BEHAVIOUR OF C-SECTION COLD-FORMED STEEL WITH MULTIPLE OPENING

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ABSTRAK

Kertas ini mewakili penyelidikan mengenai tingkah laku struktur tiang keluli terbentuk sejuk yang terjejas oleh interaksi distorsional setempat. Struktur keluli terbentuk sejuk telah digunakan secara meluas dalam industri pembinaan dan telah muncul sebagai penyelesaian pilihan untuk bangunan komersial dan perindustrian satu tingkat. Pada kebiasaan keluli terbentuk sejuk dibuat dengan lubang untutk menampung saluran paip, elektrik dan pemanasan di dinding dan siling bangunan. Kajian ini akan tertumpu pada kesan perforasi pada tiang keluli terbentuk sejuk jenis C. kaedah yang digunakan untuk eksperimen ini adalah ujian mampatan yang mana specimen tiang dimampatkan antara dua plat dengan hujung tetap. Dua siri tiang keluli terbentuk sejuk C-section akan digunakan dalam eksperimen ini dengan kedalaman yang berbeza iaitu 103 mm dan 203 mm masing-masing. Terdapat lima bilangan spesimen untuk setaip siri. Setiap spesimen mempunyai ketebalan nominal 1.2 mm dan panjang lajur 600 mm. Ajakan spesimen semasa ujian dibaca oleh transducer. Hasil kajian ini menunjukkan beban maksimum setiap spesimen berbeza dengan kedudukan perforasi dan saiz spesimen. Graf beban maximum melawan anjakan akan mengkaji pergerakan bebibir semasa ujian mampatan. Tingkah lakunya boleh dilihat sepanjang kajian dimana keleturan distorsional akan berlaku pada spesimen tersebut. Kebanyakan spesimen akan gagal di lubang.

ABSTRACT

This paper represented a research on the structural behaviour of cold-formed steel columns affected by local-distortional interaction. Cold-formed steel structural have been widely used in the construction industry and have emerged as a preferred solution for single-storey commercial and industrial building. Commonly, cold-formed steel was manufactured with holes to accommodate plumbing, electrical, and heating conduit in the walls and ceilings of the buildings. This research will be concentrated on the effect of the perforation on the C-section cold-formed steel column. The method used for this experiment was compression test which are the column specimens were compressed between bearing plate with fixed ends. Two series of single C-section cold formed steel column will be used in this experiment with different depth which is 103 mm and 203 mm respectively. There are five numbers of specimens for each series. Each member has nominal thickness of 1.2 mm and the column length of 600 mm. The displacement of the specimen during testing was read by the transducer. The result of this experiment shows the ultimate load of each specimen varies with the position of the perforation and the depth. The graph of load-displacement will studied the movement of the flange during the compression test. The buckling behaviour can be seen along the experiment which is the distortional and local buckling will occur on the specimens. Most of the specimen will failed at the hole.

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LIST OF ABBREVIATIONS

CFS	Cold-formed Steel
DSM	Direct Shear Method
UTM	Universal Testing Machine
SPCC	Steel Plate Cold rolled Common
JIS	Japanese Industrial Standard
LVDT	Lateral Vertical Displacement Transducer
T2	Transducer 2
T3	Transducer 3

CHAPTER 1

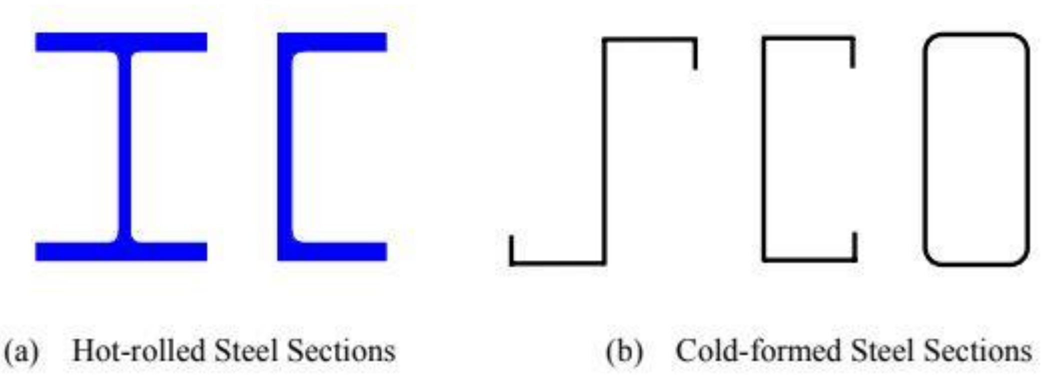
INTRODUCTION

1.1 Introduction

In the current industry sector, cold-formed steel (CFS) are wildly used specifically in building structures like transportation machineries, storage racks, domestic equipment's and others. Cold-formed steel sections are manufactured with difference process such as folding, press-breaking and rolling. Nowadays, cold formed steel are wildly available with difference sizes and shapes (Reddy et al, 2016). Cold formed steel structural members may lead to a more economic design than hot-rolled steel members as a result of their superior strength to weight ratio and ease of construction. Figure 1.1 (a) and (b) shows the differences between hot-rolled section and cold-rolled section that used in building construction. Light gauge cold-formed steel members are commonly used as wall studs and chord members of roof trusses in steel frame housing and industrial building (Young, 2008).

Cold-formed steel structural members are commonly provided with holes to accommodate plumbing, electrical, and heating conduit in the walls and ceilings of buildings. These holes are typically located in the web of C, E, and Z section and can alter the elastic stiffness and ultimate strength of a structural member (Moen et al, 2008). The holes often punched out in the webs and flanges of cold-formed members. The presences of the holes may result in a reduction of the strength of individual component elements and of the overall strength of the member (Sivakumaran, 1987). The ultimate strength is driven by local buckling and yielding the cross-section. The column lengths and cross-section dimensions are specifically chosen to explore the connection between local, distortional, and global elastic buckling modes, ultimate strength, and the resulting failure mechanism (Moen et al., 2008).

The edges stiffeners are commonly used in cold-formed steel section provide continuous support along the longitudinal edge of the flange to enhance the buckling stress. It can be easily brake-pressed or roll-formed on the free edge of an unstiffened plate. Therefore, cold-formed sections having edge stiffeners can lead to an economic design as a result of higher buckling stress of the sections. However, local buckling stress could be enhanced by adding intermediate web stiffeners (Young, 2008). The presences of holes will increase the buckling strength of the webs (Crisan et al, 2012).



(a) Hot-rolled Steel Sections (b) Cold-formed Steel Sections

Figure 1.1 Steel section used in building construction

1.1.1 Application of cold-formed steel

Nowadays, cold-formed steel member are widely used in building construction, such as wall studs, floor joists, truss members and other structural application. Figure 1.2 (a) and (b) shows the structural framing that widely used in construction. While, Figure 1.3 and Figure 1.4 shows the application of the cold-formed steel member which is residential and rack system.

(a) Commersial building (b) Residential

Figure 1.2 Structure framing

(a) House (b) Rack system

Figure 1.3 Common usage of the cold-formed steel

1.2 Problem Statements

Cold-formed steel are widely used in construction industry. Many structural cold-formed steel members are provided with cut-outs to accommodate electrical, plumbing, and heating services and the perforations are either pre-punched or punched on site. Cold-formed steel easily shaped compared to hot-rolled steel. Nowadays, in structural building construction, cold-formed structural members are becoming more popular and have a growing importance which is it have been used as a main structure such as column. As known, column is a main structure in a building which it is act as a key structure that transmitted load to foundation and then to the ground. Because of that, the steel demand is increase in construction that led to the increasing of the steel price. The price of steel is calculated based on the weight ordered from the manufactured. The cost and the weight of the steel requires in industries are major consideration during design stage of the project. If the weight from the top of the structure is reduced, it will result fewer loads transferred to the column and therefore reduce the size of other parts of the structure. Beside the installation for column structure does not have to use more man power and this is also one of the ways to reduce cost. For this experiment, the short column of cold-formed steel is used.

In order to reduce the overall cost of the project, web opening concept for purlin was introduced to reduce it weight with a manufactured of a regular pattern of multiple holes. With the presence of opening will result in a redistribution of membrane stresses because of the consequential changes in buckling and strength characteristics. The strength of steel structure that consists of more than one opening or cut-out is depends on the shape, sizes, and the location of the opening. Thus, the analysis and design of structural steel members with perforated elements was complex. Based on the numerous researchers in the past, the design rules for cold-formed steel members with perforations are limited to certain perforation sizes, shapes, orientations, and positions. However, it has been identified that due to the shape of the perforations and the thickness of the sections and for other practical reasons, reinforcement of these perforations in thin-walled members is not possible.

1.3 Objective of Research

The aim of this research is to study the behaviour of cold-formed C-section steel with multiple opening. The objectives of this research are focus on the open section of C-section cold-formed steel:

1. To determine the ultimate load of axially loaded short column with different opening arrangement.
2. To study the buckling behavior of axially loaded short column with different opening arrangement

1.4 Scope of Research

In this study, a series of short column of cold formed C-section with lipped channel section will be conducted. The columns were compressed between the fixed ends. The section of the cold formed C-section that being tested is a single section and a short column which is the depth web of the column section is 103 mm and 203 mm with the thickness is 1.2 mm. The height of the short column is 600 mm. One series of short column consist of five specimens with multiple opening with various position arrangements. The total specimens that will be conducted in this research are ten specimens. The shape of the opening used is elongated circle opening. The plate for the base is used and will act as a support and it will be welded together at end of the top and bottom of the cold-formed steel. It will act as fixed end support. The ultimate load of cold-formed C-section members with different position of perforations is tested by studying the behavior of the buckling mode of the cold-formed steel. Figure 1.5 shows the example of the cold-formed steel with different position of opening from previous research.

Figure 1.4 Example of cold-formed steel with different position of openings
Source: Kulatunga and Macdonald (2013)

1.5 Significance of Research

From this study, it will contribute to the benefits in the construction industry. The behaviour of cold-formed steel of C-section with the existence of the perforations can be studied. From the experimental study, the deformation of cold-formed steel of C-section with different position of perforations can be analysed. The strength of the cold-formed steel column will improve if the web size increases from 100 mm to 200 mm. Besides that, the strength compaction of the cold-formed steel column between opening and without opening can be analysed. Therefore, the data of the maximum load imposed to the column can be taken. Furthermore, the opening effect on the cold-formed steel column if the opening located at the mid height of the column and the opening at edge can be compared. The strength of the cold-formed steel C-section will change depends on the position of the perforations. According to previous researcher, cold-formed tend to buckle locally at stress levels lower than the yield strength of the material when they are subjected to various loading conditions. However, for the normal structural steel design classification, the failure modes are not commonly encounter. Therefore, extensive testing required to provide a guideline for the cold-formed structural members.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Cold-formed steel products such as section have been commonly used in the metal building construction industry for more than 40 years and are found in all aspect of modern life. Beside, cold-formed members are extensively used in North-America and Australia and New Zealand in residential housing as primary load-bearing structures, light-gauge building systems are gaining on popularity and compete with the traditional building material, wood (Budapest, 2009). The popularity of the products has dramatically increased in recent years due to their wide range of application, economy, and ease of fabrication, and high strength-to weight ratios. Figure 2.1 shows the common shapes of cold-formed in industries. Furthermore, cold-formed members for most application are designed in accordance with the Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington, DC.

Meanwhile, the usage of cold-formed in building construction in Malaysia did not widely applicable until recently where the use of cold-formed steel in replacing hot-formed steel had been widely accepted. But, due to the limitation of the specimen causes the usage of the cold-formed still not widely used in construction. Figure 2.2 shows the application of cold-formed steel in structure framing used in construction. Moreover, most of the local product has their own limitation with the absent of opening. The existence of the opening will make the limitation of cold-formed will be changed.

Therefore, this study will indicate whether the presence of opening will affect the strength of cold-formed steel.

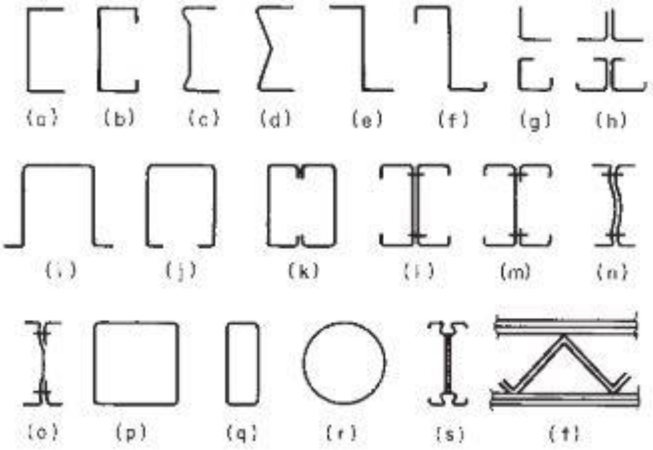


Figure 2.1 Common shapes of cold-formed steel

Source: Yu Wei-Wen, (2000).

Figure 2.2 The application of cold-formed steel in structure framing

2.2 Characteristics of C-section Cold-formed Steel

From this study, it will contribute to the benefits in the construction industry. The behavior of cold-formed steel of C-section with the existence of the perforations can be studied. From the experimental study, the deformation of cold-formed steel of C-section with different position of perforations can be analyzed. The strength of the cold-formed steel column will improve if the web size increases from 100 mm to 200 mm. Besides that, the strength compaction of the cold-formed steel column between opening and without opening can be analyzed. Therefore, the data of the maximum load imposed to the column can be taken. Furthermore, the opening effect on the cold-formed steel column if the opening located at the mid height of the column and the opening at edge can be compared. The strength of the cold-formed steel C-section will change depends on the position of the perforations. According to previous researcher, cold-formed tend to buckle locally at stress levels lower than the yield strength of the material when they are subjected to various loading conditions. However, for the normal structural steel design classification, the failure modes are not commonly encounter. Therefore, extensive testing required to provide a guideline for the cold-formed structural members.

2.3 Cold-formed Method

In manufacture of cold-formed sections, there are three general methods use which is cold roll forming, press brake operation and bending brake operation (Yu Wei-Wen, 2000). As studied by Kulatunga & Macdonald, (2013), these processes increase the yield strength and tensile strength but at the same time decrease the ductility of cold-formed steel sections, particularly at the corners where these properties can be considerably different from those of the flat steel sheet, plate, and strip or bar before forming.

The dominant cold forming process is known as roll-forming. In this process, a coil of steel is fed through a series of rolls, each of which bends the sheet progressively until the final shape is reached at the last roll stand. Figure 2.3 show the cold rolling process. Press braking normally involves producing one complete fold at a time along the full length of a section. Therefore, press braking can be used to produce a variety shape with low volume production. The process of press braking method are shown in Figure 2.4.

