COMPRESSION TEST OF BUILT-UP SIGMA-SECTION COLD-FORMED STEEL COLUMNS WITH HOLES

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Thesis submitted in Partial fulfillment of the requirements
for the award of the
B.Eng (Hons.) Civil Engineering

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

MAY 2019

SPECIAL APPRECIATION

My supportive parents:

MUHAMMAD RUSLI BIN JOHARI
ZALILAH BT SUHAILI

My siblings:

MUHAMMAD SHAHNIEZAM BIN MUHAMMAD RUSLI
NURMAISARAH BINTI MUHAMMAD RUSLI
NUR AIN ASYIKIN BINTI MUHAMMAD RUSLI

And all fellow friends. Thank you.

ACKNOWLEDGEMENTS

I honor my humble respectful appreciation and gratitude towards my most graceful and love aspiring merciful Almighty Allah S.W.T for blessing me with all required knowledge, healthy and courage to successfully accomplish and render this final year project as a requirement to graduate in a Bachelor (Hons.) of Civil Engineering from Universiti Malaysia Pahang.

I dedicated my sincere gratitude and appreciations to my final year project supervisor Mr. Khalimi Johan Bin Abd Hamid for giving me an idea and continuous support for my study and research. He was extremely helpful in giving information and guidance that is beneficial for me in writing thesis and learning about testing for Cold-formed steel.

In addition, special thanks to my parents, Muhammad Rusli bin Johari and Zalilah Bt Suhaili for a support and advice that encourage me to complete and produce a high quality thesis report. Last but not least, thanks to everyone who involve in this research directly and indirectly.

ABSTRAK

Penyelidikan eksperimen telah dijalankan untuk mengkaji ujian Mampatan seksyen sigma terbina dingin yang dibentuk pada lubang Tiang keluli sejuk dan untuk menentukan beban mampatan maksimum seksyen sigma lajur keluli terbentuk sejuk. Sebanyak 8 spesimen tiang keluli dengan lubang dan tanpa lubang dan juga ketebalan 1.2 dan 2.0 mm telah diuji menggunakan mesin ujian sejagat (UTM). Aplikasi tipikal termasuk rangka untuk tingkap, pintu masuk, dinding geser, dan bangunan berbingkai berbingkai sejuk berbentuk lantai di mana lantai bawah menggunakan kancing binaan untuk membawa beban. Stud terbina dalam kajian ini terdiri daripada lapan bahagian Sigma berorientasikan back-to-back membentuk suatu keratan rentas berbentuk I. Untuk setiap spesimen, stud disambungkan ke satu sama lain dengan dua skru penggerudian diri jarak pada jarak tertentu. Seksyen trek keluli yang terbentuk sejuk bersambung yang berfungsi tegak lurus untuk setiap hujung stud yang dibina dengan skru penggerudian sendiri melalui setiap bahagian sigma. Tujuan bahagian lajur adalah untuk mengekalkan hujung kancing bersama dan mewakili lampiran akhir biasa. Hasil penyelidikan, beban mampatan maksimum ditunjukkan dan mod kegagalan kerangka keluli terbentuk sejuk dengan pelbagai kedudukan lubang

ABSTRACT

An experimental investigation was conducted to study the Compression test of built-up sigma section cold-formed steel Column holes and to determine the maximum compression load of sigma section Cold-Formed steel column. A total 8 specimen of steel column with holes and without holes and also thickness 1.2 and 2.0 mm were tested using universal testing machine (UTM). Typical applications include framing for windows, doorways, shear walls, and multi-story cold-formed steel framed buildings in which the lower floor utilizes built-up studs to carry the load. The built-up studs in this study consisted of eight Sigma sections oriented back-to-back forming an I-shaped cross-section. For each specimen, the studs were connected to each other with two self-drilling screws spaced at a set interval. A cold-formed steel track section was connected running perpendicular to each end of the built-up stud with a single self-drilling screw through each of the sigma sections. The purpose of the column section was to keep the ends of the studs together and represents a common end attachment. As a result of the investigation, the maximum compression load was shown and the mode of failure of cold-formed steel column with the various position of holes.

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LIST OF SYMBOLS

mm	Milimetre
T1	Transducer 1
kN	Kilo Newton

LIST OF ABBREVIATIONS

CFS	Cold-formed Steel
BE	Built-up Sigma
HRS	Hot-rolled Steel
UTM	Universal Testing Machine
LB	Local Buckling
D	Distortional
W	Warping
LMB	Local Middle Back
LMF	Local Middle Front
WMB	Warping Middle Bac
DMB	Distortional Middle Back
LMF	Local Middle Front
WMB	Web buckling Middle Bottom
FMD	Front Middle Distortional
BMW	Back Middle Warping

CHAPTER 1

INTRODUCTION

1.1 Introduction

The building construction industry utilizes cold-formed steel members extensively to the advantages offered for the construction materials. Cold-formed steel (CFS) section has been increasingly used nowadays in different building construction, such as trusses members, floor joists and wall studs. Cold formed steel (CFS) sections are manufactured from steel sheets, strips or plates at room temperature. Cold-formed steel (CFS) sections are material that usually uses in construction for residential and commercial construction due to strong, safe, durable and effective cost with saves the construction time. In addition, CFS members are often thin-walled, therefore local plate buckling and cross section distortion and warping result in preliminary failure if not incorporated in the design.

The additional flexibility due to slip in connections further complicates the development of a suitable design method for built-up CFS members. CFS sections have many advantages compared to conventional hot-rolled steel sections, such as the ease of fabrication, low cost in transportation, handling and storage, fast erection and installation, and excellent strength to weight ratio. As the demand for light-weight steel structures continues to rise, efficient and accurate design of cold-formed steel elements is essential. One frequently used cold-formed steel member is a built-up member, formed by two or more attached steel elements back forming an I-shaped cross-section.

Open sections of CFS such as sigma sections area extensively used in light steel construction of wall, roof and floor framing members. Holes in cold formed steel structure can be found. It usually found in low and midrise construction while spaced holes are placed in the webs of cold-formed steel columns that to allow electrical, plumbing and heating services to pass through walls and ceilings. Distortional buckling is recognized as a design limit state for cold-formed steel columns with open cross-sections, separate from that of global (Moen, et al., 2009).

The most commonly used CFS sections are Z, C and sigma sections shows in figure 1.1 **Error! Reference source not found.** As a result, in recent years CFS sections have been widely used as structural members in residential and industrial buildings. The Z sections is nearly vertical when the sections are orientated in line with the pitch angle while C and sigma sections needs emerging modern shallow roof construction. The sigma shaped CFS member has recently been introduced to the US construction market as a compression member. This shape has typically been used in Europe, mainly as a roof purlin (Klingshirn, et al., 2010).

