AXIAL LOAD OF BUILT-UP C-SECTION COLD-FORMED STEEL WITH AN OPENING

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DIPLOMA IN CIVIL ENGINEERING

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ABSTRAK

Keluli bentuk sejuk (CFS) dibina daripada keluli kepingan berkualiti struktur yang telah dibentuk melalui beberapa acuan ke dalam bahagian C dan bentuk lain. Nama "keluli bentuk sejuk" merujuk kepada fakta bahawa tiada haba digunakan untuk menghasilkan bentuk (tidak seperti keluli tergelek panas). Untuk pelbagai tujuan struktur dan bukan struktur, ketebalan keluli yang berbeza ditawarkan. Mengikut penggunaan dan tujuannya dalam projek pembinaan, keluli berbentuk sejuk boleh didapati dalam pelbagai jenis bahagian. Bahagian terbuka tunggal, bahagian binaan terbuka dan bahagian binaan tertutup ialah tiga jenis bahagian utama. Kajian ini akan memberi tumpuan kepada bahagian C terbina terbuka. Tebukan biasanya dilihat pada anggota struktur yang diperbuat daripada keluli yang dibentuk sejuk. Keluli berbentuk sejuk diberi tebukan, yang merupakan lubang atau bukaan, untuk memudahkan operasi pembinaan. Bergantung pada tujuannya, ia biasanya ditawarkan dalam pelbagai saiz dan bentuk untuk menampung perkhidmatan paip, elektrik dan penyaman udara atau pemanasan. Namun begitu, bergantung pada peletakan, saiz dan orientasi bukaan, kewujudan perforasi boleh mengakibatkan penurunan kekuatan kedua-dua kekuatan keseluruhan ahli dan bahagian komponen individunya. Kajian ini akan melibatkan satu jenis bukaan berdiameter 20mm yang akan dibuat pada spesimen dan akan menumpukan kesan kewujudan bukaan dan kelakuan bentuk lekuk spesimen. Untuk mengkaji kesan bukaan ke atas kapasiti beban anggota lajur bahagian C terbina, pemeriksaan eksperimen keluli terbentuk sejuk yang terdedah kepada beban mampatan diadakan. Dalam eksperimen ini, sejumlah 2 keadaan berbeza yang mempunyai 3 sampel bagi setiap keadaan dengan kewujudan bukaan telah dinilai. Setiap anggota telah dimampatkan dan mempunyai ketebalan nominal 0.8 mm, panjang lajur 600 mm dan diameter bukaan 20mm digunakan untuk ujian ini. Hasil eksperimen ini adalah untuk melihat perbandingan dari segi kekuatan muktamad dan gelagat bentuk lengkok antara bahagian C terbina dengan bukaan dan juga tanpa bukaan.

ABSTRACT

Cold-formed steel (CFS) members are constructed from structural quality sheet steel that has been roll-formed through a number of dies into C-sections and other shapes. The name "cold-formed steel" refers to the fact that no heat is used to produce the shapes (unlike hot-rolled steel). For a wide range of structural and non-structural purposes, different steel thicknesses are offered. According to their use and purpose in construction projects, cold-formed steel is available in a variety of section types. Single open sections, open built-up sections, and closed built-up sections are the three primary types of sections. This study will focus on open built-up C-sections. Perforations are typically seen in structural members made of cold-formed steel. Cold-formed steel is given perforations, which are holes or openings, to facilitate construction operations. Depending on its purpose, it is typically offered in a variety of sizes and shapes to accommodate plumbing, electrical, and air conditioning or heating services. Nevertheless, depending on the placement, size, and orientation of the opening, the existence of perforations may result in a drop in the strength of both the member's overall strength and its individual component parts. This study will involve one type of 20mm diameter opening that will be made on the specimen and will concentrate on the impact of the existence of an opening and the buckling shape behavior of the specimen. To examine the impact of an opening on the load capacity of column members of built-up C-section, an experimental examination of cold-formed steel exposed to compression loading is being held. In this experiment, a total of 2 different conditions which have 3 samples for each condition with the existence of an opening were evaluated. Each member was compressed and has a nominal thickness of 0.8 mm, a column length of 600 mm also 20 mm diameter of an opening is being used for this test. The outcome of this experiment is to see the comparison in terms of ultimate strength and buckling shape behavior between built-up C-section with an opening and also without an opening.

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LIST OF ABBREVIATIONS

CFS	Cold-Formed Steel
UTM	Universal Testing Machine
SDG	Sustainable Development Goal
FKASA	Faculty of Civil Engineering & Earth Resources
UTS	Ultimate tensile strength

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Cold-formed steel (CFS) are steel structural product that are made from structural quality sheet steel that are formed such as into C-sections and other shapes. It made by bending the flat sheet at ambient temperature into shapes. Except for hot-rolled steel, no heat is used to make this kind of shapes. Currently, there are three methods involved in production of cold-formed steel which are folding, press-barking and roll forming. To accommodate a wide range of structural and non-structural uses, various steel thicknesses are offered. This method also allow it to have diversity in shapes, sizes and application. Cold-formed steel also can be produced in various shape and section such as single open section, open built-up section and closed-built-up section. Besides, cold-formed steel offers various benefits as a construction material. For instance, cold-formed steel is resistant to warping, termites, fire also won't shrink or split and will not absorb moisture. This is a sturdy, reliable building material that is frequently utilised in the foundation and frame of contemporary structures, including residences. Cold-formed steel have been produced at room temperature and has a different chemical makeup from some other shaped metals, which gives it valuable properties including strength, durability, and lightness. These characteristics are what make cold-formed steel stud framing such an excellent choice for many modern construction feats.

As was said before, cold-formed steel, also known as light gauge metal, is essential for modern building projects that call for the highest levels of safety and strength. Cold-formed steel is used to create the glossy parts you frequently see incorporated into the framework of modern homes and structures. These construction projects' structural framework is made of this steel. For instance, cold-formed steel is increasingly used in place of outdated hardwood construction techniques for home skeletons, particularly in regions where wood rots or becomes termite-infested quickly. Columns, decking, roofing, load-bearing support, and numerous more uses are also possible.

However, this research will focus on the effect of the existence of an opening on built-up C-section. So additionally, built-up C-section cold-formed steel is a combination of two steels that made into one specimen. It is connected using bolts. In this project, back-to-back connected built-up c- section is used in order to get a symmetrical shape open section.

Besides, cold-formed steel structural elements with opening usually used for heating, electrical and plumbing which frequently seen in building walls. These opening usually found in the web of a few sections might change a structural member's ultimate strength and elastic stiffness.

