# AXIAL LOAD OF BUILT-UP SIGMA SECTION COLD FORMED STEEL WITH HOLE.

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Thesis submitted in fulfillment of the requirements
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# ABSTRAK

Objektif kertas ini adalah untuk menentukan beban maksimum yang boleh dibawa oleh keratan keluli sejuk terbuka dengan jarak yang berbeza antara lubang E-seksyen dan juga menentukan kegagalan seksyen sigma dengan tekanan mampatan. Keluli terbentuk sejuk biasa digunakan sebagai anggota mampatan untuk mengangkat muatan yang lebih berat. Spesimen dimampatkan di antara plat galas dengan hujung rata. 8 angka spesimen dengan ketinggian 600 mm dengan dua tanpa bukaan dan 6 yang lain dengan bukaan telah digunakan dalam eksperimen ini. Bentuk bukaan ini adalah berbentuk memanjangkan. Eksperimen ini diuguji dengan menggunakan Universal Testing Machine (UTM). Semasa eksperimen ini, tiga transduser digunakan dan diletakkan di spesimen. Fungsi transduser adalah untuk membaca sesaran spesimen semasa ujian di mana graf telah di plot. Jarak antara bukaan dan jarak bukaan dari sokongan akan menunjukkan satu kelainan keputusan. Selepas ujian, lenggokan tempatan dan lenggokan distortional boleh dilihat di spesimen. Lenggokkan tempatan hanya berlaku di spesimen yang tiada bukaan manakala untuk spesimen yang mempunyai bukaan, lenggokan distortional berlaku.

# ABSTRACT

The objective of this paper is to determine the maximum load of open built-up steel and to study the built-up sigma section cold-formed steel with hole. Cold-formed steel commonly used as compression members to carry heavier loads. The column specimens were compressed between bearing plate with flat ends. Two series of E-section will be used which is BE103-2.0 and also BE203-2.0. All specimens with same height of 600 mm with two without opening and the other 6 with different position of openings from support. The shape of openings that have been used for all specimen is same which is elongated. This experiment is testing by using Universal Testing Machine (UTM). During the experiment, three transducers is used and been located at the specimen. The function of transducer is to read the displacement of the specimen during testing where the graph had been plotted. The opening distance from the support and specimen without opening will show a difference of the results. After the test, local buckling and distortional buckling can be seen at the specimen. Most of the specimen without opening shows the maximum load compared to the specimen with opening.

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# LIST OF SYMBOLS

| | |
|---|---|
| mm | milimeter |
| kN | kilonewton |
| T1 | Transducer 1 |
| LVDT | Linear Vertical Displacement Transducer |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| CFS | Cold-Formed Steel |
| BE | Built-up E-section |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Cold-formed steel structures have been in service for many years and are used to fulfil numerous applications. Typically, cold-formed steel structures are used as shelters for both domestic and industrial purposes including protection for people, cars, livestock, farm implements, industrial/commercial facilities. As shelters are a necessity, it is one of the most important consumer products in the world, especially for the domestic market. The domestic market is extremely competitive and as a result, manufacturers need to provide a competitively priced product for economic survival.

Cold formed steels are made by bending a flat sheet of steel at room temperature into shape that will support more load than the flat sheet itself. The section itself are formed by press brake or bending brake operation from material such as carbon, low alloy steel, or stainless-steel sheet, strip, plate, or flat bar. Compared with other materials like concrete and timber, cold form steel can give more advantages which is in lightness, high strength and stiffness, ease of fabrication and mass production. Other than that, cold form steel structure also can contribute for the economy in transportation, handling, easy and fast in fabrication and installation.

Cold formed steel can be manufactured in two processes, such as brake pressing and rolled formed. Roll forming consist of feeding a continuous steel strip through a series of opposing rolls to progressively deform the steel plastically to form the desire shape. Roll forming is usually used to produce sections where very large quantities of a given shape are required. Figure 1.0 and Figure 1.1 shows various shape of cold-formed steel.

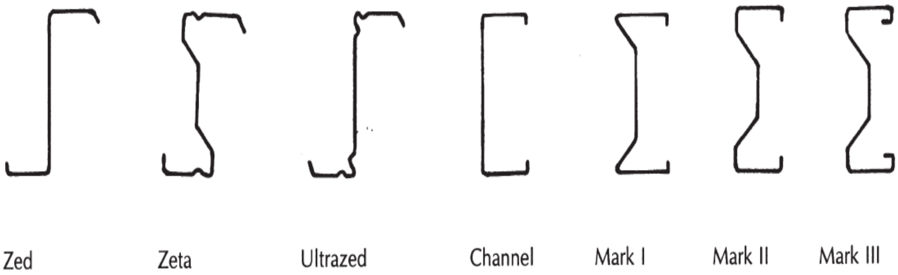


Figure 1.0 Evolution of cold-formed purlin sections.

