AXIAL LOAD OF SIGMA SECTION COLD-FORMED STEEL WITH AN OPENING

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ABSTRAK

Kertas kerja ini membentangkan mengkaji tingkah laku lengkokan seksyen sigma tunggal sejuk terbentuk dengan pembukaan. keluli sejuk terbentuk adalah istilah umum untuk produk yang dibuat oleh bergolek atau menekan keluli menjadi barang separuh siap atau siap pada suhu yang agak rendah. Kaedah yang digunakan untuk eksperimen ini adalah ujian mampatan. Spesimen tiang telah dimampatkan antara dua plat galas dengan hujung rata. nombor 8 spesimen dengan ketinggian 600 mm yang 4 dengan pembukaan dan lain 4 tanpa pembukaan. Bentuk bukaan yang digunakan adalah bulatan dan saiz yang dikekalkan malar. Kekuatan beban muktamad seksyen keluli sejuk terbentuk dan mod kegagalan berbeza bergantung kepada saiz dan pembukaan, di mana kesimpulan yang membuat berdasarkan perbandingan antara saiz spesimen dan bukaan. Transduser digunakan untuk membaca anjakan spesimen semasa ujian di mana graf telah diplot. beban - kajian Graf anjakan beban muktamad spesimen. Spesimen antara pembukaan dan tanpa pembukaan saiz yang sama telah membuat perubahan kepada keputusan tetapi perbezaan tidak menyatakan banyak berbeza kerana hanya satu dibuka pada pertengahan spesimen. lengkokan tempatan dan lengkokan distortional boleh dilihat pada spesimen. lengkokan tempatan hanya berlaku pada spesimen yang tidak mempunyai bukaan manakala bagi spesimen yang mempunyai bukaan, lengkokan distortional berlaku di mana flanged memutarbelitkan zahir atau batin dapat dilihat.

ABSTRACT

This paper presents study the buckling behaviour of cold-formed single sigma section with an opening. Cold-formed steel is the common term for products made by rolling or pressing steel into semi-finished or finished goods at relatively low temperatures. The method used for this experiment are compression test. The column specimens were compressed between two bearing plates with flat ends. 8 number of specimens with height of 600 mm which are 4 with an opening and another 4 without opening. The shape of openings used are circle and the size is kept constant. The ultimate load strength of the cold-formed steel section and failure modes differs depend on the size and an opening, where the conclusions are make on the basis of the comparisons between the size of the specimens and the openings. Transducers used to read the displacement of the specimen during testing where the graph had been plotted. The load – displacement graph study the ultimate load of the specimens. The specimens between opening and without opening of the same size did make a difference to the results but the difference did not varies much due to only one opening at the middle of the specimen. Local buckling and distortional buckling can be seen at the specimen. Local buckling only happen at the specimen that did not has openings while for specimen that have openings, distortional buckling occurred where the flanged distort outward or inward can be seen.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the past years, cold-formed channel studs had been chosen as the option for a cross section for load bearing compression members by the designers and contractors. Cold formed steel sections are widely available with difference sizes and shape. Cold formed steel sections are manufactured with difference process such as folding, press-breaking and rolling. The thickness for steel sheets or strip sold-formed used ranges from 0.4 mm to about 6.4 mm whereas thicker steel plates and bars cold-formed with the thickness 25 mm can be successfully into structural shapes.

The ultimate strength and elastic stiffness of structural members can vary with perforations made especially for fastens such as bolts, screws, to make the member economical. The yield strength and tensile strength of the cold formed steel section increases but ductility decreases specially the corners. Recently, sigma shaped section has been used as the alternative to the channel section. This is because sigma shaped section have an intermediate web return and multi stiffeners. The main functions of these individual structure framing sections are to carry structural strength, load and stiffness for design purposes.

1.2 Problem Statement

Thin-walled cold-formed columns are widely used in engineering industry. Cold-formed structure has thinner and lightweight compared to hot-rolled members. This will lead cold-formed structure to an economic design than hot-rolled. This is due to its weight ratio of the structure and ease of construction. Another advantages of cold-formed structure are high strength and stiffness, uniform quality, ease of prefabrication and mass production, economy in transportation and handling, fast and easy erection and installation and its flexibility in forming different cross-section shapes. However, this flexibility makes the section difficult for a particular situation. Besides, cold-formed steel structures have complex design consideration as it shows in various design standard. However, these design rules of cold-formed were based mainly on experimental investigation. Figure 1.2 shows that house made up from cold-formed steel and Figure 1.3 shows that cold-formed steel framing.

In cold-formed members type families, typical type of cold-formed structure which is C-section has commonly encountered in normal structural steel design and make them easy to find globally whereas sigma section are hardly find in market especially in Malaysia. Meanwhile, channel and sigma sections are considered as the sensitivity of the conventional stability solution compared to C-section. Cold-formed sigma section has an optimum design structure because of the intermediate web return and multi stiffeners. The problem with the optimal design is the selection and size which the design considers as the complex and highly nonlinear constraints. This is due reduction of area of opening installation may affect the strength of the section.

A thin-walled cold-formed member under compression, there will be a possibility of local buckling to occur. Below shows the modes of failure other than local buckling:

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

Figure 1.1 House made up from cold-formed steel

Figure 1.2 Cold-formed steel framing

1.3 Objectives

The main objectives for this research are:

1. To determine the ultimate load of axially loaded cold-formed steel sigma section with an opening
2. To study the effect of the size on the behaviour of the single sigma section

1.4 Scope of Research

The scope for this research covers on the failure behaviour of cold-formed single sigma section subjected to axial compression. The structural members are fixed connected at both ends with the plates. Current design methods available to engineers for predicting the strength of cold-formed steel members with an opening and without opening are prescriptive and limited to specific perforation locations, spacing, and sizes. The section of cold-formed that being tested is a single section and a short cold-formed steels are being used which range from 1.2 mm and 2.0 mm of thick and 103 mm and 203 mm long. The total of eight specimen were used for this test where four does not have opening and the other four will have single opening. The shape of the opening used is elongated circle shape. The position of opening of perforations will be at the middle of the specimen. The plates connected at both ends will be acted as the support for the members. Three transducers are set up accordingly upon each specimen. The first transducer will detect the vertical displacement while second and the third transducer will detect horizontal displacement of the specimen during the test. The result from the test is displayed to two connected laptop. The failure mode of axially loaded columns are tested by study the behaviour of the buckling mode of the cold-formed steel.

Figure 1.3 Examples of the specimen with an opening and without opening

1.5 Significance of Research

The finding of this study will contribute to the benefit of the construction industry. The behaviour of cold-formed steel when the perforations exist can be studied. As we know, by creating an opening at the web, it will reduce the weight thus reduce the cost of the steel sections. However, it will exposed to the lack of strength since the original strength of the steel section has been changed due to the perforation. The data of either the column will show if the opening will influence the strength of the short column can be taken.

According to previous researcher, cold-formed tend to buckle locally at stress levels lower than the yield strength of the material when they are subjected to various loading conditions. However, the failure modes are not commonly encountered in normal structural steel design specifications, and therefore, extensive testing is required to provide a guideline for the design of cold-formed structural members.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will describe in detail some of research works conducted by various researches on fixed-ended Cold-Formed Steel (CFS) channel columns with complex stiffeners subjected to axial load by experimental and theoretical studies. Research works is conducted to verify the mode of failure for single Sigma sections with an opening of two different sizes against the test results that have been carried out by the previous researches. A review of post-buckling behaviour of the single sigma sections with stiffener of CFS together with the assembling of the plates welded at both ends can be used as a guidelines to get an appropriate approach in further studies to determine the mode of failure by the maximum stresses including the influence of the perforated CFS column.

CFS is the process of rolling steel into semi-finished at relatively low temperature. The CFS products are created in various shapes that are formed from steel sheet, strip, plates or flat bars in roll-forming machines or by press brake or bending brake operations. It is commonly formed in different shapes that designed in mono-symmetric open section such as C-section, U-section, Z-section and etc. which carried a variety functions itself.

In Malaysia, the cold-formed usage in building construction did not widely applicable until recently where the use of cold-formed steel in replacing hot-formed steel had been widely accepted. But, the usage of cold-formed still not widely used in construction due to the limitation of the specimen. Most local product in market has their own limitation due to the absent of opening. When the opening is being made, the limitation strength of cold-formed will likely will be changed. So, this study will show either the existing of opening will affect the strength of cold-formed steel.

2.2 Types of Cold-Formed Steel

In steel construction, there are two types of steel structure which are Hot-Rolled Steel, HRS and CFS (Laboube et al., 2010). HRS shapes are formed at higher temperature while CFS commonly used in construction industry which are individual structure framing members and panels and decks. In the past decades, the designers and the contractors had chosen the cold-formed channel studs as the only option when selecting a cross section for load bearing compression members in the wall bearing system (El Aghoury et al., 2017).

