# PERFORMANCE OF VISCOUS PLANE DAMPER WITH BOX BARREL AS A VIBRATION DISSIPATION DEVICE

By

MOHD RIDZUAN BIN MOHD ALI

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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# DEDICATION

*This thesis is dedicated to*

*My lovely wife Arffaazila Binti Rahmat, kids; Damia Najla, Damia Najwa and Muhammad Luth Najmi and family members. Not forget my Supervisor Associate Professor Dr Farzad Hejazi*

*With love, respect and a bunch of memories*
*Indeed, we belong to Allah and indeed to Him we will return.*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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**August 2020**

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Recently, many advanced energy dissipation technologies have been developed to be implanted in structures to diminish the structural vibration due to earthquake, wind, or any other sources. The viscous plane damper has currently been proven as an advantageous supplementary damping device which can be implemented to the new or existing structures to dissipate effect of imposed dynamic loads to the structures. However, the typical viscous dampers are designed requires an adequate space within the structure bays which this issue caused challenges of implementing damper device in the small, limited spaces. Therefore, this study proposes a new viscous plane damper device to address the limitations of a conventional viscous damper device. The new configuration and arrangement. The proposed viscous plane damper is comprised of cube cylinder. The rectangular of piston plate with orifices which connected with the piston rod to the head mounting to transfer the external movement to the rectangular piston plate. Therefore, flowing of viscous oil through orifices of rectangular piston plate during movement which transferred by piston rod is lead to drop pressure and flow resistant that generate damping force due to function of viscous plane damper. The numerical simulation of the new viscous plane damper has been analysed by aid of computational fluid dynamic analysis was conducted to determine the characteristic of the fluid flow pattern and evaluate performance of the damper. The flow pattern characteristics based on different consideration dimensions, configurations and arrangements of orifice and velocity of the fluid. Beside the numerical analysis, the design of viscous plane damper has improved and prototype of viscous plane damper fabricated and experimental testing has been carried out by applying cyclic load using dynamic actuator to evaluate the functionality and performance of the developed damper. Experimental study consisted of parametric study on geometry specification on developed system with pseudo dynamic tests on different dimension, configuration and arrangement of orifice and velocity of the piston plate. The results of testing and computational fluid dynamics proved the functionality of the developed plane fluid damper device in generating desirable damping force during the applied cyclic load. Moreover, the results revealed that, as expected, the smaller orifice led to higher

damping force. Therefore, the output of this study indicate that the new plane fluid damper device can be implemented in a vast range of newly designed or existing structures to dissipate the vibration effects in the extreme conditions.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PRESTASI PENYERAP BENDALIR DENGAN BERASASKAN KOTAK SEBAGAI PENYERAP GETARAN**

**Oleh**

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**Fakulti : Kejuruteraan**

Baru-baru ini, banyak kemajuan teknologi penyerap tenaga telah dikembangkan untuk dipasangkan dalam struktur bangunan untuk mengurangkan getaran pada struktur akibat daripada gempa bumi, taufan atau sumber lain. Penyerap bendalir pada masa ini telah terbukti sebagai alat penyerap tambahan yang memberi kelebihan bagi diaplikasikan ke struktur baru atau yang sedia ada untuk menghilangkan beban dinamik yang dikenakan pada struktur. Walau bagaimanapun, penyerap bendalir yang direkabentuk memerlukan ruang yang cukup di dalam ruang struktur yang mana ia akan menimbulkan cabaran untuk memasang penyerap bendalir yang baru di ruang kecil dan terhad. Oleh itu, kajian ini mencadangkan alat penyerap bendalir yang baru untuk mengatasi batasan penyerap bendalir yang sediaada di pasaran. Rekabentuk baru penyerap bendalir yang dicadangkan terdiri daripada berbentuk kubus. Plat piston berbentuk segi empat yang berlubang yang disambungkan dengan batang omboh ke ‘mounting’ supaya dapat memindahkan pergerakan luaran ke plat omboh segi empat tersebut. Oleh itu, pengaliran minyak melalui lubang plat piston segi empat semasa pergerakan yang dipindahkan oleh batang omboh menyebabkan tekanan terhasil dan kelikatan aliran yang menghasilkan daya serapan. Simulasi berangka penyerap bendalir baru telah dianalisis dengan bantuan analisis dinamik bendalir yang dilakukan untuk menentukan ciri corak aliran bendalir dan menilai prestasi penyerap. Ciri corak aliran berdasarkan dimensi pertimbangan yang berbeza, konfigurasi dan susunan lubang dan halaju bendalir. Di samping analisis simulasi, mereka bentuk penyerap bendalir bertambah baik dan prototaip penyerap bendalir dibuat dan ujian eksperimen telah dilakukan dengan menerapkan beban kitaran dengan menggunakan penggerak dinamik untuk menilai fungsi dan prestasi penyerap bendalir yang dimajukan. Kajian eksperimental terdiri dari kajian parametrik mengenai spesifikasi geometri pada sistem yang dikembangkan dengan ujian dinamis semu pada dimensi, konfigurasi dan susunan lubang dan halaju plat omboh yang berlainan. Hasil ujian dan analisa dinamik bendalir membuktikan fungsi penyerap bendalir yang dimajukan dalam menghasilkan daya redaman yang diinginkan semasa beban kitaran dikenakan. Hasilnya menunjukkan adalah seperti yang diharapkan, lubang yang lebih kecil menyebabkan daya redaman

