BEHAVIOUR OF COLD-FORMED SECTION WITH MULTIPLE OPENINGS UNDER COMPRESSION

MUHAMAD HAFIZI BIN DALHA

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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MUHAMAD HAFIZI BIN DALHA

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ABSTRAK

Unsur struktur keluli yang terbentuk sejuk telah digunakan secara meluas dalam industri pembinaan dan telah muncul sebagai penyelesaian ekonomi pilihan untuk bangunan komersial dan perindustrian satu tingkat. Bahagian terbina dalam keluli terbentuk sejuk biasanya digunakan sebagai unsur mampatan untuk membawa beban yang lebih besar apabila seksyen tunggal tidak mencukupi. Walau bagaimanapun, bahagian yang dibina menunjukkan beberapa tingkah laku yang unik yang kod-kod semasa tidak mempunyai peruntukan yang komprehensif. Ini adalah samar-samar kerana tingkah laku keluli bergulung panas berbeza daripada keluli terbentuk sejuk. Penyelidikan ini akan menumpukan pada bahagian terbina terbuka atau bahagian I. Ahli struktur keluli terbentuk sejuk biasanya datang dengan kehadiran perforasi. Tebukan adalah lubang atau pembukaan yang dibuat pada keluli terbentuk sejuk untuk memudahkan kerja pembinaan. Ia biasanya dilengkapi dengan bentuk dan saiz yang berbeza berdasarkan fungsinya seperti menampung elektrik, paip dan penghawa dingin atau perkhidmatan pemanasan. Di samping itu, sangat sedikit kajian telah dijalankan untuk mengkaji bahagian terbina keluli terbentuk sejuk seperti back-to- lajur C-channel belakang tanpa jurang, lajur C-saluran belakang dengan lajur jurang, battened, dan berlapis. Oleh itu, matlamat penyelidikan ini adalah untuk menentukan beban utama keluli terbentuk sejuk dengan dan tanpa membuka melalui kajian eksperimen. Sejumlah 8 sampel yang dengan dan tanpa pembukaan diuji dalam eksperimen ini. Setiap anggota mempunyai ketebalan nominal 1.2 mm, panjang lajur 600 mm dan panjang web yang berbeza iaitu 103 mm dan 203 mm dimampatkan di antara hujung yang disokong hanya pada kedua-dua hujungnya. Hasil percubaan ini menunjukkan bahawa beban muktamad setiap sampel sangat berbeza pada kedudukan perforasi dan panjang web. Hasilnya dibentangkan dalam tiga bahagian yang merupakan beban berbanding anjakan menegak, beban vs. anjakan melintang dan tingkah laku tenggelam.

ABSTRACT

Cold-formed steel structural elements have been widely used in the construction industry and have emerged as a preferred economical solution for single-storey commercial and industrial buildings. Cold formed steel built-up sections are commonly used as compression elements to carry larger loads when a single section is insufficient. However, the built-up sections exhibit some unique buckling behaviors which the current codes do not have comprehensive provisions. This is ambiguous as the behavior of hot rolled steel is different from cold formed steel. 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 is 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 In addition, very few studies have been carried out to study cold formed steel built-up sections such as back-to-back C-channel column without a gap, back-to-back C-channel column with a gap, battened, and laced columns. Thus, the aim of this research is to determine the ultimate load of cold-formed steel with and without opening through experimental studies. A total of 8 samples that with and without opening were tested in this experiment. Each member has nominal thickness of 1.2 mm, column length of 600 mm and different web length which is 103 mm and 203 mm were 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 and the web length. The result is presented in three section which are load vs. vertical displacement, load vs. horizontal displacement and buckling behavior.

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LIST OF ABBREVIATIONS

LBW	Lateral back
CFS	Cold-Formed steel
FKASA	Fakulti Kejuruteraan Alam Dan Sumber Alam
n.d	No date
LBF	Lateral torsional buckling at top support (front)
LTF	Lateral torsional buckling at top support (front)
DTF	Distortional buckling at top support (front)
DTB	Distortional buckling at top support (back)
DMF	Distortional buckling at middle span (front)
DBF	Distortional buckling at bottom support (front)
DBB	Distortional buckling at bottom support (back)
WMB	Warping buckling at middle span (back)
WMF	Warping buckling at middle span (front)
WBF	Warping buckling at bottom support (front)
WTB	Warping buckling at top support (back)
FE	Finite Element
SFIA	Steel Framing Industry Association
CH1	Transducer 1 – Vertical Displacement
CH2	Transducer 2 – Horizontal Displacement
CH3	Transducer 3- Horizontal Displacement

CHAPTER 1

INTRODUCTION

1.1 Introduction

Cold–formed steel members have been increasingly used in many industrial, residential and commercial steel buildings due to their relatively good strength to weight ratio and speedy construction. Further, unlike conventional hot–rolled sections, cold–rolled sections are usually thinner and are generally associated with high strength and stiffness to weight ratios, as a result of rolling process at ambient temperature. According to Steel Framing Alliance report, the use of cold-formed steel framing in the recent years has increased expressively in residential, commercial and industrial construction. Statistics shows that cold-formed steel framing occupies 39% of commercial applications, with 81% of all non-load bearing cases and 23% of structural applications. Hence, in comparison to hot-rolled steel members, cold-formed steel members are more vulnerable to instabilities like local, global and distortional buckling. In terms of physical characteristics, cold rolled steels are typically harder and stronger than standard hot rolled steels. As the metal is shaped at the lower temperatures, the steel's hardness, resistance against tension breaking, and resistance against deformation are all increased due to work hardening.

There have been some significant developments in cold-formed steel structures over the past few decades, mainly due to improving technology of manufacture (higher quality steels, more complex section shapes, improved forming technology) and corrosion protection. This leads to greater competitiveness of this structural solution which has been translated into an increasing market share throughout the world. Cold-formed steel members are made from cold bent steel sheets of 0.5–3.0 mm thickness. Researchers have been focused on the behaviour of cold-formed steel structures. Regarding the behaviour of cold-formed steel columns, research has been mainly focused on open sections, such as plain and lipped channels, channels with simple and complex edge stiffeners, with and without holes and angles as shown in Figure 1.1. More recently built-up members have also been investigated by some researchers

The main advantages of cold-formed steel systems as non-structural and structural ,low seismic forces due to lightness of the material, practicability in the field (easy erection),dimensional superiority high level of ductility and energy absorption capacity and environmental issues.

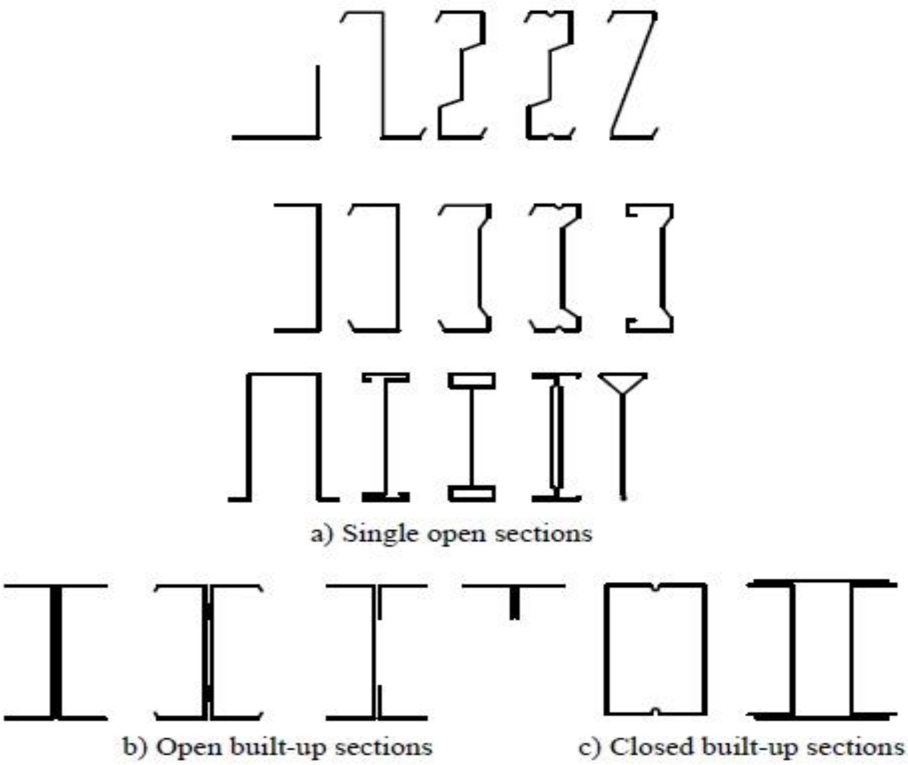

Figure 1.1 Variation of cold-formed steel
Source: (Dubina, et al., 2012)

Openings are often introduced in structural members to facilitate the building services such as pipeline, electric wire and heating conduits, as well as inspection and maintenance work of buildings. These openings are usually pre-punched perforations, which could lead to the redistribution of membrane stresses in the members and greatly influence the elastic stiffness and ultimate strengths of structural members. The behaviour of perforated structural members significantly depends on the shape, size, location and number of openings.