Different shape of sections such as C-section, E-section, I-section and tubular section are classified as individual structure framing members or sections which typically used in lightweight structure such as joists and purlins due to thin and light behaviour. However, second type of CFS which is panels and decks generally used for floor deck, wall panel, roof decks and others. Typical CFS members such as studs, track, purlins, and grits are mainly used for carrying loads while panels and decks constitute a useful surface such as floor, roof and walls. Figure 2.1 shows common shapes for cold-formed steel shapes.

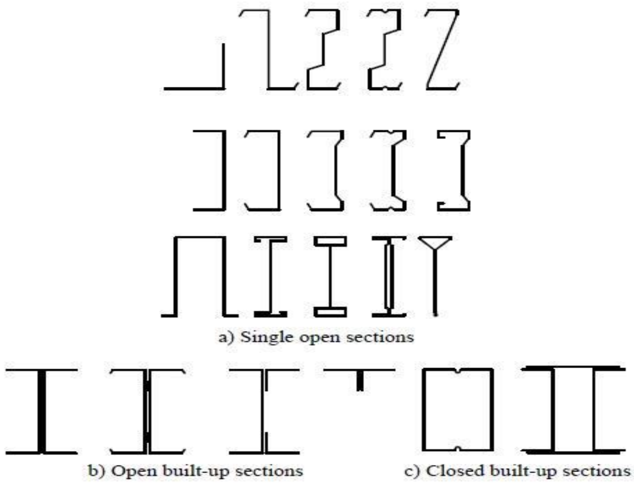


Figure 2.1 Common shapes for cold-formed steel

2.3 Applications of Cold-Formed Steel Columns

Recently, the use of thin-walled steel structure members has increased in building construction. The popularity of CFS thin-walled structure arise due to its lightweight design, high strength and stiffness, uniform quality, ease of prefabrication and mass production, economy in transportation and handling, fast and easy erection and installation and also economy in transportation and handling. (Gholipour, 2011).

CFS thin-walled structure had been developed in variety of shapes that can be proposed in variety of applications with its own functions (refer Figure 2.2 cold-formed steel use as roof system). Although the thin-walled members are apparently simple structural shapes used in various applications, their design is quite complicated and has yet to be analyzed thoroughly. (Shanmugam & Dhanalakshmi, 2001). This is due to thin-walled nature instability phenomena and lack of symmetry (singly-symmetric member), this sections need to be examined in term of failure, local, torsional and global buckling modes.

CFS is produce with a thin sheet behaviour which able to create a different opening holes at the web. Because of that, CFS is designed not only to cater the loads, but also help to carry an electrics conduits or piping systems (refer Figure 2.3). Holes can be found in most CFS structural components such as in low and midrise construction, evenly-spaced holes are placed in the webs of CFS columns and beams, allowing electrical, plumbing, and heating services to pass through walls and ceilings (Kim et al., 2010).

Figure 2.2 Roof system using cold-formed

Figure 2.3 CFS with opening to accommodate piping system

2.4 Advantages of Cold-Formed Steel

(Anbarasu et. al., 2010) indicate that, following advantage can be realized for cold-formed light gauge steel structural members in building construction:

a) Cold rolling can be employed to produce almost any desired shape to any desired length.
b) Pre-galvanized or pre-coated metals can be formed, so that high resistance to corrosion, besides an attractive surface finish, can be achieved.
c) All conventional jointing methods, for example riveting, bolting, welding and adhesive can be employed.
d) High strength to weight ratio is achieved in cold rolled products.
e) They are usually light making it easy to transport and erect
f) As compared with thicker hot rolled shapes, more economical design can be achieved for relatively light loads and/or short spans
g) Unusual sectional configuration can be economically produced by cold-forming operation, and consequently favourable strength to weight ratios can be obtained.
h) Load carrying panels and decks can provide useful surfaces for floor, roof, and wall constructions, and in other cases they can provide enclosed cells for electrical and other conduits.

2.5 Sigma Shaped Section

Mono-symmetric open C-Sections and Z-sections are commonly used especially for light steel construction industry such as floor joist. But, they are created by having an unsymmetrical centroid and shear centre of the cross-section. However, this kind of sections could fail by lateral torsional buckling due to the location of its shear centre and centroid of the cross-section. By replacing the conventional sections to sigma section as an alternative to the channel section. This is because the sigma section shaped section having an intermediate web return and multi stiffeners. (El Aghoury et al., 2017). Figure 2.4 (a) shows section without web stiffener and (b) shows section with web stiffener. Meanwhile, Figure 2.5 (a) shows lipped channel section without web stiffener and (b) lipped channel section with web stiffener.

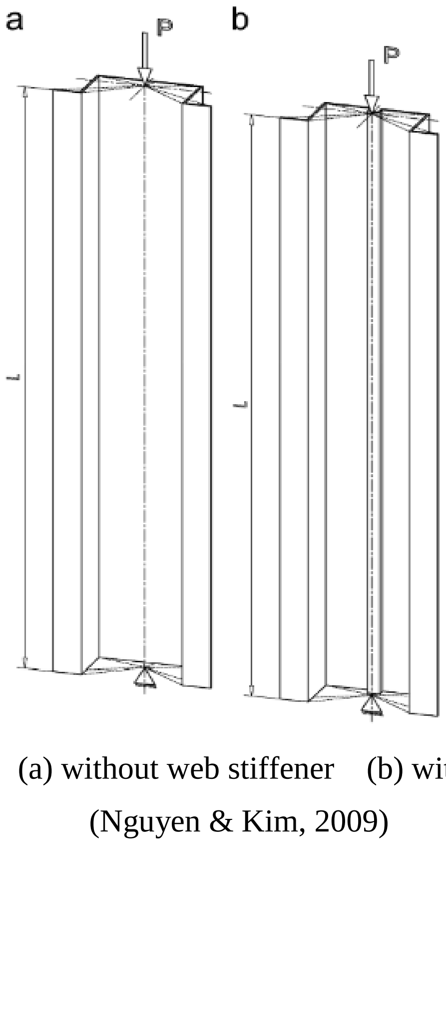


Figure 2.4 (a) without web stiffener (b) with web stiffener
(Nguyen & Kim, 2009)

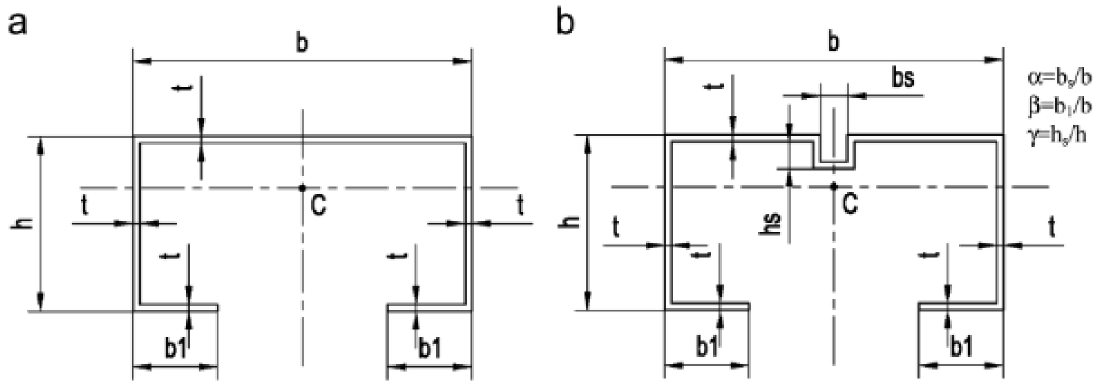
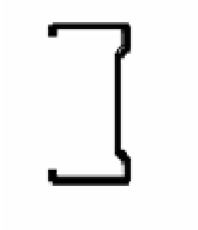
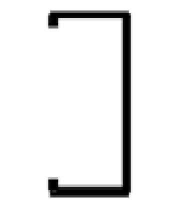


Figure 2.5 Lipped channel section (a) without web stiffener (b) with web stiffener (Nguyen & Kim, 2009)

2.5.1 Comparison between Sigma Section and C-section

Table 2.1 Differences between sigma section and C-section

Sigma Section		C - Section
	Types of sections	
Intermediate web return with complex web stiffener	Web stiffener	Simple web stiffener
Lipped channel section	Lip	Lipped channel section
Have residual stress pattern	Residual stress	Do not have residual stress pattern

2.5.2 Advantages and Disadvantages of Sigma Section

Advantages of Sigma sections:

i) Recently used as an alternative to the channel section due to the shape having an intermediate web return and multi stiffener

ii) Follow the design optimization requirements which to minimize the weight of the structure to resist a given load.

iii) Sigma sections as an illustrative example to explain the sensitivity of the conventional stability solution, modal decomposition, and modal identification solutions.

