EFFECT OF PERFORATIONS ON COLD-FORMED STEEL BUILT-UP I-SECTION

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ABSTRAK

Keluli sejuk terbentuk mempunyai pelbagai jenis bentuk berdasarkan fungsi mereka dalam kerja pembinaan. Terdapat tiga jenis bentuk iaitu bentuk terbuka tunggal, bentuk tertutup dan bentuk bina terbuka. Kajian ini menumpukan kepada bentuk bina terbuka. Struktur keluli sejuk terbentuk biasanya datang dengan kehadiran tebukan. Fungsi tebukan lubang atau bukaan yang dibuat pada keluli terbentuk sejuk untuk memudahkan kerja pembinaan. Ia biasanya disediakan dengan pelbagai bentuk dan saiz berdasarkan fungsinya seperti untuk menampung elektrik, paip dan penghawa dingin atau pemanas. Walau bagaimanapun, kehadiran tebukan boleh menyebabkan pengurangan kekuatan elemen komponen individu dan kekuatan keseluruhan anggota itu bergantung kepada kedudukan, saiz dan orientasi pembukaan. Kajian ini akan memberi tumpuan kepada kesan kedudukan dan bentuk tebukan pada kekuatan struktur tiang keluli terbentuk sejuk yang paksi dimuatkan. Satu siasatan experimen untuk keluli sejuk terbentuk tertakluk kepada mampatan loading untuk mengkaji kesan tebukan pada kapasiti beban ahli lajur terbina I-seksyen diadakan. Sebanyak 8 sampel yang mempunyai kedudukan tebukan yang berbeza telah diuji dalam eksperimen ini. Setiap ahli mempunyai ketebalan nominal sebanyak 1.2 mm, panjang 600 mm dan telah dimampatkan. Hasil daripada eksperimen ini menunjukkan bahawa beban muktamad setiap sampel amat berbeza pada kedudukan tebukan. Keputusan ini dipersembahkan dalam tiga bahagian yang beban vs anjakan menegak, beban vs anjakan mendatar dan tingkah laku lengkungan.

ABSTRACT

Cold-formed steel comes with various type of section based on their function and purpose in construction work. There are three main types of sections which are single open section, open built-up section and closed built-up section. This research will be concentrating on open built-up section or I-section. Structural members of cold-formed steel usually come with the presence of perforations. Perforations are a hole or opening that are made on the cold-formed steel to ease construction work. It usually provided with different shapes and size based on its function such as to accommodate electrical, plumbing and air conditioner or heating services. However, the presence of perforations may cause a reduction in strength of individual component elements and the overall strength of the member depending on the position, size and orientation of the opening. This research will focus on the effect of position and shape of the perforations on the structural strength of the axially loaded cold-formed steel column. An experimental investigation of cold-formed steel subjected to compression loading to study the effect of perforations on the load capacity of column members of built-up I-section is held. A total of 6 samples that have different position of perforations were tested in this experiment. Each member has nominal thickness of 1.2 mm, column length of 600 mm and was compressed between a simply supported ends at both end. The result of this experiment shows that the ultimate load of each sample varies greatly on the perforation position. The result is presented in three sections which are load vs vertical displacement, load vs horizontal displacement and buckling behavior.

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LIST OF ABBREVIATIONS

CFS	Cold-formed steel
CRS	Cold-rolled steel
FKASA	Fakulti Kejuruteraan Awam & Sumber Alam
UMP	Universiti Malaysia Pahang
mm	millimetre
UTM	Universal Testing Machine
LT	Local buckling at top
LM	Local buckling at middle
LB	Local buckling at bottom
DTf	Distortional buckling at top (front)
DTb	Distortional buckling at top (back)
DMb	Distortional buckling at middle (back)
DMf	Distortional buckling at middle (front)
DBf	Distortional buckling at bottom (front)
DBb	Distortional buckling at bottom (back)
WTf	Warping Buckling at top (front)
WTb	Warping Buckling at top (back)
WMf	Warping Buckling at middle (front)
WMb	Warping Buckling at middle (back)
WBf	Warping Buckling at bottom (front)
WBb	Warping Buckling at bottom (back)
FE	Finite Element
CH1	Transducer 1 - Vertical Displacement
CH2	Transducer 2 – Horizontal Displacement
CH3	Transducer 3 – Horizontal Displacement

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Cold steel products, such as bar stocks and cold steel sheets, are typically used in all areas of durable goods manufacturing, such as equipment or cars, but cold-formed steel phrases are most commonly used to describe construction materials. In the construction industry these two structural and structural elements are made of thin steel gauges. These building materials include columns, beams, loops, buttons, floor deck, built-in parts and other components as shown in Figure 1.1. Cold construction materials are cold-formed from other steel construction materials known as hot-rolled steel. Production of cold-formed steel products occurs at room temperature using rolling or pressing.

Built-up cold formed steel is usually a regular composition of normal cold formed steel such as C, Z, Sigma, or parts of the hat to produce new parts as shown in Figure 1.2. This part is connected using bolts, screws, or welding. The cold formed steel common build section used for compressors and members of tension. Built-up cold-formed steel products, such as bar stocks and cold steel sheets, are typically used in all areas of durable goods manufacturing, such as equipment or cars, but cold-formed steel phrases are most commonly used to describe construction materials. In the construction industry these two structural and structural elements are made of thin steel gauges. These building materials include columns, beams, loops, buttons, floor deck, built-in parts and other components. Cold construction materials are cold-formed from other steel construction materials known as hot-rolled steel. Production of cold-formed steel products occurs at room temperature using rolling or pressing.

Figure 1.1 Building made up from the cold-formed steel

Source: Steel Study Company (SCAFCO) (2014).

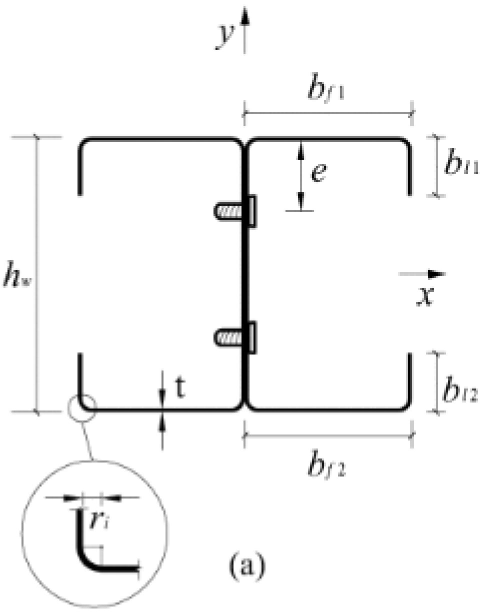

Figure 1.2 Build-up cold-formed steel C-section

Source: Marino Ware Company (2009).

1.2 Problem Statement

Members of the cold formed steel structure are usually produced with holes to accommodate pipelines, electricity, and heating in walls and building ceilings. However, the special properties of steel formed by cold members require special consideration when it comes to applications under construction. Due to the various opening arrangements, some special research tasks to provide practical designs should be carried out where stability and strength may be mitigated by perforation. Many problems have increased due to existing openings as the design process will become more complicated and require additional expert reviews and has resulted in a collapse of the building. This leads to the use of cold-formed steel with openings in a limited industry and this can be changed with many studies by experts.

Cold-formed steels with openings have their own advantages and disadvantages to their own columns and structures. Opening can be found in the desired opening, especially in circles, rectangles, oval or rectangles. The existence of the opening will reduce the area of the cold and theoretically formed steel surface, its strength may be reduced to a cold formed form without opening. Perfection due to residual pressure due to folding cold-formed steel is among the issues in this study. The resulting pressure pressures are inevitable because during cooling, some stresses need to be used to make the desired shape cold.

1.3 Research Objective

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

i. To determine the ultimate load of cold-formed steel built-up I-section short column.

ii. To investigate experimentally the effects of various perforation position of cold-formed steel built-up I-section.

1.4 Research Scope

In this study, a series of column tests on build-up cold formed steel C-shaped were conducted. The columns were compressed between fixed ends. Current design methods available to engineers for predicting the strength of cold-formed steel members with holes are prescriptive and limited to specific perforation locations, spacing, and sizes. The section of cold-formed that being tested is a build-up I-section and a short column cold-formed steel are being used which size of width 103 mm with thickness which is 1.2 mm. The specimen of cold formed steel will be used with one does not have opening and the others with elongated circle shape whereas with different location. Support for the steel to test is using a base plate which is act as fixed support as it will be welding at the end both of the cold formed steel.

1.5 Significance of Research

The finding of this study will contribute to the benefit of the construction industry. The behaviour of cold-formed steel when the perforations exist can be studied. The deformation of cold-formed at the different position of perforations also can be analysed by the experimental study. The data of either the column will show an effect if the position of perforations varies or not can be taken. The strength of the cold-formed steel will likely will change depend on the position of 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, the failure modes are not commonly encountered in normal structural steel design specifications, and therefore, extensive testing is required to provide a guideline for the design of cold-formed steel structural member for the industry now days.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Cold-formed steel (CFS) is the common term for products made by rolling or pressing steel into semi-finished or finished goods at relatively low temperatures also known as cold working. Cold-worked steel products, such as cold-rolled steel (CRS) bar stock and sheet, are commonly used in all areas of manufacturing of durable goods, such as appliances or automobiles, but the phrase cold-formed steel is most prevalently used to describe construction materials. The usages of cold-formed steel have been commonly used in the metal building construction industry for more than 40 years (Sunil & Patil, 2012). In the construction industry both structural and non-structural elements are created from thin gauges of sheet steel. These building materials encompass columns, beams, joists, studs, floor decking, built-up sections and other components.

Cold-formed steel (CFS) members are made from structural quality sheet steel that are formed into C-sections and other shapes by roll forming the steel through a series of dies (Jakab & Dunai, 2008). In Malaysia, the cold-formed usage in building construction did not widely applicable until recently where the use of cold-formed steel in replacing hot-formed steel had been widely accepted. But, the usage of cold-formed still not widely used in construction due to the limitation of the specimen. Most local product in market has their own limitation due to the absent of opening. When the opening is being made, the limitation strength of cold-formed will likely will be changed. So, this study will show either the existing of opening will affect the strength of cold-formed steel.

2.2 Method of Manufacturing

There are many type of method in manufacturing of cold-formed steel. The three-main methods are press-barking and cold-rolling. These manufacturing methods can also be called as cold-forming process. Cold-forming is a term used to describe the manufacture of products by forming material from a strip or sheet of uniform thickness. Cold-formed steel members are manufactured by one of the three processes that are roll forming, folding and press braking (Zhao, 2005). Roll forming consists of feeding a continuous steel strip through a series of opposing rolls to deform the steel plastically to form a desired shape. It is often used to produce sections where large quantities of a given shape are required. The shortcoming of roll forming is the high initial costs and the difficulty of changing to a different size section. Press baking normally involves producing one complete fold at a time along the full length of a section. Usually for sections with several folds, it is necessary to move the steel plate in the press and to repeat the pressing operation several times. Therefore press baking can be used to produce a variety shape with low volume production (Tsavdarid & D'Mello, 2011).

2.2.1 Press-Barking

A press brake is a machine pressing tool for bending sheet and plate material, most commonly for steel. It forms predetermined bends by clamping the work piece between a matching punch and die. Press-barking is widely used in manufacturing of cold-formed steel. The cold-formed steel is formed from a length of strip by pressing the strip between shaped dies to form a profile shape. Press-barking offers a greater variety of cross-sectional compared to folding. By using this method, each bend is formed separately. However, press barking has certain limitations in it design. The profile geometry that can be formed and length of section that can be accommodating by this method is still limited (Quach et al., 2010).