1.1.1 Example of Usage of Cold-formed Steel

Cold-formed steel column are normally use in structural around the world as shown in Figure 1.2 and in Figure 1.3 from the column to the roof overall is using cold-formed steel column. This will give an advantage to the client as the project will not use long period of time. In Malaysia the use of cold-formed steel is limited because of people are not aware of the advantages of cold-form steel.

Figure 1.2 House made up from cold-formed steel

Source: (Georgieva, et al., 2012)

Figure 1.3 Cold-formed steel framing

Source: (Satpute & Varghese, 2012)

1.2 Problem Statement

The use of cold-formed steel has become wide in industrial to install it as structural and non-structural material. In non-structural which commonly manufactured with holes to accommodate plumbing, electrical, and heating conduits in the walls and ceilings of buildings. It will come into many consideration when it applied as construction material encompass columns, beams, joists, studs, floor decking, built-up sections and other components. The existence of opening will reduce the surface area of cold-formed steel and theoretically, their strength will likely to be reduced form the cold-formed without opening.

A research will be conducted to investigate influences of elongated on stub column as opening. Different location of the elongated opening also take part in greatly influence the elastic stiffness and ultimate strengths of structural members. The behaviour of cold form steel (CFS) columns with circular openings is mainly governed by the column slenderness ratio (L/D and Le/r), the opening size ratio (d/D) and the number of openings. Many problem had risen due to impact of the opening location because it will affect the behavioural of the steel. Experiments on cold-formed steel columns with holes are conducted to observe the interaction between elastic buckling, load–deformation response, and ultimate strength.

For cold form steel with opening there's limitation of design code procedure which we can't refer to any design code for the type of steel. 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 ultimate strength of the opening cold form steel need to be determined due to different location of the opening. Compression test will be used to determine the ultimate strength of axially loaded cold form steel with opening. This study will review ultimate strength that will determined due to different location of opening.

1.3 Research Objective

The main aim of this research is to study the condition of cold-formed steel lipped single "C" section and built-up "I" section with and without opening under compression. In order to achieve this, several objectives are identified as follows:

i. To determine the ultimate load of cold-formed steel with and without opening.

ii. To study the of failure mode behaviour of axially loaded column with openings.

1.4 Research Scope

A series of column tests on cold-formed steel lipped single "C" section and built-up "I" section. The columns were compressed between fixed ends. Cold-formed steel members with holes are prescriptive and limited to specific perforation locations, spacing, and sizes for current design methods which is available for engineers to predicting the strength. The section of cold-formed that being tested is cold-formed steel lipped single "C" section and built-up "I" section are being used which size of width 103 mm and 203 mm. Specimen of cold-formed steel will be used with and without opening. 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

This research of this study is can be used for study in society which is the behaviour of the cold form will vary if there is an opening exist and it can learn through experimental study. This study also give benefit to player in industry which is engineer that can implement on using steel structure with perforation on designing project structure. This is agreed by (Vijayanand & Anbarasu, 2017) the built up columns have unique buckling behaviour for which the current codes do not have code provisions The data collect from this experimental can be used for construction industry. Useful of this research for society that people will more aware on using steel with opening as building construction. Furthermore, cold form steel is cost effectiveness material. Web width which is 103 mm and 203 mm will be observe towards the tendency to buckle. It is obvious, that design standards were needed to establishing requirements and laws to control the buckling and strength characteristics.

CHAPTER 2

LITRATURE REVIEW

2.1 Introduction

Cold-formed steel structures have been considered as an efficient solution for rapidly growing construction demand particularly for low-rise and mid-rise buildings according to (Soyoz & Karabulut, 2017). Agreed by (Kulatunga, et al., 2014) cold-formed steel members have become competitive building products in modern building construction due to their inherent favourable characteristics over conventional hot-rolled steel members. Due to the advantages of cold-form steel which is their wide range of application, economy, ease of fabrication and high strength to weight ratios it is widely used in 1850`s and it shows a drastic use after being introduced in the building. Figure 2.1 shows the various shape of cold-form steel which include the single open section, open built-up section, closed built-up section. Commonly cold-form steel open section which C shape were using for the light load and medium span situations which is using in roof structures as shown in Figure 2.2 .

The cold-formed steel has recently been brought into Malaysia's construction but has not been fully accepted since it has specimens' limitations. Most local products have limitations depending on the presence of openings on cold form steel. When opening exist on the cold-form steel the limitation will likely change. So, in this study will indicate whether the opening has an effect on cold-form steel strength.

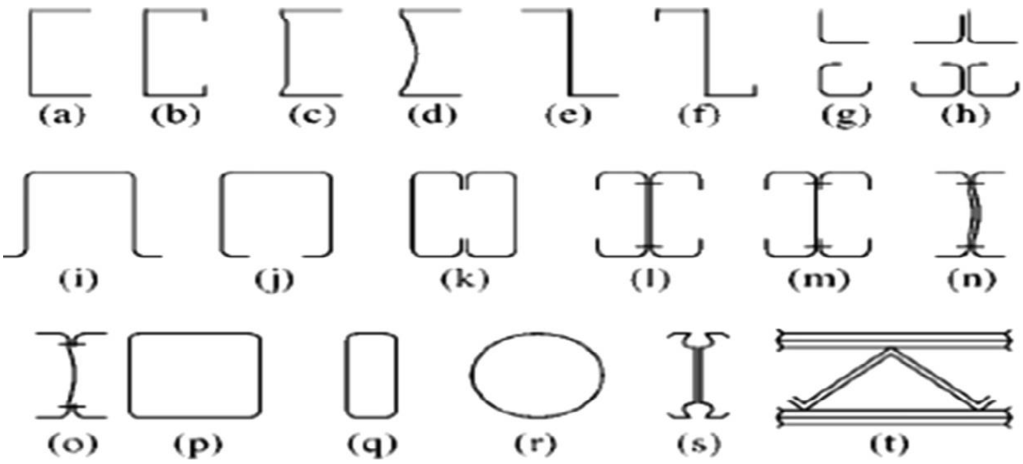

Figure 2.1 Various shape of Cold-form steel

Source : (Javed, et al., 2017)

Figure 2.2 Cold-form steel roof trusses

Source : (Soyoz & Karabulut, 2017)

2.2 Characteristic of Cold-form steel

There is two type of steel which is hot rolled steel and cold-form steel. According to (Satpute & Varghese, 2012) a cold-formed steel structure is the product made by bending flat sheets of steel at ambient temperatures into shapes which it can support more than the flat sheet themselves. Cold-formed steel is one of the popular material choice for loadbearing interior exterior walls, non-structural interior walls floor joist and curtain walls. Architect enables to design structures that safer and more durable, dynamic and sustainable regarding on many performance-based characteristic and green attribute of cold-formed steel framing.

2.3 Cold-forming Process

(Zhou & Jiang, 2017) Stated that cold-formed steel members are manufactured by one of the three processes that are roll forming, folding and press braking. Based on Steel Framing Industry Association (SFIA, n.d.), cold-formed Steel members are made from structural quality sheet steel that are formed into C-sections and other shapes usually by roll forming the steel through a series of dies. Penetrations for plumbing and electrical runs are also punched at pre-determined locations. No heat is required to form the shapes (unlike hot-rolled steel), and thus the name cold-formed steel. A Variety of steel thickness is available to meet a wide range of structural and non-structural applications. Press braking is the easiest way to form a steel the process with a piece of sheet metal is formed along a straight axis as shown in Figure 2.3. This may be accomplished usually for section with several fold such as V shaped, U shaped, or channel-shaped by punch and die set. However press barking has certain limitations in it design. The profile geometry that can be formed and length of section that can be accommodate by this method is still limited.

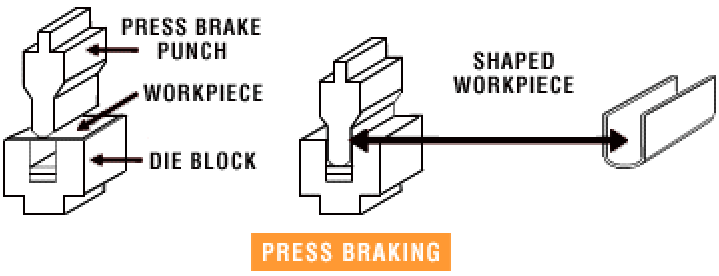

Figure 2.3 Press braking of cold-formed steel process

2.4 Advantages of Cold-form steel

Cold-form steel are among the good material to use in construction due to the advantages that cold-form steel have to attract people to use.

i. Strength.

