EXPERIMENTAL INVESTIGATION OF PASSIVE TUNED MASS DAMPER AND FLUID VISCOUS DAMPER ON A SLENDER TWO DIMENSION STEEL FRAME

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To my beloved mother and father

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ABSTRACT

Vibration is a serious concern for tall buildings added to a natural disaster such as earthquake, wind storms, sea waves and hurricanes. The risk of occurrence of structural damage can be decreased by using a controlled vibration system to increase the damping characteristics of a structure. Damping is defined as the ability of the structure to dissipate a portion of the energy released during a dynamic loading event. The aims of this study are (1) to investigate a 4-storey 2D steel frame retrofit with tuned mass damper to reduce its vibration as well as compare the results with response displacement of the structure using viscous damper. In this project, the focus is limited to present an experimental model with semi-rigid connections and to show its validity by comparing the experimental results (achieved from shaking table test) with the analytical results obtained from theoretical model (SAP2000 software), (2) to demonstrate the performance of such a damper when fitted to a structure by analysis and tests the models and (3) comparison the dynamic responses of the structure in three verify of: a) using passive tuned mass damper, b) using viscous damper and c) using the combination of these two damping devices. Therefore, a series of shaking table tests of the 4-storey 2D steel frame $(scale{:}\frac{1}{4})$ with and without passive tuned mass damper (PTMD) and viscous damper (VD) was carried out to evaluate the performance of the buildings. The results of the experimental tests illustrate that damping devices decrease the structural responses of slender frame on shaking table. In addition, effectiveness of passive tuned mass damper is greater than viscous damper.

ABSTRAK

Getaran adalah satu kebimbangan yang serius untuk bangunan tinggi ditambah kepada bencana alam seperti gempa bumi , ribut angin, ombak laut dan ribut taufan. Risiko berlakunya kerosakan struktur boleh dikurangkan dengan menggunakan sistem kawalan getaran untuk meningkatkan ciri-ciri redaman struktur. Redaman ditakrifkan sebagai keupayaan struktur untuk menghilangkan sebahagian daripada tenaga yang dibebaskan semasa acara muatan dinamik. Tujuan kajian ini ialah (1) untuk menyiasat bingkai keluli (4 tingkat) 2D yang diselaras dengan peredam untuk mengurangkan getaran. Ia membandingkan keputusan anjakan bebas struktur dengan struktur diperkuat degan menggunakan redaman likat. Dalam projek ini , sambungan separa tegar diguna pada ujian dengan keputusan analisis yang diperolehi daripada model teori (perisian SAP2000) , (2) untuk menunjukkan prestasi peredam yang dipasang pada struktur dengan analisis dan (3) perbandingan respons dinamik struktur dalam tiga keadaan : a) peredam massa pasif ditala, b) yang menggunakan peredam likat dan c) menggunakan gabungan kedua-dua peranti peredam. Oleh itu , satu siri ujian kerangka 4 tingkat kerangka keluli 2D (skala : 1/ 4) tanpa peredam massa pasif (PTMD) dan peredam likat (VD) telah dijalankan untuk menilai prestasi kerangka. Keputusan ujian uji kaji menunjukkan bahawa peranti redaman mengurangkan tindak balas struktur di atas meja getaran. Di samping itu, keberkesanan peredam massa pasif ditala adalah lebih besar daripada peredam likat.

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LIST OF SYMBOLS

A	-	Amplitude of the motion
c	-	Damping coefficient
C	-	A constant determined
c_d	-	Damping coefficient of damper
d	-	Wire diameter
D	-	Mean diameter
F	-	Output force
f_{opt}	-	Optimum natural frequency
f_d	-	Natural Frequency of Damper
f_n	-	Natural Frequency of Structure
G	-	Spring steel modulus
ξ, ξ_e	-	Damping Ratio
$\xi_{d_{opt}}$	-	Optimum Damping Ratio of damper
k	-	Stiffness of structure
k_d	-	Stiffness of damper
m_{Total}	-	Mass of the structure
m_d	-	Mass of damper
n	-	A constant exponent
n	-	Number of active coils
N	-	Number of total coils
ω	-	Circular frequency of the motion
ω_d	-	Frequency of damper
p	-	Excitation
t	-	Time

$\dot{u}$	-	Velocity
$\ddot{u}$	-	Acceleration
$x(t)$	-	Displacement of the damper
μ	-	Mass ratio

