COMPRESSION TEST OF BUILT-UP C SECTION COLD-FORMED STEEL WITH OPENINGS

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ABSTRAK

Kajian ini bertujuan untuk menentukan beban muktamad bagi bahagian C yang terbina terbentuk sejuk dengan bukaan berbanding dengan bahagian C tunggal dan mengkaji tingkah laku lengkokan mod kegagalan bahagian C yang terbina. Keluli terbentuk sejuk digunakan secara meluas dalam industri pembinaan, teknologi pembuatan dan piawaian yang berkaitan. Keluli terbentuk sejuk boleh didapati secara meluas dengan perbezaan saiz dan bentuk. Bahagian keluli terbentuk sejuk dibuat dengan proses yang berbeza seperti pembentukan gulung sejuk dan operasi tekan brek. Dalam ujian mampatan, pemuat mampatan telah dikenakan pada lajur pendek yang telah ditetapkan dengan siri pembukaan. Terdapat 8 model yang dijalankan untuk mendapatkan hasil yang tepat untuk menunjukkan kelakuan dan kekuatan keluli terbentuk sejuk. Tiang terbina terdiri daripada dua saluran keluli terbentuk sejuk yang diletakkan di belakang dan disambungkan di web menggunakan dua pengikat skru penggerudian sendiri pada jarak yang ditetapkan sepanjang tiang. Kedua-dua hujung setiap tiang akan dikimpal dengan plat keluli untuk bertindak sebagai sokongan tetap. Kajian ini membentangkan penerangan yang terperinci mengenai kajian percubaan dan teori untuk menyiasat beban maksimum dan tingkah laku lengkokan mod kegagalan bagi tiang keluli terbentuk sejuk. Mod kegagalan terbahagi kepada 4 categori iaitu lengkokan tempatan, belitan, meleding dan lengkokan lenturan. Semua model dalam bukaan memberikan data yang berbeza. Model tanpa bukaan memberi beban maksimum lebih tinggi berbanding model dengan bukaan. Penggunaan transducer dalam ujian mampatan juga memberikan tanda awal bagaimana struktur lajur berkelakuan di bawah beban paksi.

ABSTRACT

This paper aims to determine the ultimate load of built-up C section cold-formed steel with openings compared to single C section and study the buckling behavior of built-up C section. Cold-formed steels are widely used in construction industry, manufacturing technologies and relevant standards. Cold-formed steels are widely available with difference sizes and shapes. Cold-formed steel sections are manufactured with difference process such as cold roll forming and press brake operation. In the tests, compression loading were imposed on fix ended short columns with opening series. There are total of 8 specimens was conducted as to get an accurate result to show the behavior and strength of built-up cold-formed steel. The built-up column consists of two individual cold-formed steel lipped channels placed back-to-back and connected at the web using two self-drilling screw fasteners at specified spacing along the column length. Both end of each columns will be welded with a steel plate to act as fixed support. This paper presents a detailed descriptions of an experimental and theoretical studies to investigate the maximum load and buckling behavior of cold-formed steel columns. Mode of failure split into four categories such as local buckling, distortional buckling, warping and flexural buckling. All of specimen in openings give different data. Specimen without opening give more higher maximum load compare to specimen with opening. The use of transducer in the compression test gives the earlier sign how column structures behave under axial load.

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LIST OF ABBREVIATIONS

CFS	Cold-Formed Steel
FE	Finite Element
FKASA	Fakulti Kejuruteraan Awam dan Sumber Alam
UTM	Universal Testing Machine
AISI	American Iron and Steel Institute
JIS	Japanese Industrial Standard
SPCC	Steel Plate Cold Rolled Common
BC	Built-up C
SC	Single C
DB	Distortional Bottom
DBB	Distortional Bottom Back
DTB	Distortional Top Bottom
DTF	Distortional Top Front
DMB	Distortional Middle Back
DMF	Distortional Middle Front
LM	Local Middle
LT	Local Top
LBF	Local Bottom Front
LBW	Local Bottom Web
LTF	Local Top Front
WBB	Web Bottom Back
WBF	Web Bottom Front
WMF	Web Middle Front

CHAPTER 1

INTRODUCTION

1.1 Introduction

Cold-formed steel has been recently brought into Malaysia construction. The use of this structures is expanding quickly around the world due to the many approach in construction and manufacturing technologies and relevant standards. It is a steelwork innovation that has high potential to be developed in Malaysia, that can offer advantages such as fast erection, lightness of weight, clean and easier construction. Cold-formed steel structure is widely available with difference sizes and shape. Cold-formed steel members usually have symmetrical cross-sections, higher of strength and better resistance out-of-plane resistance.

In addition, cold-formed steel is a steel product that is formed by a steel strip or sheet of uniform thickness, in cold state. It is regarded as steel strip with uniform profile along its length and it is usually used in load bearing application. The use of cold-formed steel section can be found in automobile industry, shipbuilding, rail transport and construction industry. In building construction, the cold-formed steel is utilised in both structural and non-structural. As non-structural members, the advantages are more on rust resistance and aesthetic purposes. Figure 1.1 shows the building that used cold-formed steel sections. Cold-formed steel is a thin walled section and it is available with different sizes and shapes. It provided with holes to accommodate plumbing, electrical, and heating conduits in the walls and ceilings of buildings. The thicknesses of material for thin wall sections usually range from 0.373 mm to 6.35 mm. One of the best ways to perform this study is to connect two single members together to form a built-up I section.

Figure 1.1 Building composed entirely of cold-formed steel sections

Source: (Specifying cold-formed steel to meet project goals - Construction Specifier, 2017)

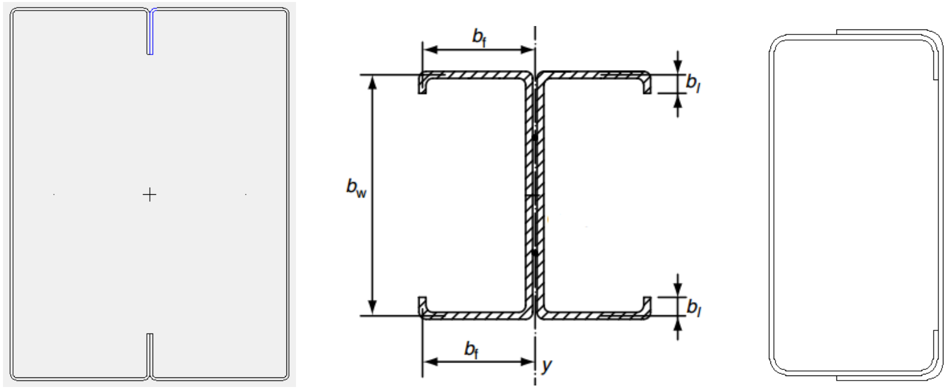
Next, for built-up section, it has symmetric cross sections, higher strength and better resistance against out-of-plane. It is easily failed in overall buckling, if not laterally supported. A built-up section can spend more distance, higher torsional; stiffness and higher load bearing capacity. Therefore, the use of built-up sections can be a major advantage of economic since the whole manufacture process remains the same. When structure section modified with opening, it will be represented in thin-walled structural members to facilitate access for services and inspection. It will obviously result in changes in stress distribution within the member. A reduction of strength and variations in the buckling characteristics of the plate elements.

In building construction, there are primarily two types of structural members: hot rolled steel shapes and cold rolled steel shapes. Cold-formed steel shapes are formed at room temperature while hot rolled steel shapes are formed at elevated temperatures. Cold-formed steels are made from structural quality sheet steel and formed into shape, either through press braking blanks sheared from sheet or coils by rolling forming the steel through a series of dies. Due to the relative method of manufacturing process, a large number of different compositions can be produces to fit the demands of optimized for both structural and economical purposes.

1.2 Problem Statement

Cold-formed steel can be productive in many applications where conventional hot rolled steel proves uneconomic. Cold-formed steel is a thinner material compared to the other type of hot rolled steel. The buckling stability will be different compared to conventional structural steel. When it is thin and lightweight, the strength not strong than hot rolled steel. Effect strength of cold-formed steel due to position of opening also need to be taken because the difference behaviour of failure mode occurs when different position of opening. Next, the stiffener is commonly used in cold-formed steel section to provide a continuous support along a longitudinal edge of flange to increase the buckling stress. It can be easily brake pressed on the free edge of an unstiffened plate. Further, the stiffeners also may transform considerably their distortional buckling, post buckling and collapse behaviour.

In most past researches, cold-formed steel built-up sections as cold-formed C face-to-face (Figure 1.2(a)) and nested section (Figure 1.2(c)), were studied. In building construction, cold-formed steel C back-to-back sections (Figure 1.2(b)) were applied. However, there are few researches on this type of built-up section. Since the torsional is much smaller than the C face-to-face section, more detailed investigation on buckling behaviour of the C back-to-back section is needed.



(a) Face-to-face C section (b) Back-to-back C section (c) Nested C section

Figure 1.2 Sorts of built-up sections

Source: (Kang, 2017)

Normally, people only use one section for built-up as column members or column frame walls, but the problem is shear centre or centre of gravity is located at outside. When it located at outside, it is unstable when subjected to load. When structure section modified with opening, it will reduce the area, stress become high and easy to failure. Openings can be found in most cold-formed steel structural components. For example, in low and midrise construction, evenly spaced openings are place in the webs of cold-formed steel columns and beams, allowing electrical, plumbing and heating services to pass through walls and ceilings. Openings are generally assumed to decrease the elastic local buckling load of a flat plate loaded in uniform compression.

1.3 Objective of Study

This study was conducted to achieve the following objectives:

i. To determine the ultimate load of built-up C section with conventional.

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

1.4 Scope of Study

The scope of this study was cover on the analysis of failure mode for built-up C section cold-formed steel column with open section. The numbers and position of opening at the cold-formed steel members will be varies and the shape of opening used is elongated circle. There are eight specimens back-to-back C section and a short column cold-formed steels are being used with 1.2 mm of thickness and 203 mm for width that is going to be tested using Universal Testing Machine. Both end of each columns will be welded with a steel plate to act as fixed support. Buckling modes of cold-formed steel columns that can occur are;

1. Local Buckling
2. Distortional Buckling
3. Warping
4. Flexural Buckling

1.5 Significant of Study

After this study have been conducted, the ultimate load and buckling behaviour of built-up C section can be determined. We can know that when structure section is modified, it will reduce area and stress become very high. Built-up section has possibility to carry load compare to single section. However, by creating an opening at the web, it will reduce the weight thus reduce the cost of steel section.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Cold-formed steel sections can be widely used in many sectors of construction including industrial buildings, commercial buildings, hotels and gaining greater acceptance in the residential sector. Cold-formed steel members as shown in Figure 2.1 approximately used in building construction, bridge construction, drainage facilities, highway products, storage racks, grain bins, transmission towers, railway coaches, car bodies and various type of equipment. (Yu and LaBoube, 2010) The use of cold-formed construction material has become increasingly popular since the introduction of summarize standards in 1946. (Prakash et al., 2014)

Cold-formed steel structural members are commonly provided with opening to accommodate electrical and plumbing of building. The use of cold-formed steel on building constructions has started since a long time ago. Nevertheless, the use in the building was not extensively employed until 1940's. In any case, modes of failure are not commonly experienced in typical steel structural design details and thus extensive testing is required to supply a guideline for the design of cold-formed thin walled structural members. Figure 2.2 shows some of cold-formed sections normally used as structural framing in buildings up to four or five stories in height. The familiar shapes are channels (C-section), Z-section, angles, I-section, T-section and tubular member.

