EXPERIMENTAL AND NUMERICAL STUDY ON SHEET METAL LATERAL BENDING WITH BOTH ENDS FIXED

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A report submitted in partial fulfillment of
The requirements for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

BACHELOR OF ENGINEERING
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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*experimental and numerical study on sheet metal lateral bending with both ends fixed*" is written by *Mohd Shahril Bin Mohd Hassan*. I have examined the finalcopy of this project and in our opinion; it is fully adequate in terms of scope and qualityfor the award of the degree of Bachelor of Engineering. I herewith recommend that it beaccepted in partial fulfillment of the requirements for the degree of Bachelor ofMechanical Engineering with Manufacturing Engineering.

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I hereby declare that this report entitled "*experimental and numerical study on sheet metal lateral bending with both ends fixed*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Dedicated truthfully for supports,
encouragements and always be there during hard times, to
my beloved family.

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ABSTRACT

The main aim of this study is to compare the buckling phenomenon of sheet metal strip under both ends fixed setting. This study begins with a literature study. It was followed by design and fabrication of test equipment for strip buckling test. Initial research works was on design the test rig using solidwork software. The fabrication test rig consists of four different buckling test conditions. In this thesis, experimental and numerical investigation was dedicated to both ends fixed. Using the fabricated test rig, experimental was conducted to determine displacement and strain of the buckle specimen. Data from experiment have been compared with numerical modeling using Abaqus software. The results show good agreement between experimental and numerical analysis.

ABSTRAK

Tujuan utama kajian ini adalah untuk membandingkan fenomena lengkokan jalur logam nipis dimana kedua-dua hujung adalah dalam keadaan yang tetap. Kajian ini bermula dengan rujukan awal dari bahan rujukan yang berkaitan. Seterusnya diikuti oleh reka bentuk dan pembuatan peralatan ujian bagi ujian jalur lengkokan. Kerja-kerja penyelidikan asal adalah pada reka bentuk pelantar ujian dengan menggunakan perisian solidwork. Pelantar ujian yang dihasilkan terdiri daripada empat keadaan berbeza ujian lengkokan. Dalam tesis ini, penyiasatan eksperimen berdedikasi pada satu keadaan iaitu kepada kedua-dua hujung yang ditetapkan. Menggunakan pelantar ujian yang dihasilkan, eksperimen telah dijalankan untuk menentukan perubahan panjang pada lengkukan dan jarak perubahan spesimen. Data dari eksperimen telah berbanding dengan model yang sama seperti eksperimen menggunakan perisian Abaqus. Hasil kajian menunjukkan perbubungan antara analisis eksperimen dan simulasi.

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LIST OF ABBREVIATIONS

FEM	Finite Element Method
FEA	Finite Element Analysis
PDE	Partial Differential Equations
3D	3 Dimensions
SMAW	Shielded Metal Arc Welding
CNC	Computer Numerical Control
WF	Wide-Flange

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter gives a short description of the project background including several approaches. It then introduces objectives, scopes, problem statement of this project on fabricate the laboratory test equipment for sheet metal lateral bending(buckling) condition where the both ends are fixed.

1.2 Project Background

This project focus on design new experimental for buckling test equipment, beside, run the experiment of strip buckling which both condition are fixed. It is also explain about concept and practically on buckling process and simulation by using finite element method (FEM).

1.2.1 Buckling Phenomena

Buckling is one of the natural phenomena in engineering field which is related to unstable structure of the object. Theoretically,buckling is a mathematical instability, leading to a failure mode and caused by a bifurcation in the solution to the equations of static equilibrium. At a certain stage under an increasing load or force, further load is able to be sustained in one of two states of equilibrium. In practice, buckling is characterized by a sudden failure of a structural subjected to high compressive stress, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding. Mathematical analysis of buckling makes use of an axial load eccentricity that introduces a moment, which does not form part of the primary forces to which the member is subjected. When load is constantly being applied on a member, such as strip, it will ultimately become large enough to cause the member to become unstable. Further load will cause significant and somewhat unpredictable deformations, possibly leading to complete loss of load carrying capacity and failure of structures stability.

1.2.2 Buckling of Strip

When a structure subjected to compression undergoes visibly large displacements transverse to the load then it is going to buckle. Buckling may be demonstrated by pressing the opposite edges of a flat sheet of cardboard towards one another. For small loads the process is elastic since buckling displacements disappear when the load is removed. Local buckling of plates or shells is indicated by the growth of bulges, waves or ripples, and is commonly encountered in the component plates of thin structural members. Buckling proceeds in manner which may be either:

(i) Stable: Condition in which case displacements increase in a controlled fashion as loads are increased. The structure's ability to sustain loads is maintained.

(ii) Unstable: Condition in which case deformations increase instantaneously, the load carrying capacity loses, thus it is dives and the structure collapses.

(iii) Neutral equilibrium: It is also a theoretical possibility during buckling and this is characterized by deformation increase without change in load.

Buckling and bending are similar in that they both involve bending moments. In bending, moments are substantially independent of the resulting deflections, meanwhile in buckling the moments and deflections are mutually inter dependent and also moments, deflections and stresses are not proportional to loads. If buckling deflections become too large then the structure fails, this is a geometric consideration, completely separate from any material strength consideration. If a component of part is prone to buckling then its design must full fill both strength and buckling safety constraints.

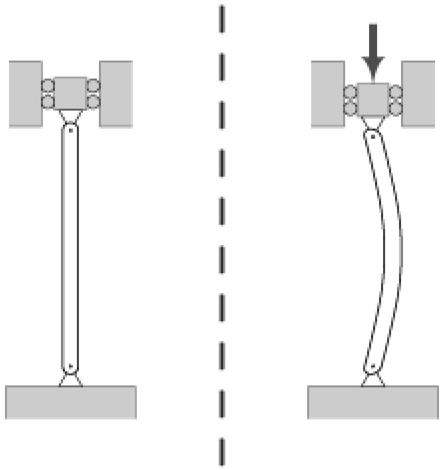


Figure 1.1: Strip Buckling

Source: Fae q. A.A Radwan, 2008

1.2.3 Critical load

For an axially loaded straight strip with any end support conditions, the equation of static equilibrium, in the form of a differential equation, can be solved for the deflected shape and critical load of the strip. With hinged or pinned, fixed or free end support conditions the deflected shape in neutral equilibrium of an initially straight strip with uniform cross section throughout its length always follows a partial or composite sinusoidal curve shape.

Elements of critical load:

E = modulus of elasticity

I = area moment of inertia

Le = strip effective length factor

1.2.4 Finite Element Method (FEM)

Finite Element Method **(**FEM) divides a structure into several elements or pieces of the structure.Then it is reconnecting the elements at nodes if nodes were pins or drops of glue that hold elements together.This process results in a set of simultaneous algebraic equations.The term finite element was first coined by Clough in 1960. In the early 1960s, engineers used the method for approximate solutions of problems in stress analysis, fluid flow, heat transfer, and other areas. In the late 1960s and early 1970s, the FEM was applied to a wide variety of engineering problems.

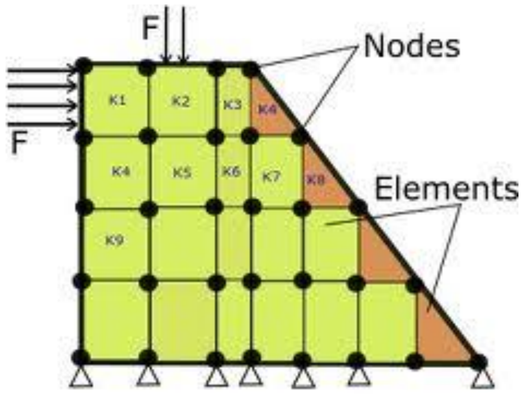


Figure 1.2: Finite Element Method
Source: http://www.ilearncae.com, 2010

The finite element method (FEM) which is practical application or known as finite element analysis (FEA) is a numerical technique for finding approximate solutions of partial differential equations (PDE) and also known as integral equations. The solution approach is based either on eliminating the differential equation completely steady state problems, or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc. FEM are allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of modeling and analysis of a system. Similarly, the desired level of accuracy required and associated computational time requirements can be managed simultaneously to identify most engineering applications. FEM also allows entire designs to be constructed, modify, and optimized before the design is manufactured.

1.3 Problem Statement

Buckling phenomenon one of the natural phenomena in engineering field, thus, by this project, new design of buckling test equipment are going to be produce so that the phenomena of strip buckling can be study on more clear. The design of the test equipment should be friendly used and portably. Current teaching practices are preferring hands on or practically. Thus, it is easy and fast to understand the related engineering problem. The simple engineering problem can be investigated (by experimental) in lab and a buckling problem can be tested in lab and Finite element software can be used to develop similar model to verify the result.

1.4 Project Objective

The objectives of the project are to:

1. To design and fabricated new test rig for buckling test.
2. To run the experiment ofbuckling test under fixed-fixed setting.
3. Comparing result by experimental and Finite Element Software (FEM).

1.5 Scope of Project

In order to achieve the objectives of this project, the scopes are list as below:

1. Come out with new mechanical drawing for all part involve.
2. Come out with new complete design for buckling test equipment.
3. Fabricate the buckling test rig based on the early design (3D).
4. Run the experiment for buckling test of using sheet metal of Galvanize Mild Steel.
5. Simulate the buckling phenomenon in Abaqus software as same with experimental setup.
6. Compare the result from experimental and simulation.

1.6 Chapter Summary

Chapter 1 has been discussed generally about project, problems statement, objective and the scope of the project in order to achieve the objective as mention. This chapter is as a fundamental for this project and as a guidelines to complete the project research. Synopsis in this chapter is this project involve in design new model, fabricate the test rig of buckling, run the experiment and comparing the result between experimental and FEM software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides the detail description literature review done according to the title of "*Experimental and Numerical Study on Sheet Metal Lateral Bending with Both Ends Fixed*". Since the aim of this project is to design and fabricate the buckling test equipment, there some are related software, methods and process. Obviously literature review related with definition of buckling phenomenon by run the experimental and simulation. This literature review will give an overview or a brief introduction of the techniques and methods that are suitable to be used in this project.