dihasilkan adalah lebih tinggi. Oleh itu, hasil kajian ini menunjukkan bahawa alat penyerap bendalir baru dapat dilaksanakan dalam pelbagai struktur yang baru atau yang yang sediaada bagi menghilangkan getaran dalam bangunan keadaan yang melampau.

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To complete the study with writing the thesis and manage the time and life as student and husband was helped me to develop a strong sense of self by follow the process of study how to think critically and make judgements in the real world. Constantly humble nevertheless with a strong and confident attitude in carrying out responsibilities and continuing the life. Always be grateful for every blessing received from ﷲ as a reminder that no matter how high the knowledge, qualification and everything, ﷲ is the most powerful.

Thank you.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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| | |
|---|---|
| $V$, $Q$ | Flowrate ($m^3$/sec) |
| $A$ | Area ($m^2$) |
| $A_o$ | Area of orifice |
| $A_{pp}$ | Area of piston plate |
| $v$, $V$ | Velocity (m/sec) |
| $v_{vf}$ | Velocity of viscous fluid |
| $v_{pp}$ | Velocity of piston plate |
| $P$ | Pressure |
| $P_{vpd}$ | Pressure of viscous plane damper |
| $F_{vpd}$ | Force of viscous plane damper |
| $C_c$ | Coefficient of contraction |
| $A_j$ | Area of the jet |
| $A_h$ | Area of the hole |
| $z$ | Elevation |
| $yz$ | Hydrostatic pressure |
| $\dot{m}$ | Mass flowrate |
| $\dot{m_{in}}$ | Net flow was into control volume |
| $\dot{m_{out}}$ | Net flow was out control volume |
| $\rho$ | Density of the incompressible fluid |
| $\Delta W$ | Dissipated energy |
| $D_1, D_2$ | Displacement value for experimental testing |
| $L_1, L_2$ | Loading value for experimental testing |
| $K_b$ | Stiffeners |

| | |
|---|---|
| $D_{max}, D_{min}$ | Maximum and minimum of the displacement value for experimental testing |
| $L_{max}, L_{min}$ | Maximum and minimum loading value for experimental testing |
| $\varphi$ | Damping ratio |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Dampers refer to an additional device that is installed to enhance the aspect of stability in buildings or structures. High-rise building is sensitive, especially when it becomes unstable due to external energy. This made designers to innovate a new technology to ensure the stability and safety of buildings and structures. A number of additional devices have been installed in buildings or structures, for example, rubber damper, tuned mass damper (TMD), base isolator, tuned liquid damper (TLD), tuned liquid column damper (TLCD), and viscous damper (VD). This study investigated the function of viscous damper, which refers to a device that can be installed on either new or existing buildings. Viscous damper is a cost-effective device because of its easy installation, requires less workers, short installation period, and less maintenance. Despite its practicality, viscous damper has constriction in space and area, hence unable to dissipate energy in building. Replacement of the existing viscous damper with other devices by better performance is a suggestion to ensure building stability. Nevertheless, in order to improve the capacity of the damper to dissipate energy; the shape and the dimension of the damper would be changed and increased, respectively. by increasing the damper dimension, the damper would not fit in assigend place . In fact, the area would require major repair work for installation of damper. In this study, a viscous damper has been designed in order to minimise repairwork which is required to install the new damper with higher capacity, in comparison to previous dampers. This proposed viscous damper has displayed better ability to dissipate more vibration energy to reduce building movement. As such, the proposed viscous damper had been assessed to produce comparable dimensions of the viscous plane damper.