Figure 2.3 Cold-roll forming method

Figure 2.4 Press braking method

2.4 C-section Cold-formed Steel Column

The cold-formed steel column is designed based on the North American Specification For The Design Of Cold-Formed Steel Structural Members, the AISI Cold-Formed Steel Design Manual of 2002 edition and the Australia/New Zealand Standard 4600:2005. While, the design of single C0section members in compression is covered by the application rules of Eurocode 3. Figure 2.5 shows the cross section of the C-section from the studied by (Weng & Pekoz, 1990).

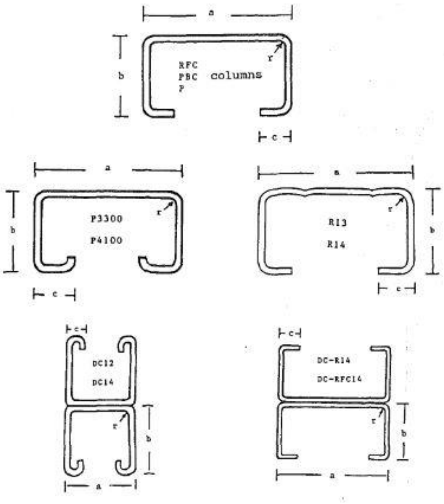


Figure 2.5 Cross section of the C-section

2.4.1 Short Column

Weng & Pekoz (1990) stated that, for the determination of the length of the short column are based on the recommendation of The Technical Memorandum No.3 of the Structural Research Council Guide (Johnson 1976). The length of the short column was suggested should not less than three times the largest dimension of the section, nor greater than 20 times the radius of gyration about the weak axis of the section. The objective of choosing a proper length is to ensure that the short column is short enough so that the influence of overall buckling is minimized, but long enough so that the end effect can be neglected. Figure 2.6 indicates the typical short column and intermediate column with slotted holes (Moen & Schafer, 2009a).

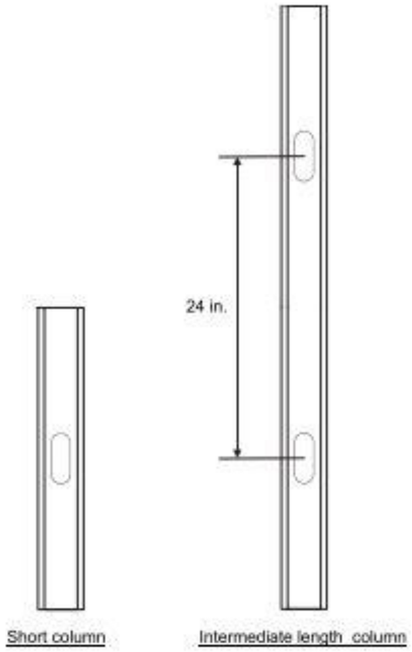


Figure 2.6 Typical column specimens with slotted holes
Source: Moen & Schafer, (2009)

2.5 Advantaged of Cold-formed Steel

The research from Anbarasu et al., (2010) indicate that, cold-formed light gauge steel structural members provide the following advantages in building construction:

a) Cold rolling can be employed to produce almost any desired shape to any desired length.

b) Pre-galvanized or pre-coated metals can be formed, so that high resistance to corrosion, besides an attractive surface finish, can be achieved.

c) All conventional jointing methods such as riveting, bolting, welding and adhesives can be employed.

d) High strength to weight ratio is achieved in cold-rolled products.

e) They are usually light making it easy to transport and erect

f) As compared with thicker hot rolled shapes, more economical design can be achieved for relatively light loads and/or short spans.

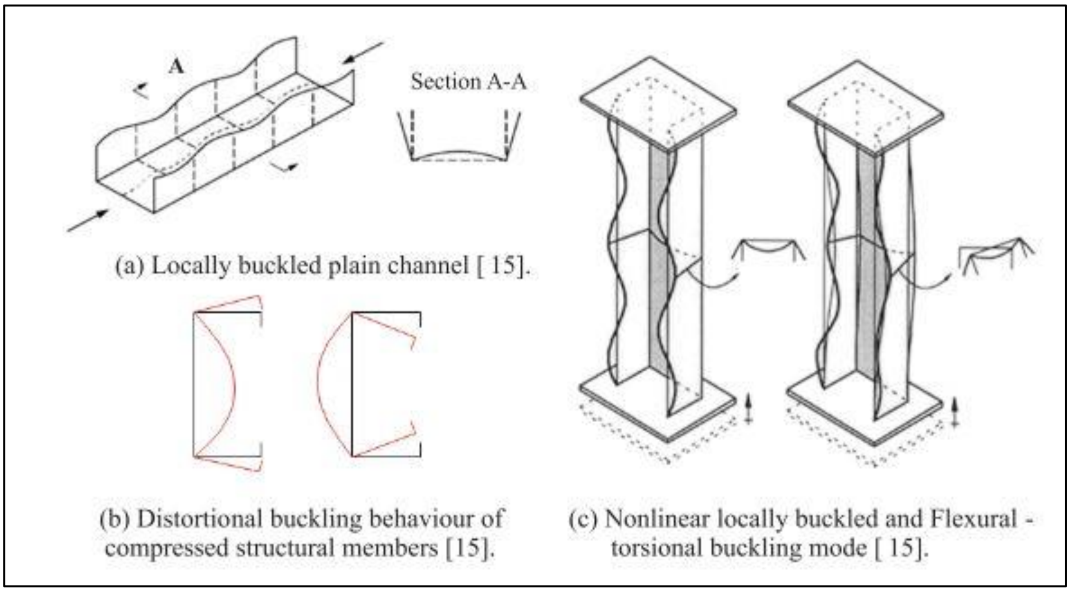
g) Unusual sectional configuration can be economically produced by cold forming operation, and consequently favorable strength-to-weight ratios can be obtained.

h) Load carrying panels and decks can provide useful surfaces for floor, roof, and wall constructions, and in other cases they can provide enclosed cells for electrical and other conduits.

i) Load carrying panels and decks not only withstand loads normal to their surfaces, but they can also act as shear diaphragms to resist force in their own planes if they are adequately inter connected to each other and to supporting members.

2.6 Buckling Mode of C-section Cold-formed Steel In Compression

Unlike heavy hot-rolled steel sections, cold-formed thin-walled sections tend to buckle locally at stress levels lower than the yield strength of the material when they are subjected to various loading conditions. However, these members do not fail at these stress levels and continue to carry further loads. In thin-walled cold-formed steel structures, elastic bucking and load deformation response are closely related. Besides that, the influence of perforations may promote unique buckling modes and can encourage collapse mechanisms at the ultimate state (MacDonald & Kulatunga, 2013). Liu et al, (2004) indicated that, for a typical C-shape column under pure axial compression, the local buckling is the dominant. In compression, cold-formed members can exhibit three modes of instability which is local, distortional and flexural or flexural–torsional buckling. Local modes and global modes (i.e. flexural and flexural–torsional buckling) are largely covered in the main design codes by means of effective widths, for the plate elements, and by column design equations, for global buckling (Rondal, 2000). There are different buckling modes as illustrated in Figure 2.6 which is local buckling, distortional buckling and Euler buckling (flexural or torsional-flexural) as illustrated by (MacDonald & Kulatunga, 2013).



(a) Locally buckled plain channel [15].

(b) Distortional buckling behaviour of compressed structural members [15].

(c) Nonlinear locally buckled and Flexural - torsional buckling mode [15].

Figure 2.7 Types of buckling mode

Source: MacDonald & Kulatunga, (2013).

2.6.1 Local Buckling

As defined in the Australian/New Zealand Standard, local buckling is a mode involving plate flexure alone without transverse deformation of the line or lines of intersection of adjoining plates (Hancock, 2003). Local buckling involves deformation of the component plate elements of the section, with the plate junctions remaining straight and occurs as plate buckling of individual slender elements in a cross-section. The influence of local buckling on column strength depends on the following factors such as the slenderness ratio of the column, the shape of the cross section, influence of cold work, the type of steel used and its mechanical properties, the type of governing overall column buckling, effect of imperfection, effect of welding, interaction between plane components, effect of perforations and effect of residual stress. In general, local buckling near the perforation controls the elastic buckling stress of the plates.

2.6.2 Distortional Buckling

Distortional buckling, also known as “stiffener buckling” or “Local torsional buckling” is mode characterized by a rotation of the flange at the flange web junction in numbers with edge stiffened elements (Anbarasu et al., 2010). Hancock et al. (2006)

stated that distortional buckling consists of the membrane and flexural deformation of the cross section at intermediate half wavelengths. In members with intermediately stiffened elements distortional buckling is characterized by displacement of the intermediate stiffener normal to the plane of the element.

2.6.3 Flexural-Torsional Bucklin

As defined in the Australian Standard for Cold-formed Steel Structures Australia/New Zealand Standard, flexural-torsional buckling is the lateral and torsional deformation of the section without change of cross-sectional shape. Besides that, flexural-torsional is a mode in which compression members can bend and twist simultaneously without change of cross-sectional shape (Hancock, 2003). Flexural-torsional buckling in cold-formed steel occurs simultaneous between bending and twisting due to the smaller thickness of the section that have low torsional stiffness and their shear center and centroid are located away from each other (Anbarasu et al. 2010).

2.7 Effect of Axially Loaded C-section Cold-formed Steel Column

As studied by Wang et al, (2016), he discovered a typical failure modes of short column which is local buckling and distortional buckling. While, Kulatunga & Macdonald, (2013) indicated that mostly the column tested failed by local and distortional buckling. Moen et al (2008) in their study revealed that the presences of opening only caused a slight decrease in the ultimate compressive strength.

According to Yu Wei-Wen (2000), the overall column strength was effected by the interaction of the local and overall column buckling. Hence, the design provision or the overall flexural buckling and the effect of local buckling on column strength have been included in the AISI Specification. Generally, the influence of local buckling on column strength depends on:

a) Shape of cross section

b) Slenderness ratio of column

c) Types of governing overall column, buckling (flexural buckling, torsional buckling, or flexural-torsional buckling)

d) Type of steel used and its mechanical properties

e) Influence of cold work

f) Effect of imperfection

g) Effect of welding

h) Effect of residual stress

i) Interaction between plane components

j) Effect of perforations

2.8 Previous Research Paper

2.8.1 Elastic Buckling of cold-formed steel columns and beam with holes

Research done by Moen & Schafer, (2009) was used the simplified method to develop and summarized the global, distortional, and local critical elastic buckling loads of cold-formed steel columns and beams. These methods are developed as a convenient alternative to shell finite element eigen-buckling analysis which required laborious and subjective visual identification methods. The proposed methods are verified with shell finite element eigen-buckling studies. Unambiguous, simple methods for elastic buckling prediction of members with holes are central to the extension of the Direct Strength Method (DSM) for cold-formed steel member ultimate strength. Based on the experimental investigation, as the global elastic buckling load decrease relative to the squash load, the global slenderness of the column increases and the more slender column has less capacity. The quantifying reduction caused by the presence of holes can be achieved with Finite Element eigen-buckling analysis, although the option is subjective, laborious, and not typically accessible to practicing engineers. The elastic global buckling decreases with increasing hole, and that the flexural-torsional mode is more sensitive to hole diameter than the weak-axis flexural mode. The distortional buckling is recognizes as a design limit states for cold-formed steel columns and beams with open cross-sections, separate from that of global or local global buckling interaction. The approximate prediction method for distortional buckling of column with holes was verified with 78 lipped C-section column specimens from an experiment. The conclusion for the experiment are the global, distortional, and local buckling of cold-formed steel members with holes can be approximated using simple, unambiguous procedures that may readily be employed in engineering design.

2.8.2 Behaviour of cold-formed steel perforated section in compression. Part 1-Experimental investigation

This research was done by Crisan et al., (2012) was aimed to study the interaction buckling of steel pallet racks. The upright members of two different cross-sections, with and without perforation, were tested in order to determine the ultimate strength for specimens of length corresponding to local buckling such as stub column, and the length equal to the distance between two subsequent nodes of upright frame. The ends of experimental testing, the distortional buckling of upright members was observed. The stub column tests were performed to observe the influence of the perforations and the effect of local buckling on the ultimate strength of these members. The test result of two sections studied experimental program according to EN15512, which are stub columns and upright specimens do not characterise the distortional buckling mode. The upright specimens considered for the call distortional. It can be conclude that the pure distortional tests are necessary to be introduced in the experimental program according to EN15512, if the interaction between distortional and overall modes. Moreover, the perforation can be considered as a kind of imperfections. A perforated section is more imperfect than an unperforated one.

2.8.3 Investigation of cold-formed steel structural members with perforations of different arrangement subjected to compression loading

Research done by Kulatunga & Macdonald (2013) described a series of compression test performed on cold-formed steel column member of lipped channel. The test done by using Finite Element Analysis to study the effect of perforation position and the finite element model will be developed using ANSYS to verify its accuracy between experimental and theory. From the study, it is showed that the ultimate load of the lipped channels under compression varied greatly with the perforation position. Furthermore, the result from the finite element and the test result were compared by the existing design specification. To predict the ultimate strength of thin-walled section, the buckling prediction rules in British Standards and Eurocode has been used. In this research, load was applied through a load bearing plate that represents the actual loading conditions applied in the experiments. In addition, the displacement control method was employed to control the loading to stimulate the buckling behaviour observed in the experimental investigation. The aim of the experiment was to investigate the influence of perforation positions on the ultimate strength and the failure modes of lipped section column. Therefore, the size of the perforation will kept constant and the perforation positions were varied in order to investigate the effect of perforation positions on the ultimate strength. Besides, a channel section without perforations was also tested. The column lengths, cross-section dimensions, and perforation area were kept constant. In this investigation, specimens were tested on a Titanus Olsen testing machine. The result obtained from the finite element investigation into the load capacity of column members of lipped channel cross-section subjected to compression loading were compared against the failure load predicted by experimental and theoretical investigations. The investigation showed that the ultimate load of the structure under compression greatly varied with the perforation position. The experimental and numerical investigations showed that in the case of slender cross sections, which are substantially affected by local buckling, the incorporation of perforations in the areas near to ends has a greater weakening effect than the same perforations at other locations.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The method that involved in this study is experimental compression test on short column. The process of setting up the specimens during testing is started by placing the transducer first. After placing the transducer, the specimen then is placed on the machine. Next, the transducer places at the position according to the focusing study. There is three transducer used which is the first transducer is placing on the top of the specimens while transducer two on the left side and transducer three on the right side. Then, the loading rate of the Universal Testing Machine needed to be set-up. The Universal Testing Machine will compressed the specimen until the machine are stop by the user when the displacement is 6.0 mm.

Research done by Moen and Schafer (2009) tittle, Direct strength design of cold-formed steel members with perforations, (2009) had been used as a standard to do the experiment. From this research, it also provided the basic guide to develop all the research on cold-formed steel members.

The result of the behavior and performance between cold-formed steel C-section and the position of openings with the axial load applied to the cold-formed steel column were obtained by using the experimental study at the laboratory. The aim of the experiment is to study the influence of opening position on the ultimate strength and the failure modes of single C-section column.

