STRUCTURAL BEHAVIOUR OF STIFFENED STEEL PLATE SHEAR WALL UNDER CYCLIC LOADING

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structure)

School of Civil Engineering
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FEBRUARY 2021

DEDICATION

This project report is dedicated to my whole family for their endless support and motivation. It is also dedicated to my admired supervisor for her continuous guidance and knowledge. Lastly, a huge thank you to everyone for lending hands out either directly or indirectly.

ACKNOWLEDGEMENT

Firstly, I would like to say Alhamdulillah and all praises to Allah for the strength and blessing in completing my master report in this semester. The journey was worth the energy and sweats as it was rich in experience and discover future potential.

First and foremost, I owe my deepest gratitude to my supervisor, Dr. Roslida Abd Samat for her supervision and support. I also very thankful for all the positive attitude that she has showed to my work and always allowing me to question and giving prompt replies for my uncertainties in all the fields including theories, simulation, and others. She also has given invaluable help of constructive comment and suggestion for my master report.

Next, I would like to express my appreciation to Universiti Teknologi Malaysia (UTM) and all lecturers of Faculty of Civil Engineering for their co-operation and their sincere guidance as well as giving me this opportunity to complete my master report.

Lastly, special thanks to all my family and friends for sharing their experiences, time, and commitment especially throughout the journey. I am forever grateful.

ABSTRACT

The structural behaviour of stiffened steel plate shear wall (SPSW) with various stiffener configurations and manipulated parameters under cyclic loading was investigated by using nonlinear inelastic analysis. The main objective of the study is to investigate the effect of diagonal stiffeners with different configuration, thickness, width, and total cross-sectional area to energy dissipation, lateral displacement, ductility ratio, and lateral load capacity of SPSW under cyclic loading. The study focus on single and multiple diagonal stiffeners. Finite element models of the SPSWs were developed as two-dimensional element models and were analysed by using ABAQUS commercial software. The cross-sectional properties of the boundary elements and the thickness of infill steel plate remained constant for all models. Three different configurations of the stiffeners were used while the width and thickness of the stiffeners were varied. Cyclic horizontal loading was applied in accordance to ATC24 – Guidelines for Cyclic Seismic Testing of Components of Steel Structures at the top of the SPSW models and the lateral displacement at the top of the SPSW was recorded. Hysteresis curves of all models were plotted to determine energy dissipation, lateral displacement, lateral load capacity and ductility ratio. Finally, the result of the study indicates that the energy dissipation of the SPSWs models was increased between 9 percent to 56 percent when diagonal stiffeners with different cross-sectional dimensions were added. The main factors that influence the value of the energy dissipation are the number of stiffeners followed by the thickness of the stiffeners. Lateral load capacity of the models was affected significantly only when the total cross-sectional area of the stiffeners was larger than 1600 mm2. Moreover, the ductility ratio of the diagonally stiffened SPSWs that had the same total cross-sectional area, and the same number of stiffeners, increased when the thickness of the infill plate was 10 mm, instead of 5 mm.

ABSTRAK

Perilaku struktur dinding ricih plat keluli (SPSW) yang dikukuhkan dengan pelbagai konfigurasi dan parameter dimanipulasi pengukuh di bawah beban berkitar telah dikaji dengan menggunakan analisis tak anjal tak lelurus. Objektif utama kajian adalah untuk menyiasat kesan pengukuh pepenjuru dengan konfigurasi, ketebalan, kelebaran, dan jumlah luas keratan rentas yang berbeza terhadap kapasiti lesapan tenaga, anjakan sisi nisbah kemuluran dan kapasiti beban sisi SPSW di bawah beban kitaran. Kajian ini menumpu kepada pengukuh pepenjuru tunggal dan berbilang. Model unsur terhingga SPSW telah dibangunkan sebagai model element dua dimensi dan telah dianlisis dengan menggunakan perisian komersial ABAQUS. Sifat keratan rentas elemen sempadan dan ketebalan plat keluli isian kekal malar bagai semua model. Tiga konfigurasi berbeza bagi pengukuh telah digunakan sementara kelebaran dan ketebalan pengukuh diubah-ubah. Beban mengufuk kitaran telah dikenakan berpandukan ATC24 - Guidelines for Cyclic Seismic Testing of Components of Steel Structures pada bahagian atas model SPSW dan anjakan sisi di bahagian atas SPSW telah direkod. Lengkuk histeresis bagi semua model telah diplot untuk menentukan tenaga lesapan, anjakan sisi, kapasiti beban sisi dan nisbah kemuluran. Akhirnya, hasil kajian menunjukkan bahawa kapasiti lesapan tenaga SPSW meningkat di antara 9 hingga 56 peratus apabila pengukuh pepenjuru dengan dimensi keratan rentas berbeza ditambah. Faktor utama yang mempengaruhi nilai lesapan tenaga adalah bilangan pengukuh, diikuti oleh ketebalan pengukuh. Kapasiti beban sisi model berubah dengan ketara hanya apabila jumlah luas keratan rentas pengukuh melebihi 1600 mm2. Seterusnya, nisbah kemuluran bagi SPSW terkukuh pepenjuru yang mempunyai jumlah luas keratan rentas yang sama dan bilangan pengukuh yang sama, telah meningkat apabila ketebalan plat isian ialah 10 mm, dan bukannya 5 mm.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	**iii**
	DEDICATION	**iv**
	ACKNOWLEDGEMENT	**v**
	ABSTRACT	**vi**
	ABSTRAK	**vii**
	TABLE OF CONTENTS	**viii**
	LIST OF TABLES	**x**
	LIST OF FIGURES	**xi**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Introduction	1
1.2	Background of Study	2
1.3	Problem Statement	3
1.4	Research Goal	3
1.5	Scope of Study	4
CHAPTER 2	**LITERATURE REVIEW**	**5**
2.1	Introduction	5
2.2	Earthquake	5
2.3	Seismic Loading	7
2.4	Shear Wall System	7
	2.4.1 Steel Plate Shear Wall System	8
	2.4.2 Disadvantage of SPSW	12
	2.4.3 Advantages of SPSW	13
	2.4.4 Advantages of Stiffened SPSW	15
2.5	Material Properties	15
	2.5.1 Material properties of ASTM A36 Steel	16
	2.5.2 Material Properties of ASTM A992 Steel	18