Figure 1.1 Example building made up from the CFS

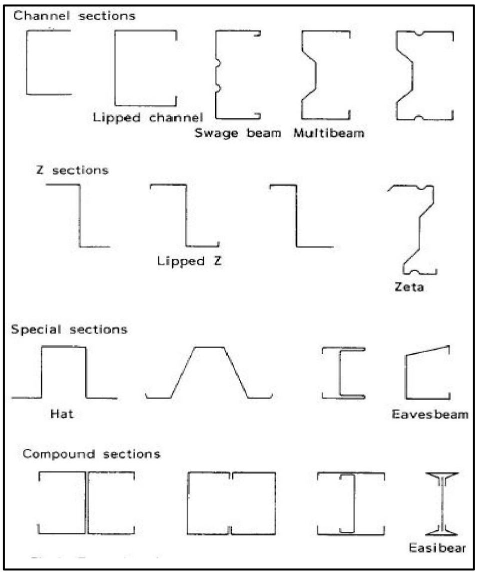

Figure 1.2 Diversity shapes for CFS

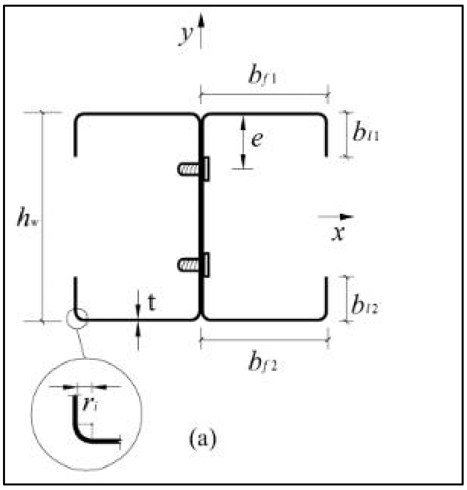

Figure 1.3 Build-up CFS C-section

1.2 Problem Statement

For the purpose of easing construction work, cold-formed steel members are frequently equipped with an opening of various sizes and shapes to accommodate pipelines, electricity, and heating in walls and building ceilings. However, these opening may affect the ultimate strength and elastic stiffness of the structural member. So, depending on where the opening are on the cold-formed steel, the size of diameter and shape of the opening, the ultimate strength and elastic stiffness can be vary.

1.3 Objectives

The main aim of this research is to study the condition of build-up C-section cold formed steel under compression. In order to achieve this, several objectives are identified as follows:

i. To determine the compressive strength of the built-up C- section with an opening under axial loading.

ii. To study the buckling behaviour of built-up C-section with an opening.

1.4 Scope of Study

The scope of these research covers on the compression test for axially loaded built-up C-section cold-formed steel with an opening. All of the experiment will be done at the laboratory. The scope are:

i. Existence of an opening

ii. The back-to-back section of the cold-formed steel

1.5 Significant of study

The finding of this study will contribute to the benefit of the construction industry. The behaviour of cold-formed steel when the opening exist can be studied. For this research, compression test will be conducted on multiple samples to determine the ultimate load of axially loaded built-up cold-formed steel column with an opening. These sample is different in terms of its condition where there are samples with an opening also samples without an opening. Both of these sample conditions use the same length. The cold-formed steel that are going to be used in this experiment is a back-to-back cold-formed steel section.

By conducting this experiment, parameters such as ultimate strength can be determined. A better understanding towards the failure and buckling behaviour can also be gain by conducting the experiment. The buckling behavior may be different due to the existence of openings at the specimen.

1.5.1 Sustainable Development Goal (SDG) No.11

Sustainable Development Goal (SDG) No.11 which is about Sustainable cities and communities. Goal 11 is about making cities and human settlements inclusive, safe, resilient and sustainable. Today, more than half the world's population live in cities.

Concern for sustainable development is not a recent issue. Its concept arose in 1972 as part of the United Nations Conference (Stockholm) (Mata-Lima et al., 2016). The term sustainable development was defined in the document resulting from the Brundtland Commission, entitled Our common future ("Our common future," 1987), as the capacity of humanity to develop, ensuring present needs, without compromising the ability of future generations to meet their own needs. So, technology and society must progress together to economic development, without harming the environment. Thus, the three elements forming the pillars of sustainability (or sustainability tripod) are environment, economy, and human development. Sustainable development is only achieved if the three criteria are met and are in balance (Daly, 1991).

Few research about how cold-formed steel relates with SDG has been made by other researcher. So. to relate with this research, the use of cold-formed steel has been widely used due to the rise of modern times. This CFS also has been proposed as a solution for vertical addition of some studied buildings. From the analysis obtained, the result has provided cold-formed steel system as dominant solution for improving the energetic behaviour of the buildings (G. Terracciano, G. Di Lorenzo, A. Formisano & R. Landolfo, 2015). An innovative solution combining the use of light materials with structural typologies distributing vertical loads uniformly on all the masonry walls is represented by the use of this CFS (Calderoni, De Martino, Formisano, & Di Lorenzo, 2002). To meet these SDG requirements, CFS can be manufactured continuously. Whether with or without perforations, it is depends on the function of each CFS that will be used. Although the existence of perforation will reduce the strength of CFS, it provides benefits in another way, which is to facilitate installation such as wiring at certain area. For instance, the used of CFS also helps to keep the structure last longer compared to structured that use material such as timber. Since SDG No.11 is about resilience and sustainability, it shows that the use of CFS structures requires less maintenance than structures that use wood, where structures that use wood require more detailed care and more often to avoid the growth of insects that can affect the durability of the structure. So, to avoid this kind of thing, the use of CFS needs to be increased and developed day by day.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Modern living encompasses a wide range of cold-formed steel goods. There are numerous and different uses for these items. Cold-formed steel (CFS) structures are made up of structural sections that are folded at ambient temperature without being heated. The usual manufacturing method is roll forming, which is when coil steel is passed through a number of rollers until it attains the desired shape. Cold-formed steel also one of the two types of steel sections that currently utilised in building construction.

Different shapes and sections can be made utilising cold forming work to meet the requirements of the construction process. Cold-formed steel can be categorised into three primary groups based on its shape and cross section which are single open section, open built-up section, and closed built-up section. Traditionally, simple C-channels (Cs), zeds (Zs), and hat sections have been utilised primarily in roof and wall systems, steel storage racks, steel-framed houses (residential), and numerous other secondary applications of a same nature. However, for this research, the experiment will be conducted on built-up open section or also known as I-section with an opening.