Buildings tend to collapse when the structure was moved or swayed more than the allowable displacement. The movement failed by the external energy. Similarly, Petti & De Iuliis (2008) asserted that damages are incurred in buildings due to movement of structures either horizontally or rotationally. Hence, an unstable building is bound to weaken its structures until it collapses.

The stability of a building is based on the strength of the whole structures of the building. Therefore, the structural control system refers to an additional devices, which serves to dissipate the vibration energy to enhance the stability of a the building due to external energy. Most variable to study is stiffness of the structures, has been vastly investigated in researches concerning development of devices meant to reduce buildings response due to seismic activities Farzad Hejazi, Jamaloddin Noorzaei, Mohd Saleh Jaafar, Waleed A. Thanoon, & Abang Abdullah Abang Ali, (2009). According to Love & Tait (2012) claimed that the system used to maintain the stability of the structures is called dynamic vibration absorber (DVA). The purpose of DVA is a device capable to dissipate the external energy that was reacted on the building.

Additional devices can be installed in new or existing buildings. However, installation of the devices are easier in the new compared the existing structures. Factors of space, area, location and type of devices were decided at the design stage. However, replacement old damper to the new damper because of demand more capacity of the damping forces have caused difficulties in installation work to the new damper. More critical to identify the new suitable location in the existing building to ensure the new device capable to well functioning during the building movement. Easy to install, maintenance and cost effective was made the viscous damper is a practical damper for the buildings Ahsan Kareem et al., (1999); Love & Tait, (2015); Wei Cui & Luca Caracoglia, (2015).

Viscous damper is an isolator used in many mechanisms, such as vehicle suspension, high rise building, bridge support, and machinery suspension. According to Baikuntha Silwal, Robert J. Micheal, and Osman E. Ozbulut (2015),viscous damper can disperse energy in a building at varied levels of vibration, simultaneously being stiff at the same time. viscous dampers are choosing in strengthening and retrofitting for the buildings. Common viscous dampers consist of damper housing or barrel, rod and piston allocated in the housing.

Movement of the piston is based on the movement of the building due to external load activities, such as seismic, wind loading, and wave. Figure 1.1(b) portrays two types of mountings; fixed and movement mounting. The movement mounting refers to a point that receives movement of the building. When the mounting moves, the piston moves together, and liquid in the barrel starts moving to eliminate the energy and eventually reduces the movement of the building. According to Soda (1996), in the attempt of abolishing energy in the building, changes in design are insufficient since magnitude and type of dampers should be taken into account. Soda (1996) claimed, the size of the damper able to affect the capacity of the damping forces. This means; increasing the strength of viscous damper is in line with the dimension of the damper. Specificly, barrel diameter, $D_b$, and length, L, of the viscous damper, as displayed in Figure 1.1(b).