	2.6	Structural Behavior	20
		2.6.1 Lateral Force Capacity	20
		2.6.2 Ductility of Structure	21
		2.6.3 Energy Dissipation	22
	2.7	Method of Analysis	23
	2.8	Research Gap	24
CHAPTER 3		**METHODOLOGY**	**29**
	3.1	Introduction	29
	3.2	Research Flowchart	29
	3.3	Simulation Setup of SPSW Model	31
	3.4	Stiffener Configuration of SPSW Model	33
	3.5	Procedure in ATC-24 SPSW Model	34
	3.6	Calculation of Energy Dissipation	36
CHAPTER 4		**RESULT AND ANALYSIS**	**41**
	4.1	Introduction	41
	4.2	Energy Dissipation	41
	4.3	Lateral Load Capacity	53
	4.4	Lateral Displacement and Ductility	55
CHAPTER 5		**CONCLUSION**	**71**
	5.1	Conclusion	71
REFERENCE			**73**

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	The Disadvantages of Structural Behavior & Performance of SPSW against RC Shear Wall	13
Table 2.2	The Advantages of Structural Behaviour & Performance of SPSW against RC Shear Wall	14
Table 2.3	The Advantages of Structural Behaviour & Performance of Stiffened SPSW against Unstiffened SPSW	15
Table 2.4	Chemical Compositions of A36 Steel	16
Table 2.5	Mechanical Properties of A36 Steel	17
Table 2.6	Chemical Compositions of ASTM A992 Steel	18
Table 2.7	Mechanical Properties of ASTM A992 Steel	19
Table 2.8	Research Gaps	25
Table 2.9	Research Gaps (Conti..)	26
Table 2.10	Research Gaps (Conti..)	27
Table 3.1	Stiffener Configuration of SPSW Model	33
Table 3.2	Recommendation for Number of Cycle in ATC 24	34
Table 4.1	Energy Dissipation of All Models	52
Table 4.2	Lateral Load Capacity of All Models	54
Table 4.3	Maximum Displacement, Displacement at Yield, and Ductility Ratio of All Models	66

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Different Type of Fault Line due to Earthquake (Bruce, 2010)	6
Figure 2.2	(a) Displacement/Time Graph (b) Velocity/Displacement Graph (c) Acceleration/Velocity Graph (Amato et al., 2012)	6
Figure 2.3	(a) Typical SPSW Schematic Layout (b) Typical SPSW Numerical Simulation Layout (Sajid & Kiran, 2018)	9
Figure 2.4	HBE and VBE of SPSW (Berman et. al., 2010)	10
Figure 2.5	Stress/Strain Graph of Mild Steel, Cast Iron and Concrete according to the National Precast Concrete Association	14
Figure 2.6	Stress/Strain Curve of A36 Steel (Turnquist, 2017)	17
Figure 2.7	Stress/Strain Curve of A36 and A992 Steel (Joseph A. & Fahim, 2014)	19
Figure 2.8	Lateral Capacity Configuration (Marabi, 2016)	21
Figure 2.9	Stress/Strain Graph for Brittle and Ductile Structure (Woo, 2017)	22
Figure 2.10	Hysteretic Curve (Nie & Zhu, 2014)	23
Figure 3.1	Research Flowchart	30
Figure 3.2	Simulation Modelling Setup of SPSW	31
Figure 3.3	Stiffener Configuration for All SPSW.	32
Figure 3.4	Deformation History for Multiple Step Test as accordance to ATC 24.	34
Figure 3.5	Determination of Yield Values Q_y and d_y and Elastic Stiffness K_e as according to ATC 24	36
Figure 3.6	Calculation of the Area Above the x-axis	37
Figure 3.7	Calculation of the Area Below the x-axis	38
Figure 3.8	Calculation of Area 1	39
Figure 3.9	Calculation of Area 2	39
Figure 4.1	Hysteresis Curve of Control Model	42