Additionally, cold-formed steel sections are frequently used in bridges, storage racks, grain bins, automobile bodies, railroad coaches, highway products, transmission towers, transmission poles, drainage facilities, weapons, various pieces of equipment, and other items. These kinds of sections are cold-formed using roll forming equipment from steel sheet, strip, plate, or flat bar using a press brake, also known as a machine press, or by performing bending operations. Such thin-walled steel members' material thicknesses typically range from around 6.35 mm to 0.373 mm. In Malaysia, the application of this cold-formed steel is still limited due to the limitation of the specimen compared to other developing country since it is only used for roof and trusses also purlin.

2.2 Method of Manufacturing

Although there are many ways to make cold-formed steel, the three basic ways are folding, press-barking, and cold rolling. The term cold forming can also be used to describe this manufacturing process. Cold forming is a term used to describe the manufacture of products by forming materials from strips or sheets of uniform thickness. Cold-formed steel members are manufactured by one of the three processes that are roll forming, folding and press braking (Zhao, 2005).

2.2.1 Folding

The simplest cold-forming technique is the folding technique. Series of bends (folds) of material sheets were used during manufacture. This technique allows for the production of a small length of cold-formed steel with an easy geometry. The limitations of its design and application, however, prevent this technology from being widely employed. According to Chen and Liew (2003), this method has a relatively limited use in the building sectors.

2.2.2 Press-Barking

Cold-formed steel is frequently manufactured by press-barking. A length of strip is pressed between shaped dies to create the profile shape of the cold-formed steel. When compared to folding, press-barking offers a wider range of cross-sectional. This technique results in distinct bends for every bend

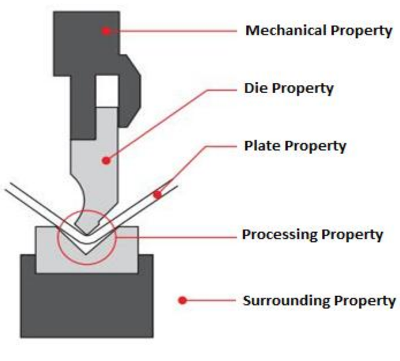

Figure 2.1 Press-barking process.

2.2.3 Cold-Rolling

The primary technique used to produce cold-formed steel is cold-rolling. It has a high manufacturing capacity, making it a more cost-effective option. With this technique, the strip material is shaped into the desired profile shape and then run through one or more pairs of rolls to thin it out and even out the thickness. These rolls bring the form of strip progressively closer to the final profile shape.

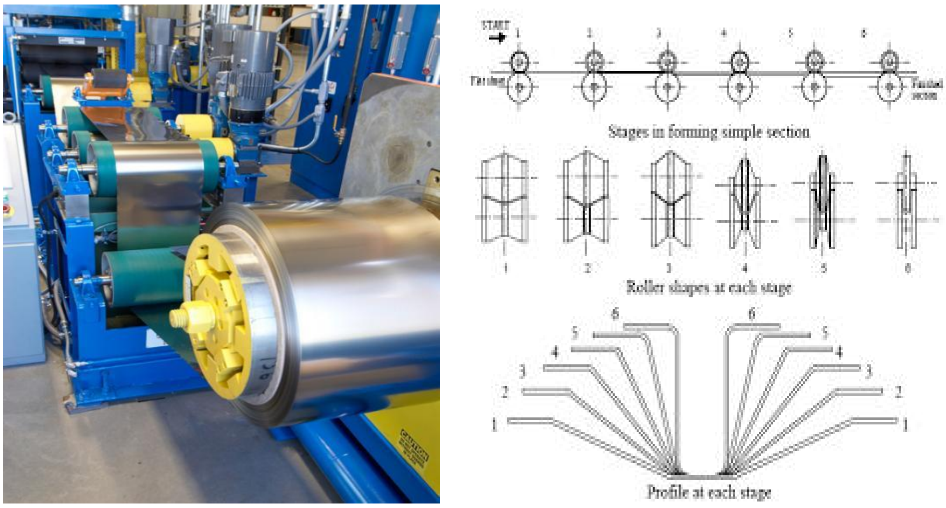

Figure 2.2 Roll forming machine and stages of roll forming

2.3 Advantages of Cold-Formed Steel

In comparison to other building materials like hot-rolled steel, timber, and conventional reinforced concrete, cold-formed steel has a number of advantages. All of these benefits contribute to cold-formed steel's solid reputation in the construction industry.

2.3.1 Strength

CFS is around 20% stronger than hot-rolled steel according to ScienceDirect. The strain hardening that takes place as the rollers compress is largely responsible for the strength of cold-formed steel. Cold rolled steel is resistant to rot, mould, mildew, and damage from insects, termites, and vermin due to the high pressure under which it is created. This resilience is what makes cold-formed steel such a great material for building. Cold-formed steel doesn't crack or shrink, and it doesn't swell or shrink in response to moisture content. Steel studs don't bend, twist, or bow either. A study by the

NAHB that found that the zinc coating on steel frame materials may guard against corrosion for hundreds of years when combined with its inherent toughness makes for one exceptionally solid construction.

2.3.2 Sustainability

There is at least 25% recycled material in every piece of cold-formed steel. 67% of recycled material is average for steel frame. In other words, it is entirely recyclable. The size and framing are precise using cold-formed steel as well. Due to the total recycling of the refuse, this regularity in manufacturing reduces waste. Unexpectedly, cold-formed steel is good for the environment and for people who have allergies or asthma. No volatile organic compounds are released by cold-formed steel, which means that everyone will have less respiratory irritation as a result of less air pollution.

2.3.3 Simplicity

Cold-formed steel also offers benefits to the construction process itself. Steel that has been cold-formed is lightweight and simple to handle. In addition, cold-formed steel products are roll-formed into the precise sizes and shapes needed, and each piece is labeled precisely, making assembly quick and easy. For example, cold-formed steel is perfect for trusses and panels since it is lightweight and has consistent manufacturing standards. Cold-formed steel panels that have perforations which make it possible to run electrical cables, connect plumbing, and install mechanical equipment quickly, steel framing even cuts down on construction time.

2.3.4 Suitability and Durability

In commercial construction, col-formed steel already predominates the market for internal, non-load bearing partition walls. Cold-formed steel, however, is now suited for a wide range of structural applications, including low to mid-rise construction, multi-unit structures, residential dwellings, and etc. For durability, few building materials can match the lifespan of cold-formed steel due to its durability, which includes its resistance to corrosion, mould, and vermin. The fact that cold-formed steel (CFS) framing is immune to environmental conditions that often jeopardise the stability, longevity, and integrity of other framing materials is one of its key material benefits.