LIST OF ABBREVIATIONS

2D	-	Tow dimension
ATMD	-	Active Tuned Mass Damper
TMD	-	Tuned Mass Damper
PTMD	-	Passive Tuned Mass Damper
PED	-	Passive Energy Dissipation
MTMD	-	Multiple Tuned Mass Dampers
STMD	-	Smart Tuned Mass Damper
TLD	-	Tuned Liquid Dampers
TLCD	-	Tuned Liquid Column Damper
TSD	-	Tuned Sloshing Damper
VD	-	Viscous Damper
SDOF	-	Single Degree Of Freedom

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

In last decades a large number of tall structures have been proposed and built worldwide. In our modern society, tall structures are an essential component of new civilization. Generally, these structures are designed to resist static loads. On the other hand, they may be subjected to dynamic loads like earthquakes, winds, waves, and traffic. These loads can cause intensive and continuous vibrational motions that damage to the structure and human inhabitants. Because of this, safer tall buildings should be designed.

1.1 Types of Loads

There are two types of forces that may act on structures, namely static and dynamic forces (Filiatrault, 2002).

1.1.1 Static Loads

Static loads are those that are gradually applied and remain in place for longer duration of time. These loads are not time dependent. As an illustration, a live load on a structure is considered as a static load. Most loading applied to civil-engineering structure, includes seismic loads, are usually considered as an equivalent static loads. The amplitude, direction and location of a static load do not vary with time (Filiatrault, 2002).

1.1.2 Dynamic Loads

Dynamic loads are time dependent. Earthquake loads, machinery vibrations and blast loadings are examples of dynamic loads. The amplitude, direction and location of a dynamic load vary with time. The main purpose of structural dynamics is to evaluate the time variations of stresses and deformations in structures caused by arbitrary dynamic loads (Filiatrault, 2002). Dynamic loads on tall structures; such as those stemming from wind and earthquake can cause human discomfort, motion sickness and sometimes endanger structural safety and integrity (Aldawod, Samali, Naghdy, & Kwok, 2001).

Random loads are described by statistical parameters (mean, standard deviation, frequency contents, etc.) (Filiatrault, 2002).

The amplitude, direction and location of a deterministic load are known at all times. Two classes of deterministic loads can be differentiated: periodic loads and non-periodic loads (Filiatrault, 2002).

Wind is a phenomenon of great complexity because of the many flow situations arising from the interaction of wind with structures (Mendis, Ngo, Haritos, & Hira, 2007).

Modern structures move toward taller and more bendable designs, hence the problems of wind effects on these types of structures endanger structural integrity as well as increase human discomfort. As a result, a various group of contributions must be considered, as illustrated in Figure 1 (Kijewski, Haan, & Kareem, 2001).

