AXIALLY LOADED BUILT-UP C-SECTION COLD-FORMED STEEL WITH HOLES

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Thesis submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2018

ACKNOWLEDGEMENTS

In the name of Allah, The Most Gracious and the Most Merciful

Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis. Special appreciation goes to my supervisor, Mr Khalimi Johan Abd Hamid, for her supervision and constant support. Her invaluable help of constructive comments and suggestions throughout the thesis works have contributed to the success of this research.

My deepest gratitude goes to my beloved parents; Mr. Harisfadzill bin Wan ariffin and Mrs. Tunis binti Kadir; and also, my brothers and sisters who had been supporting me all the time with their motivating and encouraging words, and also their never-ending love and prayers had made me to go thru this study.

I would like to express my appreciation to all lecturers in Faculty of Civil Engineering and Earth Resources for the assistance, guidance and encouragement throughout the study in completing this program successfully.

Lastly, special thanks to all my friends especially, my coursemates intake 2014/2015 for their kindness and moral support during my study. To those who indirectly contributed in this research, your kindness means a lot to me.

Thank you very much.

ABSTRAK

Kajian eksperimen dijalankan untuk mengkaji kelakuan keluli terbentuk sejuk terbina. Kancing binaan dalam kajian ini terdiri daripada dua bahagian C berorientasikan back-to-back membentuk suatu keratan rentas berbentuk I. Dimensi untuk spesimen diameter diameter terbahagi kepada dua iaitu 103mm dan 203mm untuk disiasat. Untuk setiap spesimen, stud disambungkan kepada satu sama lain dengan dua skru penggerudian diri yang dijarakkan pada selang yang ditetapkan. Seksyen trek keluli yang terbentuk sejuk telah bersambung dengan tegak lurus ke setiap hujung stud terbina dengan skru penggerudian sendiri melalui setiap bebibir bahagian C. Tujuan bahagian trek adalah untuk mengekalkan hujung kancing bersama dan mewakili lampiran akhir biasa. Spesimen dikimpal dengan saiz plat keluli spesifik sebelum diuji. Tujuan spesimen dikimpal adalah untuk memegang spesimen semasa ujian dan untuk mendapatkan hasil yang lebih tepat diperoleh. Keputusan spesimen boleh diperolehi oleh beban muktamad dari setiap spesimen dan untuk mengkaji tingkah laku tengkuk disebabkan oleh kedudukan pembukaan yang berbeza dalam spesimen.

ABSTRACT

An experimental investigation was conducted to study the behavior of built-up cold-formed steel. The built-up studs in this study consisted of two C-sections oriented back-to-back forming an I-shaped cross-section. The dimension for diameter built-up specimens are divided into two that are 103mm and 203mm to be investigated. 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 flange of the C-sections. The purpose of the track section was to keep the ends of the studs together and represents a common end attachment. The specimens are welded with the specific size of steel plate before being testing. The purpose of welded specimen are to hold the specimens during testing and for more accurate result obtain. The result of the specimen can be obtained by the ultimate load from each specimen and to study the buckling behavior due to the different opening position in specimens.

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LIST OF ABBREVIATIONS

LBW	Lateral back
CFS	Cold-Formed steel
AISI	American Iron Steel Inside
BS	British Standard
BTB	Back-to-back
FKASA	Fakulti Kejuruteraan Alam Dan Sumber Alam
n.d	No date
LBF	Lateral torsional buckling at top support (front)
LMB	Lateral torsional buckling at middle span (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

Steel is one of the material of construction and is a basic ingredient needed in construction. In steel structures, there are two types of structural steel members that are hot-rolled steel members and cold-formed. The usage of cold-formed steel structures in the building construction industry is rapidly increasing due to their potential benefits including high strength to weight ratio, rapid constructability and ease of transportability than hot rolled steel. Cold-formed steel structural members are commonly provided with holes to accommodate electrical and plumbing of building.

Cold-Formed Steel (CFS) industry have improved in technology and low production cost to produce more structurally efficient and economic cross section shapes. One of the most favourable ways to perform this task is to connect two or more single members together to form a built-up section, e.g. simply connecting two channel sections back to back to form a built-up I-section. Members with built-up section can carry more load and span more distance. There are different between the built-up C-section with plain and lipped angle. These types of sections can be shown in Figures 1.1. Loading is rarely concentric due to attachments along the angles legs. For plain and lipped channel have different centroid that will affect the angles legs. Plain angles have no primary warping resistance and local-plate buckling and global torsional buckling have nearly identical deformations.

1.2 Background of Study

Opening in cold formed steel columns section (CFS) are widely used in steel frames structures to facilitate piping, electrical, mechanical and sanitary works for maintenance services and inspections. Openings also made specifically for fasteners such as bolts and screws. By considering openings in steel columns sections are to reduce the materials volume without affecting the structural strength or serviceability requirement in addition to reduce the cold bridging effect when opening channel section steel column are used in the external wall panels at cold region. The ultimate strength and elastic stiffness of a structural member can vary with opening position, size, shape and orientation. In evaluation of the section properties of members in compression, openings need to be considered. The perforations can be divided by pre-punched or punched-on-site but mostly pre-punched are more favourable due to the problem that will rise later if the holes are not accurately made.

Use of built-up cold-formed steel got several advantages. The first advantages are production and handling such as ease of production. To produce new shapes without built special production method is fastened the standard -C and Z shape by a bolt, screw, or weld. Formation of (CFS) structure can be more easier and faster without heavy lifting equipment that suitable to up to semi high building. Strength and stability are the second advantages. Higher stability and capacity for built-up section due to combination of two or more standard section that produce greater cross-section properties. The eccentricity between the shear can be devastate with the symmetry of built-up section. Built-up section with Back-To-Back (BTB) advantages to strengthening external frame column and closed built-up section used to support long beam and double storey house.

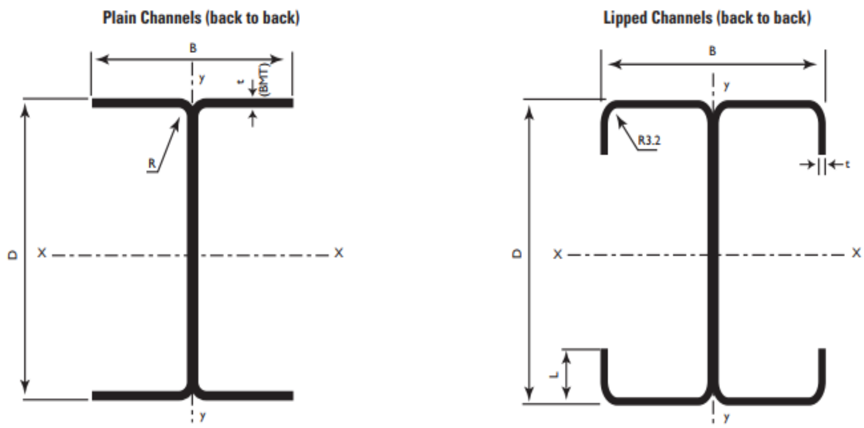


Figure 1.1 Dimension of the built-up C-section plain and lipped angles
Source: LYSAGHT (January 2010).

Table 1.1 Table of properties of plain and lipped channel with centroid position
Source: LYSAGHT (January 2010).

Plain Channels — Dimensions and Properties

Catalogue No.	Nominal Dimensions D	B	R	t	Section Area	Mass Galv.	Black	Second Moment of Area I_x	I_y	Centroid c
	mm	mm	mm	mm	mm^2	kg/m	kg/m	$10^6 mm^4$	$10^6 mm^4$	mm
LC05130	51	25	3.2	3.0	290	2.15	2.12	0.09960	0.01600	7.80
LC06425	64	23	2.5	2.5	250	2.00	1.96	0.13900	0.01110	5.88
LC07630	76	38	3.2	3.0	420	3.34	3.30	0.36400	0.57900	10.91
LC08330	83	34	3.2	3.0	420	3.34	3.30	0.41500	0.04530	9.18
LC08930	89	31	3.2	3.0	420	3.34	3.30	0.45700	0.03560	7.84
LC09530	95	37	3.2	3.0	465	3.70	3.65	0.59300	0.05340	9.09
LC10330	103	34	3.2	3.0	465	3.70	3.65	0.66100	0.03890	7.42
LC10230	102	55	3.2	3.0	600	4.78	4.71	0.98400	0.18080	15.67
LC12730	127	50	3.2	3.0	660	5.26	5.18	1.58200	0.17050	13.22
LC15230	152	51	3.2	3.0	735	5.86	5.77	2.42000	0.17970	12.02

Lipped Channels — Dimensions and Properties of Full Unreduced Sections

Catalogue No.	Nominal Dimensions D	B	L	t	Section Area	Mass Galv.	Black	Second Moment of Area I_x	I_y	Centroid c
	mm	mm	mm	mm	mm^2	kg/m	kg/m	$10^6 mm^4$	$10^6 mm^4$	mm
LL06425	64	38	13	2.5	363	2.90	2.85	0.2280	0.0680	14.2
LL07610	76	44	11	1.0	175	1.43	1.37	0.1682	0.0464	15.3
LL07625	76	44	16	2.5	438	3.49	3.44	0.3920	0.1156	15.7
LL10225	102	51	18	2.5	550	4.39	4.32	0.8870	0.1980	18.2
LL10230	102	51	19	3.0	660	5.25	5.18	1.0450	0.2370	18.6
LL12725	127	51	18	2.5	612	4.89	4.81	1.4870	0.2140	16.5
LL12730	127	51	19	3.0	735	5.85	5.77	1.7600	0.2570	16.9
LL15230	152	64	21	3.0	900	7.16	7.07	3.1800	0.4980	20.9
LL20330	203	76	24	3.0	1 40	9.07	8.95	7.1150	0.8750	23.1

1.3 Problem Statement

Cold-formed steel with openings have their own advantages and disadvantages to the column and structure itself. Openings can be found in any various shape of opening especially in circle, rectangular, elongated and rectangle. 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. The imperfection due to the residual stress because of folding the cold-formed steel are among the issue in this study. The yield stress that formed cannot be avoid because during forming the cold-formed, some stress need to be applied to make a desired shape of cold-formed.

