INFLUENCE OF STAGGERED STEEL PLATE SHEAR WALL TO RESPONSE OF BUILDING DUE TO EARTHQUAKE

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DEDICATION

This Master Project Report is dedicated to my late father, *you are my forever strength. I love you and will always do.*

To my beloved mother, *thanks for the love and the never-ending support.*

To my respected supervisor*, Dr. Roslida bt Abd Samat, thanks for the guidance, advice, knowledge, and encouragement. You are a great supervisor.*

May all your good deeds be accepted by Allah.

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ABSTRACT

This study presents the influence of the staggering elements in the steel plate shear wall (SPSW) to the response of the building due to earthquakes. Previously, Malaysia is not concerned about the earthquake since it is located in the earthquake free zone. However, the earthquake has now become a concern in the design of buildings in Malaysia as the tremors from the neighbours' earthquake events can be felt in the country and thus, affects the building structures. The designers and engineers start to take initiative to overcome this issue by adapting the shear wall system that has been used widely in the countries affected by the earthquake. The system is made of infill steel plates called steel plate shear wall (SPSW) and it was being used in tall buildings since the 1980s. The two first countries that used this system are the USA and Japan which has become a starting point of the SPSW system to be developed widely. Accordingly, various modifications and strategies have been applied to the conventional system to fulfil the needs and conditions of the tall buildings in resisting the lateral seismic forces. Though, among the various modifications, there is no established modification on the arrangements of the steel plates. Therefore, this study is trying to find out what will happen to the performance of the tall buildings if the steel plates are arranged in a staggered manner. To fulfil the needs of this study, ten 5-storey models building were analysed using Abaqus software. The models are Model 1 which modelled without SPSW, Model 2 which modelled with two-bays SPSWs, Model 3 which modelled intermittently within two-bays from top to bottom level, Model 4 also modelled intermittently within two-bays but from top to level 2 only, Model 5, 6, 7, 8, and 9 were modelled with SPSWs within three-bays with various arrangements but only Model 9 have no SPSWs at the top level, and Model 10 was modelled with SPSWs that continuous vertically from top to bottom level. Then, the comparisons of the maximum displacement and maximum acceleration of all models were carried out accordingly. Models 3 and 4 have the best arrangement of the SPSWs as they have the lowest acceleration while models 2, 6, and 9 have the worst arrangement of the SPSWs due to their high acceleration values. All models with SPSWs are capable to lower the maximum displacement to the desired value.

ABSTRAK

Kajian ini membentangkan tentang pengaruh elemen plat keluli yang disusun secara tak serentak dalam dinding ricih plat keluli (SPSW) terhadap sambutan bangunan akibat gempa bumi. Sebelum ini, Malaysia tidak perihatin terhadap gempa bumi kerana ia terletak di zon bebas gempa. Walau bagaimanapun, gempa bumi kini menjadi perhatian dalam reka bentuk bangunan di Malaysia kerana gegaran akibat kejadian gempa di negara jiran dapat dirasakan di negara ini dan dengan itu, mempengaruhi struktur bangunan. Pereka dan jurutera mula mengambil inisiatif untuk mengatasi masalah ini dengan menyesuaikan sistem dinding ricih yang telah digunakan secara meluas di negara-negara yang mengalami gempa bumi. Sistem ini diperbuat daripada plat isian keluli yang dipanggil sebagai dinding ricih plat keluli (SPSW) dan digunakan dalam sistem bangunan tinggi sejak tahun 1980an lagi. Dua negara pertama yang menggunakan sistem ini adalah Amerika Syarikat dan Jepun yang telah menjadi titik permulaan sistem SPSW untuk berkembang secara meluas. Dengan demikian, berbagai pengubahsuaian dan strategi telah diterapkan pada sistem konvensional untuk memenuhi keperluan dan keadaan bangunan tinggi dalam menahan beban daripada gempa bumi. Walau bagaimanapun, antara pengubahsuaian tersebut, tidak ada pengubahsuaian mantap pada susunan plat keluli. Oleh itu, kajian ini berusaha untuk menyelidik tentang apa yang akan terjadi pada prestasi bangunan tinggi sekiranya plat keluli disusun secara tak seragam. Untuk memenuhi keperluan kajian ini, sepuluh model bangunan 5 tingkat telah dianalisis menggunakan perisian Abaqus. Model-model tersebut adalah Model 1 yang dibina tanpa SPSW, Model 2 yang dibina dengan dua ruang SPSW. Model 3 yang dibina dengan susunan SPSW terputus-putus merangkumi dua ruang dari tingkat atas sampai tingkat bawah, Model 4 juga dibina dengan susunan SPSW yang terputus-putus, tetapi hanya dari tingkat atas sampai tingkat 2 sahaja, Model 5, 6, 7, 8, dan 9 telah dibina dengan susunan SPSWs merangkumi tiga ruang dengan pelbagai susunan tetapi hanya Model 9 yang tidak diletakkan SPSWs di tingkat paling atas, dan Model 10 telah dibina dengan susunan SPSWs yang selanjar secara tegak dari tingkat atas sampai tingkat bawah. Setelah itu, perbandingan anjakan maksimum dan pecutan maksimum semua model telah dilakukan. Model 3 dan 4 mempunyai susunan SPSWs yang terbaik kerana kedua-dua model tersebut mempunyai pecutan maksimum yang paling rendah sementara Model 2, 6 dan 9 mempunyai susunan SPSWs yang terburuk kerana mempunyai nilai pecutan maksimum yang tinggi. Semua model yang ada SPSWs mampu untuk mengurangkan anjakan maksimum ke nilai yang dikehendaki.

