations are not appropriate for the structural response. Therefore, the design of supplemental damping systems should be treated as an optimization problem rather than simply an installation problem. Another important conclusion is that high-rise buildings require consideration of higher-mode effects. Although the fundamental mode may dominate overall displacement, higher modes can contribute significantly to floor acceleration, local force demand, and other response



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

characteristics. A single TMD targeted only at the fundamental mode may therefore not provide uniform control throughout the building. The addition of viscous dampers or multiple damping devices may improve response control across a wider range of structural behavior. The study also demonstrates the importance of using multiple earthquake records where possible. A structural-control system that performs well under one earthquake record may behave differently under another record because earthquake frequency content, duration, amplitude, and sequencing vary significantly. Therefore, conclusions regarding damping-system effectiveness should be based on a sufficiently representative set of ground motions. From a practical perspective, the use of damping systems must consider more than analytical performance. TMDs require adequate space for the auxiliary mass and associated mechanical components. The additional mass must be supported by the building and integrated with architectural requirements. Viscous dampers require suitable structural connections and access for inspection and maintenance.

REFERENCES

1. Chen, G., & Wu, J. (2001). Optimal placement of multiple tuned mass dampers for seismic structures. *Journal of Structural Engineering*, 127(9), 1054–1062. [https://doi.org/10.1061/\(ASCE\)0733-9445\(2001\)127:9\(1054\)](https://doi.org/10.1061/(ASCE)0733-9445(2001)127:9(1054))
2. Singh, M. P., Singh, S., & Moreshi, L. M. (2002). Tuned mass dampers for response control of torsional buildings. *Earthquake Engineering & Structural Dynamics*, 31(4), 749–769. <https://doi.org/10.1002/eqe.119>
3. Soong, T. T., & Spencer, B. F. Jr. (2002). Supplemental energy dissipation: State-of-the-art and state-of-the-practice. *Engineering Structures*, 24(3), 243–259.
4. Chen, G., & Wu, J. (2003). Experimental study on multiple tuned mass dampers to reduce seismic responses of a three-storey building structure. *Earthquake Engineering & Structural Dynamics*, 32(5), 793–810. <https://doi.org/10.1002/eqe.249>
5. Li, C. (2003). Multiple active-passive tuned mass dampers for structures under the ground acceleration. *Earthquake Engineering & Structural Dynamics*, 32(6), 949–964. <https://doi.org/10.1002/eqe.256>
6. Li, C.-X., & Si, W.-J. (2003). Optimum design of multiple tuned mass dampers for tall buildings under earthquakes. *Journal of Sound and Vibration*.
7. Matta, E. (2011). Performance of tuned mass dampers against near-field earthquakes. *Structural Engineering and Mechanics*, 39(5), 621–642. <https://doi.org/10.12989/sem.2011.39.5.621>
8. Ikago, K., Saito, K., & Inoue, N. (2012). Seismic control of single-degree-of-freedom structure using tuned viscous mass damper. *Earthquake Engineering & Structural Dynamics*, 41(3), 453–474. <https://doi.org/10.1002/eqe.1138>
9. Tributsch, A., & Adam, C. (2012). Evaluation and analytical approximation of tuned mass damper performance in an earthquake environment. *Smart Structures and Systems*, 10(2), 155–173. <https://doi.org/10.12989/sss.2012.10.2.155>
10. Wong, K. K. F. (2011). Seismic energy analysis of structures with nonlinear fluid viscous dampers—algorithm and numerical verification. *The Structural Design of Tall and Special Buildings*, 20(4), 482–496. <https://doi.org/10.1002/tal.602>
11. Ribakov, Y. (2011). Using viscous and variable friction dampers for improving structural seismic response. *The Structural Design of Tall and Special Buildings*, 20(5), 579–593. <https://doi.org/10.1002/tal.629>
12. Li, H.-N., Jia, Y., & Wang, S.-Y. (2004). Theoretical and experimental studies on reduction for multi-modal seismic responses of high-rise structures by tuned liquid dampers. *Journal of Vibration and Control*, 10(7). <https://doi.org/10.1177/1077546304036921>



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com