"I hereby declared that I have read this thesis an in my opinion this thesis is sufficient in terms of scope and qualify for the award of the Degree of Bachelor Mechanical Engineering (Structure & Material)"

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AN EXPERIMENTAL STUDY ON THE PROPAGATION OF VIBRATION AND COMPARISON OF DAMPING IN A STEEL SUPPORT STRUCTURES

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A project report submitted in partial
fulfillment of the requirements for the award of
the Degree of Bachelor Mechanical Engineering (Structure & Material)

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MAY 2008

"I hereby declared that this thesis is my own work except the ideas and summaries which I have clarified their sources"

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Date : 28 · 04 · 2008

Specially dedicated to my family, friends and companion

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ABSTRACT

This thesis presents an experimental study on propagation of vibration and comparison of damping in a steel support structures. Vibration transmission occurs in the steel columns that are used to build railway stations are meant to support railway line and applied to other problems of structural and mechanical vibration. This study is mainly focused on the vibration in the structures as vibration can be transmitted to various parts and then radiated as structure-borne noise. Impact hammer testing is used to test the modal damping, with and without damping to obtain the natural frequency, damping ratio and mode shapes for different damping materials that shall be used such as sand, wood dust and used vehicle lubricating oil. An experiment test rig is built up for vibration testing. An impact hammer with plastic tip, SKF Microlog CMVA 65 Data Analyzer and Machine Analyst (MA) software are used to conduct the experiment. The steel column is attached by accelerometer at different positions on outer surface to find out the accurate results whether the noise disturbance occur during experiment. The vibration spectrums will be analyzed through the MA software. From the results obtained, when the mass of damping material increases, the natural frequency decreases and the damping ratio also increases. The impact force did not bring any changes to the natural frequency on vibration spectrums whether the impact force increased or decreased but it will change the vibration displacement only while the damping ratios remain constant. The experiment results correspond to the expected results based on the theory. This can be proven by using *Half Power Law's* equation. The objectives which are with and without adding the damping material in the steel column and the different natural frequencies for each height level of the column are achieved.

ABSTRAK

Tesis ini adalah mempersembahkan kajian tentang penyebaran getaran and perbandingan redaman di dalam penyokong struktur besi. Penyiaran getaran boleh berlaku dalam tiang bulat besi. Biasanya, tiang bulat besi ini digunakan sebagai pembinaan stesen kereta api dan juga menyokong lintasan kereta api. Kajian ini menumpukan utama kepada getaran dalam struktur yang membolehkan getaran menyiarkan ke bahagian-bahagian yang berlainan dan menyebarkan sebagai struktur bunyi bising. Ujian penghentaman digunakan untuk menguji corak kelembapan getaran. Eksperimen ini dibahagikan kepada dua jenis iaitu kelembapan getaran dan tanpa kelembapan getaran. Ini bertujuan untuk mendapatkan frekuensi tabii, nisbah redaman dan bentuk mod dalam eksperimen ini. Eksperimen ini dijalankan dengan menggunakan bahan redaman yang berbeza iaiu pasir, abuk kayu dan minyak pelincir kereta yang terpakai. Satu ujian eksperimen pelantar minyak dibentuk untuk ujian getaran. Sebuah tukul yang kesan dengan hujung plastik, SKF Micrologic CMVA 65 Data Analyzer dan perisian Machine Analyst (MA) digunakan mengendalikan eksperimen. Ruangan keluli adalah dilampirkan oleh meter pecut di tempat permukaan luar berbeza untuk mengetahui keputusan yang tepat untuk mencegah gangguan bunyi bising berlaku sepanjang eksperimen. Spectrums getaran akan dianalisis melalui perisian MA. Daripada keputusan diperolehi, apabila pertambahan jisim bahan redaman, frekuensi tabii berkurang dan nisbah redaman juga bertambah. Daya hentaman tidak membawa sebarang perubahan untuk frekuensi tabii di spectrums getaran tetapi sesaran getaran akan berubah dan nisbah redaman masih sama. Hasil uji kaji berpadanan dengan keputusan yang dijangka berdasarkan teori. Ini boleh dibuktikan dengan menggunakan persamaan "Half Power Law". Objektif telah dicapai iaitu menambah bahan redaman dengan tanpa bahan redaman dalam ruangan keluli dan frekuensi tabii yang berbeza pada setiap ketinggian ruangan keluli.