2.3.5 High Strength and Stiffness

Sections made of cold-formed steel (CFS) are made of light materials. In comparison to other building materials, it also boasts the best strength-to-weight ratio. The cold-formed steel will then be shaped, press-barked, or folded, increasing the structure's overall strength. The thinness of the material gives a huge advantage on cold-formed steel over hot-rolled steel as it has a higher strength-to-weight ratio (Kulatunga et al., 2014). Because of cold-formed steel having a high strength and stiffness, it gives more diversity and flexibility in design while allowing design in longer spans with better material usage. Various section configurations can also be produced economically by both folding and press barking, resulting in the favourable strength-to-weight ratio (Yu, 2000; Wang et al., 2016).

2.3.6 Versatility of Shape and Design

Cold-formed steel has variety of section design and this may ease the designing process of a project. The versatility of the cross-sectional and section design gives the architect more flexibility in deciding the end design of a structure. Besides, the unusual sectional configuration can be produced economically (Rondal, 2000). Any desirable cross-sectional shape can be produced by cold rolling, such as Z-section, T-section hat section and angle section (Mahmood, 2007 ; Zhang and Young, 2012 ; Kulatunga et al., 2014).

2.3.7 Non-Combustibility of Material

Cold-formed steel is one of the most resilient building materials available since it is non-combustible, resilient to harsh weather and seismic stresses, blast threats, and ballistic penetration. It will not contribute to the spread or intensity of a fire unlike certain construction material. As a result, the design of cold-formed steel project can easily meet the code of fire resistance requirements.

2.3.8 Cost Effectiveness

Utilizing cold-formed steel is cost-effective from the beginning of production, through transportation and material use, through the completion of the construction process. Cold-formed steel can be produced more cheaply than hot-rolled steel since the manufacturing process is simpler. The cost of the materials used in cold-formed steel is very reasonable. Cold-formed steel required less material to attain a given strength and stiffness than hot-rolled steel. This is agreed by Schafer that described that the usage of material for a given strength and stiffness requirement is appeared to be much less than hot-rolled section. Steel farming systems are conducive to prefabrication at or away from the job site (Schafer, 2008).

2.4 Material and Mechanical Properties

The cold-formed steel strength can be further explained through material and mechanical properties. In the structural viewpoint, the most important steel properties should be described at its yield point and its strength, tensile strength, relationship stress relationships, modulus of elasticity and ductility.

2.5 Buckling Behaviour

The amount of compression loading that can be applied to cold-formed steel structural members is frequently constrained by the possibility of failure. However material-efficient cold-formed steel is, it is strongly anticipated that it will fail in one of several buckling modes. Slandering the members increases the problems brought on by cold-formed steel's properties. These should be considered in the design of a cold-formed steel structural member.

There are three main buckling mode that are common in cold-formed steel which are local buckling, torsional buckling and flexural-torsional buckling. There seems to be a consensus on these classifications of buckling modes but there is no consensus on the exact meaning of the models (Chen et al., 2016).

2.5.1 Local Buckling

Local buckling is the simplest buckling behaviour in cold-formed steel failure mode. When a thin plate is loaded in compression, there is a considerable possibility that local buckling may ensue. The plate elements of cold-formed sections are normally thin higher plate slenderness ratio and hence they buckle locally before yield stress is reached. Local buckling mode of a given thin-walled member depends on its cross section geometry which is shape and dimensions and also the support conditions (Kwon

& Seo, 2012). While, Hancock (2003) explains that local buckling is a mode involving plate flexure alone without transverse deformation of the lines of intersection of adjoining plates.

Local buckling of this cold-formed steel is caused by a number of factors, including the slenderness ratio of the column, the mechanical properties of cold-formed steel, the effect of cold forming, the effect of imperfections, the forms of the cross sections, and many more. This causes cold-formed steel compression members to locally buckle before the applied load reaches the column's total collapse load. Additionally, the total column strength has a significant impact on the interaction between local and overall column buckling.

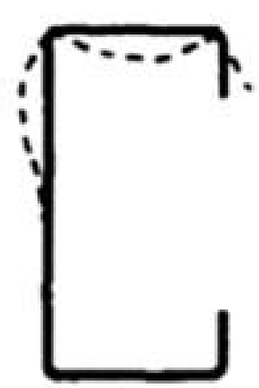

Figure 2.3 Example of local Buckling

2.5.2 Distortional Buckling

Distortional buckling is known as 'stiffener buckling' or 'local-torsional buckling' and its mode are characterized by rotation of the flange at the flange or web junction in members with edge stiffened element. In members with intermediately stiffened elements distortional buckling is characterized by displacement of the intermediate stiffener normal to the plane of the element (Sadovskýa et al., 2012). The wavelength of distortional buckling lies between local buckling and global buckling which place it in the practical range of member length. When pointed out that distortional buckling generally encourages failure more quickly than local buckling (Pedro et al., 2012).

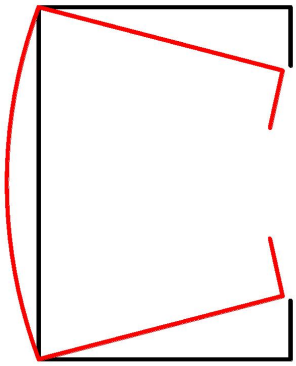

Figure 2.4 Example of distortional buckling

2.5.3 Flexural-Torsional Buckling

Flexural-torsional buckling is a mode of buckling in which long compression members bend and twist simultaneously. It usually occurs in long member that are loaded in compression and failure occur due to overall buckling. The cross-section that is familiar to flexural-torsional buckling is closed shape doubly symmetric, point symmetric or cylindrical shape. When an open column section buckles in flexuraltorsional mode, bending and twisting will occur simultaneously as seen in figure below (Kulatunga & Macdonald, 2013).

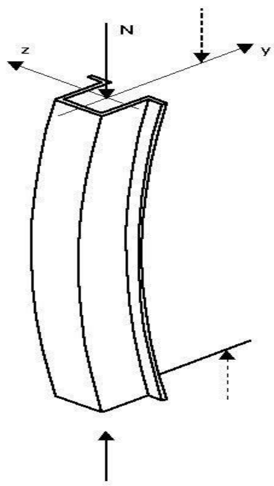

Figure 2.5 Example of flexural-Torsional Buckling

2.6 Built-up Section

Built-up section is also known as I-section. It is a combination of two single open sections that are being connected, usually by welding, and forming and I section. It is usually made by welding two channels back-to-back or by welding to angles to a channel. In this research paper, the test will be conducted on I-section. The compression members composed of two or more shapes in contact or separated from one another shall be interconnected in such a way that the slenderness ratio of any component, based on its least radius of gyration and the distance between interconnections, shall not exceed that of the built-up member (Liu et al., 2009).