Figure 2.1 Various shapes of Cold-Formed Steel section

Source: (Yu and LaBoube, 2010)

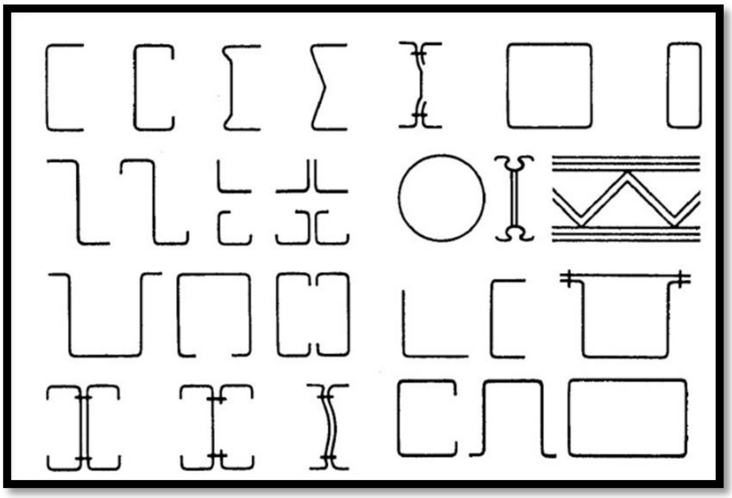


Figure 2.2 Various shapes of Cold-Formed Steel section

Source: (Brockenbrough, 2000)

2.2 Method of Forming

Generally, there are two methods used in manufacture of cold-formed section such as:

1. Cold Roll Forming

2. Press Brake Operation

2.2.1 Cold Roll Forming

The process of cold roll is widely used to produce building component and corrugated sheeting. The machine used in cold roll forming in Figure 2.3 consist of pair of rolls from a strip which is formed progressively into the final required shape. A simple section may be produced by as few as six pairs of rolls. Although, a complex section may require as many as 15 sets of rolls. The resistances in roll forming are basically affected by the section size, the type of product and the thickness of material. (Yu, Ph and Wiley, 2000)

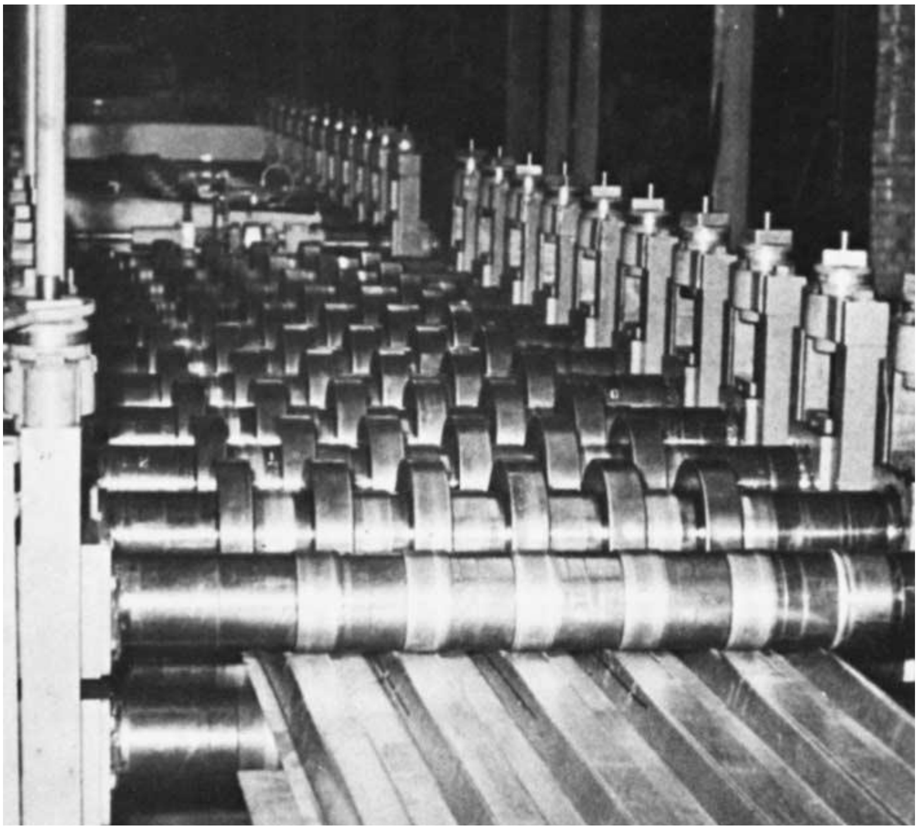


Figure 2.3 Cold Roll Forming Machine

Source: (Yu, Ph and Wiley, 2000)

2.2.2 Press Brake Operation

In these processes, the equipment used press brake operation in Figure 2.5 shows the short length of strips are provide into the brake and bent or pressed round shaped dies to form the final shape. Refer Figure 2.4, Normally, each bend is formed personally and the complexity of shape is limited that which die can fit. (Structures and Ii, 2008) Press brake operation can produce a simple section such as angles, channels and Z-sections from sheet, strip, bar or plate not more than two operations. Sections that more complicated may take several operations.

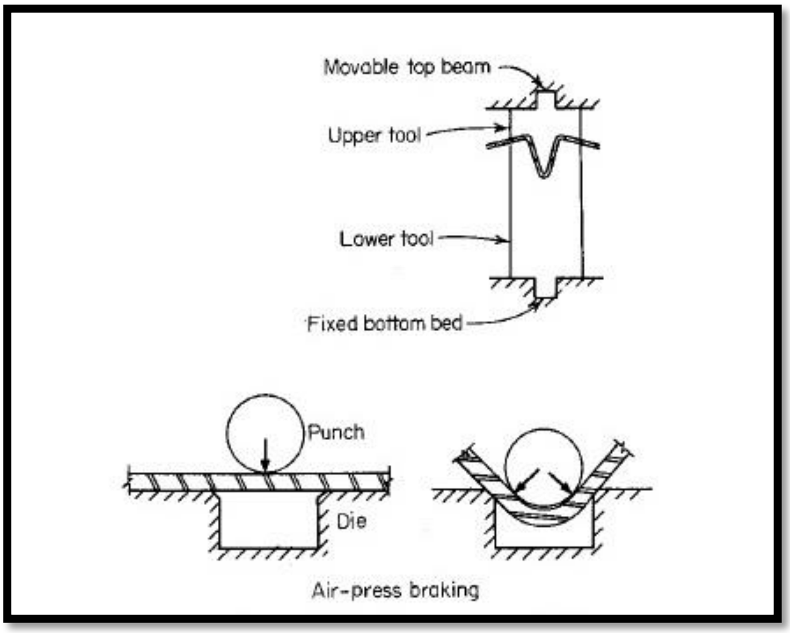


Figure 2.4 Press Braking System

Source: (Yu, Ph and Wiley, 2000)

Figure 2.5 Press Brake Operation Machine

Source: (West Memphis Steel, 2019)

2.3 Classification of Section

2.3.1 Built-up Section

Normally, built-up cold-formed steel section is the back-to-back lipped channel I-section, where the individual cold-formed steel (lipped channel) studs are fastened together using self-drilling screws and welds. (Fratamico et al., 2018) The current design of built-up cold-formed steel columns is particularly simplified. Figure 2.6 shows the typical built-up structural section. Form the previous research on built-up cold-formed steel members showed, in addition of buckling, fastener flexibility also affects the member stability and strength especially when screw is used to interconnect the specimens are provided to ensure ease of assembly.

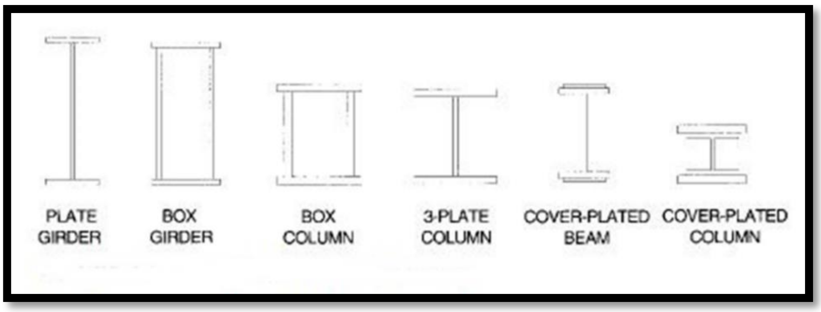


Figure 2.6 Typical built-up structural sections

Source: (Built-Up Sections _ Civil Engineering, 2019)

The advantages of built-up members are it have symmetric cross sections, higher of strength and better resistance against out-of-plane movement. Because of manufactured method stay unchanged, cold-formed steel members are easily fail in overall buckling, if not laterally supported. (Georgieva et al., 2012)

2.4 Opening

Opening in cold-formed steel section are often to facilitate access for services and inspection. Figure 2.7 show the opening in cold-formed steel section. The size of opening can be a remarkable part of the member dimension across the opening itself, to the extent of 60% or more. The appearance of openings in structural members will clearly result in changes in stress distribution within the member thus a decreasing of strength and differential in the bulking aspect of the plate elements. (Shanmugam, Thevendran and Tan, 1999)

Figure 2.7 Cold-formed steel with opening section

Source: (ClarkDietrich Building Systems, 2017)

A significant drop in the overall weight of the structure will be presence on the result of opening. Nowadays, cold-formed steel members used in racking structures, for example, it manufactured with regular pattern of multiple holes. These openings result in a reconstruct of membrane stresses because of the following changes in buckling and strength characteristic. (Shanmugam, Thevendran and Tan, 1999)

2.5 Comparison of Cold-Formed Steel and Hot Rolled Steel

It is important to note that the main difference between hot rolled and cold rolled steel is one of process. “Hot rolling” refers to processing done with heat. Meanwhile “Cold rolling” refers to processing done at or near room temperature. Steel of different grades and specifications can be either hot rolled or cold rolled including both basic carbon steel and another alloy steels. It could appear self-evident, but some of steel are better suited for certain applications. Knowing which to use can help avoid over-spending on raw materials. It can also save time and money on additional processing and understanding the differences between hot and cold steel is integral to choosing one over the other. (Reliance Foundry, 2017)

Cold-formed steel is basically hot rolled steel that has been through advance preparing. The typical uses of cold-formed steel are for strips, bars, rods, home appliances, metal furniture, roof and wall systems and aerospace structural members. A rolling process at temperatures that are close to normal are used to produce cold rolled steel. Figure 2.8 shows the manufacturing process of cold-formed steel. The strength of the finished product using strain hardening increased by 20 percent and it will become a grey finish that feel smooth to the touch.