3.2 Experimental investigation

Cold-formed lipped channel sections subjected to compression loading were considered in the investigation. Figure 3.1 below show the overview of the process where the experiment will be conducted.

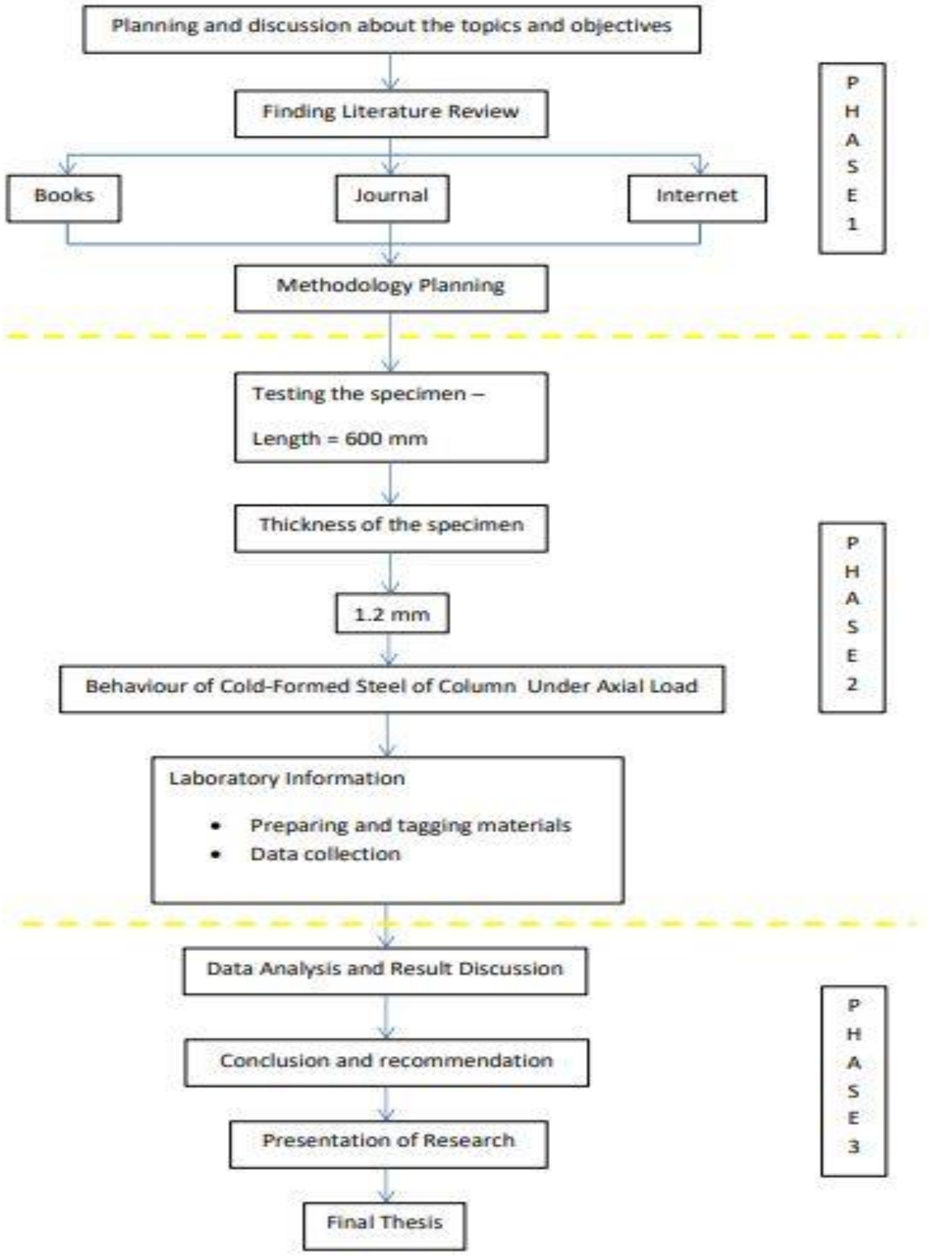


Figure 3.1 Project Flow Chart

3.3 Material Used

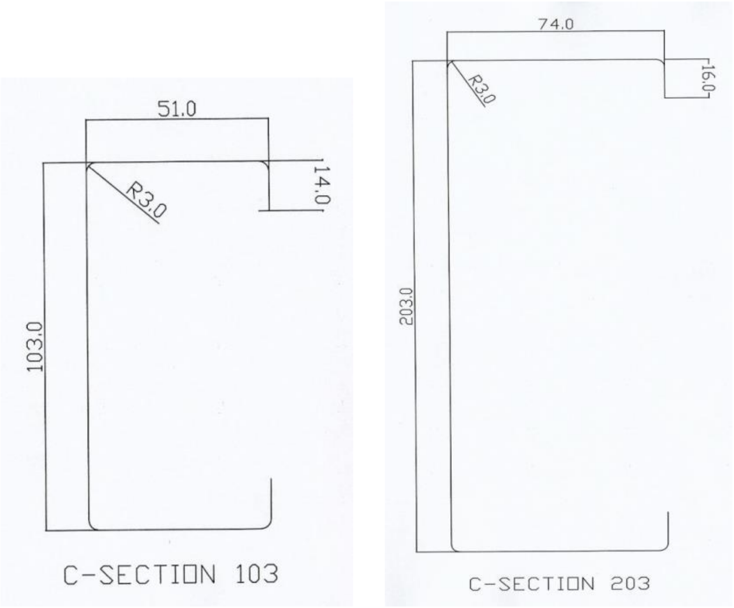
Cold-formed C-section is selected for this test. The selection of the material based on previous research and also consideration on Universal Testing Machine (UTM) on the laboratory. The cold-formed sections were brake-pressed from steel plate cold rolled common (SPCC) cold rolled sheet which is the standard of Japanese Industrial standard (JIS) “Cold-reduced carbon steel sheets and strips” having the material grade and designation defined in JIS G 3141. The tensile strength of the SPCC Steels is must be at least 270 MPa. The maximum height of the specimen that Universal Testing Machine on the laboratory can support is average 700 mm. The height of the specimen is including the base plate.

3.4 Section Parameter

The parameter and the magnitude of the C-section cold-formed are shown in Table 3.1. Figure 3.2 (a) and (b) shows the cross section of the C-cold-formed steel for section 103 mm and 203 mm. While, Figure 3.3 shows the schematic drawing of cold-formed steel with section 103 mm.

Table 3.1 Parameter and magnitude of the cross-section

Parameter	**Section 103**	**Section 203**
Depth, H	103 mm	302 mm
Thickness, t	1.2 mm	1.2 mm
Flange, B	51 mm	74 mm
Edge stiffener, L	14 mm	16 mm
Length, l	600 mm	600 mm



(a) (b)

Figure 3.2 Cross section of Cold-formed steel

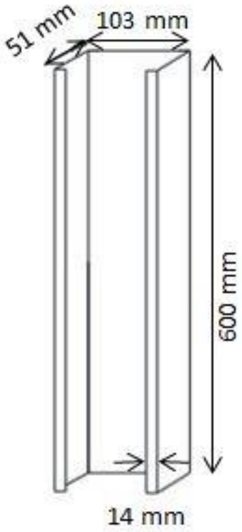


Figure 3.3 Schematic drawing for cold-formed steel with section 103 mm

3.5 Naming Convention

The specimen naming convention, as it relates to the testing parameters is defined in Figure 3.4.

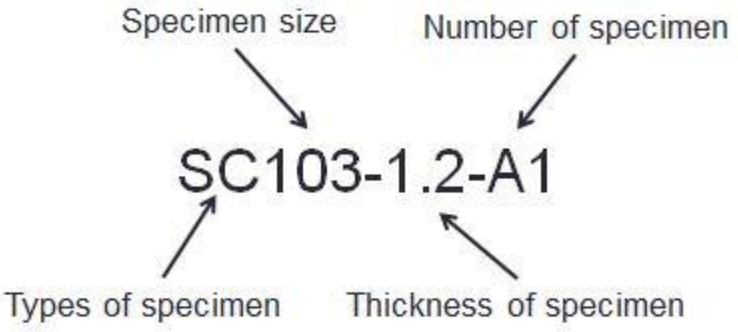


Figure 3.4 Naming convention of specimen

3.6 Preparation of Specimen

Before starting the experiment testing, the specimens that will be used must be prepared first. Figure 3.5 below shows the cold rolled sheet before it been shaped into C-section. This cold rolled sheet was came with the present of holes on it that already prepared by the supplier. Figure 3.6 show the process of shaping the cold rolled sheet and the result of the process can be seen clearly in Figure 3.7. After that, the specimens will be measured and naming as shown in Figure 3.7. Lastly, before starting the testing, the specimens will be welded at the both end of it and Figure 3.8 shows the process of welding done by the lab technician.

Figure 3.5 Cold rolled sheet

Figure 3.6 Process of shaping the cold rolled sheet

Figure 3.7 Results of the specimens after been shaped

Figure 3.8 Process of measuring and naming specimens

Figure 3.9 Welding process

3.7 Schematic Diagram

The diagram of the specimens and machines used are described by drawing. All dimensions are in millimeter (mm). The size of the opening are kept constant as shown in Figure 3.8 and the position of the transducer also constant as shown in Figure 3.9. Figure 3.10 (a), (b) and (c) illustrated varies of opening position in order to investigate the effect of opening position on ultimate strength. The set-up of the transducer location and the position of the specimens during testing have shown on the Figure 3.11 and Figure 3.12. Figure 3.13 show the set-up of the apparatus in the laboratory, while, Figure 3.14 show the apparatus set-up from the previous research.

Figure 3.10 Schematic diagram of opening

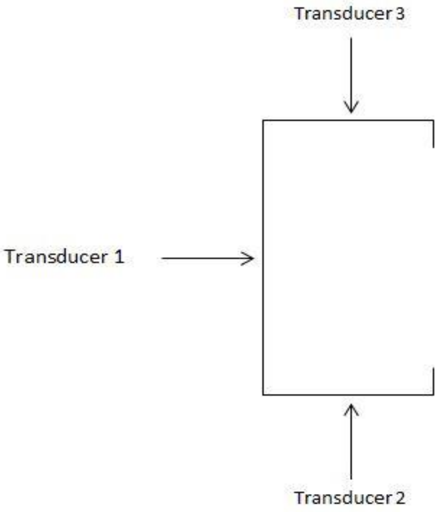
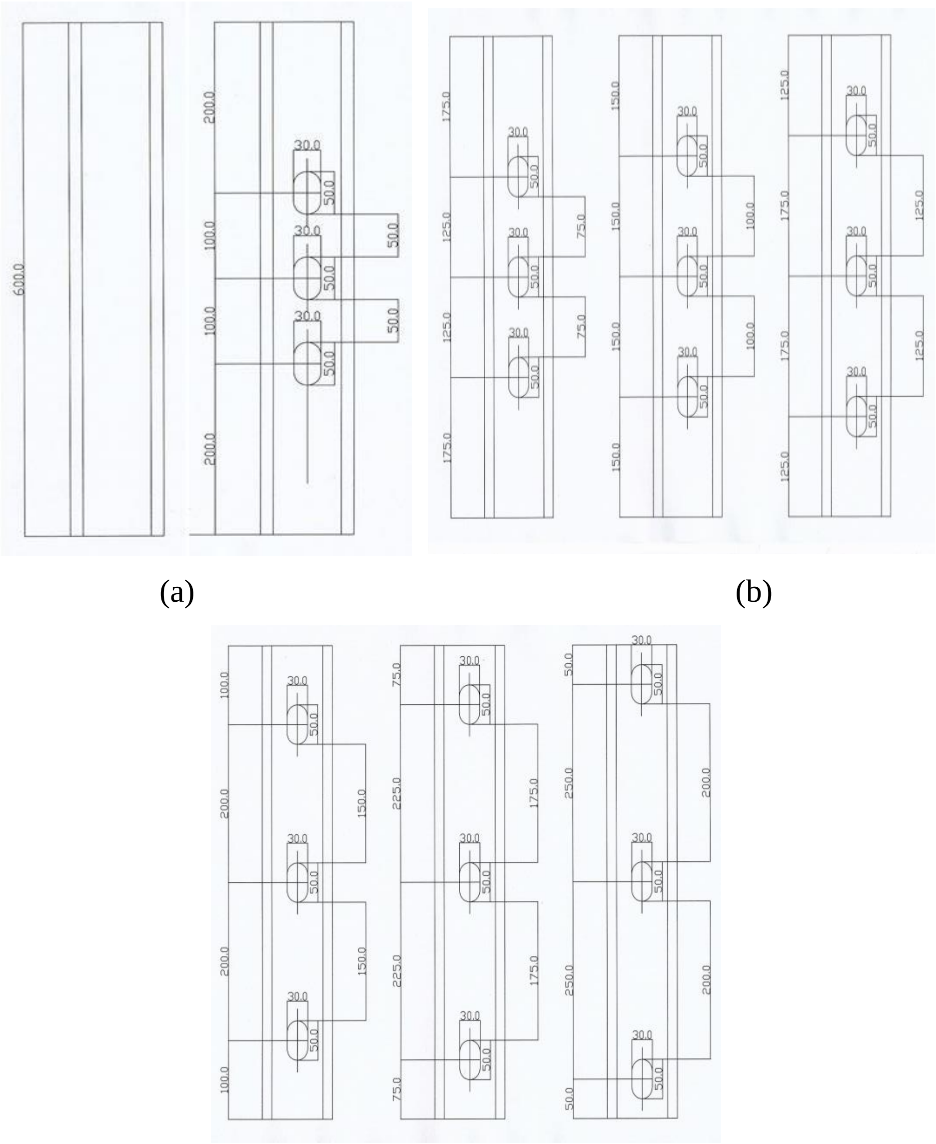


Figure 3.11 Location of transducer



(a) (b)

(c)

Figure 3.12 Pictures (a), (b) and (c) indicates the schematic drawing of series of cold-formed C-section

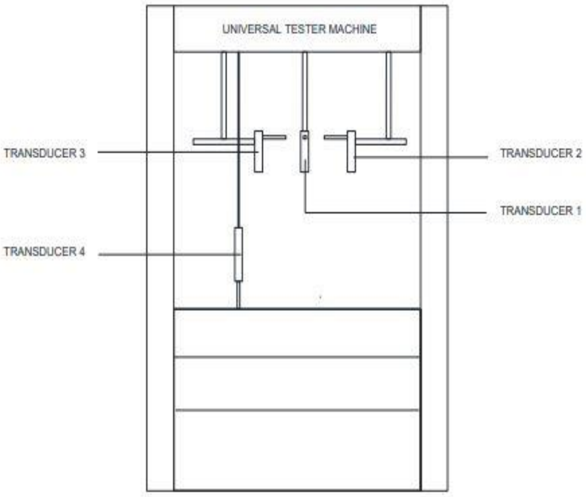


Figure 3.13 Universal testing machine and transducer set-up

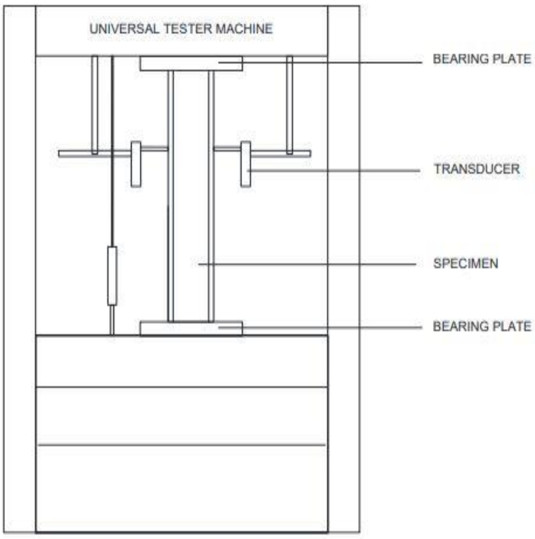


Figure 3.14 Schematic diagram of specimen set-up

3.8 Operation Set-up and Loading

This experiment will be conducted by using Universal Testing Machine and transducers. The Universal Testing Machine will impose load to the specimens and the axial load will be read and the data will be collected by the computer. The transducers will read the displacement on the specimens. The data will be collected by the laptop.