2.7 Perforations

A perforation is a hole or opening that is made on the cold-formed steel to ease construction work. As seen on Figure, it usually provided with different shapes and size based on its function such as to accommodate electrical, plumbing and air conditioner or heating services. The function of perforations is to facilitate various services in building construction.

The presence of perforations may cause a reduction in strength of individual component elements and the overall strength of the member depending on the position, size and orientation of the opening. Exact analysis and design of steel with perforations elements is complex especially with unusual arrangements and shapes. Perforations on cold-formed steel are a major concern especially on a thin-walled structural member and the critical buckling loads for perforated plates and members have been studied by numerous investigators (Crisan et al., 2012).

This research will focus on the effect of the existence of an opening on the structural strength of the axially loaded cold-formed steel column.

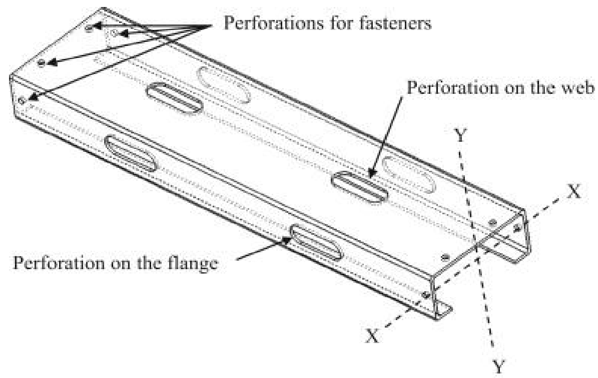

Figure 2.6 Example perforations on cold-formed steel

2.8 Previous Research

Previous researches that have been made by multiple researchers from around the globe have been referred to in completing this research. The reason of doing so was to strengthen the arguments and ensuring the quality in the outcome this research.

2.8.1 Behaviour of Cold-Formed Steel Built-Up I-Section

This research was done by T.A. Stone and R.A. LaBoube in 2005 and it was done to study the behaviour of built-up cold-formed steel studs. This research has used North American Specification for the Design of ColdFormed Steel Structural Members as their reference and the researcher also intended to determine if the AISI design methodology is valid for cold-formed steel members. This experimental study was performed at University of Missouri-Rolla concentrating on the behaviour of built-up compression members, specifically I-sections. The specimens tested in this investigation were constructed of C-shaped sections oriented back-to-back with edge stiffened flanges and track sections and the lengths of each specimens is 178mm and it is tested using universal testing machine. Pin connection was used at the top and bottom of the stud (Stone & LaBoube, 2005).

2.8.2 Design Of Built-Up Cold-Formed Steel Columns According To The Direct Strength Method

This research is describe about the normal force capacity of columns with built-up cross-section shapes from CFS profiles is evaluated according to the direct strength method. Linear buckling analysis solutions from the finite strip method software

CUFSM are used to derive the critical loads in local, distortional and overall buckling. The good agreement with experimentally obtained normal capacities suggests that a similar design methodology can be adopted in structural standards for built-up CFS columns. Despite many uncertainties with such members various buckling effects, initial imperfections, residual stresses and unknown material properties, the columns sustained substantially increased loads and showed a repeatable response with scatter in the ultimate resistance between identical specimens lower than 4.5 %, which is very low for CFS members in general (Georgievaa et al., 2012).

2.8.3 Compression Test and Numerical Analysis of Web-Stiffened Channels with Complex Edge Stiffeners

This study describes a series of pin-ended compression test and numerical analysis of channels with complex edge stiffeners and two different types of web stiffeners. In the experimental investigation, axial and eccentric compression loading were imposed respectively on 18 and 12 specimens. The purpose of this paper is mainly to investigate the stability capacity, buckling mode and deformation behaviour of these specimens. The outcome of this experimental investigation was that the longitudinal intermediate stiffeners could reduce the web width-to-thickness ratio effectively and increase the stability capacity of members subjected to axial loading or eccentric loading with the eccentricity close to the web site (Wang et al., 2016).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines the methodology of the study to achieve the objectives. Before the project began, a work flow plan was established to guarantee that it would be completed within the estimated time limit. These work flow procedures serve as a guide to ensure that the project's goals are achieved and that the final result is successful. All of the specimens preparation including the experiment is conducted at Structural and Material Lab, Universiti Malaysia Pahang which is located at Gambang, Pahang.

3.2 Methodology of Study

Figure below illustrates the flowchart of the study. The structure used for this project is built-up C-section which connected using bolts. The specimens preparations need to be done before it is ready to use in order to start the experiment. There are two different conditions of the specimens which is built-up C-section with an opening also built-up C-section without an opening were used for the data collection where there are three specimens for each conditions. The final result collected is observed based on the compressive strength and also buckling shape behaviour. The experiments were conducted at the laboratory using Universal Testing Machine with transducers.

