Vibration Control of a Frames Structure Using Tuned Mass Damper

Jandala Kasim Peera[1] Mallikarjuna[2]
[1,2]Department of Structural Engineering
[1,2]SVR Engineering College, Nandyal, India

Abstract— The need for high rise structures in construction and real estate industry is increasing all over the world. These structures are light weight and flexible, which have low value of damping, which in turn makes them vulnerable to unwanted vibration. This creates problem to serviceability requirement of the structure and also reduce structural integrity with possibilities of failure. Current trends use several techniques to reduce earthquake and wind induced structural vibration. Tuned mass damper (TMD) is widely used for controlling structural vibration under wind load but its effectiveness to reduce earthquake induced vibration is an emerging technique. To study the effectiveness of tuned mass damper to reduce translation structural vibration, a numerical study is proposed. In total three type of models, i.e., shear building with single TMD, 2D frame with single TMD and 2D frame with double TMD are considered.

Keywords: TMD, TLD, Damping Ratio

I. INTRODUCTION

The number of tall buildings being built is increasing day by day. Today we cannot have a count of number of low-rise or medium rise and high-rise buildings existing in the world. Mostly these structures are having low natural damping. So, increasing damping capacity of a structural system, or considering the need for other mechanical means to increase the damping capacity of a building, has become increasingly common in the new generation of tall and super tall buildings. But, it should be made a routine design practice to design the damping capacity into a structural system while designing the structural system. The control of structural vibrations produced by earthquake or wind can be done by various means such as modifying rigidities, masses, damping, or shape, and by providing passive or active counter forces. To date, some methods of structural control have been used successfully and newly proposed methods offer the possibility of extending applications and improving efficiency.

A. *Classification of Control Methods:*

1) *Active Control:*

The active control method requires an external source to activate the control system that generates a control signal to modify the structural response. Typically the control signal is generated according to a control algorithm that uses the measured response of the structure. Active control systems have been implemented for vibration control in many building in Japan. Different types of sensors are placed at various locations to measure the structural response. The position of the sensors plays a very important role in control of the structural vibration in active control systems.

2) *Passive Control:*

All vibrating structures dissipate energy due to internal stressing, rubbing, cracking, plastic deformations, and so on; the larger the energy dissipation capacity the smaller the amplitudes of vibration. Some structures have very low damping of the order of 1% of critical damping and consequently experience large amplitudes of vibration even for moderately strong earthquakes. Methods of increasing the energy dissipation capacity are very effective in reducing the amplitudes of vibration. Many different methods of increasing damping have been utilized and many others have been proposed. Passive energy dissipation systems utilises a number of materials and devices for enhancing damping, stiffness and strength, and can be used both for natural hazard mitigation and for rehabilitation of aging or damaged structures

a) Semi-Active Control:

Semi-active control systems are a class of active control systems for which the external energy requirements are less than typical active control systems. Typically, semi-active control devices do not add mechanical energy to the structural system (including the structure and the control actuators), therefore bounded-input bounded-output stability is guaranteed. Semi-active control devices are often viewed as controllable passive devices. In this methodology the amount of external power required to activate the system is comparatively less in comparison to the active control methodology. In this report we would deal with the effect of the TMD in controlling the structural vibrational response.

b) Hybrid Control:

The term "hybrid control" implies the combined use of active and passive control systems. For example, a structure equipped with distributed viscoelastic damping supplemented with an active mass damper near the top of the structure, or a base isolated structure with actuators actively controlled to enhance performance.

c) Semi-Active Control:

Semi-active control systems are a class of active control systems for which the external energy requirements are less than typical active control systems. Typically, semi-active control devices do not add mechanical energy to the structural system (including the structure and the control actuators), therefore bounded-input bounded-output stability is guaranteed. Semi-active control devices are often viewed as controllable passive devices. In this methodology the amount of external power required to activate the system is comparatively less in comparison to the active control methodology. In this report we would deal with the effect of the TMD in controlling the structural vibrational response.

B. *Types of Passive Control Devices:*

1) *Metallic Yield Dampers:*

One of the effective mechanisms available for the dissipation of energy, input to a structure from an earthquake is through inelastic deformation of metals. The idea of using metallic energy dissipaters within a structure to absorb a large portion of the seismic energy began with the conceptual and experimental work of Several of the devices considered include torsional beams, flexural beams, and V-strip energy dissipaters. Many of these devices use mild steel plates with triangular or hourglass shapes so that yielding is spread almost uniformly throughout the material. A typical X-shaped plate damper or added damping and stiffness (ADAS) device is shown in Fig below.