2.2.2 Cold-Rolling

The cold rolled steel is basically the next hot-rolled steel. The steels are further processed in a cold reduction plant, where the material is cooled at room temperature followed by annealing or rolling tempering. This process will produce steel with closer dimensional tolerance and a wider surface finish. Cold Rolled terms are mistakenly used on all products, when the actual product name refers to roll sheets and flat coil products. The speed of rolling varies from 10 m per min up to 100 m per min. the speed depends on the complexity of profile. This method eliminates the limitations that press-barking. Cold-rolling can produce prismatic sections with a high degree of consistency and accuracy to any desired length (Chen & Liew, 2003).

Figure 2.1 Machine use in the press breaking process

Source: ANHUI LAIFU NC Machine Tool CO.LTD (2014).

2.3 Advantages of Cold-Formed Steel

Cold-formed steel is a versatile structural product for use in load bearing and curtain wall construction. The popularity of corrosion resistant galvanized steel can be attributing to these benefits:

2.3.1 High Strength and Stiffness

The reduced dead load may result in primary frame and foundation material savings. Exterior retrofits are less likely to require expensive reinforce of the existing structure. In load bearing construction, a light weight steel framing system is a benefit when the site is plagued by poor soil conditions. Multi-story residences requiring unique ground level construction such as parking structure, meeting facilities and dining facilities, benefit from the reduce dead weight applied to the supporting structure. The thinness of the material gives a huge advantage on cold-formed steel over hot-rolled steel as it has a higher strength-to-weight ratio (Kulatunga et al., 2014). Because of cold-formed steel having a high strength and stiffness, it gives more diversity and flexibility in design while allowing design in longer spans with better material usage. Various section configurations can also be produced economically by both folding and press barking, resulting in the favourable strength-to-weight ratio.

2.3.2 Versatility of Shape and Design

Curtain walls in various finishes and profiles are attainable. Whether used as floor joists and roof rafters or in mansard and truss framing works well independently or in combination with other structural systems. Steel framing is adaptable to numerous applications traditionally constructed with hot rolled structure steel or masonry. Cold-formed steel has variety of section design and this may ease the designing process of a project. The versatility of the cross-sectional and section design gives the architect more flexibility in deciding the end design of a structure. Besides, the unusual sectional configuration can be produced economically (Rondal, 2000).

2.3.3 Non-Combustibility of Material

The use of steel structural, protected with fire resistive materials, offers the designer numerous rated non-combustible assemblies. As an alternate to conventional wooding framing, increases in floor areas or building heights may be attained. Non-combustible ratings may also yield long term insurance savings. Cold-formed steel often translates into lower cost and extensive coverage for many types of construction insurance. The non-combustible properties of cold-formed steel results in lower insurance premium for a structure in construction building (Young, 2008).

2.3.4 Cost Effectiveness

The cost effectiveness of using cold-formed steel covers from the phase of production, transporting, usage of material to the end of construction process. The method of manufacturing of cold-formed steel is simpler compared to hot rolled steel, making it more economical in the production. Cold-formed steel also economical in terms of it material usage. Compared to hot rolled steel, cold-formed steel used less material to achieve a given strength and stiffness. This is agreed by Schafer that described that the usage of material for a given strength and stiffness requirement is appeared to be much less than hot-rolled section. Steel farming systems are conducive to prefabrication at or away from the job site (Schafer, 2008). Quality is improved due to the controlled work atmosphere while its efficiency of construction may result in earlier building enclosure and ultimate occupancy.

2.4 Material and Mechanical Properties

The cold-formed steel strength can be further explained through material and mechanical properties. In the structural viewpoint, the most important steel properties should be described at its yield point and its strength, tensile strength, relationship-stress relationships, modulus of elasticity and ductility (Cristopher & Schafer, 2009).

2.4.1 Typical Stress-Strain Curve

The strength of cold formed steel structural members depends on the yield point or yield strength, except in connections and in those cases where elastic local buckling or overall buckling is critical. Yield point of steels listed in most codes ranges from 165 N/mm² to 552 N/mm².There are two types of stress-strain curves, one is of sharp yielding type and the others are of gradual yielding type. The first curve as shown in Figure 2.2 is the sharp-yielding while on Figure 2.3, the gradual-yielding type. Hot-rolled steel usually experience sharp yielding where the yield stress is defined by level at which the stress-strain curve becomes horizontal (Schafer & Ádány, 2005).

Steel produced by hot rolling are usually sharp yielding. For this type of steel, yield point is defined by the level at which the stress- strain curve becomes horizontal. Steel that are cold formed shows gradual yielding. For gradual yielding steel, the stress strain curve is rounded out at the ‘knee’ and the yield strength is determined by either offset method or strain under load method (Yao & Rasmussen, 2012).

The load carrying capacity of cold formed steel flexural and compression members are usually limited by yield point of buckling stresses that are less than yield point of steel, particularly for those compression elements having relatively large flat width ratio and for compression members having relatively large slenderness ratio.

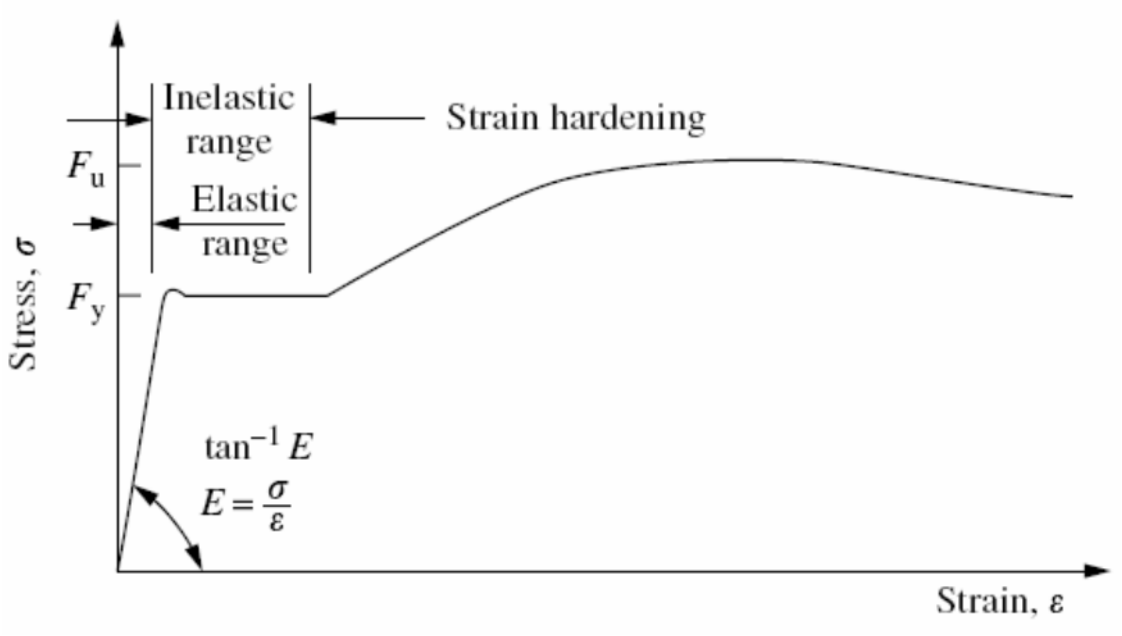

Figure 2.2 Sharp Yielding Stress-Strain Curves

Source: Structural Analysis Book (2012).

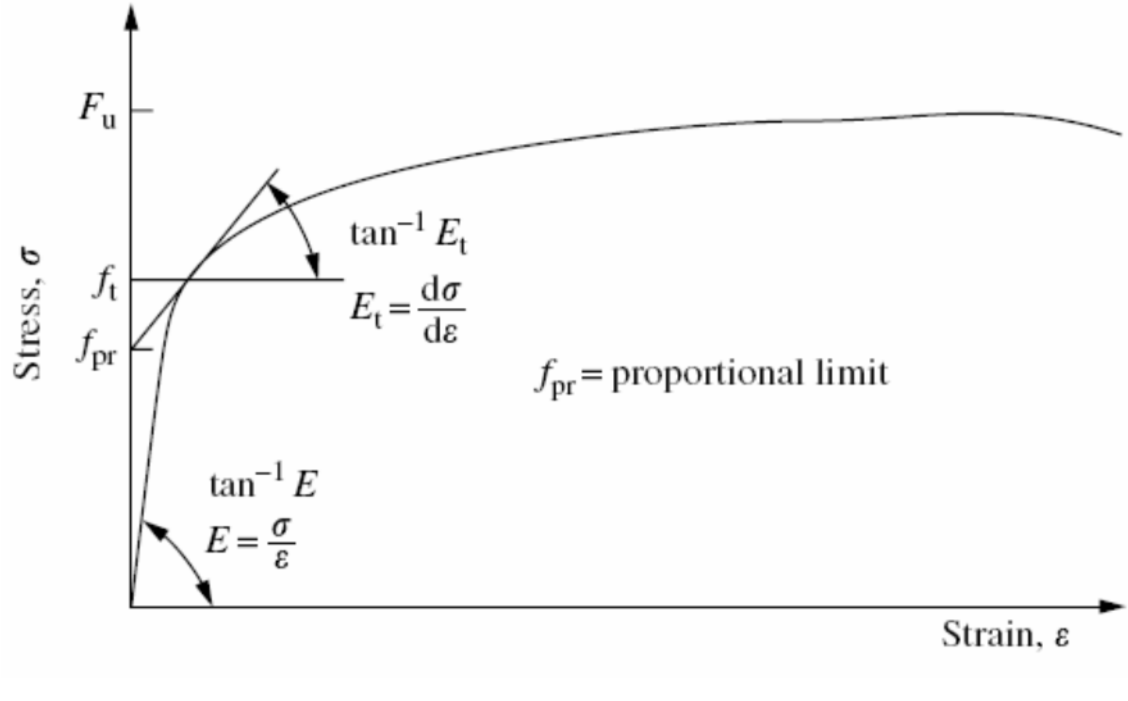

Figure 2.3 Gradual Yielding Stress-Strain Curve

Source: Structural Analysis Book (2012).

2.5 Buckling Behaviour

When cold-formed steel structural members are loaded in compression, it is often limited due to occurrence of failure mode. Although cold-formed steel is highly efficient in the usage of material, they are highly predicted to fail in various buckling mode. The complications due to characteristic of cold-formed steel are increase when the members are made slender. When designing a cold-formed steel structural member, these should be taken into consideration.

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

2.5.1 Local Buckling

Local buckling happen when a thin plate is loaded in compression, the possibility of local buckling to occur is high. The plate elements of cold-formed sections are normally thin higher plate slenderness ratio and hence they buckle locally before yield stress is reached. Local buckling mode of a given thin-walled member depends on its cross section geometry which is shape and dimensions and also the support conditions (Kwon & Seo, 2012). The elastic local buckling of thin elements does not immediately lead to failure. The elements can carry additional load in the post-buckling strength before failure occurs. The post-buckling strength of elements having relatively large flat width to thickness ratio may be several times the load that causes local buckling. Consequently all the cold-formed design specifications take into account the post-buckling strength (Haidarali & David, 2012).

2.5.2 Distortional Buckling

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

2.5.3 Flexural-Torsional Buckling

Flexural-torsional buckling is a mode of buckling in which long compression members bend and twist simultaneously. It usually occurs in long member that are loaded in compression and failure occur due to overall buckling. The cross-section that is familiar to flexural-torsional buckling is closed shape doubly symmetric, point symmetric or cylindrical shape. When an open column section buckles in flexural-torsional mode, bending and twisting will occur simultaneously as seen in Figure 2.4 (Kulatunga & Macdonald, 2013).