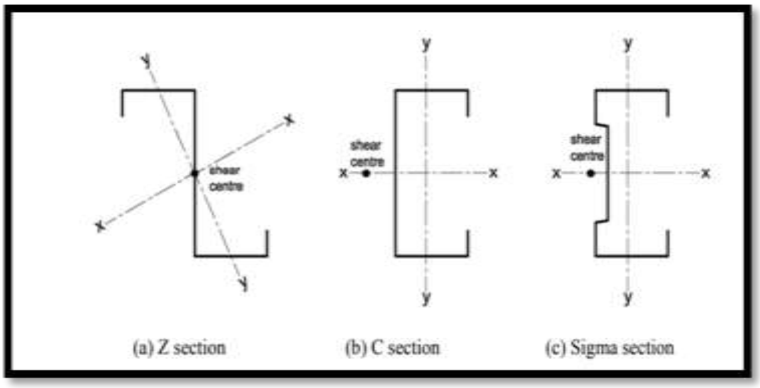


Figure 1.1 Typical CFS Z, C and sigma sections

1.2 Problem Statement

CFS sections have many advantages compared to conventional hot-rolled steel sections, such as the ease of fabrication, low cost in transportation, handling and storage, fast erection and installation, and excellent strength to weight ratio. Cold formed section usually thinner and have mode of failure and deformation as shown in Figure 1.2. Usually Cold formed section are not commonly encountered in normal structural steel design. In addition, cold formed produce structural imperfections which are quite different from traditionally hot rolled and welded members. A thin walled member under compression are possibility will occur the buckling. So that, the mode of failure such as local buckling, web buckling, Distortional buckling, flexural buckling will happen for this section.

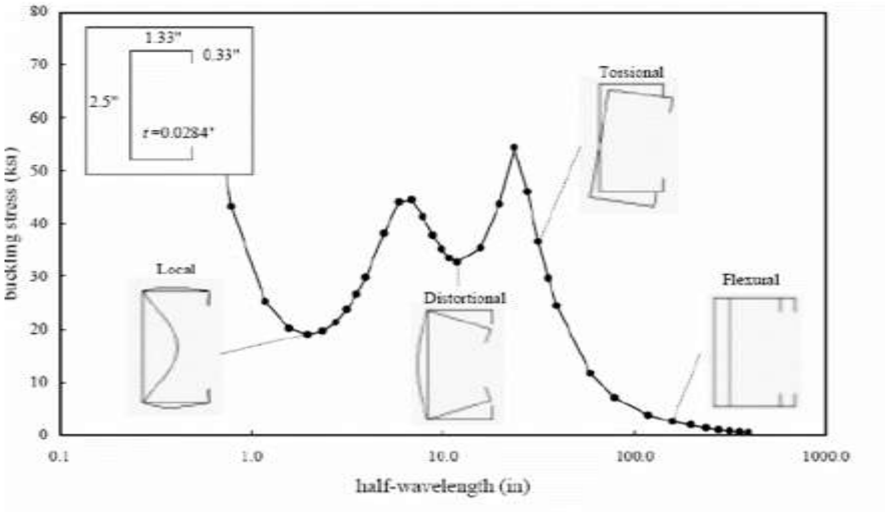


Figure 1.2 Mode of Failure

1.3 Objectives

i. To determine the maximum compression load that can be carry by open built-up steel section before failure.

ii. To identify the mode of failure of the sigma section under compression with hole and without holes.

1.4 Scope of study

To achieve these objectives, the testing in the lab will conducted to get the data analysis. The scope of this research covers the analysis of mode of failures of built-up open sections. In Figure The different distances of the opening holes with the width 103mm and thickness 1.2 mm and also 2.0mm of the specimen. The point Load has been marked to as reference of transducer was applied at the specimen. So that, the list of the Specimen needs to be tested as shown in table 1.1:

Table 1.1 The list of Specimen

Specimen	Number of opening	Length of the specimen (mm)	Thickness of the Specimen (mm)
BE103-1.2-A1	0	600	1.2
BE103-1.2-A2	1	600	1.2
BE103-1.2-A3	3	600	1.2
BE103-1.2-A4	3	600	1.2
BE103-2.0-A1	0	600	2.0
BE103-2.0-A2	1	600	2.0
BE103-2.0-A3	3	600	2.0
BE103-2.0-A4	3	600	2.0

1.5 Significant of Study

The experimental of Cold-formed steel (CFS) built-up sections was tested by universal testing machine. As we know, by creating an opening at the web will reduce the weight of the steel beside also will reduce the cost of the uses of steel sections. From the testing, we can determine the mode of failure of the CFS that caused by perforation.

Other than that, sigma shaped CFS member has recently been introduced to the US construction market as a compression member. This shape has typically been used in Europe, mainly as a roof purlin (Klingshirn, et al., 2010). In addition, Sigma section have higher web stiffness which helps them to carry more loads. It was more better than the conventional steel sections because it has stronger performance to resisting the loads.

Universal testing machine are usually used to test the tensile stress and also compressive strength of the steel members. This machine can perform many standard tensile and compression tests on materials, components and structures. The parameters for this machine is to determine the stress-strain curve obtained during test the tensile strength, yield strength, elastic modulus and percent elongation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will describe the details and advantages of the sigma section which is to be testing by various of the specimen that to determine the mode of failure of the built-up sigma section of Cold-formed steel (CFS) column using Universal machine test. CFS commonly used to its high strength and stiffness. The reviewed literature will be presented for the testing is the initial Buckling Load, peak-buckling, post-buckling strength and ultimate strength of the steel. From this, the results will show the graph of stress-strain curve that will resulting from the experiment.

In industry, CFS are created in various shape that made up by bending sheet or strip. The diversity of cold formed steel shapes and the multiplicity of purposes to which they are put to, makes it a difficult task to provide general solution procedures covering all potential uses. One such material is the CFS where CFS have been used extensively as the primary load bearing structural member in many applications due to a variety of advantages (Muftah et al., 2016).

In addition, CFS also have higher web stiffness which helps them to carry more loads. These also have shear centre close to the web (Anna, 2016). CFS is a process of rolling steel into semi-finished at relatively low temperature. It is commonly formed in various shape that designed in open section such as C- section and Z-section. A series of column tests on cold-formed steel I-shaped open sections with edge and web stiffeners were conducted. The columns were compressed between fixed ends (Zhang et al., 2012).

2.2 Types of Cold-Formed Steel

In construction, there are two methods of forming the steel structure such as Hot-Rolled Steel (HRS) and Cold-formed Steel (CFS). HRS are formed at higher temperature while CFS are formed at low temperature. Cold-formed steel structural members has two types which is Individual structural framing members, Panels and decks.

As refer to the Figure 2.1 below, it was shows that the other types which is sigma section has high load-carrying capacity, smaller blank size, less weight, and larger torsional rigidity as compared with standard channels. An important characteristic of cold formed shapes is that the thickness of section is substantially uniform. Lastly, figure 2.2 shows the usual shapes of individual structural framing members are channels (C-sections), Z-sections, angles, hat sections, I-sections, T-sections, and tubular members.