Regarding to strength-to-weight ratio steel has the highest ratio compares to any building material. Additionally, the cold-formed steel strength also provides architects with greater flexibility, enabling designs that combine longer spans and other architectural features

ii. Durability

Steel is inorganic, and therefore cannot resist termites, rot and mould. Protective zinc coatings and other metal coating seams provide long-term resistance indicating research can be hundreds of years without any deterioration

iii. Fast and Easy installation

Because of its lightweight cold-form steel are easy for workers to install it. Cold-formed steel is easy to transport as it has a very lightweight. American Iron and Steel Institute (2010) described that the process of transporting the cold-formed steel is easy to handle as they can be nested and bundled hence reducing the required shipping and storage space. This work using cold-form steel can be done quickly within time given. Hence this is a good advantage for workers and client to achieve the goal on time.

iv. Cost Effectiveness

As compared with thicker hot rolled shapes, more economical design can be achieved for relatively light loads and/or short spans. Moreover, Cold-formed steels offer cost savings on some parts. By helping reduce the risk of fire, the use of cold-formed steel causes lower insurance costs for builders and owners.

v. Sustainable

Cold-form steel is the most sustainable building material in the world. Reusable and recyclable steel repeatedly without losing its quality as a building material. This unique feature provides all the high economic value steel at all stages of its life cycle which, unlike some other construction materials.

2.5 Perforation

Perforation is a form of opening on the sheet metal which has been punch or stamped to produce the opening. According to (Kulatunga, et al., 2014), Cold-formed members are typically manufactured with perforations to facilitate various services in building construction. These perforations are varied with respect to their position, size, shape, number of perforations, and orientation. As shown in Figure 2.5 there will be different shape of perforation and it can be more than one perforation.

The presence of the perforation may affect the strength of the steel which it will reduce the normal strength of cold-form steel due to different size, position and orientation of opening. According to (Yuana, et al., 2017) because of the wide variety in the size and configuration of perforations, it is rather difficult to directly calculate the critical buckling stresses of cold-form steel with perforation sections. Different type of cold-form steel perforation will have different properties and also different compressive strength.

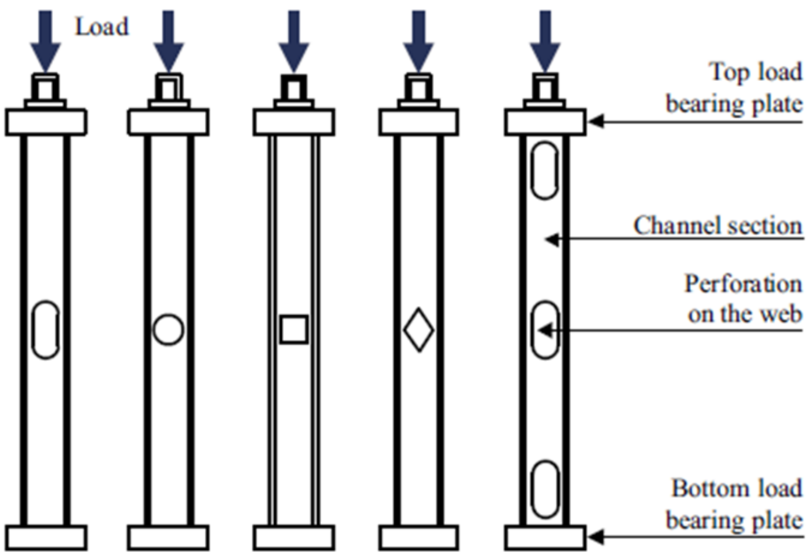

Figure 2.4 Different shape of perforations.
Source: (Kulatunga, et al., 2014)

2.6 Steel Behavioural

A large number of researcher have been investigate the steel behavioural of different type of steel properties. Cold-formed steel sections have distinct structural stability problems, which are not observed in hot-rolled steel sections. In steel compression members, behavioural of failure which is at least three competing buckling modes namely local, distortional, and Euler (flexural or torsional-flexural) buckling is likely to occur.

2.6.1 Built-up cold-formed steel

Built-up cold formed steel column is fix-ended and consists of two cold-formed steel channels placed behind at different intersections. Both channels are connected using their self-drilled screws. According to (Georgieva, et al., 2012)built-up cold-formed steel 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 are a relatively cheap alternative to single profiles, which easily fail in overall buckling, if not laterally supported. Built-up solutions are adopted in practice, regardless of the lack of design rules to predict the member strength. However, according to (Young, et al., 2008) open sections would likely fail by twisting in addition to other buckling modes depending on the dimension of the cross sections and the length of the members

2.6.2 Failure Mode

Some steel restrictions include susceptibility to corrosion, strength reduction when exposed to temperatures commonly found in most fires, and easily susceptible to high compression and bending pressure. In addition to these limitations, a design engineer must ensure that their steel structure is strong enough to prevent the following failures which is, flexural failure, compression failure and tensile failure.

According (Georgieva, et al., 2012) to the failure of all specimens is characterised by mode coupling between the typical buckling effects for thin-walled members. Compression failures normally occur in compression members, such as columns. When the compressive axial load is applied to the members caused the members to either buckle or become overstressed. Similar to beam, column members when applied to high compressive stress may experience buckling. In this research cold-form steel will be test to failure by compression test

2.6.3 Buckling Mode

In steel common buckling failure occur are in various form which is local buckling, distortional buckling, and flexural-torsional buckling as shown in Figure 2.5. According to (Moen & Schafer, 2008), the column lengths and cross-section dimension are typically chosen to explore the connection between local, distortional and global elastic buckling mode, ultimate strength and resulting failure mechanisms. Buckle are affected by the length and thickness of a specimen, therefore it will have different form itself. This is agreed by (Fratamico, et al., 2018) and (Li, et al., 2014) all columns were expected to buckle in global, minor-axis flexure potentially with local buckling interaction.

Local buckling happened when a thin plate of cold-form steel buckle locally in compression before other buckling modes take part. According (Whittle & Ramseyer, 2009) to cold-formed, built-up members are common compression elements in cold-formed steel joists, and these built-up members are susceptible to unique buckling behaviours. Thinner the plate, the lower will the load at which the buckle will form. The plate elements of cold-formed sections are normally thin higher plate slenderness ratio and hence they buckle locally before yield stress is reached. This is agreed by (Kulatunga, et al., 2014) and they explain that due to this factor, cold-formed steel compression member can buckle locally before the applied load reached the overall collapse load of the column

Distortional buckling mode is a mode characterised by a rotation of the flange at the flange/web junction in numbers with edge stiffened elements. It is also known as “stiffener buckling” or “local torsional buckling”. According to (Moen & Schafer, 2008) boundary conditions and the presence of holes have an influence on the observed distortional buckling mode shapes and buckling loads.

Flexural-torsional buckling or global buckling mode failure occurs in which simultaneous bending and twisting in cold-formed steel. This is due to the thickness of the plate, if the thickness is smaller the section will have low torsional stiffness and their shear centre and centroid are located away from each other. This agreed by (Lu, et al., 2017), elastic global buckling loads of the cold-formed built-up I-section columns can be obtained by considering the cross section as whole, which had been experimentally verified.

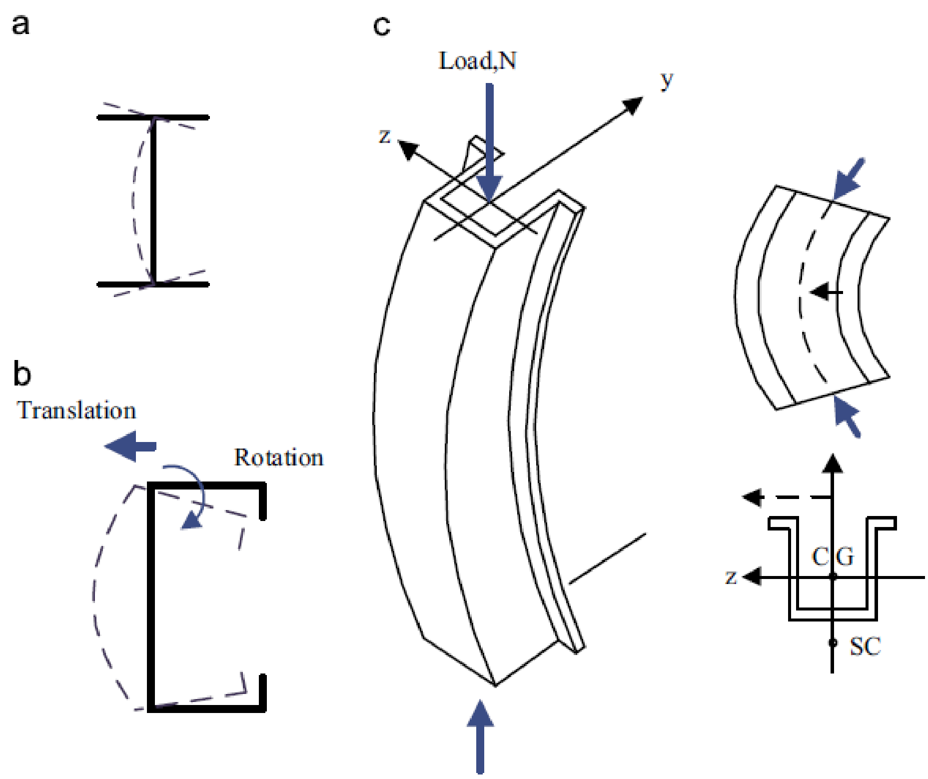

Figure 2.5 Different buckling modes, (a) local, (b) distortional, and (c) flexural or torsional–flexural.