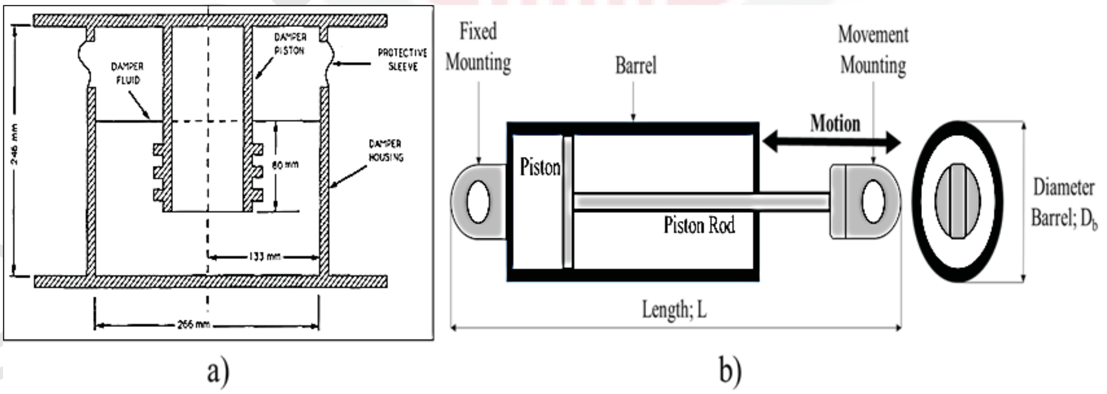


**Figure 1.1 : a) Typical viscous damper studied by Makris and Constantinou (1991), and b) Typical viscous damper**

Replacement of the old viscous damper to the high capacity of the damping force generate by viscous damper was demanded to increase the dimension of the viscous damper. However, the damper not able to install because inadequate space and area. Therefore, more rectify work and cost to design and prepare for the that location. Therefore, to maintain the space and area, new design of the viscous damper would be proposed and the damper also able to produce high capacity of damping forces compared to the previous damper. The new design of viscous plane damper was changed in shape compared typical viscous damper. The new damper is more shorter and wider than typical damper.

## 1.2 Problem Statement

The frequency of calamities, such as earthquake, tsunami, and tornados, have increased in annual basis. The wide range of impacts from such events can severe affect buildings and structures. Buildings that cannot withstand the tremors of an earthquake have the potential to collapse due to over limitation movement of the building. Failure in buildings encourages advanced and more resilient building designs. Enhancing building performance is trending in the research arena due to natural disasters. Failure factor is the collapse of building structures after receiving design load more than the building can withstand. The effect of that, the building moves more than its permissible level. With such a condition, the structure components would fail to control the deformation. The components cannot dissipate the energy that causes the movement. Excessive energy causes a structure to become exhausted, especially the connectors between the structural components.

After a disaster, most buildings would have major or minor defects on the structural components. Remedial work for buildings, such as retrofitting and strengthening techniques, is proposed to improve the strength and the integrity of the building to the safety level. One method to improve affected buildings is to dampers as additional devices. Dampers serve as a device or an isolator to dissipate energy as a building responds to external load, apart from improving the damping ratio in the building. There are a wide range of dampersthat can be used during remedial work. Martinez-Rodrigo and Romero (2003), as well as Ying Zhou, Xilin Lu, Dagen Weng, and Ruifu Zhang (2012), asserted that viscous dampers are practical to be used for existing buildings because they are cost-effective, easy to install, and requires only a short period for installation work.

Viscous dampers are easy to handle and install due to their small dimension, when compared to other dampers. Martinez-Rodrigo and Romero (2003) asserted that installation of viscous damper does not require large area, especially in existing buildings, hence easy to repair work and that is within a short time. however, to improve the capacity of the viscous damper, most of the damper would be increased the dimension and shape. Effect of that, the damper not easy to install on th same location, especially for existing buildings or structures. Additionally, more work for rectifiying the space and area to allow the new damper to install. Besides, finding an area in existing buildings causes additional work. In order to enhance device capacity, the dimension of viscous damper also needs to be increased. Based on the typical configuration and arrangement of a common viscous damper, as shown in Figure 1.2, an appropriate area but long space is required to install the device.

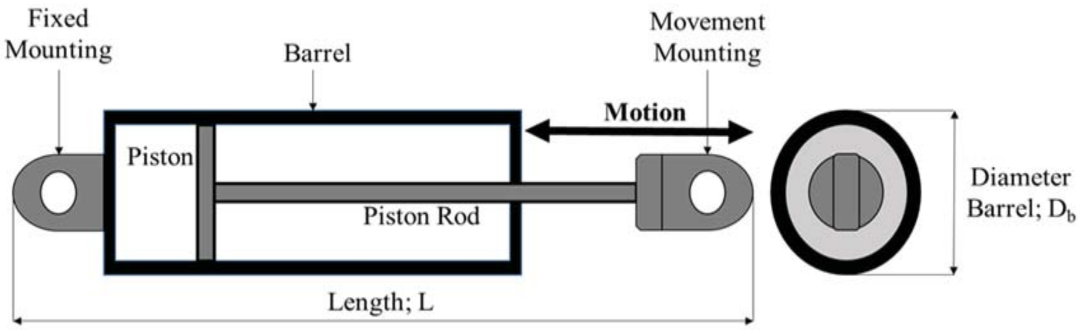


**Figure 1.2 : Typical damper**

A typical viscous damper can be easily installed in a new building, as the position would have been embedded in the design after considering the shape and dimension of the damper. The common location to install viscous damper is between two columns, above or below beams or slabs, or at the side of column or piers. Figure 1.3 shows the configuration and arrangement of a common viscous damper was installed or fixed in the limited space for an existing building.