2.2 Buckling of Structures

A strip in structural engineering is a vertical structural element that transmits, through compression, the weight of the structure above to other structural elements below. Other compression members are often termed strip because of the similar stress conditions. Strip can be either compounded of parts or made as a single piece. Strip are frequently used to support beams or arches on which the upper parts of walls or ceilings rest. The term strip in architecture refers specifically to such a structural element that also has certain proportional and decorative features. If the load on a strip is applied through the center of gravity of its cross section, it is called an axial load. A load at any other point in the cross section is known as an eccentric load. A short strip under the action of an axial load will fail by direct compression before it buckles, but a long strip loaded in the same manner will fail by buckling (bending), the buckling effect being so large that the effect of the direct load may be neglected. The intermediate-length column will fail by a combination of direct compressive stress and bending. As the axial load on a perfectly straight slender strip with elastic material properties is increased in magnitude, this ideal strip passes through three states: stable equilibrium, neutral equilibrium, and instability. The straight strip under load is in stable equilibrium if a lateral force, applied between the two ends of the column, produces a small lateral deflection which disappears and the strip returns to its straight form when the lateral force is removed. If the strip load is gradually increased, a condition is reached in which the straight form of equilibrium becomes so-called neutral equilibrium, and a small lateral force will produce a deflection that does not disappear and the strip remains in this slightly bent form when the lateral force is removed. The load at which neutral equilibrium of a strip is reached is called the critical or buckling load. The state of instability is reached when a slight increase of the strip load causes uncontrollably. Growing lateral deflections leading to complete collapse.(Fae q A.A Radwan, 2008)

2.2.1 Strip buckling

Local buckling occurs in short a strip that is long enough not to fail due to crushing which mean when the compression strength of the material is not reached (Barbero, 1998). For pultruded wide-flange (WF) sections, the strip will compress axially until flanges develop wave like deformations along the length. The flange deformations can be large, often greater than the thickness of the flanges. Therefore the local buckling load can be used as failure criteria for a short strip. The short strip buckling load PL can be determined from a short strip test (Tomblin and Barbero, 1994) or predicted using analytical or numerical techniques (Banks and Rhodes, 1983).For members which are not susceptible to local buckling, there are three main different buckling modes to be considered, and they are:

(i) Flexural buckling
(ii) Torsional buckling
(iii) Flexural-torsional buckling

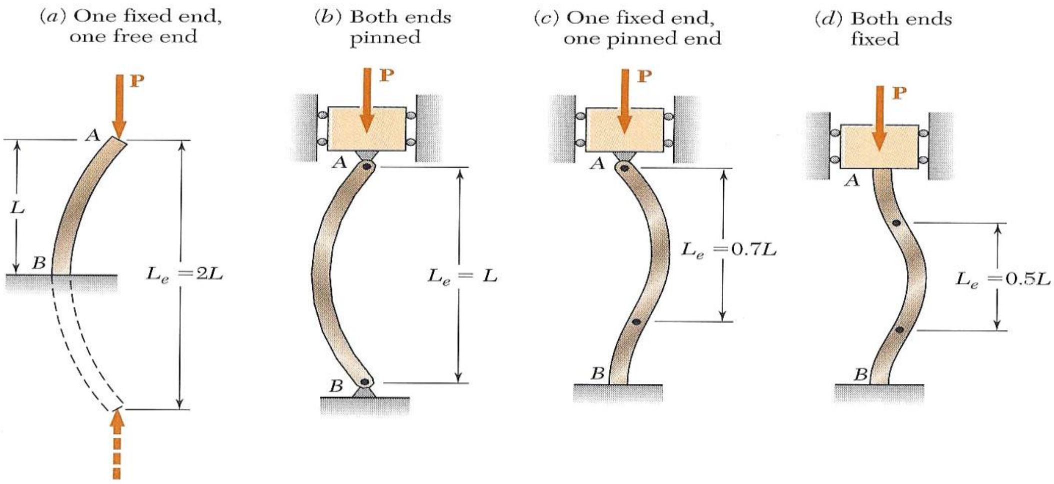


Figure 2.1: Cases of Strip Buckling

Sources: http://www.aplaceofsense.com, 2010

Figure 2.1 shows some cases of strip buckling cases under a uniform axial compression, the two unsupported edges tend to shape the Euler type buckles. At the fold, the amplitude of the buckle is virtually zero. A horizontal cross section at mid height of the strut shows that the cross-section rotates relative to the ends. This mode of buckling is essentially torsional in nature and is initiated by the lack of support at the free longitudinal edges. This case illustrates buckling in torsion, due to the low resistance to twisting (polar moment of inertia) of the member. Thus the strip curves of the type discussed before are only satisfactory for predicting the mean stress at collapse, when the strut buckles by bending in a plane of symmetry of the cross section, referred to as "flexural buckling". Members with low torsional stiffness (angles, tees etc made of thin walled members) will undergo torsional buckling before flexural buckling. Cruciform sections are generally prone to torsional buckling before flexural buckling. Singly symmetric or un-symmetric cross sections may undergo combined twisting about the shear centre and a translation of the shear centre. This is known as "torsional-flexural buckling".(Fatimah Denan et al, 2010)

2.3 Design

Design is an innovative and highly iterative process. It is also a decision-making process. Decisions sometimes have to be made with too little information, occasion ally with just the right amount of information, or with an excess of partially contradictory information (Richard G. Budynas and J. Keith Nisbett, 2010). Design is a communication-intensive activity in which both words and pictures are used and written and oral forms are employed. Engineers have to communicate effectively and work with people of many disciplines. Design is the human power to conceive, plan, and realize products that serve human beings in the accomplishment of any individual or collective purpose. It is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life cycles. Therefore, design is the central factor of innovative humanization of technologies and the crucial factor of cultural and economic exchange.

2.3.1 Design Process

The design process is an iterative, complex, decision-making engineering activity that lead to detailed drawings by which manufacturing can economically produce a quantity of identical products that can be sold. The design process usually starts with the identification of a need, and decision to do something about it. After much iteration, the process ends with the presentation of the plans or satisfying the need. Depending on the nature of the design task, several design phases may be repeated throughout the life of the product, from inception to termination (Richard G. Budynas and J. Keith Nisbett, 2010).

2.4 Fabrication of Structural

The steel framed building derives most of its competitive advantage from the virtues of prefabricated components, which can be assembled speedily at site. Unlike concreting, which is usually a wet process conducted at site, steel is produced and subsequently fabricated within a controlled environment. This ensures high quality, manufacture offsite with improved precision and enhanced speed of construction at site. The efficiency of fabrication and erection in structural steelwork dictates the success of any project involving steel intensive construction. Current practices of fabrication and erection of steel structures in India are generally antiquated and inefficient. Structural steel passes through various operations during the course of its fabrication. (Ghoshal.A, 2000)

2.5 Euler's Rule

In general, strip do not always terminate with simply-supported ends. Therefore, the formula for the critical buckling load had been generalized. The generalized equation takes the form of Euler's formula, mathematician Leonhard Euler derived a formula that gives the maximum axial load that a long, slender, ideal strip can carry without buckling. An ideal column is one that is perfectly straight, homogeneous and free from initial stress. The maximum load, or called the critical load, causes the strip to be in a state of unstable equilibrium, that is any increase in the load, sometimes the introduction of the slightest lateral force, will cause the strip to fail by buckling. Simple beam bending is often analyzed with the Euler-Bernoulli beam equation. The formula derived by Euler for strip with no consideration the value of critical load remains approximately same. The Euler mode occurs in slender strip and involves a sudden lateral deflection without deformation of the cross-section, as shown in equation below:

$$F = \frac{\pi^2 EI}{(Kl)^2}$$

F = maximum or critical force

E =modulus of elasticity

I =area moment of inertia

I =unsupported length of strip

K = strip effective length factor:

For both ends pinned, K = 1.0

For both end fixed, K = 0.50

For one end fixed and the other end pinned, K =1.0

For one fixed and the other end free to move laterally, K =2.0

The Euler buckling equation accurately predicts the critical buckling load for slender strip in terms of the bending stiffness *(EI)*, the strip length *L*, and the end-restraint coefficient *k*. Therefore, the Euler buckling load can be used as failure criteria for a slender strip. The reduction of buckling load due to shear deformation can be accounted for by dividing the result of Equation by *1+PE/(GA)*, where *(GA)* is the shear stiffness of the section (Gaylord and Gaylord, 1972). In addition to being a small effect, the shear stiffness *(GA)* is not reported in product literature and it is difficult to measure accurately. It is customary in steel design to predict *(GA)* as the product of the material shear modulus times the area of the web, when bending occurs about the strong axis. (Fae q A.A Radwan, 2008)]Some common boundary conditions are shown in the Figure 2.2:

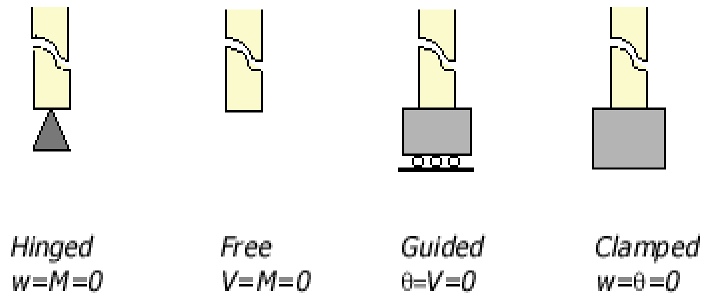


Figure 2.2: Boundaries condition for Buckling

Sources: http://www.aplaceofsense.com,2010

2.6 Strain Stress Curve

As we can see in Figure 2.3, the initial portion of the stress-strain diagram for most materials used in engineering structures is a straight line. For the initial portion of the diagram, the stress σ is directly proportional to the strain, ε. Therefore, for a specimen subjected to a uniaxial load, it is can write as equation below:

$$\sigma = E\,\varepsilon$$

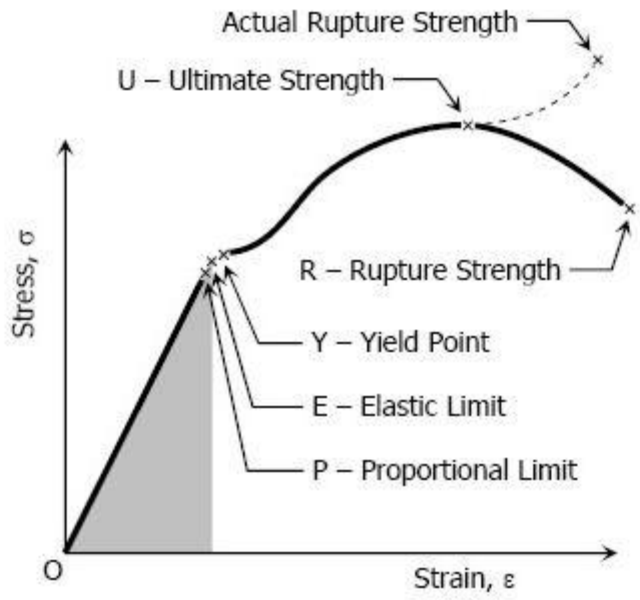


Figure 2.3: Strain Stress Curve

Source: http://www.keytometals.com/Article107.htm, 2009

i. Elastic Limit

The elastic limit is the limit beyond which the material will no longer go back to its original shape when the load is removed, or it is the maximum stress that may developed such that there is no permanent deformation when the load is entirely released.

ii. Elastic and Plastic Ranges

The region in stress-strain diagram from O to P is called the elastic range. The region from P to R is called the plastic range.

iii. Yield Point

Yield point is the point at which the material will have an appreciable elongation or yielding without any increase in load.

iv. Ultimate Strength

The maximum ordinate in the stress-strain diagram is the ultimate strength or tensile strength.

v. Rapture Strength

Rapture strength is the strength of the material at rupture. This is also known as the breaking strength.