There are three transducers that will be used to take data. The initial load used is 0.5 N per mm, while the loading rate used is 0.5 mm per minutes which is it was the most suitable rate for this specimens according to the previous researcher. Figure 3.5 shows the series of cold-formed C-section with various position of perforation. The support being used for the specimen is flat end as shown in Figure 3.6 and Figure 3.7.

Figure 3.15 Series of cold-formed C-section with various position of perforation

Figure 3.16 The support of the specimens

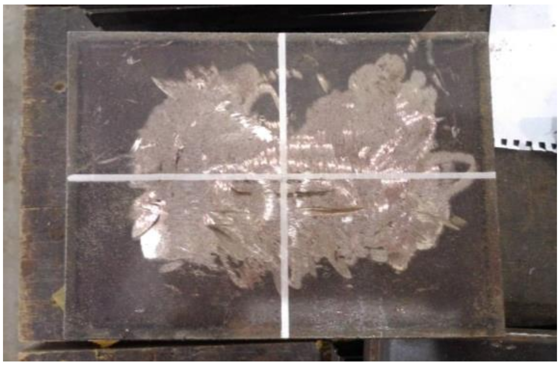


Figure 3.17 Bearing plate for the top and bottom

Figure 3.18 Apparatus set-up in laboratory

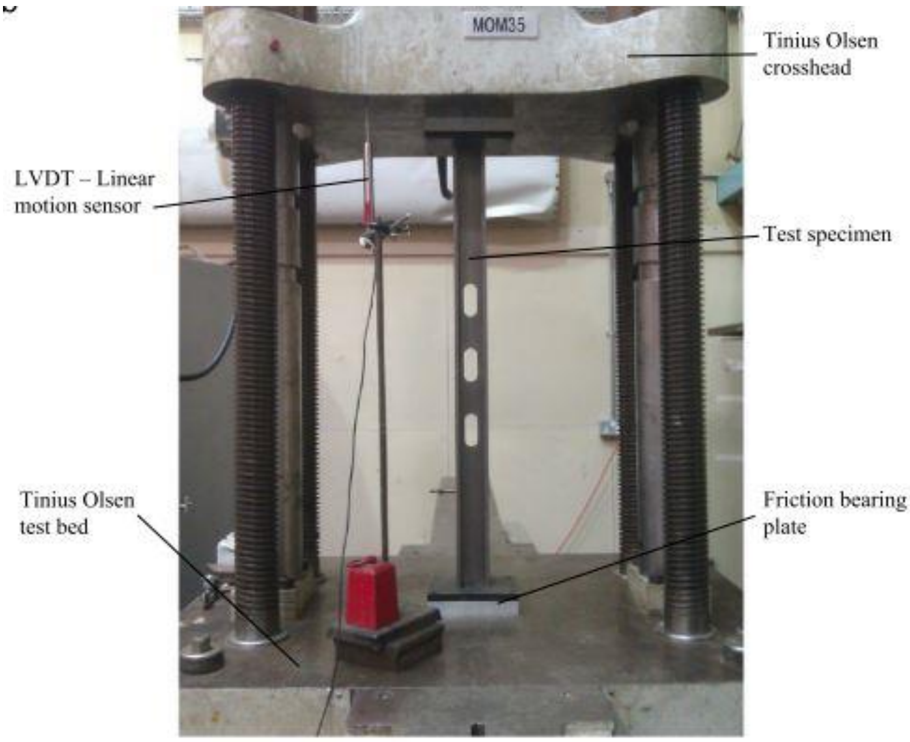


Figure 3.19 Tinius Olsen testing machine

Sources: Kulatunga, M. and Macdonald, M. (2013).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result obtained from the compression test will be discussed. The vertical and horizontal displacement result of the specimen had been taken during testing. The maximum displacement taken was kept constant that is 6 mm. Besides, the maximum axial load exerted on the specimen is taken. The data lodger was used to collect the data by connect it with transducer. For lateral displacement, two transducers are placed at the both side of the flange of column while for vertical displacement one transducer had been placed at the top plate of specimen. The experimental investigation was aimed to studying the influences of the different opening position on the ultimate load and the buckling behaviour of C-section short column. The size of the opening was kept constant and the opening positions were varied.

4.2 Ultimate Strength

The peak tested compression load for column specimens are provided in Table 1. The load exerted on the specimen from the Universal Testing Machine was collected by the computer. Table 1 shows the measurement of specimens dimension and experimental result of SC103-1.2 and SC203-1.2. 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.

Table 4.1 Measured Specimen Dimensions and Experimental Results

	No.	**Thickness, t (mm)**	**Depth, H (mm)**	**Flange, B (mm)**	**Lip, L_1 (mm)**	**Lip, L_2 (mm)**	**Length, L (mm)**	**H/t**	**B/t**	**H/B**	**Experimental ultimate load, P (kN)**
SC103-1.2	A1	1.2	103	51	14	14	600	85.83	42.5	2.02	36.34
	A2	1.2	103	51	14	14	600	85.83	42.5	2.02	41.41
	A3	1.2	103	51	14	14	600	85.83	42.5	2.02	39.17
	A4	1.2	103	51	14	14	600	85.83	42.5	2.02	41.48
	A5	1.2	103	51	14	14	600	85.83	42.5	2.02	41.47
SC203-1.2	A1	1.2	203	74	16	16	600	169.17	61.67	2.74	48.33
	A2	1.2	203	74	16	16	600	169.17	61.67	2.74	45.71
	A3	1.2	203	74	16	16	600	169.17	61.67	2.74	47.15
	A4	1.2	203	74	16	16	600	169.17	61.67	2.74	46.59
	A5	1.2	203	74	16	16	600	169.17	61.67	2.74	45.93

4.3 Axial Load versus Vertical Displacement

The ultimate strength values of compression members are illustrated in buckling behaviour by using linear vertical displacement transducer (LVDT) device. For the vertical displacement, transducer 1 was used to measure the displacement from the top plate of specimens. The load-displacement graph was used to determine the ultimate strength.

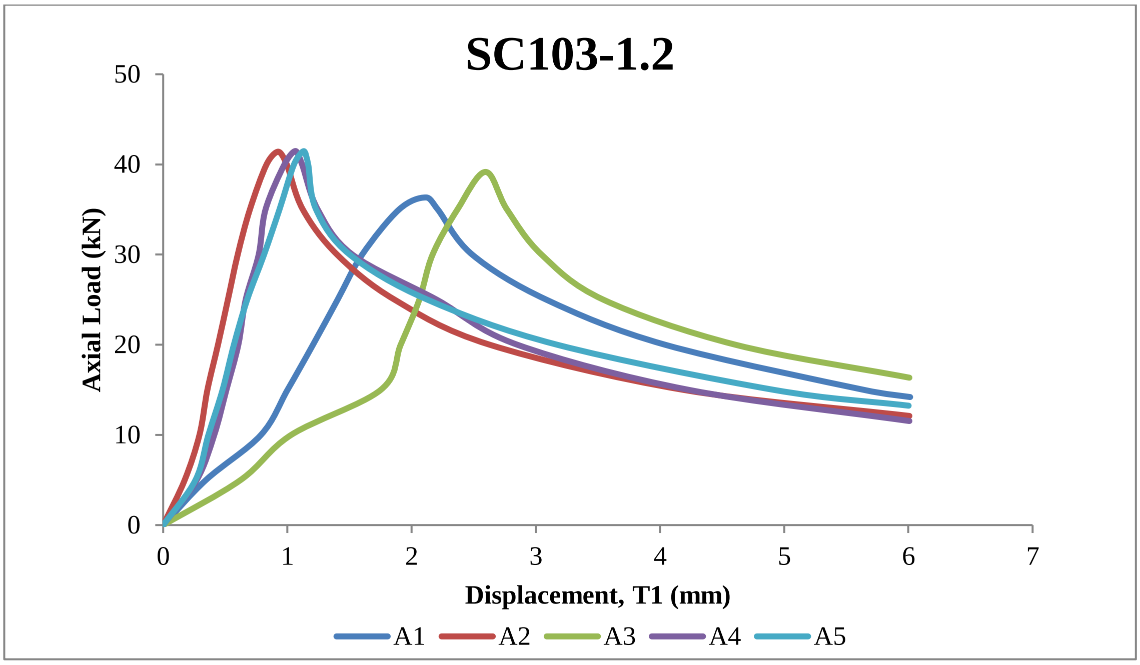


Figure 4.1 Axial load versus vertical displacement graph

For specimen SC103-1.2 there is five specimens that are tested under compression load. Figure 4.1 below shows the axial load versus displacement graph while Table 4.2 shows the maximum load of the specimens.

Table 4.2 Maximum load of SC103-1.2

Specimen	Load(kN)	T1(mm)
A1	36.34	2.116
A2	41.41	0.926
A3	39.17	2.595
A4	41.48	1.065
A5	41.47	1.132

As illustrated in Figure 4.1 it shows that the specimens will reach it maximum point when the load exerted on it. From the graph in Figure 4.1 it shows that A1 has the lowest ultimate load with 36.3375 kN. Based on Figure 4.1 and Table 4.2, the specimen that has the highest ultimate load is A4 with 41.4838 kN.

For the specimens with depth 203 mm with thickness 1.2 mm, there are five specimens tested under compression load in this experiment. Figure 4.2 below shows the graph of axial load versus vertical displacement for SC203-1.2 specimens and Table 4.3 below shows the maximum load of the specimens.

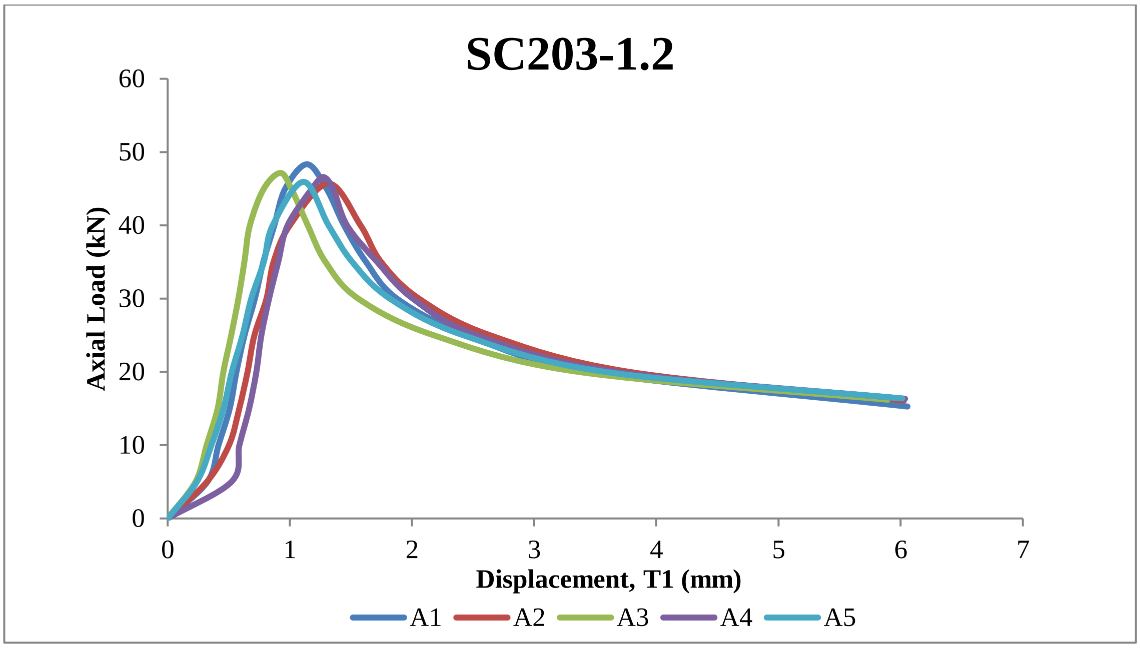


Figure 4.2 Axial load versus vertical displacement graph

Based on graph in Figure 4.2 it indicated that all the specimens only has a slightly difference of ultimate load. From the graph it can be seen that the highest ultimate load of the specimen SC203-1.2 is A1 with 48.33437 kN while, the lowest ultimate load is A2 with 45.70937 kN.

Table 4.3 Maximum load of SC203-1.2

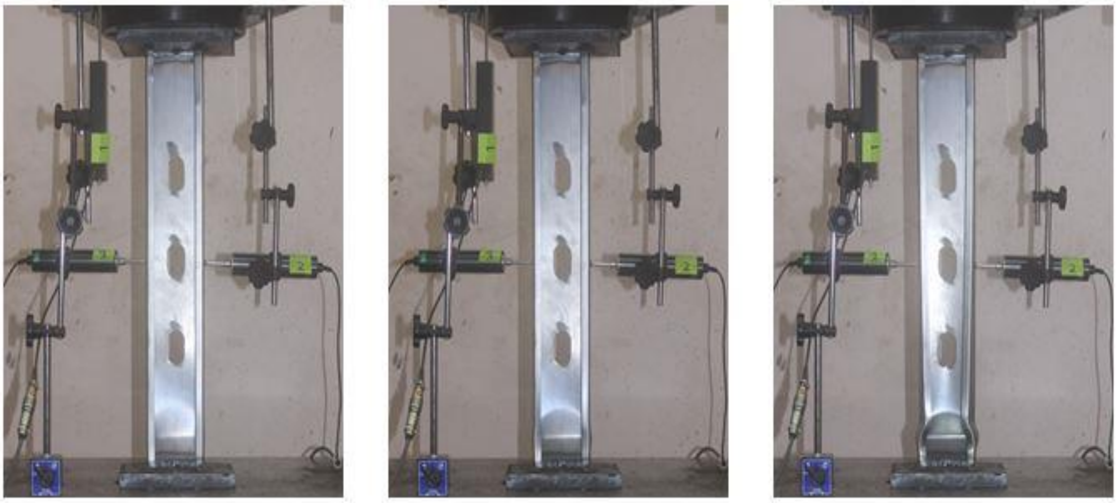
Specimen	Load (kN)	Displacement, T1 (mm)
A1	48.33	1.14
A2	45.71	1.316
A3	47.15	0.923
A4	46.59	1.273
A5	45.93	1.112

4.4 Buckling Behaviour

The short columns tests were performed in order to observe the influence of perforations on the ultimate strength of the columns. According to (Crisan, Ungureanu, & Dubina, 2012b) the column will experienced local buckling on the ultimate strength. The buckling behaviour of the column can be observed based on Load-Lateral Displacement graph.