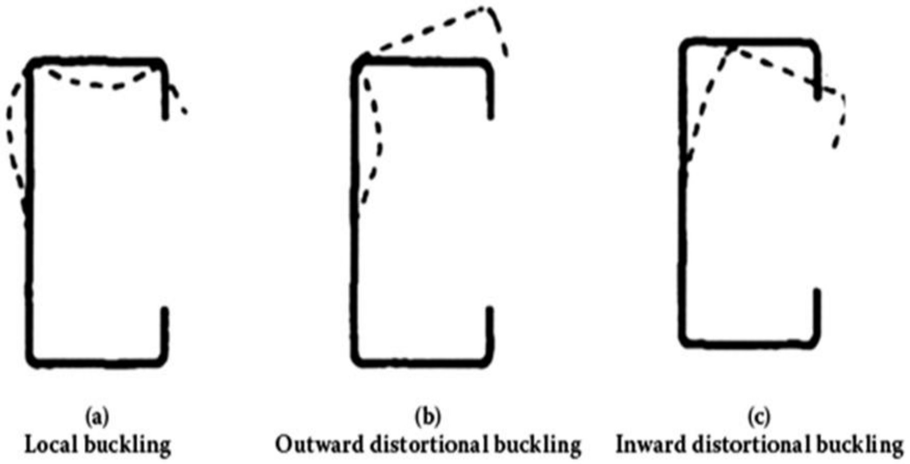

Figure 2.4 Type of buckling on cold-formed steel

Source: The Civil Engineering Handbook (2012).

2.6 Built-up Section

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

2.7 Perforations

A perforation is a hole or opening that is made on the cold-formed steel to ease construction work. As seen on Figure 2.5, it usually provided with different shapes and size based on its function such as to accommodate electrical, plumbing and air conditioner or heating services. The function of perforations is to facilitate various services in building construction.

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

Figure 2.5 Perforation on cold-formed steel
Source: Zhangjiagang Ever Faith Industry Co. Ltd.(2005).

2.8 Previous Research

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

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

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

2.8.2 Design of Cold-Formed Steel Built-Up Closed Sections with Intermediate Stiffeners

This research is describe about the experiment of the CFS built-up closed sections wit In this study, three different methods were used to obtain the elastic local and distortional buckling stresses of the cross sections as required in the calculation of the direct strength method stiffeners. The appropriateness of the direct strength method on cold-formed steel built-up closed sections with intermediate web stiffeners has been assessed. It is shown that the direct strength method using single section to obtain the elastic buckling stresses are generally conservative and reliable (Young & Chen, 2008).

2.8.3 Design of built-up cold-formed steel columns according to the direct strength method

This research is describe about the normal force capacity of columns with built-up cross-section shapes from CFS profiles is evaluated according to the direct strength method. Linear buckling analysis solutions from the finite strip method software CUFSM are used to derive the critical loads in local, distortional and overall buckling. The good agreement with experimentally obtained normal capacities suggests that a similar design methodology can be adopted in structural standards for built-up CFS columns. Despite many uncertainties with such members various buckling effects, initial imperfections, residual stresses and unknown material properties, the columns sustained substantially increased loads and showed a repeatable response with scatter in the ultimate resistance between identical specimens lower than 4.5 %, which is very low for CFS members in general (Georgievaa et al., 2012).

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

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

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discuss the method involved in this study that was experimental compression test on short columns. Built-up cold-formed steel (CFS) members usually have symmetric cross-sections, higher strength and better resistance against out-of-plane movement. Because the production method remains unchanged, composed CFS members were a relatively cheap alternative to single profiles, which easily fail in overall buckling, if not laterally supported. Built-up solutions were adopted in practice, regardless of the lack of design rules to predict the member strength.

Research study by T.A. Stone and R.A. LaBoube in 2005, title “Behaviour of Cold-Formed Steel Built-Up I-Section”, had been used as a standard to do the experiment and provided the basic guidance to develop all the research on cold-formed steel members. Eight specimens had been used where all specimens have different position of openings. The thickness and length of the specimens used were consistent to get an accurate result and to do comparisons.

The result of the performance and behaviour between cold-formed steel lipped build-up I-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 experimental investigation was aimed at studying the influence of opening positions on the ultimate strength and the failure modes of build-up I-section of short columns.

3.2 Flow Chart

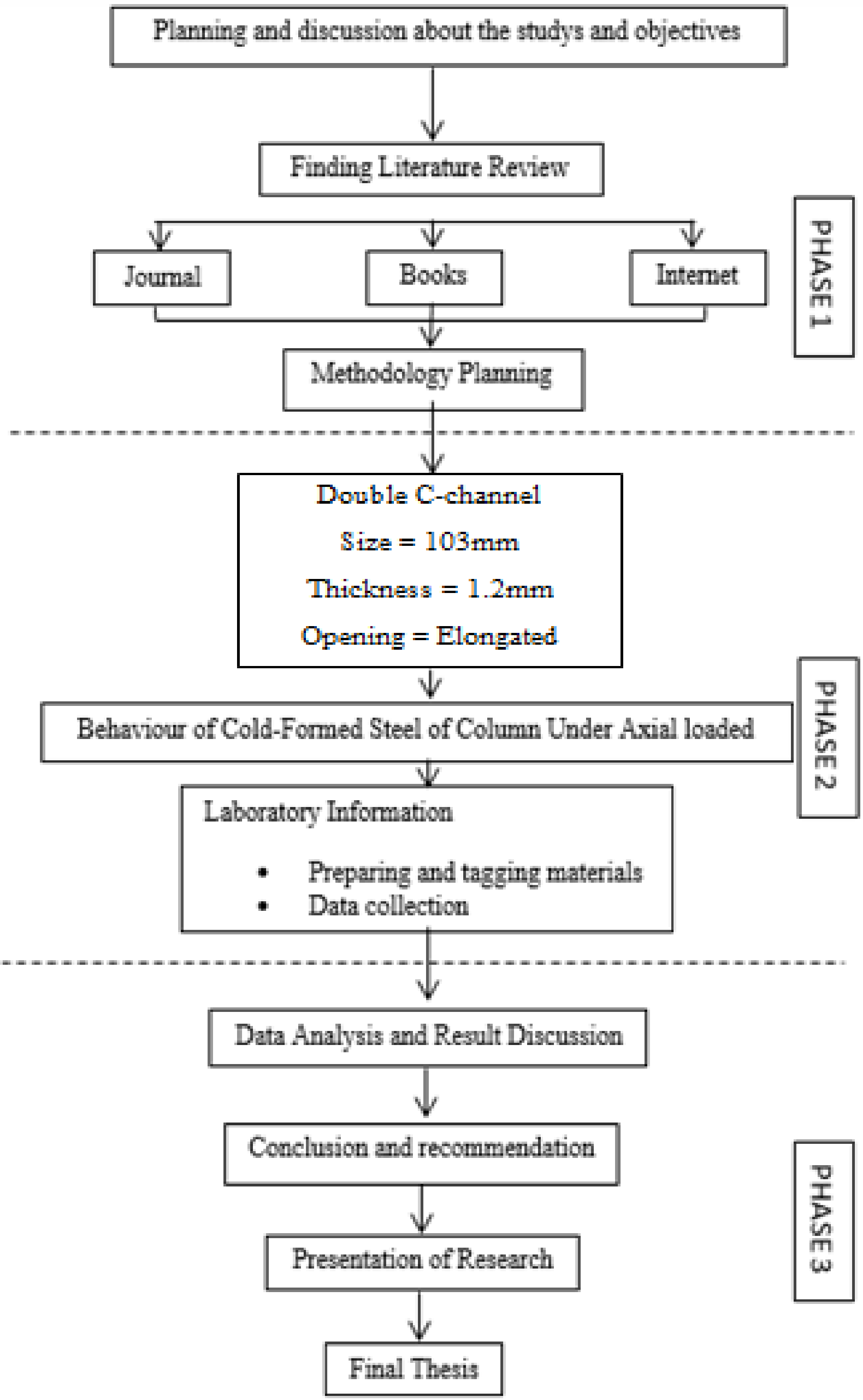

Figure 3.1 Flow chart for this project

3.3 Research Design

The sample was design and calculation of maximum axial load was done to ensure that the machine available in the laboratory can cater with the design during the investigation. The sample used for this project has 600 mm length due to the limitation of height that the can be cater by the machine in the laboratory. The size of the section of each sample was 1.2 mm x 103 mm x 51 mm x 14 mm. The size of section was also decided after further discussion with the supplier of the cold-formed steel and the size was change according to what the factory able to provide.

Cold-formed build-up I-section sizes were selected based on the previous researcher and the capability of the laboratory of Faculty of Civil Engineering & Earth Resources (FKASA) in Universiti Malaysia Pahang (UMP). The maximum height of specimen that Universal Testing Machine can take was average 700 mm including the bearing plate. The purpose of this paper was first to present a series of column tests on the cold-formed steel built-up I-sections, as shown in Figure 3.2. The section could be failed in distortional buckling of the webs in addition to flexural buckling for short columns.

Figure 3.2 The cold-formed steel built-up I-sections

In the preparation of the I-shape cold-formed steel built-up sections, two identical C-section columns were fastened together with self-drilling screws to form an I-section column. Table 3.1 shows the parameter and magnitudes of the cross-section used in this experimental investigation. The dimensions of the specimen have been used as shown in Figure 3.3. The cold-formed steels were ordered and produced by Semambu Engineering & Supplies Sdn Bhd, a local company in Kuantan, Pahang. The plates for the cold-formed steel were ordered by Kin Kee Metal Sdn Bhd, in Bandar Indera Mahkota, Kuantan, Pahang. The shapes of the plates used were square, the thicknesses were 20 mm and the sizes were 200 mm x 200 mm.

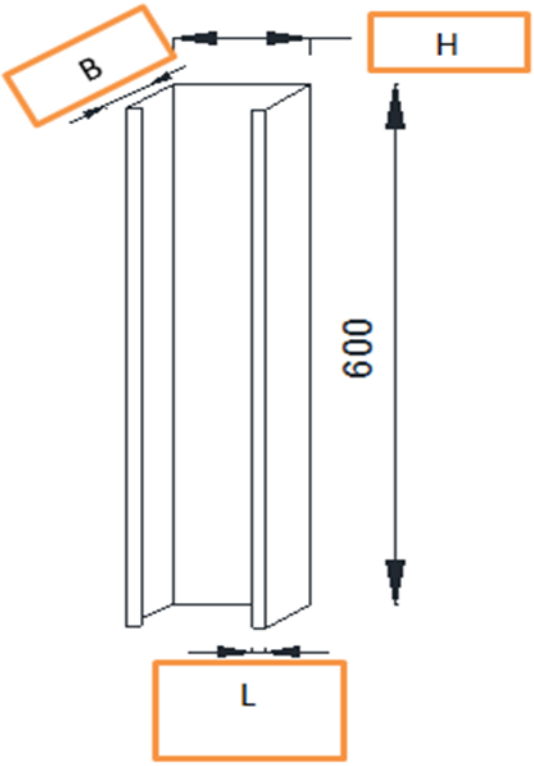

Figure 3.3 Dimension of C-section sample

Table 3.1 The parameter and magnitudes of the cross-section

Parameter	**Magnitude (mm)**
Thickness, t	1.2
Depth, H	103.0
Flange, B	51.0
Edge Stiffener, L	14.0

The perforations of the cold-formed steel were made using an elongated circle shape with the size in millimetre (mm) as shown in Figure 3.4. There were three perforations made on each sample and these perforations were at different location on each sample as shown in Figure 3.5. The screw spacing starts at 50 mm from one end with a constant gap of 100 mm later. The screw spacing is made constant for all samples while the diameter of the perforations was also fixed to 50 mm each. The detail of the screw spacing was presented in Figure 3.6.