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LIST OF ABBREVIATIONS

SPSW	-	Steel Plate Shear Wall
SPSWO	-	Steel Plate Shear Wall with Outrigger
PSPSW	-	Perforated Steel Plate Shear Wall
CSPSW	-	Corrugated Steel Plate Shear Wall
SSPSW	-	Staggered Steel Plate Shear Wall
PGA	-	Peak Ground Acceleration
UC	-	Universal Column
UB	-	Universal Beam
ASTM	-	American Society for Testing and Materials

LIST OF SYMBOLS

δ	-	Inter-Storey Drift
h	-	Storey Height
D	-	Diameter of the Holes
d	-	Height of the Panel
σ	-	Stress
ε	-	Strain
E	-	Modulus of Elasticity
f_{sy}	-	Yielding strength of the steel

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Throughout history, Malaysia rarely involves with earthquake phenomenon for the reason that the location of the country is basically at the earthquake free zone. Based on geographical position, Malaysia is located on the Sunda Tectonic Plate, encompassing a large part of Southeast Asia (Simons et al, 2007). The Sunda Tectonic Plate is bounded by the Philippine Sea Plate and Eurasian Plate on the Borneo of Malaysia, whereas Australian and Eurasian Plate in the west of Peninsular Malaysia. Thus, the distance between Malaysia and the active seismic fault zone is considered quite a distance.

However, Malaysia is still able to feel the tremors from the earthquake occurred in neighbour countries. This is because, within 100 to 200km radius from the epicentre, significant damages due to an earthquake can occur, and in the worst case, the damages can spread up until 700km like the occurrence in Mexico during 1985 (Megawati et al, 2005). Frequently, the tremors due to the earthquake occurred in Sumatra, Indonesia which is one of the neighbour countries can be felt in Malaysia (Balendra et al, 2008 and Marto et al, 2013). Nevertheless, there was no effect on existing buildings or on-going building construction.

In the past 20 years, Malaysia has recorded 16 cases of earthquake phenomenon in Sabah with the magnitude in the range of 4.0 to 6.0 Richter scale which was a weak earthquake to a strong earthquake (Jabatan Meteorologi Malaysia). These events sure caused fatalities and still did not affect buildings especially high-rise buildings. Therefore, the design of the buildings in Malaysia did not consider resistance to lateral forces due to the earthquake. However, the biggest earthquake event that occurred in Malaysia since 1976 Sabah Earthquake with 6.0 Richter scale occurred in Ranau, Sabah in June 2015 followed by three aftershocks ("Shedding new light on Sabah Earthquake," 2015). This event has caused severe damages in which about 23 schools in six dissimilar areas were affected, some infrastructure was damaged, and Ranau Mosque experienced some damage (Sabah quake: 23 schools in six districts affected, 2015).

Shockingly, the fact that Malaysia is a country that is free from earthquake start to become ambiguous when one of the prime disasters which brought disastrous impacts has occurred. It was an earthquake event that befalls near the northwest coast of Aceh, Indonesia in 2004 with a magnitude of 9.3 Richter scale which in the category of a major earthquake. This earthquake event has triggered another large natural disaster called tsunami which occurred in series that have cause fatalities and destruction (Hock et al, 2009). Since then, researchers and practitioners start to distress the resistance of the buildings especially tall buildings in Malaysia towards seismic forces.