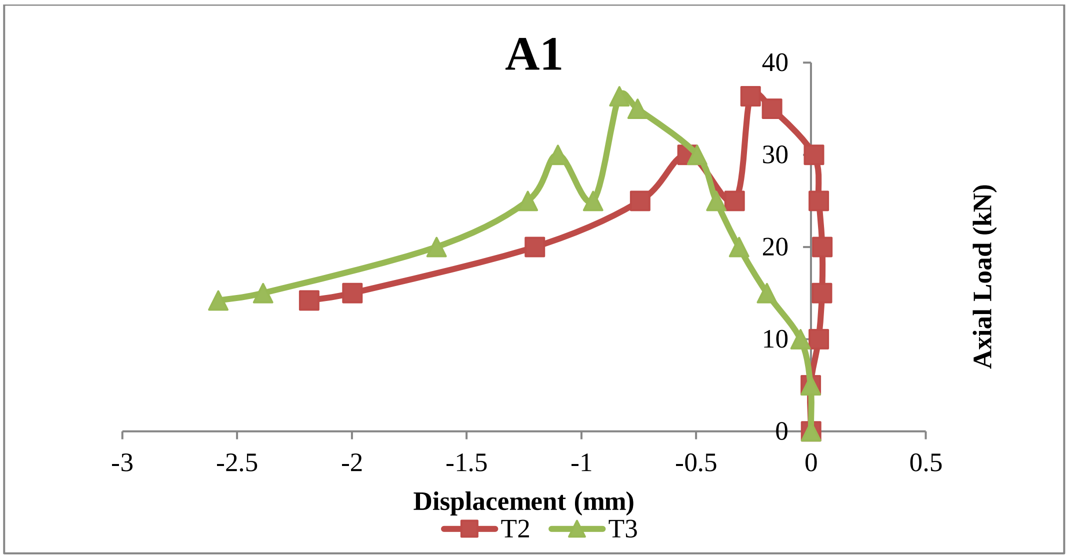
The lateral displacement was read by the linear vertical displacement transducer (LVDT) places at the right and left side of the specimen. The right transducer was label as T2 and the left transducer was label as T3. According to (Wang et al., 2016) for the short column, the distortional deformation mainly occurs at the mid-height of the column and presented a symmetrical internal concave deformation on column.

4.4.1 SC103-1.2



Initial buckling mode Peak load Post peak load

(a)

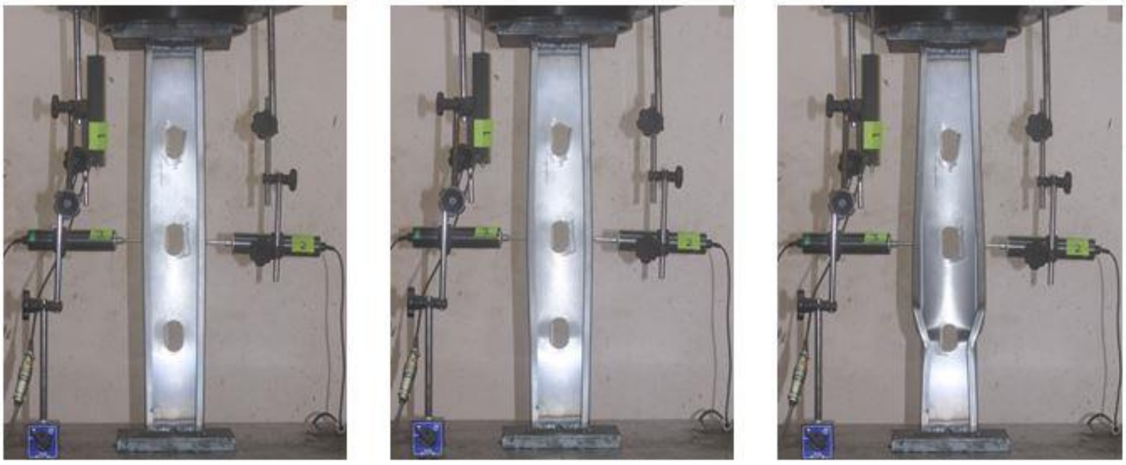


(b)

Figure 4.3 (a) and (b) SC103-1.2-A1

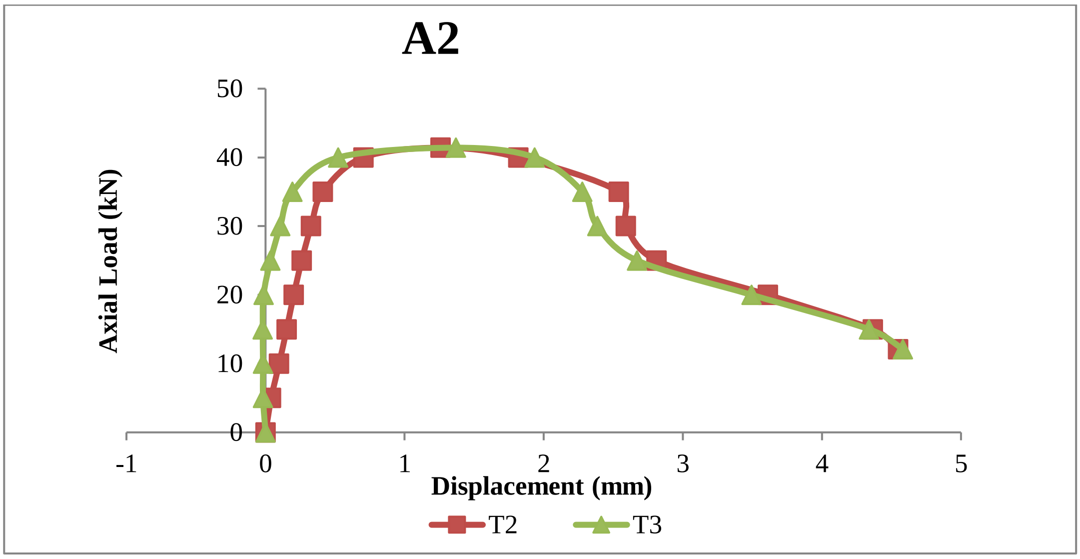
Figure 4.3 (a) shows the buckling behaviour of column during the initial load, peak load and the post load while Figure 4.3 (b) shows the axial load versus horizontal displacement. From Figure 4.3 (b) it can be seen that the displacement value for T2 and

T3 are negative where it show that the flange warping due to compression. While, during the initial load there is buckling at the bottom web. After reach the peak load, the flange of column buckle outward due to negative displacement. On the post load, the flange also experience distort inwards.



Initial buckling mode	Peak load	Post peak load

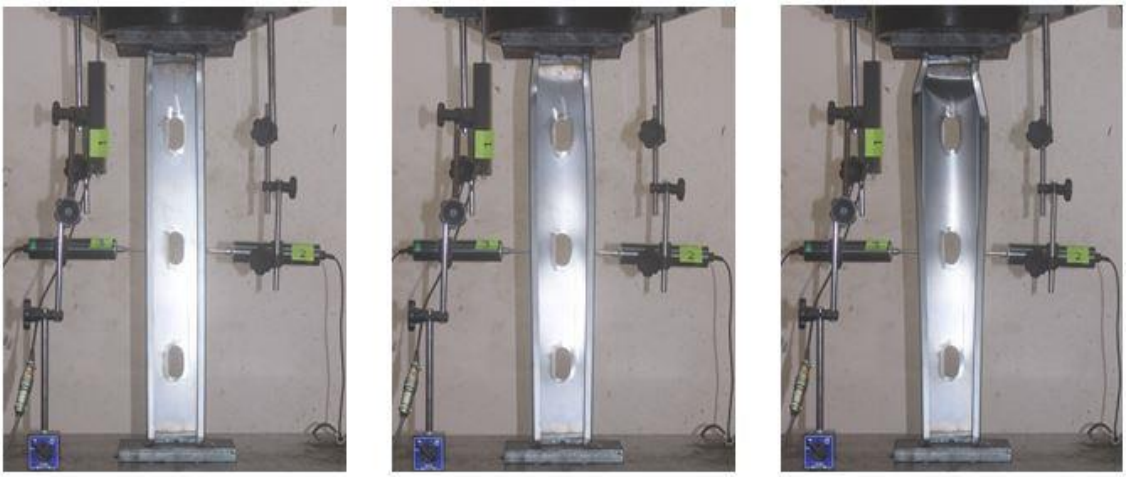
(a)



(b)

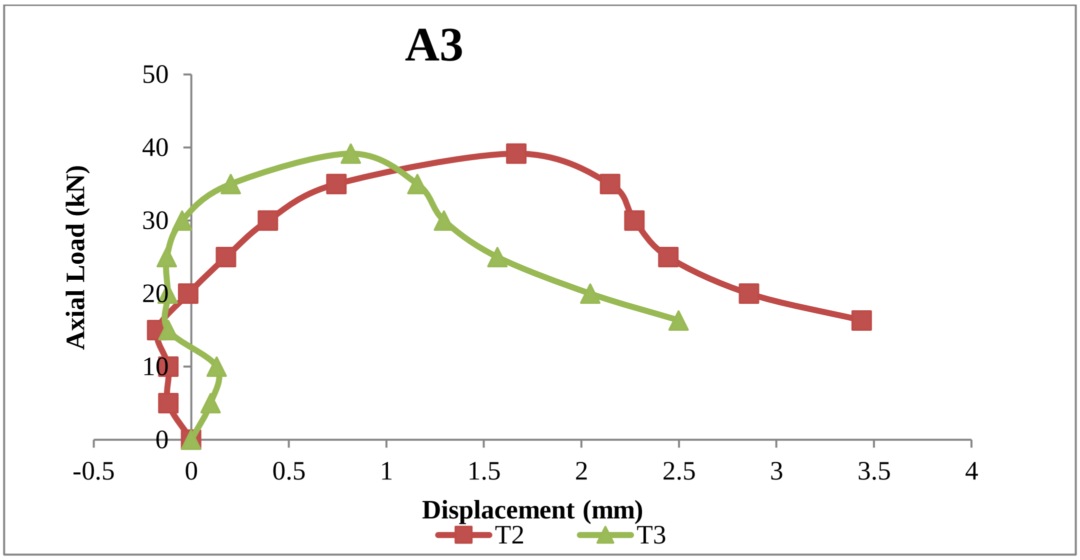
Figure 4.4 (a) and (b) SC103-1.2-A2

From Figure 4.4 (b), result shows the displacement moving towards positive displacement for both transducers until it reach the failure. It shows that the displacement slowly moving towards positive after the maximum load. From Figure 4.4 (a) web buckling occur at the initial load followed by warping at the flange on the peak load. The result after the post load shows that the warping and distortional buckling occurs at the flange and web buckling occur at the hole.



Initial buckling mode Peak load Post peak load

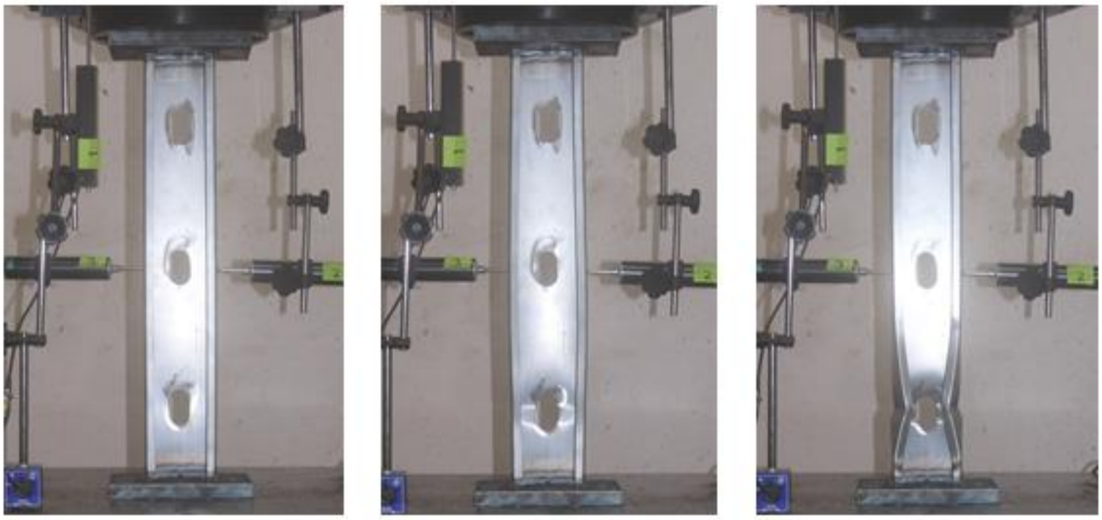
(a)



(b)

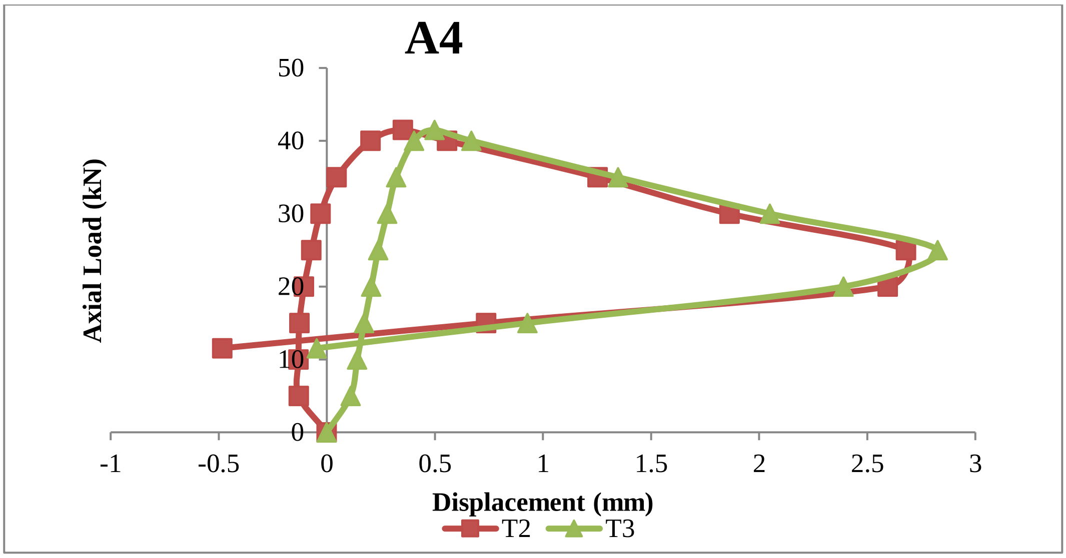
Figure 4.5 (a) and (b) SC103-1.2-A3

Figure 4.5 (a) shows that during the initial load the specimens experience a local buckling at the top lips and followed by web buckling at top when it reach peak load. On the post load, the specimen A3 experience warping at top which it can relate to the Figure 4.5 (b) where the transducer moving into positive displacement.