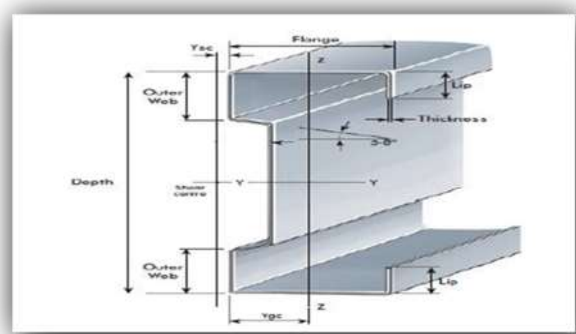


Figure 2.1 Typical view of sigma section (Anna et al., 2016)

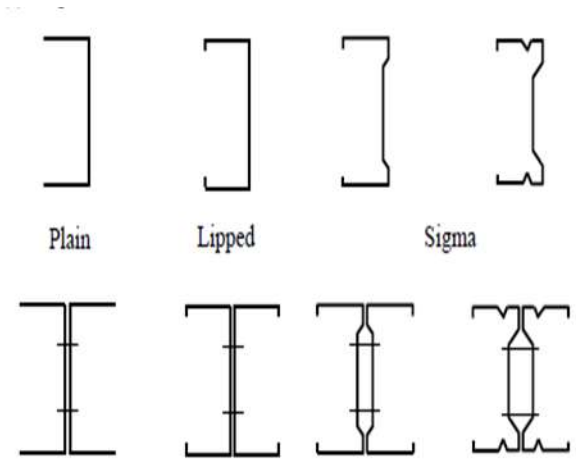


Figure 2.2 Cold-formed sections used in structural framing (Siang, 2009)

2.3 Application of Cold-Formed Steel

Usually, Cold-formed steel structural components have been used in low-rise buildings and residential steel framing. Cold-formed steel (CFS) section used for products which are made by rolling or pressing thin gauges of steel sheets into goods. The applications of CFS includes the buildings, bridges, car bodies, storage tanks, highway products, railway coaches, transmission towers, drainage facilities. In comparison to the hot rolled section with the cold rolled sections, CFS have more moment of inertia and section modulus. Cold-formed steel structural members are commonly provided with holes to accommodate plumbing, electrical and heating conduits in the walls and ceilings of buildings (Moen, et al., 2009)

Besides that, the reduction of strength and variation in the buckling characteristics of the plate elements was presence of such openings in structural members will obviously result in changes in stress distribution within the members. As cold-formed steel structure has load carrying panels and decks can provide useful surfaces for floor, roof, and wall construction. In other cases, CFS can also provide enclosed cells for electrical and other conduits. Furthermore, the uses of cold-formed steel sections are used in car bodies, railway coaches, various types of equipment, storage racks, grain bins, highway products, transmission towers, transmission poles, drainage facilities, and bridge construction. As shown in figure 2.3, cold-formed sections are also used as web members of open web steel joists, space frames, arches, and storage racks.

Figure 2.3 Cold-formed steel sections used in space frames

2.4 Buckling Behaviour of cold-formed structural members

Thin-walled steel structures are highly efficient in their use of material, but it was sensitive to the failure through various buckling modes. It because of the thin-walled structural members is the thinness of individual elements which leads to an extremely light-weight construction. A thin walled member under compression as shown in figure 2.4, there a possibility of local buckling to occur. Besides local buckling, other mode of failure such as;

1. Distortional buckling
2. Flexural buckling
3. Torsional buckling
4. Flexural-torsional buckling

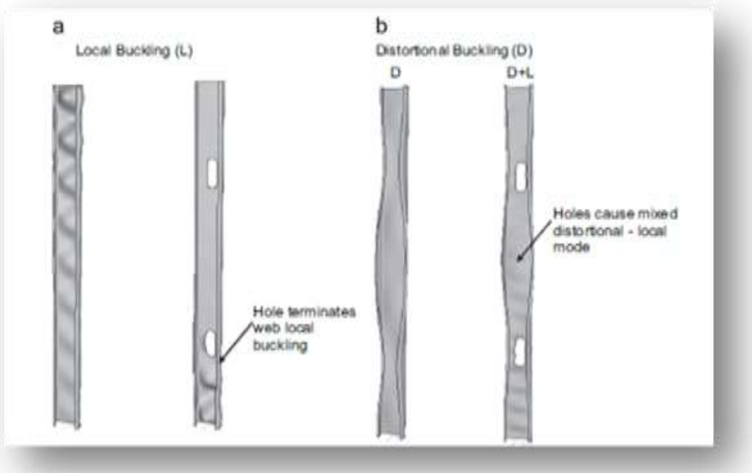


Figure 2.4 The behaviour of Cold-formed steel (Moen, et al., 2009)

Firstly, analysis methods which is local buckling effects, including post-buckling strength, were accounted for through an effective width concept. The effect of web opening spacing/web opening depth of web-posts was effects the effective 'strut' action of the web-post buckling. In other words, local buckling will reduce the compressive stiffness and also the strength of the column. The factors affecting the buckling moment capacity are edge distance, number of opening, and also the opening spacing (Ling, et al., 2015). For the thin elements, the buckle locally occurs at a maximum level lower than the yield stress of steel while after compression in flexural bending, axial compression, shear, Then, elastic buckling are used to provide the varies deformation response under load.

For the others types of buckling which is Distorsional buckling, cold-formed steel sections are relatively thin and in some sections the centroid and shear centre do not occur simultaneously, torsional flexural buckling may be a critical factor for compression members. Furthermore, distortional buckling is a buckling mode which increasing role with the use of thinner sections and higher strength steels. When an open section column buckles in the torsional flexural mode it will occur bending and twisting of the section occur simultaneously. The wavelength of distortional buckling are usually intermediate between of local buckling and global buckling places it firmly in the practical range of member lengths. It's generally happened by a flange distortion in the section.

Then, the others types of failure will occur by global buckling which can be flexural, torsional or flexural-torsional buckling. For the flexural buckling are effects the slender axially loaded column. When the column members becomes unstable it will deflects laterally until were approaches the critical buckling load. Furthermore, torsional buckling has happened on the open thin-walled section by testing about the shear centres. Torsional does not occur for closed section because of the higher torsional rigidity (Zhao, 2005)

2.4.1 Comparison of Hot-rolled and Cold-formed section

In building construction, the two main types of steel section namely the hot-rolled and cold-formed sections. The cold-formed steel sections were increased considerably as world steel industry moves from the production of hot-rolled sections and plates to coil and strip with galvanized and painted coating. It is more easily delivered from the steel mill to the manufacturing plant where it usually cold-rolled into open and closed section members.

As compared to the conventional hot-rolled steel members, the cold-formed steel members was easier delivered, enhancement of the tensile properties after cold-formed, lower weight (higher strength to weight ratio) and faster and also simple installation. In addition, the cold-formed steel were usually slender (thinner) and not doubly symmetric. Cold-formed section can be employed to produce any desired shape to any desired length while Hot rolled section has limited types of shapes can be produces and limited weight to its length.

2.5 Built-Up Sigma Sections

Cold-formed steel structural members can be divided into two types such as Individual structural framing members and the panels and decks Cold-formed steel (CFS) framing provides a structural system that consists of columns (studs) or beams (joists) to frame out the building. The multiple members are connected together to form a built-up CFS member. The built-up members formed by two or more attached steel elements. In addition, Built-up members generated of two interconnected shapes, such as back-to-back angles or channels, in contact or separated only by plates. Furthermore, the doubly symmetric section shape can delay some of the buckling modes commonly encountered by the conventional cold-formed open sections such as C, Z and sigma sections

The back-to-back lipped channel produces a doubly symmetric cross section. More complex CFS built-up columns including combinations of Zee, sigma, and track sections usually uses in construction. Built-up columns are important components of CFS framed building (Fratamico et al., 2018b).