Figure 2.8 Cold-formed steel

Source: (Reliance Foundry, 2017)

Hot rolled steel is a rolling process at temperatures over 1,000-degree Fahrenheit that use to produce hot rolled steel. The process of steel easier to form and resulting in products that are easier to work with. It will have a blue grey finish that feels rough to the touch. Figure 2.9 shows the manufacturing process of cold-formed steel. To process hot rolled steel, manufacturers start for the first way with a large, rectangular length of metal called a billet. The billet is heated and then sent for pre-processing where it is compress into a large roll. From there, it is kept at a high temperature and go through a series of rollers to fulfil its finish dimensions.

Hot-rolled steel approximately used in railroad tracks, I-beams, agricultural equipment, sheet metal and automotive frames. It is regularly having a textured surface finish. For situations in which the appearance of the material is a concern, the scales can be evacuated by a few procedures: pickling, grinding, or sand-blasting. (National Material Steel Group, 2019)

Hot rolled steel is more workable, allowing it to be constrained into a variety of different shapes. The white-hot strands of steel are pushed through the rollers at high speeds. A rolled steel for sheet metal is swing into coils and cleared out to cool. For other shapes, such as bar or plates materials are segmented and packaged. Since hot rolled steel is cooled after handling, there is less control over its final shape, making it less reasonable for precision applications. Table 2.1 shows the comparison of cold-formed steel and hot rolled steel.

Figure 2.9 Hot Rolled Steel

Source: (Reliance Foundry, 2017)

Table 2.1 Comparison of Cold-Formed Steel and Hot Rolled Steel

COLD-FORMED STEEL	HOT ROLLED STEEL
• A finished product that is more precise dimensionally. • It has sharper corners than a hot rolled product. • More finished surfaces with closer tolerances. • Smooth surfaces that are often oily to the touch. • It can increase the strength of steel (strain hardening) • Strong but thinner and lightweight with smooth and shiny finish.	▪ Steel that has been rolled at very high temperature. ▪ Easier to form and results in products that are easier to work with. ▪ Typically, cheaper to manufacture.

2.6 The Behaviour of Cold-Formed Steel

2.6.1 Local Buckling

Local buckling shows in the longitudinal axis of the member remains undeformed. It is very important aspect in cold-formed steel parts because the very thin elements used will invariably buckle before yielding. On the other hand, local buckling is a common buckling failure in compression members, which is made of slender plate elements. The cross section and the typical mode of failure are shown in Figure 2.10. The half-wavelength of local buckling mode is the shortest one among the other mode of failure. When a higher post buckling range, it is not evaluated as failure of the whole column when columns buckle locally.

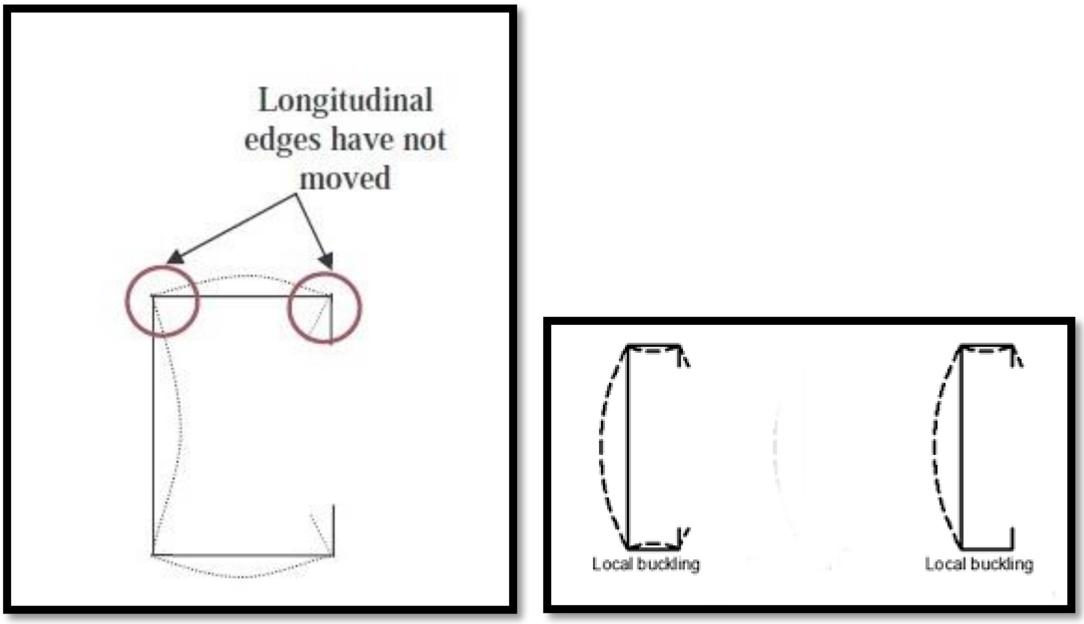


Figure 2.10 Local Buckling Mode of Compression Members

It is familiar local buckling reduces the compressive stiffness and strength of a column. Although, local buckling can also influence the mode of failure for a column; for example, it can cause singly symmetric column to fail by flexural yielding, instead of by flexural buckling. (Mulligan and Pekoz, 2008)

2.6.2 Distortional Buckling

Distortional buckling of cold-formed steel structure members is defined by the distortion of the shape of the cross section excluding the suffering related to local buckling. It is also known as stiffener buckling or local distortional buckling. Figure 2.11 shows the rotation of the flange at the flange web junction for the members with edge stiffeners and rearrangement of the intermediate stiffeners normal to the plane of the element for the intermediately stiffener members.

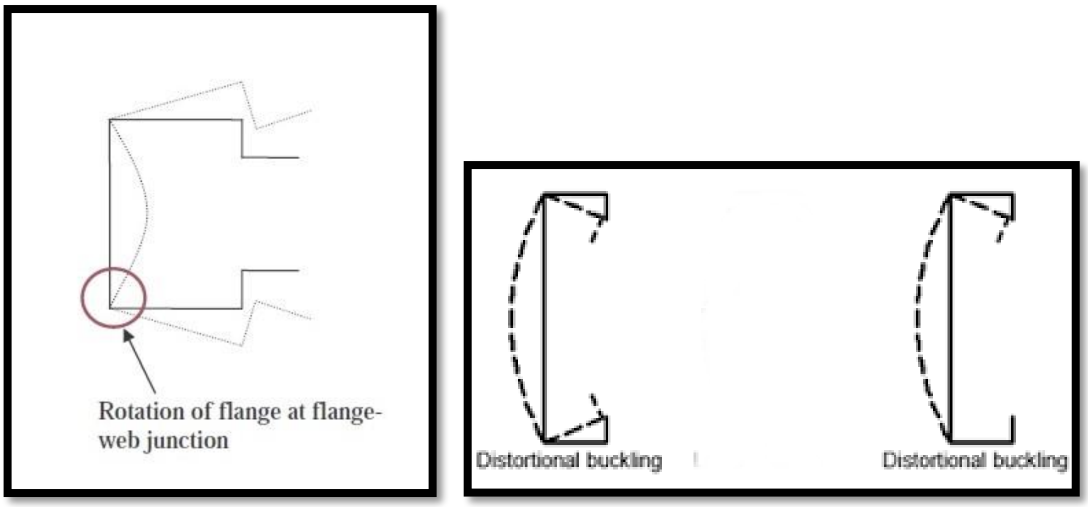


Figure 2.11 Distortional Buckling Mode of Compression Members

Since distortional buckling mainly occurs due to the rotation and lateral bending of the flanges, these illustrations have been derived by considering only the flanges. Nevertheless, the buckling of lipped channels with narrow flanges show lateral bending overall cross section while the flange web junction of the buckling of lipped channels with deep flanges remain nearly straight. (Ranawaka, 2016) However, distortional buckling exists at an intermediate half-wavelength between local buckling and flexural torsional buckling. It can be safely ignored if members are designed to achieve the lower local buckling stress than the distortional buckling stress.

2.6.3 Warping

Warping occurs when the twisting of a member results in the cross sections distorting out-of-plane along the guidance of the members longitudinal axis. Most of cold-formed steel members except closed hollow circular sections have cross sections which contribute to warp when subject to torsion. When the out-of-plane distortion is laid back or blocked at any cross section, the longitudinal shear stress and strain are developed in the member. The torsional stiffness may be significantly greater than it would be if the section could warp freely when warping restraint is applied to a member.

2.6.4 Flexural Buckling

Generally, flexural buckling mode can be defined as global buckling. Figure 2.12 shows the flexural buckling mode of compression members. The cross-sectional shape remains unchanged in flexural buckling and it has only lateral or lateral torsional movements. This buckling mode also known as rigid body buckling since the cross section remains unchanged at any given section after global buckling occurs. The lateral deflection of the flexural mode is larger than the local and distortional mode. The largest flexural mode is half-wavelength among the buckling modes. When loaded in the plane of the web, cold-formed steel flexural members may twist and deflect vertically if braces are not sufficiently provided.

