EFFECT OF PASSIVE TUNED MASS DAMPER AND VISCOUS DAMPER IN A SLENDER TWO DIMENSIONAL FRAME

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Specially dedicated to my family and faithful friends

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ABSTRACT

Vibration induced dynamic loads such as earthquake load and wind excitation is one of the most critical issues of a slender structures. Hence structural damage due to motion induced dynamic loads in high-rise structures and other slander structures is a serious concern. One of the best solutions to decrease the sensitivity of the structures without disturbing the building to vibration is by utilizing a damping devices like Tuned Mass Damper and Viscous Damper. The goals of this project are to study the possibility of using a simple Passive Tuned Mass Dampers (PTMD) system in a 2D steel frame. It is to reduce its vibration in lateral direction. Investigations of the theoretical modeling for a 4-storey 2D frame are made in SAP2000 (version 16) and Autodesk Simulation Mechanical (version 2014). Comparing the outcomes with the results from experimental model in the laboratory by the companion author illustrate that damping devices especially passive tuned mass damper (PTMD) decreases the response displacement of the structure effectively. Even though the deviation between the test and analysis exist, various improvement can farther be made in the modeling. It also found out that the effectiveness of the PTMD was more than Viscous Damper (VD) in two dimensional frame system.

ABSTRAK

Getaran disebabkan beban dinamik seperti beban gempa bumi dan angin adalah salah satu isu yang paling kritikal untuk struktur langsing. Kerosakan struktur kerana gerakan beban dinamik dalam struktur bertingkat dan adalah satu kebimbangan yang serius. Salah satu penyelesaian yang terbaik untuk mengurangkan sensitiviti struktur tanpa mengganggu bangunan adalah dengan menggunakan satu peranti redaman seperti peredam massa ditala dan peredam likat. Matlamat projek ini adalah untuk mengkaji kemungkinan menggunakan mudah Passive Tuned Mass Damper (PTMD) pada rangka keluli 2D. Ia adalah untuk mengurangkan getaran pada arah sisi. Siasatan model teori untuk bingkai 2D 4 tingkat dibuat pada SAP2000 (versi 16) dan Autodesk Simulasi Mekanikal (versi 2014). Membandingkan hasil dengan keputusan daripada model eksperimen di dalam makmal oleh rakan penulis menggambarkan bahawa peranti redaman terutamanya Passive Tuned Mass Damper (PTMD) mengurangkan anjakan tindak balas struktur gecara berkesan. Walaupun perbezaan antara ujian dan analisis wujud, pelbagai penambahbaikan boleh dibuat dalam pemodelan. Ia juga mendapati bahawa keberkesanan PTMD adalah lebih baik daripada Viscous Damper (VD) dalam kerangka dua dimensi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

f_{opt} - Optimum natural frequency

f_d - Natural Frequency of Damper

f_n - Natural Frequency of Structure

ξ, ξ_e - Damping Ratio

$\xi_{d_{opt}}$ - Optimum Damping Ratio of damper

m, m_T - Mass of structure

m_d - Mass of damper

K - Stiffness of structure

k_d - Stiffness of damper

C - Damping coefficient

c_d - Damping coefficient of damper

Ω - Frequency

ω_d - Frequency of damper

U - Displacement responses

u_d - Displacement responses of damper

$\hat{u}$ - Displacement amplitude

$\hat{u}_d$ - Displacement amplitude of damper

$\dot{u}$ - Velocity

$\dot{u}_d$ - Velocity of damper

$\ddot{u}$ - Acceleration

$\ddot{u}_d$ - Acceleration of damper

P - Excitation

δ - Phase shift

F - Output force

V - Relative velocity across the damper

C - A constant determined

n - A constant of exponent

μ - Mass ratio

LIST OF ABBREVIATIONS

TMD - Tuned Mass Damper
PTMD - Passive Tuned Mass Damper
MTMD - Multiple Tuned Mass Damper
PVMT - Passive Vibration Mitigation Techniques
TLD - Tuned Liquid Dampers
TSD - Tuned Sloshing Damper
TLCD - Tuned Liquid Column Damper
VD - Viscous Damper
SDOF - Single Degree Of Freedom
ASM - Autodesk Simulation Mechanical

CHAPTER 1

INTRODUCTION

1.1 Background of Research

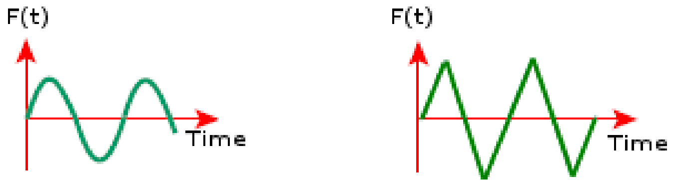
The lack of spaces and high price of lands in metropolis, that has a big population, structures need to be higher. When structures getting taller, it is slender and the effect of lateral loads due to wind and earthquake will be becoming a major issues. Besides, the uncontrolled movement, excessive deflection will cause a discomfort to the occupant.