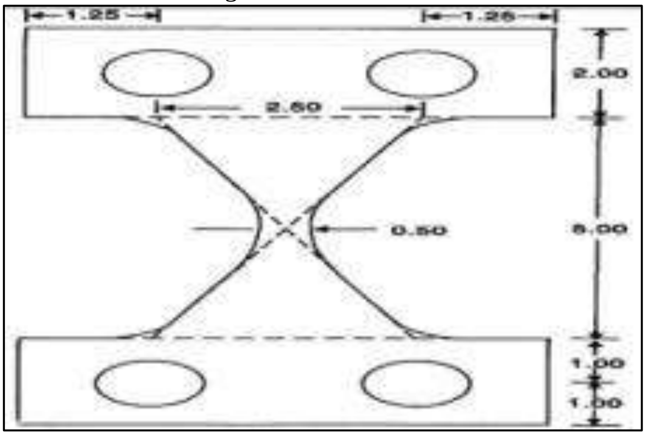


Fig. 1: X-Shaped ADAS Device

2) Friction dampers:

Friction provides another excellent mechanism for energy dissipation, and has been used for many years in automotive brakes to dissipate kinetic energy of motion. In the development of friction dampers, it is important to minimize stick-slip phenomena to avoid introducing high frequency excitation. Furthermore, compatible materials must be employed to maintain a consistent coefficient of friction over the intended life of the device. The Pall device is one of the damper elements utilizing the friction principle, which can be installed in a structure in an X-braced frame as illustrated in the figure

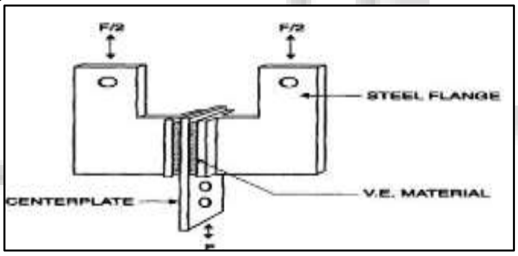


Fig. 2: Parallel Frictions Damper

3) Viscoelastic Dampers:

The metallic and frictional devices described are primarily intended for seismic application. But, viscoelastic dampers find application in both wind and seismic application. Their application in civil engineering structures began in 1969 when approximately 10,000 visco-elastic dampers were installed in each of the twin towers of the World Trade Center in New York to reduce wind-induced vibrations. Further studies on the dynamic response of viscoelastic dampers have been carried out, and the results show that they can also be effectively used in reducing structural response due to large range of intensity

Viscous fluid dampers Fluids can also be used to dissipate energy and numerous device configurations and materials have been proposed. Viscous fluid dampers are widely used in aerospace and military applications, and have recently been adapted for structural applications (Constantinou et al. 1993). Characteristics of these devices which are of primary interest in structural applications are the linear viscous response achieved over a broad frequency range, insensitivity to temperature, and compactness in comparison to stroke and output force. A viscous fluid damper generally consists of a piston in the damper housing filled with a compound of silicone or oil

4) Tuned Liquid Dampers:

Tuned liquid column dampers (TLCDs) are a special type of tuned liquid damper (TLD) that rely on the motion of the liquid column in a U-shaped tube to counteract the action of external forces acting on the structure. The inherent damping is introduced in the oscillating liquid column through an orifice. The performance of a single degree-of-freedom structure with a TLD subjected to sinusoidal excitations was investigated by Sun (1991), along with its application to the suppression of wind induced vibration by Wakahara et al. (1989).Welt and modi (1989) were one of the first to suggest the usage of a TDL in buildings to reduce overall response during strong wind or earthquakes.

C. Tuned Mass Dampers:

The concept of the tuned mass damper (TMD) dates back to the 1940s (Den Hartog 1947). It consists of a secondary mass with properly tuned spring and damping elements, providing a frequency-dependent hysteresis that increases damping in the primary structure. The success of such a system in reducing wind-excited structural vibrations is now well established). Tuned mass dampers (TMDs) are passive control devices that are generally installed at the tops of buildings to control the responses of buildings produced due to wind or an earthquake. Tuned mass damper is also known as a harmonic absorber, their application can prevent discomfort, damage, or outright structural failure. They are frequently used in power transmission, automobiles, and buildings. TMD have been successfully implemented to control the responses of some well-known towers (buildings) produced by winds,

1) Tuned Liquid Dampers:

Tuned liquid column dampers (TLCDs) are a special type of tuned liquid damper (TLD) that rely on the motion of the liquid column in a U-shaped tube to counteract the action of external forces acting on the structure. The inherent damping is introduced in the oscillating liquid column through an orifice. The performance of a single degree-of-freedom structure with a TLD subjected to sinusoidal excitations was investigated by Sun (1991), along with its application to the suppression of wind induced vibration by Wakahara et al. (1989).Welt and modi (1989) were one of the first to suggest the usage of a TDL in buildings to reduce overall response during strong wind or earthquakes.