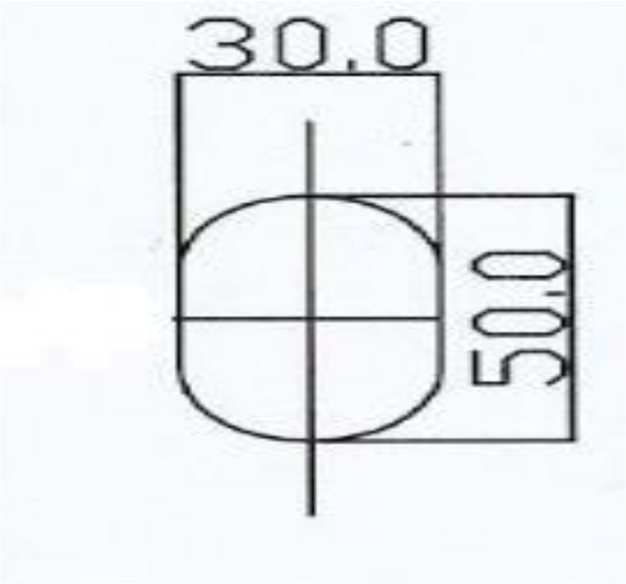

Figure 3.4 Size of the elongated circle in mm

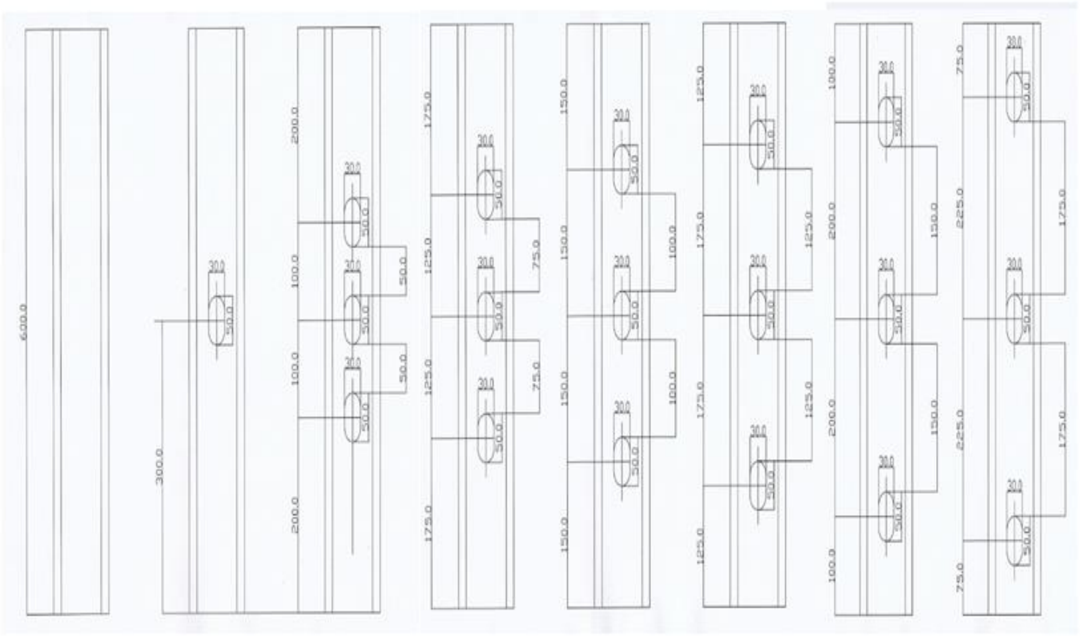

Figure 3.5 The position of perforation

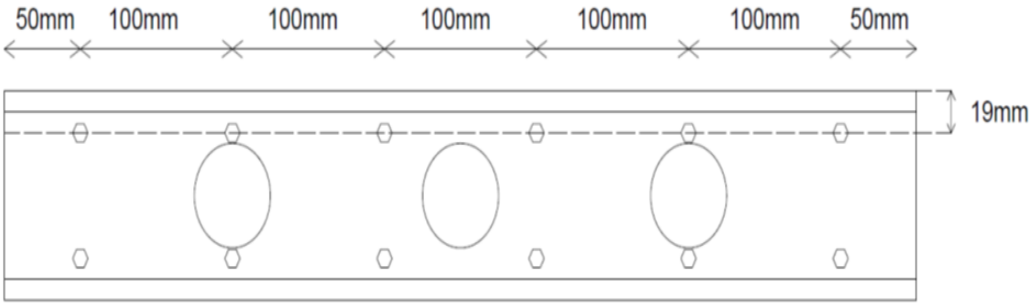

Figure 3.6 Screw spacing of the sample

3.4 Research Procedure

After completing the literature review, the methodology for the experimental investigation was planned. The sample was design and calculation of maximum axial load was done to ensure that the machine available in the laboratory can cater with the design during the investigation.

3.4.1 Instrumental

The main instrumental used to conduct this experiment was Universal Testing Machine and transducers. The Universal Testing Machine will read the displacement of the specimens. The loading rate that will be used was 0.5 mm per minute which it was the most suitable rate for these specimens according to the previous researcher. The data taken from this machine will be in the form of graph. The transducers were being used to read the reading of buckling mode of specimens. Three transducers were used to take the accurate data. Figure 3.7 show the Universal Testing Machine (UTM) that be used in this experiment.

Figure 3.7 The Universal Testing Machine

3.4.2 Test Setup and Operation

The testing of sample was made in the laboratory of Faculty of Civil Engineering and Earth Resources (FKASA) in University Malaysia Pahang (UMP). Upon testing was made, a discussion was made with the technician involved to know further about the machine and how the testing was going to be conducted. As there were no standards that were available for the testing of steel, the research by T.A. Stone and R.A. LaBoube in year 2005, title “Behaviour of Cold-Formed Steel Built-Up I-Section” was made as the main reference in conducting this experiment. The research was chosen as reference due to the factor of similarity between the samples used in the experimental investigation

The sample was design and calculation of maximum axial load was done to ensure that the machine available in the laboratory can cater with the design during the investigation. The sample used for this project has 600 mm length due to the limitation of height that the can be cater by the machine in the laboratory. First, the specimen needs to be label with maker as shown in Figure 3.8. Next, the specimen needs to be connected to the plate that has been design. The connection use was welded connection as show in Figure 3.9. After that, process was setting up the specimen during testing start by putting up the transducer.

After the transducers were placed, the specimen then was placed on the machine. Next, the transducers were put at the position according to the focussing study. There were three transducer that be used in this test. One transducer was placed on the universal testing machine. On the specimen, the transducer was placed on middle which was in left and right of the specimen. The function of the transducer was to calculate the horizontal displacement that were cause by the buckling of each specimen.

In this test, transducer CH1 was placed at the universal testing machine, transducer CH2 was placed at the middle (left) of the specimen, and transducer CH3 at the middle (right) of the sample. The details can be referred from Figure 3.10. The placing of the transducer was according to the prediction of the buckling behaviour that was made prior the test by comparing with other research paper.

Then, the loading rates of machine have been set-up. The universal testing machine was setup and the displacements that were test in this testing was set to 6 mm. This means, for every sample, the test will be end once the displacement of the sample that were caused by the axial load from the machine, reach 6 mm. The result and data from each test will be provided into two set for each sample. The first set was from the data of axial load and vertical displacement from and the second set was from the data produced from the transducer which were the horizontal displacement.

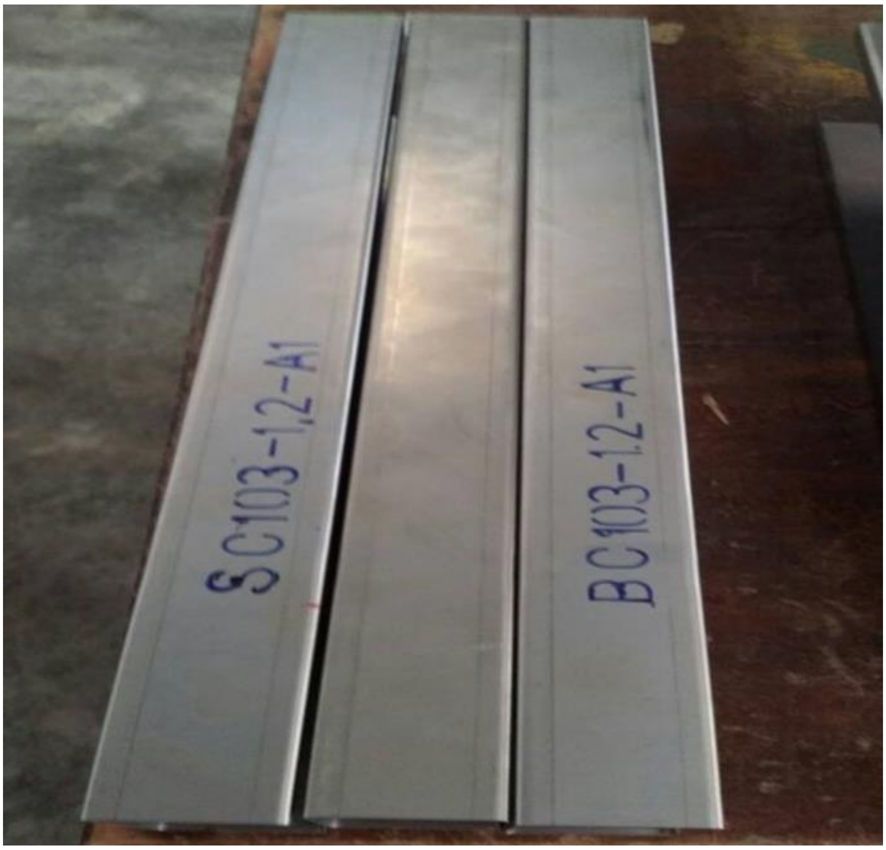

Figure 3.8 The specimens have been label

Figure 3.9 Process to welding the plate

Figure 3.10 Position of the transducers

3.5 Result and Data Analysis

Upon completing the testing in the laboratory, the result and analysis phase may start. The result from the testing comes in three type which were the buckling behaviour of the sample, reading of axial load that were being applied to the sample and the displacements that were a result of the compression of the sample. Usually the data and result will be analysing by calculation, approximate graph, figure and table with the help of standard specification. On the other hand, the buckling behaviour was observed through presentation of picture of sample after the testing was done. For this testing, the result was then analysed and graph of load and displacement were plotted for each sample.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results from the compression test were measured from the maximum loads that were applied on the sample before it buckles, buckling behaviour and the displacement of transducer. The data is presented through graph of load vs vertical displacement and load vs horizontal displacement where it compared the axial load and the displacement of the sample.

4.2 Compression Test for All Specimens

For this part, the overall result of compression test as shown in table 4.1. The ultimate load was obtained by specimen A1. Specimen A1 has the higher ultimate load because it doesn’t have perforation. Table 4.1 also show the type of buckling behaviour of the specimens that have been tested.

Table 4.1 Load displacement progression

Build-up	Initial Buckling (kN)		Peak Load (kN)		Post Load (kN)	
A1	84.24	LT/LM/LB	92.03	LT/LM/LB/DTf/DTb	27.41	LT/LM/LB/DTf/DTb
A2	84.77	LT/LM/LB	91.95	WMf/DMb	29.60	WMf/DMb
A3	83.93	LT/LM/LB	89.20	DMf/WMb	27.60	DMf/WMb
A4	83.97	WMf/DMb	90.13	LT/WTf/DTb	26.98	LT/WTf/DTb
A5	83.84	WBb	88.66	LB/DBf/DBb	26.71	LB/DBf/DBb
A6	90.13	DTf/WTb	91.02	DTf/WTb	26.31	DTf/WTb
A7	83.55	LT	85.94	LT/DTf/WTb	27.43	LT/DTf/WTb
A8	80.73	DTf/WTb	82.12	LT/DTf/WTb	26.60	LT/DTf/WTb

4.2.1 Compression Test on Specimen BC103-1.2-A1

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 84.24 kN and the observation on specimen occurred local buckling happened at top, middle and bottom as shown in Figure 4.1. The specimen failure was at 92.03 kN due to distortional and local buckling as shown in Figure 4.1. The overall observation, the distortional buckling occurred at the top was obviously shown in Figure 4.1.