Effect of strength of cold-formed steel due to position of opening also need to be taken because different behaviour of failure mode occurs when different position of opening. Experimental study needed to be done because there will be different in behaviour of buckling if the position of opening were different. The structural behaviour of the cold-formed steel members characterized by different position of openings is not yet fully understood. Holes are generally assumed to decrease the elastic local buckling load of a flat plate loaded in uniform compression.

Web stiffeners is commonly used in cold-formed steel sections to provide a continuous support along a longitudinal edge of the flange to enhance the buckling stress. The stiffeners can be easily brake-pressed on the free edge of an unstiffened plate. In addition, the web stiffeners also may alter considerably their distortional buckling, post-buckling and collapse behaviour. Due to the problem, some research need to be consider where the web stiffeners can affect the ultimate strength of the cold-formed steel. The structural behaviour of the cold-formed steel members characterized by different shapes of openings is not yet fully understood. Holes are generally assumed to decrease the elastic local buckling load of a flat plate loaded in uniform compression.

1.4 Research Objective

The objectives of the research are as follow:

RO1. To determine the ultimate load of axially loaded of built-up c-sections cold formed steels (back-to-back) with holes.

RO2. To investigate the failure mode behaviour of axially loaded of built-up c-sections cold-formed steel with different location of holes.

1.5 Research Scope

In this study, a series of column tests on cold-formed double steel C-shaped back to back sections with edge and web stiffeners were conducted. The columns were compressed between fixed ends. Current design methods available to engineers for predicting the strength of cold-formed steel members with holes are prescriptive and limited to specific perforation locations, spacing, and sizes. The section of cold-formed that being tested is a double (back to back) section and a short cold-formed steel are being used which range between 700 mm to 1000 mm with the thickness around of 1.6 to 2.0 mm. The shape of the opening used is circular and elongated shape. The position of opening of perforations at the cold-formed steel member also varies. The plate will be used as a base that will act as a support and will be welding together with one of the ends of cold-formed and act as a fixed support. There will be 2 type of section size during experiment. The failure mode of axially loaded column with different position of perforations is tested by study the behaviour of the buckling mode of the cold-formed steel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Cold formed steel materials have been produced for more than a century since the first time in steel sheets produced by steel mills. The use of cool cold-formed construction materials has become increasingly popular since the introduction of codified standards in 1946 (Prakash, 2014). Steel parts are formed thin, cold-punched (CFS) is often used as structural members in residential buildings and for the construction of storage shelves. For example, in the construction of low and middle bank construction hole before it occurs in the latch structure to accommodate service lines in the walls and roofs of buildings; while in pole frame construction model chute is provided to allow the configuration of a variable frame (Wang, 2016). In India, due to the increase in industrial industrialization and the weight of population, cold-formed structural steel as frame structure of industry and housing mass is the need of the hour, of which the steel frame formed in cold it can be tried as an alternative to very economic and efficient (Kubde, 2018) Cold-Formed Steel Process.

The cold formed steel frame is made of a structured steel sheet fed through the roll forming machine with a series of dies that progressively form steel into a C-shaped piece, or is formed in several other ways, including "U", "Z", as well as shaped hat, to meet the needs of certain applications (Yu, 2000). The creations of chilled steel frames can be formed from a variety of material thicknesses that allow them to meet the needs of almost all structural and non-structural applications. Methods in the production of cold-formed steel sections (Structures, 2008) which are cold-rolling, press braking,

2.1.1 Hot rolled steel

The hot-rolled steel is heated above the recrystallization temperature of the metal (about 1700 ° F or more), which facilitates bending and metal formation (Brakefield, 2017). The steel used for hot-formed steel can be larger and the end result is weaker than the cold-formed steel, which makes it cheaper. This process is often used in the construction of elements such as rail links, beams and other products that do not require a form. Its appearance is scalier and round and has an inaccurate angle of cold formed products.

2.1.2 Cold rolled steel

Cold rolled steel is pressed at very cold temperatures, often at room temperature, which means that it does not contract or change shape (Structures, 2008). It is a product stronger than steel formed by heat and has a finer appearance. The dimensions and dimensions are more precise, allowing its use for clearer and clearer external applications. Cold formed steel is used more frequently in the construction world to compose shapes and structure panels.

2.1.3 Press braking

The brake press is one of the oldest mechanical deformation processes. According to (Metals, n.d), During the process, a piece of sheet metal was formed along the straight axis. This can be done with a "V" shape, a "U" shape or a punch shaped punch and set the die.

Although braking pressure seems to be a simple concept, maintaining accuracy is often quite difficult. Precision bending is a function of the press, the tool and the work piece. Material characteristics such as creep strength, ductility, hardness and material condition affect the return amount of the material spring.

The most common industrial press brake process is called air bending. The bending of air depends on three points of flexion. The bent corner is determined by the extent to which the punch finishes penetrating into the "V" cavity. The greater the penetration of the punch tip, the greater the angle reached. The main advantage of air flexing is that it uses less energy than other methods to achieve a 90 ° wound due to the influence of leverage.

2.1.4 Advantages of cold-formed

The cold formed steels are stronger than the heat generating alternatives, this does not mean that the steel is forming a weak heat. Instead, it is used to form I-Beams and other very strong structure and construction components. However, in the construction world, especially when it comes to visible finishing, the right edge and the uniform finish are important. Therefore, generally prefer products made with cold formed steel (SFIA, 2016). And, since steel is pressed without the use of heat, there are fewer possibilities of weaknesses that lead to future weaknesses and settlement panels.

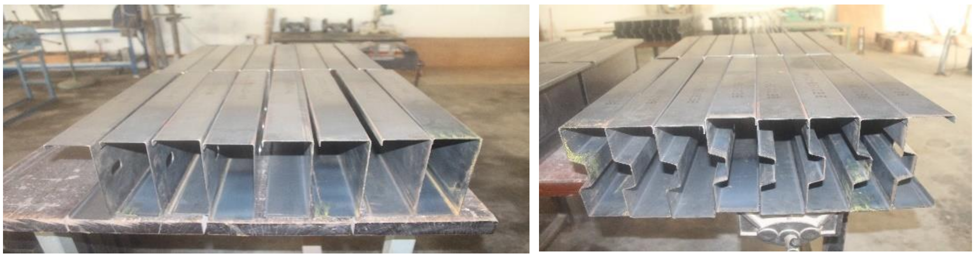
According (Team, 2014) Hot or cold, steel is the most recycled product in North America. This means that cold formed steel for your construction project is made of a large volume of steel and sand and post-consumer metals, and everything can be recycled at the end of its useful life. In addition, steel construction materials are very durable, which means that their maintenance and repair costs can be significantly reduced (Prague, 2010). It opposes pests, fires, and other natural and artificial improvements to the thinning and longevity of steel compared to traditional wood building materials.

2.2 Classification of section

Cold formed steels have different types of sections depending on their function and purpose in the construction work. This unique section is made by forming the cold mentioned above in this research document, boiling and rolling. As a result, it offers a wide selection of designs with minimal limitations and increases the popularity of cold formed steel as a member of the structure. This was agreed by (Mahmood, 2007)who illustrates a cold formed steel to have a versatile profile shape that can be produced in a controlled production line. There are three main types of sections that are simple open sections, open sections and closed sections.

2.2.1 Single section

The single section is the basic form produced by the cold formed steel formed in cold. It is formed in an operation of a material. Examples of unique open sections are sections Z and C-sections (Eduardo, 2010). This section is generally used for the construction of the belt and the roof.



(a) (b)

Figure 2.1 Shows the (a) C-section and (b) Z-section

2.2.2 Built-up section

The open built-up section is also known as an I-section. It is a combination of two open openings that are currently connected, usually by welding, and training and my part. (Yu, 2000) agreed that generally welded two channels attached or welded to the corner of the channel. In this research work, the specimen was being connected using self-drilling screw with rubber.

Figure 2.2 Show the built-up c-sections specimen

2.3 Built-up cold-formed steel

One of the most favourable ways to perform this task is to connect two or more single members together to form a built-up section, e.g. simply connecting two channel sections back to back to form a built-up I-section. Members with built-up section can carry more load and span more distance (Georieva, 2012). The section members are connecting using self-drilling screw with rubber using drilling machine.

.

2.3.1 Advantages of built-up C-section

Built-up CFS members usually have symmetric cross-sections, higher strength and better resistance against out-of-plane movement (Georieva, 2012). Use of built-up cold-formed steel got several advantages. The first advantages is production and handling such as ease of production. To produce new shapes without built special production method is fastened the standard -C and Z shape by a bolt, screw, or weld. Formation of (CFS) structure can be more easier and faster without heavy lifting equipment that suitable to up to semi high building. Strength and stability are the second advantages. Higher stability and capacity for built-up section due to combination of two or more standard section that produce greater cross-section properties. The eccentricity between the shear can be devastate with the symmetry of built-up section. Built-up section with Back-to-Back (BTB) advantages to strengthening external frame column and closed built-up section used to support long beam and double storey house.

2.4 Buckling behaviour

One of the biggest challenges in handling a cold formed steel design is the prevention of buckling. Buckling is the main design consideration for all cold-formed steels, unlike hot-rolled steel conductors where steel production is a leading design consideration (Kang, 2013).