D. Tuned Mass Dampers:

The concept of the tuned mass damper (TMD) dates back to the 1940s (Den Hartog 1947). It consists of a secondary mass with properly tuned spring and damping elements, providing a frequency-dependent hysteresis that increases damping in the primary structure. The success of such a system in reducing wind-excited structural vibrations is now well established). Tuned mass dampers (TMDs) are passive control devices that are generally installed at the tops of buildings to control the responses of buildings produced due to wind or an earthquake. Tuned mass damper is also known as a harmonic absorber, their application can prevent discomfort, damage, or outright structural failure. They are

frequently used in power transmission, automobiles, and buildings. TMD have been successfully implemented to control the responses of some well-known towers (buildings) produced by winds,

II. LITERATURE REVIEW

In this section, we summarize the investigations of various authors working in the field of Structural control investigating the performance of Tuned MassDampers (TMDs) towards control of structures subjected to wind loads. The authors have made extensive measurements on a significant number of tall buildings and structures which were fitted with passive or active tuned mass damper systems to determine the effectiveness of their performance. The authors observed that an additional

Kongoli, X., Minami [1] spotting the shortcomings of curve-becoming models, mechanical models have been proposed as a possible technique for predicting the connection conduct based on physical meanings. In mechanical models, the various components of a joint are conceived as a set of rigid and deformable elements represented with the aid of springs with particular load-deformation traits. The constitutive laws describe the behavior of the diverse springs including both linear and nonlinear relationships; permitting for a complete second-rotation curve to be built through the contribution of the diverse components modeled, even as taking into consideration their deformation and innovative yielding. In the case of top and seat- angle with double net-attitude connections, the numerous additives include angles, bolts, and the column panel region.

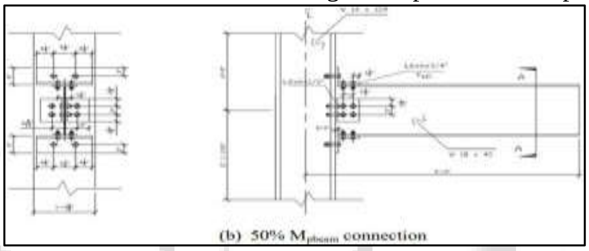
Hidalgo, P.A., Jordan [2] Various experimental and analytical studies on semi- inflexible connections in beam to-column subassemblies, which include top-and seat-attitude with double-web angle connections, were performed. Results of the studies were utilized in some of frame analyses that protected action-deformation relationships which can be idealized and now not properly representative of the complex inelastic nature of the relationship conduct. Such technique highlights the need for accurate and more subtle machine-stage approach for the seismic assessment of metal frames with semi inflexible connections. With development in modeling techniques, computing energy, and experimental facilities, a device-level hybrid simulation approach is the subsequent logical step for engaging in reliable seismic evaluation of metallic frames.

III. METHODOLOGY

The structural vibrations produced by wind are controlled by modifying rigidities, masses, damping, or shape, and by providing passive counter forces. In this case tuned mass damper is considered based on the following factors which include efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety. Tuned mass damper made with welded steelwork is attached on the top of the structure consists of a mass (m2), spring and a damper, which is attached to one side of the building to control the responses in two directions. Steel is used because it's more prone to vibration and high damping capacity. Furthermore, by placing the TMDs eccentrically, the torsional response of the building may also be controlled. The mass rests on bearings that function as rollers and allow the mass to translate laterally relative to the floor. Springs and dampers are inserted between the mass and the adjacent vertical support members, which transmit the lateral "out-of-phase" force to the floor level and then into the structural frame. Bidirectional translational dampers are configured with springs/dampers in two orthogonal directions and provide the capability for controlling structural motion in two orthogonal planes. When wind load induced vibration, the damper will absorb the vibration so that the amplitudes of the vibration will be diminished.