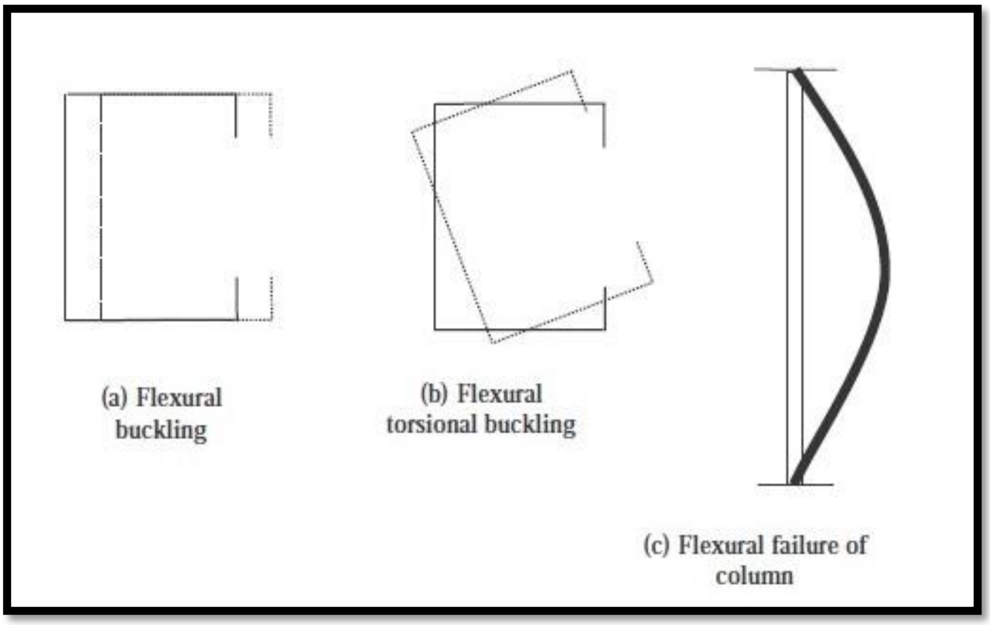


Figure 2.12 Flexural Buckling Mode of Compression Members

2.7 Previous Research Paper

2.7.1 Behaviour of Cold-Formed Steel Built-up Section

This research was done by (Stone and LaBoube, 2005) and it was done to study the behaviour of built-up cold-formed steel studs. This paper refers North American Specification for the Design of Cold-Formed Steel Structural Members as their guidance and to determine if the American Iron and Steel Institute (AISI) design methodology is valid for cold-formed steel members. This experimental study was performed at University of Missouri-Rolla to focus on the behaviour of built-up compression members, especially I section. The specimens were constructed of C shaped sections oriented back-to-back with edge stiffened flanges and track sections.

2.7.2 Cold-Formed Steel Built-up Section with Web Opening to Compression Loading

The experimental investigation was done by (Reddy, R and Sankh, 2016) and it was aimed at studying the influence of opening positions on the ultimate strength and the failure modes of lipped section columns. The research uses Finite Element Analysis to study the effects of opening positions on the load capacity of column members of lipped channel cross-section. For this purpose, a finite element model was developed using ANSYS and its accuracy was verified using experimental and theoretical results. The study showed that the ultimate load of the lipped channels under compression varied greatly with the opening position. Comparisons of the finite element results and the test results are also made with existing design specifications and conclusions are drawn on the basis of the comparisons.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, it would discuss about the procedure of the studies method from first step until the end of experiment test. Eight specimens of built-up cold-formed steel column with opening were conducted at Heavy Structure Laboratory at Universiti Malaysia Pahang Gambang Campus by using Universal Testing Machine. All of specimens are connected fix at both ends onto the plate. The thickness and the length of the specimens are consistent to get an accurate result and make a comparison with conventional.

The cold-formed sections were brake-pressed from steel plate cold rolled common (SPCC) cold rolled sheet which is the standard of Japanese Industrial Standard (JIS). "Cold reduced carbon steel sheets and strips" having the material grade and designation defined in JIS G 3141. Based on previous done research by M. Meiyalagan (2010), it was made as a guideline in conducting this research. Before testing, a discussion with technician was involved to know more about the machine and how to conduct the testing.

At the end of this study, the result that were obtained show the behaviour and strength of built-up cold-formed steel C-section with opening. The experimental investigation was aimed at the study of the influence of opening on the ultimate strength and the mode of failure for built-up C-section.

3.2 Flow Chart of the Study

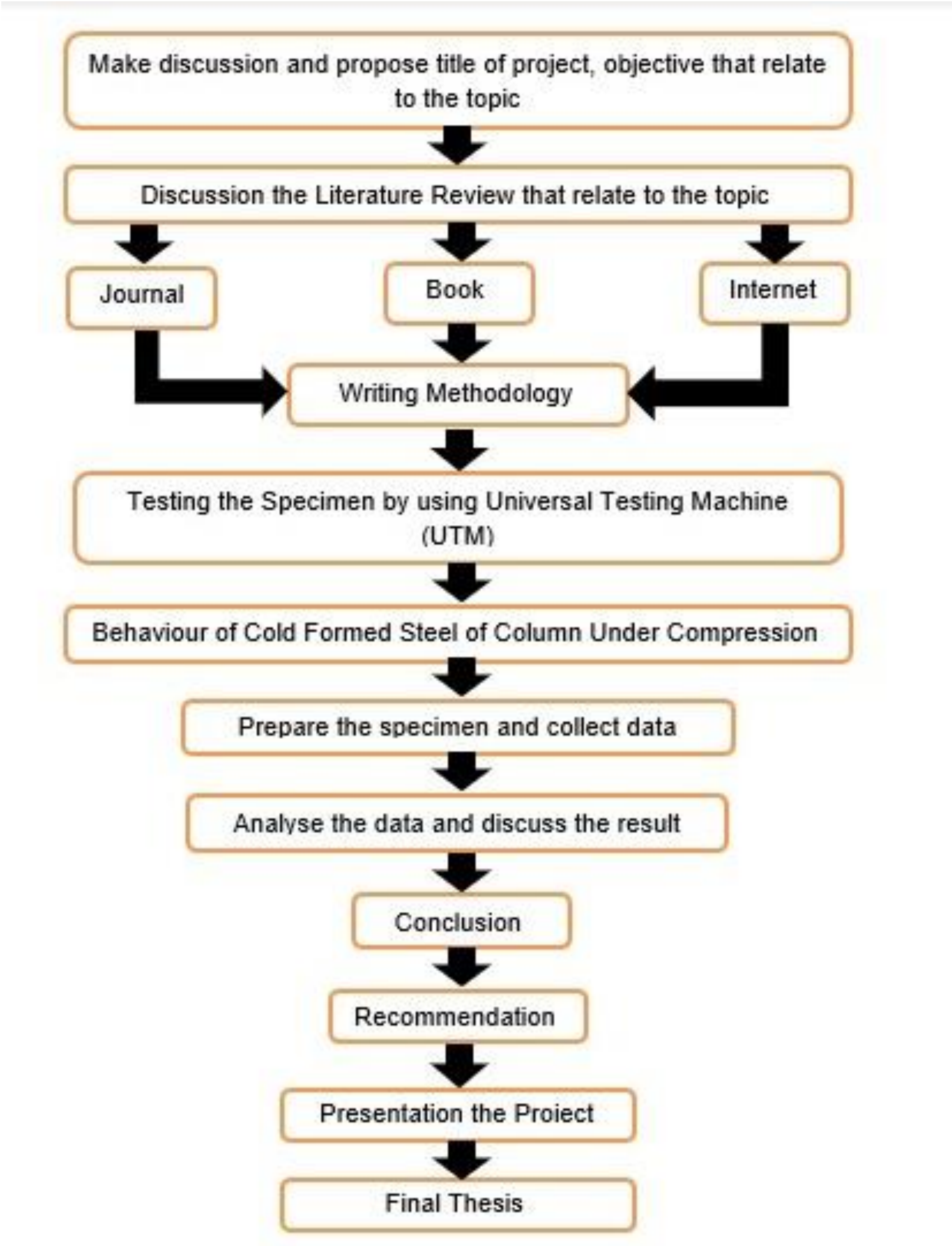


Figure 3.1 Flow Chart of the Research

3.3 Section Parameter

Figure 3.2 illustrates typical built-up C-section and Figure 3.3 illustrates the definition for built-up C-section label. All column specimens were 600 mm and the cross-section parameters of the built-up C-sections used in this study varied as follows in Table 3.1:

Table 3.1 Parameter of built-up C-section

Parameter	Description
Types of Section	Built-up
Shape of Section	C-section
Height of Column	600 mm
Width of Column	203 mm
Thickness of Column	1.2 mm
Shape of Perforation	Elongated Circle

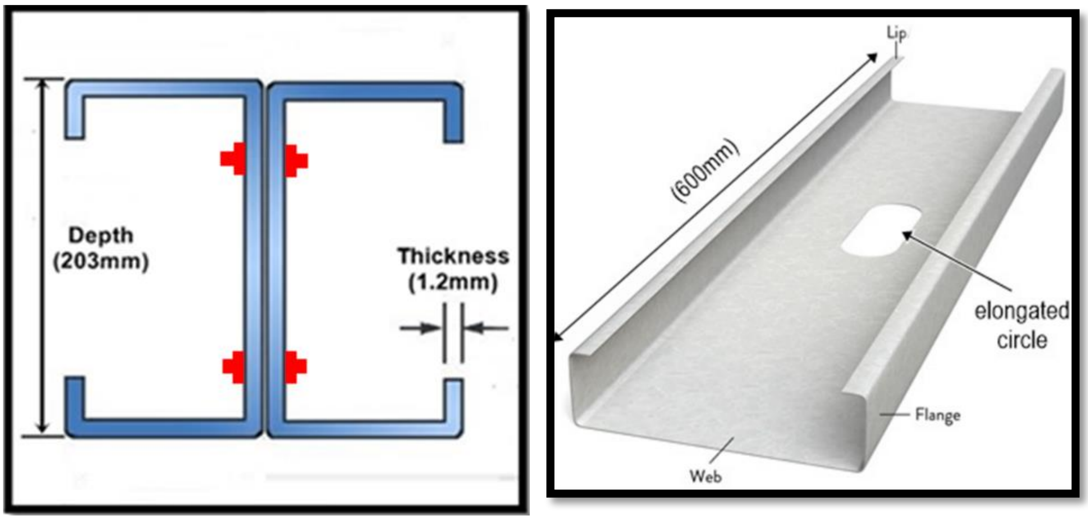


Figure 3.2 Typical built-up C-section

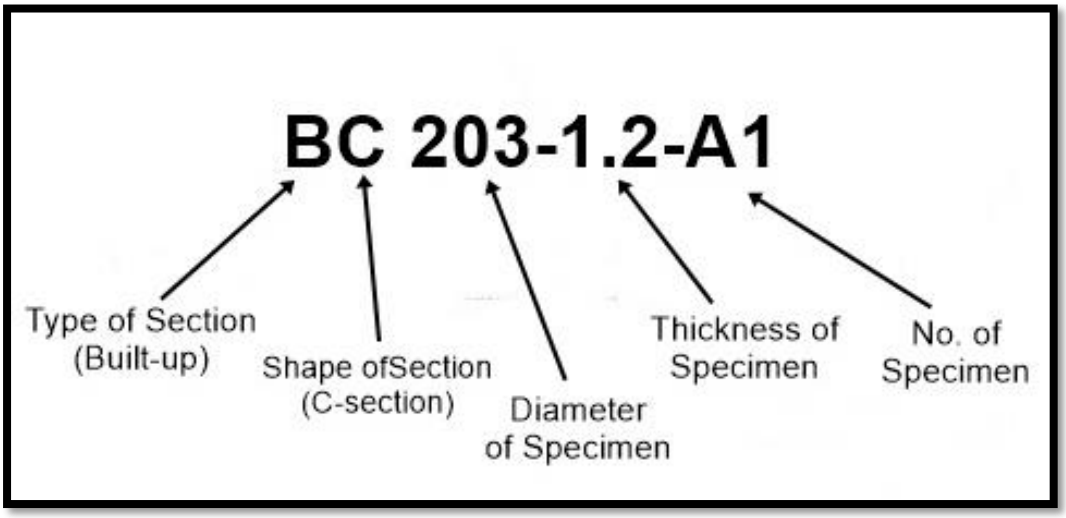


Figure 3.3 Label definition for Built-up C-section

3.3 Specimen Preparation

The specimens of built-up C section were fastened together with screwed through the web starting 50 mm from one end, the screw spacing, a, for the test specimen using the spacing value of 100 mm and 20 mm from the inside of flange. The screw layout is illustrated in Figure 3.6 – 3.7. For the connection type of cold-formed steel, the weld connection should not be used since heating may destroy the coating material of cold-formed steel.