2.4.1 Local buckling

Local buckling is a very important aspect in cold-formed steel parts because the very thin elements used are always agile before production (Laim, 2016). The weaker the plate, the lower the load in which the shape of the buckle will form.

There are many factors that contribute to the increase of cold formed iron columns, the ratio of column loads, the mechanical properties of the cold formed steel, the cooling effect, the imperfect effects, the transverse shape and the other. This was agreed by (Kulatunga M. P. and Macdonald, 2013)and explained that because of this factor, cold-formed steel compression members can be wound locally before the applied load reaches the full load of collapse of the column. In addition, the effect of the effects of local and general column curve depends to a large extent on the strength of the entire column.

2.4.2 Distortional buckling

Distortional buckling, also known as "buckling stiffener" or "local torsion buckling", is a mode characterized by a flange rotation at the flange / band intersection within members with firm elements, (Schafer, 2002). In members with distortion fracture elements that are firmly mutually characterized by the normal intermediate displacement to the elementary plane. This study focuses on the fall of the distortion of the limbs with firm elements.

The distorted disturbance of the wave lies between the local throat and the global buckling that places it in a wide range of practical members. (Kulatunga M. P. and Macdonald, 2013)claim that distortion slides generally promote a more rapid failure than local buckling.

2.4.3 Flexural buckling

There are two types of flexural buckling that are:

I. Flexural buckling type of capture can occur in any compression member that has a deviation caused by a dent or bending. Bending waves are produced around the axes with the greatest slenderness ratio and the smallest turning radius.

II. Flexural-torsional buckling types only occur in compression members that have an asymmetric section with a symmetric axis. The flexible spindle is flexible and simultaneously rotates simultaneously. This occurs mainly in channels, structural shirts, two-corner shapes and the same feet individual corner.

2.5 Presence of holes in cold-formed steel

The presence of hole can lead to the reduction of the strength of the individual components and the general resistance of the members depending on the position, size and opening orientation. The precise analysis and design of steel with thick elements are complicated especially with designs and fabulous shapes. According (YU, 2010), cold-formed steel stains are a major concern especially in the structures of thin-walled structures and critical curved loads for perforated plates and experts have been studied by many researchers.

According (Shanmugam, 1997), opening in thin wall structure (1997), The presence of such openings in structural members will obviously cause changes in the distribution of tension in the members, in addition to the reduction in strength and variation in the buckling characteristics of the plate members. Elastic and final loads. The behaviour of these experts will also be significantly altered by the presence of openings. The performance of the member of the structure containing holes is influenced by the types of stresses applied (eg, compression, tension, shear, etc.), as well as by shapes, sizes, locations and numbers.

2.6 Previous researches

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

2.6.1 Compression test of cold-formed steel columns

Researchers, (Pekoz, 1990) presents a detailed description of the experimental study on the resistance of the flexible slider for the cold formed steel column. A total of 68 columns and 25 columns were analysed. It is worth noting that some types of columns show a lower resistance than the value predicted by the pole design formula of the American Iron and Steel Institute. In some cases, it was found that the difference between the results of the AISI tests and the forecasts was greater than 15%. From the experimental findings, it was found that the dimensions of the cross section and the magnitude of the residual stress had a consistent correlation with the weaknesses of the column resistance. Other parameters, such as the deformation pressure curve (acute or gradual yield) are obtained from tensile strength tests and the methods used to form parts (pressed or formed by roller) do not have a definite influence on the resistance of the column.

2.6.2 Analysis for local buckling capacity of cold-formed steel section with web opening

The research that was done by (Sivakumaran, 1987)back in 1987 focus on investigating local buckling behaviour of C-shaped lipped channel cold-formed sections, with and without a large web opening subject to the concentric axial load presented. The isoperimetric layer element is used for a one-quarter model. The opening of the website is generated using the option of birth / death element. Cold formed steels have been considered linear variety.

Elastic plastic material with von Mises produces criteria. The non-linear analysis material and the results of the nonlinear analysis of the material and the geometry were presented and compared with the experimental results. The final load predicts correctly with non-linear analyses of material and geometry. However, the sub-final behaviour does not match the results of the experiment, probably due to the imperfections exist to study the effect of perforation position on the load capacity of column members of lipped channel cross-section. However, these researches also are done through the method of Finite Element rather than just doing the laboratory experiment.

2.6.3 Buckling capacities of axially loaded, cold-formed, built-up C-channels

According to the researchers, (Jessica Whittle, 2009), Cold incorporated members are a common compression element in cold formed steel sliders, and these built-in members are prone to unique bracelet behavior. Designs made by experts are discussed in Section C4.5 of the 2001 Specifications of the American Iron and Steel Institute. More than 150 test compression tests in closed sections, builders established with intermediate welds channel c was performed, and the experimental values were compared with the buckling capacity based on the modified slenderness ratio SectionC4.5. The use of the modified slenderness ratio is very conservative. Capacity based on the unmodified slenderness ratio and C4.5 fastener and conservative distance allocation consistently.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methods involved in this study which is an experimental compression test in a short column. Sample configuration process during test begins by placing transducer first. After laying the transducer, the sample is placed inside the machine. Next, transducers are positioned according to focus studies. Then, the speed of loading the machine needs to be configured. The universal test machine will compress the sample so that the user stops it based on the displacement value study.

Research investigate by (Jessica Whittle, 2009) tittle, buckling capacities on axially loaded, cold-formed, built-up C-channels, (2008) had been used as a standard to do the experiment and provided the basic guidance to develop all the research on cold-formed steel members. Seven specimens were used where all the specimens had different opening positions. The thickness and length of the sample used are consistent to get the right results and make comparisons.

The result of the performance and behaviour between cold-formed steel built-up members were created with two, lipped c- channels welded together at the top and bottom. The experimental investigation was aimed at studying ultimate strength and the failure modes of lipped double (back to back) C-section columns.

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

iv. Phase 4: Conclu-0001.sion and recommendation

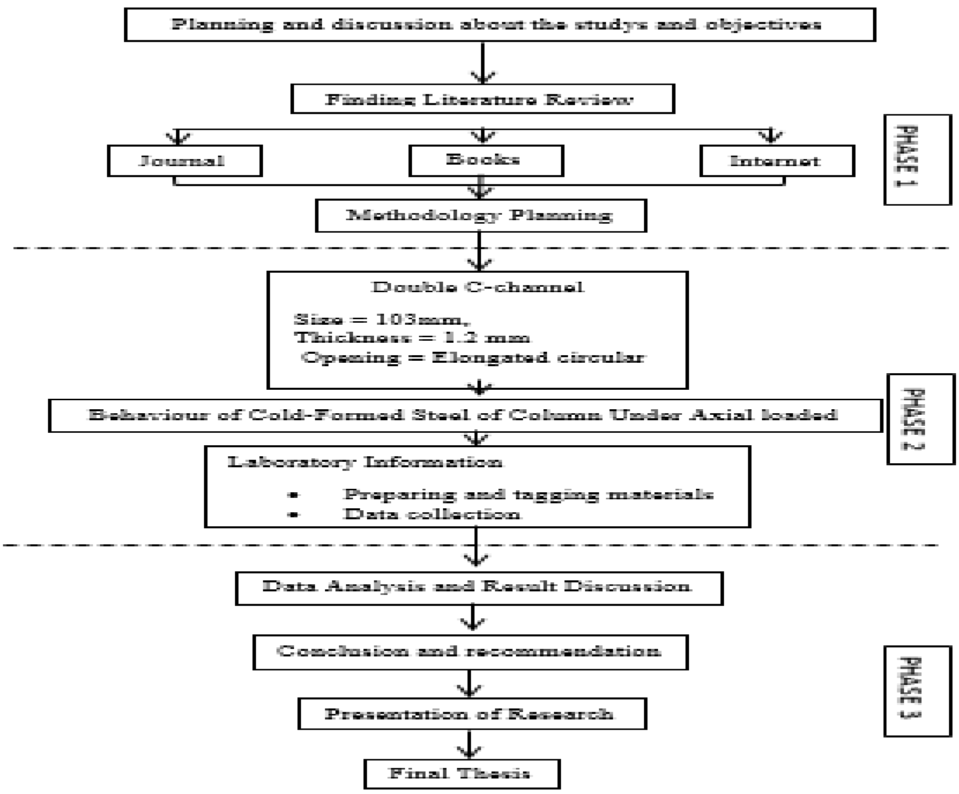


Figure 3.1 Planning work process

3.2.1 Phase 1: Planning and discussion of study

The objectives of study were obtained from the discussion about the demand for cold-formed steel in construction and problem solving when presence of holes in cold-formed steel. Hole are used for the mechanical and electrical facilities for maintenances and inspections. The topics that obtained from objectives were "Axially loaded built-up c-section cold-formed steel with holes".

3.2.2 Phase 2: Finding Literature review and Methodology planning

After the topic of "Axially Loaded Built-up C-section Cold- formed Steel with Holes" have been finalise, the writing of literature review starts. Upon writing the literature review, one must gather information and knowledge to understand the topic better. The information provided in literature review must have accurate and useful information to ensure the objective of research may be obtained.

A well-written literature review will give good understanding to the person reading the research project paper later. The information and knowledge gather must only come from reliable source to ensure the quality and reliability of the complete research project later. There are three main source that can be used in obtaining information which are previous journal and books, internet reading within reliable website and a direct discussion with supervisor and lecturers.

After completing the literature review, the methodology for the experimental investigation is planned. The sample is design and calculation of maximum axial load is done to ensure that the machine available in the laboratory can cater with the design during the investigation. The sample used for this project has 600 mm length due to the limitation of height that the can be cater by the machine in the laboratory. The testing of sample made in laboratory of Faculty of Civil Engineering and Earth Resources (FKASA) in Universiti Malaysia Pahang (UMP). To obtain an accurate result and researches in right ways, (Jessica Whittle, 2009) has being guide lance to researches study.