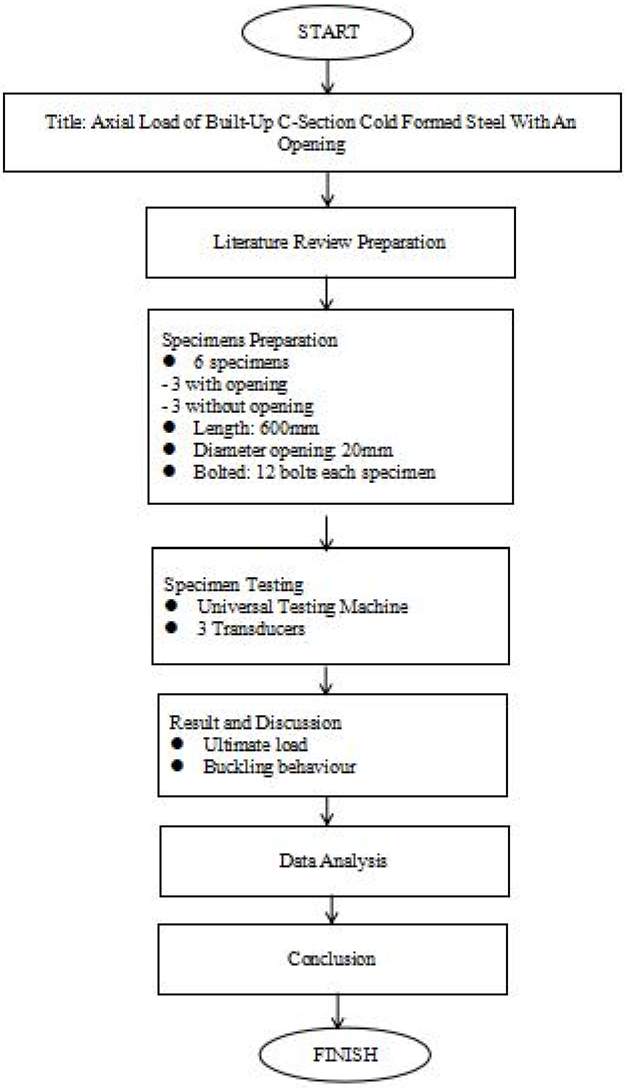

Figure 3.1 Flow chart for this project

3.3 Specimens Preparation

The sample used for this project has 600 mm length due to the limitation of height that the can be cater by the machine in the laboratory. Cold-formed build-up C-section were selected based on the previous researcher and the capability of the laboratory of Faculty of Civil Engineering & Earth Resources (FKASA) in Universiti Malaysia Pahang (UMP).

Figure 3.2 The CFS built-up C-sections

In the preparation process of the built-up cold-formed steel sections, two identical C-section columns were fastened together with self-drilling bolts to form an I-section column. The cold-formed steels were ordered and produced by a local company in Selangor. The size of the section of each sample having thickness 0.8mm, width 74mm and height 600mm. The size of bolts is 10mm and 12 bolts will be used to connect each specimen.

The opening of the cold-formed steel were made using 20mm in circular size. There were only one opening made on the sample. The screw spacing starts at 50mm from one end with a constant gap of 100 mm later and then end with 50mm again at the end of the specimen. The screw spacing is made constant for all samples while the diameter of the opening also was also fixed to 20mm each. The detail of the bolts spacing was presented in Figure 3.3.

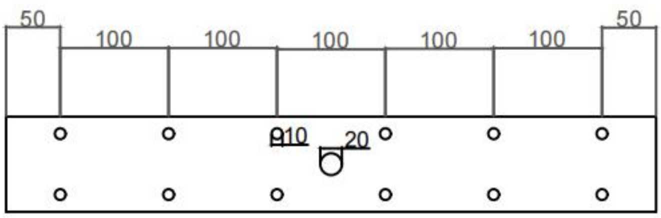

Figure 3.3 Detail of the specimen being connected

3.4 Testing Procedure

After completing the literature review, a methodology for the experimental testing was planned. The samples used were determined after further discussion with supervisor and laboratory staff to match the capabilities of the machine to be used.

3.4.1 Preparation of Literature Review

After the topic of this project has been finalise, writing of literature review must starts. When writing this literature review, one must gather information and knowledge to a deeper understand on the topic. The information provided in literature review must have accurate and useful information to ensure the objective of research may be obtained. A well-written literature review will give good understanding to those who is reading this research project paper later on. Information and knowledge gather must only come from reliable sources to ensure the quality and reliability of a complete research paper.

3.4.2 Planning and Testing Samples

While completing literature review, methodology for the experimental is planned. The specimens used for this project has 600mm length due to the limitation of height that can be cater by the machine in the laboratory. The testing of sample is made at the Structural & Material Laboratory of Faculty of Civil Engineering in Universiti Malaysia Pahang. Upon testing is made, a discussion with the technician is involved to know further about the machines, how to used it and also how the machines is going to be conducted.

Transducers and the Universal Testing Machine served as the main instruments for this experiment. The displacement of the specimens is read by the universal testing machine. According to the previous researcher, the loading rate of 2 mm per minute was the best rate for these specimens. Graphs will be used to represent the data that is extracted from this machine. The reading of specimens' buckling modes was being done with the help of transducers. To collect precise data, three transducers were used.The Universal Testing Machine (UTM) utilised in this experiment is shown in Figure below.

3.4.3 Results and Analysis

Upon completing all the testing in the laboratory, the result and analysis phase may start. The result from testing comes in three types which are reading of axial load that being applied to the specimens, displacement and buckling behaviour. Usually, the data and result will be analyse by calculation, graph and figure. On the other hand, buckling behaviour is observe through picture of sample after the testing is done.

3.4.4 Conclusion

At the end of this research, conclusion is made based on the findings that were obtained from the experiment. The conclusion made were corresponding and answering the objectives of this project. This phase should also summarize the whole research and giving recommendations for future improvements regarding the research topic.

Figure 3.4 The Universal Testing Machine (UTM)

3.4.5 Test Setup and Procedure

As described above, there are three transducer that are used in this test. Three of it is placed on the specimens while on was placed on the top of the universal testing machine. On the sample, the transducer is placed at the middle right and left of the specimens. The function of the transducer is to calculate the horizontal displacement that were cause by the buckling of each sample. For this test, transducer 2 is placed at the middle left side and transducer 3 at the middle right side of specimens.

The universal testing machine is setup and the displacement that are test in this experiment is set 2mm per minute. This means, for each specimen, the test will be end once the displacement of sample that were caused by the axial load from the machine reach 2mm. The results and data from the experiment will be available in two conditions for each specimen which is for built-up without an opening and also built-up with an opening.

Figure 3.5 The placing of transducer from front view

Figure 3.6 The placing of specimen from side view

3.5 Result and Data Analysis

The result and analysis phase may begin after the laboratory testing is complete. Three types of testing results were obtained: the sample's buckling behaviour, readings of the axial loads applied to the sample, and displacements brought on by the sample's compression. Typically, a simple graph and figure will be used to analyse the data and results. On the other hand, the buckling behaviour was seen following testing by displaying a picture of the sample. Following analysis of the testing results, graphs of load and displacement were drawn for each sample.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result obtained from compression test will be discussed. The vertical and horizontal displacement result of the specimen had been taken during testing. The results from the compression test were measured about the maximum loads that were applied on the sample before it buckles, buckling behaviour and the displacement of transducer. The data is presented through graph of load vs horizontal displacement where it compared between both specimens also the axial load and the displacement of the sample.