2.5.1 Advantages and Disadvantages of Built-Up Section.

a) The advantages of built-up Cold-formed:

   a) have symmetric cross-sections

   b) Built-up columns are widely used in steel construction especially when the effective lengths are great and the compression forces light.

b) The disadvantages of built-up Cold-formed:

   a) It is difficult to connect them.

   b) They have low fire resistance.

   c) There is residual stress on the cross-section this affects the buckling resistance of the steel.

2.6 Cold-formed with web perforation

Usually, CFS structural member such as C and sigma sections are commonly provided with perforations to accommodate plumbing, electrical conduit and piping system in the buildings. The perforations are located at the web of the sections and help to produce the elastic stiffness and ultimate strength of members. Normally, Perforated beams with provide with the standard circular, hexagonal and elongated web openings are mostly used nowadays.

As reference from the previous research by Konstantinos Daniel Tsavdaridis, 2011, the effect of the web opening depth and web thickness was also studied to investigate the stability (slenderness) of the web-post subjected to vertical shear load. The specimens were handled by self-tapping screws from two plain channels or lipped channels. Furthermore, the critical elastic load and distortional buckling moments was determined with different location of the holes. The holes at cold-formed steel reduced the web local buckling capacity, causing the column to rely more on the flanges and lip stiffeners to carry load with a distortional-type failure.

Mostly, the web holes may modify the local and distortional elastic buckling half-wavelengths. So that, the presence of holes or perforations in a structural member often complicates the design process. Holes at cold-formed steel reduced the web local buckling capacity, causing the column to rely more on the flanges and lip stiffeners to carry load with a distortional-type failure.

2.7 Experimental study

The previous experimental was undertaken by Konstantinos Daniel Tsavdaridis, Web buckling study of the behaviour and strength of perforated steel beams with different novel web opening shapes (Tsavdaridis, et al., 2011). Experimental work was conducted on seven full scale steel perforated beams with various web openings. A total of eight specimen of sigma section cold-formed steel having three cross-section sizes with different hole distances were tested using Universal Testing machine (UTM).

The experimental ultimate moments and corresponding failure modes for CFS built-up open and closed section are summarized. The Various non-standard web opening shapes are introduced through this paper for first time. The reduction factor of moment capacity each specimen due to the holes was calculated using the specimen with the holes diameter-to-web depth ratio.

2.8 Analytical Study from previous researcher

The Universal testing machine has used for testing on a wide range of built-up CFS beams with different sizes of perforations with three transducer. The web opening shapes improve the structural performance of the perforated beams when examined under the web-post buckling failure mode. The presence of such openings in structural members will obviously result in changes in stress distribution within the member, besides a reduction of strength and variation in the buckling characteristics of the plate elements.

The elastic and ultimate load behaviour of such members will also be altered significantly by the presence of openings. The performance of structural members containing holes is influenced by the type of applied stress (e.g. compressive, tensile, shear etc.).

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the analytical procedures of determining the design capacities for both the cold-formed steel sections and the column connections were explained in detail. The discussion followed by the joints designed for column connection. Methods proposed by previous researchers (Reyes, et al., 2011) says that on the compression of CFS column using Universal testing machine were adopted in accordance to the guidance for this study.

3.2 Research flow

Work flow process has been implanted in research study before the project start to ensure that the project in the right ways with expected duration of time. These work flow process acts as benchmark to obtain result as the objective needed. Work flow process is divided into four main phases. The four phases are:

i. Phase 1: Planning and discussion of study

ii. Phase 2: Finding literature review and Methodology planning

iii. Phase 3: Data analysis and result discussion

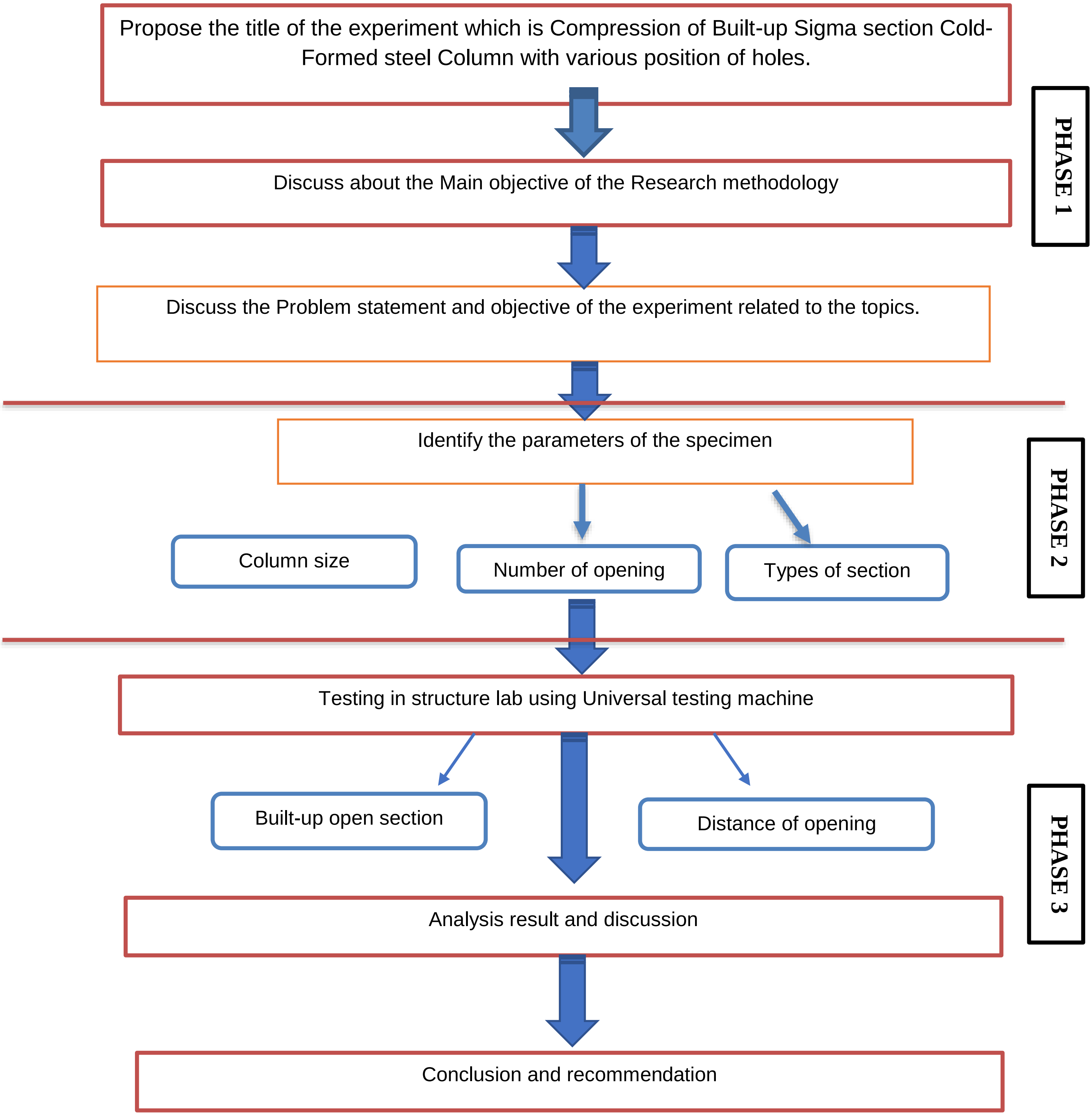


Figure 3.1 Flow chart of the research

3.3 Compression testing for Built-up open section

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. A parametric study covering different overall and individual slenderness ratios was performed to compare with the measured buckling loads. The effects of built-up member characteristics, such as member thickness weld attachments were explored to obtain abroad-range of experimental data that could more thoroughly represent built-up Sigma section buckling behaviours. the maximum slenderness ratio of component parts between fasteners or welds shall be based on an effective length factor of 1.0 when the fasteners are snug tight bolts and 0.65 when welds or pretensioned bolts are used.