Figure 3.4 Self Drilling Screw

As shown in Figure 3.4, the type of screw connection was normally used to connect two C-sections to form built-up C-section. Self-drilling screws were suitable and effective for applying to the cold-formed steel section with the condition that total thickness should be enough for installation. For the installation, the hand drilling machine as shown in Figure 3.5 is adopted. For the self-drilling screws which are practically used to connect both C-section columns and the diameter was 20 mm as shown in Figure 3.5.

Figure 3.5 Screw connection for the specimen

Figure 3.6 Typical screw spacing and layout

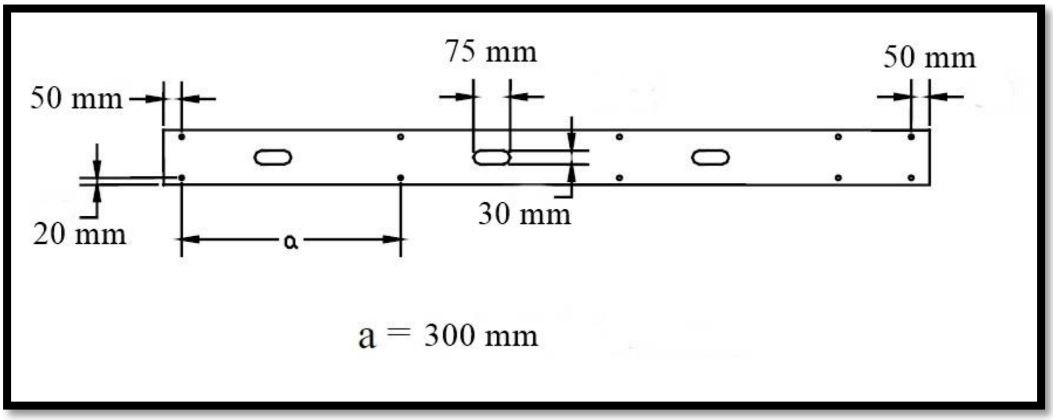


Figure 3.7 Schematic of screw spacing and layout

The base plate needs to weld both sides as it is considered to be fixed end. Figure 3.8 shows how the technician welding the specimen.

Figure 3.8 Technician welding the specimen

3.4 Test Setup

The built-up compression members were conducted at Heavy Structure Laboratory at Universiti Malaysia Pahang Gambang Campus by using Universal Testing Machine as shown in Figure 3.11. The process of setting up the specimen during testing started by setup the transducers that containing three of them labelled as Transducer 1, Transducer 2 and Transducer 3. All of three transducers in Figure 3.9 are setup to determine the record deformation and determine the vertical and horizontal displacement for each specimen.

Figure 3.9 Transducers

Universal Testing Machine will be connected to a computer which is assisted by a person during the testing to accommodate the data for the results. The data taken will be in the form stress-strain graph and it was recorded by using a data logger as shown in Figure 3.10. All of this instrumentation, specimens and materials shown in Figure 3.11 until Figure 3.15.

Figure 3.10 Data Logger

Figure 3.11 The position of setup the transducer before testing

The criterion to stop the testing was determined by the point where failure load was reached (ultimate load capacity). The test was stopped after reaching in that point at which point the force-displacement curve started decreasing.

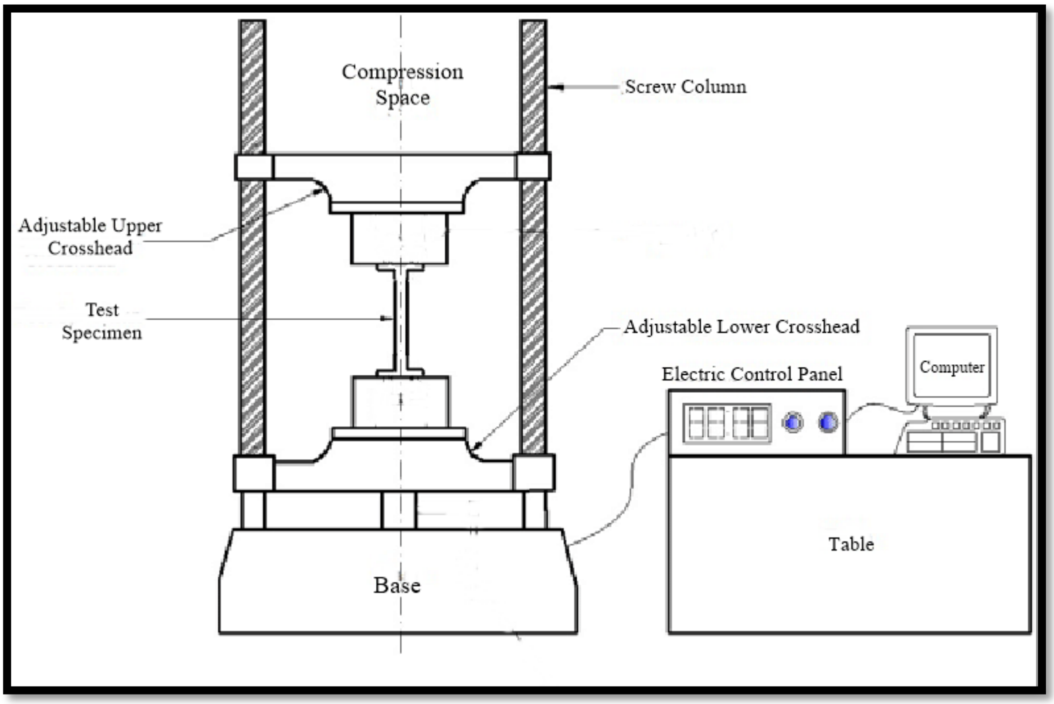


Figure 3.12 Schematic of test setup

Figure 3.13 The specimen's position of opening for section 203mm

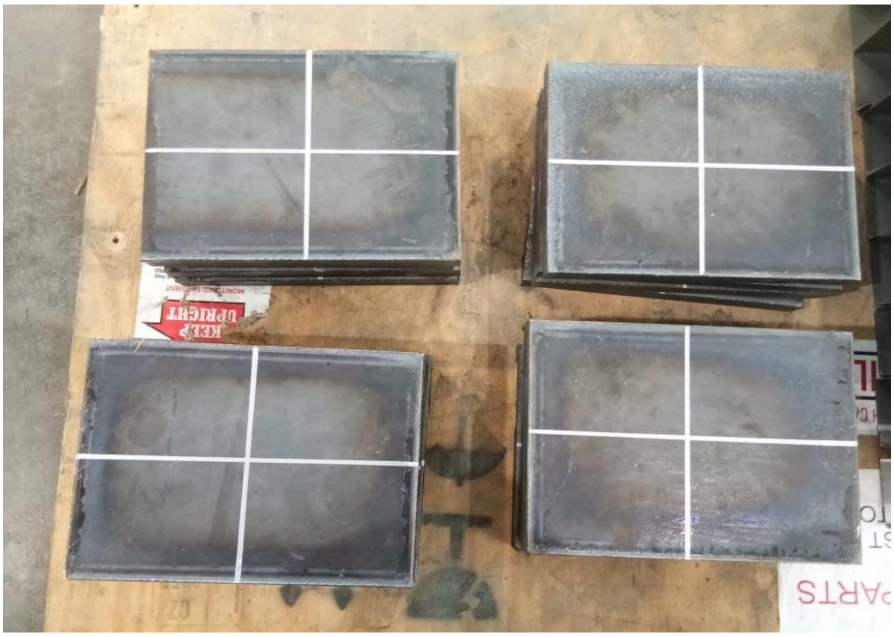


Figure 3.14 Base plate that used for welded at the top and bottom of the specimen

Figure 3.15 Specimen welded at top and bottom support

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, all the results and data collected from the testing will be discussed. The discussion of the analysis is related to research objectives. The result from column test was measured from the maximum load that was applied on the specimen before it buckles and the buckling behaviour that occur during and after the experiment.

4.2 Load versus Vertical Displacement

For this part, the result obtained from the testing that are the maximum load obtain from different section, presence of opening and different location of opening. Refer Table 4.1, specimen without opening can sustain more maximum load that is specimen BC203-1.2-A1. From Table 4.1, BC 203-1.2-A1 comes out with 103.963kN higher from another specimens. From Table 4.2, SC 203-1.2-A4 comes out with 48.33kN higher from another specimens. Specimen BC 203-1.2 can sustain more maximum load compare to specimen SC 203-1.2.

A comparison graph of load vs vertical displacement for specimen BC 203-1.2 and SC203-1.2 are plotted at the end of the test and it could be seen in Figure 4.1 and Figure 4.2. The maximum load is not predictable because of few reasons during the testing.