3.2.3 Phase 3: Data analysis and result discussion

The result and analysis phase come from research objective and three main point the collected that were ultimate load, reading of displacement from three transducers and behaviour of buckling for each specimen. Data and result analyse from the calculation and approximate graph that obtain data from the testing and transducers data logger. Buckling behaviour was observe through the presentation of specimen before and after being test.

3.2.4 Phase 4: Conclusion and recommendation

At the end of this research, conclusion is made based on the findings that were obtain from the experimental investigations. The conclusions made were corresponding and answering the objectives of the research. This phase should also summarise the whole research and giving recommendations for future improvements regarding the research topic.

3.3 Research Design

Cold-formed C section size are selected based on the previous researcher and the capability of the Universal Testing Machine at the laboratory. The maximum height of specimen that Universal Testing Machine can take is average 700 mm including the bearing plate, so sample of specimen are 600 mm length. The section size is section203.Thickness of specimen that 1.2 mm used. Two of C-sections specimen are bind together using bolt to form Built-up back to back. The opening types that used is elongated circle. For addition, the location of openings is different between the specimen. Refer to Figure 3.5 for different location of openings. Both top and bottom of the specimen are welded with the steel plate. This can be shown in Figure 3. below.

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

103mm	**203mm**
BC103-A1	BC203-A1
BC103-A3	BC203-A3
BC103-A5	BC203-A5
BC103-A8	BC203-A8

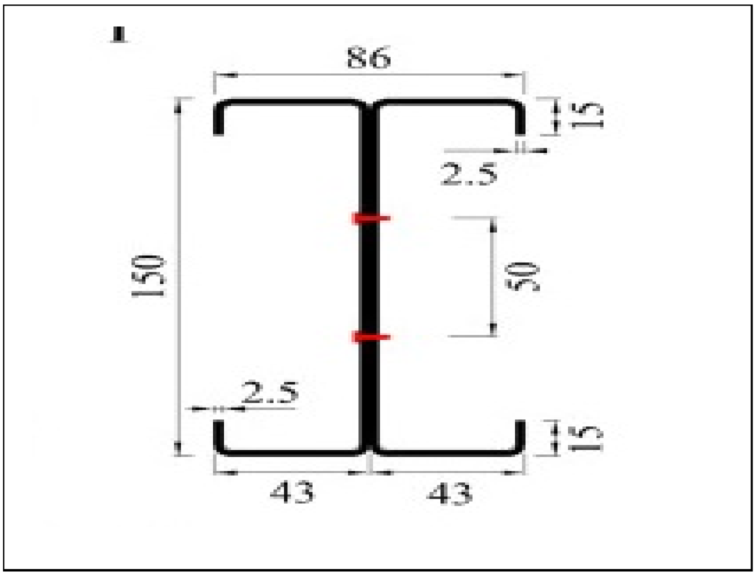


Figure 3.2 Show the Built-up C-section with dimension

3.4 Research Procedure

As for forming the built-up section of C-channel requires two specimens and be bind togethers using bolt. Top and bottom of the specimens are welded with the steel plate for the fix end supported. The testing are been used are Axially loaded test or compression test. The machine that will be used to conduct this experiment is Universal Testing Machine and transducers. The Universal Testing Machine will read the displacement of the specimens. The loading rate that will be used is 0.5 mm per minute which it was the most suitable rate for this specimen according to the previous researcher.

The data taken from this machine will be in the form of graph. The transducers are being used to read the reading of buckling mode of specimens. Four transducers will be used to take the accurate data. All of this instrumentation, specimen and materials shown in Figures 3.3 until 3.11.

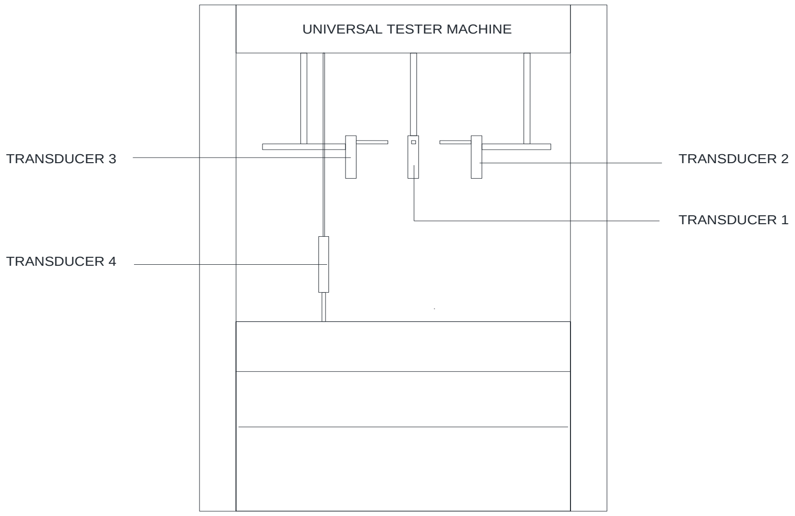
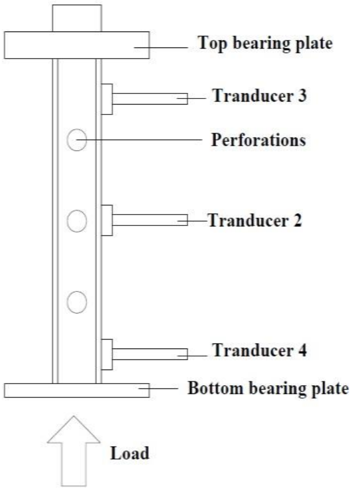


Figure 3.3 Schematic diagram for universal tester machine with transducer



(a) (b)

Figure 3.4 Pictures (a) and (b) show the universal tester machine and schematic diagram for testing set-up

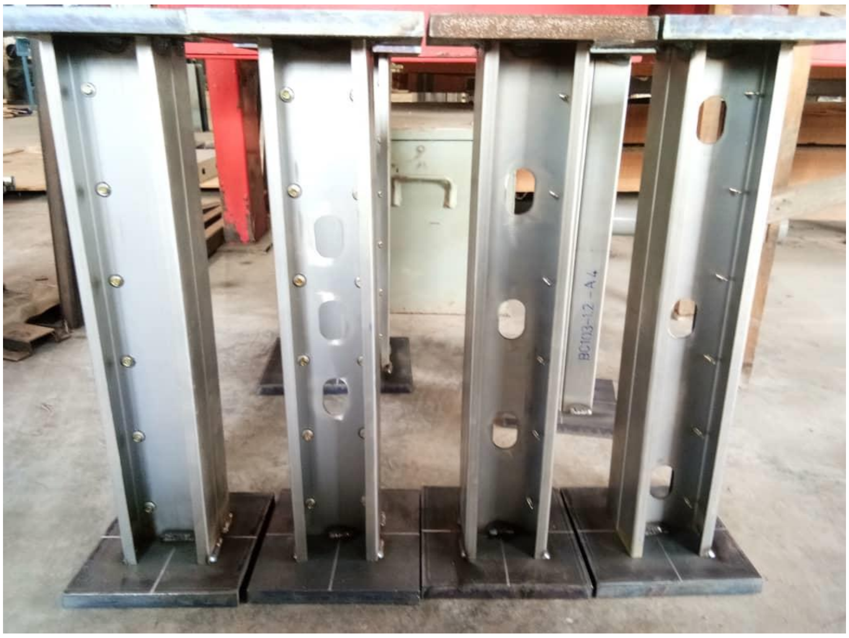


Figure 3.5 The different position of holes for section 103mm

Figure 3.6 The different position of holes for section 203 mm

Figure 3.7 Self-Drilling Screws that will be used to form Built-up Section

Figure 3.8 Labelling the specimen

Figure 3.9 Forming the built-up specimen with self-drilling screw

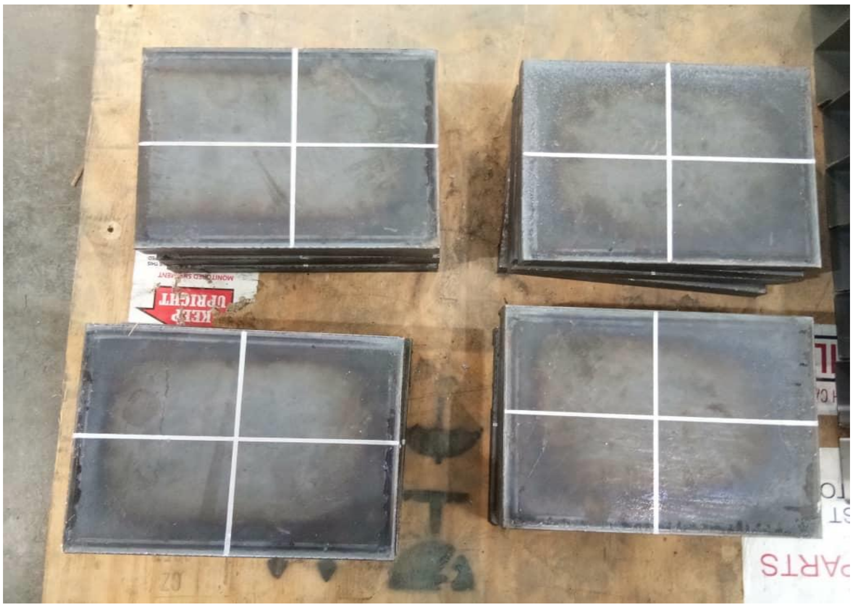


Figure 3.10 Base plated that used for specimen tested

Figure 3.11 Specimen welded at bottom support

CHAPTER 4

FINDINGS AND DISCUSSION

4.1 Introduction

This chapter will discuss about the analysis of the data and the result of the analysis. The discussion of the analysis is related to research objectives. The hypotheses for this research will be tested whether it is accepted or rejected.