Initial buckling mode Peak load Post peak load

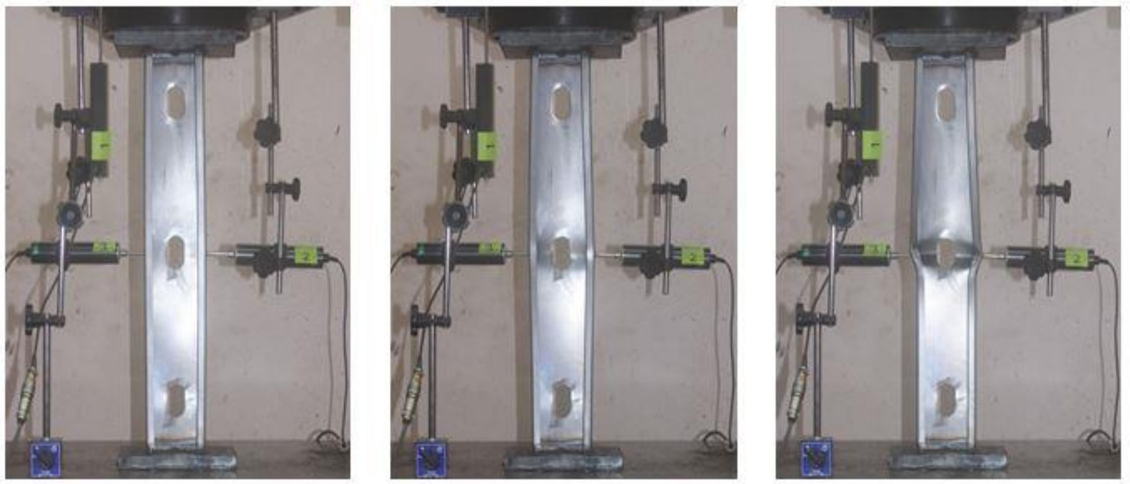
(a)



(b)

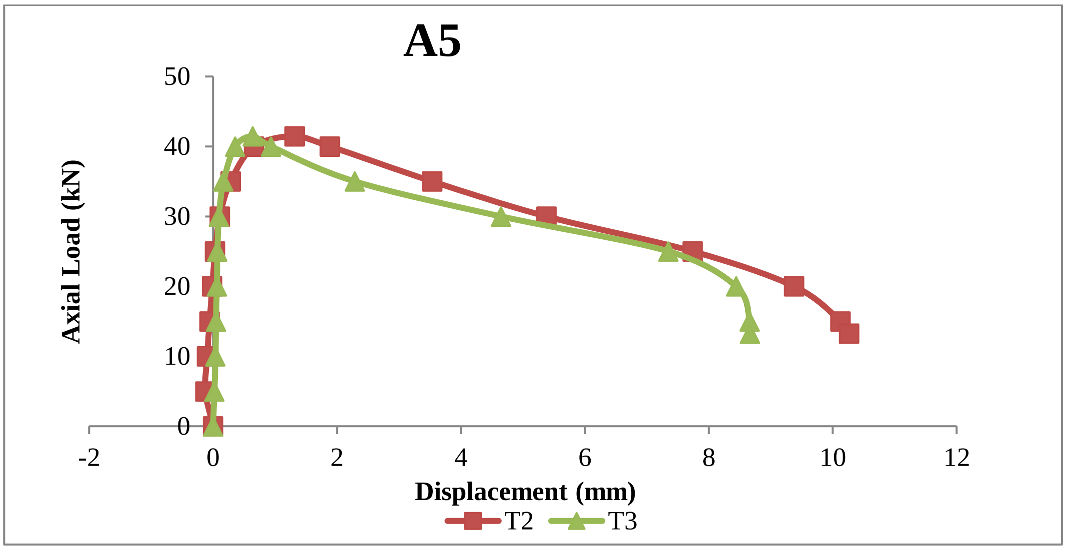
Figure 4.6 (a) and (b) SC103-1.2-A4

From Figure 4.6 (a) it indicate that during the initial load, the buckling occur at the web on the hole and followed by the warping at flange in the middle during the peak load. During the post load, the specimen A4 experience distortional buckling at flange at the bottom. Figure 4.6 (b) shows that after reach the maximum load, the displacement move to positive displacement but it suddenly move to the negative displacement which is shows that the specimen experience distortional buckling.



Initial buckling mode Peak load Post peak load

(a)

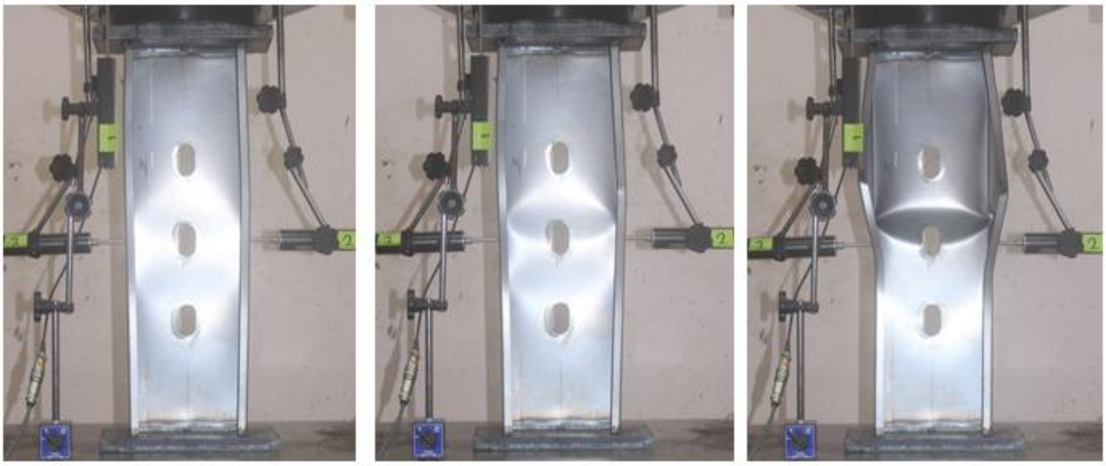


(b)

Figure 4.7 (a) and (b) SC103-1.2-A5

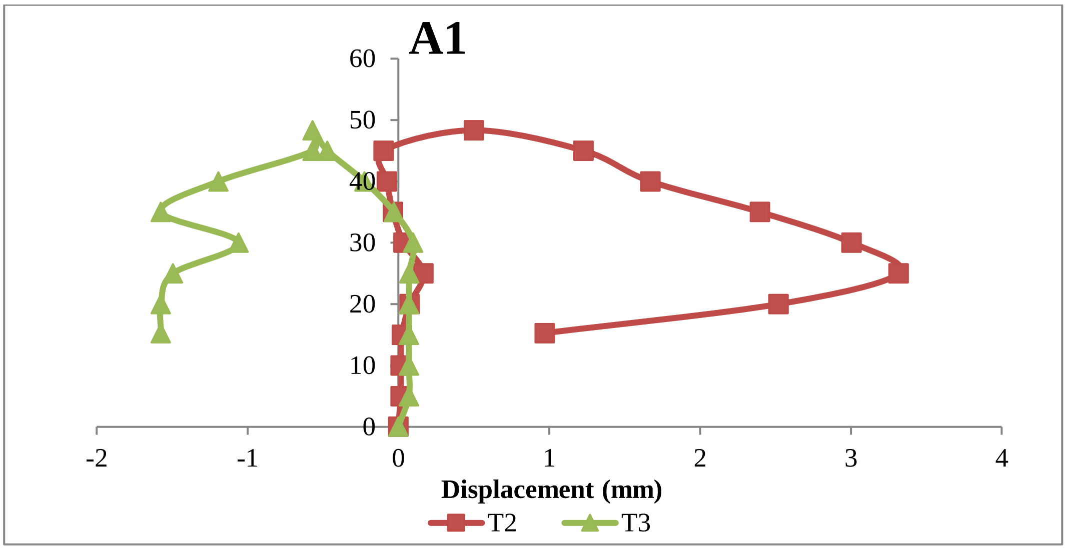
Figure 4.7 (a) indicate that there are a buckling at the web during the initial load and it can be seen clearly at the peak load where the buckling occur at the hole and it followed by warping at the middle flange. The result at the post load shows that specimen A5 experience web buckling at hole and warping at the middle and the Figure (b) shows the displacement move to the positive.

4.4.2 SC203-1.2



Initial buckling mode Peak load Post peak load

(a)

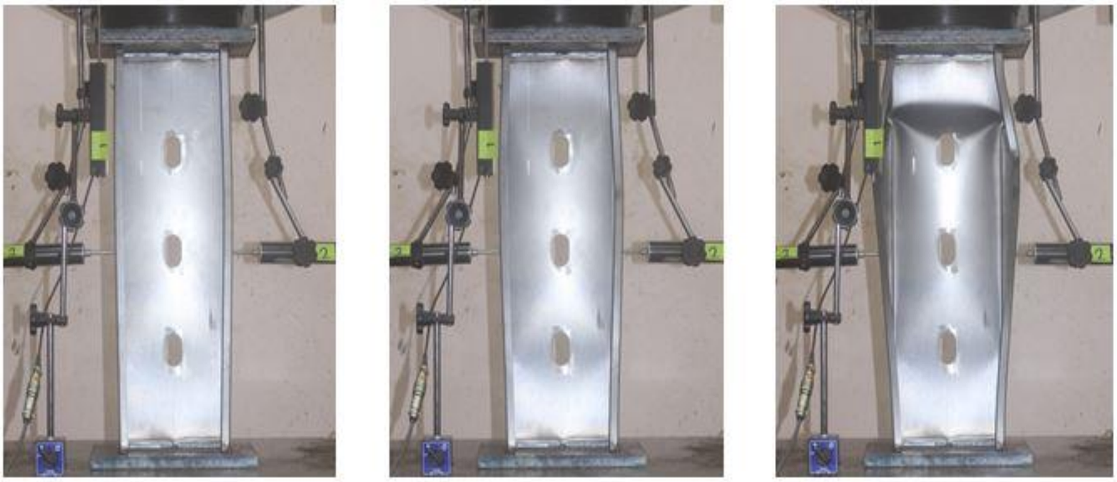


(b)

Figure 4.8 (a) and (b) SC203-1.2-A1

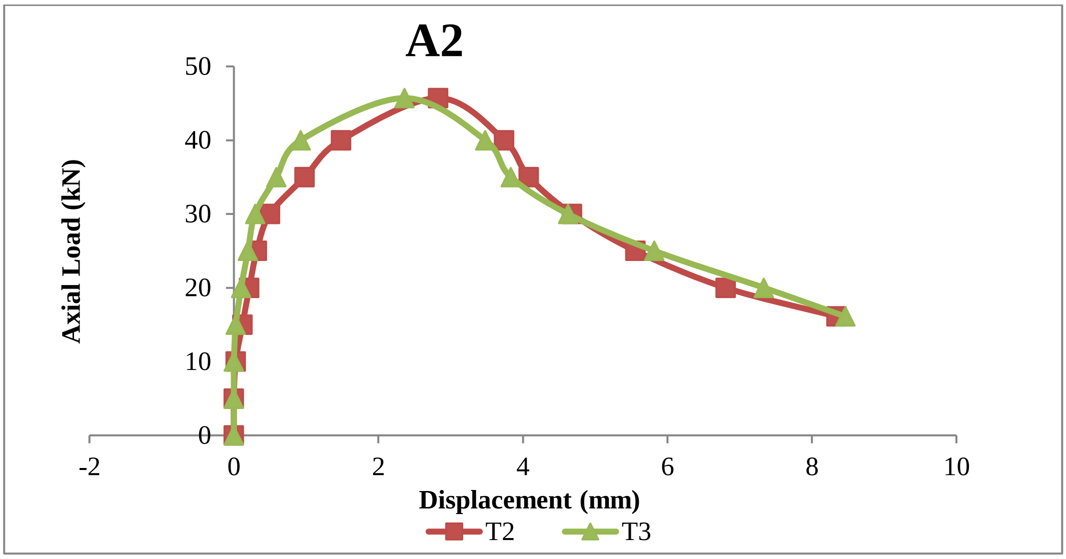
From Figure 4.8 (a) it can be seen clearly that during the initial load the specimen experience buckling at web and followed by the warping at flange after it reach the peak load. The result from the Figure 4.8 (b) shows that the direction of the graph was opposite to each other which are T2 move to the positive displacement while

T3 move to the negative displacement. It is because at the post load, T2 experience warping while T3 experience distortional as shown in Figure 4.8 (a).