Source: (Kulatunga, et al., 2014)

2.7 Effect of Opening for Compression Test

Compression test is the test that applied load towards top and bottom of the specimen. The test will be conduct until failure of the specimen that will form the object into different form. Local, distortional, and global buckling modes are created when a hole is placed in the web of an intermediate length structural stud. (Boube, et al., 2010) explains that the load carrying-capacities of cold-formed steel flexural and compression members are made limited by the yield stress or buckling stresses that are less than the yield stress of steel, especially for those compression elements that have a relatively large flat-width ration and compression members having relatively large slenderness ratio The effect of specimen will be shown at the end of the specimen test. Opening or holes of cold-form steel will affect the strength of individual component and overall strength of the members. This is agreed by (Feng, et al., 2016) the behaviour of perforated structural members significantly depends on the shape, size, location and number of openings.

Since the use of cold-form steel with opening is frequently impractical in construction. Therefore it is necessary to include the effect of opening in the design of cold-form steel with opening. Regarding to the limitations of cold-form steel theoretical determination and lack of research result on various type of opening on cold-form steel, there were no specific design provisions are included in the standard for the design of opening cold-form steel members.

2.8 Previous Research

Many of researcher from around the world have been made a study on cold-formed steel with different objective and type of specimen being used in every research. In completing this research there a few of researcher has been referred. The reason of doing so is to strengthen the arguments and ensuring the quality in the outcome this research.

2.8.1 Load capacity of cold-formed column members of lipped channel cross-section with perforations subjected to compression loading.

This research was done by (Kulatunga, et al., 2014) it was done to study on experiment into the influence of perforations of various shapes on the buckling behaviour of cold-formed column members of lipped channel cross-section. However, this experiment are using finite element analysis using ANSYS, an experimental investigation, and design code predictions using the AISI Specification, British Standards(BS) and EU Standards, are employed to determine the buckling load capacity. This study found that effect of the circular perforation area of the column specimen are all failed this is considered in the buckling analysis. The specimen failed after ultimate load was applied with a sudden loss in the load carrying capacity.

2.8.2 Experiments on cold-formed steel columns with holes.

Research that were conducted by (Moen & Schafer, 2008) were provided a compression test with 24 short and intermediate length of cold-formed steel with and without hole to observe and quantify the relationship between elastic buckling and the tested response of cold-formed steel. The columns are tested with friction-bearing boundary conditions where the columns ends are milled flat and parallel, and bear directly on steel plates. They found that the presence of slotted holes caused only a slight decrease in the ultimate compressive strength of the tested columns.

2.8.3 Buckling Resistance Of Axially Loaded Cold-Formed Steel Columns

Collaboration of (Craveiro, et al., 2016) on their research in 2016 provided an experimental campaign on the buckling behaviour of compressed single and built- up cold-formed steel columns. The specimen use in this investigation is single, open built-up and closed built-up cross-sections were tested. The open built-up cross-section was fabricated using two lipped channels positioned back-to-back (I) and fastened on the web using self-drilling screws along the length of the column. From the study, failure modes were observed and thoroughly characterized for each cross-section tested. From the test the advantages of using built up member was clear since the increasing on the buckling load was significant.

2.8.4 Experimental Investigation and A Novel Direct Strength Method for Cold-formed Built-Up I-Section Columns.

(Lu, et al., 2017) they were conducting research 2016 which was about investigating the structural response and predicting the ultimate strength of the cold-formed built-up I-section columns affected by local, distortional, global and in particular by the local-distortional (LD) interactive and local-distortional-global (LDG) interactive buckling modes. Specimen use in this research which include total of 18 single C-section columns and 18 built-up I-section columns were tested under uniaxial compression load. The cross-section dimensions, thickness and length of the tested member are changed in the test to cover a range of local, distortional and overall slenderness. From the research provided that when the screw spacing is larger than local buckling, local buckling cannot be restrained for cold-formed I-section columns. Below that conditions, local buckling strength of the cold-formed built-up I-section column is approximately two times of the C-section.

2.8.5 Compression Tests of Built-Up Cold-Formed Steel Hollow Flange Sections

This research were done by (Kesawan, et al., 2017) made a research on the section compression capacity of built-up cold-formed steel hollow flange section. An experimental study performed to investigate the behaviour of built-up cold-formed steel hollow flange sections in compression, where more than 45 stub columns were tested. Their type of specimen can be of different forms including hollow flange I- and channel sections, which are generally fabricated by first cold-forming a single sheet to form the desired shape and then connecting their flange web elements by continuous welding and. From their findings has shown that although hollow flange I-sections made of three elements with a 100 mm fastener spacing can perform similar to continuously welded sections, hollow flange channel sections undergo premature failures even with a 50 mm fastener spacing. Their observation in this study conservatively recommends a screw or spot weld spacing of 100 mm.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter focus on discuss the method involved in this study that is experimental axially loaded test of short columns. The process of setting up the specimen is starting by self-drilled for the built up section. Next, welding the base for specimen as we use fix end for both support with metal plate as shown in Figure 3.1. With this experimental system it was attempted to simulate both fixed-ended conditions in order to assess lower and upper bounds of the buckling load of the tested CFS short columns. After the CFS base welded, transducer is putting up to place the specimen on the machine. The transducers is setting up base on the position that were focussing in this research which located at centre of the flange. Then the loading rate for the machine need to be set up for the compression on the CFS .Machine use is Universal Testing Machine which it will compressed the specimen until failure to achieve the displacement value of study by user.

Research study by (Moen & Schafer, 2008) titles, Experiments on cold-formed steel columns with holes which is investigated the relationship between elastic buckling and structural response of cold-formed steel columns with holes by conducting the compression tests on stub and intermediate cold-formed steel columns with and without opening. For this study, tests were conducted on 24 short and intermediate length cold-formed steel columns with and without slotted web holes.

The result of the performance and behaviour between cold-formed steel lipped single “C” section and built-up “I” section with and without openings with the axial load applied to the cold-formed steel column were obtained by using the experimental study at the laboratory. An experimental study was conducted to evaluate the influence of industry-standard slotted holes on short and intermediate length cold-formed steel structural studs.

Figure 3.1 Base plate welded for top and bottom

3.2 Experimental Investigation

Cold-formed steel lipped single “C” section and built-up “I” section with different web length were subjected for compression test were considered in the investigation. Below show the flow process for experiment on cold-formed steel column in Figure 3.1 for Phase 1preparation and planning for the topic and research through the source of reference material that already exists. Phase 2, specimen for the specimen after methodology for the experiment done. Phase 3, data collect and conclusion for the experiment.