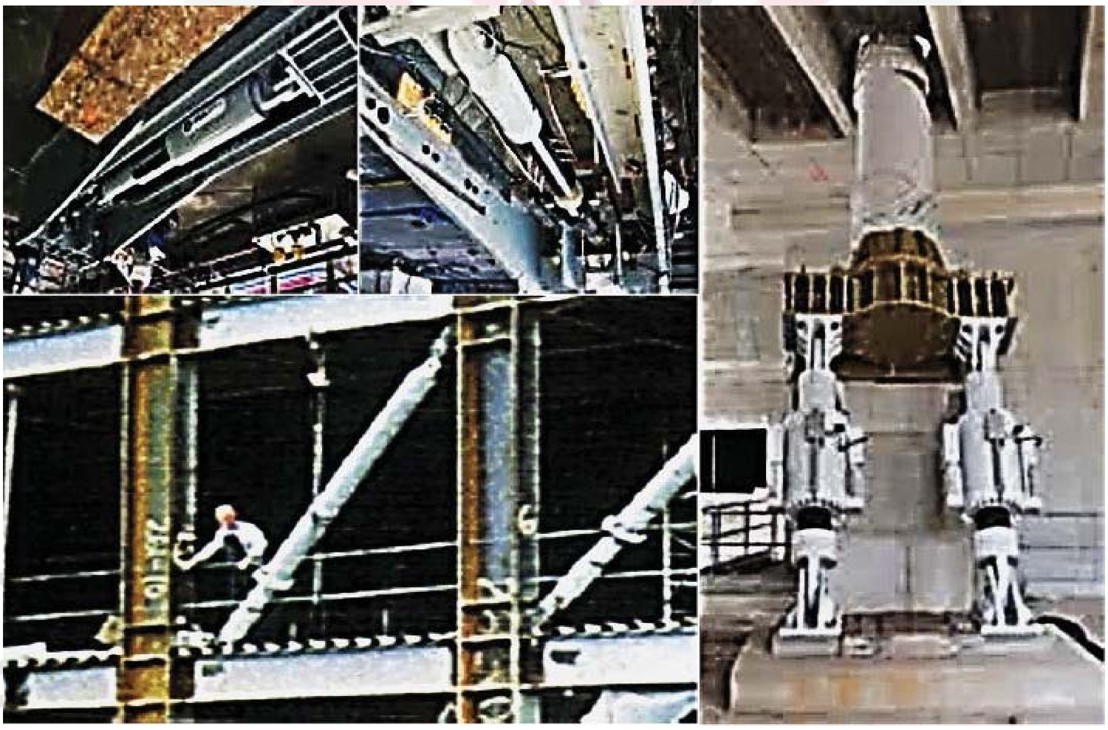

**Figure 1.3 : Application of viscous damper**

Figure 1.4 displays a truss structure, which refers to offshore structure built in the middle of the sea. The work space and area obviously hinder the installation of a damper. The damper, thus, is placed at the impending shock that reflects boat impact.

Figure 1.4 vividly portrays the difficulty faced in installing the damper in the right place with limited work area.