On the other hand, the number of tall buildings in Malaysia is snowballing due to the population growth along with the degradation of land to build on ground buildings. This matter is showing that the demand for tall buildings intended for residential and commercial is accelerating (Ahmad et al, 2017). Consequently, to meet both conditions which are demand for tall buildings and to strengthen the capacity of tall buildings in resisting seismic forces, an alternative should be considered as a preparation for any future possibilities of the earthquake events in Malaysia. The alternative must be suitable to be applied for both existing high-rise buildings and new high-rise buildings. In other words, it is important to include the seismic resistance system during the design stage of the tall buildings and to install a system that is able to work with the existing tall buildings.

As has been practiced by other earthquake-affected countries to improve the buildings' resistance to the lateral forces from seismic, Malaysia also starts to practice the same scheme which is by installing a steel plate shear wall (SPSW) system to the tall buildings. According to Wang et al (2019), the SPSW system is frequently used to develop the seismic performance of building structures. Comprehensively, SPSW system consists of vertical steel plate infills that interconnected to their surrounding beams and columns in a form of cantilever wall by installing them in a bay or more along the height of the structure (Yu et al, 2019, Meghdadaian et al, 2019, Wang & Yang, 2018 and Shafaei et al, 2017). It also can be venerated as a vertical cantilever plate girder since SPSW system optimizes the performance of the components by making the post-buckling behaviour of steel infill panels as an advantage where the columns act like the flanges, the beam act as transverse stiffeners and the steel plate act as the web (Pachideh et al, 2019).

Historically, SPSW has been broadly used in the construction industry especially buildings construction since the early 1980s which already around four decades. In the early invention of SPSW, it has been practiced in a number of buildings in Japan and North America as part of the lateral force-resisting system. The researchers and practicing engineers started to study and implement the SPSW system to a greater extent since the acceptable performance of the SPSW structural system due to the earthquake in Northridge, the USA in 1994 and Kobe, Japan in 1995 (Ghosh and Kharmale, 2010).

According to Ignius et al (2005), SPSW has been considered as a major system in resisting lateral forces which initiate by an earthquake. Apart from that, Kulak et al (2001) also stated that it is an innovative system capable of effectively bracing a building to go against the lateral forces from an earthquake. This statement was further strengthened by a statement from Moghimi and Driver (2015) stating that the SPSW system is indubitably well-matched for high seismic provinces and also beneficial for resisting other types of dynamic loading such as blast. Besides, Gorji and Cheng (2017) stated that the SPSW system is also a cost-effective seismic force-resisting system. Thus, this shear wall system is very advantageous for building structures especially tall buildings in numerous ways.

Throughout these decades, SPSW has become an important alternative to strengthen the buildings mainly from seismic energy and as for the installation, can be either during the construction or during their service life. Furthermore, Moghimi and Driver (2014) indicated that through experimental and numerical studies, it is proven that the SPSW system has high shear strength and exceptional ductility which demonstrate excellent performance. This reassuring the ability of the system as one of the top platforms as means of resisting earthquakes and later wind in high-rise buildings (Pachideh et al, 2019).

In point of fact, there are bunches of modified SPSW systems that exist nowadays with altered design and detailing approaches (Lu et al, 2018). For instance, steel plate shear walls with un-bonded stiffeners, steel plate shear walls with outriggers, perforated steel plate shear wall, corrugated steel plate shear wall, staggered steel plate shear wall, and many others. In numerous types of the SPSW system, this research study attempts to explore more on the staggering SPSW system. This study will model the tall buildings with a staggering SPSW system to identify their ability in handling the seismic forces with a various staggering arrangement of the steel plates. As enlightenment, a staggering SPSW system is a method to stagger the web plates over the height of the frame (Verma and Sahoo, 2017). Instead of arranging the steel plates in a vertical arrangement from the ground floor to the top floor of the tall buildings, some steel plates are going to be positioned at the right or left bay of the arrangement.

To sum up, the use of the SPSW system in the construction of tall buildings or existing buildings has long been practiced in the construction industry especially in earthquake-affected countries. There are even different types of SPSW system that are designed to be used as appropriate in certain cases. Since Malaysia may start to suffer from earthquakes which is initiated from neighbour countries (Marto et al, 2013), the SPSW system is seen as one of the ways to protect the tall buildings in Malaysia from the effects of the earthquake.