Figure 4.2	Hysteresis Curve of Model T1	42
Figure 4.3	Hysteresis Curve of Model T1B	43
Figure 4.4	Hysteresis Curve of Model T1C	43
Figure 4.5	Hysteresis Curve of Model T2	44
Figure 4.6	Hysteresis Curve of Model T2B	44
Figure 4.7	Hysteresis Curve of Model T2C	45
Figure 4.8	Hysteresis Curve of Model T3	45
Figure 4.9	Hysteresis Curve of Model T3B	46
Figure 4.10	Hysteresis Curve of Model T3C	46
Figure 4.11	Hysteresis Curve of Model W1	47
Figure 4.12	Hysteresis Curve of Model W1B	47
Figure 4.13	Hysteresis Curve of Model W1C	48
Figure 4.14	Hysteresis Curve of Model W2	48
Figure 4.15	Hysteresis Curve of Model W2B	49
Figure 4.16	Hysteresis Curve of Model W2C	49
Figure 4.17	Hysteresis Curve of Model W3	50
Figure 4.18	Hysteresis Curve of Model W3B	50
Figure 4.19	Hysteresis Curve of Model W3C	51
Figure 4.20	Lateral Load Capacity of 40 mm Wide Stiffener with Different Stiffeners' Thickness	53
Figure 4.21	Lateral Load Capacity of 5 mm Thick Stiffener with Different Stiffeners' Width	53
Figure 4.22	Definition of Maximum Displacement from The Hysteresis Curve	55
Figure 4.23	Yield Displacement of Control Model	56
Figure 4.24	Yield Displacement of Model T1	56
Figure 4.25	Yield Displacement of Model T1B	57
Figure 4.26	Yield Displacement of Model T1C	57
Figure 4.27	Yield Displacement of Model T2	58
Figure 4.28	Yield Displacement of Model T2B	58
Figure 4.29	Yield Displacement of Model T2C	59

Figure 4.30	Yield Displacement of Model T3	59
Figure 4.31	Yield Displacement of Model T3B	60
Figure 4.32	Yield Displacement of Model T3C	60
Figure 4.33	Yield Displacement of Model W1	61
Figure 4.34	Yield Displacement of Model W1B	61
Figure 4.35	Yield Displacement of Model W1C	62
Figure 4.36	Yield Displacement of Model W2	62
Figure 4.37	Yield Displacement of Model W2B	63
Figure 4.38	Yield Displacement of Model W2C	63
Figure 4.39	Yield Displacement of Model W3	64
Figure 4.40	Yield Displacement of Model W3B	64
Figure 4.41	Yield Displacement of Model W3C	65
Figure 4.42	Stress Contour of SPSW Model with Zero Stiffener	67
Figure 4.43	Stress Contour of SPSW Model with Single 40 mm wide x 15 mm thick Stiffener	68
Figure 4.44	Stress Contour of SPSW Model with Single 200 mm wide x 5 mm thick Stiffener	68
Figure 4.45	Stress Contour of SPSW Model with Four 40 mm wide x 5 mm thick Stiffeners	69
Figure 4.46	Stress Contour of SPSW Model with Four 80 mm wide x 5 mm thick Stiffeners	69
Figure 4.47	Stress Contour of SPSW Model with Four 40 mm wide x 15 mm thick Stiffeners	70

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is located on a one of the stable plates on earth which leads to false believe that Malaysia would not experience any major disturbance due to earthquake. However, in June 2015, Malaysia was stunned with the first major earthquake that struck in Ranau, Sabah which lasted for nearly 30 seconds. The event was significantly affecting many regions around Sabah.

As a developing modern country, the numbers of high-rise building being designed and constructed, are growing and thus, the obligation of inducing seismic design consideration is now a necessity. As a result, Malaysian National Annex of Eurocode 8 (MS EN 1998) was published in late 2017 by Department of Standards Malaysia. The practicality of replacing British Standard (BS8110) with MS EN 1998 is definite because BS8110 does not consider seismic loading in its design consideration which was absurd. Ignorance of seismic loadings leads to structural failure and loss.

