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VIBRATION CONTROL OF A FRAMES STRUCTURE USING TUNED MASS DAMPER

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ABSTRACT

Vibrations are one of many environmental factors that act on a buildings and potentially reduce their lifetime. Current trends in construction industry demands taller and lighter structures, which are also more flexible and having quite low damping value. This increases failure possibilities and also problems from serviceability point of view. Now-a-days several techniques are available to minimize the vibration of the structure, out of the several techniques available for vibration control; concept of using Tuned Mass Damper is a newer one. This study was made to study the effectiveness of using Tuned Mass Damper for controlling vibration of a frames structure. This report proposes a passive control of vibration of single degree of freedom and multi-degree of freedom structural frames subjected to dynamic (wind) excitation and a general understanding of the structural dynamics through MATLAB simulations. Preliminary results on the passive control of the structural response of single degree of freedom (SDOF) and two dimensional multi-storeyed frames using Tuned Mass Damper (TMD) are presented. At first a numerical analysis was developed to investigate the response of a shear building fitted with a tune mass damper. Then another numerical was developed to investigate the response of a 2D frame model fitted with a Tuned Mass Damper and then without Tuned Mass Damper (TDM). From the study it was found that, tuned mass damper can be effectively used for vibration control of structures. Tuned mass damper (TMD) was more effective when damping ratio of the structure is less. Gradually increasing the mass ratio of the tuned mass damper results in gradual decrement in the displacement response of the structure. It is also observed that due to increase in tuned mass damper damping ratio, the movement of tuned mass damper is also decreases.

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.

Vibration control is a set of technical means aimed to reduce the undesired vibrations in a structure. 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.

The selection of a particular type of vibration control device is governed by a number of factors which include efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety. Vibration control of structures like tall buildings subjected to earthquake and wind excitations are important for human comfort and structural safety. Generally tall structures do not have sufficient damping; therefore control of the vibration response of the structures is very essential. Passive control devices like Tuned Mass Dampers (TMD) are elegant solutions for increasing damping in a structure, thereby, reducing the response due to external loading.

1.1 Objectives of the Research

a) To understand the concept of tuned mass damper (passive) in controlling vibration of a frames structures.
b) To evaluate the response of single degree of freedom system (SDOF) and multi-degree of freedom system (MDOF) frames structures with and without tuned mass damper using MATLAB simulation.
c) To understand the dynamics of the frames structures subjected to wind excitation load.
d) To investigate the effect of the damping ratio of the TMD on the response of the structure subjected to a dynamic load excitation.

1.2 Classification of Control Methods

1.2.1 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.

1.2.2 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.

1.2.3 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.

1.2.4 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.

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1.3 Types of Passive Control Devices

1.3.1 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 Kelly et al. (1972) and Skinner et al. (1975). 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.

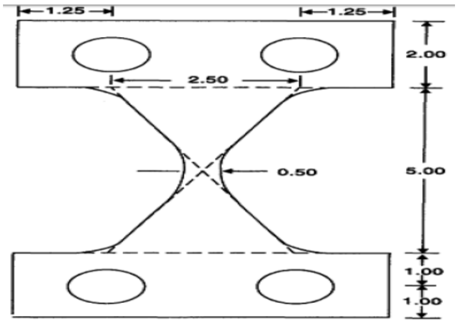


Fig 1.1 X-shaped ADAS device

1.3.2 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 (Palland Marsh 1982).

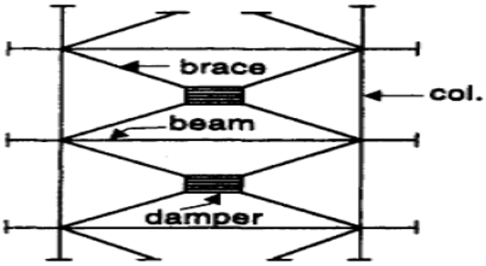


Figure 1.2 Parallel Frictions Damper

1.3.3 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 levels of earthquake. Viscoelastic materials used in civil engineering structure are typical copolymers or glassy substances. A typical viscoelastic damper, developed by the 3M Company Inc., is shown in Fig. It consists of viscoelastic layers bonded with steel plates.