1.1.1 Sources of Dynamic Excitation

One of the important necessities in applied engineering is design based on the determine the causes of dynamic excitation. Their effect is not completed to statistical loads. It is fairly simple to calculate the static loads rather than in dynamic loads. Some of the structures may show resonance against dynamic loads, especially the flexible and those ones are lightly damped. Therefore, the relation between the sources of dynamic excitation, the structural form and the purpose of the structure should be considered seriously at the design stage.

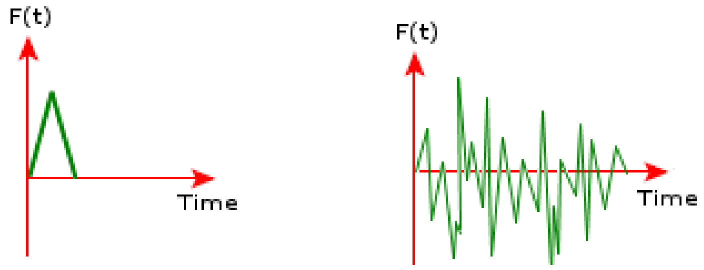
1.1.2 Dynamic Load

Dynamic loads can be categorized as periodic, harmonic, transient and impulsive as shown in Figure 1.1. Shaking table or rotating machinery can be recognized as sinusoidal or harmonic loads. Periodic loads are like rhythmic human activities. Transient loads are general loading that is like a movement of people such as running and walking. Single motion similar jumping or dropping can be given examples of impulsive or shock loads.



Harmonic loadir

Periodic loading



Impulsive loading
(Shock loading)

Transient loading
(General loading)

Figure 1.1 Types of Dynamic Loadings (Murray, Allen & Ungar, 1997)

1.1.3 Consequences of Vibration

Vibration of structures is unwelcome for a number of reasons. For example, overloading, cracking or other damages requiring repair. Sometimes it causes a collapse to structures. Extreme structural vibrations in building of houses, office, and hospitals need to be eliminated for their occupant comfort.

Human are highly sensitive to vibration (Drugă C, 2007). Therefore, an incompatible human response to buildings should be considered at the design stage. Although vibrations that causing discomfort for occupants are usually creating small stresses, but it may lead to fatigue.

Fatigue causes fracture are subjected to cyclic, periodical movement and fluctuating loads (Crane, Charles, & Furness, 1997). Fracture of fatigue usually occurs in metal specifically in welded part of steel by a small cracks that invisible to naked eyes. For example, high-mast lighting or billboard are subjected to a continuous wind load, that causing a milliard of cycles of significant stress to the structures and could effect in structural fatigue that lead to failure.