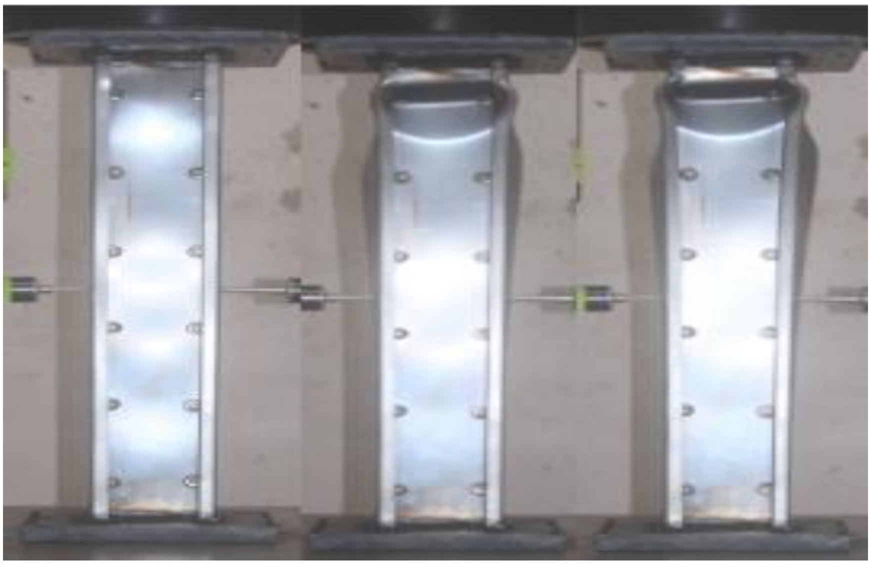

Figure 4.1 Buckling behavior of specimen BC103-1.2-A1 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.2, the ultimate axial load applied was 92.03 kN with 1.59 mm displacement.

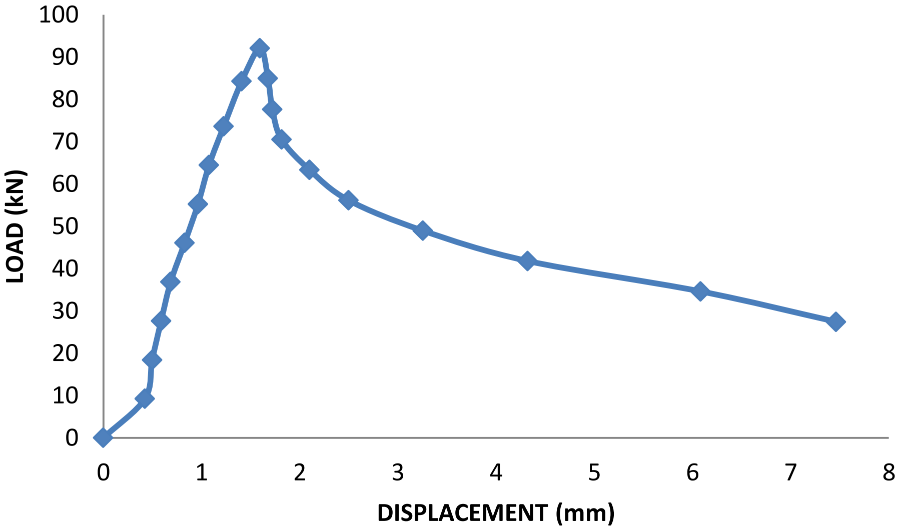

Figure 4.2 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.3, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A1 was 27.41 kN and the maximum displacement was 0.36 mm which happened at the transducer 2.

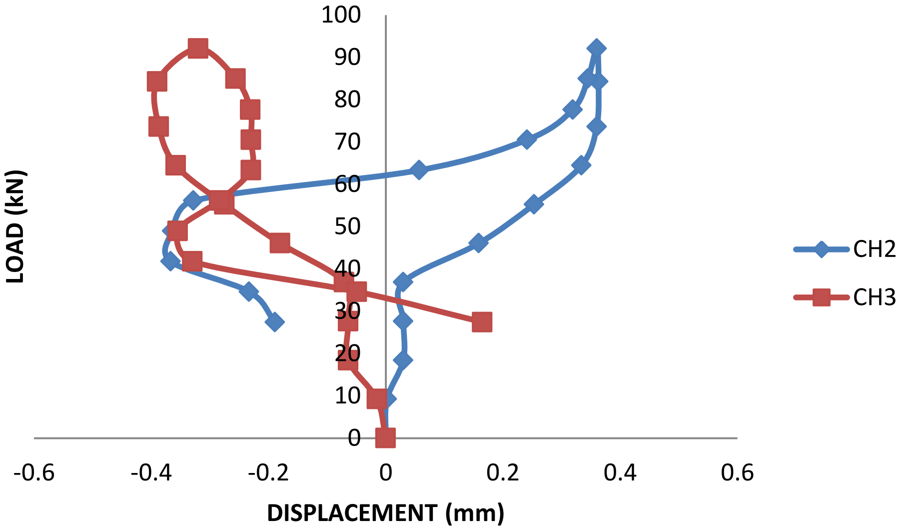

Figure 4.3 Load vs horizontal displacement graph

4.2.2 Compression Test on Specimen BC103-1.2-A2

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 84.77 kN and the observation on specimen occurred local buckling happened at top, middle and bottom as shown in Figure 4.4. The specimen failure was at 91.95 kN due to distortional buckling and warping as shown in Figure 4.4. The overall observation, the distortional buckling occurred at the middle (back) and warping buckling at the middle (front) of the specimen was obviously shown in Figure 4.4.

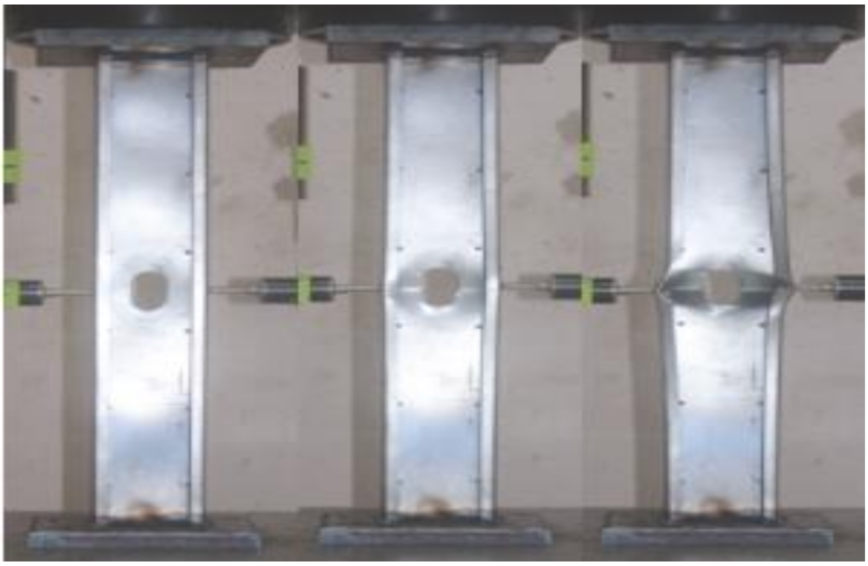

Figure 4.4 Buckling behavior of specimen BC103-1.2-A2 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.5, the ultimate axial load applied was 91.95 kN with 0.97 mm displacement.

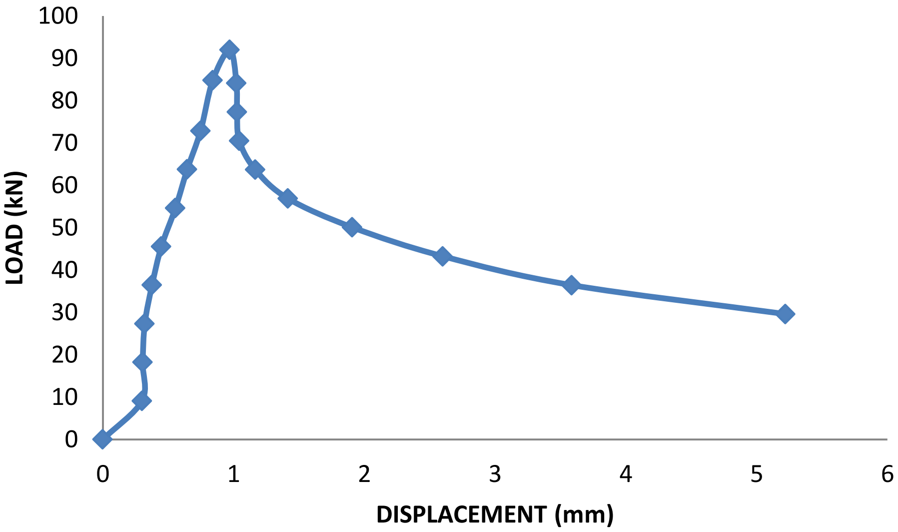

Figure 4.5 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.6, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A2 was 29.60 kN and the maximum displacement was 10.12 mm which happened at the transducer 3.

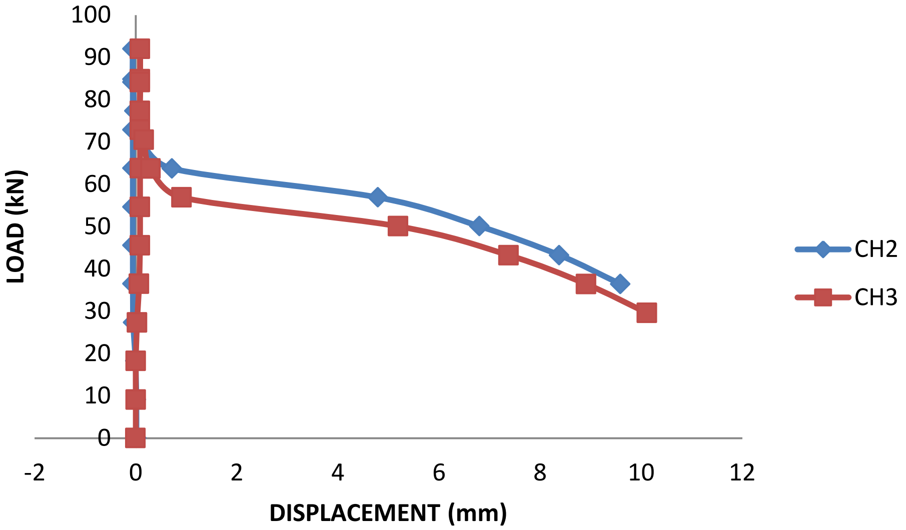

Figure 4.6 Load vs horizontal displacement graph

4.2.3 Compression Test on Specimen BC103-1.2-A3

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 83.93 kN and the observation on specimen occurred local buckling happened at top, middle and bottom as shown in Figure 4.7. The specimen failure was at 89.20 kN due to distortional buckling and warping as shown in Figure 4.7. The overall observation, the distortional buckling occurred at the middle (front) and warping buckling at the middle (front) of the specimen was obviously shown in Figure 4.7.