4.1.1 Load vs Horizontal Displacement

Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength is the maximum stress that a material can withstand while being stretched or pulled before failed. According to (Moen et al., 2008) the presences of holes has only a small influence on compressive strength. The distance between the opening has influences to the ultimate strength where the higher the distance between the opening, the higher the ultimate strength. Besides, the horizontal displacement is the corresponding data that has been collected from the present of transducer that were placed on three different point at the specimens in order to measure the value of horizontal displacement. The position of transducers 2 and 3 are placed at the mid-height of specimen This data will be presented by using graph through load vs horizontal displacement where each graph represent that two transducers that has been attach to the specimen. Each figures are presented as load vs horizontal displacement which the graph starting from figure 4.1 until 4.3.

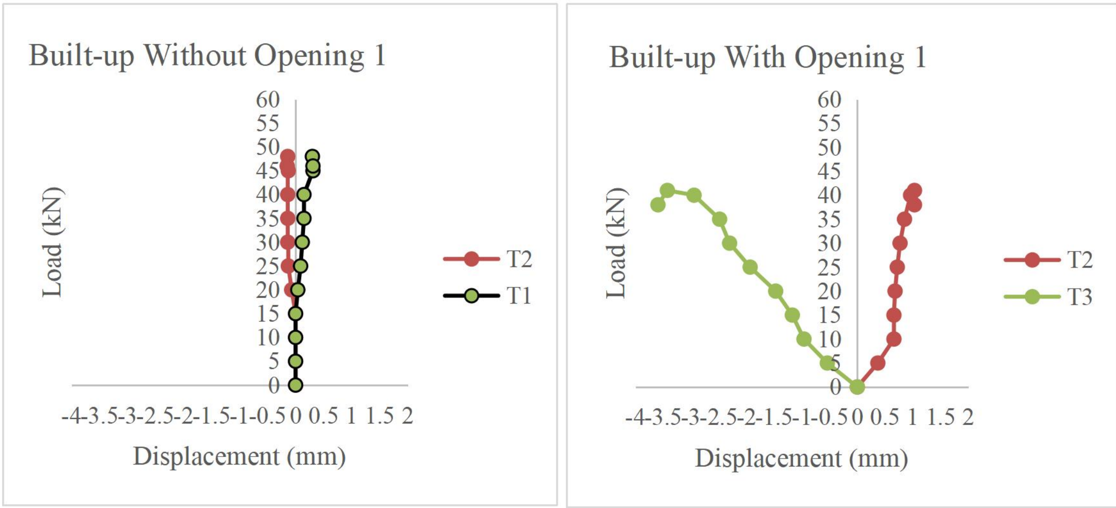

Figure 4.1 Result of built-up with and without opening (1)

Load vs vertical displacement for specimen built-up with an opening (1), the maximum axial load for the sample is 41.67kN and the maximum displacement is 3.58mm while for specimen built-up without an opening (1), the maximum axial load for the sample is 48.02kN and the maximum displacement is 2.18mm. Load vs horizontal displacement for specimens built-up with opening also built-up without opening (1), the graph shown in Figure 4.1. The horizontal displacement was the results obtained from compression of the machine and from transducer 2 and 3.

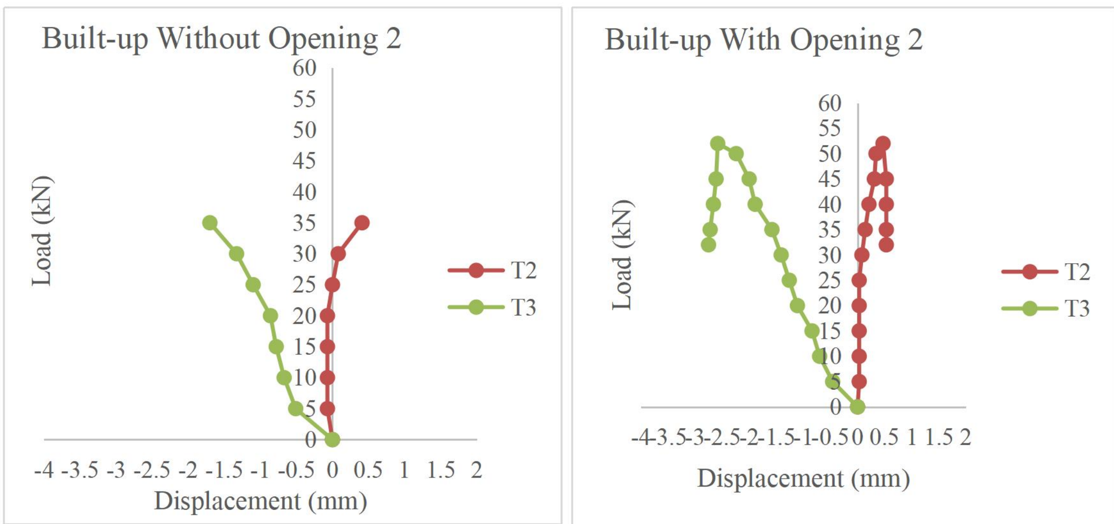

Figure 4.2 Result of built-up with and without opening (2)

Load vs vertical displacement for specimen built-up with an opening (2), the maximum axial load for the sample is 52.22kN and the maximum displacement is

3.03mm while for specimen built-up without an opening (2), the maximum axial load for the sample is 43.47kN and the maximum displacement is 2.66mm. Load vs horizontal displacement for specimens built-up with opening also built-up without opening (2), the graph shown in Figure 4.1. The horizontal displacement was the results obtained from compression of the machine and from transducer 2 and 3.

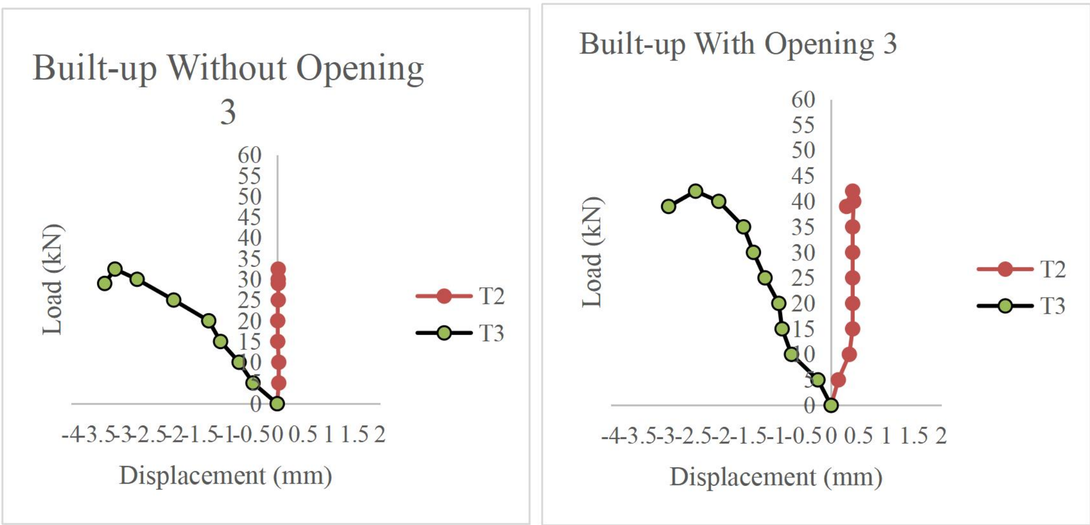

Figure 4.3 Result of built-up with and without opening (3)