2.7 Experimental

A wealth of experimental data is available for plates but these show no interacting stable post buckling paths (Arbocz et al, 1985, Esslinger and Geier, 1975). Guidelines for testing metallic strip are provided by Galambos in 1988 but these mostly involve interaction of a buckling mode with yield of the material. Buckling-mode interaction is investigated using conventional test procedures (Barbero and Tomblin, 1994) coupled with the shadow moiré technique (Schwarz, 1988), capable of measuring full field, out-of-plane displacements. The contributions of the local and Euler modes to the overall buckling behavior of intermediate strip is readily observed, because the two conventional buckling modes (local and Euler) as well as the emerging interactive mode are characterized by distinct and measurable physical deformations.(Ever J.Barbero et al, 1999)

2.8 Compression Test

The difficulties are due to the complicated boundary conditions associated with the compression loading. The difficulties are also due to the variations in the compressive strengths with the sample lengths. Unlike the uniform fixed boundary condition in the tensile experiments, it was possible for the ends of a compressed sample to move on the platen surfaces of the fixtures that were used to apply loads to the samples. It should be noted the lubricant was used in the platen surfaces of the fixture. The right angle of a triangle was used to check the alignment. The movement of sample ends on the fixture faces may result in different boundary conditions. The possible boundary conditions are ends are movable, two ends are pinned, and one end is pinned and the other end can move. The first type of boundary condition is not desirable. The data from such tests were, therefore, discarded. The latter two types of boundary conditions correspond to two types of buckling modes, and the corresponding strengths were different. Since struts in real lattice block structures are considered to be pinned at both ends, tests are considered to be valid only when there is no movement on the fixture platen for either end of the tested sample. In order to obtain the second type of boundary condition, it is important to make the top and bottom surfaces parallel. This is a necessary condition for a valid test. However, there are numerous other factors that could not be controlled in the testing process. Hence, only a limited number of valid test data were obtained, even though a large number of compression tests were performed on individual struts extracted from the lattice block structure. (Ever J.Barbero et al, 1999)

2.9 Strain Gauge

Strain gauge is a one of the device that used to detect the deformation of the surface bonding on the surface of the material selected. If a strip of conductive metal is stretched, it will become skinnier and longer, both changes resulting in an increase of electrical resistance end-to-end. Conversely, if a strip of conductive metal is placed under compressive force (without buckling), it will broaden and shorten. If these stresses are kept within the elastic limit of the metal strip, thus the strip does not permanently deform, the strip can be used as a measuring element for physical force, the amount of applied force inferred from measuring its resistance. Such a device is called a strain gauge, it is frequently used in mechanical engineering research and development to measure the stresses generated by machinery.

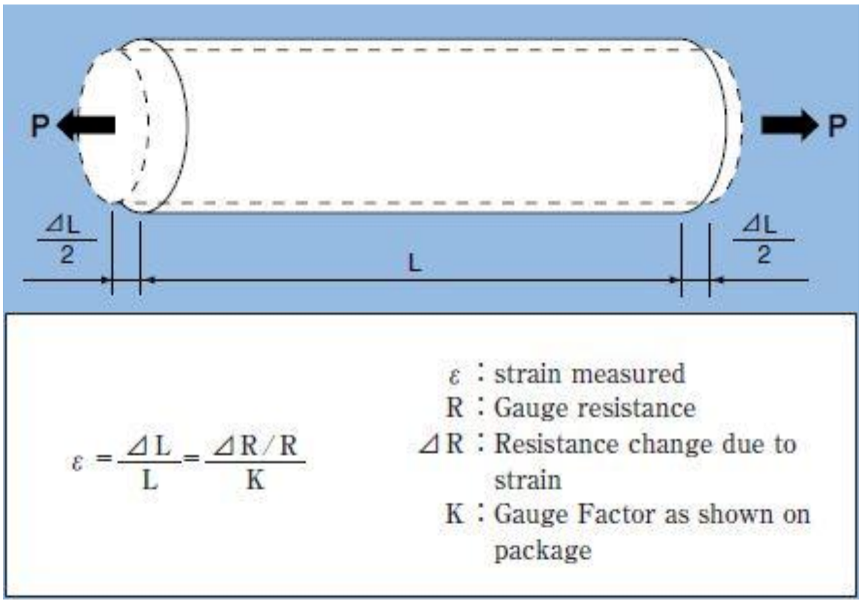


Figure 2.4: Principle of Strain Gauge

Source: Tokyo Sokki Kenkyujo, 2011

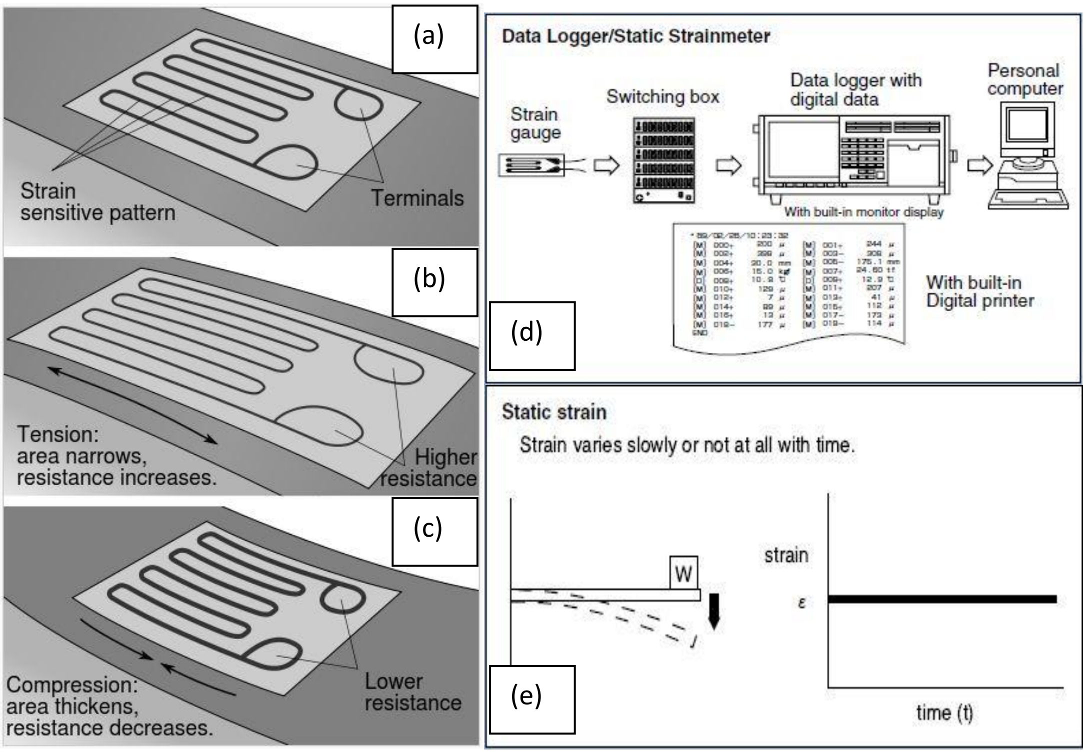


Figure 2.5: a) Strain Gauge in stable, b) Tension on Strain Gauge, c) Compression on Strain Gauge, d) Connection of Strain Gauge to Data Collection, e) Static curve

Source: Tokyo Sokki Kenkyujo, 2011

But, when no force applied to the test specimen, both strain gauges have equal resistance and the bridge circuit is balanced.

2.10 Finite Element Method (Software Simulation)

Software tools are widely used today in the classroom and are proving to be very effective teaching aids. One of the benefits of software tools is that they provide a means for visualization of abstract, concepts and ideas. If used properly software tools can improve teaching efficiency in many instances. As a teaching tool, computer software can provide a new way to link abstract concepts with tangible visualizations. Specialized computer software offers students the option of self-learning and can also be instrumental in motivating them to learn abstract engineering concepts (Sergio Tonini Button, 2000). Johnson states that “experimental work used to teach metal forming shows an important feature when we analyze the great development observed in the numerical simulation of processes, mainly the finite element method”. The increasing capacity of these methods and commercial software must be accompanied by a consistent practical learning which will allow the manufacturing engineer to provide the correct pre-processing information such as initial conditions of temperature, speed and friction, and workpiece material properties and to analyze the simulation results like strain, stress and temperature distributions in the products and tools to predict and prevent process problems like defects in the products or tools damage.(En Yu et al, 2007)Numerical simulation does not provide itself a definitive response about the process analyzed because of the uncertainties related to the plastic behavior of the deformed material, and to the tribological conditions in the interface workpiece dies. Physical modeling has been applied to validate numerical simulation results, because it involves low investments in equipment and tools and allows the analysis of metal flow preventing forging defects (Sergio Tonini Button, 2000).