Table 4.1 Finalize of buckling behaviour for each specimen BC 203-1.2

SPECIMEN	MAXIMUM LOAD (kN)
BC 203-1.2-A1	103.96
BC 203-1.2-A2	96.01
BC 203-1.2-A3	93
BC 203-1.2-A4	95
BC 203-1.2-A5	98.01
BC 203-1.2-A6	92
BC 203-1.2-A7	96.03
BC 203-1.2-A8	99

Table 4.2 Finalize of buckling behaviour for each specimen SC 203-1.2

SPECIMEN	MAXIMUM LOAD (kN)
SC 203-1.2-A1	45
SC 203-1.2-A2	48.17
SC 203-1.2-A3	45.54
SC 203-1.2-A4	48.33
SC 203-1.2-A5	45.71
SC 203-1.2-A6	47.15
SC 203-1.2-A7	46.59
SC 203-1.2-A8	45.93

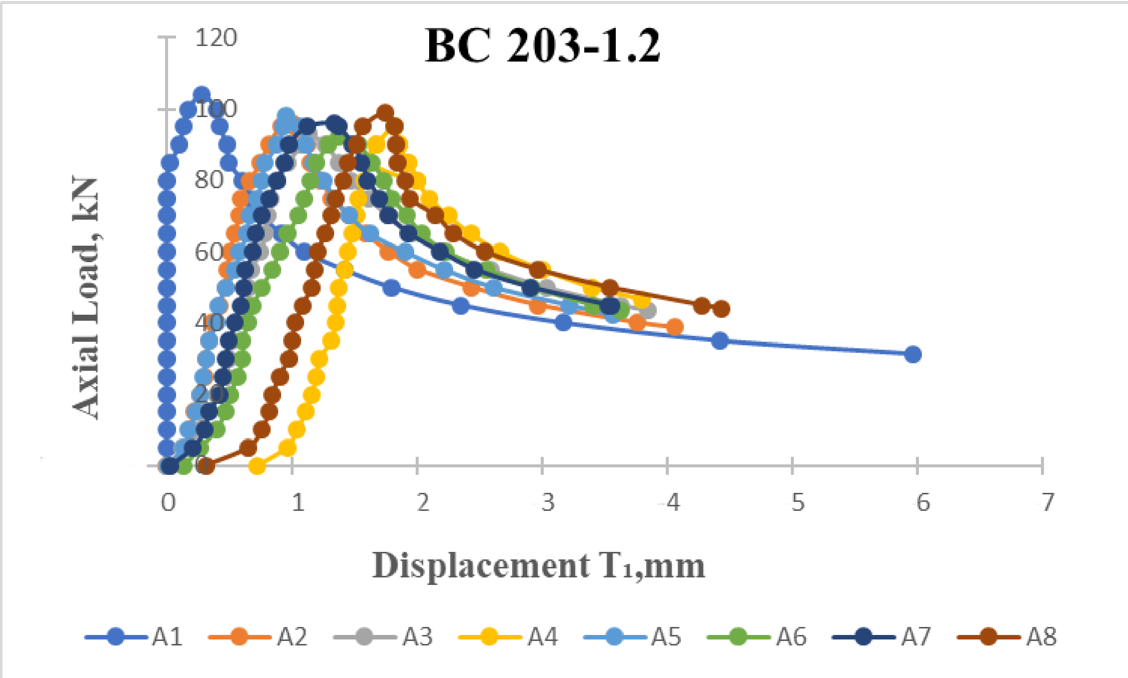


Figure 4.1 Load versus vertical displacement for specimen BC 203-1.2

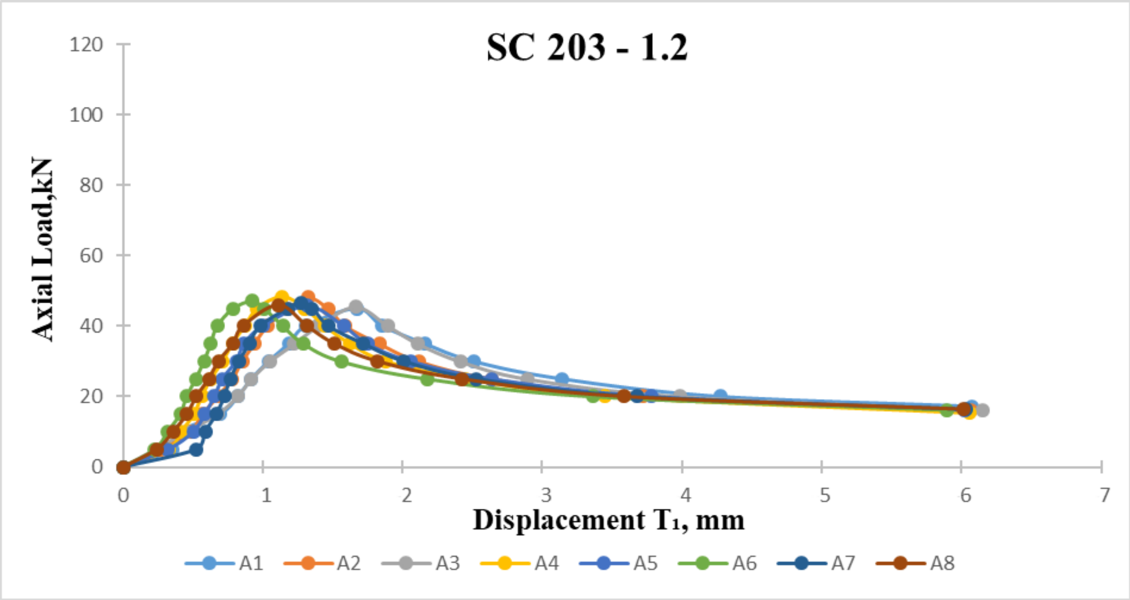


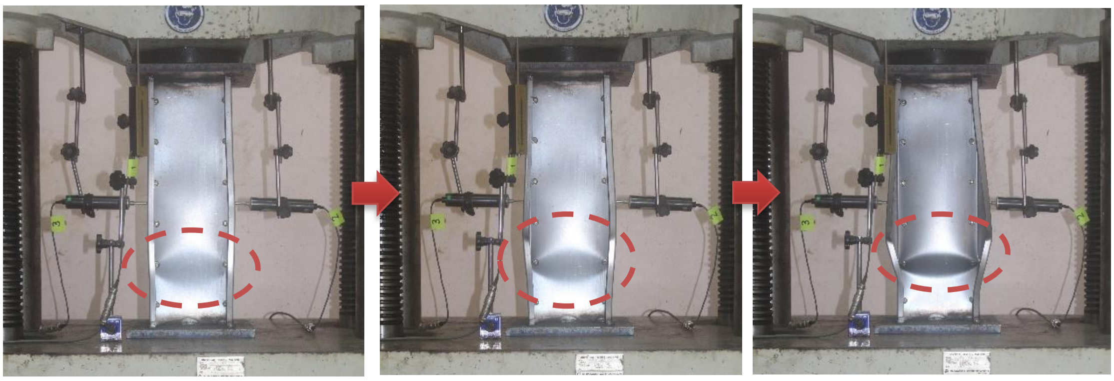
Figure 4.2 Load versus vertical displacement for specimen SC 203-1.2

4.3 Buckling Behaviour

The specimens show a buckling behaviour occurs which is the effect on the column during and after the testing. There are several types of buckling behaviour in this testing. Mostly the buckling behaviours in testing were local buckling, web buckling and distortional buckling. In this study, the observation of buckling behaviour for each specimen during the initial load, peak load and post load. Table 4.3 shows the buckling behaviour for each specimen BC 203-1.2.

Table 4.3 Finalize of buckling behaviour for each specimen BC 203-1.2

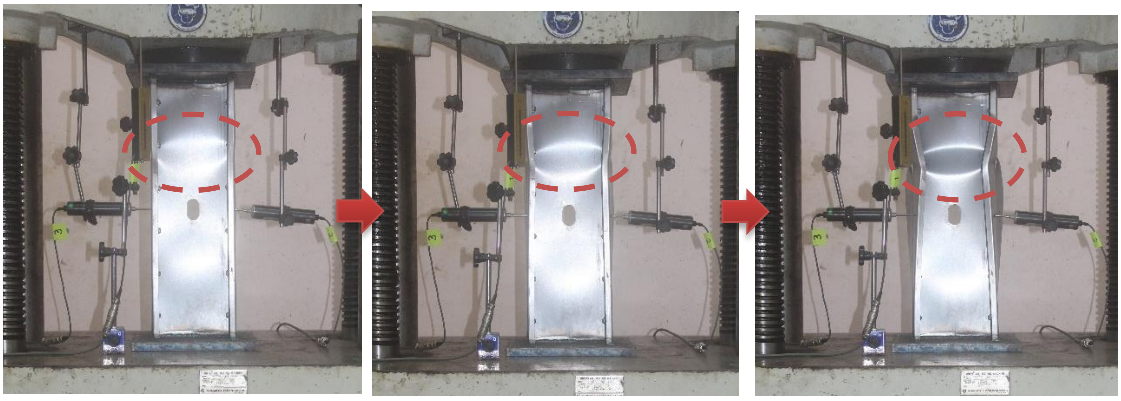
SPECIMEN	BUCKLING BEHAVIOUR
BC 203-1.2-A1	DBB/WBF/LBW
BC 203-1.2-A2	LTF/DTF
BC 203-1.2-A3	WBF/DTB
BC 203-1.2-A4	WBB/DMF
BC 203-1.2-A5	LBF
BC 203-1.2-A6	LM/WBB
BC 203-1.2-A7	WMF/DMB/LM
BC 203-1.2-A8	LM/LT



(a) Initial Load (b) Peak Load (c) Post Load

Figure 4.3 Buckling behaviour of specimen BC 203-1.2-A1

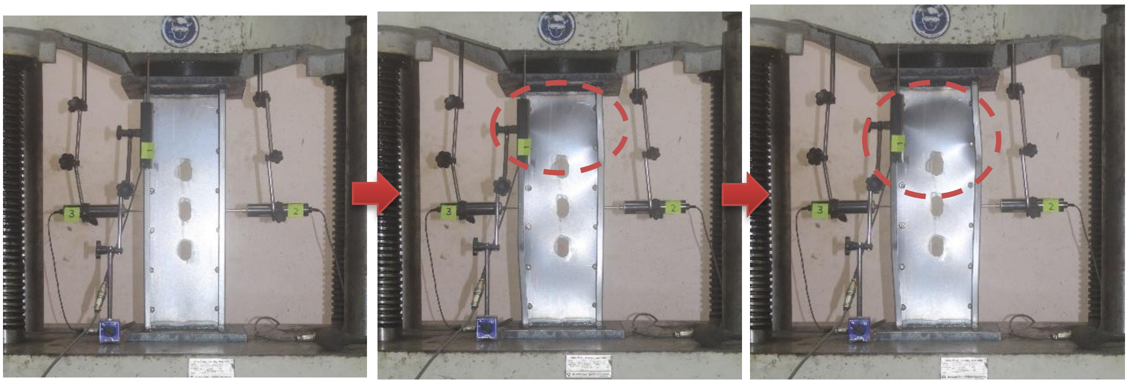
Figure 4.3 shows the specimen for BC 203-1.2-A1 experiences distortional buckling for the initial buckling period and continues warping at the bottom support at front view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A1 comes out with finalize buckling behaviour that are distortional at the bottom support at back view (DBB), web at the bottom support at front view (WBF) and local at bottom support with web (LBW).