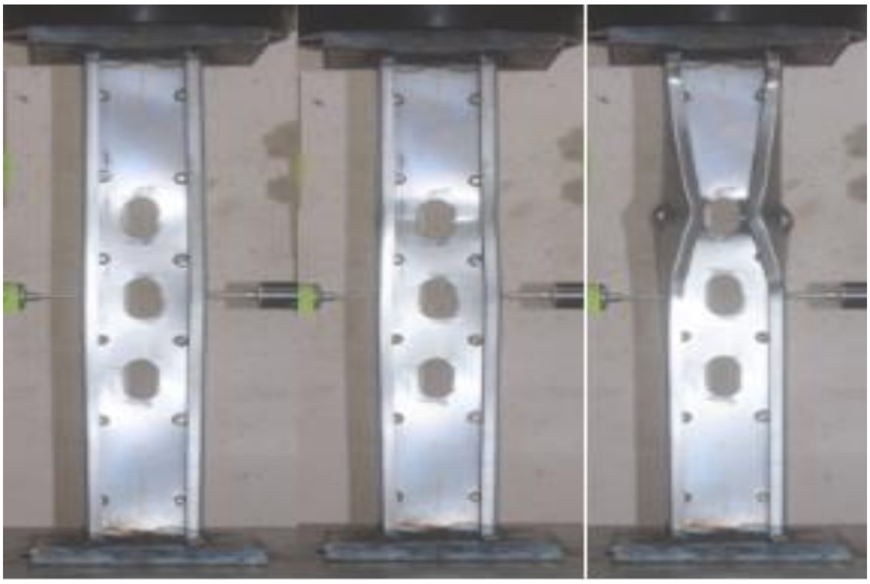

Figure 4.7 Buckling behavior of specimen BC103-1.2-A3 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.8, the ultimate axial load applied was 89.20 kN with 1.22 mm displacement.

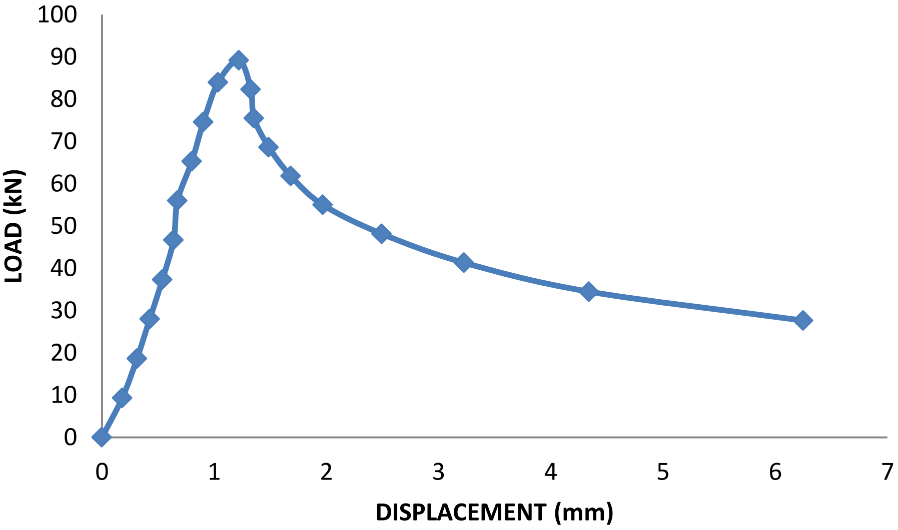

Figure 4.8 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.9, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A3 was 27.60 kN and the maximum displacement was 1.61 mm which happened at the transducer 2.

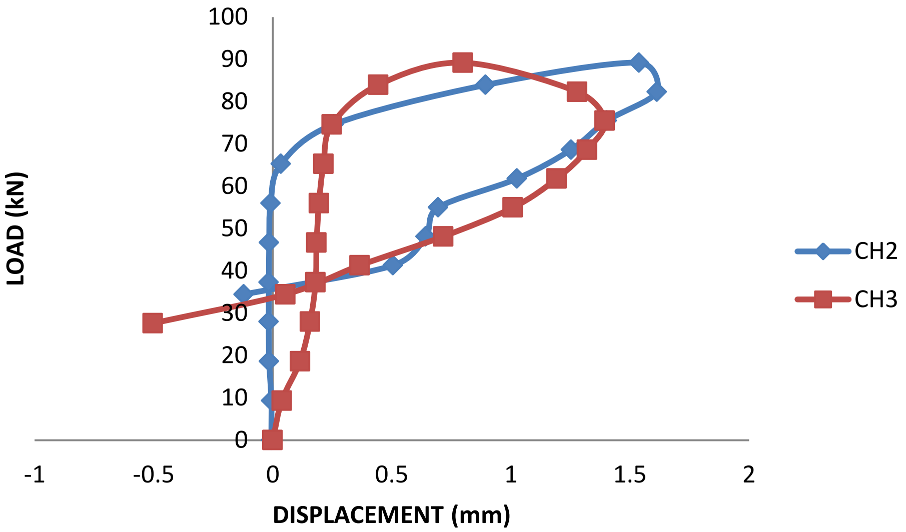

Figure 4.9 Load vs horizontal displacement graph

4.2.4 Compression Test on Specimen BC103-1.2-A4

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 83.97 kN and the observation on specimen occurred warping buckling happened at middle (front) and distortional buckling at middle (back) as shown in Figure 4.10. The specimen failure was at 90.13 kN due to local buckling, distortional buckling and warping buckling as shown in Figure 4.10. The overall observation, the distortional buckling occurred at the top (back) and warping buckling at the top (front) of the specimen was obviously shown in Figure 4.10.

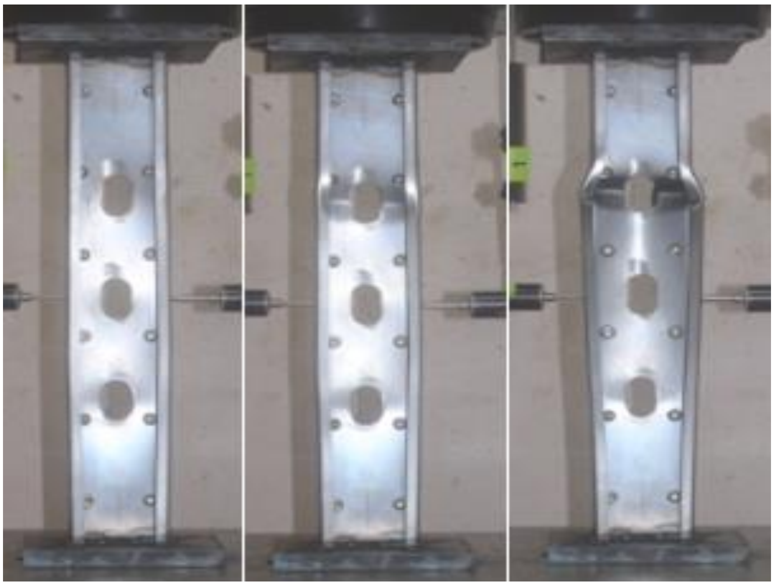

Figure 4.10 Buckling behavior of specimen BC103-1.2-A4 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.11, the ultimate axial load applied was 90.13 kN with 1.37 mm displacement.

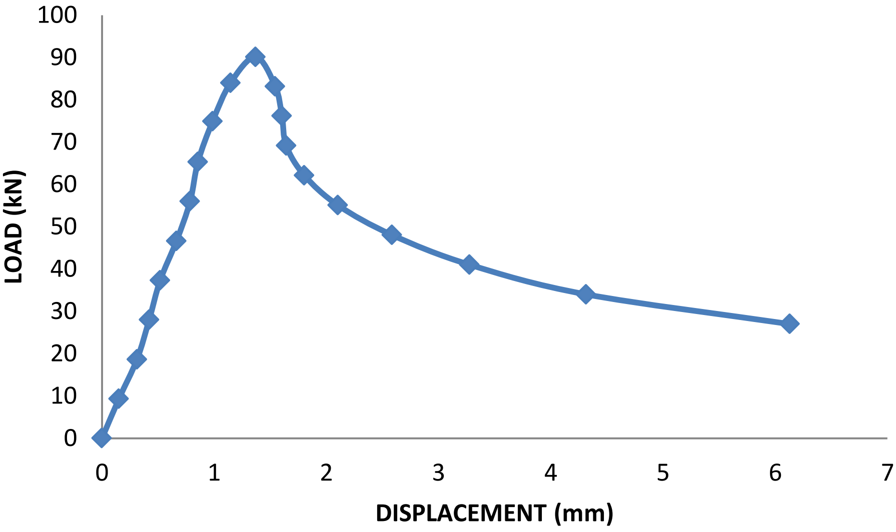

Figure 4.11 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.11, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A4 was 26.98 kN and the maximum displacement was 4.24 mm which happened at the transducer 2.

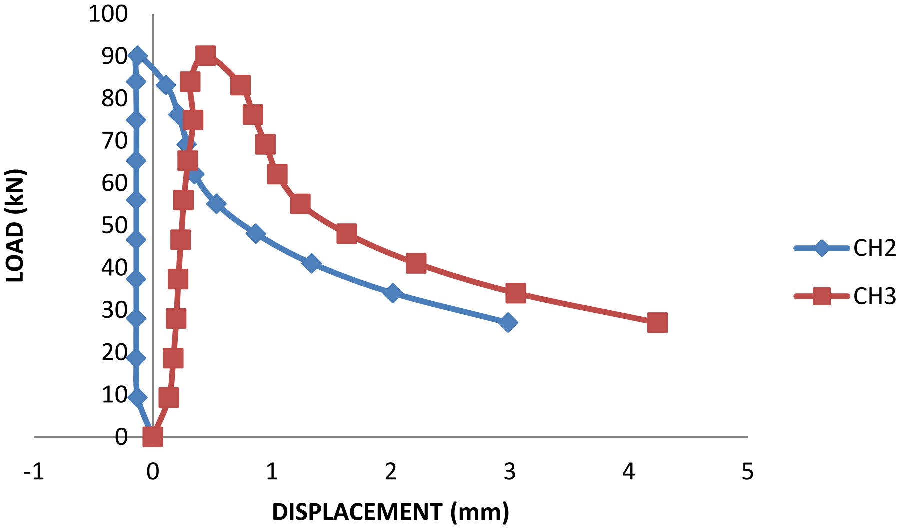

Figure 4.12 Load vs horizontal displacement graph

4.2.5 Compression Test on Specimen BC103-1.2-A5

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 83.84 kN and the observation on specimen occurred warping buckling happened at bottom (back) as shown in Figure 4.13. The specimen failure was at 88.66 kN due to local buckling and distortional buckling as shown in Figure 4.13. The overall observation, the distortional buckling occurred at the bottom (back and front) of the specimen was obviously shown in Figure 4.13.

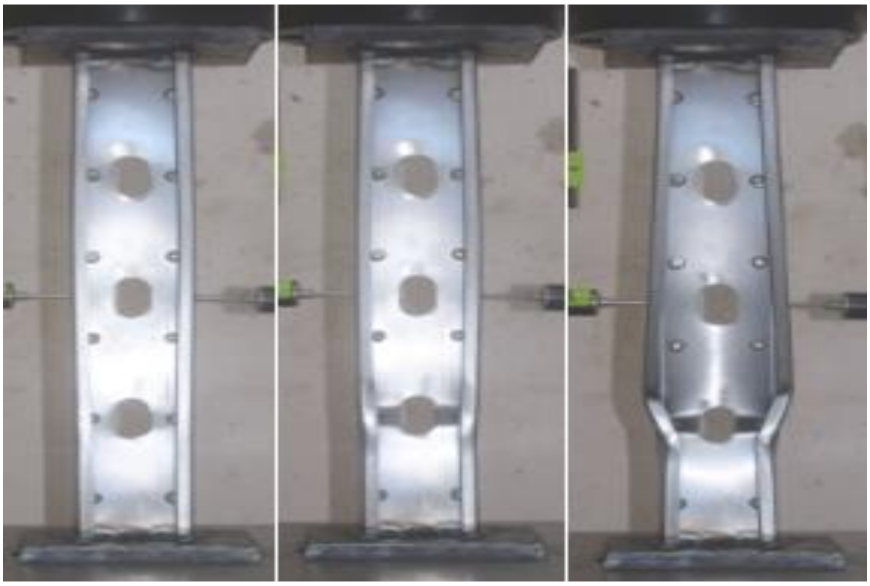

Figure 4.13 Buckling behavior of specimen BC103-1.2-A5 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.14, the ultimate axial load applied was 88.66 kN with 1.43 mm displacement.