Load vs vertical displacement for specimen built-up with an opening (3), the maximum axial load for the sample is 42.47kN and the maximum displacement is 2.84mm while for specimen built-up without an opening (3), the maximum axial load for the sample is 32.47kN and the maximum displacement is 3.51mm. Load vs horizontal displacement for specimens built-up with opening also built-up without opening (3), the graph shown in Figure 4.1. The horizontal displacement was the results obtained from compression of the machine and from transducer 2 and 3.

4.1.2 Buckling Behaviour of Specimen

Overall, the specimen shows a series of local buckling and distortional buckling. Mostly, it happen at the top and bottom of specimen. Figure 4.7 shows the final result and the condition of all specimens after being test.

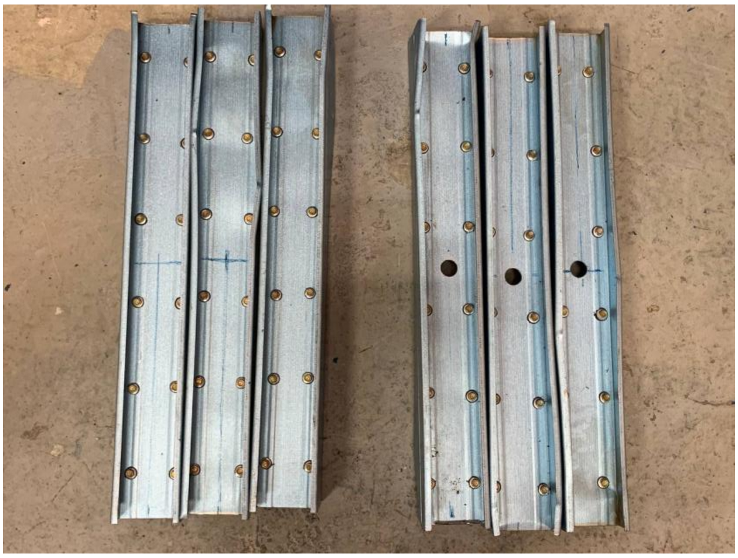

Figure 4.7 Final result of buckling shape behaviour

CHAPTER 5

CONCLUSION

5.1 Conclusion

From the result of the experiment, several conclusions can be made. First, the position of opening plays an important role in determining the ultimate load of the sample. The position of opening also must not be located at the centre of the sample, as it is the critical buckling position. As seen from the experimental result, the existence of an opening reduce the strength of that specimen which make it easier to buckle compare to specimens with no opening. Specimens with no opening also experience buckling but not that clear and can bear more heavy loads before failure and buckle. Next, a short cold-formed steel column will only fail in either local buckling or distortional buckling. As seen from the buckling behaviour of the samples after the compression test, all sample experience local buckling. Even though the ultimate load of axially loaded cold-formed steel with opening changes with the distance between opening, it only minimally reduces the tested column's ultimate compressive strength. To conclude, built-up C-section without an opening have more strength compared to built-up with an opening

5.2 Recommendation

There are few recommendations that can be used in future research regarding cold-formed steel column. First, use different size of section. In this research, only one section size is used. In future research, multiple size of section can be used to study on the effect of size of section in the buckling behaviour of the sample. This is relevant to the various section used by the construction industry as part of the precast component. Considering different type of section or an innovation of new geometrical section may contribute to new effective section that may apply in future.

Next, use different perforation shape and size. As the construction industry may use different perforation shape and size to cater the need of construction, future research can be done to study the effect of different shape and size of the perforations on the ultimate load and the buckling behaviour of the sample. Lastly, to do an analysis of Finite Element was needed. This research only used experimental investigation to study the effect of perforation on the axially loaded cold-formed steel column. The buckling behaviour can be predicted accurately using Finite Element (FE). The used of FE in the research can help give additional information and the comparison of ultimate load and displacement of the sample can be done.

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APPENDIX A
SAMPLE APPENDIX 1

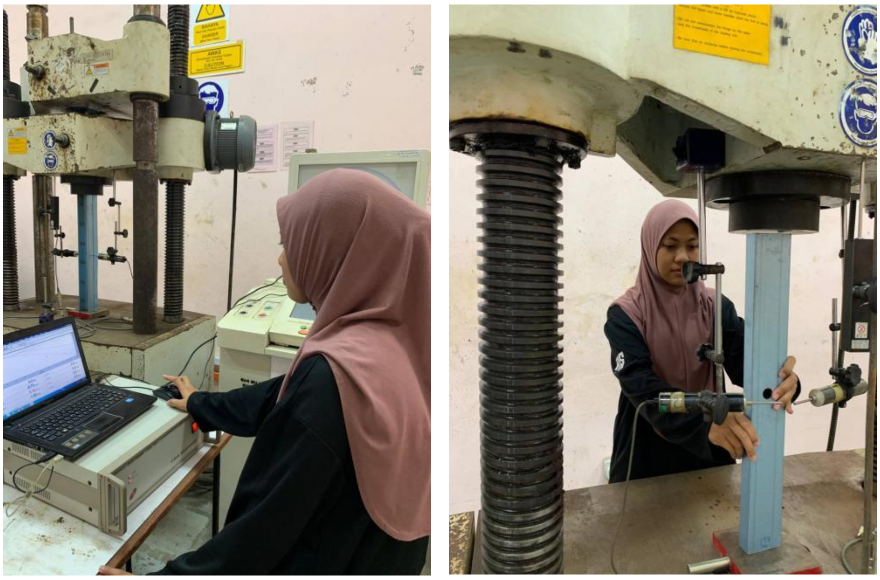
PREPARATION OF BUILT-UP C-SECTION.

Cut the specimen into 600mm

Put marks and bolts on the specimen

APPENDIX B
SAMPLE APPENDIX 2

SPECIMENS LABORATORY TESTING



Test the specimens using UTM and transducers