CHAPTER 3

METHODOLOGY

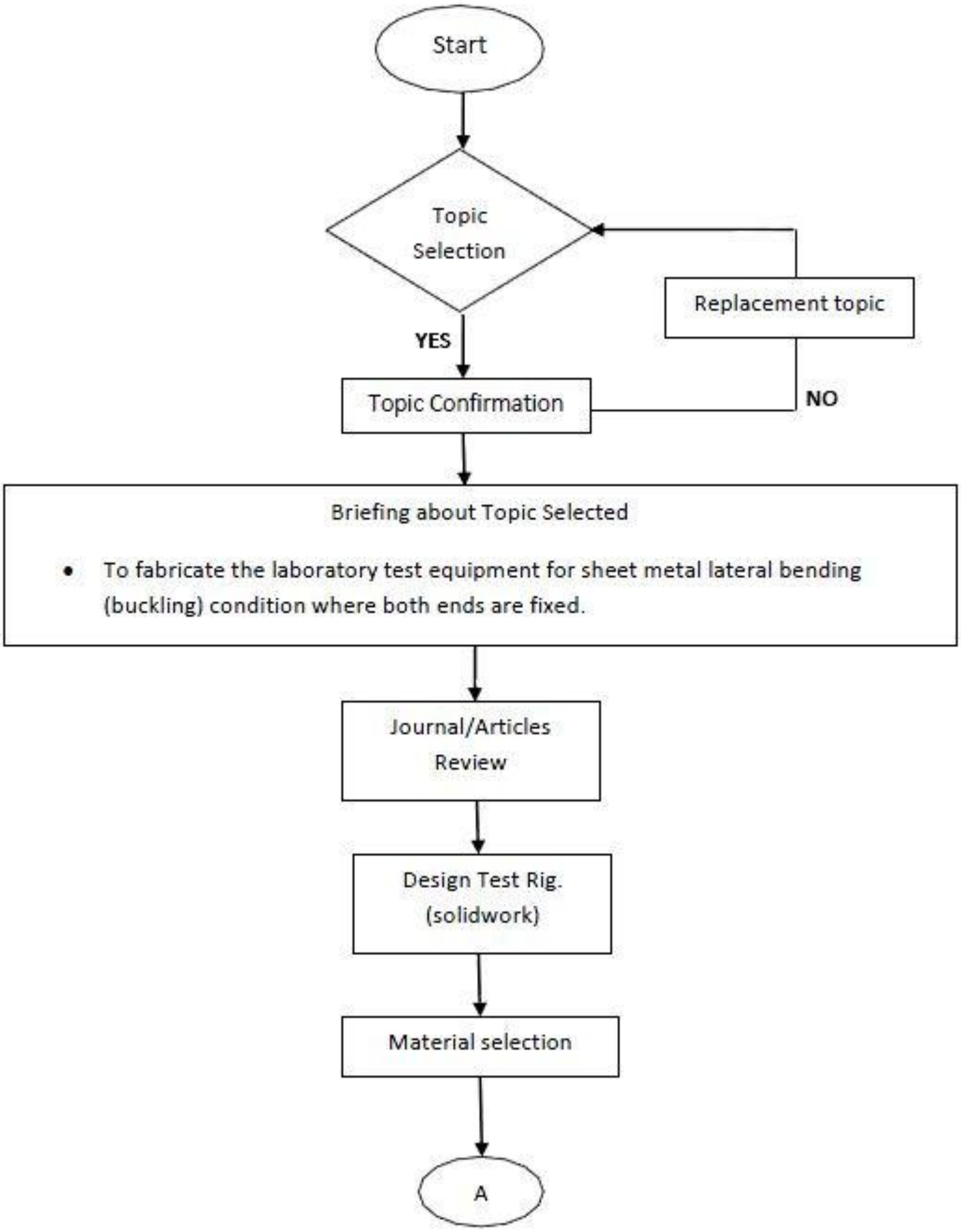
3.1 Introduction

Chapter 3 discusses methodology of the project in general, with a specific focus on fabrication of lateral bending (buckling) of sheet metal which condition of both ends are fixed. The work is based on methodology flow chart. Chapter 3 presents current progress on research by fabricate and software simulate (ABAQUS). Understanding prior and current research in this project provides method for the research contributions outlined in subsequent chapters.

3.2 Methodology Flow Chart

Methodology flow chart is use as guidelines and the sequences to make this project go smoothly. Thus, the process begin with title selection and conformation of the title selected. Then, the process continue with finding the articles relate and identify the objectives, project background and the problem statement related to this project. The process proceeds by starts with design/sketch and identifies the material needed to fabricate the test equipment for this lateral bending experiment. There are brainstorming process in decided the best material for the test equipment fabrication. Thus, the selection material had been decide in which for the basic base, the material that been used is rectangular hollow steel (50mm x 50mm x 250mm),the upper base is also rectangular hollow steel (38mm x 38mm x 250mm).For the side support, the material used is L-shape steel (25mm x 25mm x 600mm).The additional material for the structure are solid aluminum (50mm x 50m x 150mm),sheet metal (250mm x 250mm x

1mm) for the cover of the main structure. Lastly for the specimen of buckling test, the material used is 1mm of thickness sheet metal Galvanize Mild Steel.



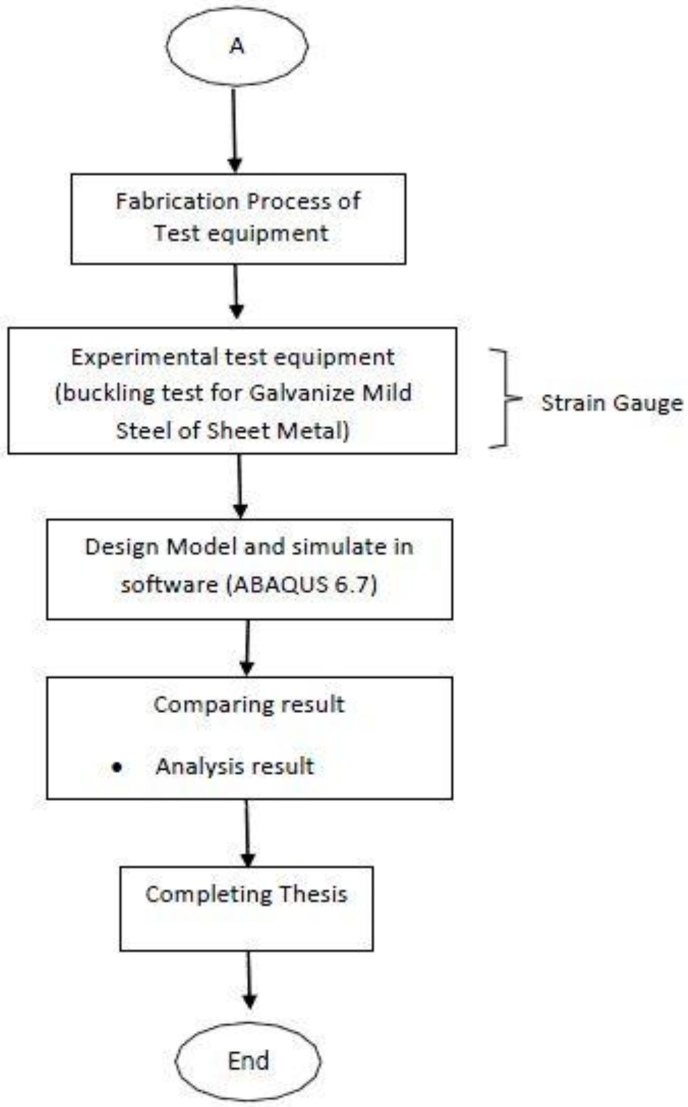


Figure 3.1: Methodology flow chart

3.3 Gather information

This project is required to do preliminary study and research about project. The various resources have been searching from books, articles, journals, and internet webpage to develop a personal plan for information processing. Materials of the chief area of interest to generate the basic idea in fabricate the test equipment for the lateral bending (buckling) test process.

3.4 Identify Problem

Of the entire step in the engineering design process, problem definition is the most important. Understanding the problem thoroughly at the beginning aids immeasurably in researching on outstanding solution. However in machining process, consideration on the selection of the material and machine used for the making parts is important and while the part will lead to the failure on lateral bending (buckling) test equipment. Lateral bending or strip buckling defines as relatively long, slender member of load subjected on compressive stress. Local buckling of plates or shell is indicated by growth of bulges, waves or ripples, commonly encounter in the component of the thin plate members. There are several factors that affect the buckling phenomena in which are the strength of the material, the ends condition of the strip and design for each end condition.

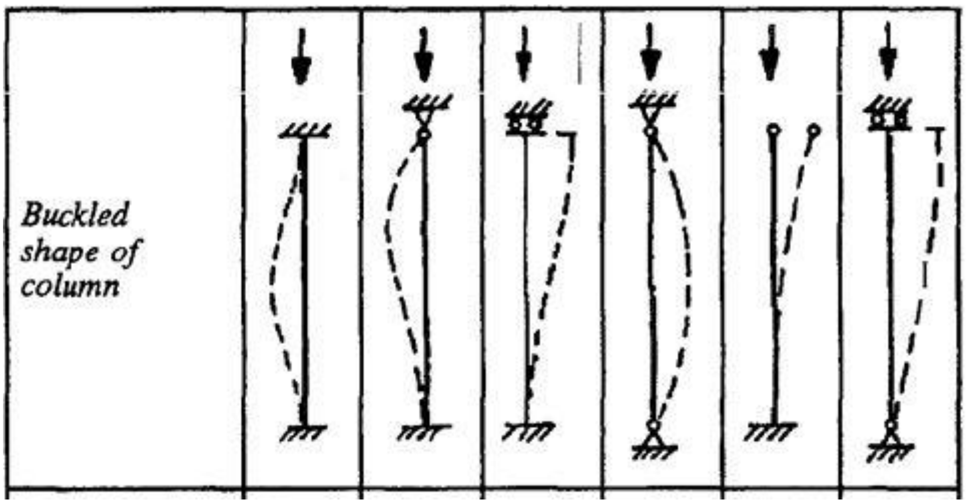


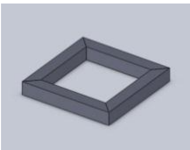
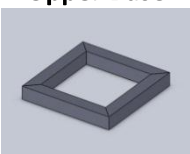
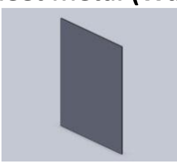
Figure 3.2: Ends condition of strip buckling

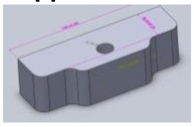
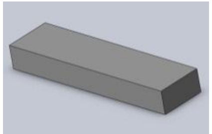
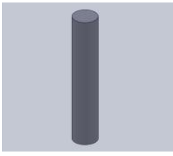
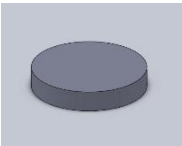
Source: http://www.ejsong.com/MDME/modules/FEA/Beams.htm, 2008

3.5 Design of equipment.

SolidWorks is a Parasolid-based solid modeler, and utilizes a parametric feature-based approach to create models and assemblies. Building a model in SolidWorks usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of SolidWorks means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside of the sketch.

Table 3.1: Design Component of Test Equipment (3D)

Component	Material	Dimension (mm x mm x mm)
Lower Base 	Rectangular Hollow	50 x 50 x 250
Upper Base 	Rectangular Hollow	38 x 38 x 250
Side Support 	L-shape steel	25 x 25 x 600
Sheet Metal (Wall) 	GI steel	250 x 250 x 3

Component	Material	Dimension (mm x mm x mm)
Upper Holder 	Solid Aluminum	35 x 35 x 80
Lower Holder 	Solid Aluminum	50 x 50 x 80
Upper Holder Shaft 	Solid Aluminum	D=15 L=100
Load Holder 	Aluminum	D=80 t=10

3.6 Fabricate Test Equipment.

3.6.1 Band Saw

Band saw is a one of the cutter machine that been used during this fabricate process of test equipment. Band saw mainly used for cutting solid steel in which no more than 600mm x 60mm.For this project, the solid rectangular aluminum and solid bar aluminum ware cut by using band saw machine. The angle allows cutting the material use this machine is 0 degree.

Figure 3.3: Band Saw Machine

3.6.2 Disc Cutter

Disc cutter used for cutting hollow material or non-solid material. For this project, disc cutter is used to cut rectangular hollow steel and L-shape steel. It is manually used and the precaution steps must be following such as wearing goggle, safety shoes and other safety wear. Besides, this machine can be used for cutting material with angle 0 degree, 30 degree, 45 degree.

Figure 3.4: Disc Cutter Machine

3.6.3 Shield Metal Arc Weld

Shielded Metal Arc Welding (SMAW) is defined as an arc welding process in which coalescence of metals is produced by heat from an electric arc that is maintained between the tip of a flux covered electrode and the surface of the base metal in the joint being welded. The electrode consists of solid metal core, which is covered by a metallic coating. The coatings composition is dependent on the type of electrode and welding polarity. It serves various functions during the welding process. These include; provide a shielding agent from the atmosphere which protects the molten pool which is act as fluxing agents to cleanse the weld metal deposit, establish electrical characteristics of the electrode, provide a slag covering during cooling which can improve weld properties, enhance the ability to weld out of position, improve bead profile and appearance, and can add alloying elements weld.Thus, the component cut especially for the upper and lower base, the best joining process that been used is SMAW welding. The component made up from the mild steel and it is easy to weld by using this weld process besides it lower in cost.