For a complete design, estimates of strength for modes other than minor-axis flexure (e.g. local buckling, distortional buckling, and global modes including torsion) are required, as is the consideration of end boundary conditions (Fratamico *et al.*, 2018a). A parametric study covering different overall and individual slenderness ratios was performed to compare with the measured buckling loads.

3.4 Test Set-up, Instrumentation and Procedure for Built-up Sigma section for Compression Test

3.4.1 Prepare the material

Cold-formed steel column

The cold-formed steel column were provided in many types and sizes. Before start prepare the material, the sketch of dimension for each specimen need to be prepare for testing using the Autocad software. The figure below shown the dimension of the sigma section for Built-up steel column. The cold-formed steel then polish using wax in order to enhance the cleanliness of steel is used, the value of steel hygiene also affect the properties of steel act. Also, the dimension and thickness of the specimen has been measured. Lastly, the specimen needs to labelling at sides of the each specimen as shown in figure 3.2 & Figure 3.3 below:

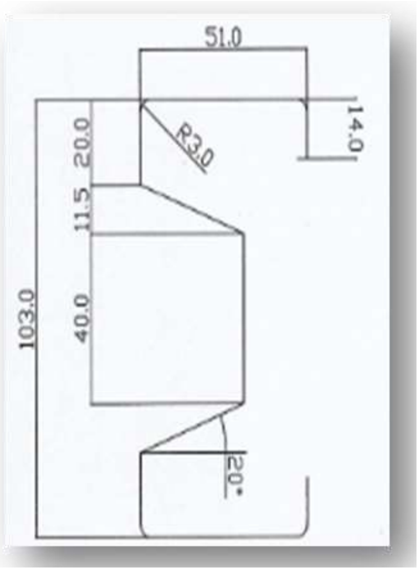


Figure 3.2 The sigma section Dimension

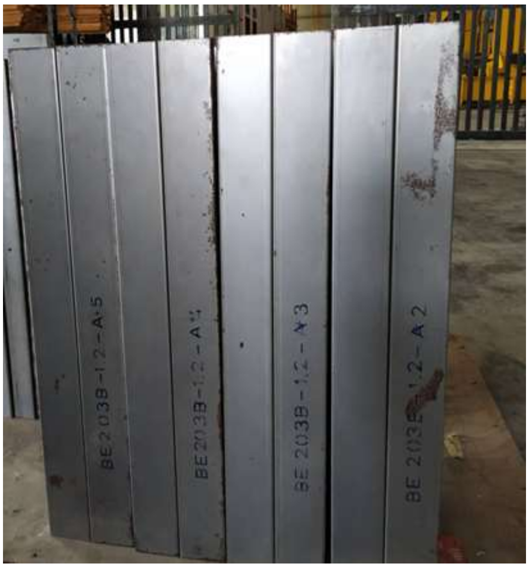


Figure 3.3 The sigma steel section with the labels

Table 3.1 The list of the Specimen for BE103-1.2 and BE103-2.0

Specimen	Number of opening	Length of the specimen(mm)	Thickness of the Specimen(mm)
BE103-1.2-A1	0	600	1.2
BE103-1.2-A2	1	600	1.2
BE103-1.2-A3	3	600	1.2
BE103-1.2-A4	3	600	1.2
BE103-2.0-A1	0	600	2.0
BE103-2.0-A2	1	600	2.0
BE103-2.0-A3	3	600	2.0
BE103-2.0-A4	3	600	2.0

- Web plate

Perforated flange and web plates that commonly occur in plate and box girders, ship, offshore and aircraft structures and dock gates can be idealized into a simple plate element supported on four sides and subjected to different types of loadings such uniaxial compression, biaxial compression. A plate is provided between the loading platen and the track for some of the tests as shows in

After that, deals with the supplier of Kin Kee Steel Kuantan to get the stock of the specimen. Kin Kee Service Centre is able to provide shearing services from steel coils into plates and sheets and slitting services from steel coils to steel strips. While, they only supplier the flat products of the cold-formed steel. Marks and draw the centre line to make sure the specimen centre in the plate.

Figure 3.4 Web plates

- Self tapping screw

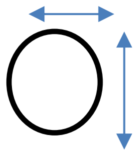
Self tapping screw is necessary to connect the steel column back to back and ensure the column not separated from each other. So that, the figure 3.5. of the self tapping types was shows below:

Figure 3.5 Self tapping screw

- Present of an opening

The specimen for the testing has to prepare with and without the holes. The method of the forming the holes for the specimen by using laser methods. In table 3.2 shows the dimension of the openings:

Table 3.2 The dimension of the openings

Opening Shapes	Elongated circle 30 mm  50mm
Column length (mm)	600
Column thickness (mm)	1.2 / 2.0

3.5 Preparation for testing

Figure 3.6 The process before testing

- **Polish the Specimen**

As we know, the steel easy to rust and corrode as the presence of air when the specimen has to be stored in lab. So, be sure to remove the rust that present right in advance and there is no foreign material contained in the steel. The span and wax were used to polish the specimen. The figure 3.7 below shows the work parts during polish the specimen.

Figure 3.7 Polish the Specimen

- **Drilling for the built-up open section**

Each specimen is made of double channels with back connected with back with bolts or welds. The bolts are usually used to link warm-formed steels and also could be used to link cold-formed steel structures as well as shown in figure 3.8. Stud rivet can be used to connect two or more pieces of cold-formed steel structures. First, make holes in the pieces, put the rivet nail in it, and then, riveting can be done by the riveter.

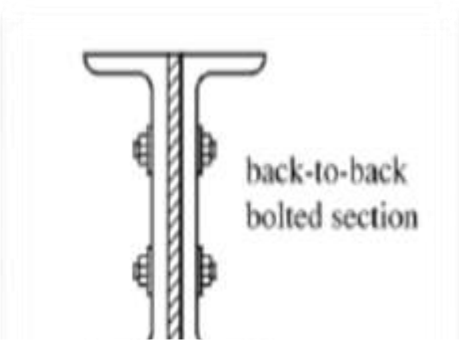


Figure 3.8 Back to back bolted section

Figure 3.9 Drilling for Built-up Sigma section

- **Welding the specimen**

The Cold-formed steel need to be tied up with the plates. Usually welding can be used in pre-fabricated connection in the place of workshop, or in lifting wall panels, and to keep a special angle for steel frame members. In addition, the welding can emphasised the importance of preventing slip at the member ends. The welding part was done in the structure Lab by technician lab. The welded or fully-tensioned bolted built-up sections were used for each the specimen. The Connections have a major effect on the overall behaviour and flexibility of a built-up member. The part of the welding in the specimen can be refer in the Figure 3.10 below:

Figure 3.10 The welding part with the plate (full welding)

- Testing the specimen by using Universal Testing machine.