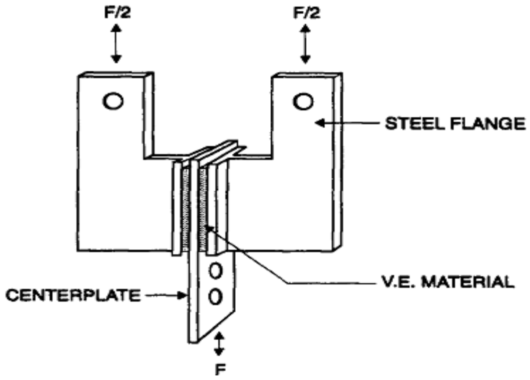


Fig. 1.3 Viscoelastic Dampers

1.3.4 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 (Makris and Constantinou 1990; Constantinou and Symans1992).

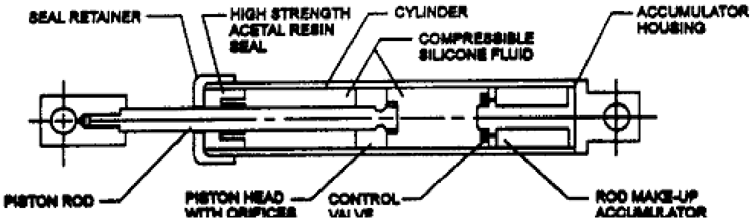


Fig 1.4 Taylor Device Fluid Damper

1.3.5 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 counter act 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.

1.3.6 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, such as Citicorp Tower, Sydney Tower, and so on.

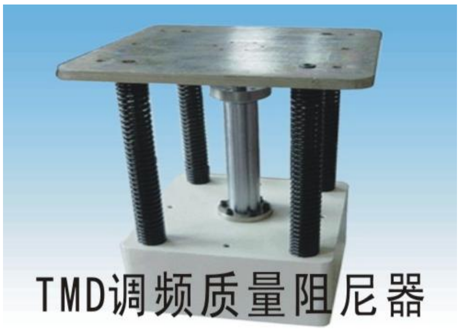


Figure 1.5 Tuned Mass Damper Description (Courtesy, suis 2011)

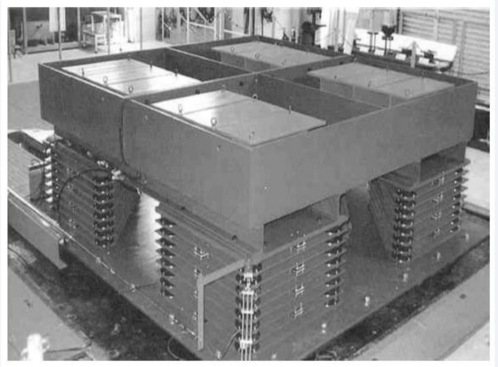


Figure 1.6 Tuned Mass Damper-Huis Ten Bosch Tower, Nagasak.

(Courtesy of J. Cannor)

1.4 Practical implementation of tuned mass dampers

Till date TMD have been installed in large number of the structures all around the globe. First structure installed is centre tower in Sydney, Australia. here are two buildings in the United States equipped with TMDs; one is the Citicorp Centre in New York City and the other is the John Hancock Tower in Boston. The Citicorp Centre building is 279 m high and has a fundamental period of around 6.5 s with an inherent damping ratio of 1% along each axis. The Citicorp TMD, located on the sixty-third floor in the crown of the structure, has a mass of 366 Mg, about 2% of the effective modal mass of the first mode, and was 250 times larger than any existing tuned mass damper at the time of installation.