Figure 3.5: SMAW weld Equipment

3.6.4 Shearing Machine

Shearing force machine had been used in this project to cut the thin wall material or sheet metal for the purpose of covering the main structure of the experimental test equipment. This machine involve of component in which cutting thin material by giving force on the plate. The dimension of the sheet metal that needs to use is 250mm x 250mm.

Figure 3.6: Shearing Machine

3.6.5 Milling Process

This project involve in milling process which is to shape the rectangular aluminum bar to the upper holder that will attach to the upper base. Thus, in this process, the milling machine will be used.Milling process can be done manually or by using CNC milling the cutting tool is moved in all three dimensions to achieve the desired part shape. The material can be turned to various orientations in the middle of the process and cutting tools of various shapes can be used. Material is usually removed by both the end and the side of the cutting tool.

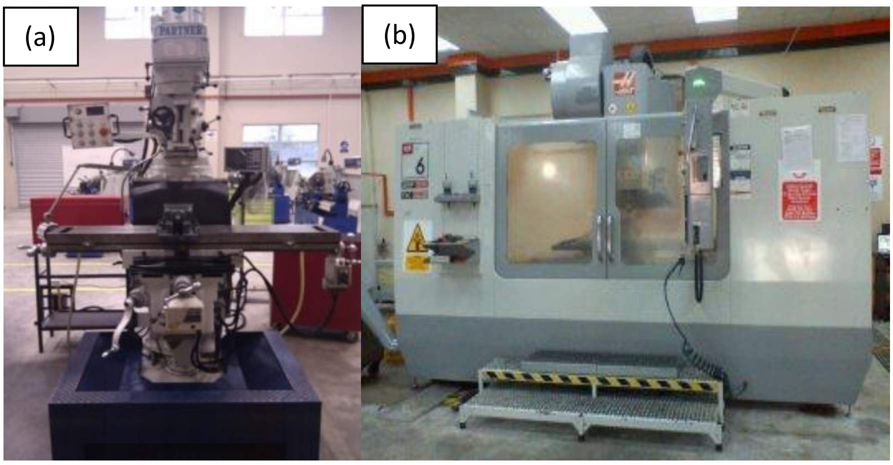


Figure 3.7: a) CNC milling machine, b) Convectional Milling Machine

3.6.6 Turning Process

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool. The work piece (aluminum solid bar 25mm x 100mm) is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine, although some operations make use of multi-point tools. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desired shape. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed. Thus, the aluminum bar for the shaft had been going thru this process to get the absolute size of load shaft and it will be located to the load holder.

Figure 3.8: Turning Machine

3.7 New Test Rig of Buckling Test (both end condition are fixed)

By follow early design and fabrication process, machining and finishing, the test rig of buckling test had been produce.

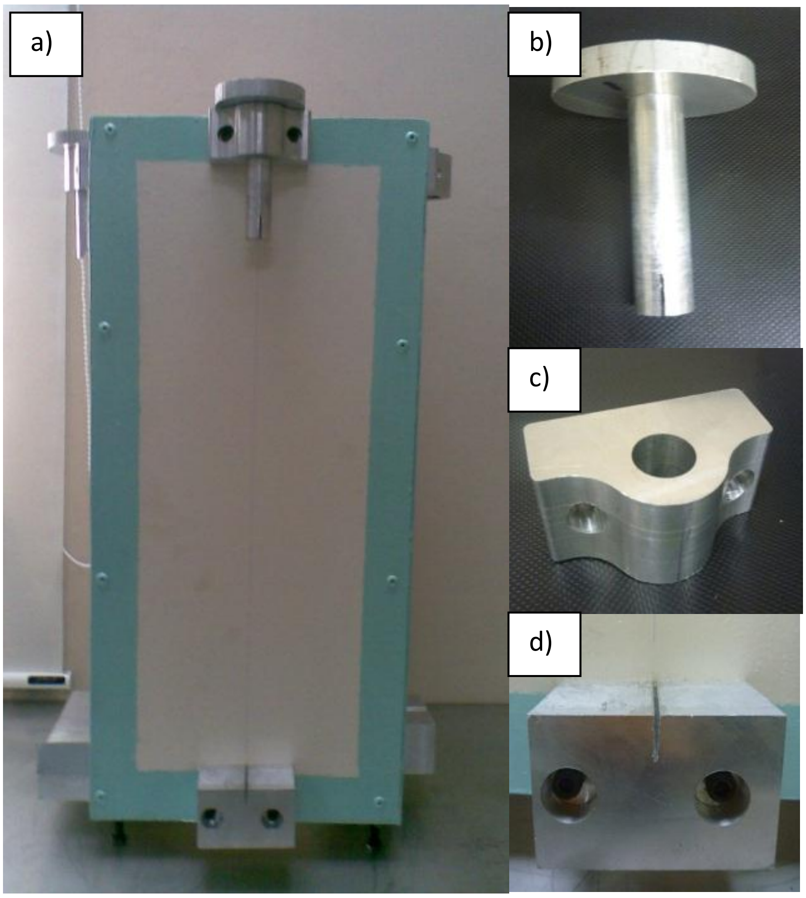


Figure 3.9: a) Buckling Test Rig, b) Load Holder and Top End Design, c) Upper Holder, d) Lower End Design.

3.8 Experimental of Lateral Bending (Buckling)

The experiment of the lateral bending (buckling) test will be run after all setup of the structure equipment had been done. In this experiment, the specimen that will be use is Galvanize Mild Steel sheet metal with length of 500mm.The experiment purpose is to calculate the bending value or in other words is the value of the strain when the buckling phenomenon occurs. Thus, load will be added on the top of the specimen on the load holder that will connect to the load shaft and directly to the specimen. The specimen is located in condition of both ends are fixed. The changes of the straight shape specimen to the buckle shape will be capture and the test read of the experiment will be record. The value of the strain at the critical point of buckle location can be measure by using strain gauge without calculate by using formula. Strain gauge was used to calculate the value of surface strain value when the position of the specimen surface was buckle. Besides, the value of the displacement of buckle also measured manually by using ruler.

3.8.1 Specimen Preparation

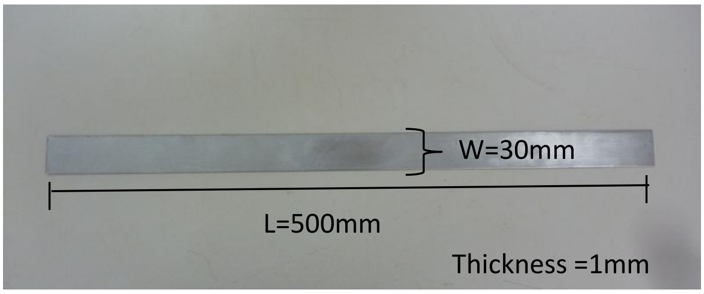


Figure 3.10: Specimen Dimension

For the specimen preparation, the Galvanize Mild Steel sheet metal is going to use for the experiment, the dimension of the specimen as Figure 3.10.

3.8.2 Test Planning (Column Buckling)

Table 3.2: Test Planning

Load (kg)	1^{st} reading	2^{nd} reading	3^{rd} reading	Average
1	x	y	z	A
2	x	y	z	B
↓	↓	↓	↓	↓
8	x	y	z	C

Table 3.2 show that the planning of the experiment.The experiment had been planned to run by using load starting 1kg until 8kg for this buckling test which both ends are fixed. The experiment of the each load will be run for three times and data of plain strain at the surface and maximum displacement at the critical buckle point gain will be collect. The value of each experiment will be total up to take the average value of each load given. Before the experiment been run, pretest of the experiment will be done first, which is the pretest specimen that is same dimension and same material properties will be used to run the experiment so that the critical point of buckle can be identify for strain gauge location to be stick on real specimen of experimental.

Figure 3.11: Test Setup

3.8.3 Strain Gauge

Strain gauge that had been used to stick on the specimen was type FLA-6-11,6mm of length. After identify the critical point and most suitable point to be locate at, the strain gauge had been stick on the specimen which is sheet metal of galvanize steel. Before that, the surface treatment of the specimen must be done first which is the coating layer of zinc on the surface of specimen must be remove by using abrasive paper of grade #120 until #180,beside of removing rust from the bonding surface of a specimen. Strain gauge installation was proceed by stick the strain gauge to the surface of the specimen that been identify as the critical buckle point by using permanent glue. The direction of the strain gauge must be directly parallel to the buckle direction. Then the process continues with soldering the lead wire attachment to the connection wire that will connect strain gauge to the data logger. They operate on the principle that as the foil is subjected to stress, the resistance of the foil changes in a defined way.

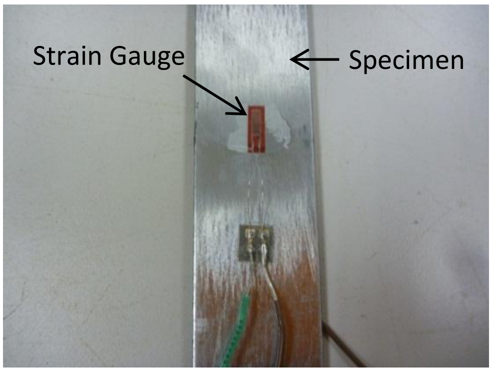


Figure 3.12: Specimen with Strain Gauge

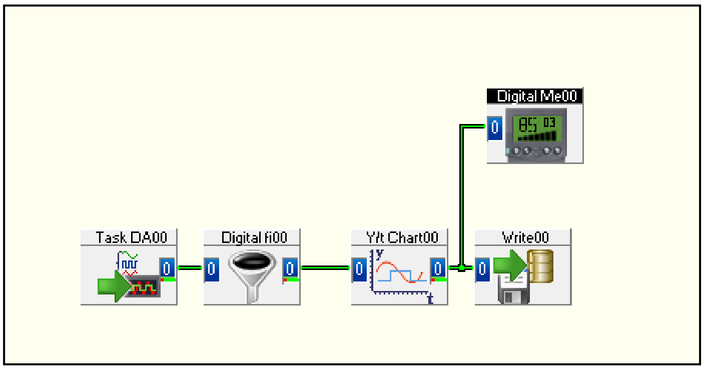


Figure 3.13: Diagram of Connection Strain Gauge in Dasy Lab Software.

3.9 Finite Element Method using Abaqus (FEM)

In this study, all models were assumed to buckle under perfect conditions, where there is no initial imperfectness and eccentric load. The buckling moments were then compared with result obtained from testing, same load and both end condition are same with the experimental to determine the maximum buckling displacement.