4.2 Load versus vertical displacement

The result obtained from the experiment that are the ultimate load obtain from different section, presence of hole and different location of hole. Table 4.1 show the ultimate load and initial load obtain from the testing for each specimen. Specimen with no presences of holes will obtain higher ultimate load that is specimen BC203-1.2-A1 and BC103-1.2-A1. As seen in table 4.1, BC103-1.2-A1 come out with 90.09 kN higher from others specimen for BC103-1.2. BC203-1.2-A1 obtain higher ultimate load that is 103.963 kN means that the strength of the cold-formed steel will increase due the increasing in size of section.

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 BC103-1.2-A8 produce less ultimate load others specimen that is 82.12 kN. Figure 4.2 and 4.3 show the graph of load versus vertical displacement.

Table 4.1 Initial and Peak load for all specimen

SPECIMEN	INITIAL LOAD (KN)	PEAK LOAD (KN)
BC103-1.2-A1	85.24	90.09
BC103-1.2-A3	83.93	89.19
BC103-1.2-A5	83.84	88.66
BC103-1.2-A8	80.73	82.12
BC203-.12-A1	85.36	103.963
BC203-.12-A3	83.43	93.05
BC203-1.2-A5	82.78	98.81
BC203-1.2-A8	79.17	99.9

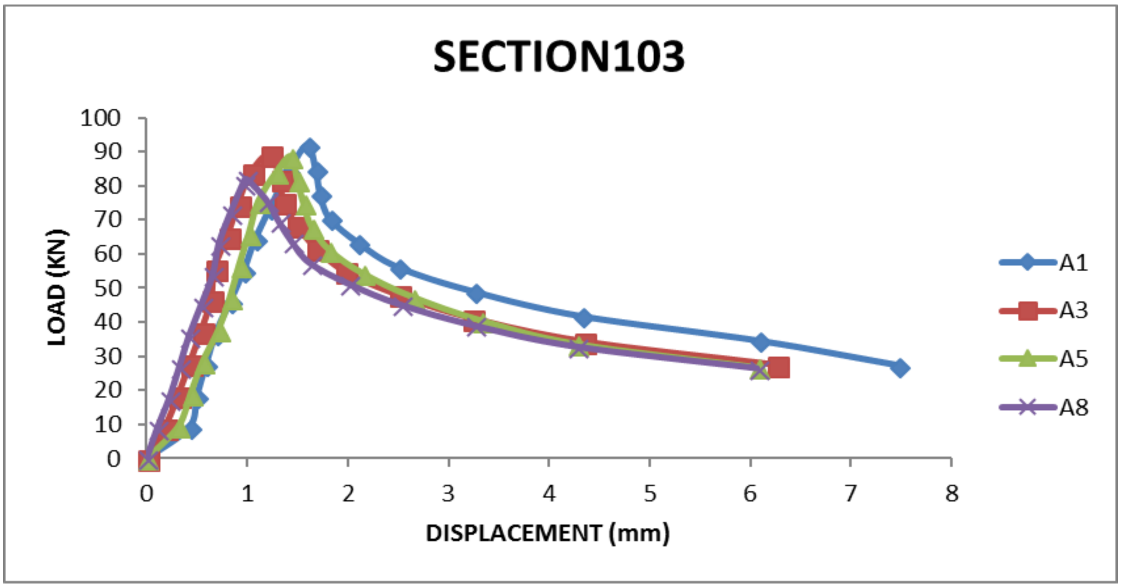


Figure 4.1 Load versus Vertical Displacement for section 103

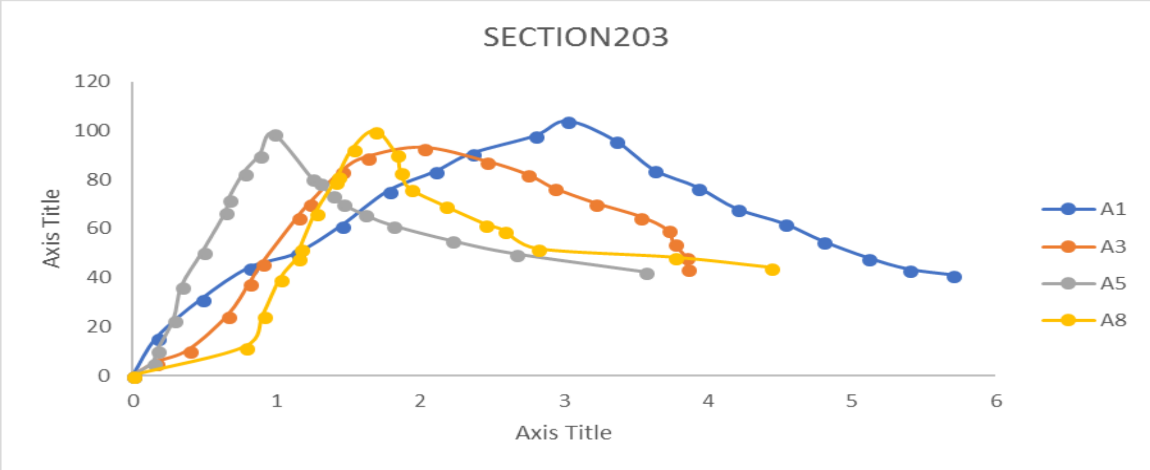


Figure 4.2 Load versus Vertical Displacement for section 203

4.3 Load versus horizontal displacement

The horizontal displacement is the corresponding data that were collected from the present of transducer that were place on three different point on the sample to measure the horizontal displacement. The data is presented though a load vs horizontal displacement graph where each graph represent each sample with two transducers attach to it.

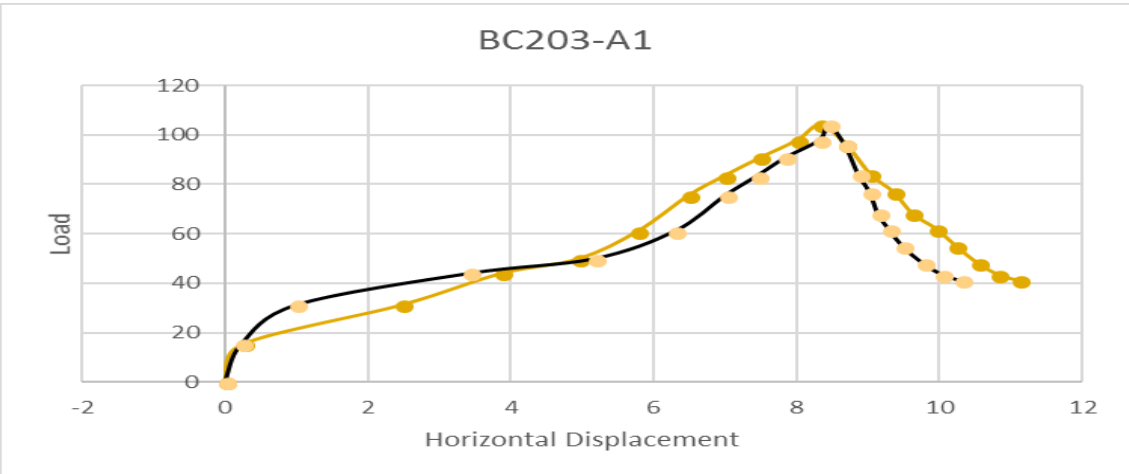


Figure 4.3 Graph of transducer 2 and 3 for specimen BC203-A1

The maximum axial load for sample BC203-A1 is 103.96 kN and the maximum displacement is 11.11 mm which happen at the transducer CH2 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.3, CH2 and CH3 intersects at 4.05 mm and 8.36 mm and both transducer get positive reading until it reaches the failure.

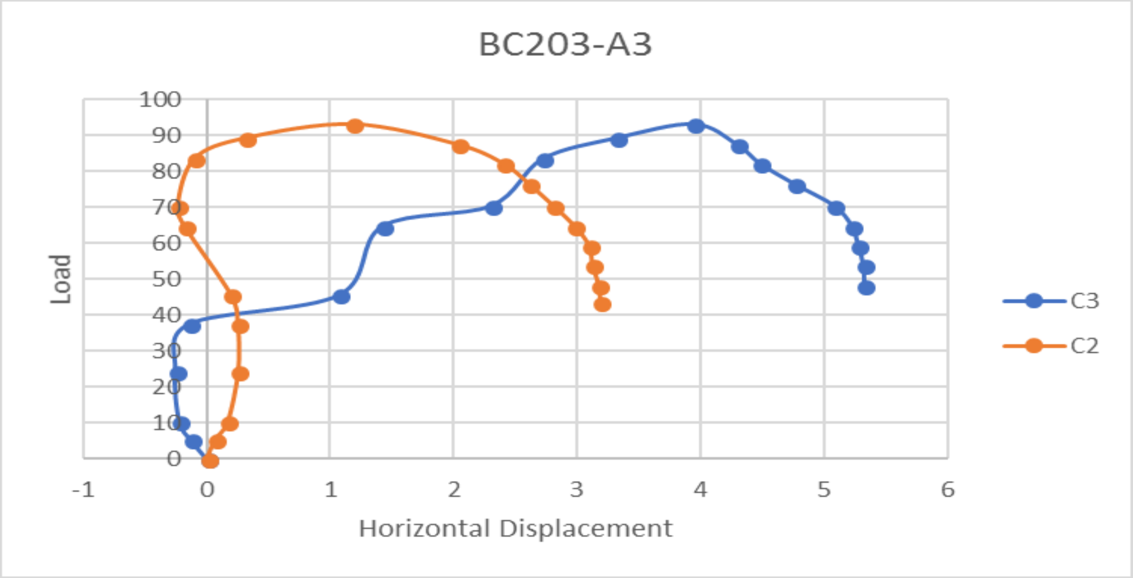


Figure 4.4 Graph of Transducer 2 and 3 for specimen BC203-A3

The maximum axial load for sample BC203-A3 is 93.05 kN and the maximum displacement is 5.32 mm which happen at the transducer CH3 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.4, CH2 and CH3 intersects at 0.28 mm and 2.56 mm. From the graph, the transducer CH3 initially get the negative reading before the load reach 40 kN and get the positive after it and get the maximum displacement for the specimen.