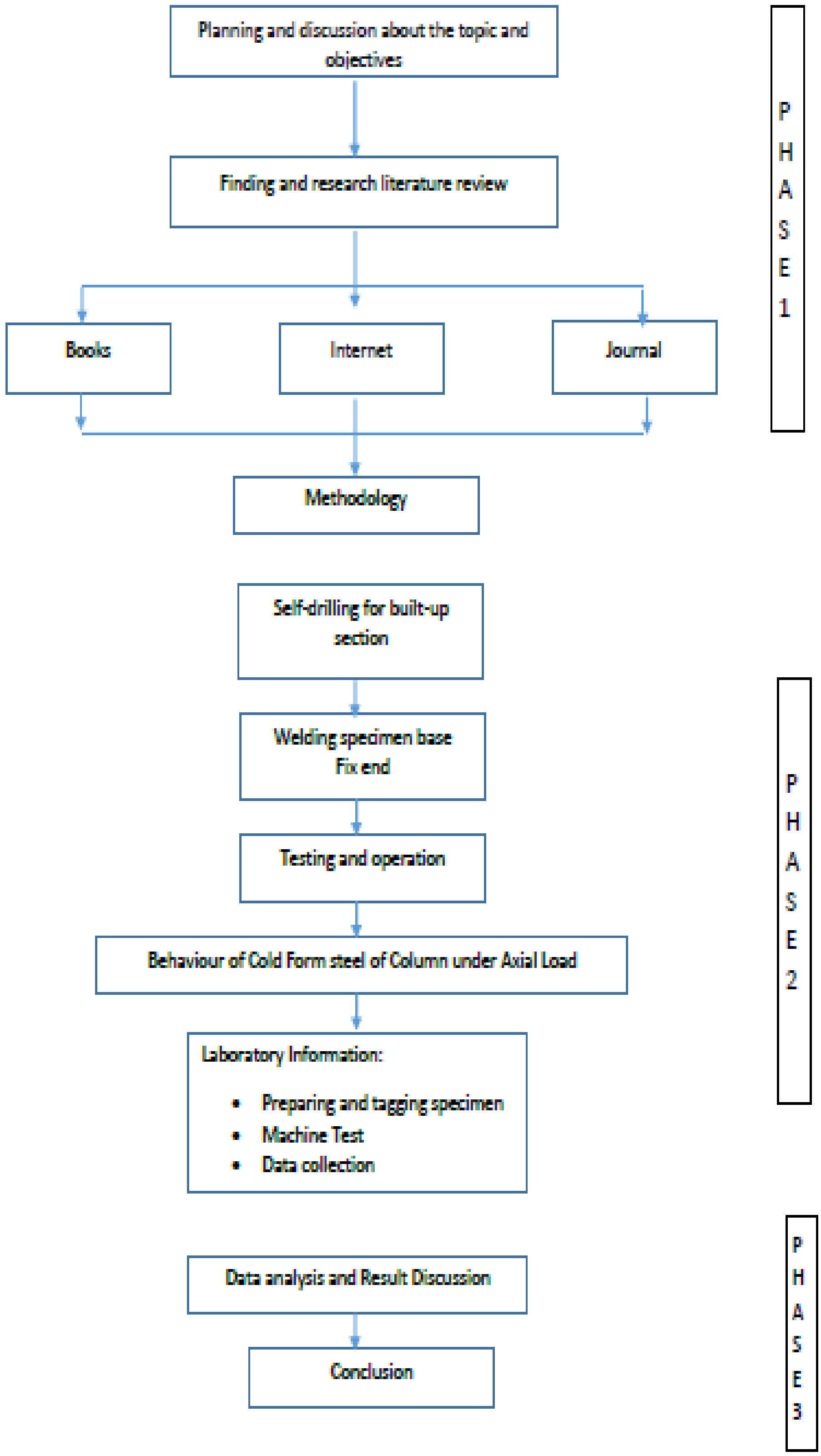

Figure 3.2 The flow process for experiment on cold-formed steel column

3.2.1 Self-drilling for built-up section

Built-up section are form of back to back two single section that produced efficiently by attaching the normal steel using self-drilling screw. According to (Muftah, et al., 2014) built-up cold-formed steel is usually a composition of normal cold-formed steel C, Z, or hat section to produce a new section. The section is connected by using bolt, screw, or weld .According to (Teh & Yazici, 2013) the bolts at the downstream ends (i.e. those closest to the member ends) were tightened as snug as possible with a wrench to prevent “global bending” of the back-to-back specimens. The spacing between screws were used from the top 50 mm and 100 mm along the flanges length. As shown in Figure there are various type of built-up section that can form from back to back and box-up with varieties of length

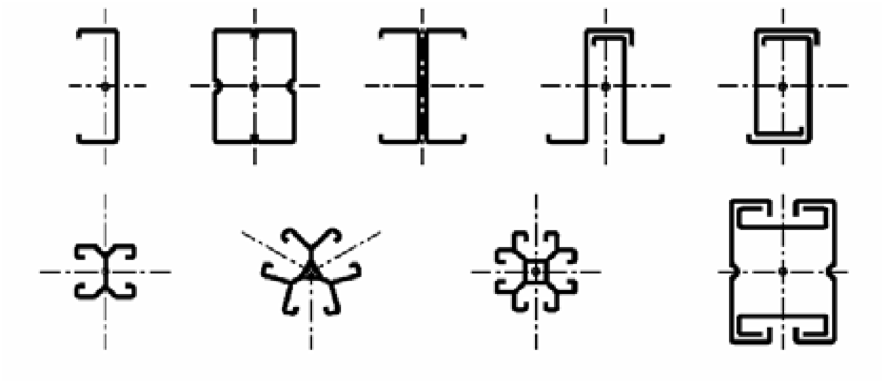

Figure 3.3 Various type of built-up
Source: Fadhluhartini (2014)

.

Figure 3.4 Self-drilled screw

3.2.2 Welding specimen

In the construction of cold-formed steel, welding is the appropriate connection method. Prefabrication of trusses, wall paneling, and hardware components are all the ideal applications where welding may be the preferred method of joining. Cold-formed sections are suitable for all types of welding, such as spot welding, steam welding, plug welding and arc welding, all of which applicable to both uncoated and zinc coated sections. Each specimen will be welded with steel plate as fix end for both end as shown in Figure 3.5 where at the centre of the specimen are also welded and at the side of the specimen in Figure 3.6

Figure 3.5 Welded connection at top and bottom

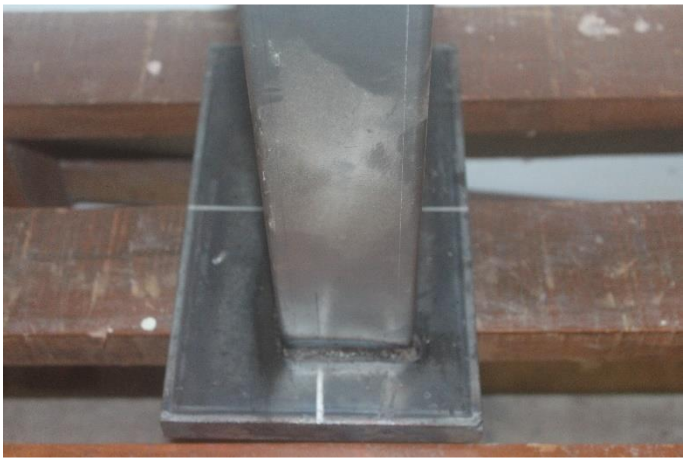

Figure 3.6 Welded connection at side of specimen

3.3 Test rig and Operation

Universal Testing Machine will be used to conduct this experiment as shown in Figure 3.7. The buckling mode of specimens will be read by transducers. For accurate data three transducers will be used which two for horizontal displacement and one for vertical displacement. Based on previous researcher (Moen & Schafer, 2008) all CFS short column are loaded in displacement control at constant rate of 0.10 mm/min. to be consistent with 21 Mpa axial stress per minute recommendation in the AISI Specification for stub column testing this rate was chosen. This research will be using loading rate 0.5 mm per minute. After specimen are placed on the machine it begin to apply an increasing load on specimen and it will sustain until failure. This is agreed by (Stone & Laboube, 2005) the ultimate failure load for each stud was defined as when the test specimen was no longer capable of sustaining additional load.

Throughout the test the data are being record. The data taken from this machine will be in the form of graph. Figure 3.3 shows the single section cold-formed steel section with openings. The diagram of the specimens and machines used are describe by drawing. All dimensions are in millimetre (mm). A channel section without openings was also tested. The column lengths, cross- section dimensions, and perforation areas were kept constant, having a thickness of 1.6 mm and specimen length of 600 mm. Detail dimension of specimen is shown in Figure 3.8.