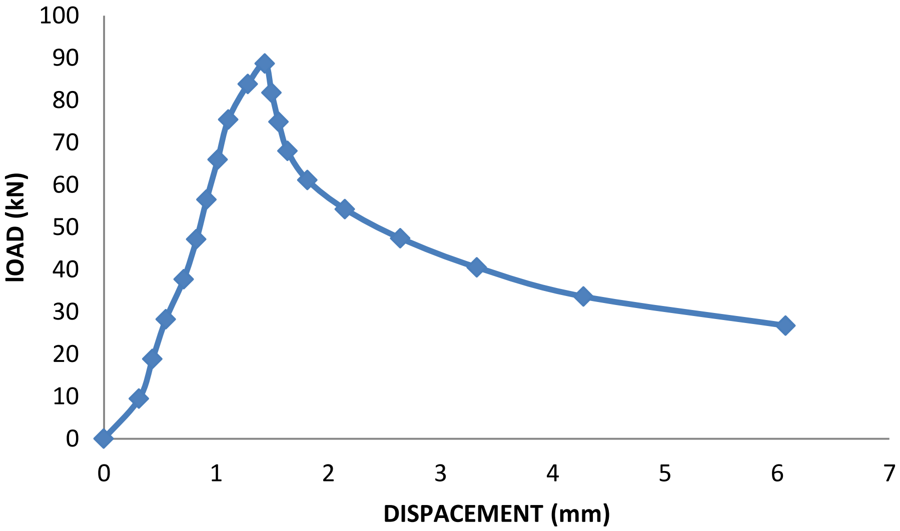

Figure 4.14 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.15, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A5 was 26.71 kN and the maximum displacement was 4.54 mm which happened at the transducer 3.

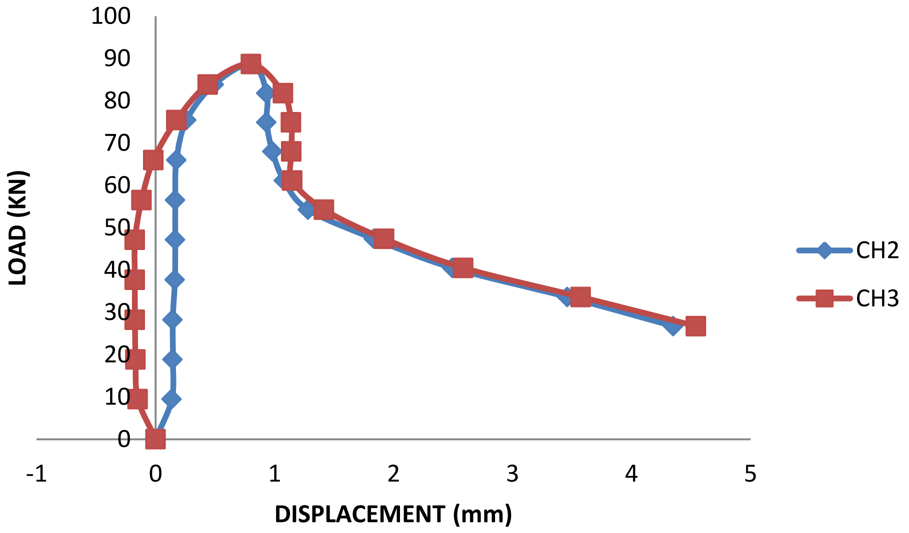

Figure 4.15 Load vs horizontal displacement graph

4.2.6 Compression Test on Specimen BC103-1.2-A6

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 90.13 kN and the observation on specimen occurred warping buckling happened at bottom (back) as shown in Figure 4.16. The specimen failure was at 91.02 kN due to local buckling and distortional buckling as shown in Figure 4.16. The overall observation, the distortional buckling occurred at the top (front) and warping buckling at the top (back) of the specimen was obviously shown in Figure 4.16.

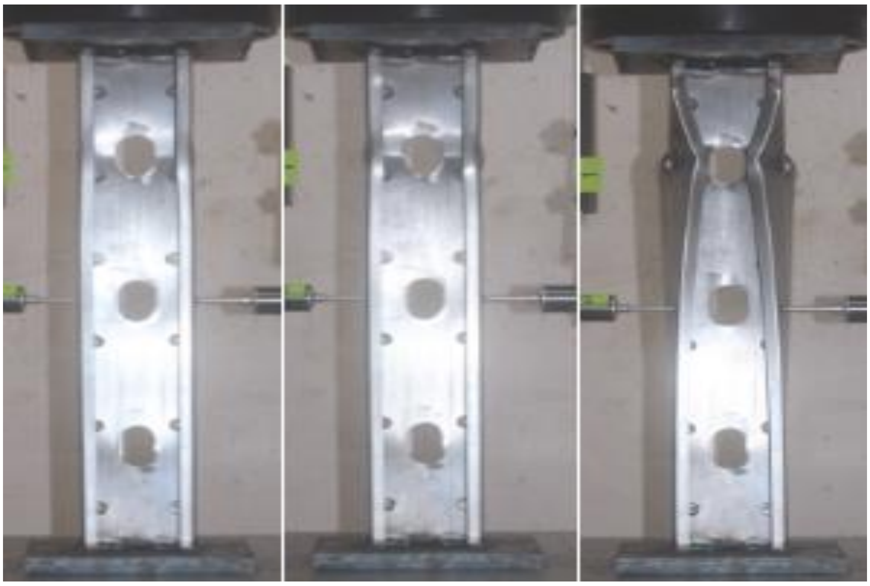

Figure 4.16 Buckling behavior of specimen BC103-1.2-A6 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.17, the ultimate axial load applied was 91.02 kN with 1.10 mm displacement.

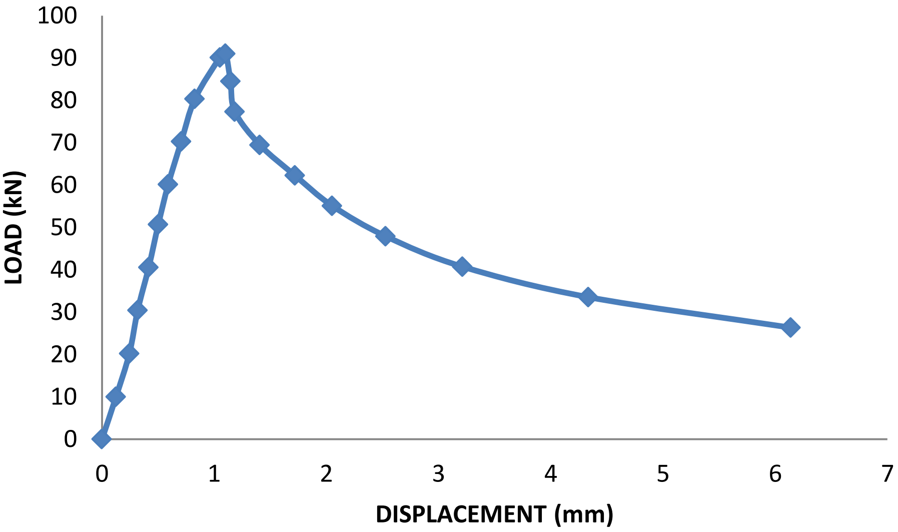

Figure 4.17 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.18, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A6 was 26.31 kN and the maximum displacement was 0.26 mm which happened at the transducer 3.

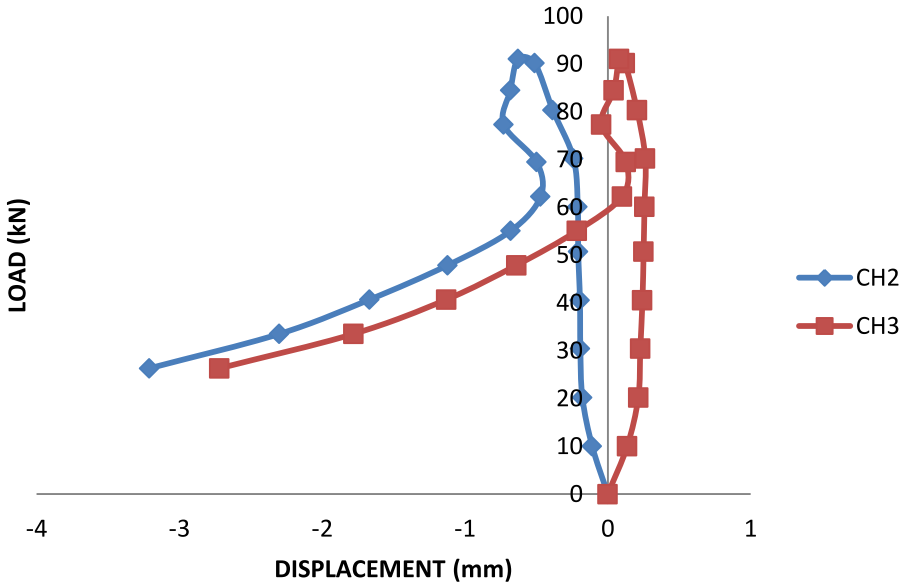

Figure 4.18 Load vs horizontal displacement graph

4.2.7 Compression Test on Specimen BC103-1.2-A7

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 83.55 kN and the observation on specimen occurred local buckling happened at top as shown in Figure 4.19. The specimen failure was at 85.94 kN due to distortional buckling and warping buckling as shown in Figure 4.19. The overall observation, the distortional buckling occurred at the top (front) and warping buckling at the top (back) of the specimen was obviously shown in Figure 4.19.

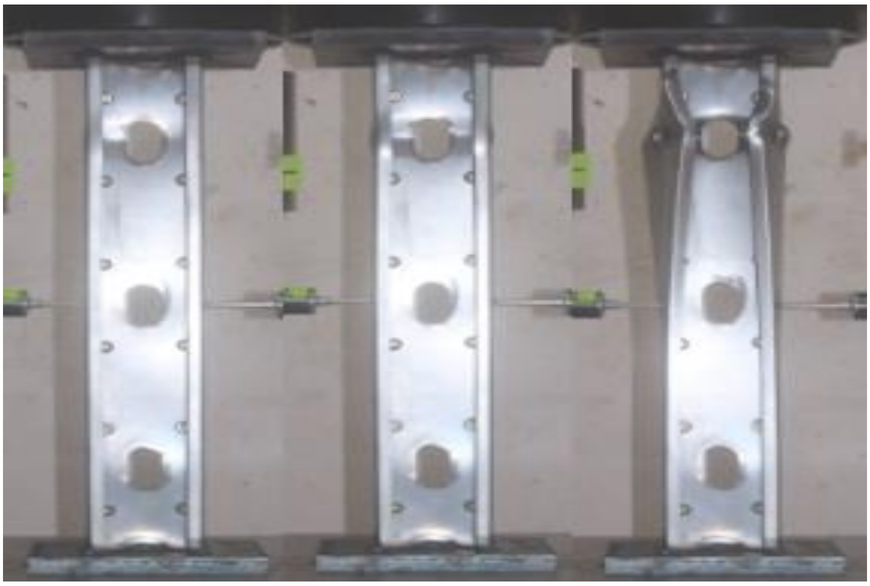

Figure 4.19 Buckling behavior of specimen BC103-1.2-A7 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.20, the ultimate axial load applied was 85.94 kN with 1.31 mm displacement.