Initial buckling mode Peak load Post peak load

(a)

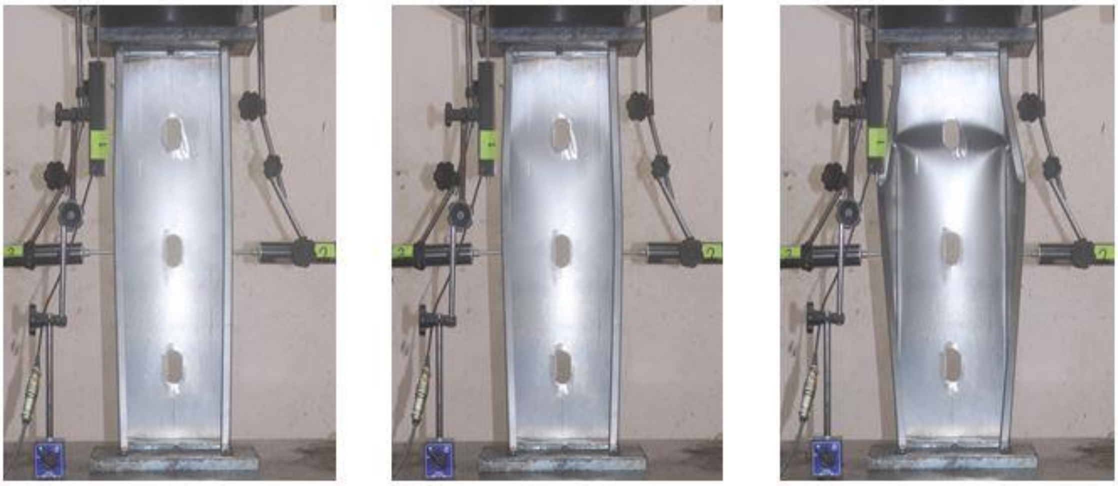


(b)

Figure 4.9 (a) and (b) SC203-1.2-A2

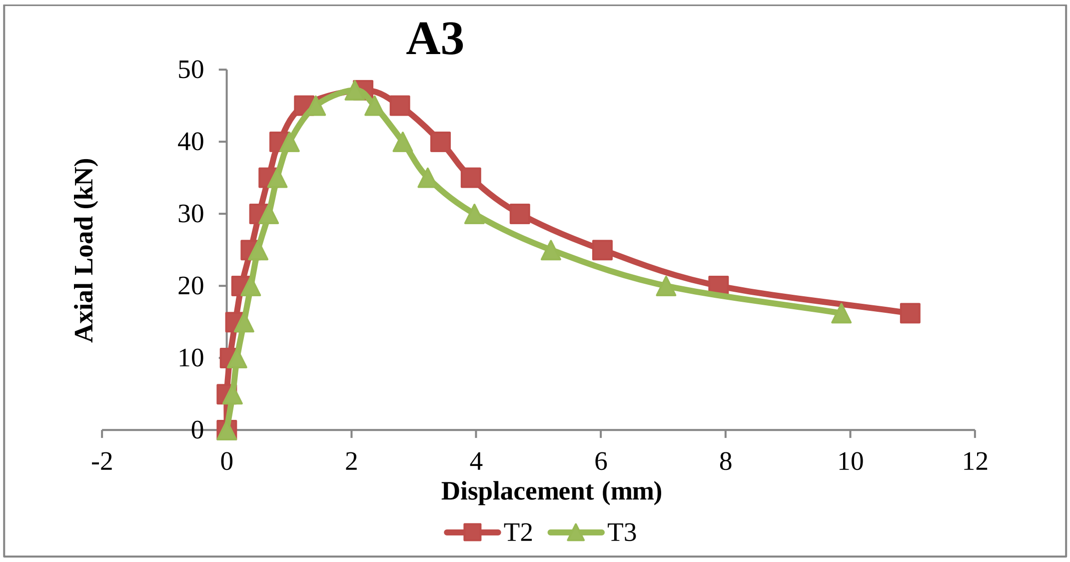
From Figure 4.9 (a) it shows that there is a warping at flange during the initial load and was followed by buckling on web during the peak load. On the post load, we can see that web buckling occur at the hole and there also a warping on the top flange.

The result from Figure 4.9 (b) shows that the transducers move to positive which means the specimens experience local buckling.



Initial buckling mode Peak load Post peak load

(a)

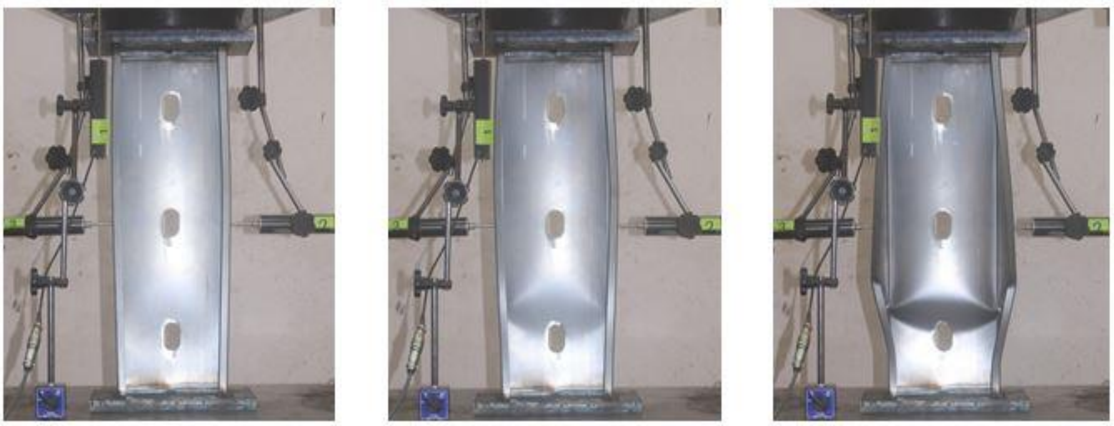


(b)

Figure 4.10 (a) and (b) SC203-1.2-A3

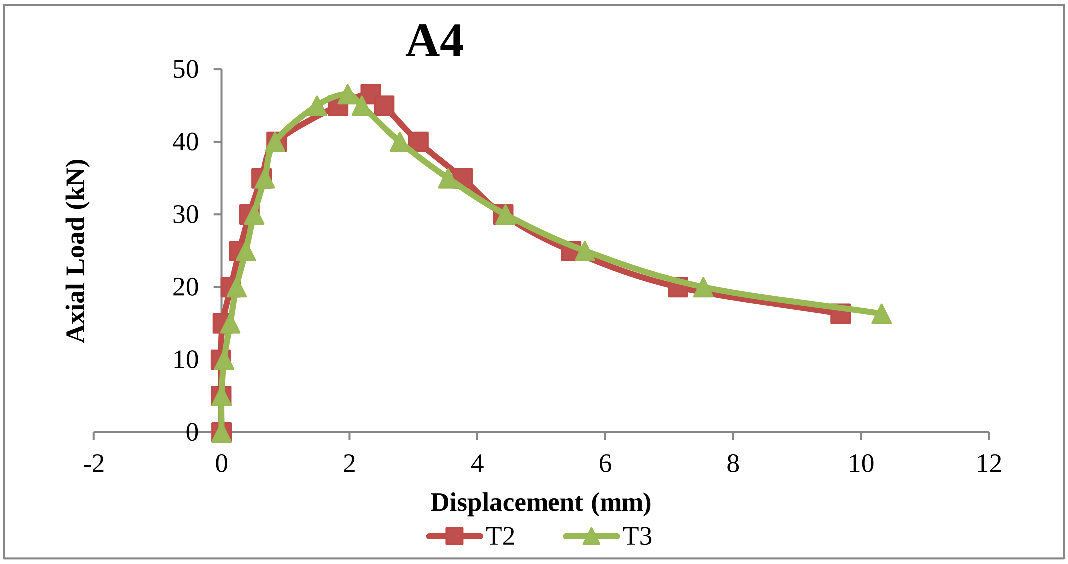
Figure 4.10 (a) shows that there are web buckling during the initial load and after reach the peak load the flange started to buckle outward. The result for specimen

A3 shows that the specimens experience buckling on web at the hole and warping at top flange as shown from Figure 4.10 (b) the transducers show the positive displacement.



Initial buckling mode Peak load Post peak load

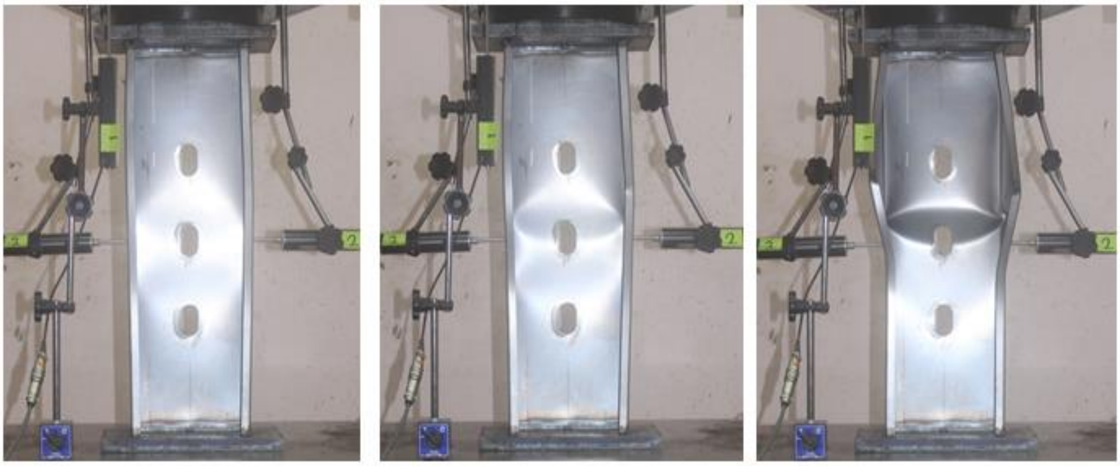
(a)



(b)

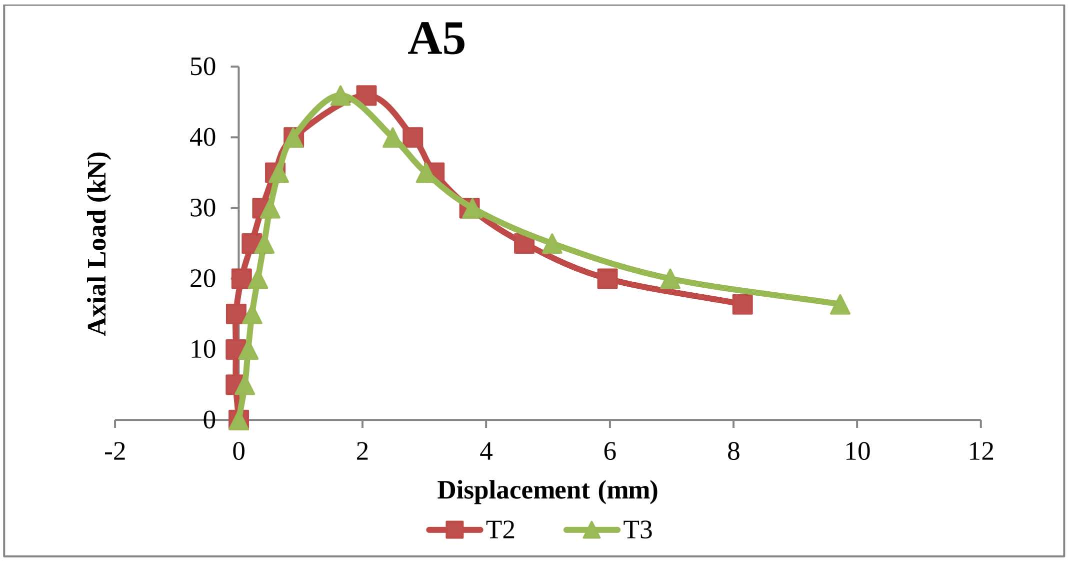
Figure 4.11 (a) and (b) SC203-1.2-A4

Figure 4.11 (a) indicate that during initial load the specimen A4 experience web buckling and it can be seen clearly when it reach peak load followed by warping at flange. The result from Figure 4.11 (b) shows that after reach the maximum axial load the transducer move to the positive displacement and at the post load the specimen experience web buckling at the hole and warping flange.



Initial buckling mode Peak load Post peak load

(a)



(b)

Figure 4.12 (a) and (b) SC203-1.2-A5

Figure 4.12 (a) shows that during the initial load the specimen experience web buckling at the middle and followed by warping at middle flange after it reach the peak load. The result from Figure 4.12 (b) for specimen A5 shows that the transducers move to the positive which during the post load the specimen experience warping at the middle flange and the web buckling occur at the hole.

CHAPTER 5

CONCLUSION

5.1 Introduction

An experimental investigation and an axially loaded method for the cold-formed C-section columns were presented in this paper. The ultimate load for all specimens had been determined using Universal Testing Machine while the displacement of the buckling behaviour was read by using linear vertical displacement transducer (LVDT) device. There are ten specimens with different size which is 103 mm and 203 mm were tested. For this experiment, the length of the specimen and the size of the elongated circle are constant. The linear analysis and linear buckling analysis has been done to analyze the deformed shape, displacement, maximum stresses and maximum value buckling load. From the analysis, the buckling behaviour of the specimens was identified and the effect of different opening arrangement was determined. The maximum stresses and maximum axially loaded are shown specifically in detail.

5.2 Conclusion

From the overall project analysis and result that already being carried out, several conclusions can be made based on the result has been presented:

i. The ultimate load of axially loaded cold-formed steel with opening varies with the distance between opening but only cause a slightly decrease in ultimate compression strength of the tested column. The column with opening near to each other has the higher ultimate load.

i. The size of the specimens influence the ultimate strength which are specimens with 203 mm has the higher ultimate strength compared to 103 mm specimens.

ii. The buckling behaviour of different opening arrangement can be predicted. The deformation response of the member with hole is similar through the data test study, the presence of holes caused only a slightly decrease in the ultimate strength of the tested columns.

iii. From the result obtained, the failure mode of axially loaded column with different opening arrangement also constant where all specimens are failed by local, distortional and web buckling at hole. The presence of the hole reduces the post-peak resistance of the web, causing the flange and lips to carry more of the column load.

5.3 Recommendation

For further studies on this research need to be conducted in the future in order to come out with better and good result. A few recommendations are proposed for tge future studies to achieve the objectives of this research as follow:

i. Use different length of the specimen.

ii. Increase the web depth in order to prevent distortional buckling.

iii. Use other types of cold-formed steel shape such as E-section and Z-section.

iv. Use different shape of openings such as rectangular, oval, or rectangle.

v. Increase the number of opening.

vi. Use software such as ANSYS to compare the result in experimental study.