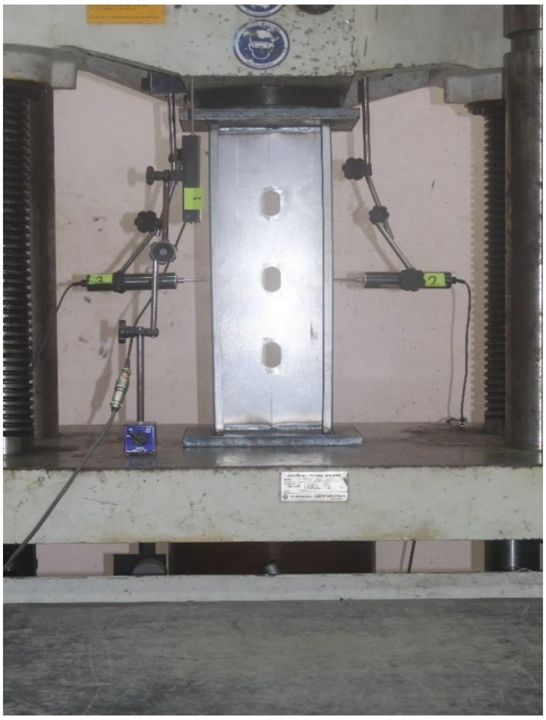

Figure 3.7 Universal Testing Machine with specimen

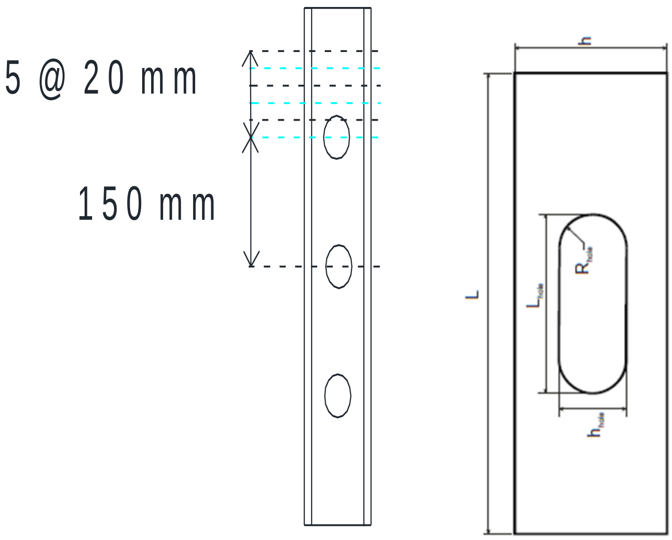

Figure 3.8 Schematic drawing of series of cold-formed C section

3.4 Transducers

Transducer linear variable displacement transducers, or LVDT, is an electric transducer used to measure linear position. Linear displacement is the movement of objects in one direction along a single axis. Measuring displacements indicates the direction of movement such as used in this research is displacement of the specimen when it buckles. For this study, three transducers are been used which 1 for vertical, 2 and 3 is for horizontal displacement.

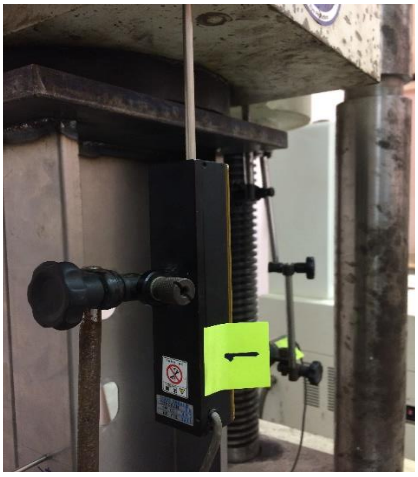

Figure 3.9 Transducers 1 for vertical displacement

Figure 3.10 Tranducers 2 and 3 for horizontal displacement

3.5 Research Design

Specimen that will be used for experiment is cold-formed steel lipped single “C” section and built-up “I” section. Web width for “C” section and built-up section are 103 mm and 203mm and there will have with and without opening. Height for the specimen is 600 mm due to limitation of the Universal Testing Machine at the laboratory which can take is average 700 mm including the bearing plate. Opening condition for the steel for testing is elongated.

Table 3.1 The parameters of the typical C-section CFS and their naming convention.

	103	**203**
Single	SC103-A1 SC103-A3	SC203-A1 SC203-A3
Built-up	BC103-A1 BC103-A3	BC203-A1 BC203-A3

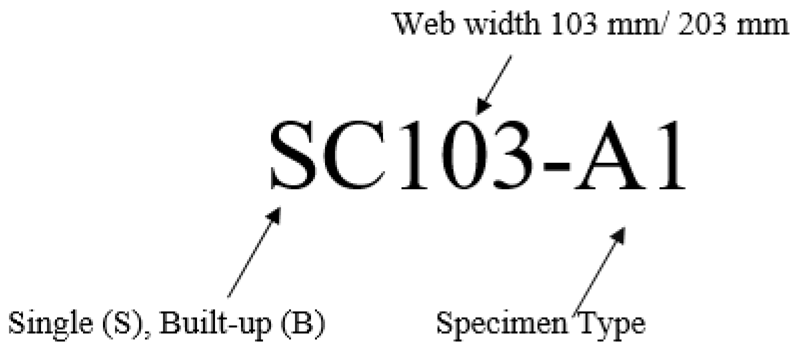

Figure 3.11 Naming convention.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Compression test that been conducted towards eight specimen using Universal Testing Machine (UTM) will provide result from the maximum load that were applied on the sample before it buckles, buckling behaviour and the displacement of transducer. The machine provide raw data that appear in Microsoft Excel and from the raw data the graph will be presented through graph of load vs displacement and load vs horizontal displacement where it analyse the axial load and the displacement of specimen.

4.2 Load vs. Vertical Displacement

In this result show the load applied on the sample compare to the displacement that occur on the specimen. From the graph in Figure 4.1 there are slightly different maximum load applied on BC103-1.2-A1 and BC103-1.2-A3 which is 91.094 kN and 89.1969 kN respectively. BC103-1.2-A3 specimen occur maximum load reaction faster than BC103-1.2-A1which show that A3 specimen occur displacement at 1.436 mm compared to A1 at 2.622 mm.

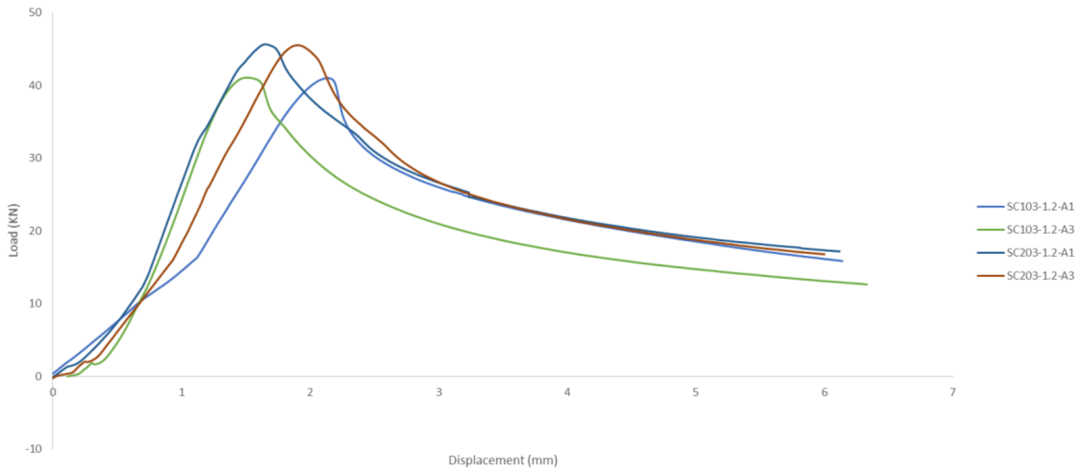

Figure 4.1 Single section 103 mm and 203 mm graph result

At single section SC103 and SC203 there are slightly differences due to their maximum load. From the graph in Figure 4.2 web length 203 mm have higher maximum load compared to 103 mm but from displacement different SC103-1.2-A1 having slow reaction towards maximum load compared to others where it occurs at 2.14 mm displacement.

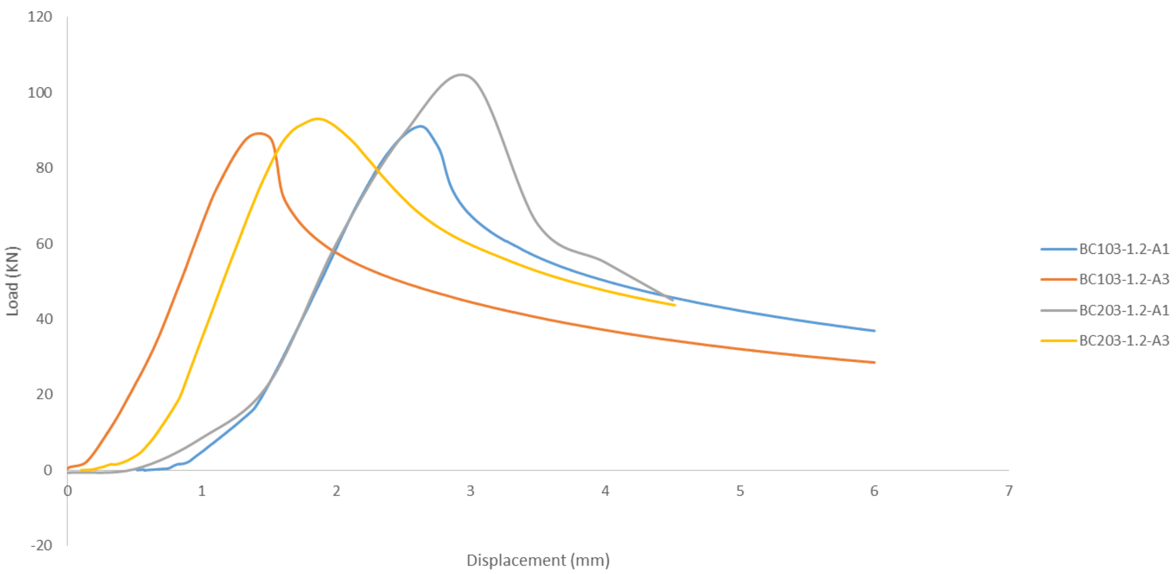

Figure 4.2 Built-up section graph

At different built-up section web length 203 mm, shows that BC203-1.2-A1 and BC203-1.2-A3 also having slightly different maximum load which is 103.963 kN and 93.015 kN respectively. It shows obviously in Figure 4.1 that A1 have higher maximum load compared to A3 and A1 moves to reach the maximum level slowly in 3 mm displacement while A3 occurs maximum level at 1.848 more faster.