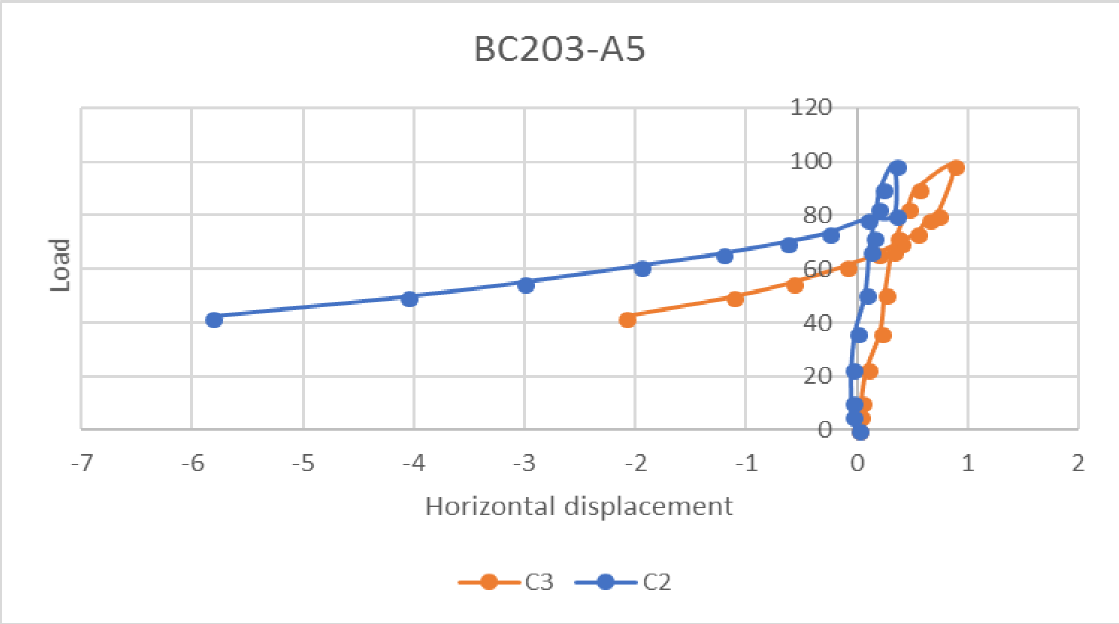


Figure 4.5 Graph of Transducer 2 and 3 for specimen BC203-A5

The maximum axial load for sample BC203-A5 is 98.81 kN and the maximum displacement is 0.869 mm which happen at the transducer CH3 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.5, there were several intersects between the transducers. Results show that both reading of transducer moving towards the negative displacement.

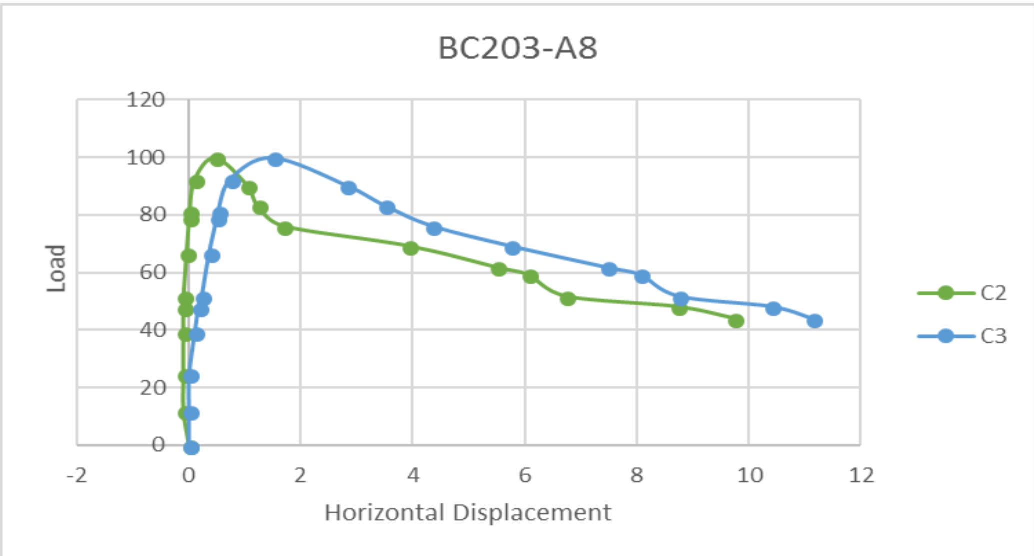


Figure 4.6 Graph of Transducer 2 and 3 for specimen BC203-A8

The maximum axial load for sample BC203-A8 is 99.9 kN and the maximum displacement is 11.127 mm which happen at the transducer CH3 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.6, the graph intersects once in the test. Intersect between CH2 and CH3 at 0.79 mm displacement. Results show that both reading of transducer moving towards the positive displacement.

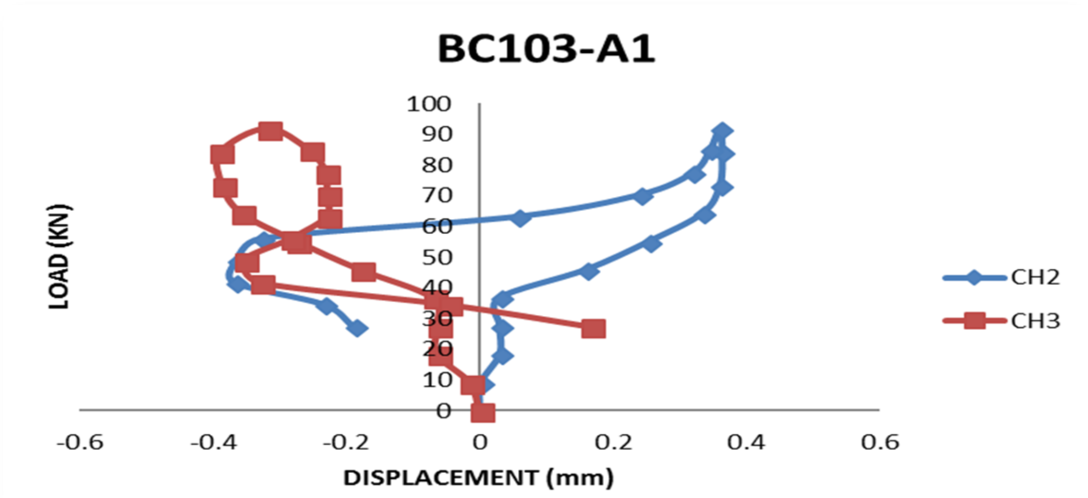


Figure 4.7 Graph of Transducer 2 and 3 for specimen BC103-A1

The maximum axial load for sample BC103-A1 is 90.09 kN and the maximum displacement is 0.363 mm which happen at the transducer CH2 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.7, there were several intersects between the transducers. Results show that both reading of transducer get the positive and negative displacement for the test

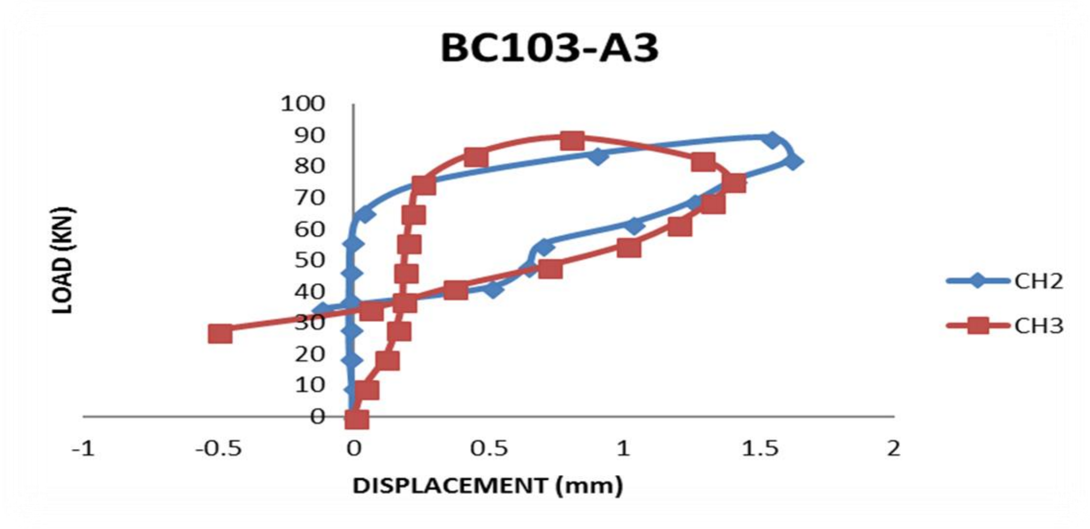


Figure 4.8 Graph of Transducer 2 and 3 for specimen BC103-A3

The maximum axial load for sample BC103-A3 is 89.19 kN and the maximum displacement is 1.614 mm which happen at the transducer CH2 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.8, there were several intersects between the transducers. Results show that both reading of transducer moving toward the positive reading displacement.