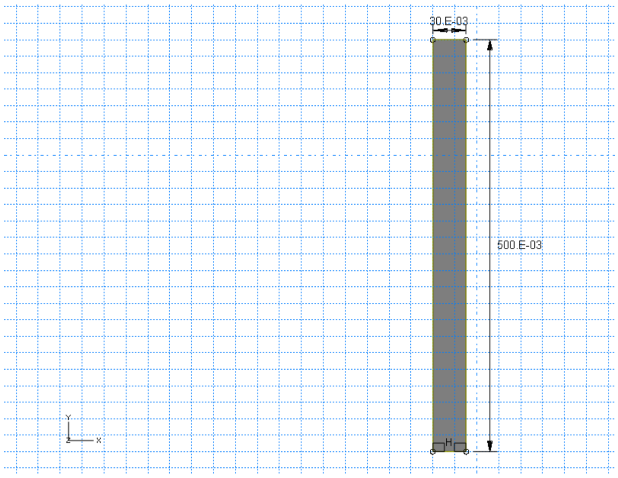


Figure 3.14: 3D Specimen Model in Abaqus

ABAQUS models are defined in terms of geometric features that must be subdivided into finite elements for solution. This process of sub division is called meshing. Mesh data sets contain information about element types, element discretisation and mesh type which is continuum are used. The specimen models were assigned Galvanize Mild Steel for its material property with Young's modulus, E= 2.2x10^11 N/mm2 ,and Poisson ratio of 0.29. The columns are simply supported and unrestrained laterally.

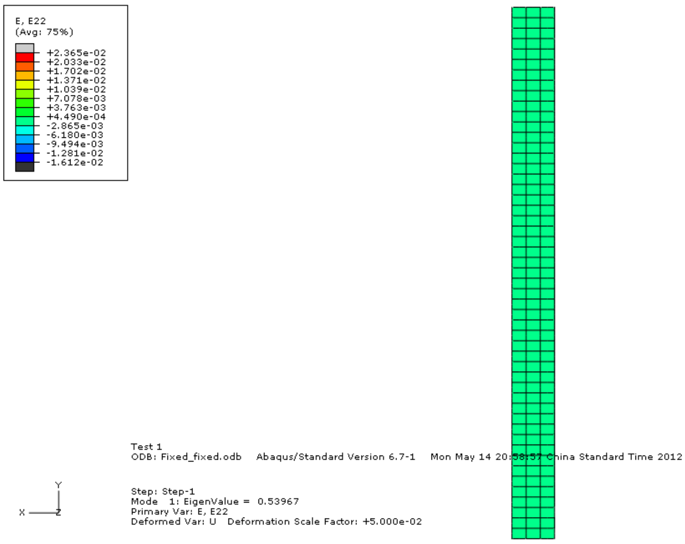


Figure 3.15: Meshing

Load is given to the model by using single step properties because of static condition of simulation and fixed boundaries condition for both ends. By using buckling type of the analysis, the model buckle depend on load apply at the top of the model in ABAQUS as show in Figure 3.15.

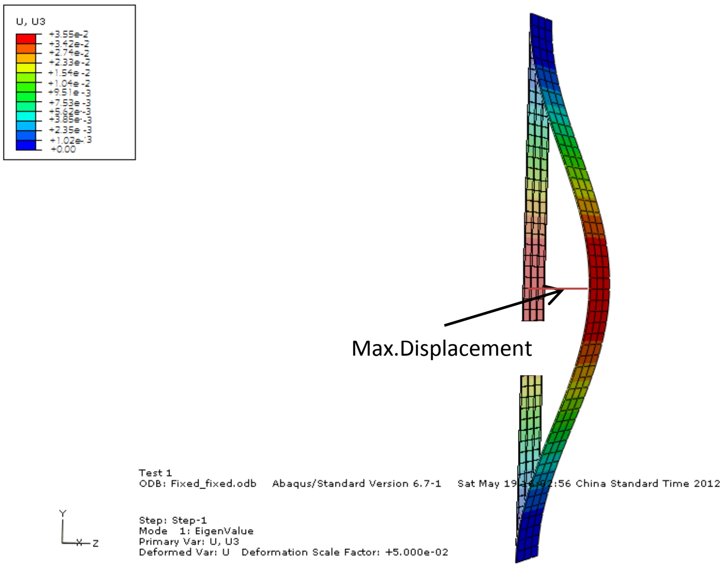


Figure 3.16: Buckle Shape

3.10 Chapter Summary

In this chapter 3, there are been discuss about the flow of fabrication process for the buckling test equipment and the machine used for the fabrication process. There are also discussing about the flow of the project which is starting with come out new design and selection of material. Then, the result from the experimental will be compare with the simulation by using FEA software as the verification for the experimental result.

CHAPTER 4

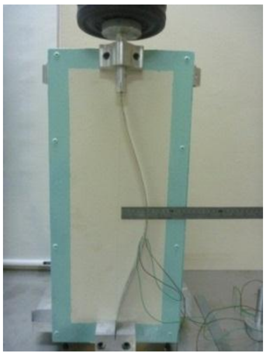
RESULT AND DISCUSSION

4.1 Introduction

Chapter 4 demonstrates the new test rig of strip buckling test which both condition are fixed that had been fabricate and data collected from experimental and by simulation by using software Abaqus version 6.7. The Experimental data collect were plain strain value from the critical point of buckle specimen and the maximum displacement (m) of critical buckle point. The simulation shows the shape of buckle due to every single additional of load and the value of maximum displacement gain from the simulation (m).

4.2 Experimental Result

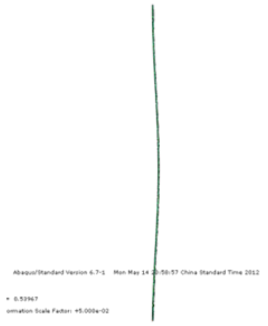
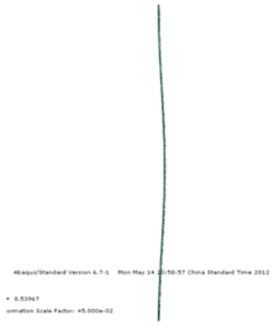
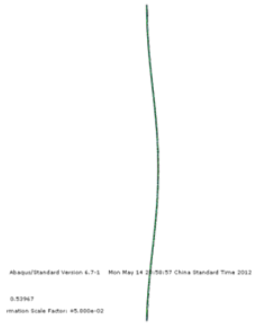
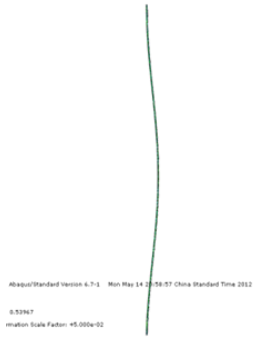
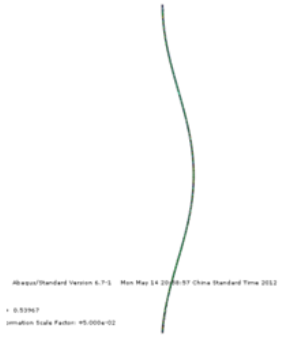
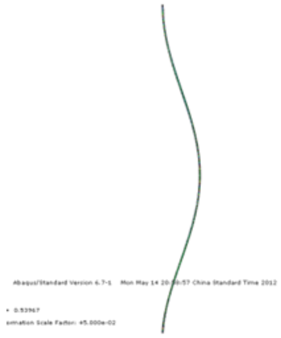
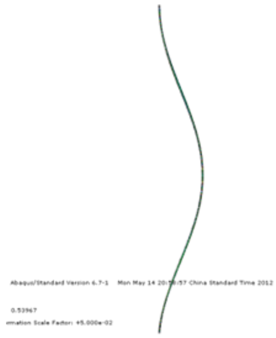
Table 4.1: Physical Shape of Buckle for different Load Apply (Experimental)

1kg	**2kg**	**3kg**	**4kg**
			
5kg	**6kg**	**7kg**	**8kg**
			

During the experiment, the physical appearance of the buckle shape was record for every single load applied besides the value of plain strain and maximum displacement also were recorded. From the Table 4.1, it is show that for every addition of load wills increases the buckle shape of the experiment and this will directly increase the maximum displacement of critical buckle point. Thus, from the experiment, we can identify the buckle shape of the sheet metal during buckling process for both end condition are fixed.

4.3 Abaqus Simulation

Table 4.2: Physical Buckle Shape for Different Load Apply (Simulation)

1 kg	2 kg	3 kg	4 kg
			
5 kg	**6 kg**	**7 kg**	**8 kg**
			

Abaqus version 6.7 show that shape of buckle for the model when load are apply to the model in the software.It is show that the shape of buckle increase due to addition of load given.The buckle shape of the model also had followed the Euler's rule of buckling shape and the shape of buckle shown in Table 4.2.

Table 4.3: Average Strain and Average Displacement (Experimental)

Load(kg)	Average Strain Value	Average Displacement (m)
0.0	-0.000054	0.0000
1.0	-0.000022	0.0012
2.0	0.000021	0.0022
3.0	0.000086	0.0032
4.0	0.000180	0.0045
5.0	0.000354	0.0077
6.0	0.000608	0.0123
7.0	0.000962	0.0196
8.0	0.001914	0.0343

Table 4.4: Comparison Displacement Between Experimental and Simulation

Load(kg)	Experimental Displacement (m)	Simulation Displacement (m)
0.0	0.0000	0.0000
1.0	0.0012	0.0010
2.0	0.0022	0.0025
3.0	0.0032	0.0042
4.0	0.0045	0.0055
5.0	0.0077	0.0083
6.0	0.0123	0.0153
7.0	0.0196	0.0224
8.0	0.0343	0.0355