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NOMENCLATURE

ω_n	=	Undamped Natural Frequency
ω_d	=	Natural Damped Frequency
ζ	=	Damping Ratio
c	=	Damping Constant
c_c	=	Damping Constant for Critically Damped
T_d	=	Damped Oscillation Period
Q	=	Q Factor

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CHAPTER I

INTRODUCTION

1.1 Overview

Vibrations gave a significant effect in many aspects of our life. For example, any unbalance in machines with rotating parts such as fans, ventilators, centrifugal separators, washing machines, lathes, centrifugal pumps, rotary presses, and turbines can cause vibrations. For these machines, vibrations are generally undesirable. Buildings and structures can experience vibrations due to operating machinery; passing vehicular, air, and rail traffic or natural phenomena such as earthquakes and winds.

Vibration is evident everywhere and in many cases greatly affects the nature of engineering designs. Vibration can be harmful and should be avoided or it can be extremely useful and desired. For examples, structural vibration testing and analysis contributes to progress in many industries, including aerospace, auto-making, manufacturing, wood and paper production, power generation, defense, consumer electronics, telecommunications and transportation. The most common application is identification and suppression of unwanted vibration to improve product quality. The term vibration describes repetitive motion that can be measured and observed in a structure. Unwanted vibration can cause fatigue or degrade the performance of a structure. Therefore it is desirable to eliminate or reduce the effects of vibration. (Silva, 2000)

In addition, the science and engineering of vibration involve two broad categories of applications; there is elimination or suppression of undesirable vibrations and generation of the necessary forms and quantities of useful vibrations. Undesirable and harmful types of vibration include structural motions generated due to earthquakes and vibration transmitted from machinery to its supporting structures caused by vibration. Recent advances of vibration are quite significant and the corresponding applications are numerous. One can then visualize several practical applications where modeling, analysis, design, control, monitoring and testing relate to vibration are important. (Meirovitch, 2001)

1.2 Objectives

The objectives of this thesis are defined as follows:

a) To study the vibration in the structures as vibration can be transmitted to various parts and then radiated as structure-borne noise.

b) To determine the natural frequency and testing the modal damping, with and without damping shall be undertaken (sand, wood dust, oil and etc).

1.3 Scopes

To achieve the above objectives, the scope of this work for the project generally involves the following:

a) To build up the experiment test rig for testing.

b) Conduct vibration measurements to obtain the natural frequency and damping value at different positions.

c) To compare the different damping materials based on experimental results.

1.4 Problem Statement

Kuala Lumpur Sentral (KL Sentral) is an ultra modern railway station. Located at the heart of Kuala Lumpur is a transportation hub that brings together the commuter, intercity and airport Express Rail Link (ERL) with Light Rail Transit (LRT) system. The arrangement of the station is Level 1 (Deck): departure hall, baggage claim, operational control centre and various administration offices; Level 2: main concourse, retail, ticket hall, baggage, storage and baggage claim; Level 3: VIP lounge, assorted retail and first class lounge; Level 4: rail company offices, retail and speculative offices. Below the station there are 21 railway lines with four commuter tracks, two through tracks for diesel goods trains and two tracks for diesel Intercity passenger trains.

Vibration and noise are generated by trains passing under the station propagates through the ground to the building structure, where it can be felt or heard by people in the station as a rumbling sound. Basically, the noise is emitted from the rails caused by the friction between the wheels of the trains and the rails as shown in Figure 1.1. Building floors, walls and ceilings are subjected to significant amplification of vibration, over a frequency range of 16-80Hz.