(a) Initial Load (b) Peak Load (c) Post Load

Figure 4.4 Buckling behaviour of specimen BC 203-1.2-A2

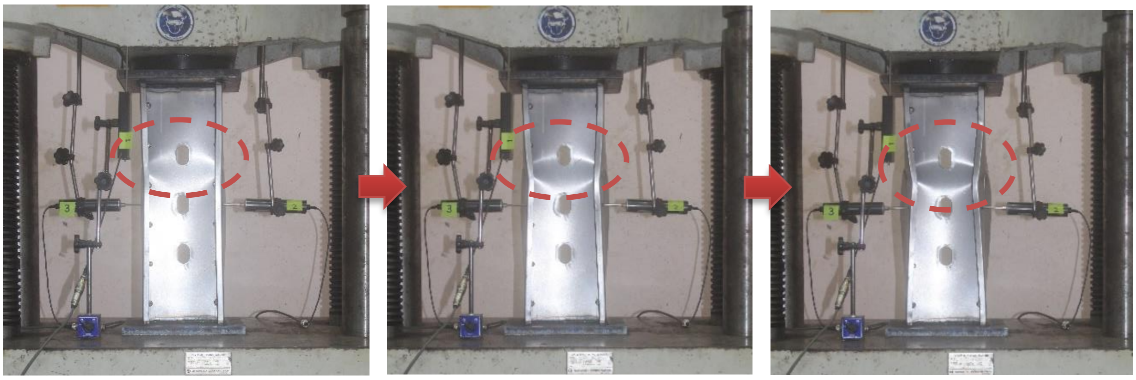
Figure 4.4 shows the specimen for BC 203-1.2-A2 experiences local buckling for the initial buckling period and continuous distortional buckling at the top support at front view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A2 comes out with finalize buckling behaviour that are local buckling at the top support at front view (LTF) and distortional buckling at the top support at front view (DTF).



(a) Initial Load (b) Peak Load (c) Post Load

Figure 4.5 Buckling behaviour of specimen BC 203-1.2-A3

Figure 4.5 shows the specimen for BC 203-1.2-A3 experiences web buckling for the initial buckling period and continuous distortional buckling at the top support at back view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A3 comes out with finalize buckling behaviour that are web buckling at the bottom support at front view (WBF) and distortional buckling at the top support at back view (DTB).



(a) Initial Load (b) Peak Load (c) Post Load

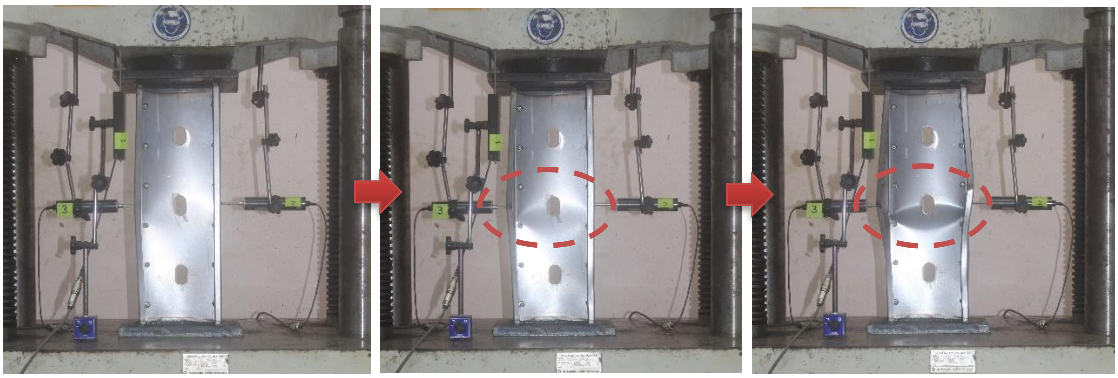
Figure 4.6 Buckling behaviour of specimen BC 203-1.2-A4

Figure 4.6 shows the specimen for BC 203-1.2-A4 experiences web buckling for the initial buckling period and continuous distortional buckling at the middle support at front view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A4 comes out with finalize buckling behaviour that are web buckling at the bottom support at back view (WBB) and distortional buckling at the middle support at front view (DMF).

(a) Initial Load (b) Peak Load (c) Post Load

Figure 4.7 Buckling behaviour of specimen BC 203-1.2-A5

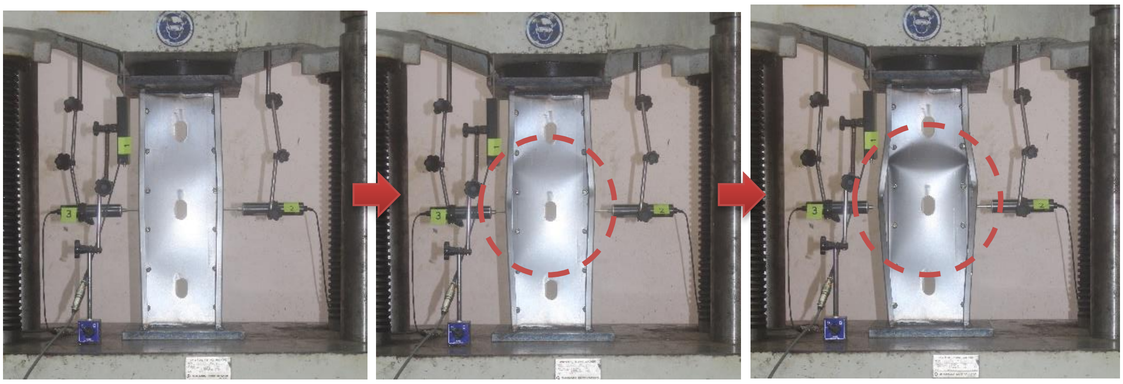
Figure 4.7 shows the specimen for BC 203-1.2-A5 experiences web buckling for the initial buckling period and continuous local buckling at the bottom support at front view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A5 comes out with finalize buckling behaviour that is local buckling at the bottom support at front view (LBF).



(a) Initial Load (b) Peak Load (c) Post Load

Figure 4.8 Buckling behaviour of specimen BC 203-1.2-A6

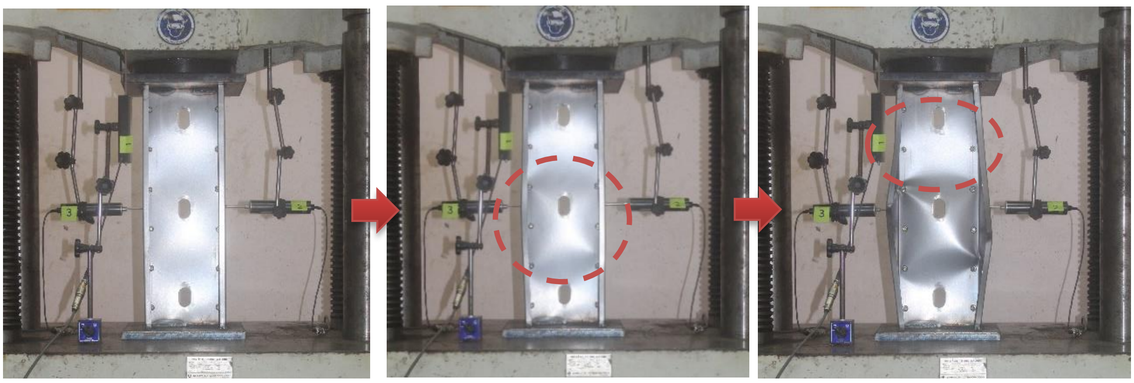
Figure 4.8 shows the specimen for BC 203-1.2-A6 experiences web buckling for the initial buckling period and continuous local buckling at the middle support at front view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A6 comes out with finalize buckling behaviour that are local buckling at the middle support at front view (LM) and web buckling at the bottom support at back view (WBB).



(a) Initial Load (b) Peak Load (c) Post Load

Figure 4.9 Buckling behaviour of specimen BC 203-1.2-A7

Figure 4.9 shows the specimen for BC 203-1.2-A7 experiences web buckling for the initial buckling period and continuous with same behaviour at middle support at front view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A7 comes out with finalize buckling behaviour that are web buckling at the middle support at front view (WMF), distortional buckling at the middle support at back view (DMB) and local buckling at the middle support (LM).



(a) Initial Load (b) Peak Load (c) Post Load

Figure 4.10 Buckling behaviour of specimen BC 203-1.2-A8

Figure 4.10 shows the specimen for BC 203-1.2-A8 experiences distortional buckling for the initial buckling period and continuous web buckling at the middle support at front view of the specimen. Last, for the post load buckling behaviour, BC 203-1.2-A8 comes out with finalize buckling behaviour that are local buckling at the middle support (LM) and local buckling at the top support (LT).

Figure 4.11 Eight specimens for BC 203-1.2 after testing

CHAPTER 5

CONCLUSION

5.1 Conclusion

From the result of testing and observation studies, there are several conclusions obtained in my study.

i. All of specimen in opening gives different data.

ii. Different specimen also contributes to the higher maximum load.

iii. Specimen without openings give more higher maximum load compare to specimen with openings.

iv. Specimen for built-up C section can sustain more maximum load compare to conventional.

v. Mode of failure split into 4 categories; local buckling, distortional buckling, warping and flexural buckling.

vi. The use of transducer in the compression test gives the earlier sign how column structures behave under axial load.

5.2 Recommendation

There are several recommendations that can be used in future research regarding cold-formed steel columns as follow:

i. Investigate the alternate innovative cold-formed steel building systems using finite element analysis.

ii. Increasing the web depth to prevent distortional buckling.

iii. Use built-up cold-formed steel as beam structure.

iv. Use different shape of openings.