The testing of the specimen needs to compression by using the Universal Testing Machine (UTM). The load has been applied for built-up members composed of two interconnected shapes, such as back-to-back angles or channels, in contact or separated only by filler plates. Sometimes it is necessary to openings away from the centre of the plates. The experimental tests were conducted using built-up columns with back-to-back double-channel sections. Maximum security is maintained on 600 kN capacity Universal Test Machine by limit switch on the lower grip and piston as well as the safety check valves on the hydraulic system. Hydraulic power unit works silently.

With open front hydraulic wedge grips user can load specimen easily with a view to obtaining an insight into the elastic buckling behaviours under shear loading of plates with holes located centrally as well as eccentrically with reference to the axes of symmetry. The three transducer was applied as the horizontal load on the flanges. The arrangement position of the transducer has been shows in figure 3.11 below. The Concentrated load was applied at the centre of the specimen and increased accordingly to the maximum deflection was found to be at the flange.

Figure 3.11 The position of transducer 1

Tests can be done fully automatic by digital control unit or computer. Load cell is used for load measurements. Strain measurement is done by the electronic displacement transducer built in the machine if required external extensometer fitted to the specimen also can be used for strain measurement. Strain measurements can be done directly from the extensometer fitted to the specimen. The distance between the grips can be set by motor driven hand set system. During tests, force sensors measure the load applied by the ram. A digital load meter shows the real-time force and stores the peak force. A digital displacement indicator measures and displays the vertical movement of the loading platform or part of the structure under testing.

Figure 3.12 Setting out the Universal Testing Machine

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result performed from the testing with compression method using Universal testing machine (UTM) was discussed. From the result obtained, the several buckling behaviours of variety deformed and contour stress value of the built-up open section will be explained. The buckling behaviour such as local buckling, distorsional, flexural and also web buckling. The effect of different distances and numbers of the opening of the specimen was compared in this analysis. The maximum buckling load were obtained from the maximum Load of the testing for each specimen by using universal testing machine. The result and data analysis are presented on figures and tables for better understanding.

The objective of the built-up of Cold-formed steel Column is to determine the maximum buckling load that can be carry by open built-up steel section before failure by using Universal Machine Test and to identify the mode of failure of the sigma section under compression with various position of holes on the compression strength and axial buckling behaviour of the columns. The results of the specimen has been tested were used as a guideline in determining the various position of the holes.

4.2 Analysis of the Compression strength testing

The analysis of the testing of perforated built-up open CFS subjected to bending was conducted to carry out the linear analysis and linear buckling analysis. The result are obtained by following the scope of study below:

i. Various position of the holes for the specimen

ii. Number of openings for each specimen

4.3 Load versus vertical displacement

The result obtained from the experiment that are the ultimate load obtain from different thickness, presence with hole and without hole. Table 4.1 show the Peak load obtain from the testing for each specimen. Specimen with no presences of holes should be obtain higher ultimate load. Specimen. BE103-1.2-A2 shows the highest peak loads. As seen in table 4.1, BE103-1.2-A2 come out with 128.91 kN higher from others specimen which is BE103-1.2-A1, BE103-1.2-A3, BE103-1.2-A4. It is because of the effects during do the testing have the some errors during testing.

For the specimen with thickness 2.0mm, Specimen with no presences of holes should be obtain higher ultimate load. Specimen with no presences of holes will obtain higher ultimate load that is specimen BE103-2.0-A1. In Table 4.1 shows the Peak load obtain from the testing for each specimen. Specimen. BE103-2.0-A1 shows the highest peak loads. As seen in table 4.1, BE103-2.0-A1 come out with 236.609kN higher from others specimen which is BE103-2.0-A2, BE103-2.0-A3, BE103-2.0-A4. In addition, the previous researcher by (Tsavdaridis, et al., 2011) has been said that failure of the specimens occurs under the combined action of shear and moment. High deformation is observed as the web-posts are subjected to high shear, accompanied by heavy distortion of the web opening.

Position of holes that located nearly to the top and bottom support and closed to the centre will decrease the strength of specimen. This can be proved from the table 4.1, specimens BE103-1.2-A4 and BE103-2.0-A4 produce less ultimate load others specimen that is 93.419kN and 209.141kN. Figure 4.1 and Figure 4.2 shows the graph of force versus vertical displacement, T1 of the specimen.

Table 4. 1 Peak load for all Specimen

SPECIMEN	PEAK LOAD (KN)
BE103-1.2-A1	103.675
BE103-1.2-A2	128.906
BE103-1.2-A3	120.081
BE103-1.2-A4	93.419
BE103-2.0-A1	236.609
BE103-2.0-A2	209.4375
BE103-2.0-A3	211.2813
BE103-2.0-A4	209.1406