Currently, the problem is commonly addressed by the installation of ballast mat or under sleeper pads. Ballast mat and under sleeper pads are well known products used for decoupling rail and associated elements from the ground to prevent the transmission of vibration and it will further lower radiated noise levels. As the more effective of the two ballast mat systems considered required a concrete base to achieve the performance, the under sleeper pad system was chosen because it was considered the most cost-effective option. (Marks, 2000)

Structure-borne noise refers to noise which is generated by vibrations induced in the ground or structure, according to the acoustic wizard. These vibrations excite walls and slabs in buildings and cause them to radiate noise. This type of noise can not be attenuated by barriers or walls but requires the interposition of a resilient such as neoprene as well as springs to break between the source and the receiver.

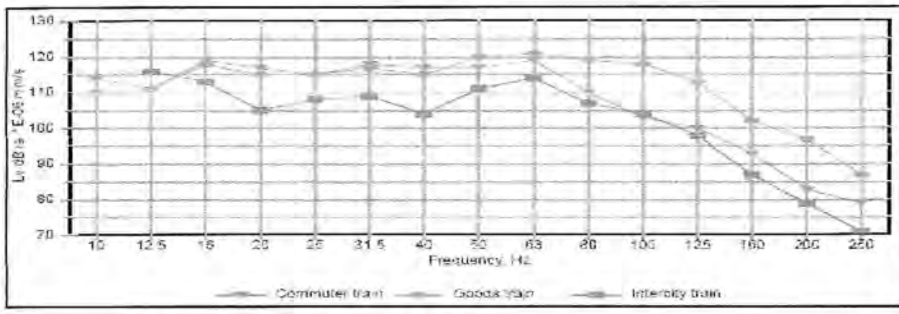


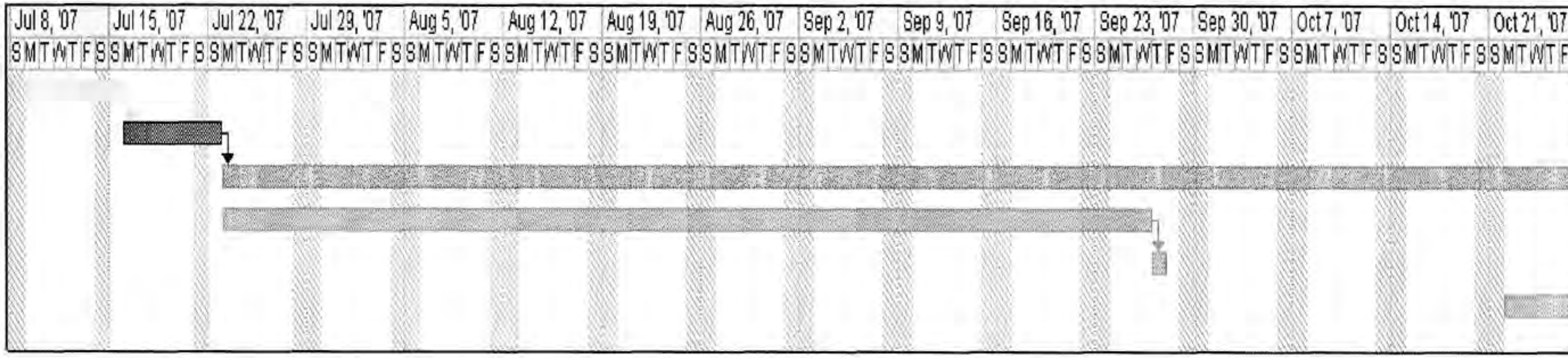
Figure 1.1: KL Sentral Vibration levels at grade

(Source: Marks, 2000)

Regarding to the situation above, the main objective of this project is to use the steel columns or steel square section by filling with sand, used lubricating oil and wood dust to damp down the propagation of vibration as vibration reduction method. The steel square section or steel columns that are suitable to be used in this experiment but steel columns are widely used in construction, especially in building structure. So, the steel columns that are used to build railway stations are meant to support railway line. Column in architecture and structural engineering is a vertical structural element that transmits through compression, the weight of the structure above to other structural elements below.