A. Theory of Single Storied Frame with Tuned Mass Damper:

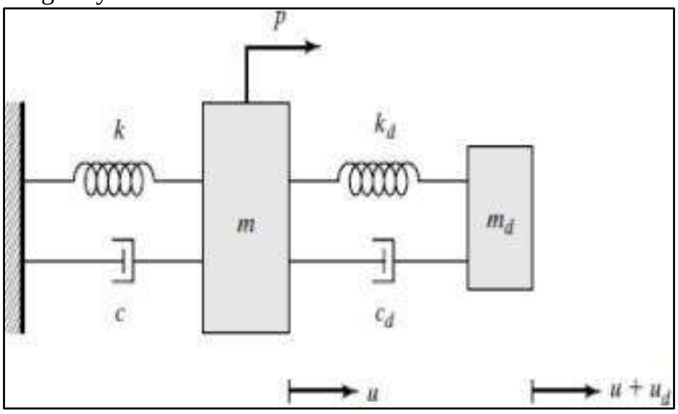
A single degree of freedom (SDOF) portal frame with a TMD placed on the top is shown in Figure The TMD typically consists of a mass that is capable of oscillating in the same direction as the host structure. Generally, the weight of the TMD is about 5% of the total weight of the structure and it is connected to the host structure through a spring and dashpot system. For investigation of the dynamic response of the structure with TMD, the following assumptions are adopted.



(b) 50% M_{pbeam} connection

1) The columns are assumed to be inextensible so that there is no axial deformation in the columns.
2) The slab is assumed to be
3) rigid and there is no bending deformation in the slab.
4) The self-weight of the columns is neglected.

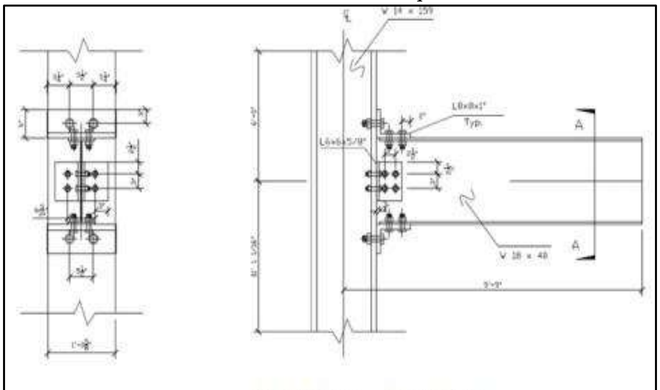
Therefore, the structure has only one degree of freedom in the horizontal direction and the TMD also oscillates in the same direction. The analysis made by using D"Alembert"s principle states that a system may be in dynamic equilibrium by adding to the external forces, an imaginary force which is known as the inertia force.



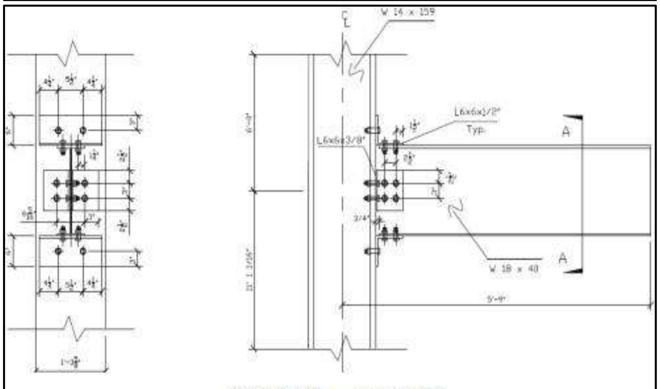
Mechanical Model of SDOF with Tuned Mass Damper

B. Connection Topology:

As previously stated, the connection investigated on this have a look at comprises top and seat-perspective with double net-attitude. The attitude additives of the connection are bolted to the beam and the column the usage of a325 excessive strength structural bolts with turn-of-nut technique.