However, the theory of seismic design implements a design which create buildings with enough characteristics of energy dissipation without a collapse but not earthquake-proof.

1.2 Background of Study

Steel plate shear wall (SPSW) is commonly used in steel structures in recent decades to withstand lateral stresses, both from the wind and from the earthquake. SPSW is made of infilled steel plate surrounded with beams and column. Horizontal boundary elements and vertical boundary elements are represented by beams and columns, respectively. SPSW serves as a cantilever plate girder with its columns as flanges, its beams serve as the stiffeners, while the steel plates are the web of the plate girder. Many supporting experimental, numerical, and statistical studies confirm that SPSW is seismically safe.

The shear wall structure in steel plate offers high elastic initial rigidity, maximum shearing capacity and large capacity for deformation, stable hysteretic behavior, as well as excellent plastic energy dissipation. SPSW's construction is similar with the steel structures and the wall can also be manufactured. Thus, SPSW implementation in real structures is quick and easy. The construction weight and thick building walls can also be reduced easily in order to save simple costs and increase the available building space. In addition, the homogenous shear wall materials improve the performance of the connections and hence, improve the structural behavior.

The steel shear wall is thus an extremely promising lateral resistance device for high-strength buildings in seismic fortification areas of high intensity and seismic strengthening. Three main types of SPSW are available. The system can be used as stiffened, unstiffened, or in composition with reinforced concrete panels. In SPSW without stiffener, the infill steel plate may buckle in compression field due to small lateral force because the infill plate is thin. Therefore, the lateral forces are resisted by developing tension filed action. This behaviour is similar to the plate girders with slender web plate. In SPSW with stiffener, the stiffeners increase the buckling capacity of the infill steel plate. Thus, the shear yield takes place in the infill plate. Based on research by Cao et. al. (2019), the efficiency of using steel plate shear wall (SPSW) as a lateral load resisting system has increased substantially throughout the advancement of previous design approach.

1.3 Problem Statement

The steel plate shear walls (SPSW) can be used to withstand extreme earthquakes, wind and low earthquake loads with infill plates attached to their boundaries. The structural behavior of SPSW is not fully understood as well as other well-known structure such as braced frame and moment frame under seismic loadings. There are small number of SPSW system that have been subjected to large earthquakes. As a result, data is limited on the actual performance of the system in terms of earthquakes.

However, considerable analytical and experimental research has been carried out since the early 1970s, with the majority taking place over the past 20 years from countries like Japan, Iran, Turkey, Canada, the United Kingdom, and the USA. These studies show that the system has great structural ductility, dissipation of energy and economical for both as a new lateral resisting system and possible retrofit scheme.

Nevertheless, SPSW has a few limitations. Several studies indicate that the limitations of using of SPSW can be countered by using stiffeners whereby the bucking capacity and deformation of a SPSW can be controlled by applying heavy stiffeners as reinforcement. However, most research has focused only on studying the behavior of the stiffened SPSW with single or multiple longitudinal stiffeners but not with multiple diagonal stiffeners. Hence, there are limited studies on structural behavior of SPSW structure with diagonal stiffeners, experimentally and analytically.

1.4 Research Goal

The unknown of the optimum configuration of stiffeners layout for SPSW is highlighted. Therefore, the goal of this research is to determine the effect of diagonal stiffener with different dimension to the behaviour of SPSW under cyclic loading. The objective of the research is:

(a) To plot the hysteresis curve and determine the energy dissipation of SPSW with different configuration and dimension of diagonal stiffeners.

(b) To investigate the effect of different diagonal stiffener configuration, thickness, width, and total cross-sectional area of stiffener to energy dissipation, lateral displacement, ductility, and lateral load capacity of SPSW under cyclic loading.

1.5 Scope of Study

The scope of the study focus on the structural behavior of SPSW that is stiffened by diagonal stiffeners, in terms of ductility, energy dissipation and lateral capacity. Both the stiffeners and the infilled steel plate used for the study is A36 steel which is a mild steel while the boundary elements are made of A992 steel, which is high yield steel. The number and the location of stiffeners as well as the cross-sectional dimension of the stiffeners will be varied. Numerical simulation which involves nonlinear analysis of the SPSW will be analysed by using Abaqus where a cyclic horizontal load was applied at the top of the stiffened SPSW. A control model and three main models were developed for the study. The dimension of the cross section of the boundary element and infill steel plate remains constant. The dimension of steel plate used is 4000 x 4000 x 5mm. The displacement that is obtained from the non-linear analysis allows the plot of hysteresis curve, which enables the calculation of energy dissipation, ductility, and lateral capacity of the stiffened SPSW.

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