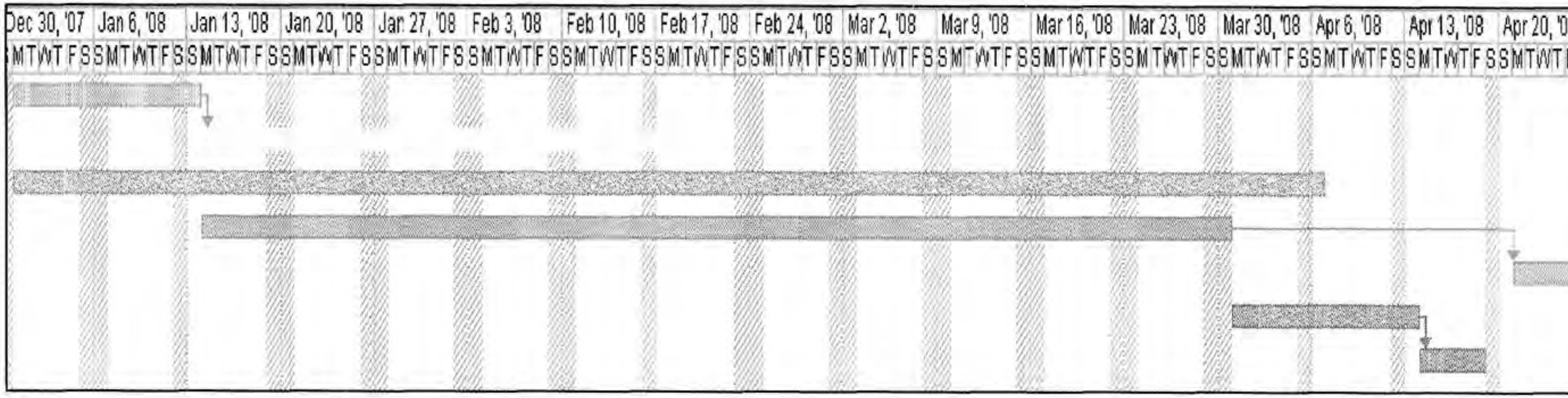
1.5 Gantt Chart

The progress of the project is shown in Figure 1.2 and Figure 1.3



No		Task Name	Duration	Start	Finish
1		Choosing title and understanding the title	6 days	Mon 7/9/07	Sun 7/15/07
2		Confirmation of the PSM title with supervisor and planning on PSM I and PSM II	6 days	Mon 7/16/07	Sun 7/22/07
3		(i) Literature review -Structural vibration -Detailed analysis of mode shapes, natural frequency, modal damping analysis and etc. (ii) Design an experiment test rig and material selection	70 days	Mon 7/23/07	Fri 10/26/07
4		Draft of PSM I	48 days	Mon 7/23/07	Wed 9/26/07
5		PSM I Report submission	1 day	Thu 9/27/07	Thu 9/27/07
6		PSM I Presentation	5 days	Mon 10/22/07	Fri 10/26/07

Figure 1.2: Progress of the PSM I



No		Task Name	Duration	Start	Finish
1		Prepare a test rig	11 days	Mon 12/31/07	Sun 1/13/08
2		Setup apparatus, Experimental analysis and etc.	26 days	Mon 1/14/08	Sun 2/17/08
3		Literature review -Structural vibration -Detailed analysis of mode shapes, natural frequency, modal damping analysis and etc.	73 days	Mon 12/31/07	Sun 4/6/08
4		Draft of PSM II	56 days	Mon 1/14/08	Sun 3/30/08
5		Final report submission	5 days	Mon 4/21/08	Fri 4/25/08
6		Prepare PSM II Presentation	12 days	Mon 3/31/08	Sun 4/13/08
7		PSM II Presentation	5 days	Mon 4/14/08	Fri 4/18/08

Figure 1.3: Progress of the PSM II

CHAPTER II

LITERATURE REVIEW

This chapter presents a general literature review on mechanical structural vibration which is then followed by a review of studies on modal damping analysis and mode shapes by using conventional impact or bump testing.

2.1 Background

Tan, et al (2002) have developed a visualization of vibration mode shapes to help student in further understanding basic vibration theory. This will allow students to perform experimental investigations to physically observe vibration mode shapes generated using external excitation. Vibrations testing by using an impact hammer to determine the natural frequencies and mode shapes. Besides, the frequency response curve can be used to determine the behaviour of object such as its natural frequencies, damping ratio and mode shapes. When adding masses onto the floors of the structure, it lowers the natural frequencies for both the one degree of freedom and three degree of freedom models. Furthermore, the mass is increased; the deflections are smaller and hence reduced the non linear behaviour in the small mass models. As a result, the resonant frequencies of both single and multiple degree of freedom models were easily measured using modal impact hammer technique.