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APPENDIX A
FAILURE MODE OF CFS C-SECTION COLUMN

SC103-1.2

Front view

Back view

SC203-1.2

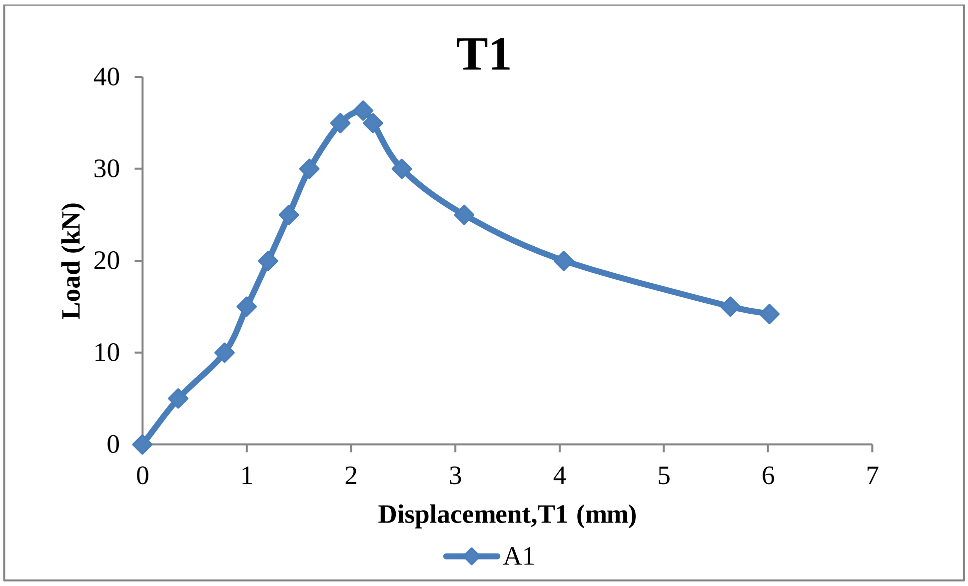
Front view

Back view

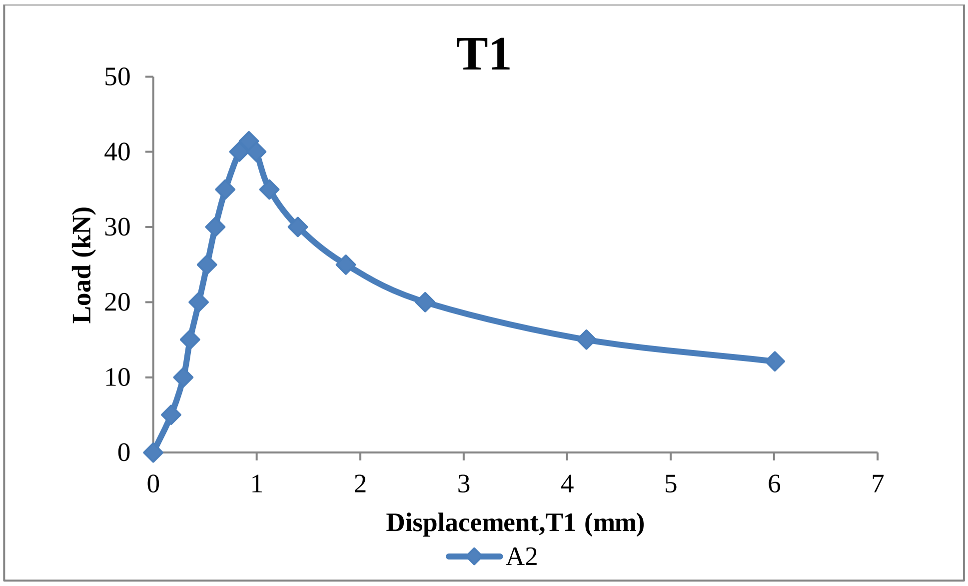
APPENDIX B
LOAD VERSUS DISPLACEMENT,T1 GRAPH

SC103-1.2

Specimen A1



Specimen A2



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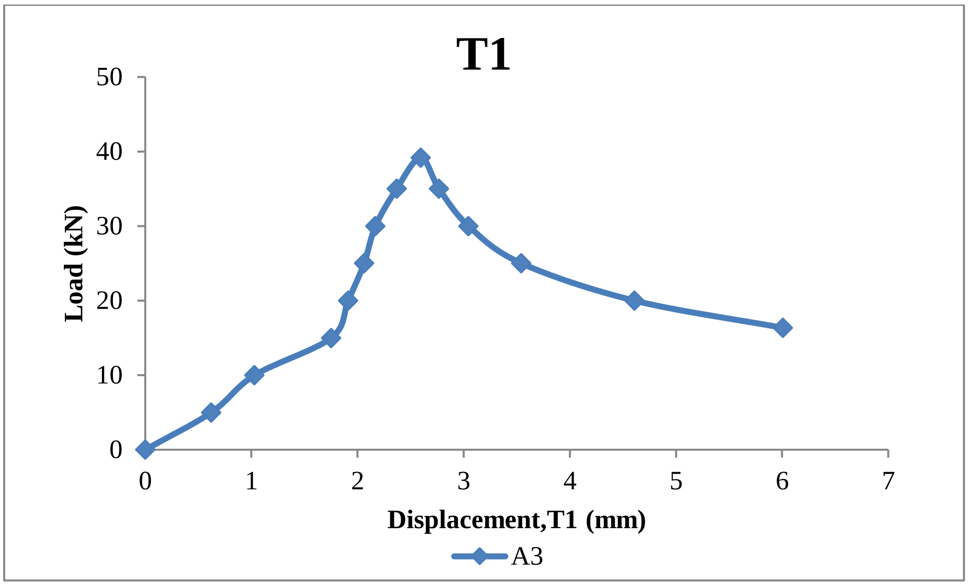

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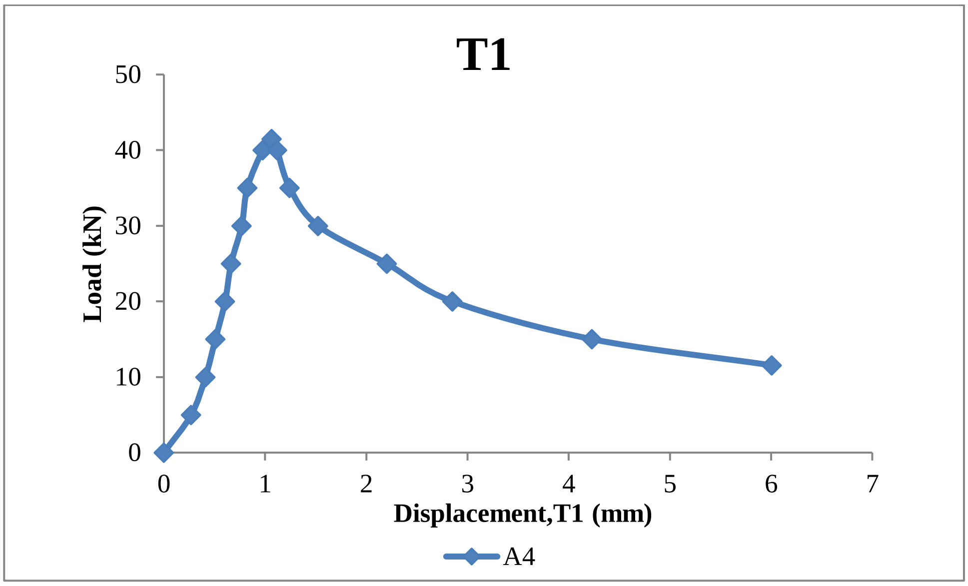

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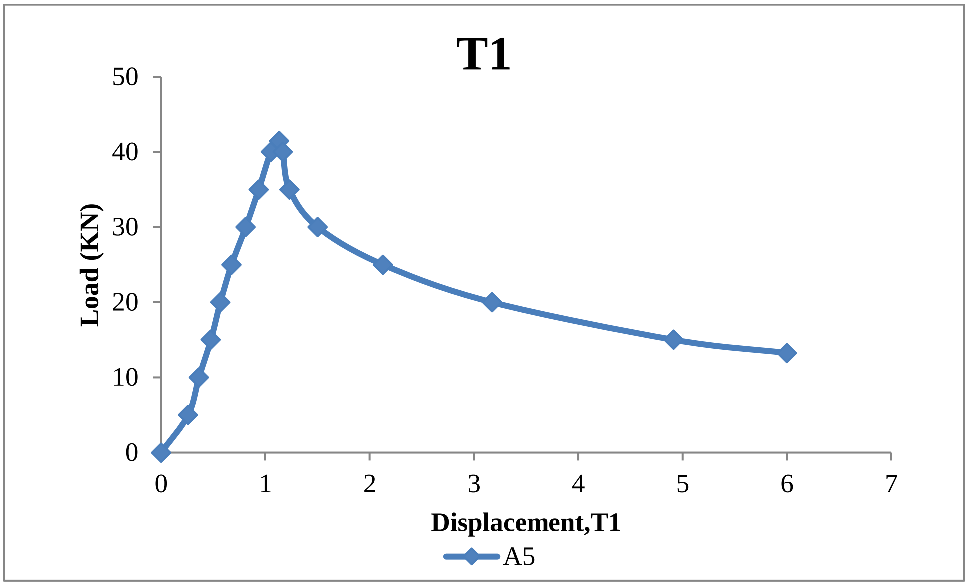
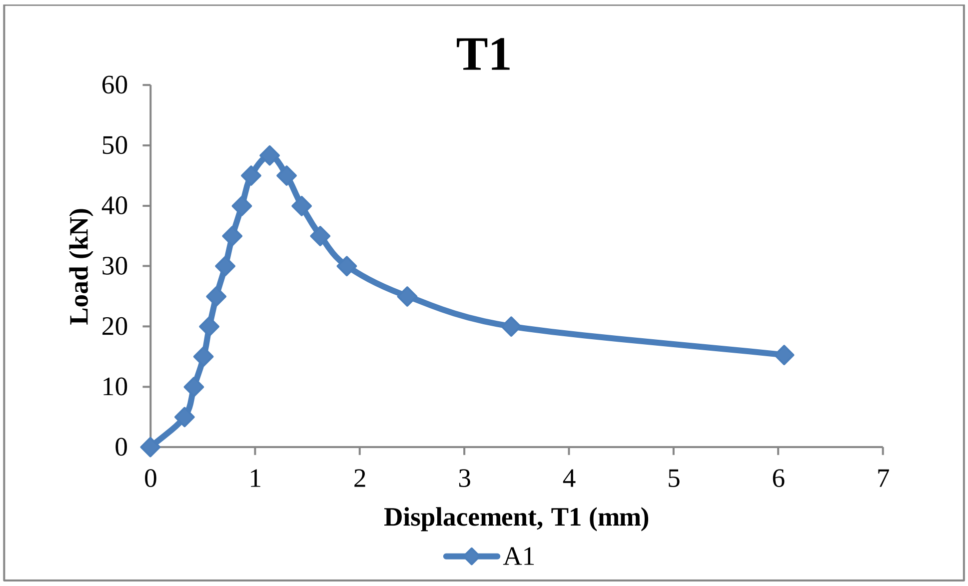


SC203-1.2

Specimen A1



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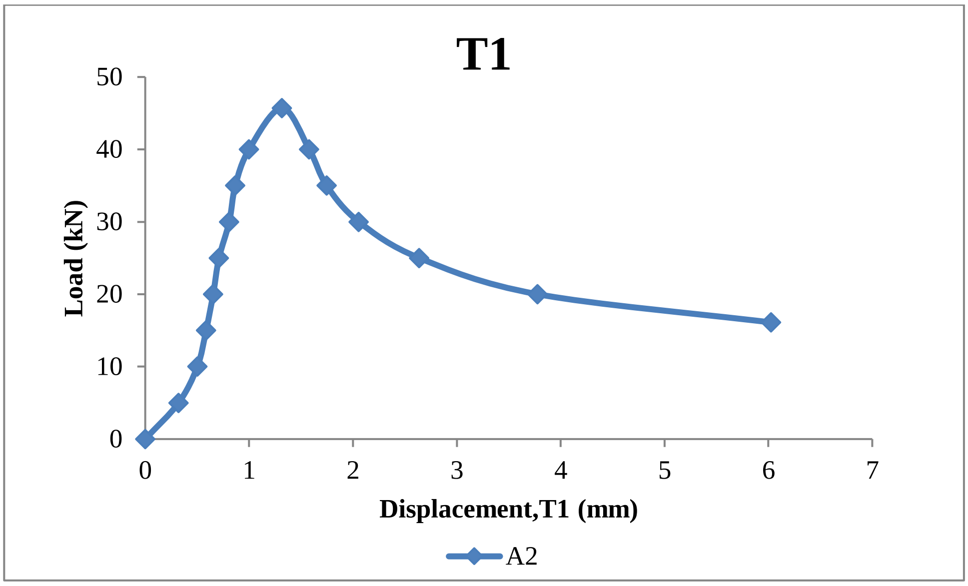

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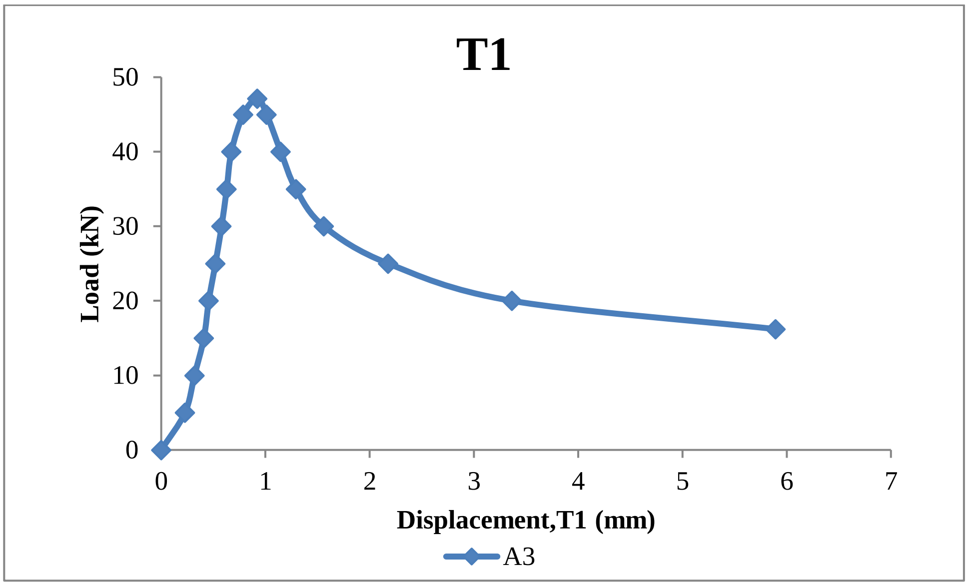
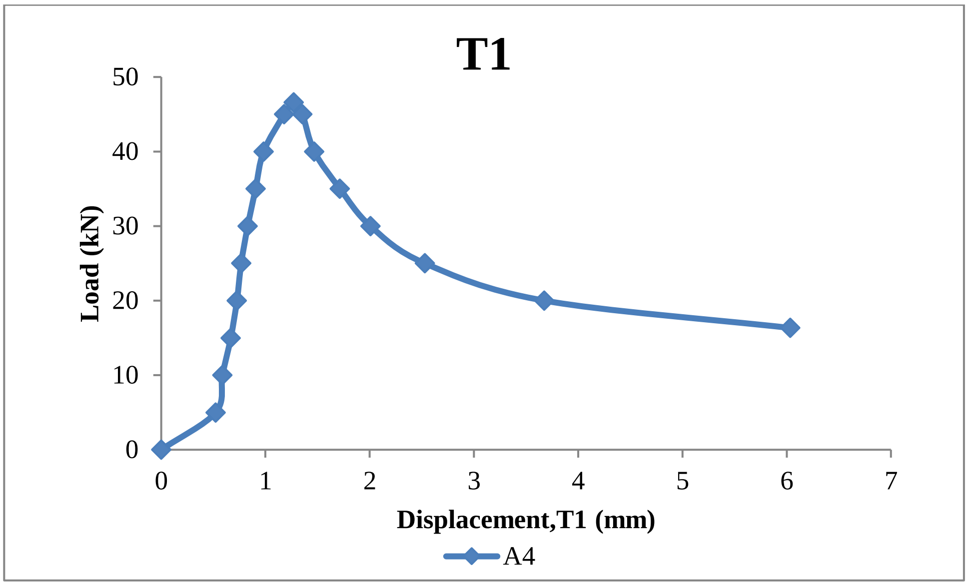


Specimen A4



Specimen A5