Designed to be bi-axially resonant on the building structure with a variable operating period soft adjustable linear damping from 8 to 14%, and a peak relative displacement of, the damper is expected to reduce the building sway amplitude by about 50%. %. Two dampers were added to the 60-storey John Hancock Tower in Boston to reduce the response to wind loading. The dampers are placed at opposite ends of the fifty-eighth story, 67 m apart, and move to counteract sway as well as twisting due to the shape of the building. Steel plate the lead-filled weight, laterally restrained by stiff springs anchored to the interior columns of the building and controlled by servo-hydraulic cylinders, slides back and forth on a hydrostatic Each damper weighs 2700 kN and consists of a lead-filled steel box about 5.2 m square and 1 m deep that rides on a 9-m-long bearing consisting of a thin layer of oil forced through holes in the steel plate. steel plate. The lead-filled weight, laterally restrained by stiff springs anchored to the interior columns of the building and controlled by servo-hydraulic cylinders, slides back and forth on a hydrostatic Each damper weighs 2700 kN and consists of a lead-filled steel box about 5.2 m square and 1 m deep that rides on a 9-m-long bearing consisting of a thin layer of oil forced through holes in the steel plate.

1.5 Mechanism of Tuned Mass Dampers

Tuned mass damper (TMDs) consists of a mass, a spring, and a damper, which is attached to one side of the building to control the responses in two directions, TMDs may be placed in two directions on the top of a building. Furthermore, by placing the TMDs eccentrically, the torsional response of the building may also be controlled. The most important feature of the TMDs is the tuning of frequencies, that is, the frequency of the TMD is made equal to the fundamental frequency of the structure. Because of various uncertainties inherent in the properties of both the TMD and the structure, perfect tuning is very difficult to achieve. As a consequence, multi-tuned mass dampers (MTMDs) have been developed for better tuning.

Tuned mass dampers stabilize against violent motion caused by harmonic vibration. A tuned damper reduces the vibration of a system with a comparatively lightweight component so that the worst-case vibrations are less intense. Roughly speaking, practical systems are tuned to either move the main mode away from a troubling excitation frequency, or to add damping to a resonance that is difficult or expensive to damp directly.

1.6 Buildings and Structures with Tuned Mass Dampers

a) Shanghai World Financial Centre in Shanghai, China.
b) Berlin Television Tower (Fernsehturm),Germany
c) Dublin Spire in Dublin, Ireland.
d) Akashi-Kaikyo Bridge, between Honshu and Shikoku in Japan.
e) Taipei 101 skyscraper, Taiwan.
f) Burj al-Arab in Dubai 11 tuned mass dampers.

1.7 Vibration

Vibrationis defined as a motion which repeats after equal interval of time and is also a periodic motion. Vibration occurs in all bodies which are having mass and elasticity. They are caused due to several reasons such as presence of unbalanced force in rotating machines, elastic nature of the system, external application of force or wind loads and earthquakes. Vibrations are undesirable in most engineering systems and desirable in few cases.

1.8 Classification of Vibration

One method of classifying mechanical vibrations is based on degrees of freedom. The number of degrees of freedom for a system is the number of kinematic ally Independent variables necessary to completely describe the motion of every particle in the system. Based on degrees of freedom, we can classify vibrations as follows:

a) Single Degree of freedom Systems.

b) Two Degrees of freedom Systems.

c) Multi-degree of freedom Systems.

d) Continuous Systems or systems with infinite degrees of freedom.

Vibration can also be classified in several ways. Some of the important classifications are as follows:

e) Freeandforcedvibration:

f) Undamped and damped vibration

g) Linear and nonlinear vibration

1.9 Sources of vibration

1.9.1 Earthquakes

The seismic waves caused by an earthquake will make buildings sway and oscillate in various ways depending on the frequency and direction of ground motion, and the height and construction of the building. Seismic activity can cause excessive oscillations of the building which may lead to structural failure.

1.9.2 Wind

The force of wind against tall buildings can cause the top of skyscrapers to move more than a meter. This motion can be in the form of swaying or twisting, and can cause the upper floors of such buildings to move. Certain angles of wind and aerodynamic properties of a building can accentuate the movement and cause motion sickness in people.