1.1.4 Vibration Control

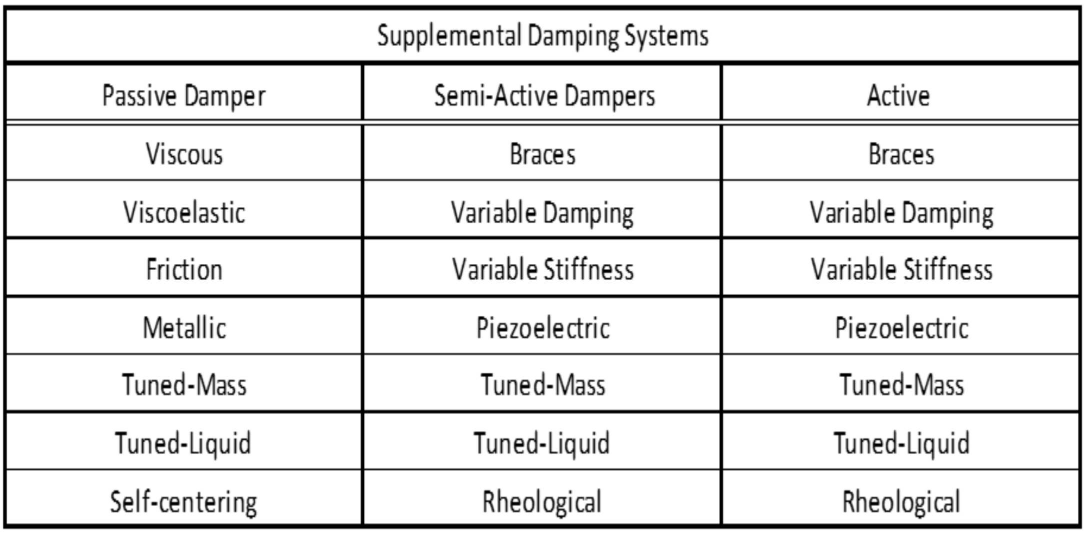
The first step to design the structure that subjected to the vibrations is to classify the dynamic loads in terms of frequency, intensity and its variation in terms of time. Analyzing the response of the structure to get dynamic displacement, shear force, stresses and frequencies come next. Finally, it is essential to check the result that calculated or measured performance by using specified standards to guarantee that there are no contradictory consequences of vibration that really applied. It is important to think forward during the initial stage of theoretical design and make necessary design changes in order to get an optimum result in the vibration susceptibility.

Active control over the natural frequency of buildings may be provided by increasing the stiffness or reducing the mass. Increasing stiffness method is usually difficult or uneconomic to reach the optimum value of dynamic acceptable state. It may be more efficient to design and use specific vibration-absorbing devices such as passive tuned mass dampers (TMDs), as part of the structural systems to reduce the effects of dynamic loads. Some of the construction techniques, such as welded steel-works, may be more delicate to vibration because of their lack of inherent damping capacity. Therefore, it may sometimes be more effective to choose materials with high damping or to install an artificial damping devices to reduce the vibration effect.

There are various types of system that can increase the resistance of structure under earthquake or wind loads. Following is a small description of common seismic protection systems.

Seismic protection systems can be categories as conventional, isolation and supplemental damping systems. The supplemental damping systems is divided into passive, semi active and active as shown in Table 1.1 (Christopoulos, Filiatrault, & Bertero, 2006). These 3 types of dampers are motivated by the movement of structure and reduce displacements of structure by dissipating energy by the use of different mechanisms.

Table 1.1 Type of Seismic Protection Systems (Christopoulos, Filiatrault, & Bertero, 2006):



Supplemental Damping Systems		
Passive Damper	Semi-Active Dampers	Active
Viscous	Braces	Braces
Viscoelastic	Variable Damping	Variable Damping
Friction	Variable Stiffness	Variable Stiffness
Metallic	Piezoelectric	Piezoelectric
Tuned-Mass	Tuned-Mass	Tuned-Mass
Tuned-Liquid	Tuned-Liquid	Tuned-Liquid
Self-centering	Rheological	Rheological

a) Active systems

Generally these systems monitor the behavior of the structure during seismic situation and then processing the information to produce a set of instruction to force change the current situation of the structure to reduce the effect of seismic vibration. This system needs a nonstop external power source; therefore the loss of power could create damage to the structure (Symans & Constantinou , 1999).

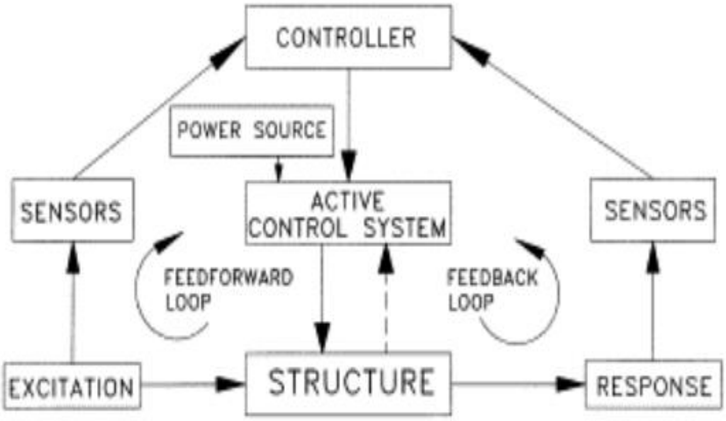


Figure 1.2 Framework of active system (Symans & Constantinou , 1999)

b) Semi-Active systems

These systems are similar to active systems, but they needs less amount of external power and excite the structure to be in adverse motion as a control forces. The amount of forces can be adjusted by using the external power source (Symans & Constantinou , 1999).