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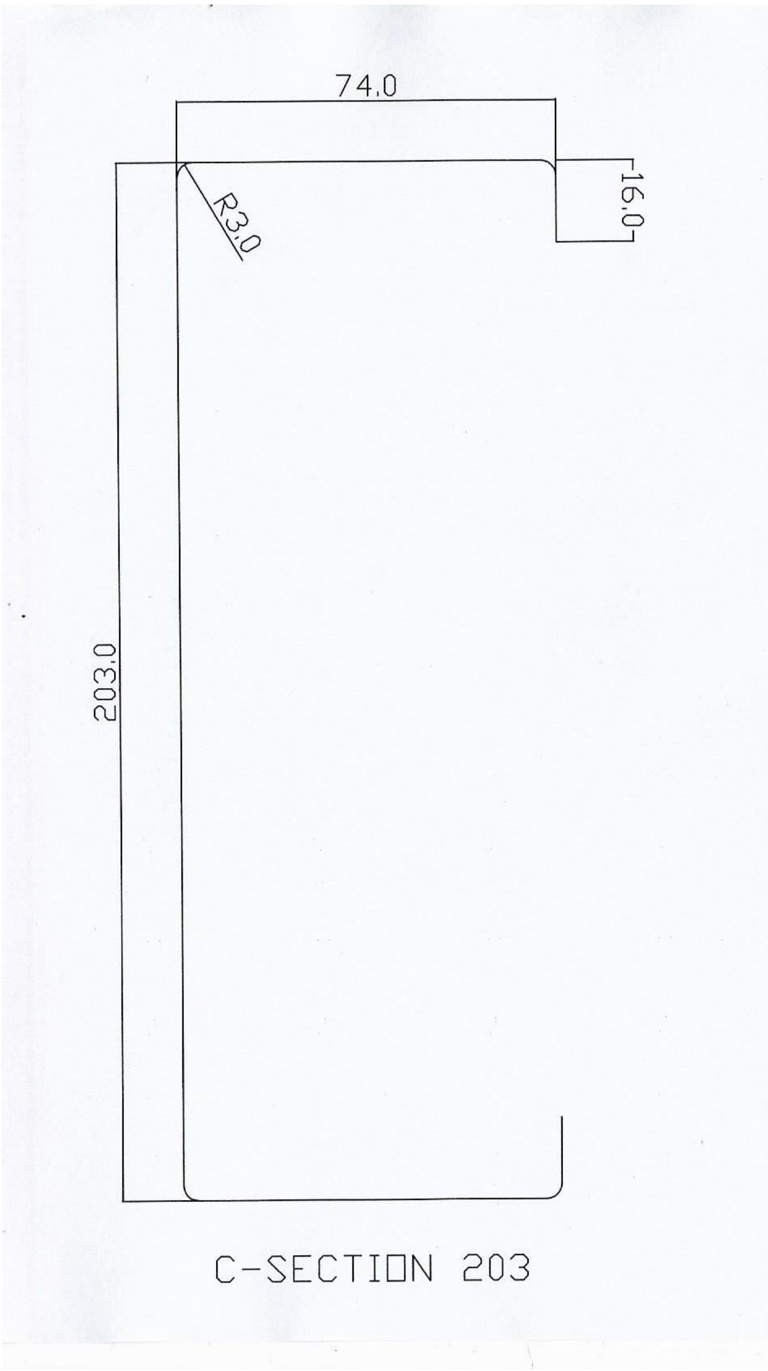
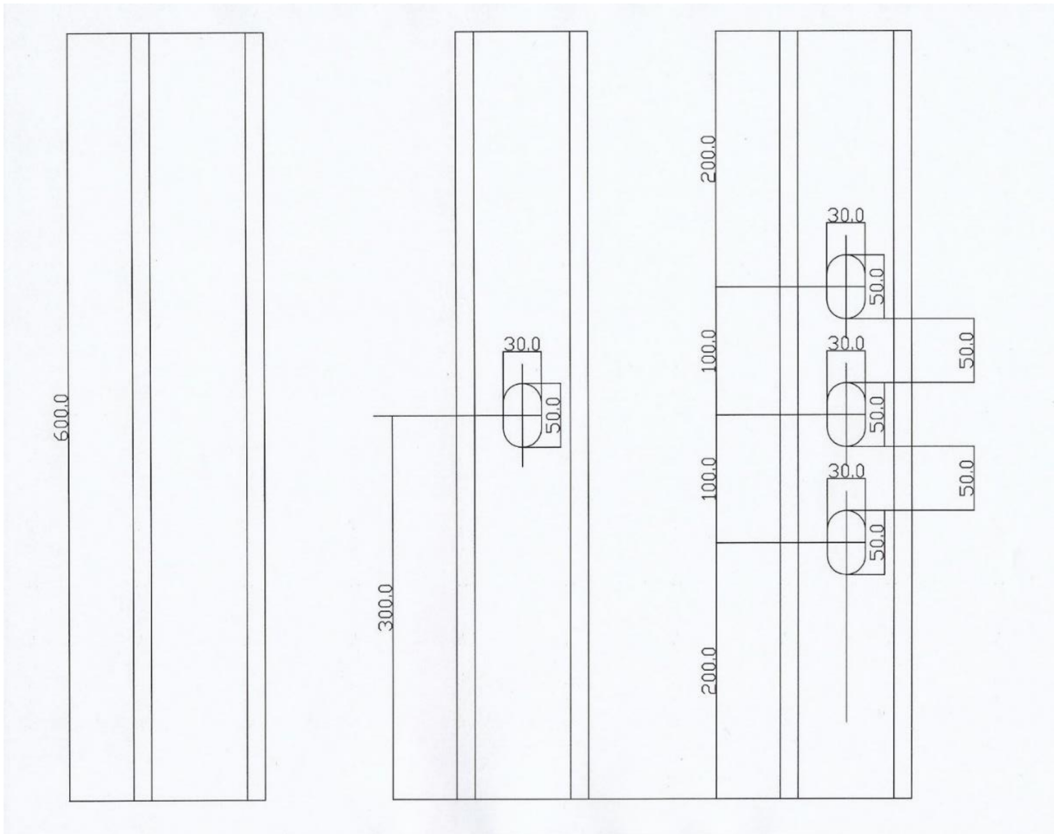
APPENDIX A
DIMENSION FOR SPECIMEN WITH OPENINGS

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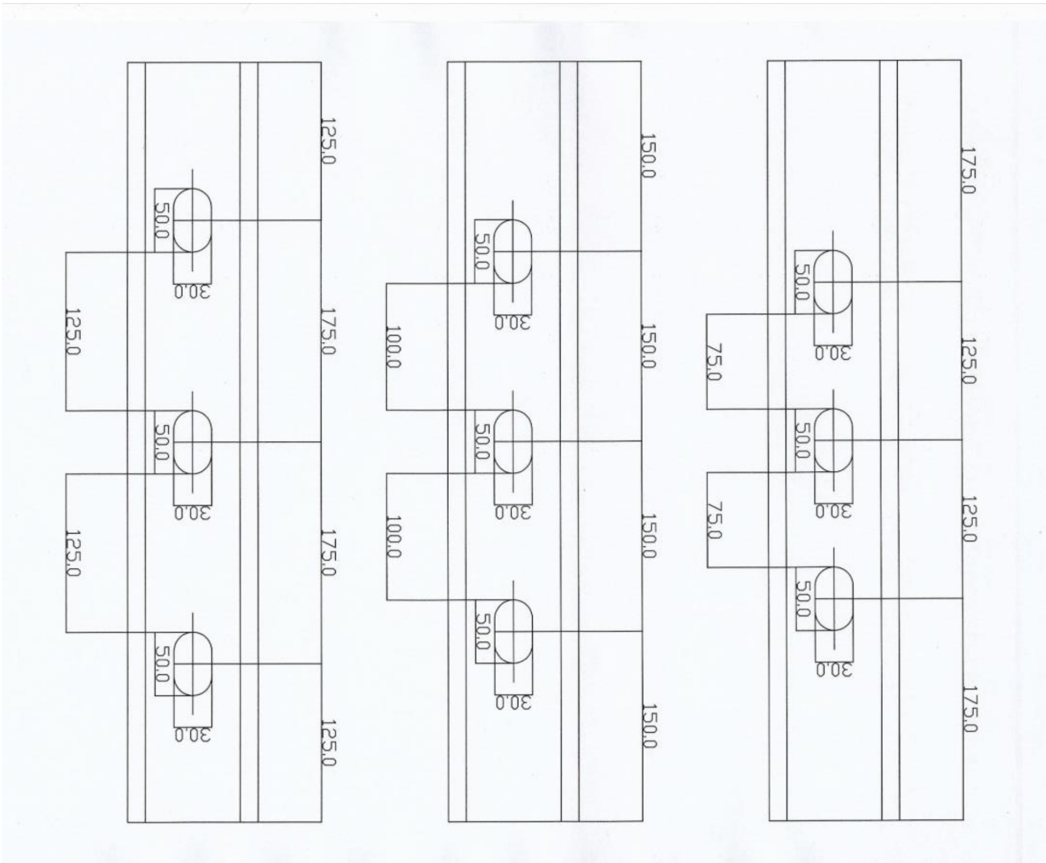

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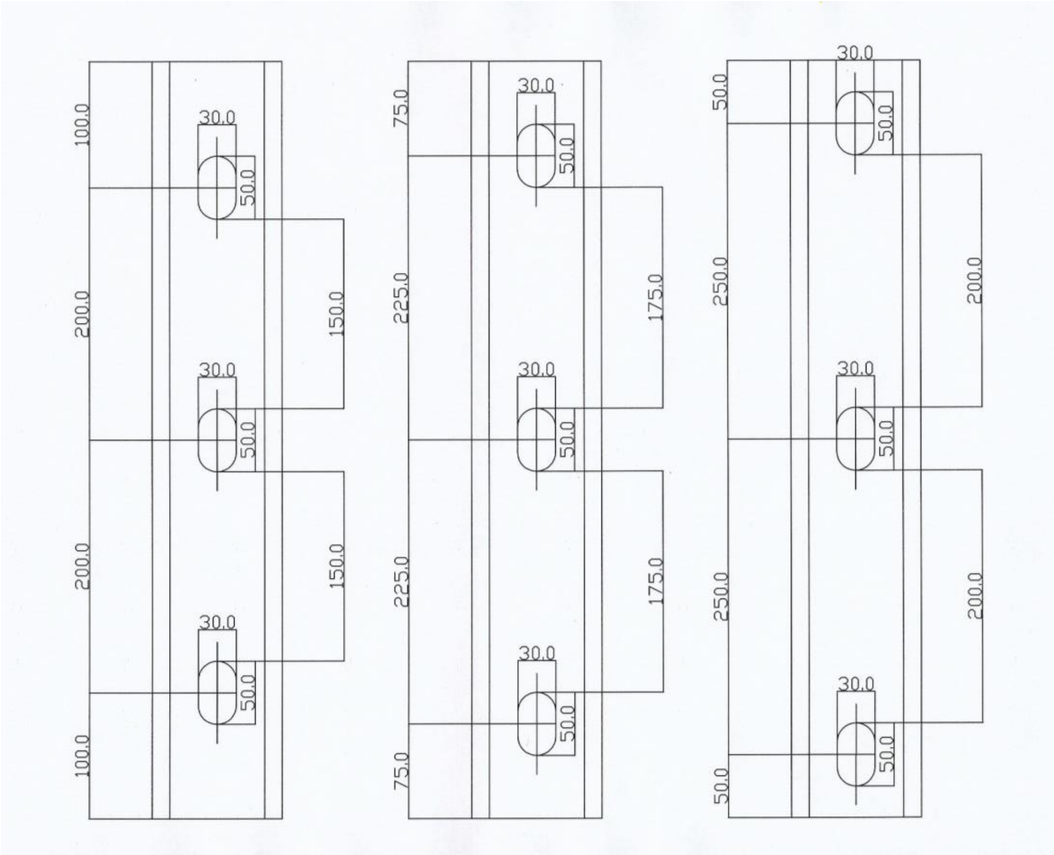
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APPENDIX B
SPECIMEN PREPARATION


BC203-20-A1


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