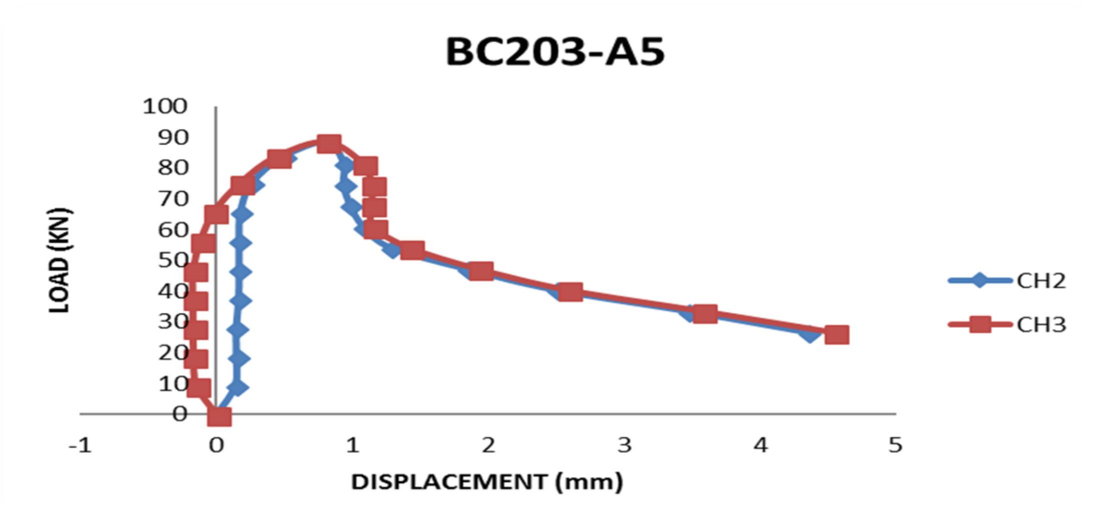


Figure 4.9 Graph for Transducer 2 and 3 for specimen BC103-A5

The maximum axial load for sample BC103-A5 is 88.66 kN and the maximum displacement is 4.541 mm which happen at the transducer CH2 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.9, there were several intersects between the transducers. Results show that transducer CH3 moving toward the positive reading displacement while all the CH2 reading at positive displacement.

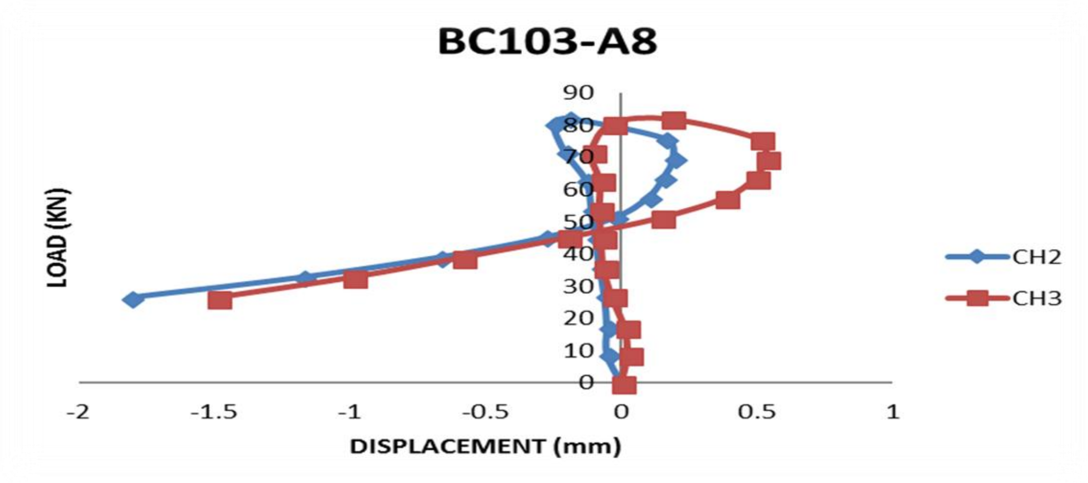


Figure 4.10 Graph for Transducer 2 and 3 for specimen BC103-A8

The maximum axial load for sample BC103-A8 is 82.12 kN and the maximum displacement is 0.529 mm which happen at the transducer CH3 around the same time that maximum axial load is subjected to the specimen. As seen from the figure 4.9, there were several intersects between the transducers. Results show that both transducer get same pattern of graph and also the reading displacement.

4.4 Buckling Behaviour

There are several types of buckling behaviour in this testing. Mostly the buckling behaviours in testing were local buckling and distortional buckling. In this research, I observers 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 size 203. Figure 4.3, specimen was experience distortional buckling at the bottom support. Figure 4.4, Buckling behaviour occurs were warping buckling at the bottom support at the back of specimens and distortional buckling at top support at the back of specimen. Figure 4.5, Specimen were experience warping buckling at the bottom support at front and lateral buckling at the front specimen. Figure 4.6 show the distortional buckling at bottom support at the back specimen and warping buckling at middle front span.

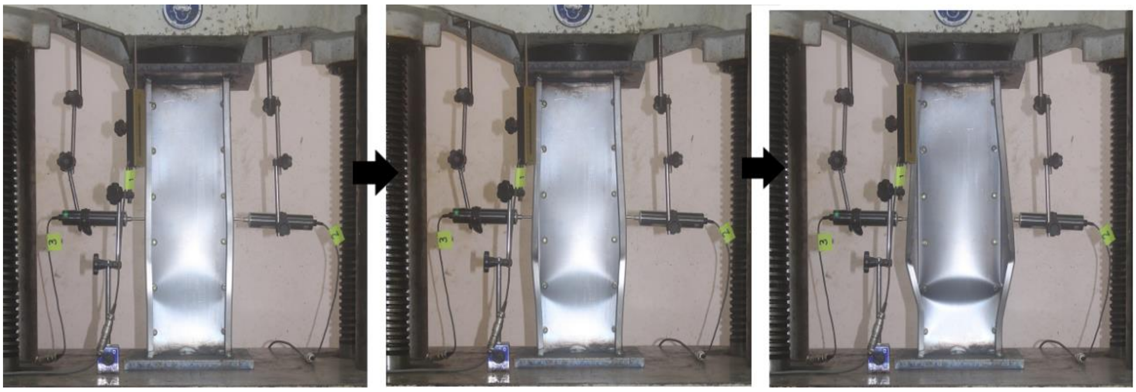


Figure 4.11 Buckling behaviour of specimen BC203-1.2-A1 (Initial, peak, post)

Specimen BC203-1.2-A1 experiences distortional buckling for the initial buckling period and continues experiences warping buckling at the bottom support at front view of the specimen. Lastly for the post peak buckling behaviour, specimen BC203-1.2-A1 comes out with finalize buckling behaviour that are (DBB), (WBF) and (LMB).

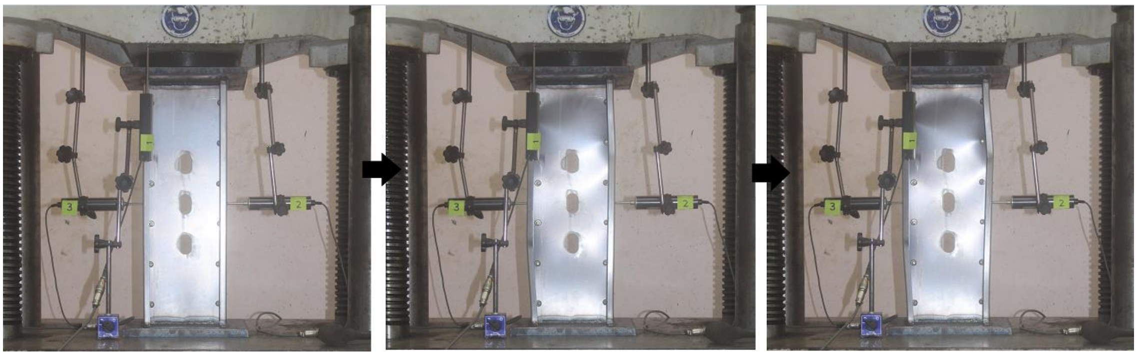


Figure 4.12 Buckling behaviour of specimen BC203-1.2-A3 (Initial, peak, post)

Specimen BC203-1.2-A3 experiences lateral torsional buckling at the front view for the initial buckling period and continues experiences distortional buckling at the top support at front view of the specimen. Lastly for the post peak buckling behaviour, specimen BC203-1.2-A3 comes out with finalize buckling behaviour that are (LTF), (DTF) and (WBF).

Figure 4.13 Buckling behaviour of specimen BC203-1.2-A5 (Initial, peak, post)

Specimen BC203-1.2-A5 experiences lateral torsional buckling at the front view for the initial buckling period and continues experiences distortional buckling at the bottom support at front view of the specimen. Lastly for the post peak buckling behaviour, specimen BC203-1.2-A5 comes out with finalize buckling behaviour that are (LBF), (DBB) and (WBB)

Figure 4.14 Buckling behaviour of specimen BC203-1.2-A8 (Initial, peak, post)

Specimen BC203-1.2-A8 experiences lateral torsional buckling at the front view for the initial buckling period and continues experiences distortional buckling at the bottom support at front view of the specimen. Lastly for the post peak buckling behaviour, specimen BC203-1.2-A8 comes out with finalize buckling behaviour that are (LBF), (DBB) and (WMF).

Figure 4.7 until 4.10 show the buckling behaviour mode for specimen size 103 mm. Figure 4.7, buckling behaviour that occurs in this specimen were distortional buckling at top support for both back and front of specimen. Figure 4.8, specimen was experience distortional buckling at the middle span at front and distortional buckling at the bottom support at the back of specimen. Figure 4.9, front and back of specimen were experience distortional buckling at the bottom support. Figure 4.10, back of specimen experience distortional buckling at top support while front of specimen experience warping buckling at the top support.