Disadvantages of Sigma sections:

i) Slightly more complicated than the other sections due to the change of the web cross section profile

ii) Requires a lot of calculations to determine the capacity of the section

iii) Hardly find and limited availability in Malaysian’s market

2.6 Experiment on Cold-Formed Steel (CFS) Lipped Sigma Column

The studies on structural behaviour of CFS is the most popular field due to its interesting failure modes for approximating the local, distortional and global buckling load. Local buckling involves a change in cross-sectional shape and includes only rotation, not translation at the fold lines (Gilbert et al., 2012). Distortional buckling which is known as local torsional buckling or stiffener buckling. It usually involves rotation of the flange in members with the edge stiffed elements. Global buckling is a combination of bending and twisting response of a member in compression. The strength and efficiency of CFS profile depend on the cross-sectional shape which controls the three functional buckling modes: load, distortional and global (Gilbert et al., 2012).

2.7 Buckling Mode of Cold-Formed Steel in Compression

Axial load is very common and very important type of loading and the requirement to deal with this type of loading in cold formed steel members vary according to type of loading, tension or compression and geometry and use of the member. Due to the small thickness of the walls in cold formed steel section and the variety of different cross sectional shapes that can be produced, types of behaviour not commonly found in hot rolled member For axially loaded cold formed steel, compression member should be designed for the following limit states (refer Figure 2.6):

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

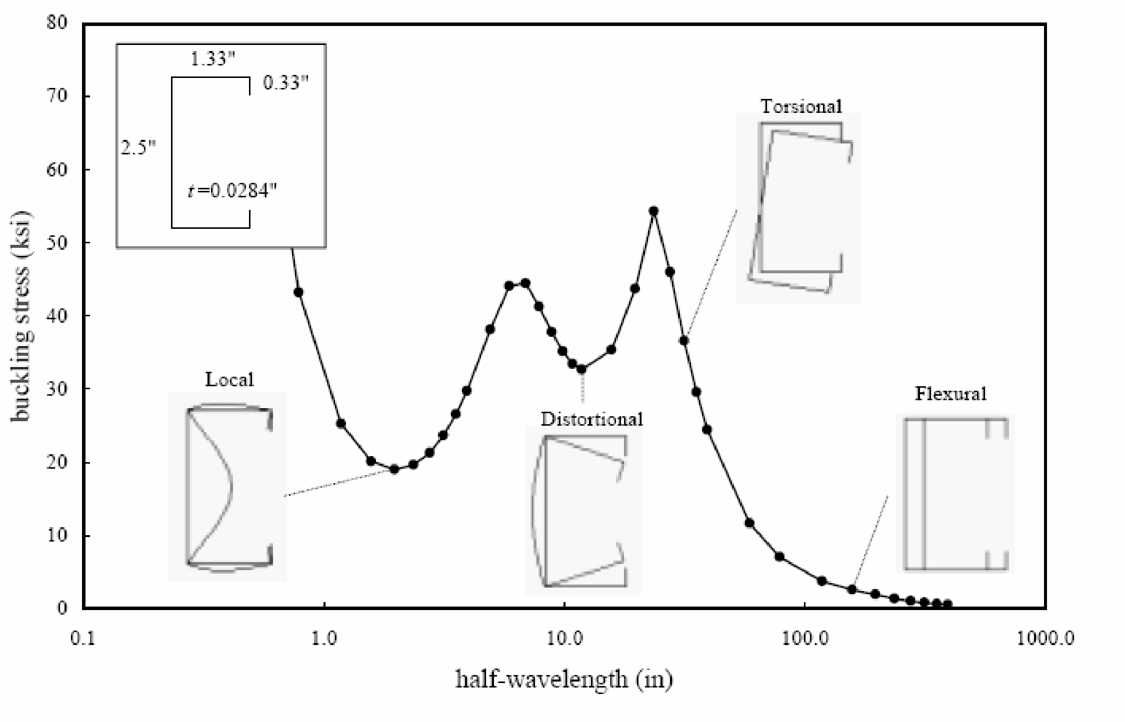


Figure 2.6 Mode of failure for cold formed steel

2.7.1 Effect of Perforated Elements and Members

Likewise, CFS structural member such as Sigma sections are commonly provided with perforations to accommodate plumbing, electrical conduit and piping system in the buildings. These perforations are typically pre-punched perforations located at the web of the sections and help to alter the elastic stiffness and ultimate strength of member. The presence of such holes may result in a reduction of the strength of individual component elements and of the overall strength of the member depending on the size, shape, and arrangement of holes, the geometric configuration of the cross section, and the mechanical properties of the material used. (Yu & Laboube, 2010.). For perforated cold-formed steel structural members the load-carrying capacity of the member is usually governed by the buckling behaviour and the post buckling strength of the component elements. In this experiment, elongated circle shape of opening is used. Figure 2.7 shows elongated shape opening.

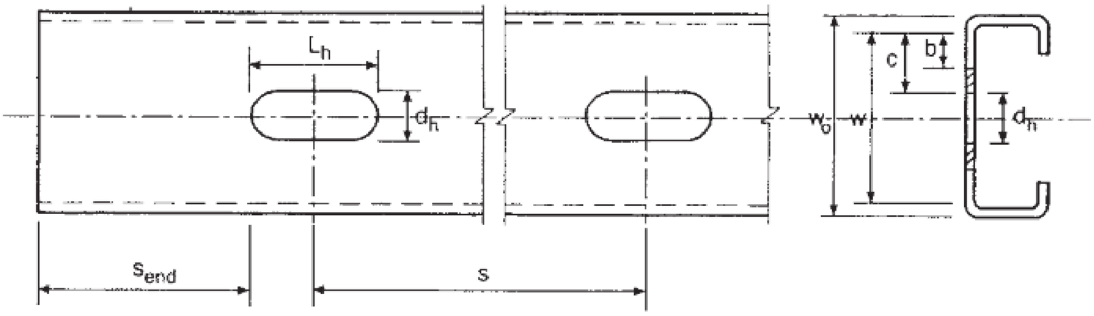


Figure 2.7 Elongated circle shape opening

2.8 Previous Research Paper

2.8.1 Compression Tests of High Strength Steel Channel Columns with Interaction between Local and Distortional Buckling

Test done by Demao Yang and G.J Hancock describe a series of compression test performed on lipped channel section columns fabricated from cold reduced high strength steel of thickness 0.42 mm with nominal yield stress of 550 MPa. The test results presented in the paper are the third stage of an Australia Research Council research project entitled 'Compression Stability of High Strength Steel Sections with Low Strain-Hardening'. A range of length of lipped channels with intermediate stiffeners in the web and the flanges were tested between fixed ends to determine strength of the section. For the lipped channel sections, failure resulted from local and distortional buckling with interaction between these modes. The tests indicated that distortional buckling and the interaction of local and distortional buckling may have a significant effect on the strength of the sections formed from such thin high strength steel. The paper presents the results obtained experimentally and theoretically using the effective width method and the direct strength method, neither of which account for interaction of local and distortional buckling.

A series of channel section column tests with intermediate stiffeners in the web and flanges and constructed from high strength G550 steel has been successfully performed. The tests were carried out to investigate the effect of local buckling and distortional buckling as well as the interaction between them.

For the stub columns, local buckling is the dominant failure mode. However for long specimen, interaction between local and distortional buckling led to failure.

The new (AISI 2001) gives an accurate prediction of the stub column strength using the new rules for an edge stiffened element with an intermediate stiffener.

1. The adverse interaction between local and distortional buckling reduced significantly the member ultimate strength for the intermediate length specimen fabricated from thin sheet steel.
2. The effect of the buckling shape on the member capacity clearly exists. The outward buckling shape mode has much higher member strength than the inward buckling shape mode.
3. AISI 2001 gives an unconservative prediction since it ignores distortional buckling.
4. The AS/NZS 4600 gives an unconservative prediction at intermediate length because it ignores interaction between local and distortional buckling.
5. Two simple design methods are proposed for intermediate length lipped channel section fabricated from G550 thin sheet steel to account for the adverse interaction of local and distortional modes. Those two method gives a lower bound of the test results.

2.8.2 Channel Column Undergoing Local, Distortional and Overall Buckling

Test done by Ben Young and Jintang Yang presents design and numerical investigations into the strength and behaviour of cold formed lipped channel columns using finite element analysis. A nonlinear finite element model is developed and verified against fixed ended channel column tests. Geometric and material nonlinearity were included in the finite element model. It is demonstrates that the finite element model was used for an extensive parametric study of cross section geometries. The column strength is obtained from the finite element analysis are compared with the design column strength calculated using American, Australia/New Zealand and Europe specification of cold formed steel structure. The fixed ended columns are designed as concentrically loaded compression members. Design column curves obtained from the three specifications are plotted. It is shown that the design column strength calculated from the three specifications is generally conservative for lipped channels having a maximum plate thickness of 6 mm. The reliability of the column strength is evaluated using reliability analysis.