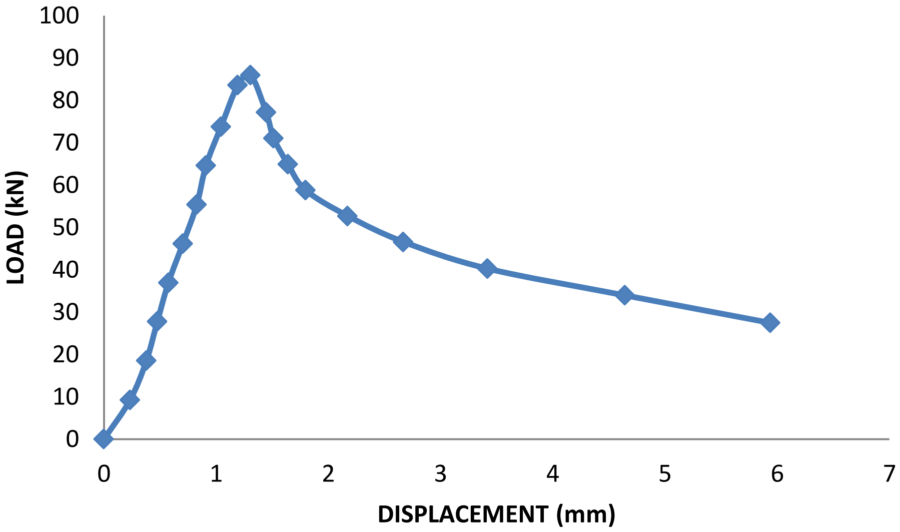

Figure 4.20 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.21, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A7 was 27.43 kN and the maximum displacement was 0.29 mm which happened at the transducer 2.

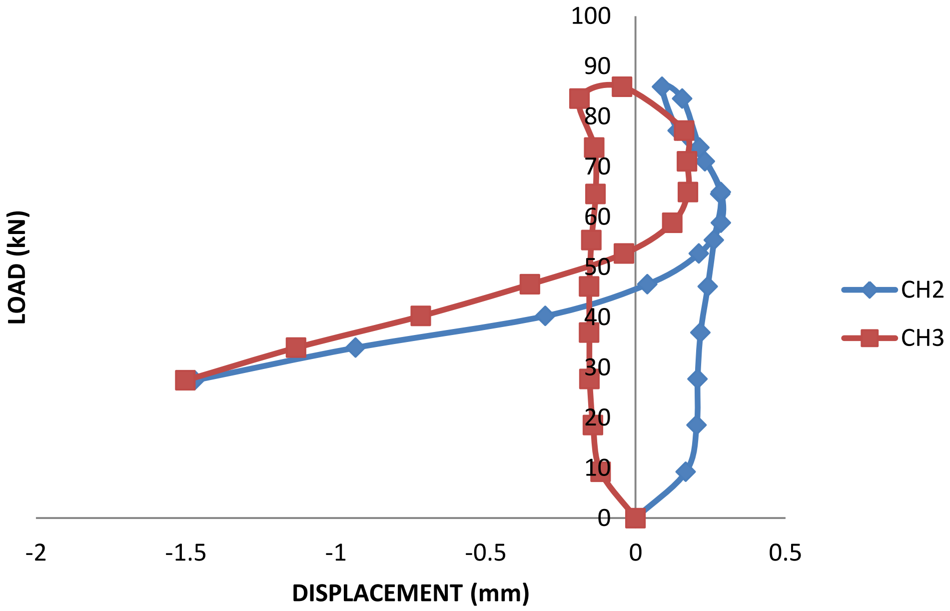

Figure 4.21 Load vs horizontal displacement graph

4.2.8 Compression Test on Specimen BC103-1.2-A8

For this specimen, the load applied on the specimen was compared to the displacement that occurs on the specimen. As seen from Table 4.1, the initial buckling load was 80.73 kN and the observation on specimen occurred distortional buckling and warping buckling happened at top as shown in Figure 4.22. The specimen failure was at 82.12 kN due to local buckling at top, distortional buckling and warping buckling as shown in Figure 4.22. The overall observation, the distortional buckling occurred at the top (front) and warping buckling at the top (back) of the specimen was obviously shown in Figure 4.22.

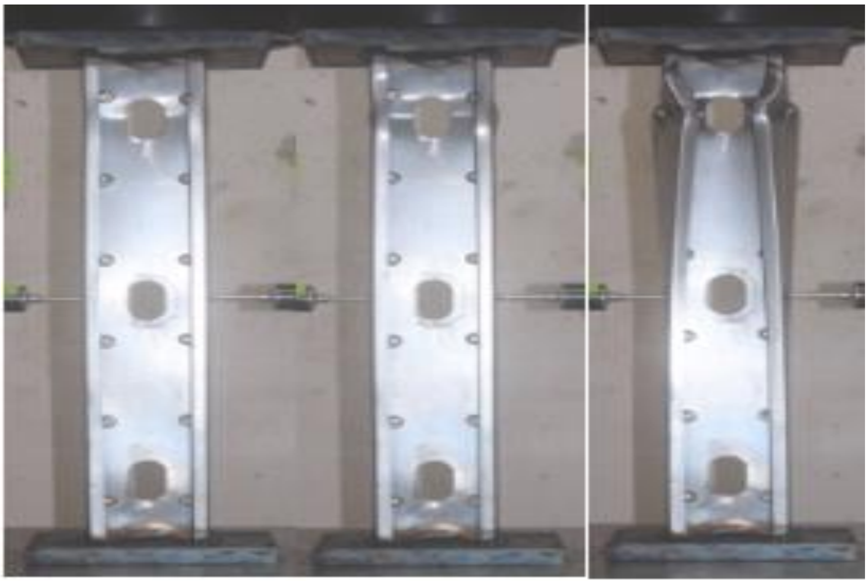

Figure 4.22 Buckling behavior of specimen BC103-1.2-A8 (initial, peak, post)

Load vs vertical displacement graph was plotted as shown in Figure 4.23, the ultimate axial load applied was 82.12 kN with 0.99 mm displacement.

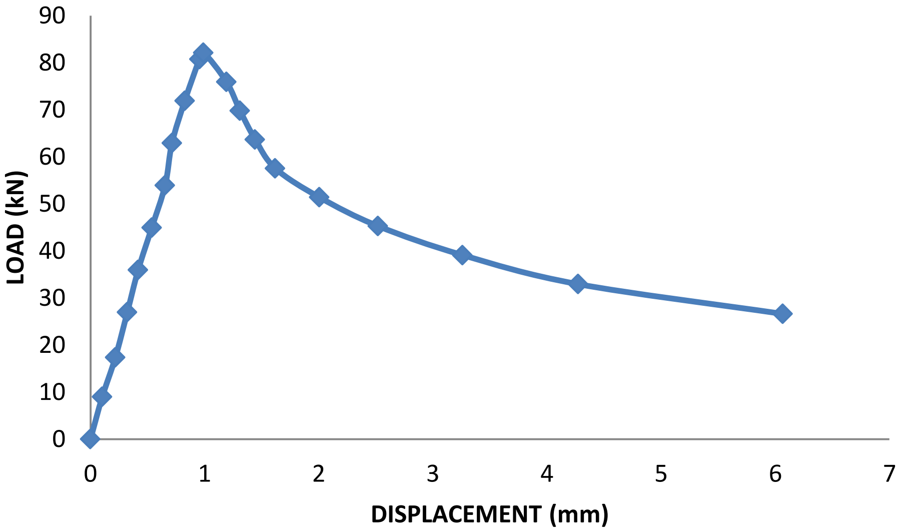

Figure 4.23 Load vs vertical displacement graph

For load vs horizontal displacement graph as shown in Figure 4.24, the horizontal displacement was the displacement that results from compressing of the machine and transducer 2 and 3. The post peak load for specimen BC103-1.2-A8 was 26.60 kN and the maximum displacement was 0.52 mm which happened at the transducer 3.

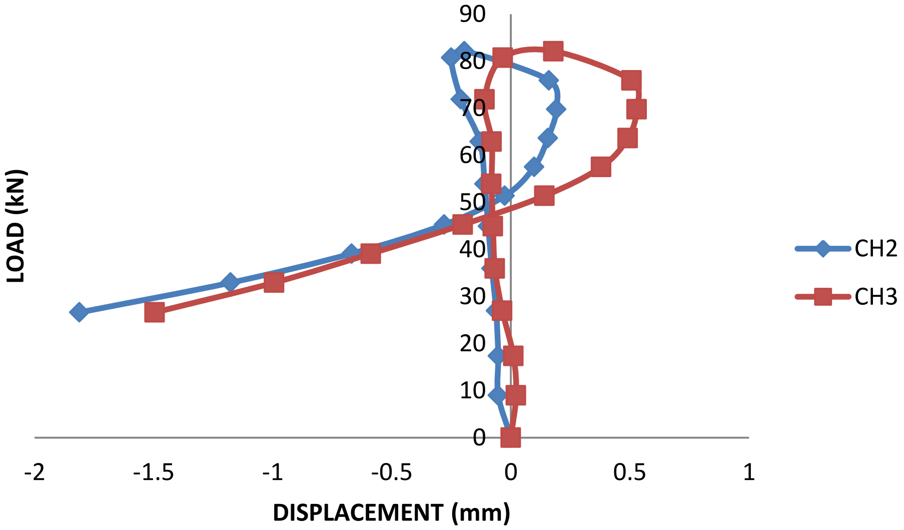

Figure 4.24 Load vs horizontal displacement graph

4.3 Ultimate Strength

For this experiment, the load applied on the specimen was compared to the displacements that occur on the sample. From the result, the maximum axial load applied was on BC103-1.2-A1 with 92.03 kN while the lowest axial load was applied on BC103-1.2-A8 which is 82.12 kN. The value shows the movement of the machine table in the act of compressing the cold-formed column.

According to the result data, the result shows that when the perforations were located close to the support or when the perforations were closed to the centre, the maximum axial load applied decrease.

4.4 Buckling Behaviour of Specimen

Overall, the specimen shows a series of local buckling, warping buckling, and distortional buckling. Four of the samples which are A1, A6, A7 and A8 buckle at the top while the other buckle at the bottom and middle. Figure 4.25 and Figure 4.26 shows the condition of all specimens after the test from the front view and back view. Figure 4.27 and Figure 4.28 shows the condition of all specimens after the test right side and left side.

Figure 4.25 Condition of specimens from front view

Figure 4.26 Condition of specimens from back view

Figure 4.27 Condition of specimens from right side view

Figure 4.28 Condition of specimens from left side view

CHAPTER 5

CONCLUSION

5.1 Conclusion

From the result of the experiment, several conclusions can be made. First, the position of perforations plays an important role in determining the ultimate load of the sample. As seen from the experimental result, the result varies greatly as the perforations position change. The result shows that, as the perforations position is placed nearing the support, the ultimate load of the sample will decrease. The position of perforations also must not be located near the centre of the sample, as it is the critical buckling position. Next, a short cold-formed steel column will fail in local buckling and distortional buckling. A short cold-formed steel column will only fail in either local buckling or distortional buckling. As seen from the buckling behaviour of the samples after the compression test, all sample experience distortional buckling.

5.2 Recommendation

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

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

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APPENDIX A
PREPARATION OF COLD-FORMED STEEL BUILT-UP I-SECTION