4.4 Discussion

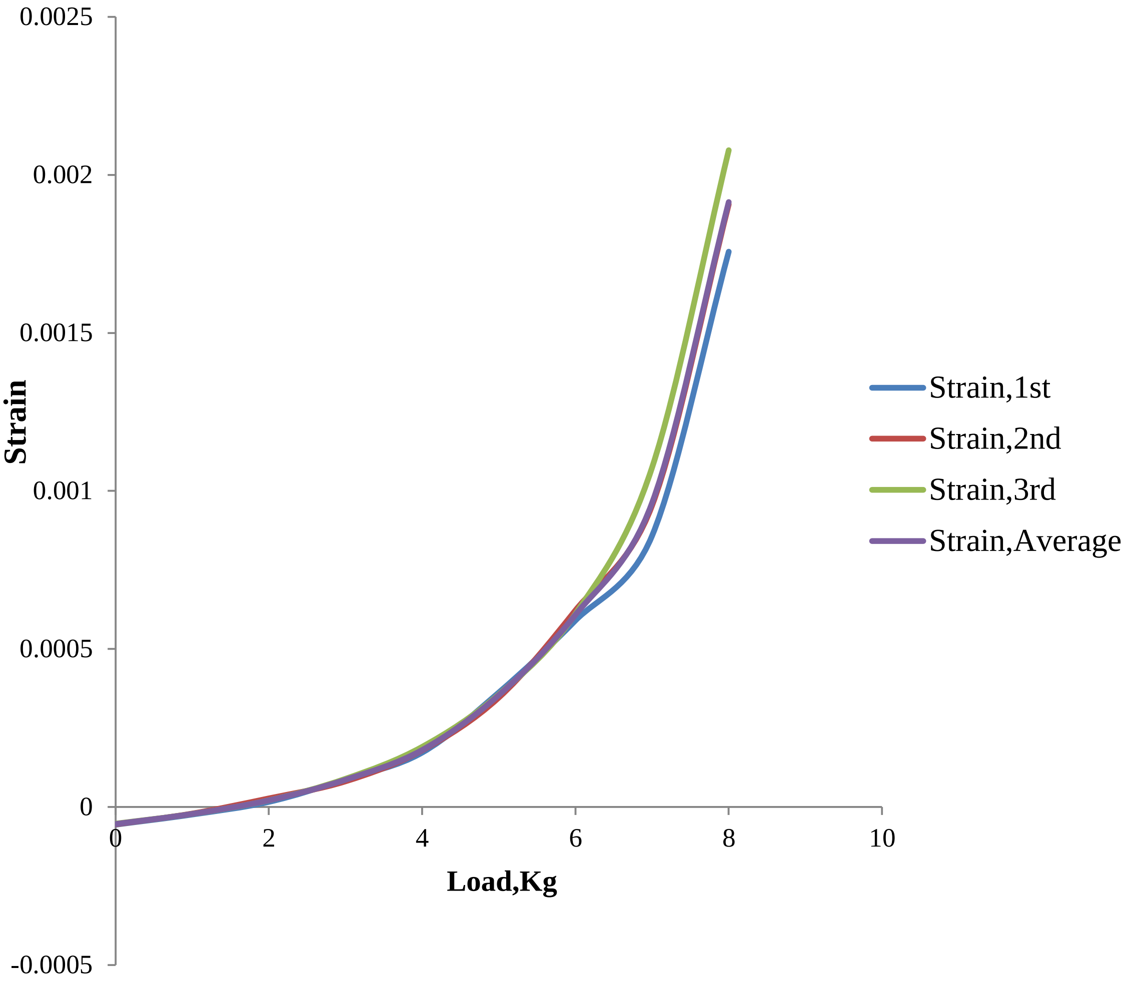


Figure 4.1: Graph of Strain vs. Load

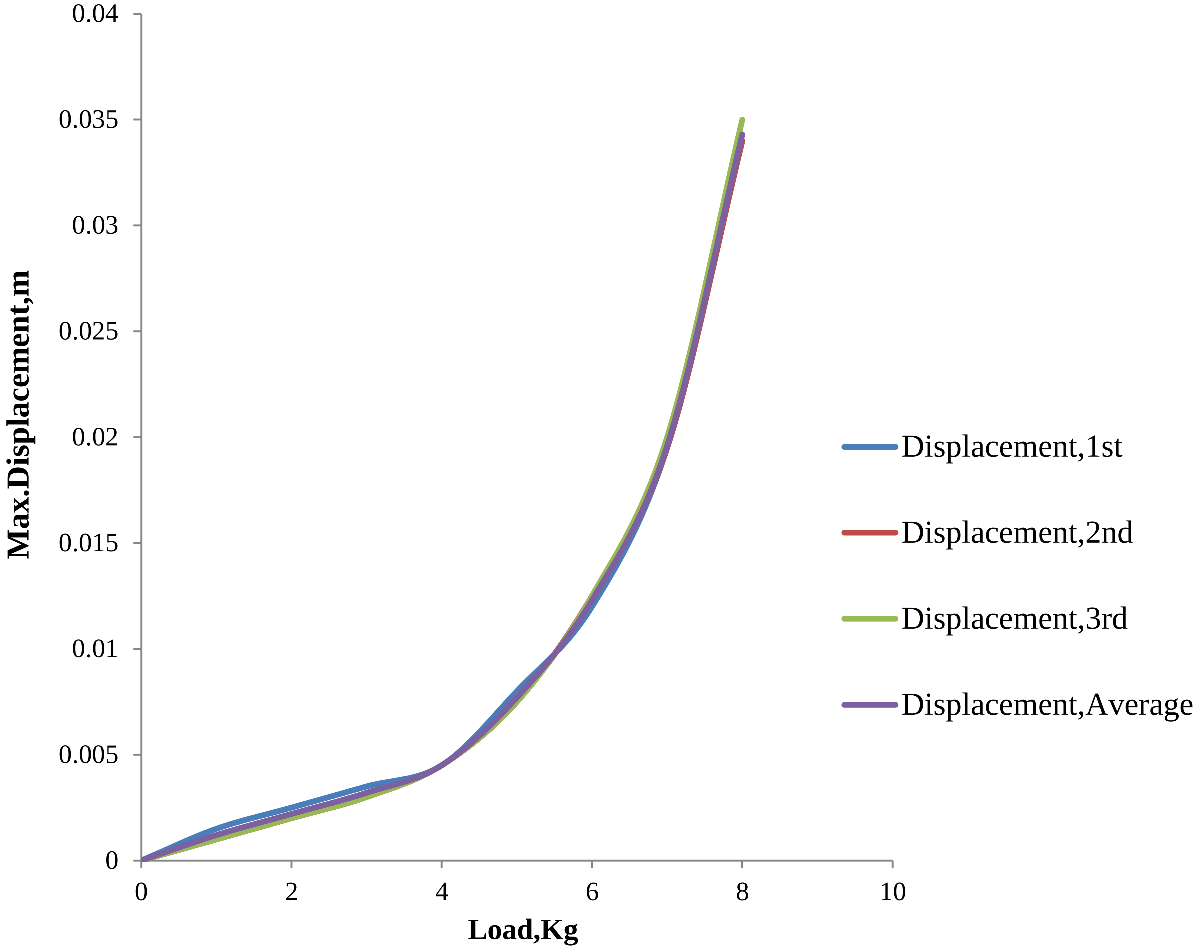


Figure 4.2: Graph of Displacement (m) vs. Load (Kg)

From the graph in Figure 4.1, it is show that the value of strain at the critical point of buckle increase when the addition of load are subjected axial to the sheet metal. This is because of typical deformation. But, at the zero load, the value of strain show negative of value because of the specimen already buckle in small quantity of opposite direction until the first load was given and it is buckle on the right direction and continually to the other addition of load. When the first load until forth load applied, the specimen elongates in proportion to the load in which called linear elastic. At this point, when the load is removed the specimen returns to its origin place and same origin shape. As the load is increase, starting with fifth load to eight loads, the specimen begin to go undergo nonlinear elastic deformation at a stress called the proportional limit. At that point, the stress and strain no longer proportional as they were in the linear elastic region, but they are still return to the origin place and shape when the load is release.

Permanent (plastic) deformation occurs when yield stress,Y of the material is reach. It is also show in Figure 4.2 in which the value of displacement of critical point in buckle also increase when the addition of load. It is also goes nonlinear when the additional load starting with fifth load to eight loads. They are show that the displacement of the critical buckle point increase in large quantity compares to load first to forth load was applied. Thus, this phenomenon occur because of the deformation of the movement particles bond in the specimen almost slip to each other but it is still in elastic condition. Beyond the elastic region, but before fracture occurs, the relationship between stress and strain is no longer linear, with small forces resulting in ever-larger deformations. This region is called the plastic region because within this range, if the force is removed, the structure will not return to its original dimensions. At the upper limit of the plastic region, the structure will fracture.

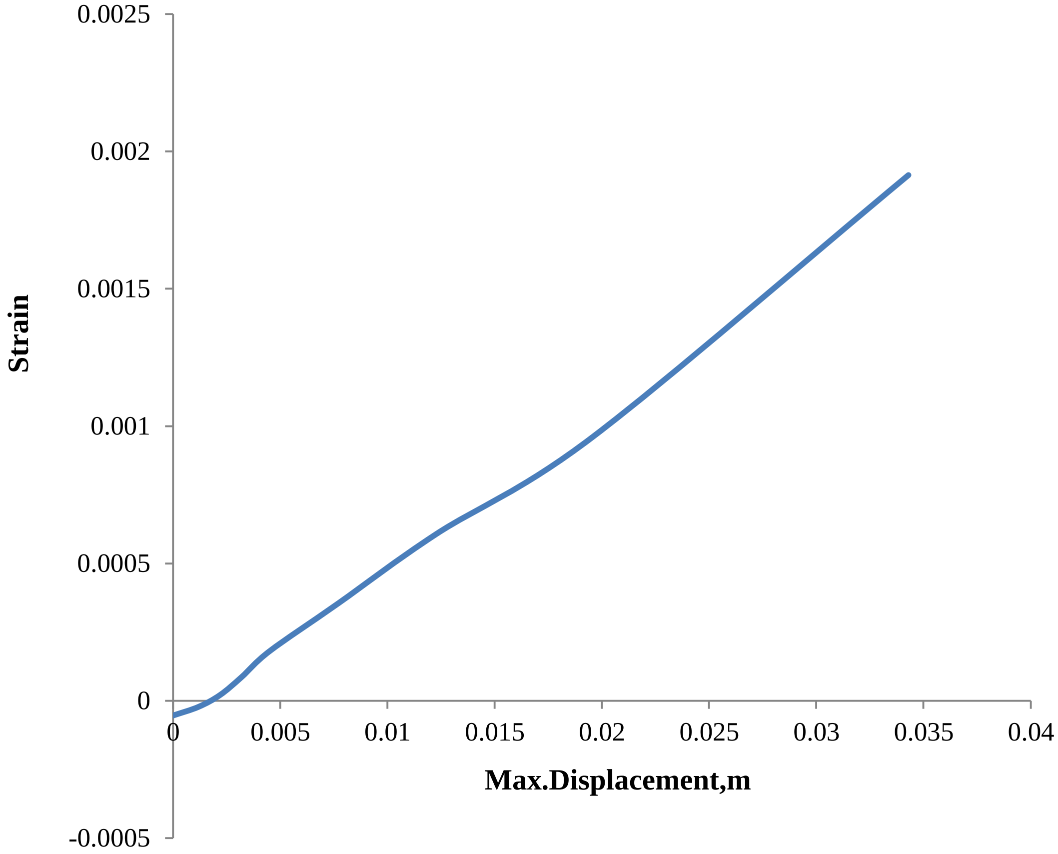


Figure 4.3: Graph Strain vs. Displacement (m)

Figure 4.3 shows that the graph of Strain vs. Displacement,m for every single load applies to the specimen. It is show that the value of displacement for critical point almost directly proportional to the value of Strain when the addition of load was applied. This is because of when a single crystal is subjected to an external force, it is goes elastic deformation process in which the value of specimen length increase (elongation process) at the critical point of buckle. It is also same goes with the distance between the critical buckle points to the origin place. This is mean for every addition of load subjected to the specimen, the buckle shape also increase and thus increases the distance of buckle point from the origin place.