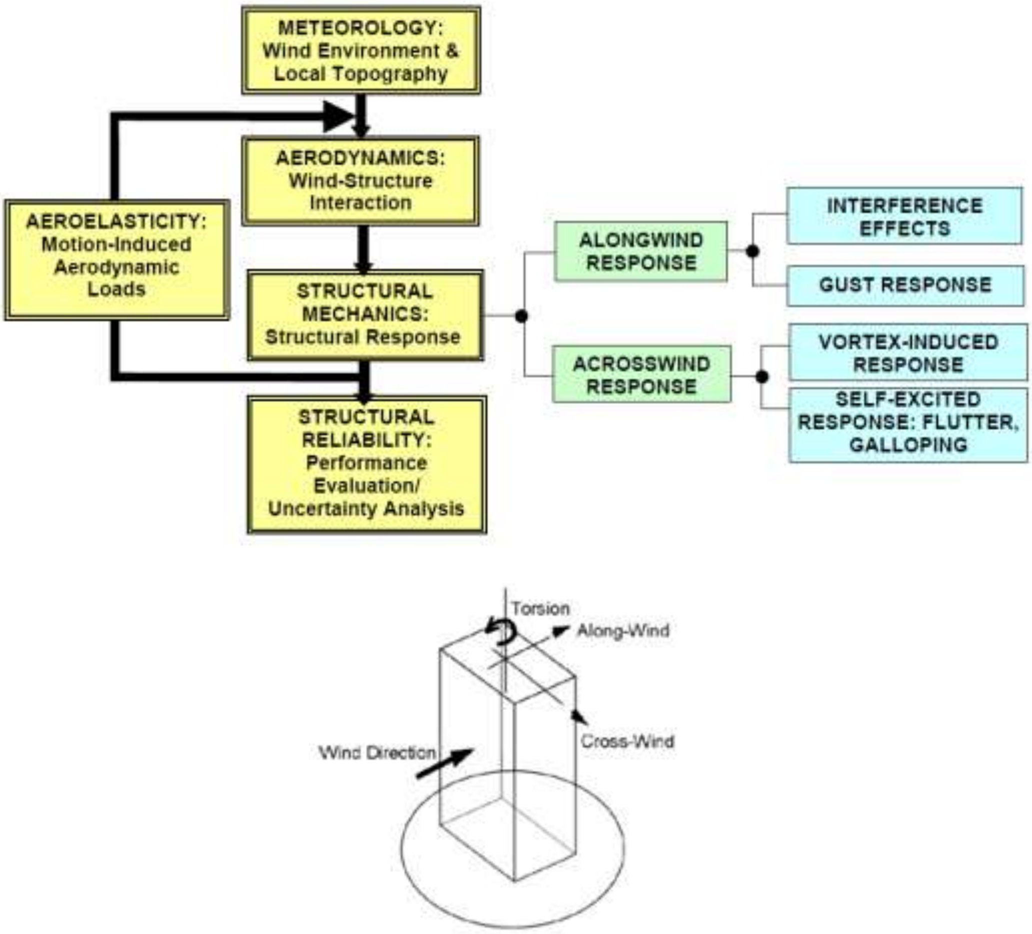

Figure 1.1 Overview of scheme to determine wind effects on structures. (Kijewski, Haan, & Kareem, 2001)

Earthquake loads are lateral loads. Ground moves suddenly in horizontal and vertical directions. Earthquakes create vibrations on the ground that are translated into dynamic loads which cause the ground and anything attached to it to vibrate in a complex manner and causing damage to buildings and other structures (S & R, 2012).

Earthquakes are occasional forces on structures that may occur during the lifetime of buildings. As seismic waves move through the ground, they create a series of vibrations. These movements are translated into dynamic loads or inertial forces that cause the ground and anything attached to it to vibrate in a complex manner. These inertial forces cause damage to buildings and other structures (S & R, 2012).In short, earthquake is focus to cause extensive damage in certain areas, and relatively little damage in others (Wen, Hu, & Chau, 2002).

1.2 Damping

Damping is associated with the energy dissipation properties of a material or system under cyclic stress. Damping in a vibrating structure is associated with the dissipation of mechanical energy, usually by converting into thermal energy (Pashaie, 2004).

Damping sources normally classified into following deferent types includes: Material Damping, System Damping, Radiation Damping, Auxiliary Damping (Pashaie, 2004).

A damper is an active or a passive control device that helps to suppress the vibration of a structure by dissipating energy through it when it is excited by dynamic forces. The role of such devices has gained considerable importance as the structures in various applications are now becoming more flexible and lightly damped (Sarkar & Gudmestad, 2013).

Dynamic vibration absorbers (DVAs) are well-established passive vibration control devices attached to structures susceptible to vibrations such as high-rise buildings, long-span bridges and light-weight floor systems. The first DVA was invented in the form of a spring supported mass in 1911. The limitations on the controlled frequency range lead to the introduction of a damping element parallel to the spring; hence the damped DVA was born in 1928.The design of DVAs involves selection of three parameters: mass, frequency and damping. Mass is usually selected based on the physical constraints pertaining to the specific application and specified as a ratio to the mass of the primary vibrating system. The frequency of a DVA is also usually specified as a ratio of damping to the frequency of the primary system (Tigli, 2012).

1.3 Research Background

Damping is a phenomenon in mechanical system where the vibrational energy is absorbed and dissipated during oscillation. Research on the damping properties of solid materials and their engineering significance was started almost 250 years ago. However, the complexity of damping phenomenon has prevented a complete understanding of the mechanisms by which the vibrational energy is dissipated (Pashaei, 2004).