Design and numerical investigation of fixed ended cold formed lipped channels column using finite element analysis have been presented. A finite element model including geometric and material nonlinearities has been developed and verified against experiment results. The finite element analysis predictions were generally in good agreement with the experimental ultimate loads and failure modes of the lipped channel columns. The channel columns undergoing local, distortional, flexural and flexural-torsional buckling. An extensive parametric study of cross section geometries has been performed using the developed finite element model. The plate thickness of the channel section ranges from 1.5 to 6.0 mm with a minimum flange to width thickness ratio of 13.3, which is considered to be stocky. The column length ranges from 500 to 3000 mm. A comparison of the column strengths obtained from the finite element analysis and the design column strength calculated using American, Australian/New Zealand and Europe specification for cold formed steel structures has been presented. It has been shown that the design column strengths calculate from the three specification were generally conservative for a fixed ended lipped channel columns. The reliability indices are generally higher than the target index of 2.5 as specified in the American specification.

2.8.3 Resistant of C-profile Cold-Formed Compression Members: Test and Standard

Test done by Gakab and L.Dunai presents a experimental and standard based analyses on C-profiled cold formed compression members under supporting conditions and arrangement not fully covered by standard calculation method are presented. The specimens used in the two cases are made of single asymmetrical C-section. The third type of specimen consists of two C-section sticking into each other connected at their flanges at certain distances using self-drilling screws. The specimens are subjected to centric or eccentric compression. The test arrangements, the observed behavior modes and the results of the tests are presented for all types of specimens. The test results are compared to standard-base design resistances. A method for the design of the double C-profile arrangement is proposed. On the basis of the obtained results and the supplementary parametric studies using the different design approaches it is concluded that in the practical design for double C members with length over 2500 mm, using C-profiles with height to thickness ratio smaller than or equal to 150, both the compressed C- and the box section based design approach can be applied. For shorter columns or more slender cross-section the simple C-based resistance can be used.

The above proposal can be extended or refined by the application of a verified advanced numerical model capable of simulating the laboratory tests.

In the case of columns with small slenderness (stub columns or columns with lateral supports) the design method can be improved by considering the web crushing at the support.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the procedures experimental and theoretical studies are carried out to investigate the behaviour and strength of cold-formed single lipped sigma columns with an opening and without opening. This experiment is subjected to a series of short columns under the compression test. The process of setting up the specimen during testing started by putting up the transducers which containing three of them labelled transducer one, transducer two and transducer three. The three transducers are set up for the purpose to determine vertical and horizontal displacement for each of the specimen during testing. The specimen is then placed on the machine and the transducers are put at the specific position. Only one specimen at a time can be set. The Universal Testing Machine (UTM) is used for this experiment. Then, the loading rate of machine need to be set-up. UTM will then compressed the specimen until the machine are stop by the user according to displacement value study.

As described earlier, total of eight specimens of cold-formed single sigma section are used. All of the specimens are connected fix at both ends onto the plate. Eight specimens are used four specimens with an opening and another four specimens without opening. Those single perforated specimens, the opening will at the centre of the short column. The thickness and length of the specimens used are consistent to get an accurate results and to do comparisons. All of the specimens are fix-welded to the plate. The centroid of the specimens are calculated and to be marked. Meanwhile, the plates are also marked at the centre. This is due to the fact so that the specimen is properly welded at the plates.

The result of the performance and behaviour between cold-formed steel lipped single Sigma section with an opening and without opening with the axial load applied to the cold-formed steel column were obtained by using the experimental study at the laboratory. The experimental investigation was aimed at the study of the ultimate strength and the failure modes and the influence of an opening on the of lipped single Sigma section columns.

3.2 Experimental Investigation

Thin-walled cold-formed lipped channel sections subjected to compression loading were considered in the investigation. Refer Figure 3.1 below.

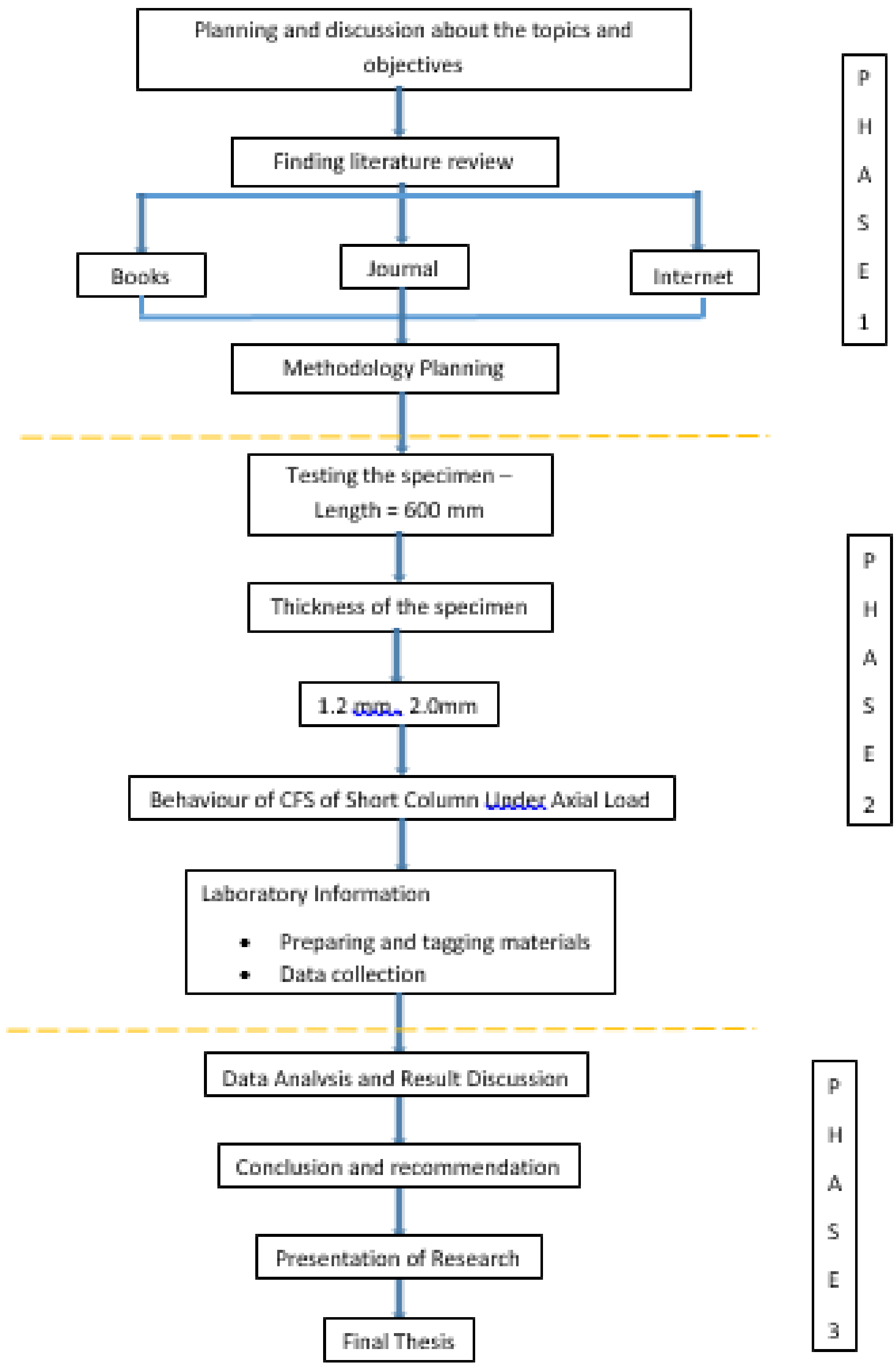


Figure 3.1 The overview of the flow process

Figure 3.2 Process of fabrication of cold-formed steel

3.3 Material Selection

Cold-formed Sigma 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.

3.4 Section Parameter

The parameters of the specimen of Sigma section cold-formed used in the experiment and their magnitudes are shown in Table 3.1, Figure 3.3 and Figure 3.4.