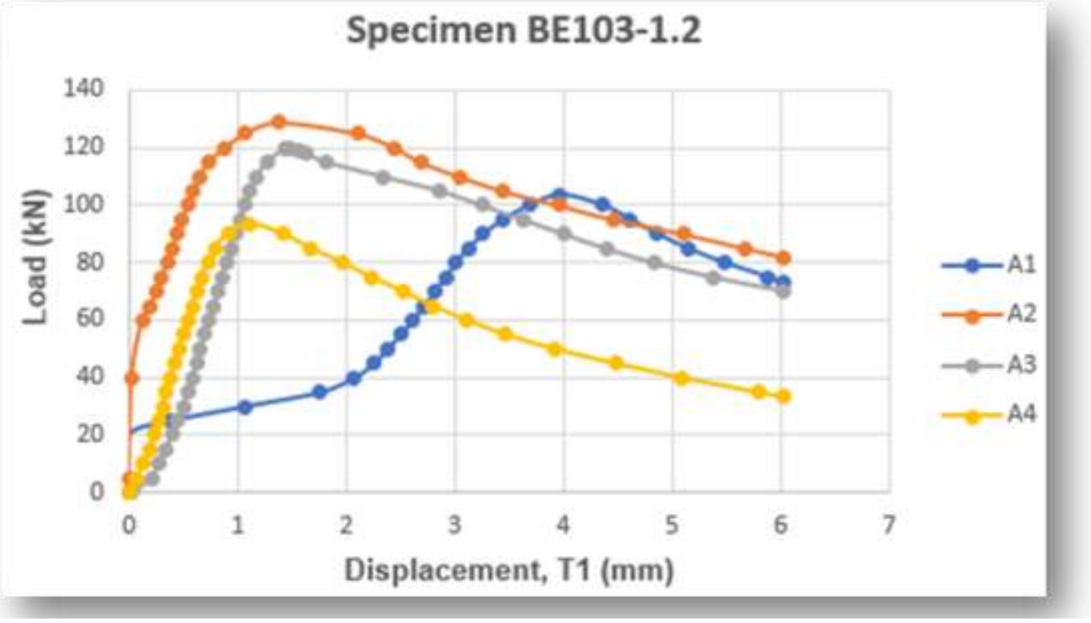


Figure 4.1 Load versus vertical displacement for BE103-1.2

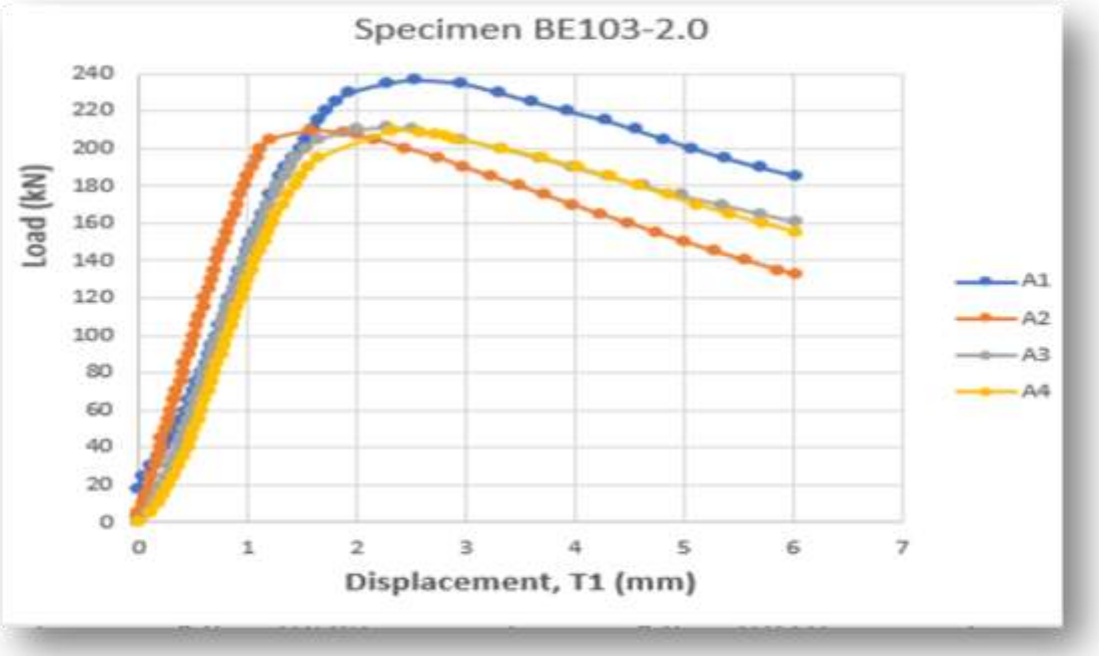


Figure 4.2 Load versus vertical displacement for BE103-2.0

4.4 Buckling Behaviour of the cold-formed steel column

There are several types of buckling behaviour in this testing. Mostly the buckling behaviours in testing were local buckling (LB) and distortional buckling (D). In this research, I was observed that the buckling behaviour for each specimen during the initial load, peak load and post peak load. Figure 4.3 until 4.6 shows the buckling behaviour for specimen width 103 and thickness 1.2mm. Figure 4.3, specimen was experience distortional buckling for the initial buckling period and continues experiences buckling at the top support at front. Figure 4.4, distortional buckling (DB) for the initial buckling period and continues experiences warping buckling (Wr) at the middle at front view of the specimen. Figure 4.5, warping buckling for the initial buckling period and continues experiences distortional buckling at the top at front view of the specimen. Figure 4.6 shows the experiences Local buckling for the initial buckling period and continues experiences warping buckling at the top at middle front & top back view of the specimen.

Figure 4.3 Buckling Behaviour for BE103-1.2-A1

Specimen BE103-1.2-A1 experiences distortional buckling for the initial buckling period and continues experiences buckling at the top support at front view of the specimen. For the post peak buckling behaviour, specimen BE103-1.2-A1 comes out with finalize buckling behaviour that are (LMB).

Figure 4.4 Buckling behaviour for BE 103-1.2-A2

Specimen BE103-1.2-A2 experiences distortional buckling for the initial buckling period and continues experiences warping buckling at the middle at front view of the specimen. For the post peak buckling behaviour, specimen BE103-1.2-A2 comes out with finalize buckling behaviour that are LMF and LMB.

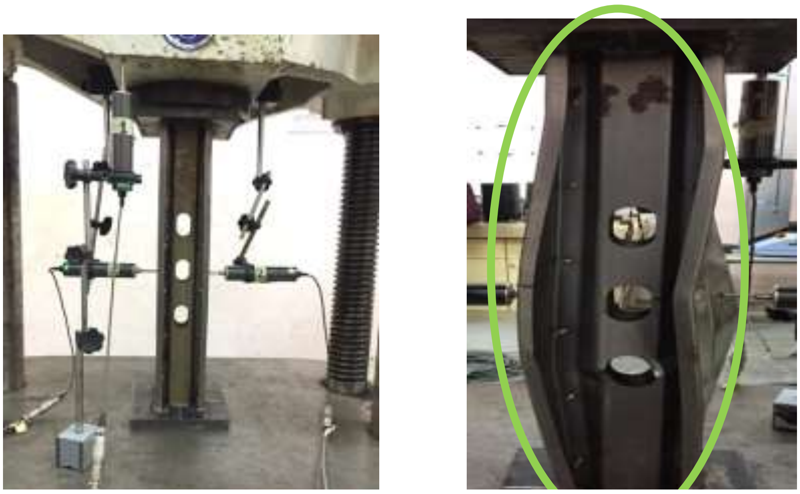


Figure 4.5 Buckling behaviour for BE103-1.2-A3

Specimen BE103-1.2-A3 experiences warping buckling for the initial buckling period and continues experiences distortional buckling at the top at front view of the specimen. For the post peak buckling behaviour, specimen BE103-1.2-A3 comes out with finalize buckling behaviour that are WMB, LMB and LMF.

Figure 4.6 Bucking behaviour for BE103-1.2-A4

Specimen BE103-1.2-A4 experiences Local buckling for the initial buckling period and continues experiences warping buckling at the top at middle front & top back view of the specimen. For the post peak buckling behaviour, specimen BE103-1.2-A4 comes out with finalize buckling behaviour that are DMB.

The buckling behaviour that occurs in this specimen were distortional buckling at top support for both back and front of specimen for specimen BE103-2.0-A1. Then, specimen BE103-2.0-A2 was experience distortional buckling at the middle span at front and distortional buckling at the bottom support at the back of specimen. For specimen BE103-2.0-A3, front and back of specimen were experience distortional buckling at the bottom support. Lastly, specimen BE103-2.0-A4 experience distortional buckling at top support while front of specimen experience warping buckling at the top support.