1.2 Problem Statement

Naturally, the tall buildings will be affected by lateral load initiated by seismic force and therefore, a system that resists this lateral load need to be introduced both in existing tall buildings and newly designed tall buildings. Simply, the taller the buildings are, the higher the risk of failure due to seismic forces. Therefore, the adaption of the lateral load resistance system is focused on enhancing the strength of the tall buildings in withstanding the lateral load without experiencing major failure. Then the tall buildings are kept in their best shape and function even after going through an earthquake event.

Shearing and bending failures may occur in the tall buildings caused by the interaction between lateral load due to earthquake shakes and transmission of compressive and tension force within the tall buildings. There are five types of failure that may occur which are break, deflect in shear, overturning, failure in tension or compression and bending deflection. These failures will give depraved impact to the strength and function of the structures which lead to the large maintenance needed or in the worst case, re-building is needed.

Based on that problem, an additional modification or provision of a system in order to resist the seismic forces should be applied both to the existing tall buildings and the new design. As widely known, SPSW system is an effective alternative to resist the lateral load of the seismic force. It is common to have the SPSW to run from the base to the top of the building. Will the performance of the building in resisting the seismic load drop if the SPSWs are staggered? Is having two-bays of SPSWs that are next to one another is better than the ones that are built apart? Subsequently, this study is needed to identify an optimized SPSW system by staggering the infill steel plates with various arrangements over the height of the tall buildings.

1.3 Aim and Objective of the Study

This study aims to determine which arrangement of SPSWs that could improve the lateral resistance of tall buildings against seismic forces, as well as the arrangement of SPSWs that should be avoided as it reduces the lateral resistance of the building. To achieve the aim of the study, the following objectives are outlined to seek the findings of the study:

1. To analyse different arrangement of the staggering SPSW system excited by earthquake load by computer simulation.

2. To establish the relationship between the arrangement of SPSWs with the ability to withstand the lateral loads due to seismic forces.

3. To propose the optimum staggering SPSW system that will improve the lateral resistance of tall buildings.

1.4 Scope of Study

Ten five-storey building models with a square plan of 30m x 30m will be analysed by Abaqus software to obtain the response of the building due to time varying earthquake excitation. The steel plate shear wall (SPSW) will be placed at the perimeter of the building at two parallel sides of the models. Three of the models are control models which are model with no SPSW at all, model with two-bay SPSW throughout the height of the model and one-bay SPSW throughout the height of the model. The other seven models have various arrangement of SPSW which indicates that the SPSW is discontinued throughout the height of the model. The aim is to find the behaviour of the responses which are the maximum displacement, maximum acceleration with different arrangement of the SPSW. The study will identify the most optimized steel plate arrangement over the height of the tall buildings to minimize displacement and acceleration due to earthquake excitation.

1.5 Significant of Study

As discussed in the introduction part before, Malaysia is no longer 100 percent safe from earthquake effect. Even though the location of the country is basically in an earthquake free zone, Malaysia is believed may encounter the tremors from earthquake event that occurred in the neighbouring countries which often experiencing events. At the same time, the tall buildings in Malaysia were not accommodated by resisting system towards lateral load specifically initiated by seismic forces. In this situation where extreme tremors from the neighbouring countries earthquake events are seen as a threat to the strength and stability of the tall buildings which lacking in lateral load resistance system. This occurrence with relation to the failure in the tall buildings shows that some addition of lateral load resisting system is totally necessary. Hence, the SPSW system should be employed in the construction of the building in Malaysia especially in tall buildings as have been practiced in other earthquake-affected countries. Since the application of the SPSW system is mainly designed for withstanding the lateral load caused by seismic forces, various modification to the SPSW system has been made throughout the years since the 1980s.

Among the many types of modification, addition, and strategies applied to the conventional SPSW system, this study decided to explore on the staggering method of SPSW system which is to be applied to the tall buildings to investigate the response of tall buildings with the lateral load resistance system to the earthquake events. Since there is not much specific research on the staggering SPSW system that has been done, this research study is seeming to be much beneficial to the engineers. This research may allow freedom for the designers on where to place the SPSW if staggering the SPSW provide the same response as the vertically continuous SPSW. Furthermore, response of the building due to earthquake may be lowered further by the addition of SPSW at certain floor instead of widening the SPSW throughout the height of the building, and thus, becomes a cost saving technique. Thus, this research project is essential to be conducted to understand the behaviour the response of the building when the SPSWs are staggered in various arrangement.

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