Table 3.1 Section Parameter of specimens

Depth	600 mm
Size	103 mm, 203 mm
Thickness	1.2 mm, 2.0 mm

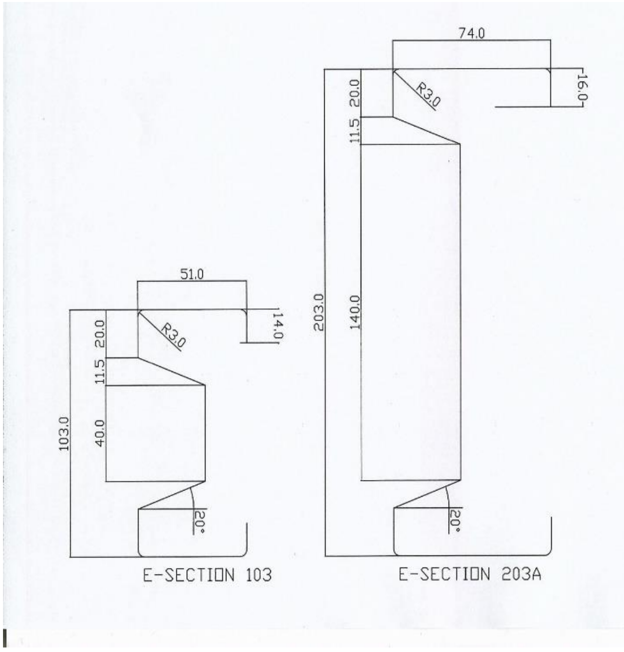


Figure 3.3 (a) Sections parameter drew in AutoCAD

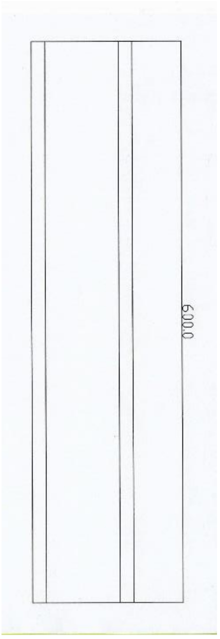


Figure 3.4 (b) Sections parameter drew in AutoCAD

3.5 Set-up and Loading Operation

The machine that will be used to conduct this experiment is called Universal Testing Machine (UTM) and three transducers. The Universal Testing Machine will read the loading rate that will be applied to each 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 specimens according to the previous researcher. To accommodate the data for the results, UTM will be connected to a computer which is assisted by a person during the testing. The data taken will be in the form stress-strain graph. The transducers are being used to read the reading of the vertical and horizontal displacement where the buckling mode of specimens happen. In this experiment, three transducers will be used to take the accurate data. The support being used for the specimen is flat end as shown in Figure 3.5.

Figure 3.5 Bearing plate that welded at the top and bottom of the specimen

3.6 Schematic Digram

The diagram of the specimens and machines used are describe by drawing. All dimensions are in millimetre (mm). Opening at the middle of the specimen as illustrated in Figure 3.6 in order to investigate the effect of opening on the ultimate strength of the single lipped Sigma section and the position of transducers also constant as in Figure 3.7. Sigma channel sections without openings were also included in the experiment. The column lengths, cross- section dimensions, and perforation areas were kept constant, having a thickness of 1.2 mm, 2.0 mm and specimen length of 600 mm. Detail dimension of specimen is shown in Figure 3.8 and Figure 3.9 shows the setup of the transducers and the position of the specimen during testing. Figure 3.10 show the setup of apparatus in laboratory.

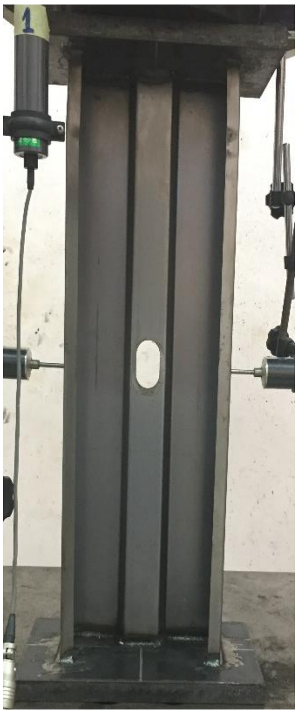


Figure 3.6 Position of an opening is constant at the middle of the specimen

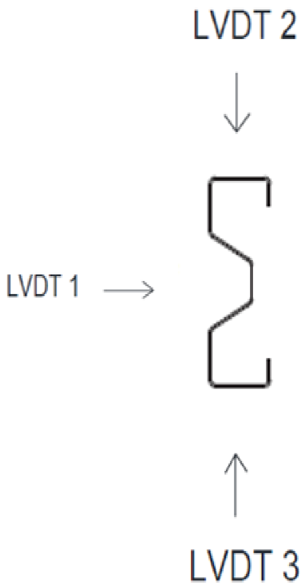


Figure 3.7 Schematic drawing of transducers position

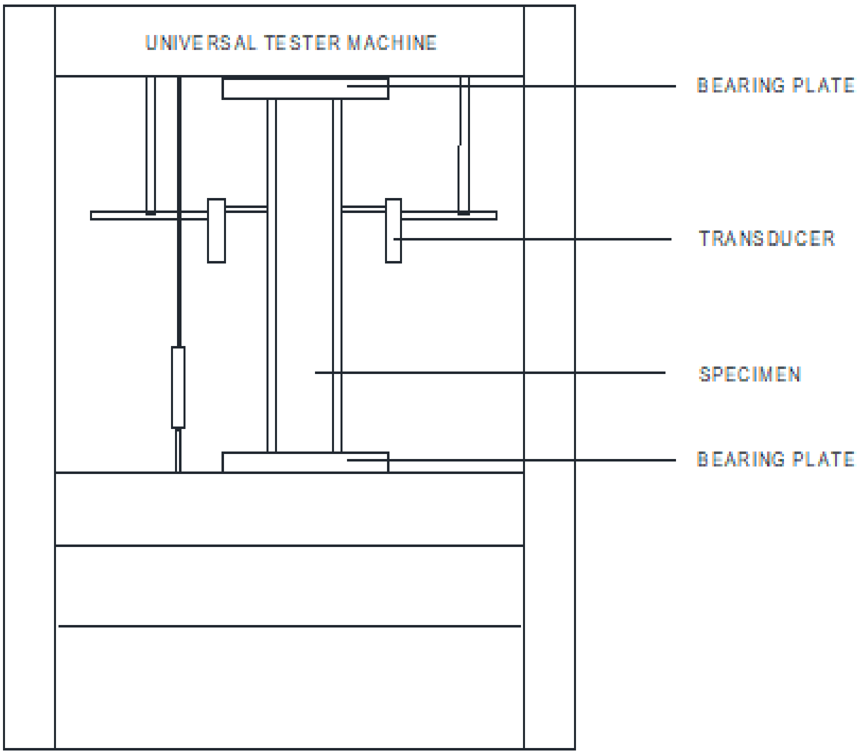


Figure 3.8 Setup of the transducers and the position of the specimen during testing

Figure 3.9 Apparatus set-up in the laboratory

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results obtained from the experiment of the compression test are presented in this chapter. Vertical and horizontal displacement result of the specimen had been taken during testing. Horizontal displacement, two transducers are placed at the middle of the specimen which is at the both side of the flange of column, while for vertical displacement, one transducer had been placed at the bottom plate of the specimen. Experimental investigation for this study was aimed at the influence of the thickness of the specimen and an opening on the ultimate strength and the failure modes of single lipped Sigma section short columns. The size and the shape of opening was kept constant and also the opening position was at the middle of the steel member. The maximum displacement taken was kept constant that is 6 mm. The results of this experiment are presented in graphical method to give better visualize and understanding. The discussions were presented within the scope has been mentioned in the previous chapter.

4.2 Ultimate Load

The vertical displacement transducer read the ultimate value of compression single lipped Sigma section column.