1.9.3 Mechanical Sources

Masses of people walking up and down stairs at once, or great numbers of people stomping in unison, can cause serious problems in large structures like stadiums if those structures lack damping measures.

1.10 Consequences of Vibration

a) Damages to safety-related equipment

b) Adverse human response

c) Fatigue fracture

d) Overstressing and collapse of structures

e) Cracking and other damages

II. LITERATURE REVIEW

In this section, we summarize the investigations of various authors working in the field of Structural control as part of the literature survey. Samali et al. (1995) have investigated the performance of Tuned Mass Dampers (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 damping of 3 to 4 % of critical damping and 40 to 50% reduction in the wind induced response could be achieved with a passive system. An additional damping of about 10% of critical damping and higher reduction in the wind induced response could be achieved with an active system.

Suzuki et al. (1996) have demonstrated a practical application of computer based active vibration control system on the response of a 33 storied building. The height of the building was 134.4m and the controlled vibration modes were the first three translational and the first torsional mode. The authors placed sensors on at the central position on the twenty-third, the sixteenth and the ninth floors and also in the foundation. The authors used two active mass dampers for control of translational and torsion modes of vibration.

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.

$$[M]\{\ddot{x}(t)\}+[C]\{\dot{x}(t)\}+[K]\{x(t)\}=\{F(t)\}$$

Where,

$[M]$ = Mass matrix of the structure having $n\times n$ elements, kg,s

$[C]$ = Damping matrix of the structure having $n\times n$ elements, N.s/m,

$[K]$= Stiffness matrix of the structure having $n\times n$ elements, N/m,

$\{\ddot{x}(t)\}$ = Acceleration vector of the structure having $n\times 1$ elements, m/s^2,

$\{\dot{x}(t)\}$ = Velocity vector of the structure having $n\times 1$ elements, m/s,

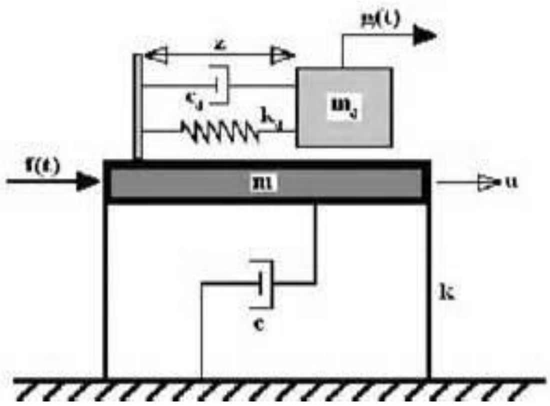
$\{x(t)\}$ = Displacement vector having $n\times 1$ elements, m and

$\{F(t)\}$ = External force vector of the structure having $n\times 1$ elements, N. **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 3.1. 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.

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 rigid and there is no bending deformation in the slab.
3) 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 which state that a system may be in dynamic equilibrium by adding to the external forces, an imaginary force which is known as the inertia force.



Structural model of Single storey frames with tuned mass damper.

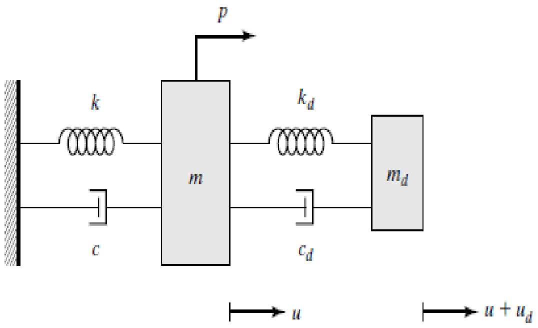
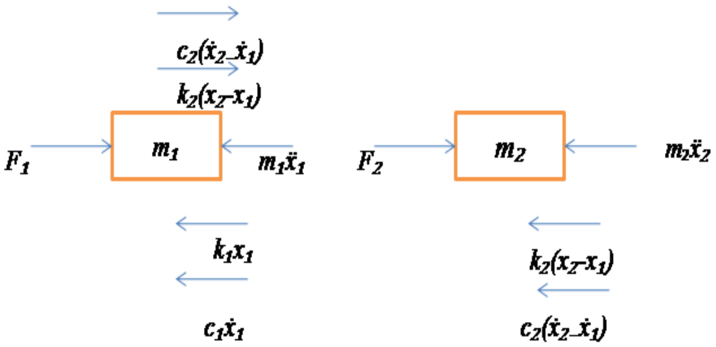