Tranxuan (1995) investigated the dynamic behavior of a steel cylindrical tank containing water. It is considered by experimental modal analysis using impact hammer method as a problem that showed a different range of structures for example oil tanker and road tankers used in petroleum industry or nuclear reactors are often subjected to random vibration due to land and sea transportation loads and earthquakes. The empty tank was first tested and then the level of liquid was changed by adding each time 10kg of water up to 70kg which the maximum water level in the tank was only 60% of the tank's height to ensure good signal-noise ratio in the impact test. As a result, the effects increasing mass of water on the dynamic behavior of the tank are with respect to the natural frequency and damping ratio corresponding to a particular mode shape. In addition, the effects of the water mass on the dynamic characteristics of the tank response should be taken into account in evaluating the strength of the structure under dynamic load.

Nobukazu, et al (2005) presented the basic performance tests on the vibration of flexible plates for the ITER major components such as toroidal field coil and vacuum vessel were performed using its small-sized model. The aim is to obtain mechanical characteristics such as dependence of the stiffness on the loading angle. The experimental results are obtained by using the hammering and frequency sweep tests. The experimental results are compared with that of numerical analyses in order to create an adequate analytical model for ITER support structure with flexible plates. It is then used to estimate the dynamic behaviors such as eigen modes and amplitude of deformation of the major components of the ITER tokamak device during earthquake in the future. As a result, the stiffness of the bolt connection of the flexible plates on the base was strongly affected. The studies on modeling the bolts found that the analytical results of finite stiffness are only in the axial direction. For infinite stiffness, the result turns to the other direction which relates well to the experimental.

Vecchio, et al (2005) performed an experimental campaign aimed at assessing the impact of vibration data uncertainties on the quality of modal models extracted from test data. Focus is given to data uncertainties induced by mass loading effect in multi-patch modal tests. Comparisons are provided for real test cases such as an aluminum lightweight thin plate and a small car turbine. Several dissimilar patterns for sensor distribution over the test article are taken into account, modal models as extracted form each test data set are compared with numerical models. For very lightweight structures, standard modal testing techniques induce sensor mass loading and lead to incorrect modal models. Another contact-less testing technique is used that makes use of particle velocity sensors and allows removing mass loading effect in modal models. Comparisons with numerical models confirm the enhanced quality of modal models extracted with contact-less particle velocity sensors.

Cameron, et al (1997) analyzed the modes of vibration of a clamped-free bar. Vibratory behavior of the clamped-free bar is predicted by theoretical calculations, modal analysis and finite analysis. Finite element analysis is a good beginning computational tool to precede an experimental modal analysis; it helps identify good and bad locations for accelerometer placement for modal analysis. If an accelerometer is placed at a location on the structure that does not vibrate at a particular frequency, then a modal analysis may not yield any useful data. The frequency range of excitation provided by a hammer is determined by the stiffness of the hammer-structure contact surfaces and the mass of the hammer head. The greatest difficulty in using an impact hammer to excite a structure is ensuring that each impact is really the same as all previous hits in terms of magnitude, position and orientation to the normal to the surface. It is very important to prevent "double hits" which result when the hammer rebounds against the surface. Double hits cause significant signal processing problems and contaminate measured data.

Haapaniemi, et al investigated numerical simulation of piping vibrations using an updated FE Model. The problem was the traditional design and condition monitoring of piping is mainly based on postulated events and on the application of allowable vibration levels. This approach gives only indirect information on the loading at the critical locations and generally leads to over conservative assessments. It is essential that developing piping failures can be monitored so that any repair work can be carefully planned and carried out during regular outages. The modal shapes of the structure were measured using an impact hammer and a shaker. Results from experimental modal analysis were used in finite element (FE) model validation and updating process carried out using the FEM tools. This project may aid in proving the dynamic behaviors of the supports as well as the interactions between the