Table 4.1 Measured Specimen Dimension and Experiment Results – Thickness 1.2 mm

Specimen	Experimental ultimate load, P (kN)
SE103-1.2-A1	48.34
SE103-1.2-A2	50.59
SE203-1.2-A1	70.47
SE203-1.2-A2	63.71

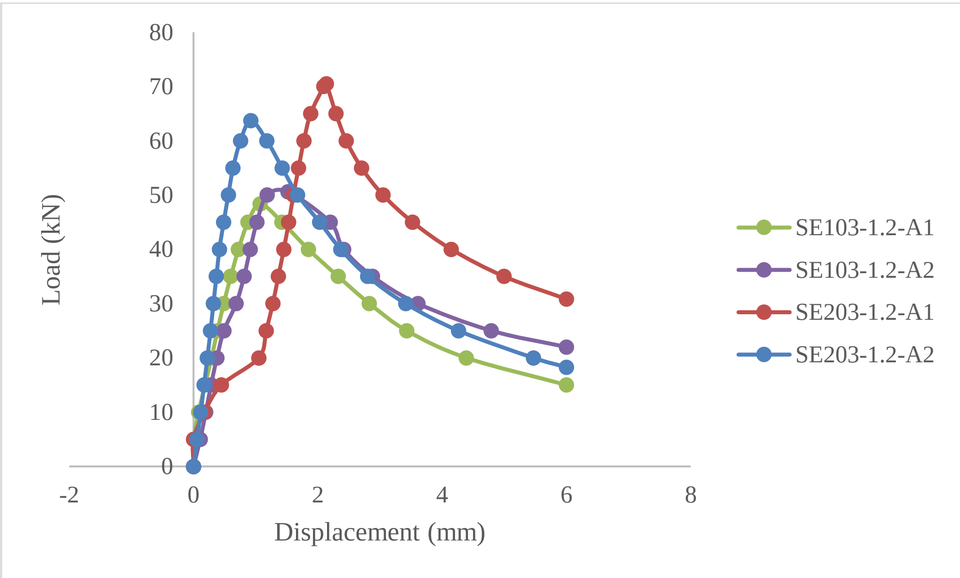


Figure 4.1 Load versus Displacement graph for thickness 1.2 mm

The ultimate strength values of compression members for thickness 1.2 mm are illustrated in buckling behaviour by using linear vertical displacement transducer (LVDT) device. The highest ultimate load is specimen SE203-1.2-A1 with 74.47 kN and the lowest ultimate load is specimen SE103-1.2-A1 with 48.34 kN.

Table 4.2 Measured Specimen Dimension and Experiment Results – Thickness 2.0 mm

Specimen	Experimental ultimate load, P (kN)
SE103-2.0-A1	130.89
SE103-2.0-A2	104.02
SE203-2.0-A1	151.19
SE203-2.0-A2	150

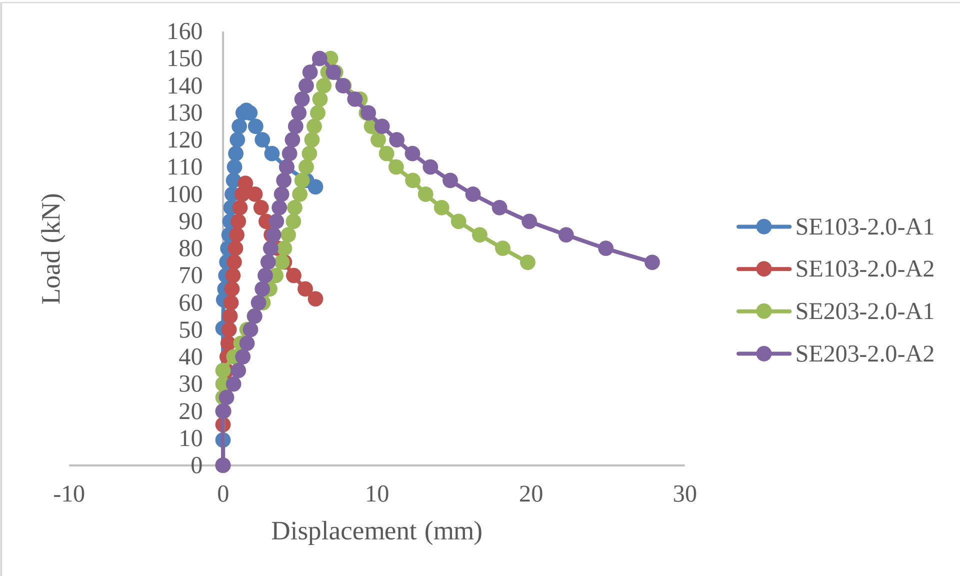


Figure 4.2 Load versus Displacement graph for thickness 2.0 mm

Next, the ultimate strength values of compression members for thickness of 2.0 mm are illustrated in buckling behaviour by using linear vertical displacement transducer (LVDT) device are obtained. The highest ultimate load is specimen SE203-2.0-A1 with 151.19 kN and the lowest ultimate load is specimen SE103-2.0-A2 with 104.02 kN.

For summary, the specimen with an opening play an important part in results produce. The reduction in area of steel columns will decreasing the ultimate load of that specimen. However, the ultimate load for the specimen without opening and without an opening did not varies much but there were slightly difference in the reading of ultimate load. The type of support used that is flat end affected the result due to the non-existing restraint at any axis during testing.

4.3 Mode of Failure

The behaviour of cold-formed members mainly depend on the failure modes. Generally, in the cold-formed steel members, there are three types of failure shapes: local, distortional and global buckling. Local buckling is defined as the buckling shape which includes plate-like deformations alone without translation of the intersecting lines of the adjacent plate elements. However, global buckling is a mode where the member bends without any deformations occurred in its cross-sectional shape. In the distortional mode the transverse deformations include both plate-like deformations and translation of one or more intersection lines of the adjacent plate elements.

The experiment were using flat end supported at the both end of the specimen. This is where all the specimen were compressed between two bearing plate by using the Universal Testing Machine. The failure mode of each specimen and all the changes in shape of steel columns were studied.

Figure 4.3 Specimen SE103-1.2-A1 before (left) and after (right)

For specimen SE103-1.2-A1, the Sigma section column without opening, it only experienced local buckling behaviour. Local buckling can be seen where there is a wave appear at the web of the specimen as seen in Figure 4.3 (right). The wavelength appear at the beginning of the stage of compression at the top part flange of the column and the wavelength continue to appear at the top part of web until the column failed.

Figure 4.4 Specimen SE103-1.2-A2 before (left) and after (right)

As for specimen SE103-1.2-A2, initial buckling happened where the wavelength can be seen at the top part of both flange and web. Local buckling is continue until the end of the test until the column failed. Distortional at the middle part of the column can be seen as shown in Figure 4.4 (right).

Figure 4.5 Specimen SE203-1.2-A1 before (left) and after (right)

Next, specimen from the same thickness but different size which is SE203-1.2-A1, it can be seen that there is local buckling happened at the top of the flange and at the middle of the web of the column. The early stage of buckling happen at the top part of the flange and at the middle of web during maximum compression, the process continue until the end of the test. The failure can be seen as shown in Figure 4.5 (right).

Figure 4.6 Specimen SE203-1.2-A2 before (left) and after (right)

For specimen SE203-1.2-A2 (right), at the early stage of testing, initial buckling at the middle of the web where the column has dent inwards. During peak compression, it buckled at top part of flange and continue until the column failed at the end of the test as shown in the Figure 4.6 (right).

Figure 4.7 Specimen SE103-2.0-A1 (left) and SE103-2.0-A2 (right) **BEFORE** testing

Figure 4.8 Specimen SE103-2.0-A1 (left) and SE103-2.0-A2 (right) **AFTER** testing

Specimen SE103-2.0-A1, initial buckling which is warping happened at the bottom right side of the column. The deformation of warping continued until maximum compression at the middle of the column and went on until the end of the test as shown in Figure 4.8 (left).

As shown in Figure 4.8 (right) for specimen SE103-2.0-A2, there is web buckling at the middle during initial process of the compression test. The failure continues until it can be seen that there is warping at the middle on the left side of the column and also distortion at the middle on the right side of the column.

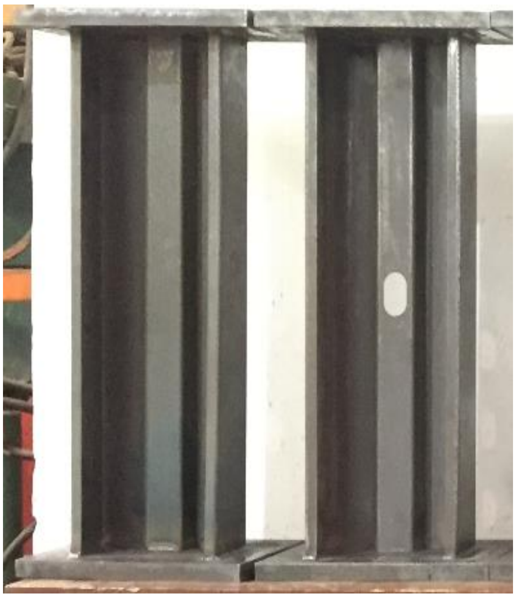


Figure 4.9 Specimen SE203-2.0-A1 (left) and SE203-2.0-A2 (right) **BEFORE** testing

Figure 4.10 Specimen SE203-2.0-A1 (left) and SE203-2.0-A2 (right) **AFTER** testing

Other than that, for specimen SE203-2.0-A1, local buckling can be seen where there is a wave appear at the web of the specimen as seen in Figure 4.10 (left). The wavelength appear at the beginning of the stage of compression where there is warping at the top on right side of the flange. Buckling also happened at the top of the web and distortion at the top on the left side.

From Figure 4.10 (left), specimen SE203-2.0-A2 buckled at the top and middle of the column. It can be seen that there is warping at the top. There is also distortion at the middle of the member and web buckling of the column.