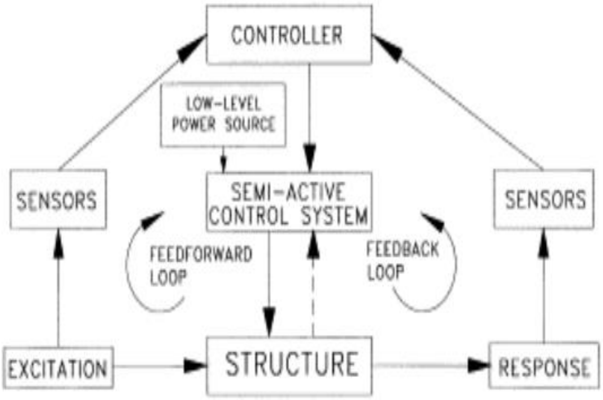


Figure 1.3 Framework of semi-active structural control systems (Symans & Constantinou , 1999)

c) Passive Systems

These systems dissipate seismic energy without any need for external power source in the structure. Their properties during the seismic vibration are constant and cannot be changed. Mainly Passive Control Systems are divided into Metallic Yield Dampers, Friction Dampers, Viscoelastic Dampers, Viscous Fluid Dampers, Tuned Mass Dampers, Tuned Liquid Dampers and Ring Spring Dampers (Girges & William, 2004).

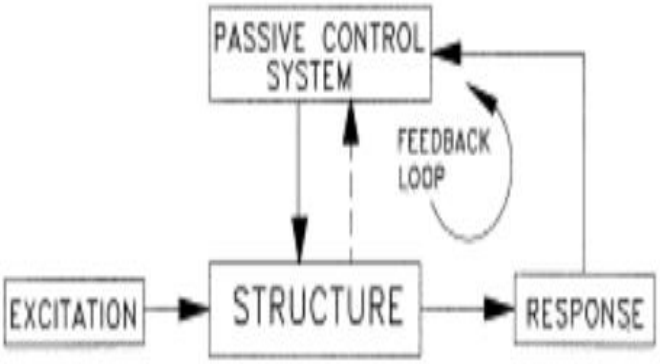


Figure 1.4 Framework of passive structural control systems (Symans & Constantinou , 1999)

1.2 Problem Statements

The design of tall buildings fundamentally involves a perceptual design, estimated analysis, initial design and optimization, to safely carry lateral and gravity loads. The important criteria for design tall structures are strength, stability, serviceability and human comfort. All criteria have limitation ranges as sufficient , safety to a standard limits; for the structural engineer to reach at suitable structural systems as well as satisfying the standards.

In a tall building one of the biggest problems is the lateral forces. These forces usually created by earthquake and wind. According to the standards and researches, with increasing the height, the effect of these loads are going to be more, therefore a new way of designing for the structure must be satisfying the limitation state. One of the ways is embedding a damper in to the structure. This will reduce the effect of lateral load and to keep the structure in the safety limits, reduce displacement and human discomfort at the highest levels of building. Another issue is to reduce the effect of cycling that makes earlier failure in the structure because of fatigue and creep phenomenon.

1.3 Objectives

The objectives of the research are:

- Investigations of model of Tuned Mass Damper (TMD) for a four-story steel frame that representing a slender structure.
- To analyses the concept of Tuned Mass Damper (TMD) for a four-story slender frame in the form of line system and 3D model system using SAP2000 and Autodesk Simulation Mechanical (ASM) 2014.
- To compare the responses of the frame with and without dampers (either TMD or Viscous Damper) in cyclic load.

1.4 Scope of work

The scope of works of the research are:

1. Performance of a concerted a 4-storey 2D steel frame is considered in earthquake loading through simulation model in Autodesk Simulation Mechanical and SAP2000.
2. This study focuses on effectiveness of tuned mass damper as well as fluid viscous damper on slender structure.
3. Tuned Mass Damper was considered as Passive Tuned Mass Dampers (PTMD).

4. Non-linear analysis was performed to determine the response of the structure.

5. In order to design an effective PTMD, its influential parameters such as frequency (to calculate the stiffness of the spring) and damper mass must be tuned in a way to significantly reduce the structural response.

6. This structure is assumed not to have a soil-structure interaction.

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