Figure 3.2 Mechanical Model of SDOF with Tuned Mass Damper



Free body diagrams of masses m_1 and m_2

The mass of the TMD in the current example is taken as 5% of the total mass of the structure, Datta, T.K. (2010). The stiffness of the TMD is obtained after tuning the frequency of the TMD to the fundamental frequency of the host structure.

Parameter	**Numerical value**
Mass of Rigid Slab(m_1)	150×10^3(kg)
Mass of the Tuned Mass Damper(m_2)	7500(kg)
Fundamental frequency of the structure(ω_1)	36.5158(rad/sec)
Equivalent Stiffness of the column(k_1)	200×10^3(kN/m)
Stiffness of the TMD (k_2)	10×10^3 (kN/m)

The values of the parameters above are taken from Datta, T.K. (2010).

IV. RESULTS PRESENTATION

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.

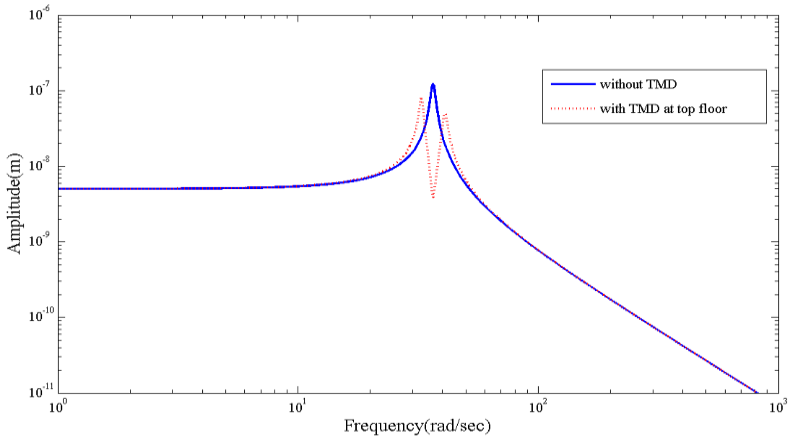


Figure 4.1(a): Transfer Function Between $x1$ and $F1$ as a Function of Frequency with and Without the TMD.

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.

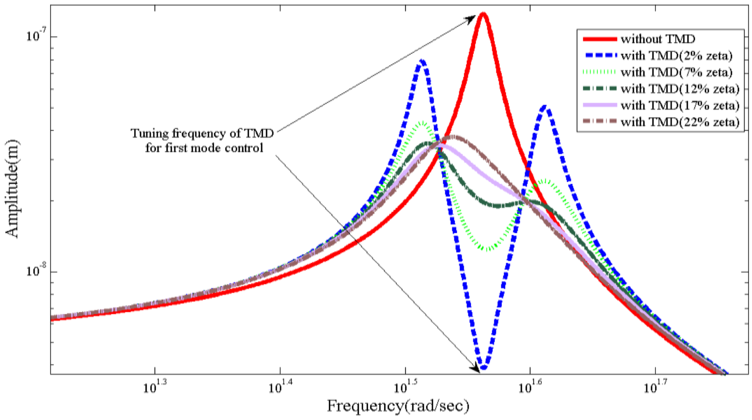


Figure above indicates the transfer function between $x1$ and $F1$ for different values of the damping ratio of the TMD.

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.

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.

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