For the summary, specimen SE103-1.2-A1 and SE103-1.2-A2 went through a failure at the top of the specimen while the other specimens went through a failure at the bottom and middle of the column. The columns for this experiment experienced local and distortional buckling. Local buckling behaviour can be seen at specimen SE103-1.2-A1, SE103-2.0-A1, SE203-1.2-A1 and SE203-1.2-A2 where there is a wave appear at the web and flange of the specimen. The wave appeared due to the load transferred to the column. Distortional buckling behaviour happened at specimen SE103-1.2-A2, SE203-2.0-A1, SE203-2.0-A2 and SE103-2.0-A2. This failure mode can be seen where the flange and web buckle at the same time.

CHAPTER 5

CONCLUSION

5.1 Introduction

From the overall project analysis and results that already being carried out, several conclusions that can be made based on the results obtained:

a) The ultimate load for all specimens had been determined by using Universal Testing Machine. The column without opening is happened to be theoretically should has higher ultimate load compared to specimen with an opening.
b) The size of the specimens have an effect towards the ultimate load of axially loaded cold-formed steel column in which bigger size of specimens possessed greater value of ultimate load.
c) The buckling deformation response for the specimens with an opening and without opening is similar through the data test study, implying that the member with opening has smaller influence on compression.
d) The failure mode of the members with an opening and without opening are varied. The deformation of peak load for the short column with an opening was less sensitive because of the presence of the opening which reduces the area of the member.

5.2 Recommendations

Further studies on the research need to be conducted in the near future in order to come out with better and good results. Several recommendations are proposed for the future studies to achieve the objectives of this research as follow:

a) Would be better to use slender column for future investigation
b) Use different shape of openings such as rectangular, oval, or rectangle.
c) Should be use different type of material such as high yield steel or mild steel.
d) The ultimate capacities of single sigma section columns using design codes is compared with finite element model results in experimental study.

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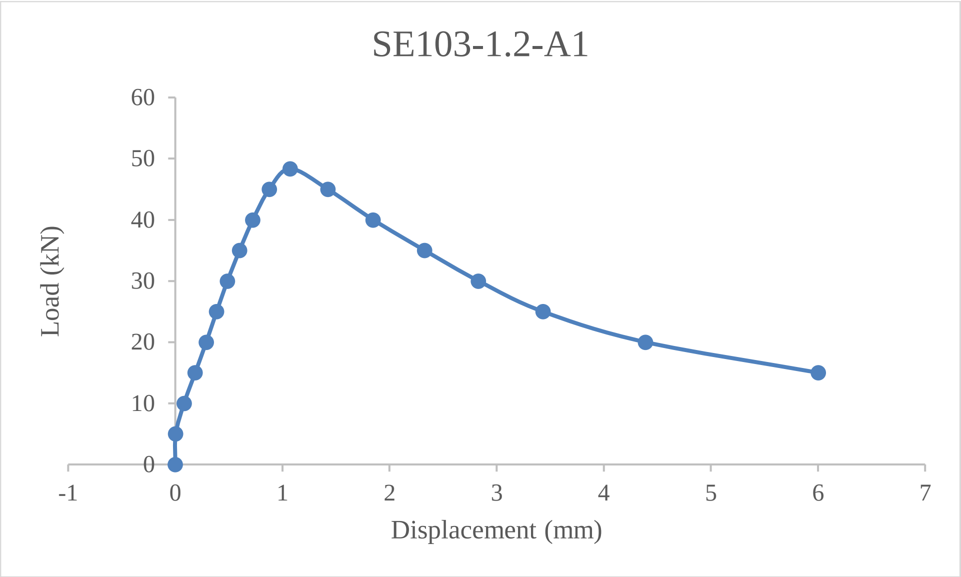
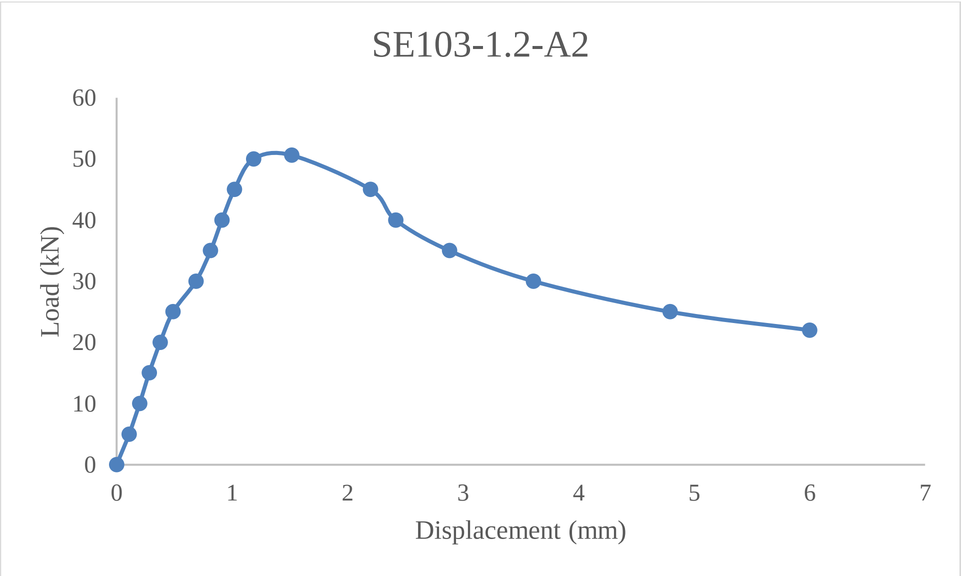
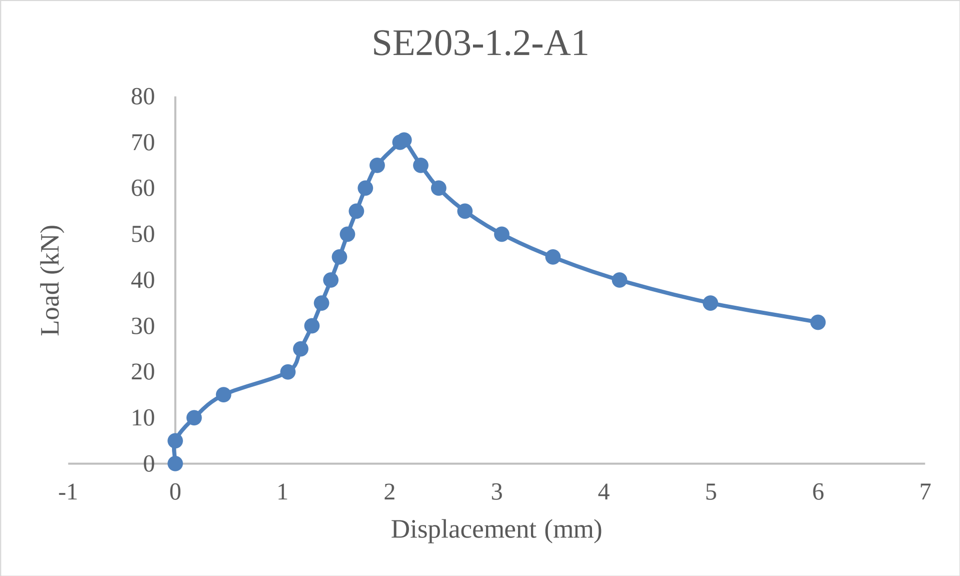
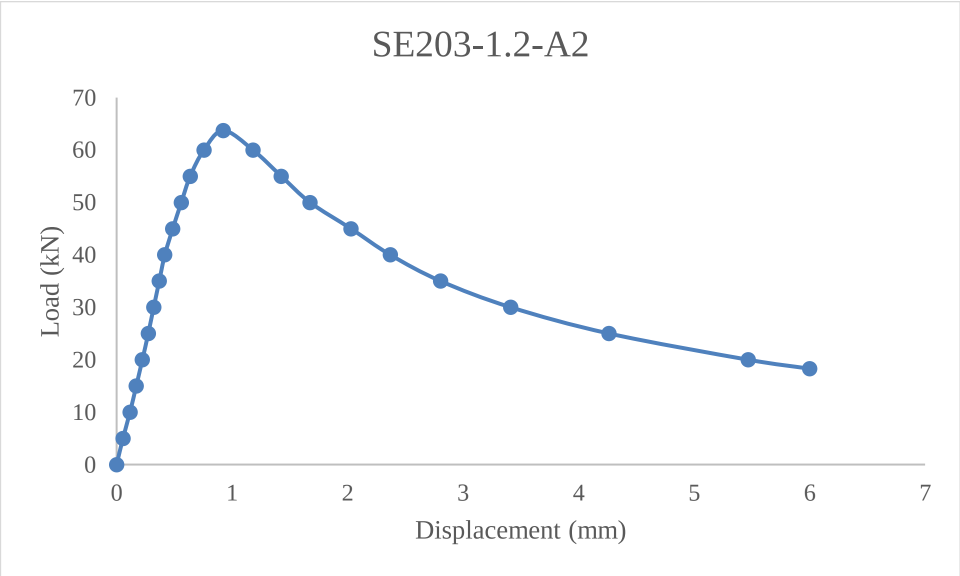
APPENDIX