4.3 Load vs. Horizontal Displacement

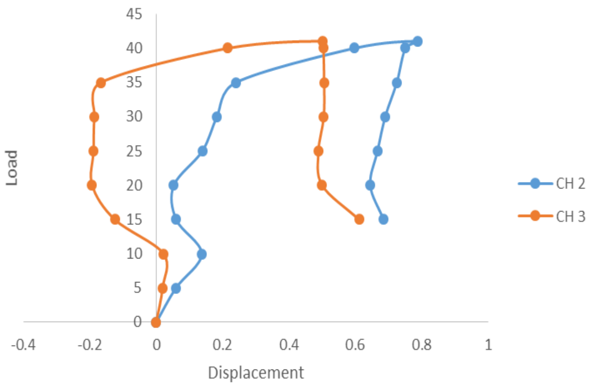

Figure 4.3 SC103-1.2-A1

The maximum axial load for SC102-1.2-A1 is 41.0219 kN and the maximum displacement is 0.788 mm which happen at the transducer CH 2 around the same time that maximum axial load is subjected to the sample. As seen from Figure 4.3, the graph intersects once in the test. Intersect between CH2 and CH3 at 0.504 displacement. The result shows that local buckling behaviour at top, middle and bottom of the specimen and distortional buckling also occur at top of the specimen. This result is similar to (Moen & Schafer, 2008) where the buckling pattern is consistent with that predicted by the elastic buckling mode shapes.

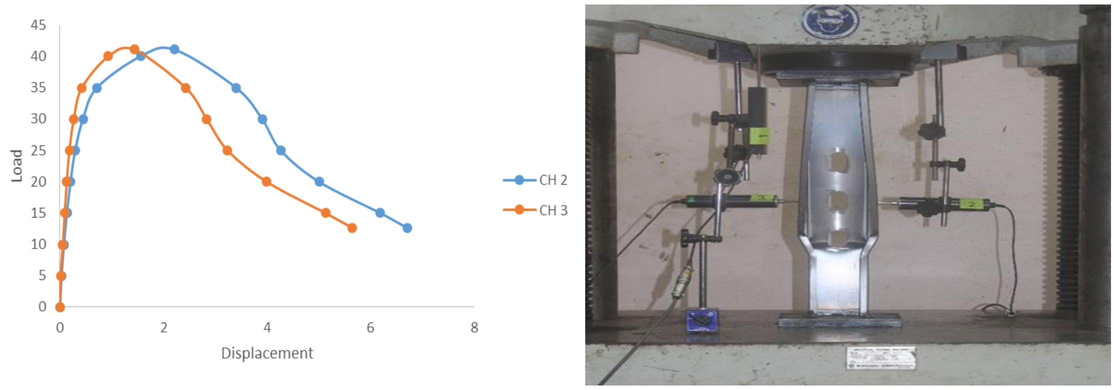

Figure 4.4 SC103-1.2-A3

For SC103-1.2-A3, the maximum axial load is 41.0781 kN and the maximum displacement of the sample is 6.702 mm that happen after the maximum axial load is applied on the sample. As seen from Figure 4.4, the sample move into positive displacement for CH2 and CH3 transducers until it reach the failure. It shows that the displacement is slowly moving towards positive after the maximum load. From the result observation made that at SC103-1.2-A3 local and warping occur at the middle of the specimen. This agreed by (Cristopher D. Moen, 2008) suggesting that distortional buckling will influence the compressive strength of this member.

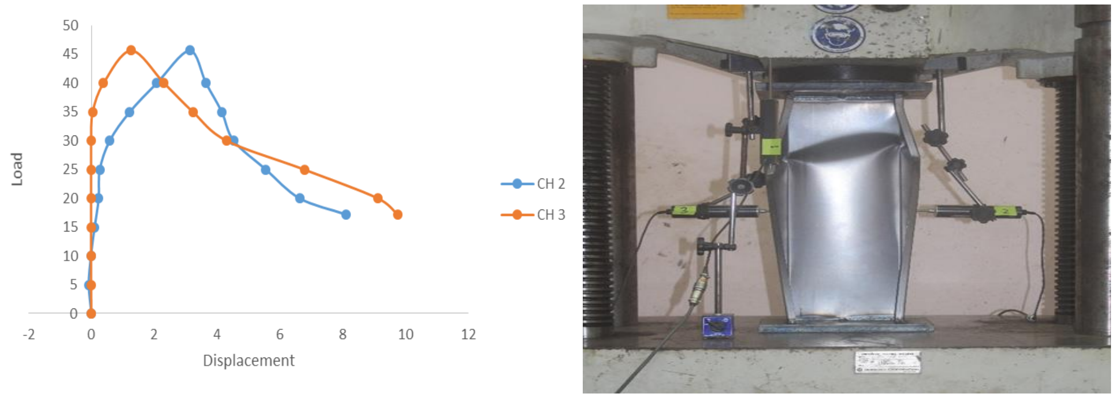

Figure 4.5 SC203-1.2-A1

SC203-1.2-A1 has a maximum axial load of 45.656 kN and a maximum displacement of 9.753 mm that happen at CH 3 at the end of the test. As seen from Figure 4.5, the graph intersects several times of the test. Results shows displacement moving towards positive displacement for the two transducers. From the figure specimen shows warping at the middle and local occur at top of specimen after the end of experiment. The buckling behaviour are same as estimated by (Javed, et al., 2017) using FE.

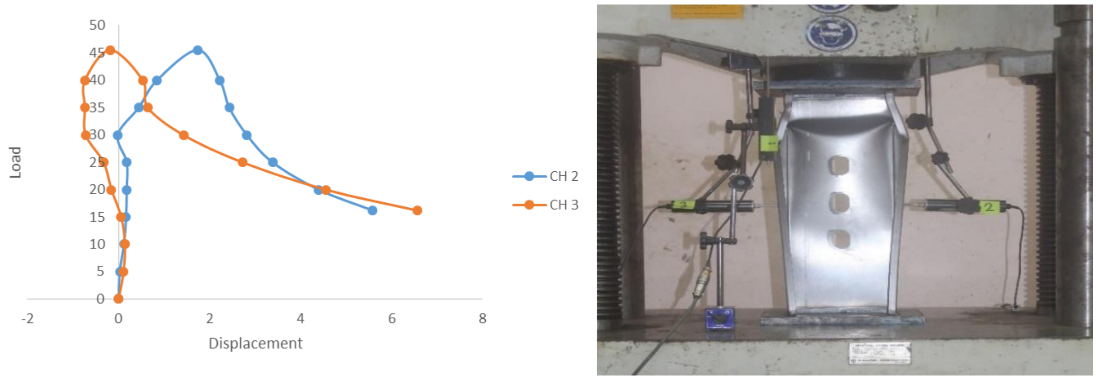

Figure 4.6 SC203-1.2-A3

SC203-1.2-A3 has a maximum axial load of 45.5375 kN and a maximum displacement of 6.557 mm that happen at the end of the test. From Figure 4.6, the sample move into the same direction at the end of the result where it move to positive displacement. At the end of the result the specimen shows warping at top and local happens at top, middle and bottom. This type of buckling behaviour are same as refer to (Craveiro, et al., 2016) experimental.

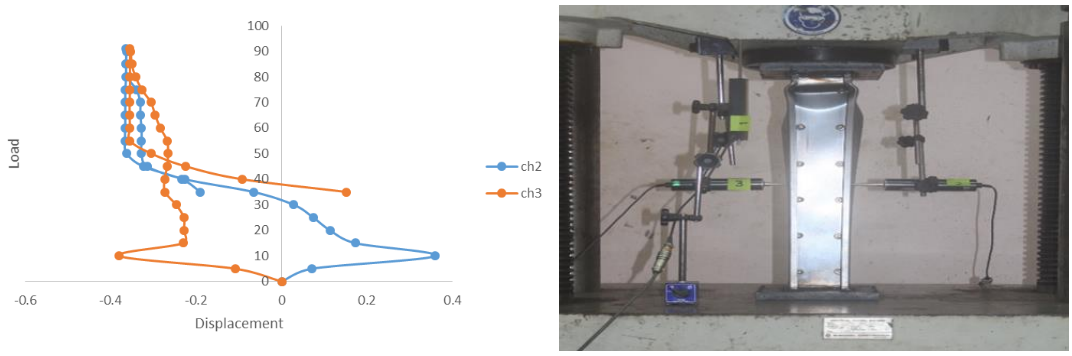

Figure 4.7 BC103-1.2-A1

Maximum load for BC103-1.2-A1 is 91.09 kN and the maximum displacement for this sample is at CH 3,-0.38 mm which occur at 10 kN axial load. The graph shows that at maximum load, displacement at CH2 and CH3 are at similar distances where place at negative position. At the end of the test shows that specimen BC103-1.2-A1 are having local buckle at the top at the middle and bottom of specimen. Result compare with (Muftah, et al., 2014) the maximum load for BC103-1.2-A1 is lower than their specimen.