(a) 70% M_{pbeam} connection



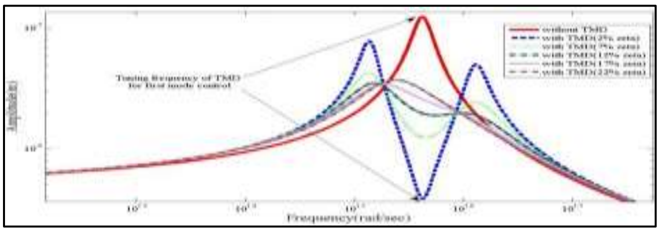
(c) 30% M_{pbeam} connection

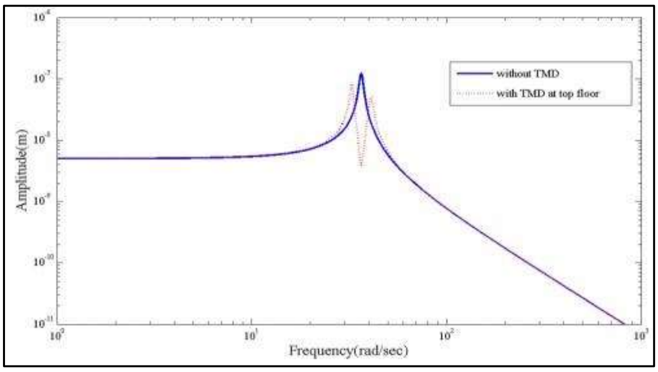
C. *Detailed Geometry of the Semi-Rigid Connections*

The geometrical variant that constitutes the difference between all 3 specimens consists of attitude length, bolt length, and vicinity of bolts (i. E. The beam and column sizes are stored the same at some stage in the investigation). The standardized parameters normally used for describing the geometry of these forms of connections are shown in discern two extraordinary assessments are carried out on every of the 3 specimens except for the 70% mp beam specimen which turned into tested simplest once. The first check protected subjecting the specimens to deformations resulting from stepping via a horizontal earthquake ground motion at some point of the hybrid simulation. After the hybrid simulation is concluded, a post-earthquake cyclic check is initiated to assess the fundamental feature of the connection which include its stiffness, residual potential, and ductility. Due to technical problems related to the lbcbs, cyclic trying out of the 70% 60 mp beam connections turned into no longer performed.

IV. RESULTS AND DISCUSSIONS

In this chapter, we present the simulation results that demonstrate the effect of the TMD on the single degree of freedom SDOF and two degree of freedom systems of the frames structure subjected to excitation force (wind) as shown in Figure 4.1 below. The figure described the transfer function between the displacement x1 and the force F1 at the slab level as a function of frequency with and without the TMD





A. *Transfer Function Between X1 and F1 as A Function of Frequency with and without the TMD.*

It is observed that due to the introduction of the TMD the resonance peak corresponding to the fundamental frequency of the structure is split into two resonance peaks. This is called the mode splitting effect. The peak with higher amplitude corresponds to the structure and the other corresponds to the TMD mode. The TMD in this simulation example is lightly damped with a damping ratio of 2%. Even then, a reduction in the structural response is observed and at the tuning frequency, the response has been reduced significantly.

It is observed that with increasing damping ratios of the TMD, the structural response also changes. In case of a TMD with a high damping ratio, the structural response decreases significantly in comparison to the case where there is no TMD. This is expected and is consistent with the observations in Sadek et al. (1997). It can also be inferred that the peak whose amplitude reduces more drastically with increase in the damping ratio of the TMD, corresponds to the TMD resonance peak.

B. *Duration of Motion and Time Step:*

To lessen the full time required to finish the simulation, the duration of motion and time step of the actual earthquake file are each changed. First, the duration of movement is reduced with the aid of doing away with the initial part of the report, characterized.

V. CONCLUSION

Tuned mass damper are designed to reduce wind responses on tall buildings, this study is made to study the effectiveness of using tuned mass damper for controlling vibration of structure due to excitation force (wind). Based on the simulation results, it shows that the response of the structure subjected to excitation force system is relatively higher without tuned mass damper which shows the effectiveness of TDM in controlling the vibration on the structure. It also observed that the displacement response is decreased by increasing damping ratio of TMD.

VI. FUTURE SCOPE OF STUDY

1) The frame model considered here is as one and two-dimensional. A further study can be done including three-dimensional structure model.
2) In current study both the frame and Damper has been modelled as linear one. Thus a further study of this problem can be carried out using a nonlinear model for frame or TMDs or both.
3) A further study includes using MTMD tuned with all the unfavourable structural frequency as well as placing them in different level of the frame. 4) A future study can be done with active multiple tuned mass dampers

REFERENCES

[1] Datta, T.K. (2010). "Seismic Analysis of Structures." John Wiley & sons (Asia) Pte Ltd.
[2] ASCM American society of civil engineers prepared for federal emergency management agency 2000.
[3] CA applied techology council –"Earthquake damage evaluation data for californaia "(1985).
[4] Chunxiang Li and Yanxia Liu " Fuurther Characteristics of multiple runed mass dampers " 2000