# ENERGY DISSIPATION AND DUCTILITY OF STEEL PLATE SHEAR WALL WITH PERFORATION

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## DEDICATION

I dedicated this project report to my beloved mother who always supported me through thick and thin. Without her, I would not be the man that I am today. I also dedicate this to my other family members. Thank you for all of your support this whole time.

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# ABSTRACT

Steel plate shear wall (SPSW) is a structure system which is mainly used in high-rise building to resist the lateral load either from the wind or earthquake. In this study, several models of perforated steel plate shear wall were analysed by using Abaqus software in order to study the behaviour of perforated steel plate shear wall with different aspect ratios when the location and size of the of opening are varied. The parameters concerned are ductility, energy dissipation and lateral load capacity of the perforated SPSW. 4 meter high perforated steel plate with varying width of 4 m and 6 m are bounded by vertical and horizontal boundary elements which is fixed at its base and restrained at z-direction at the top. The plate and boundary element were made from A36 steel and ASTM A992 steel respectively. Cyclic loadings were applied laterally for each SPSW model and the lateral displacements at the top of the model were recorded to plot hysteretic curve in order to obtain the ductility, energy dissipation and lateral load capacity. It has been found that the energy dissipation, ductility and lateral load capacity are affected by the different location of the perforation in the SPSW, where SPSW with perforation that is closer to the acting forces has lower energy dissipation, ductility and lateral load capacity. Maximum energy dissipation, ductility and lateral load capacity were achieved when the perforation was located at the centre of the SPSW. The increase in size of perforation of the SPSW caused the energy dissipation, ductility and lateral load capacity to decrease, while wider width of SPSW have larger values for energy dissipation, ductility and lateral load capacity.

# ABSTRAK

Dinding ricih plat keluli (SPSW) adalah sistem struktur yang kebiasaanya digunakan di bangunan tinggi untuk menahan beban sisi sama ada dari angin ataupun gempa bumi. Dalam kajian ini, beberapa model dinding ricih plat keluli tertebuk akan dianalisis dengan menggunakan perisian Abaqus untuk mengkaji kelakuan tembok ricih plat keluli tertebuk dengan nisbah bidang yang berlainan apabila lokasi dan saiz tebukan diubah. Parameter yang dikaji adalah kemuluran, pelesapan tenaga dan kapasiti beban sisi plat keluli SPSW tertebuk. Plat tertebuk dengan ketinggian 4 meter dan kelebaran berbeza iaitu, 4 m dan 6 m dikelilingi oleh element sempadan menegak dan mengufuk yang disokong tegar di tapak dan terhalang daripada pergerakan pada paksi z pada bahagian atas model tersebut. Plat dan elemen sempadan, masing-masing diperbuat daripada keluli A36 dan keluli ASTM A992. Beban kitaran dikenakan pada setiap model dan anjakan sisi pada bahagian atas model direkodkan untuk melakarkan graf histeresis bagi mendapatkan kemuluran, pelesapan tenaga dan kapasiti beban sisi. Kemuluran, pelesapan tenaga dan kapasiti beban sisi didapati dipengaruhi oleh lokasi tebukan yang berbeza pada SPSW iaitu, SPSW yang mempunyai tebukan yang lebih hampir dengan beban kenaan mempunyai kemuluran, pelesapan tenaga dan kapasiti beban sisi yang lebih rendah. Kemuluran, pelesapan tenaga dan kapasiti beban sisi yang maksimum boleh dicapai apabila tebukan berada di tengah-tengah plat. Peningkatan saiz tebukan menyebabkan kemuluran, pelesapan tenaga dan kapasiti beban sisi berkurang, manakala, SPSW yang lebih lebar mempunyai nilai kemuluran, pelesapan tenaga dan kapasiti beban sisi yang lebih tinggi.

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| | | |
|---|---|---|
| SPSW | - | Steel Plate Shear Wall |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $h_p$ | - | Height of Perforation |
| s | - | Distance of Perforation from the Edge of the SPSW |
| $F$ | - | Force |
| $p$ | - | Pressure |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

With the construction of the tallest twin towers currently in the world in 1996, more similar projects soon follow as Malaysia continues its rapid urban developments. These developments lead to more high-rise buildings to be constructed in order to save up more space which will be dwindling in the near future. Therefore, the technologies and skills required to build higher altitude structures needs to be emphasized more in order to expand and obtain new knowledge which can further enhance our understanding on the mechanics of tall building structures.