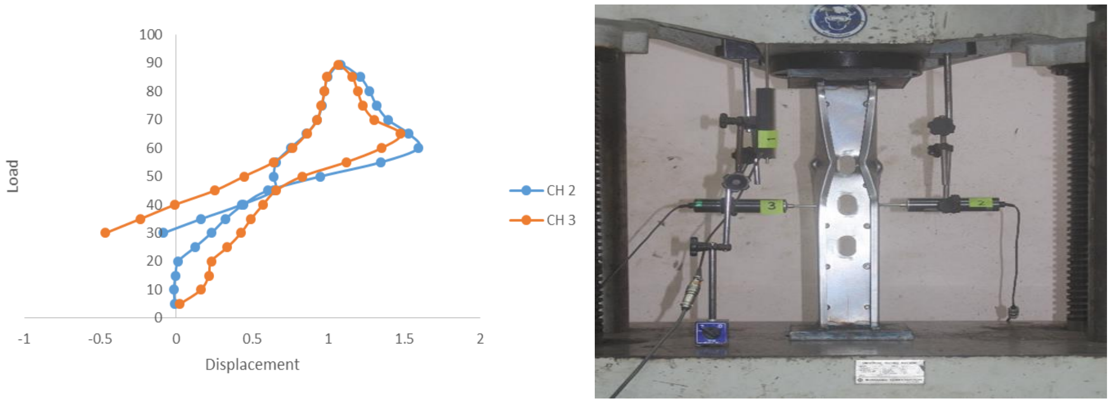

Figure 4.8 BC103-1.2-A3

From the charts shows that maximum load occur at 89.1969 kN and the maximum displacement at 1.596 mm. There's several times of intersection line of the CH2 and CH3 before the maximum load occurs and after the maximum load occurs. From the charts can be shown that at maximum load CH2 and CH3 are at the similar displacement. In Figure 4.8 BC103-1.2-A3 occur distortional at the middle of the specimen that observe at the end of the test. From (Lu, et al., 2017) for built up the displacement predict that increasing distortional buckling.

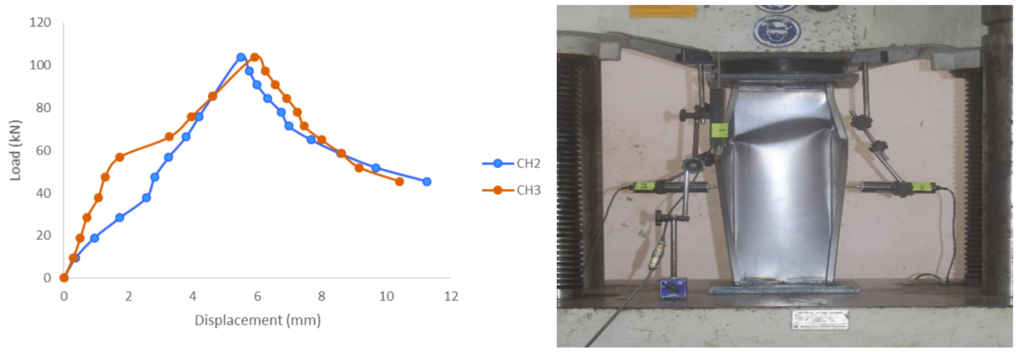

Figure 4.9 BC203-1.2-A1

BC203-1.2-A1 has a maximum axial load of 103.96 kN and a maximum displacement of 11.252 mm that happen at CH 2 at the end of the test. As seen from Figure 4.9, the graph intersects several times of the test. Results shows displacement moving towards positive displacement for the two transducers. From the figure specimen shows distortional buckling at the bottom and warping at the top after the end of experiment. This result similar to (Fratamico, et al., 2018) where the buckling occur at the top of the specimen.

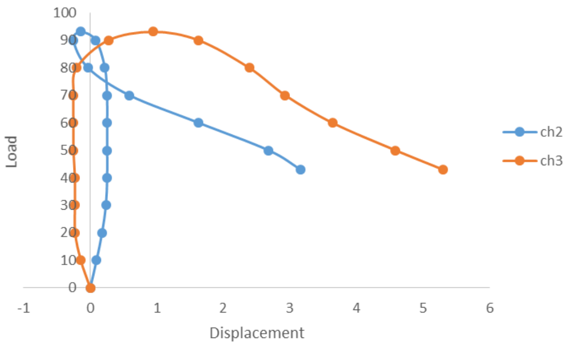

Figure 4.10   BC203-1.2-A3

Figure 4.10 shows result of BC203-1.2-A3 which maximum load at 93.06 kN and the maximum displacement at 5.303 mm that occurs at CH 3. As seen from Figure 4.10, the sample move into positive displacement for CH2 and CH3 transducers until it reach the failure. It shows that the displacement is slowly moving towards positive after the maximum load. BC203-1.2-A3 occur warping at the bottom of the specimen at the end of the test.

4.4 Ultimate Strength

The ultimate load is determined when the column load was dropped. The tested ultimate compressive strengths of the specimens from the eight experimental programs described in Table. The comparison of ultimate strength can be describe along with the behavioural the cold-formed steel. The ultimate strength been observe from initial load and peak load of the specimen.

Table 4.1 The parameters of the typical C-section CFS and their naming convention

TYPE OF SPECIMEN	INITIAL LOAD (KN)	INITIAL BEHAVIOUR	PEAK LOAD (KN)	FAILURE MODE
SC103—1.2-A1	28.63	DT	41.0219	LT/LM/LB/DT
SC103—1.2-A3	34.22	WM	41.0781	LM/WM
SC203—1.2-A1	31.52	WM	45.6563	WM/LT
SC203—1.2-A3	32.34	WT	45.5375	WT/LT/LM/LB
BC103—1.2-A1	85.24	LT/LM/LB	91.0938	LT/LM/LB
BC103—1.2-A3	83.93	LT/LM/LB	89.1969	DTF/DTB
BC203—1.2-A1	85.36	DB	103.963	DMF/WMB
BC203—1.2-A3	83.43	WBF/DTB	93.06	DBB/WBT/LBW

D = Distortional W= Warping L=Local

T=Top M=Middle B=Bottom

B=Back F=Front

CHAPTER 5

CONCLUSION

5.1 Conclusion

From the result obtained, there's a several conclusion can be made. An experimental investigation and a axially loaded method for the cold-formed built-up I-section columns were presented in this paper. Initially, a total of 4 compressed single C-section columns and 4 built-up I-section columns were tested, respectively. The cross-sectional dimension, existence of holes and the length of the test members were varied in the test so as to cover a wide range of local, distortional and overall buckling.

First of all, influences of holes affect the ultimate strength as we can see from the result there's are decreasing of strength at the peak load of specimen with and without opening. This mean that presence of opening can make a different towards the ultimate load of the specimen. The strength of single and built-up are two times different where the built-up strength are two times higher than the single section.

Besides that, the behavioural of specimen can also be affected by presence of opening where there will have different mode of buckling due to the opening. Next, different web length affect the ultimate load which the different of web is 203 mm and 103 mm. From the result the specimen with 203 mm web length have more strength compared to 103 mm which the strength increase when the web length increase. The data collected for this experimental study is approved to be applied in construction industry.

5.2 Recommendations

There are few recommendations that can be used in future research regarding cold-formed steel column. First, use different height of specimen. In this research 600 mm of height is used for experiment this is due to limitation of machine use in our laboratory which Universal Testing Machine only can exceed 700 mm height. More height can be used depends on industry needs for column in construction. In future research the height of specimen can be used to study on effect of height cold-form steel column towards buckling mode. Next, different shape of opening which can be circle, hexagon, rectangle, square or triangle depending on industry needs to apply as structural components. Research can be made on effect of different shape of opening towards ultimate strength.

In addition, size of the shape can be various due to it needs so size of shape probably can affect the ultimate strength as the size of the shape different. In this study there's 3 opening at the centre of specimen. Future research can be added perforations along the specimen flanges to study the effect of different shape and size of the perforations on the ultimate load and the buckling behaviour of the specimen. Lastly, to do an analysis of Finite Element. This research only used experimental investigation to study the effect of perforation on the axially loaded and the behaviour of failure mode of axially loaded cold-formed steel column with opening. The buckling behaviour can be predicted accurately using Finite Element (FE) and the result from FE can be compared with buckling mode from experimental investigation. 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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