Many of research centers inside and outside of universities were established all over the world to investigate damping in the structure and materials. The ‘Architecture Institute of Japan’ (ALJ) and the ‘Building Research Establishment’ (BRE) in the UK are examples of such centers. ALJ carried out dynamic tests on 123 steel structures and 66 reinforced concrete structures. In the nineteenth century, many vibration studies were undertaken on the viscosity of metals and non-linear nature of their viscosity. Some investigations were carried out on ‘initial friction’ oh iron, silver, copper and other metals. Also, the effects of variables such as amplitude and frequency of the vibration as well as the initial strain and the size of the body were studied. During the nineteenth century about 25 papers on damping were published. During the last four decades huge efforts were spent by physicists, mechanical and structural engineers to find the damping characteristics in metals, structures and buildings. During these years thousands of papers have been published. However, damping is still not exactly understood and efforts to understand the nature of this phenomenon is continued (Pashaei, 2004). Unfortunately, the study of it as a vibration is focusing on an isolated cases by not considering whole system.

Several groups of researchers are involved in research in damping with different aims. For instance the mechanical engineers are concerned about many unwanted vibrations in mechanical devices and machines. Civil engineers are another group who are involved in research on damping. They are responsible for constructing buildings to resist against powerful winds and earthquakes. The civil engineers are concerned with strong winds especially in tall buildings, frequently, cause notable vibrations which can cause anxiety and discomfort to the building’s occupants. Absorption and dissipation of the vibrational energy is one of the best methods of reducing motions induced by the winds and earthquakes in buildings and structures. Also, to predict the behavior of the structures and analyses them, it is necessary to know the damping characteristics of structures (Pashaei, 2004).

The vibrations of the tall buildings are serious concerns to both engineers and architects for the protection of the structure safety and occupant comfort. These structures are subjected to huge dynamic loadings from the winds, earthquakes, water waves, traffics and human motions. The large vibration amplitude can damage the main structures or the secondary structures. It also causes a discomfort to human. General research has been conducted to mitigate this harmful vibration, by, for example, structure design, vibration isolation systems, and auxiliary damping systems. Among these methods, the tuned mass damper (TMD) has been proved to be a very simple and effective vibration suppression device, with many practical implementations on tall buildings, such as Taipei 101 in Taipei, Citi Group Building in New York, and many others (Chey, 2007).

It is well accepted that earthquakes will continue to occur unpredictably, and cause significant social structural and economic damage. Assessing earthquake risk and improving engineering strategies to mitigate damage are thus the only viable options to create more resilient cities and communities. Geologists, seismologists and engineers are continuing their efforts to improve zoning maps, create reliable databases of earthquake processes and their effects, increase understanding of site characteristics, and develop earthquake resistant designs. As for the engineer, the ultimate goal is to design damage free, cost effective structures that will behave in a predictable and acceptable manner to maximize life safety and minimize damage. The challenges are therefore to develop new techniques and to improve on the existing practices so that the performance of these structures is predictable and acceptable. Acceptable means minimal or no damage for credible design events with no loss of life safety (Chey, 2007).

1.4 Problem Statement

The problem statements of this project are:

Slender structures face some huge vibration than short structures through wind excitations or seismic motions. Tall structure is subjected to vibration which may come from wind excitations and earthquakes. In this type of structure only natural damping is naturally present and it is not sufficiently in order to resist a strong movement. In other words, if a slender structure faces a powerful vibration such as that come from seismic motions, tall structure may collapse due to excessive displacement. Hence, it is essential to install supplement damping to assist the intensification of damping to avoid damages.

The difficulties related to the wind-induced vibrations of tall buildings are familiar. Wind-induced vibrations in tall buildings may cause many problems like displeasure of inhabitants, weakened function of tools, or structural harm. Actually displeasure of residents is more tangible in higher floors.

1.5 Objectives

The objectives of the project are:

a. To evaluate the concept of Tuned Mass Damper (TMD) and Viscous Damper (VD) for a multi-storey 2D frame.

b. To compare the performance in the form of response displacement of the slender structure with and without damping devices of (Passive Tuned Mass Damper, and Viscous Damper) through a series of vibration harmonic tests.

1.6 Scope of Study

The scopes of this study are, the dynamic Performance of 4-storey 2D steel frame that are loaded laterally with a time history to obtain the natural frequency. Focus of this study is on the effectiveness of Tuned Mass Damper as well as Viscous Damper on the slender structure.

In order to design an effective Passive Tuned Mass Damper (PTMD), its influentially parameters such as frequency (for calculation the stiffness of the spring) and mass of the damper must be tuned in a way to significantly reduce the structural response.

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