Figure 4.15 Buckling behaviour of specimen BC103-1.2-A1 (Initial, peak, post)

Specimen BC103-1.2-A1 experiences lateral torsional buckling at the front view for the initial buckling period and continues experiences distortional buckling at the top support at front view of the specimen. Lastly for the post peak buckling behaviour, specimen BC103-1.2-A1 comes out with finalize buckling behaviour that are (DTB), (DTF) and (LMB).

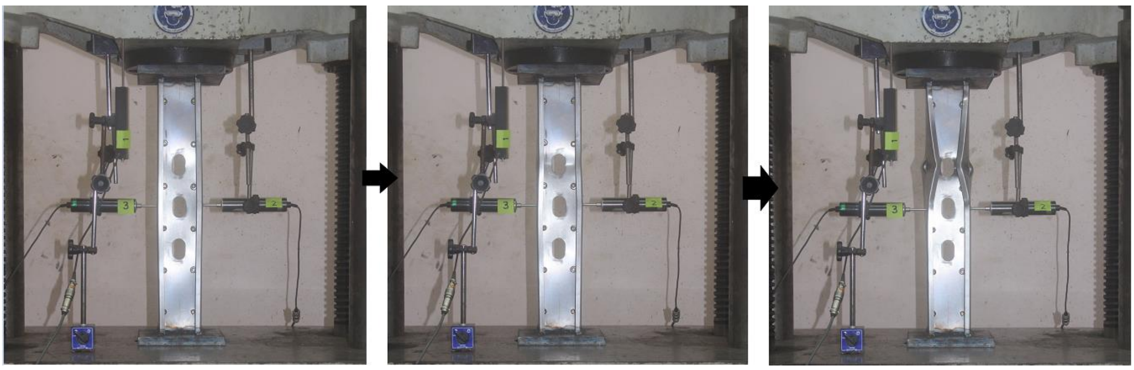


Figure 4.16 Buckling behaviour of specimen BC103-1.2-A3 (Initial, peak, post)

Specimen BC103-1.2-A3 experiences lateral torsional buckling at the back view for the initial buckling period and continues experiences distortional buckling at the middle span at front view of the specimen. Lastly for the post peak buckling behaviour, specimen BC103-1.2-A3 comes out with finalize buckling behaviour that are (LTB), (DMF) and (WMB).

Figure 4.17 Buckling behaviour of specimen BC103-1.2-A5 (Initial, peak, post)

Specimen BC103-1.2-A5 experiences distortional buckling at the back view for the initial buckling period and continues experiences distortional buckling at the bottom support at front view of the specimen. Lastly for the post peak buckling behaviour, specimen BC103-1.2-A5 comes out with finalize buckling behaviour that are (DBB), (DBF) and (WBB).

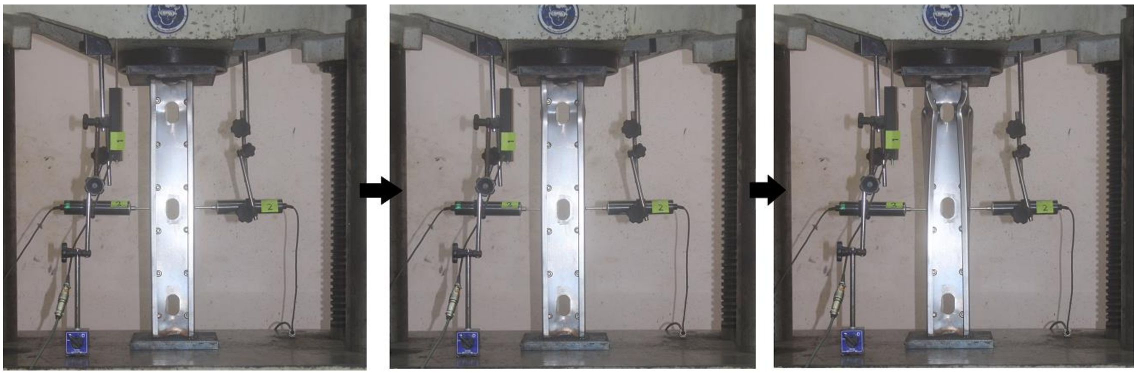


Figure 4.18 Buckling behaviour of specimen BC103-1.2-A8 (Initial, peak, post)

Specimen BC103-1.2-A8 experiences distortional buckling at the front view for the initial buckling period and continues experiences warping buckling at the top support at back view of the specimen. Lastly for the post peak buckling behaviour, specimen BC103-1.2-A8 comes out with finalize buckling behaviour that are (DTF), (DMF) and (WTB).

Figure 4.19 Specimen BC103 after being tested

Table 4.2 Finalize of buckling behaviour for each specimen

SPECIMEN	BUCKLING BEHAVIOUR
BC203-1.2-A1	LMB/DBB/WBF
BC203-1.2-A3	LTF/DTF/WBF
BC203-1.2-A5	DBB/LBF/WBB
BC203-1.2-A8	DBB/WMF/LBF
BC103-1.2-A1	DTF/LTB/WMB
BC103-1.2-A3	DBF/DBB/WBB
BC103-1.2-A5	DBF/DBB/WBB
BC103-1.2-A8	DTF/DMF/WTB

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the result of experiment and observe studies, there are several conclusions obtained in my research. Firstly, the combination of two section of cold-formed steel with produce higher ultimate load. Section size of specimen also contributes to higher ultimate load. The result show that section size of 203mm produces higher ultimate load than 103mm. Second, position of holes also plays an important role in determining the ultimate load of the specimen. From the experimental result, result shows that hole position that nearly to support will decrease the ultimate load. The position of holes also must not be located at centre of specimen, as it is the critical buckling position. Buckling behaviour occurs in stub column were local and distortional buckling.

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. 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 axial post. 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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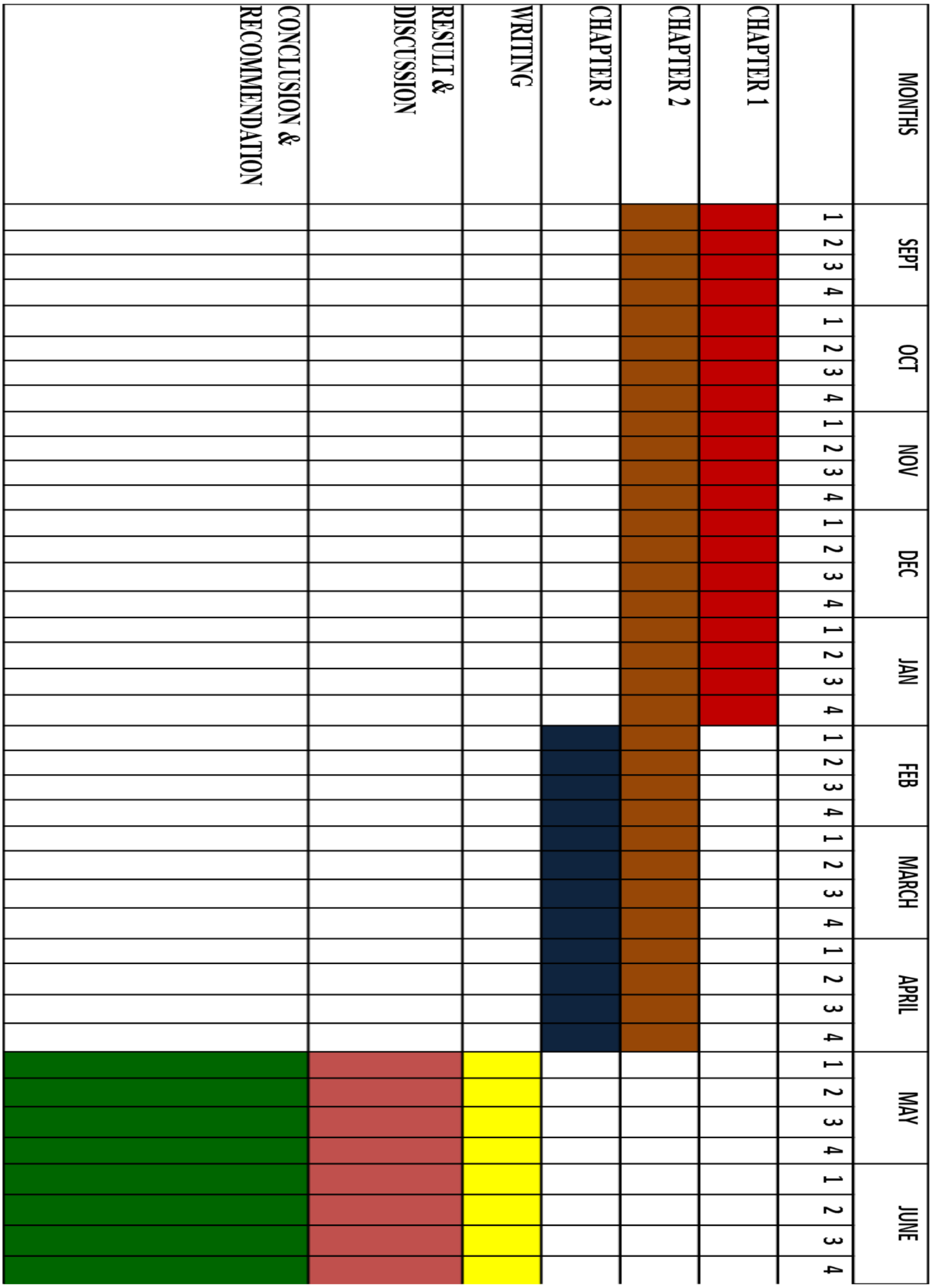
APPENDIX A

Gant Chart



APPENDIX B

Dimension for hole in specimen