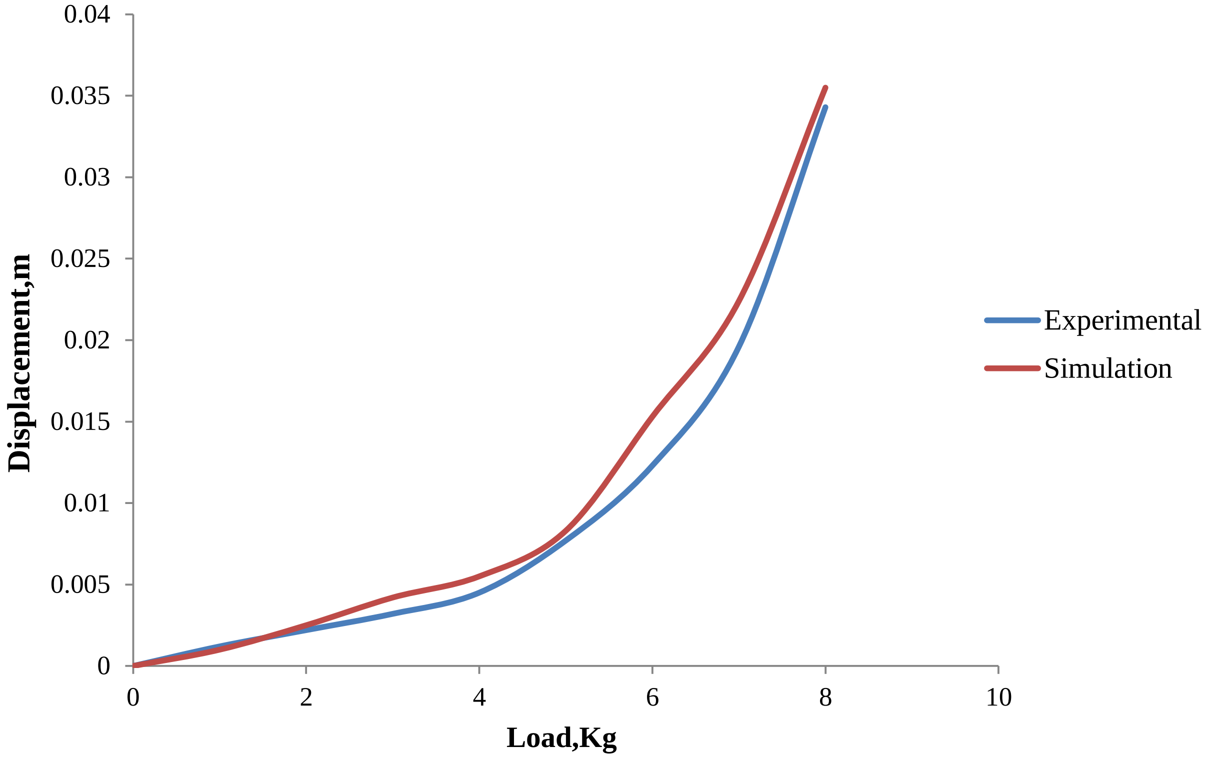


Figure 4.4: Comparison Displacement (m) between Experimental and Simulation

Figure 4.4 shows that the comparison of distance between experimental and simulation by using Abaqus version 6.7 software. The value from experimental and simulation are not similar because of the some error during experimental. For every single load apply, the value of displacement for experimental and simulation give a different value. The highest percentage between experimental and simulation were 24%

at the point of 3kg and the lowest percentage is 3.4% at the point of 8kg load are apply. Thus, from this comparison, it is already show that the experimental value are lower than simulation, this because of some error during the experimental data was recorded. The most possible problem is because of friction between test equipment when the experiment is running.

4.5 Deformation

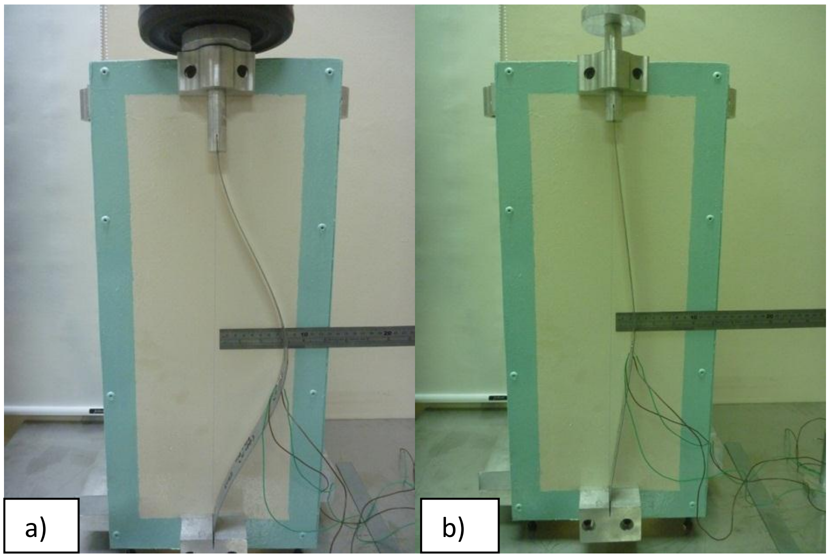


Figure 4.5: Deformation of Specimen (Galvanize Mild Steel)
a) 9kg Load Apply, b) Load release

Figure 4.5 (a) show the shape of buckle for the specimen when load 9kg are applied meanwhile Figure 4.5 (b) show the shape of deformation for specimen when load is release from the action to the specimen. In this case, if the load on the crystal structure is increase sufficiently, the crystal undergo plastic deformation or permanent deformation which mean it is does not return to the origin shape when force is removed.

CHAPTER 5

CONCLUSION

5.1 Introduction

Chapter 5 summarizes all the main research points of this dissertation. It concludes that all the important information and observation from the research recommendation for the future research is also included.

5.2 Conclusion

The study on design and fabrication for new test equipment for buckling test which both condition are fixed already give result on buckling test process that had been done on 1mm thickness of galvanize mild steel sheet metal strip. The physical shape of buckle already follow the Euler’s rule buckling shape and the critical load of the experimental give the value of 80 N. Every addition of single load apply onto specimen give the addition of buckle shape, beside the value of strain on the surface of specimen also increase. Thus, the value of maximum displacement for buckle point on the specimen also increase due to increases of addition load applies .In addition, it is can be say that for every addition of force given, give the increases of surface strain value and maximum displacement on buckle point of the specimen until it is reach the Yield’s Strength point. Furthermore, by using Abaqus software, it is give the comparison of the displacement value from the experimental and simulation. The highest percentage of differences between displacements values are 24%.Small error for measure force, strain and displacement are expected due to material deformation during the experiment. Finally, this study successfully determines good agreement between experimental and numerical.

5.3 Recommendation

From this study, there are some part on the test equipment can be modified so that the buckling test can be done effectively. The upper holder can be modified by add ball bearing to reduce friction between the surface of load shaft and the upper holder. Wall of the test equipment also can be change to aluminum so that the test equipment not too heavy and it is can be more portable. There are some other modifications on material selection so that the test equipment can be more efficient on running the experiment. Beside, for simulation, other setup can be done for gain other value based on experiment that had been done.

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APPENDIX A1

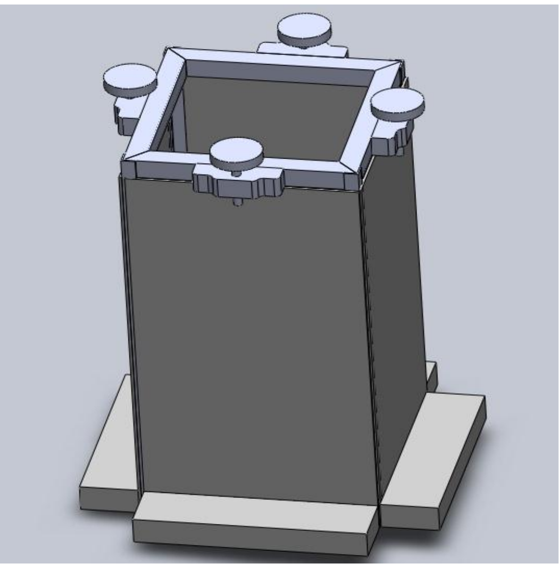

Figure A1: 3D Design of Test Equipment**.**

APPENDIX B1

Table B1: Experiment data for Strain Value

Load (kg)	Strain(1st reading)	Strain (2nd reading)	Strain (3rd reading)	Average
0.0	-0.000056	-0.000055	-0.000053	0.000054
1.0	-0.000024	-0.000021	-0.000022	0.000022
2.0	0.000016	0.000027	0.000021	0.000021
3.0	0.000087	0.000081	0.000089	0.000086
4.0	0.000172	0.000179	0.000190	0.000180
5.0	0.000362	0.000346	0.000356	0.000354
6.0	0.000590	0.000622	0.000611	0.000608
7.0	0.000858	0.000954	0.001074	0.000962
8.0	0.001757	0.001907	0.002078	0.001914

APPENDIX B2

Table B2: Experiment data for Displacement,m

Load (kg)	Displacement, m (1st reading)	Displacement, m (2nd reading)	Displacement, m (3rd reading)	Average
0.0	0.0000	0.0000	0.0000	0.0000
1.0	0.0015	0.0010	0.0010	0.0012
2.0	0.0025	0.0020	0.0020	0.0022
3.0	0.0035	0.0030	0.0030	0.0032
4.0	0.0045	0.0045	0.0045	0.0045
5.0	0.0080	0.0075	0.0075	0.0077
6.0	0.0120	0.0125	0.0125	0.0123
7.0	0.0195	0.0195	0.0200	0.0196
8.0	0.0340	0.0340	0.0350	0.0343

APPENDIX B3

Table B3: Experiment data for Average Strain and Average Displacement,m

Load(kg)	Average Strain Value	Average Displacement (m)
0.0	-0.000054	0.0000
1.0	-0.000022	0.0012
2.0	0.000021	0.0022
3.0	0.000086	0.0032
4.0	0.000180	0.0045
5.0	0.000354	0.0077
6.0	0.000608	0.0123
7.0	0.000962	0.0196
8.0	0.001914	0.0343

APPENDIX C1

Table C1: Simulation (ABAQUS) data for Displacement,m.

Load (kg)	Displacement (m)
0.0	0.0000
1.0	0.0010
2.0	0.0025
3.0	0.0042
4.0	0.0052
5.0	0.0083
6.0	0.0169
7.0	0.0224
8.0	0.0355

APPENDIX D1

Table D1: Comparison Displacement,m between Experiment and Simulation

Load(kg)	Experimental Displacement (m)	Simulation Displacement (m)
0.0	0.0000	0.0000
1.0	0.0012	0.0010
2.0	0.0022	0.0025
3.0	0.0032	0.0042
4.0	0.0045	0.0055
5.0	0.0077	0.0083
6.0	0.0123	0.0153
7.0	0.0196	0.0224
8.0	0.0343	0.0355