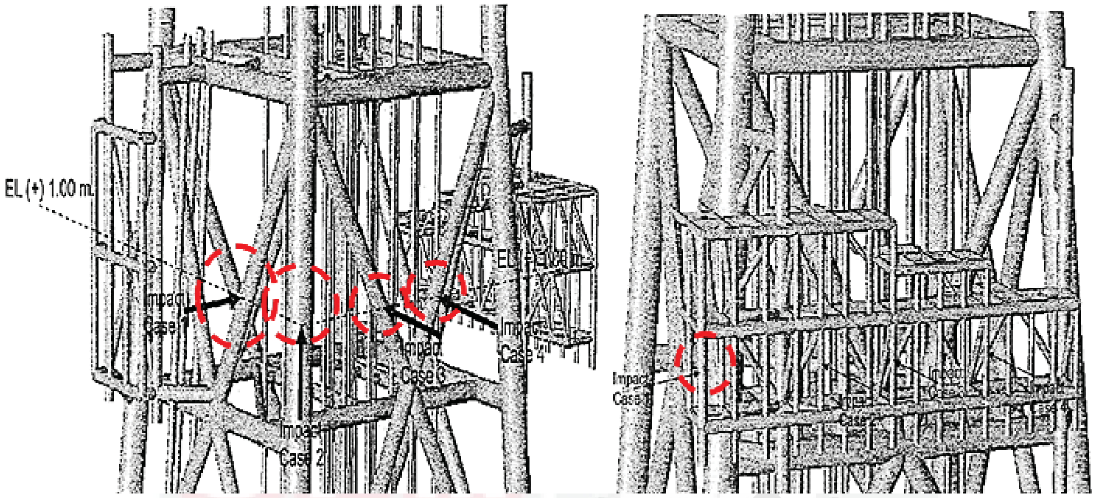


**Figure 1.4 : Location of boat impact at offshore platform**

The scenario, however, differs at jetties, yards, and ports. Figure 1.5 presents buildings constructed close to the shore as a place for loading and unloading cargos for large ships. These buildings should be able to absorb the huge burden of large impact from the ships. Referring to the received energy, the dampers should be in a high capacity to absorb high impact. In order to produce a highcapacity damper, it has to be large in size, hence difficult to install the damper due to the limited working area and its not manageable huge size. The perfect place to install a common viscous damper is under the floor approaching the seawater surface. This position is bound to affect the damper as it demands regular servicing.

**Figure 1.5 : Limited space at port and jetty.**

All the locations were explained to install the viscous damper is easy to install. However, after increasing the energy dissipate by the damper, dimension and shape would be improved and was difficulted to reinstall the new damper on the existing location due to the space and area constraint. Configuration and arrangement of the common viscous damper is impractical to install due to the limited space and area in existing buildings. A new building may face a similar problem if no space or area is embedded in the building design to damper installation because each space has their own purpose and function.

This study developed a viscous plane damper based on cyclic load applied on the device via experimental testing and simulation to assess its performance at implementation.

## 1.3 Objectives of the Study

The objectives of this study are listed in the following:

a. To formulate the viscous plane damper force and conduct the parametric study the different viscous fluid flow pattern that affect to determine the damping forces of the damper through computational fluid dynamics modelling.

b. To design and fabricate the new viscous plane damper applicable in limited space areas as a device to dissipate energy

c. To determine the damping forces of the viscous plane damper prototype subjected to the cyclic load via experimental test.

d. To assess and optimize the performance of the new viscous plane damper device through computational fluid dynamics and experimental test.

## 1.4 Scope of the Study

The scope of this study is the damper is viscous damper. The typical viscous damper is cynlinderical and circular would be changed to the cubus and square shape. The study only considered one type of viscous fluid would be used inside the barrel. Configurations and arrangement of the new design of viscous plane damper is different. On the piston plate plate has variuos of diameter of orifices and three types of consigurations were called A, B and C.

Performace of the new design of viscous plane damper would be analysed by numerical simulation is computational fluid dynamics and physical testing to determine the workability of the damper. Experimental test in this study made through applying the cyclic load using dynamic actuator. The study focused on performance of the new design of viscous plane damper. The damper capable to install at the limited space and area. The damper also easy to handle and assemble because not heavy compared existing damper for same dimension and shape.

## 1.5 Limitation of study

The limitation of this study is given as follows:

a. Only one type of viscous fluid was used in this study

b. Direction of the load from one direction.

## 1.6 Layout of Thesis

The thesis will be divided into the following chapters:

Chapter 1 outlines the background of the study and the overview of the overall research.

Chapter 2 presents the literature review based on prior studies and current issues. This chapter identifies the theory, the methodology, and any information related to this study. Sufficient information is gathered in this chapter to complete the research.

Chapter 3 explains the research methodology of the study towards achieving the study objectives.

Chapter 4presents the results obtained from experimental and simulation analyses. The data are analysed and presented in both chartsand table to ease comprehension.

Finally, Chapter 5 concludes the study and offers several recommendations for future study.

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# LIST OF PUBLICATIONS

Paper 1: Performance of the Innovative Viscous Plane Damper Device, submitted

Paper 2: Development of a Fluid Plane Damper for Structures Subjected to Dynamics Load, submitted

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