On 5 June 2015, earthquake struck Ranau, Sabah, Malaysia with a moment magnitude of 6.0 which lasted about 30 seconds and took 18 lives on Mount Kinabalu and caused several structural damages on the buildings of the surrounding regions. It is also considered the strongest earthquake that affected Malaysia since 1976. The event came out as a surprise due to the location epicentre location of the earthquake which is in Sabah, a place not well-known for destructive earthquake unlike Sumatra, Nepal, Taiwan and Japan, which straddle fast-moving tectonic plate boundaries. Therefore, most structures on the surrounding areas are susceptible to earthquake due to lack of standards for earthquake-resistant structural design in Malaysia. Ever since then, awareness on the importance of earthquake-resistant design raised and Malaysia quickly responded by introducing the standards for earthquake design in which the Ministry of Science, Technology and Innovation (MOSTI), through the Department of Standards Malaysia developed a Malaysian Standards (MS EN 1998-1:2015 (NATIONAL ANNEX:2017)) for earthquake-resistant building design code based on European Eurocode 8 'Design Of Structures For Earthquake Resistance — Part 1: General Rules, Seismic Actions and Rules For

Buildings'. Therefore, earthquake become one of the important factors that needs to be considered in designing structures in Malaysia ever since.

With the consideration of earthquake in structural design, the lateral effects from the earthquake on a structure can be minimized. However, tall buildings have other source of lateral actions included acting on the structure in the form of wind load which increases with altitude. Therefore, tall buildings are not only susceptible to earthquake, but also from the wind load. Numerous methods and innovations are being researched and studied thoroughly in order to reduce the effects of lateral load on a structure. One such method is to use the steel plate shear wall (SPSW) in order to reduce the energy released by the earthquake and wind thus stabilizing the structure from swaying and minimize the damages.

Steel plate shear wall (SPSW) consists of thin steel infill plates called the web plate which is bounded by boundary elements which is columns and beams with bolted or welded connections. SPSWs have been used in the US since the 1970s primarily for seismic retrofits, as most practicing engineers usually hesitate to use systems due to the lack of standard codes and clear history of past performance. However, recent studies and researches have raised the prospect of using SPSWs as a promising alternative to conventional systems in high-risk seismic regions due to the energy dissipating qualities of the web plate under extreme cyclic loading. Compared to reinforced concrete shear walls, SPSWs is significantly faster to construct and much lighter thus reducing the material construction duration and materials which is essential factors affecting the overall cost of the project.

## 1.2 Problem Statement

SPSW is one of the most efficient tall building systems to resist earthquake. However, SPSW sometimes need to be perforated to allow people to go through it or to serve as windows. Research proves that perforation of SPSW will reduce its capacity to resist the lateral load. Previous research did study the effect of the size of the perforation and the location of the perforation to the shear capacity of the SPSW.

However, does the relationship remain the same when the size of the SPSW is altered? The height of the SPSW may always be about 4 meters but the breadth may change from one building to the other building. The answers to these questions are important to enable engineers and architects to make the correct decision regarding the size and location of perforation of the SPSW they design.

Furthermore, ductility and energy dissipation are important in the seismic resistance structure design. Ductility factor required for structure is typically in the range 3 to 6 (Park, 1988). The seismic input energy imparted to a structure is dissipated by hysteretic behavior. It is generally recognized that there is a strong correlation between the energy dissipated by hysteretic action and the seismically induced level of damage. Thus, how do energy dissipation and ductility of SPSW are affected by the size and the location of the perforation?

## 1.3 Research Objectives

The objectives of the research are :

(a) To obtain ductility, energy dissipation and shear capacity of the SPSW when the size and location of the perforation are varied.

(b) To find the effect of the width of the SPSW to ductility, energy dissipation and lateral load capacity for different location and size of the perforation

## 1.4 Scope

This study will focus on the behavior of ductility, energy dissipation of perforated steel plate shear wall (SPSW). The material used for the steel plate web is A36 mild steel, which is commonly used. Only numerical simulations of the SPSW will be performed. The SPSW has a height of 4 meters and fix supported at the

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