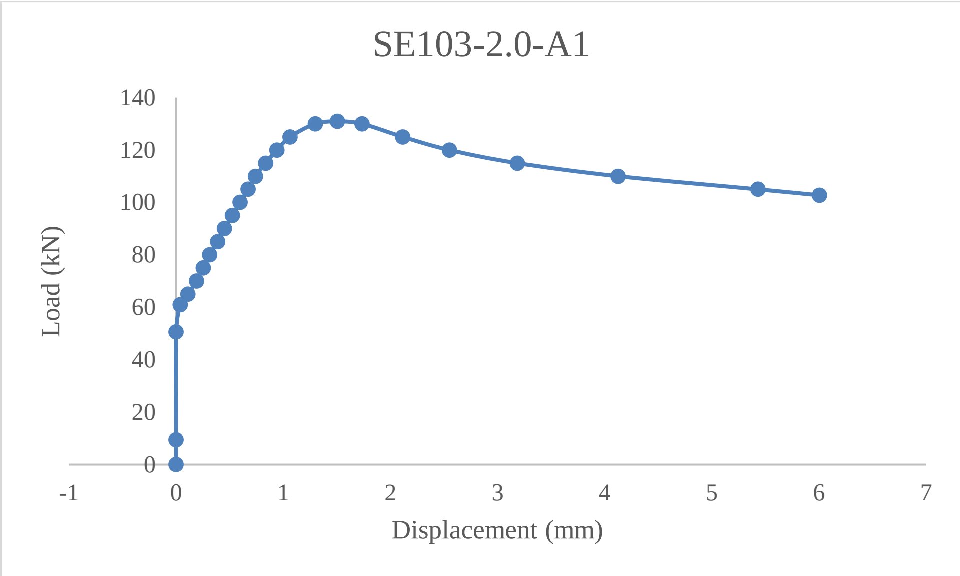
Graph Load VS Displacement for all the specimens involved:

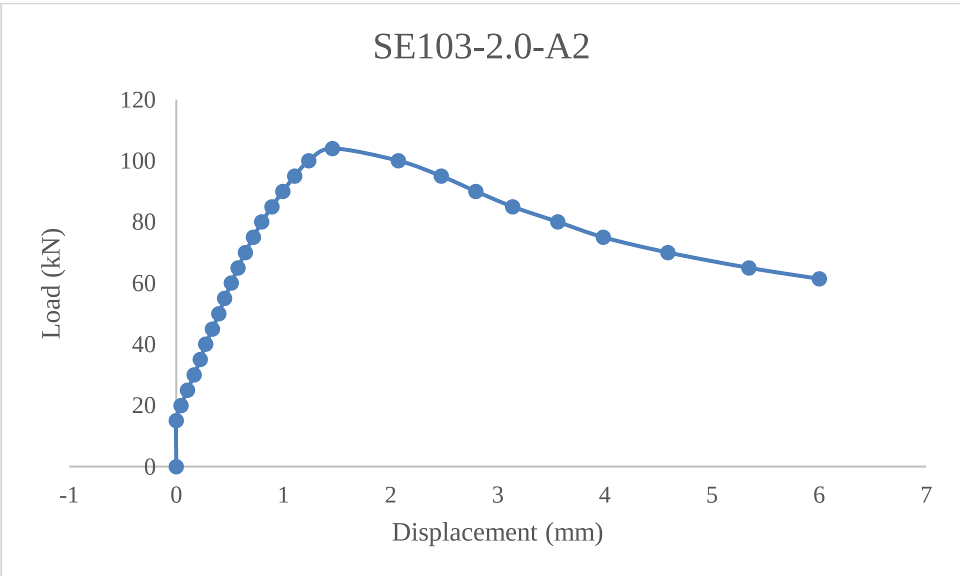


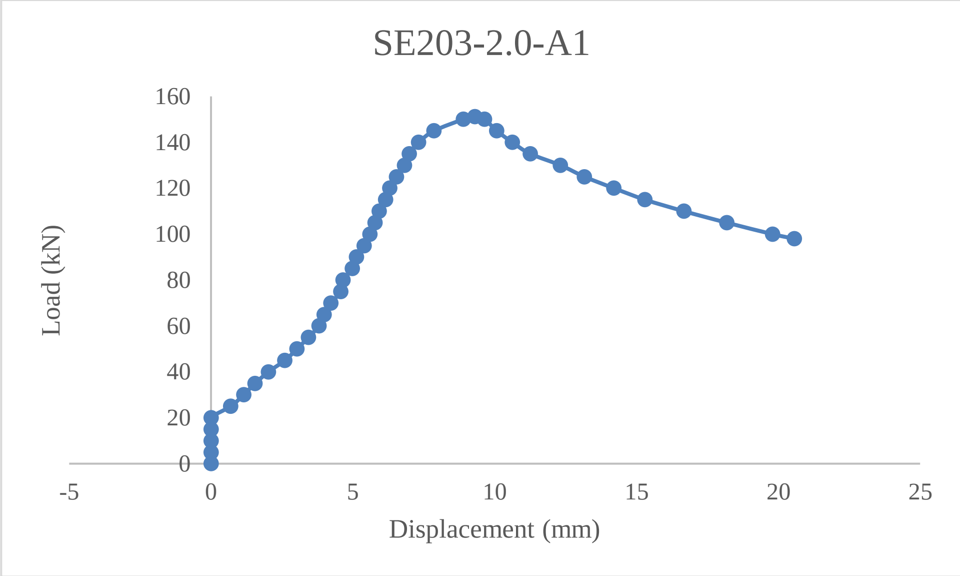


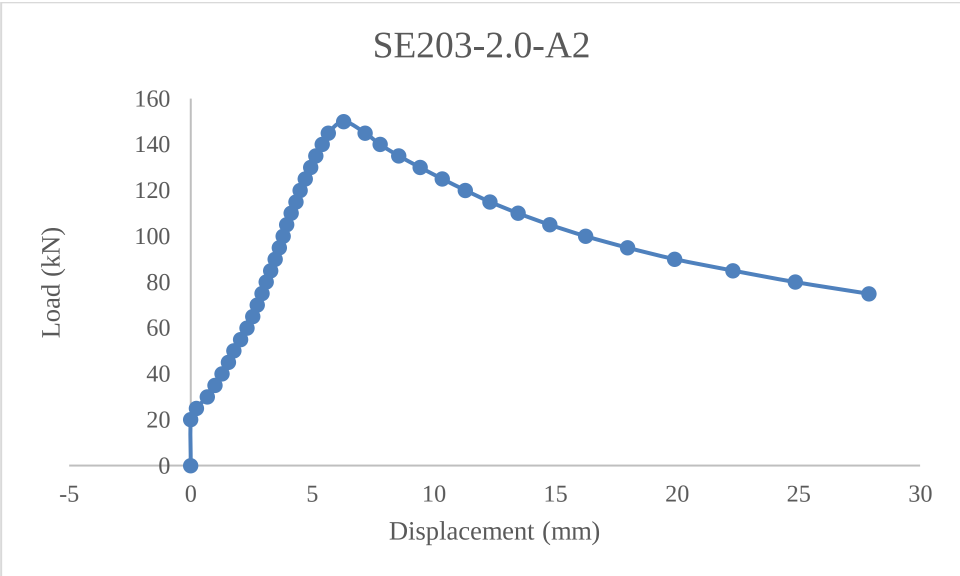

SE203-1.2-A1
Load (kN)
80
70
60
50
40
30
20
10
0
-1
0
1
2
3
4
5
6
7
Displacement (mm)


SE203-1.2-A2
Load (kN)
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
Displacement (mm)


SE103-2.0-A1
Load (kN)
140
120
100
80
60
40
20
0
-1
0
1
2
3
4
5
6
7
Displacement (mm)


SE103-2.0-A2
Load (kN)
120
100
80
60
40
20
0
-1
0
1
2
3
4
5
6
7
Displacement (mm)


SE203-2.0-A1
Load (kN)
160
140
120
100
80
60
40
20
0
-5
0
5
10
15
20
25
Displacement (mm)


SE203-2.0-A2
Load (kN)
160
140
120
100
80
60
40
20
0
-5
0
5
10
15
20
25
30
Displacement (mm)