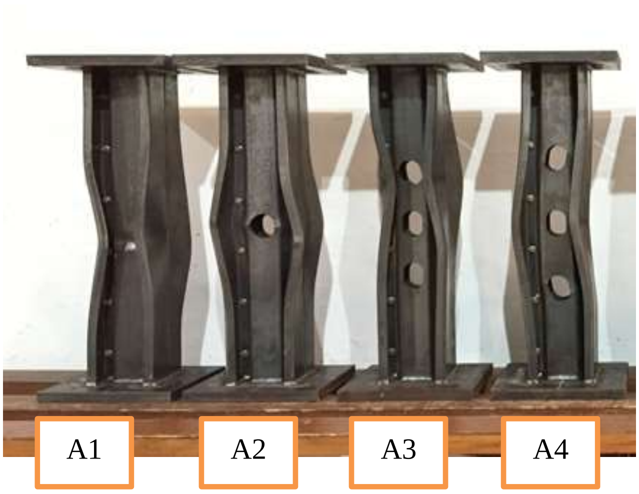


Figure 4.7 Buckling Behaviour for BE103-2.0

In Figure 4.7 shows the buckling behaviour mode for all specimen size 103 mm with thickness 2.0mm

Figure 4.8 Bucking behaviour for BE103-2.0-A1

For the Specimen BE103-2.0-A1, it shows in figure 4.8 the experiences Local buckling for the initial buckling period and continues experiences warping buckling at the top at front view of the specimen. For the post peak buckling behaviour, specimen BE103-2.0-A1 comes out with finalize buckling behaviour that are FrMD, BMW and Wb.

Figure 4.9 Bucking behaviour for BE103-2.0-A2

Then, Specimen BE103-2.0-A2 experiences Web buckling for the initial buckling period and continues experiences warping buckling at the top at middle front view of the specimen. For the post peak buckling behaviour, specimen BE103-2.0-A2 comes out with finalize buckling behaviour that are WrMB.

Figure 4.10 Bucking behaviour for BE103-2.0-A3

Specimen BE103-2.0-A3 experiences Distorsional top for the initial buckling period and continues experiences warping buckling at the top at middle back view of the specimen. For the post peak buckling behaviour, specimen BE103-2.0-A4 comes out with finalize buckling behaviour that are DMF

Figure 4.11 Bucking behaviour for BE103-2.0-A4

Lastly, Specimen BE103-2.0-A4 experiences does not happened buckling for the initial buckling period and continues experiences warping buckling at middle of the specimen. For the post peak buckling behaviour, specimen BE103-2.0-A4 comes out with finalize buckling behaviour that are web buckling.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

The deformed shape and maximum stress are obtained from the compression tests by using Universal testing machine (UTM). The buckling behaviour for the initial buckling, peak and post buckling and loading conditions after the testing have been described in this study. The testing was validated by following the parametric study in this research. The linear analysis and linear buckling analysis have been done to analyse the various positions of the holes, displacements, maximum stresses and maximum buckling load. From the analysis, the failure modes of the specimens are identified and the effect of different distances and number of opening to perforated built-up open CFS columns are determined. The maximum stresses and maximum buckling load are calculated and specifically described in detailed.

From the compression testing using Universal testing machine (UTM) on various position of the holes built-up open CFS columns, the following conclusions has been presented:

i. To determine the maximum compression load that can be carry by open built-up steel section before failure.

    o From linear buckling analysis result, the maximum value of buckling load for CFS column without perforations is lowest compare to CFS column with perforations. When the number of opening increases, the value of buckling load is decreases. So, the deformation of buckling criteria also changes. The shortest perspective span created the lowest value of the buckling load compared to others. Failure of the specimens occurs under the combined action of shear and moment

ii. To identify the mode of failure of the sigma section under compression with hole and without holes

- The perforations aspect is effects the linear analysis and linear buckling analysis of built-up open CFS columns. From the linear analysis, it shows that the built-up open CFS section with elongated openings will gives the different distances with the closer the loading point to the shear centres, the lower the critical buckling load.

- By comparing the number of openings and the distances of openings to the shear centres, built-up open CFS columns with three openings will having the higher deformation on the flanges compared to the specimen with no openings . So that, the closer the loading point to the shear centre, the lower the critical buckling load. The highest number of circular openings with shortest perspective span shows the lowest tension stress than others while, the highest number of square opening with longest perspective span shows the lowest tension stress than others. In other factors, the technical errors also will effects the deformation buckling of the specimen.

- High deformation is observed as the web-posts are subjected to high shear, accompanied by heavy distortion of the web opening.

5.2 Recommendation

There are several suggestions that can be used in future research on cold formed steel columns. First, use different parts. In this study, only one-part size is used. In future research, several section sizes may be used to study the effect of part size on the behaviour of the sample. This is related to the various parts used by the construction industry as part of a prefabricated component. Since different types of sections or innovations in new geometric parts can contribute to new effective sections that can be applied in the future

Next, use different shapes and sizes of perforation such as square, rectangle and circular. Since the construction industry can use different shapes and sizes of drilling to meet construction requirements, future research can be conducted to study the effects of different shapes and sizes of drilling on final load and sample behaviour.

Finally, do a finite element analysis. This research only uses experimental investigations to investigate the effects of drilling on a cold-formed steel on the compression. The sliding behaviours can be accurately predicted by the finite element (FE). Using Fusion Excel in research can help provide additional information and load comparisons and sample changes.

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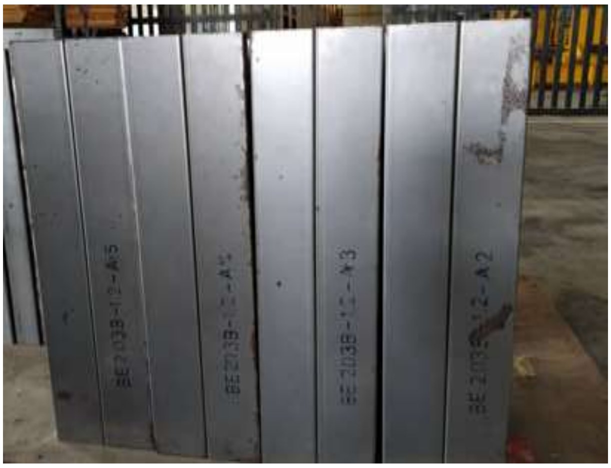
APPENDIX A

Testing preparation

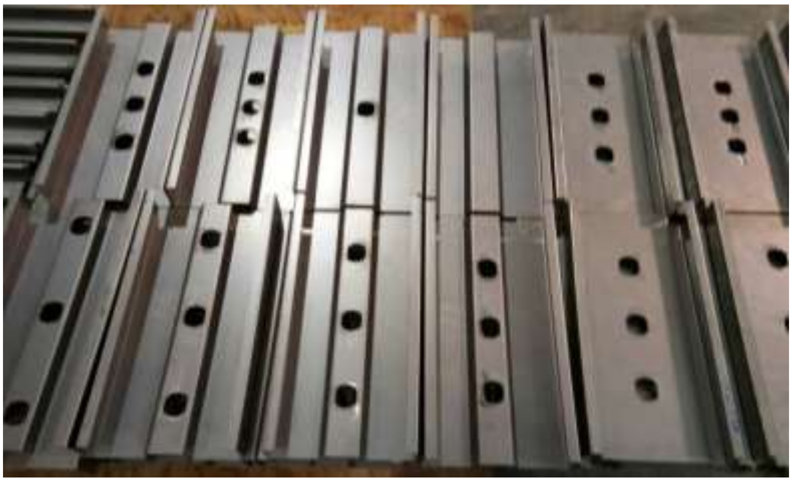
- Polish the specimen



APPENDIX B

Preparation of Built-up Sigma section

- Sigma Section steel column



- Measuring, Marking and Drilling the specimen