(Davies, 2000)

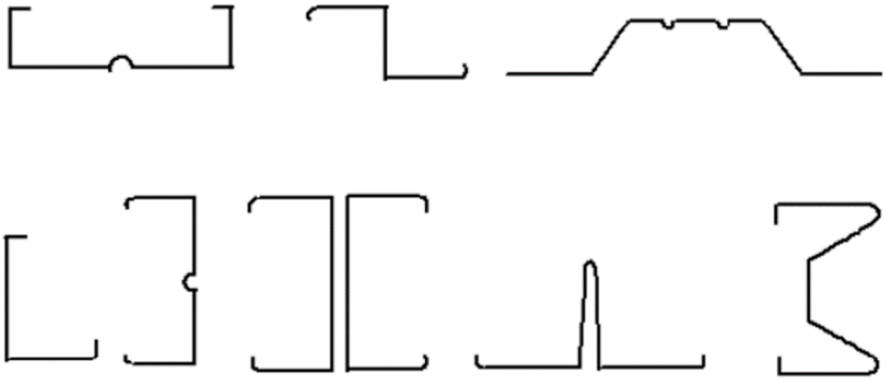


Figure 1.1 Typical light steel framing cross sections

(Ortiz et al., 2012)

## 1.2 Problem statement

Cold formed steel structure can be competent in many applications likes conventional hot rolled members and show that its uneconomic. Usually, the cold form steel is thinner and at the same time have mode of failure and also deformation. This factor, are not commonly encountered in normal structure steel design. Furthermore, through the cold forming process it produces residual stresses and structural imperfections where it's quite different from those traditionally hot rolled and welded members. There are few of mode failure by (Kulatunga and Macdonald, 2013) which is local buckling modes and also distortional buckling modes as shown in Figure 1.2 and Figure 1.3

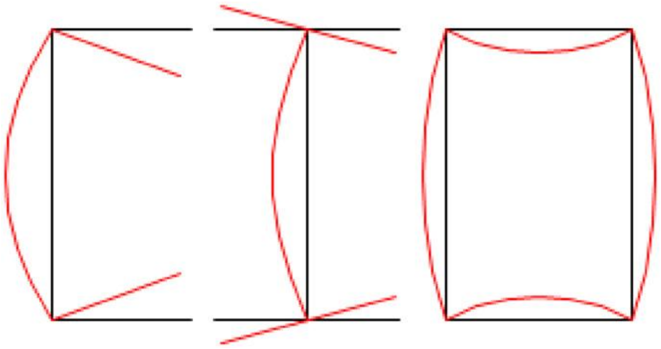


Figure 1.2 Local buckling modes of typical cross-sections in compression. (Kulatunga and Macdonald, 2013)

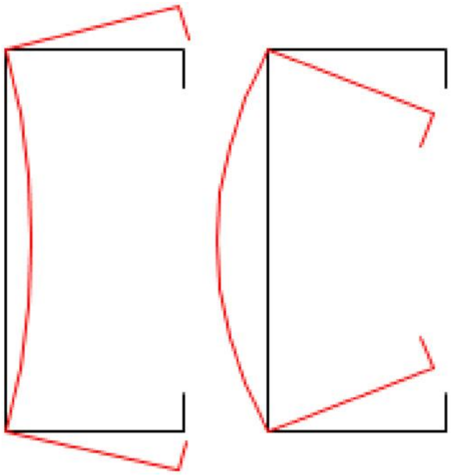


Figure 1.3 Distortional buckling modes of typical cross-sections in compression. (Kulatunga and Macdonald, 2013)

## 1.3 Objective.

i. To determine the ultimate load of open built-up steel
ii. To study the built-up sigma section cold-formed steel with hole.

## 1.4 Scope of study

In this of scope study, this project mainly focuses on a series of column test for cold-formed steel with sigma or E- section shaped open section. This sigma section have an edge and web stiffeners that were conducted. During the test on specimen at the lab the columns were compressed between fixed end. In this experiment, the section of cold-formed steel that being tested is built-up sigma section and a short cold-formed steel are being used that have a measurement of 600mm. The built-up sigma section that being test is classified into two category which is BE203 and BE103. This both of specimen have the same thickness which is 2.0mm. Four specimens from BE203 and four specimen from BE103 of cold-formed steel will be used with two with no opening and the other six will have an opening. The shape of opening for the both specimen of cold-formed steel that have been used is elongated shape. shape. The of opening of perforations at the cold-formed steel member also varies. For both of this specimen cold-formed steel 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.

## 1.5 Significant of Research

This survey results will give various information towards cold type steel post behaviour during "buckling initial"," buckling post" and load during maximum. Apart from that, this study will also help in deciding load during "buckling initial"," buckling post" and maximum load. This study can identify the effect of distance between various post deep hole. Therefore, information achieved through this study can help usage cold type steel post for the construction.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Old days, cold formed steel hardly used in development sector because information that is limited. Anyway, with technological progress, cold type steel has utilized being developed industry. Therefore, there are various studies that was carried out in seeking information that is more detailed towards cold type steel. Usually, steel hot rolled become developer choice in structure building construction. However, with the existence of cold type steel, its able give very big impact in building structure. By consumes cold type steel as building post, it gives huge impact because cold type steel very has been managed easily.

A multiplicity of widely different products, with a tremendous diversity of shapes, sizes, and applications are produced in steel using cold forming processes such as folding, press-braking and rolling (Kulatunga and Macdonald, 2013). The usage of cold-formed steel has been commonly used in the metal building construction industry for more than 40 years (Anbarasu, Bharath Kumar and Sukumar, 2014). Cold Form Steel is a procedure of folding steel into semi-completed at moderately low temperature. The CFS items are made in different shapes that made up by bowing sheet or strip steel in roll-framing machines, press brakes or twisting brakes. It is generally framed in various shapes that planned in mono-symmetric open area, for example, C-segment, U-segment, Z-segment and furthermore cap formed segments which conveyed an assortment capacity itself.

## 2.2 Cold-formed steel

In building 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 shapes are formed at low temperature. There are two types of CFS commonly used in construction industry which are individual structure framing members and panels and decks. CFS is used for structure framing such as truss, rafters and wall studs (Ye et al., 2016).

Different shape of sections such as C-section, Z-section, I-section, T-section, hat-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. There is cold formed steel that have an open section and closed section as shown in Figure 2.1.

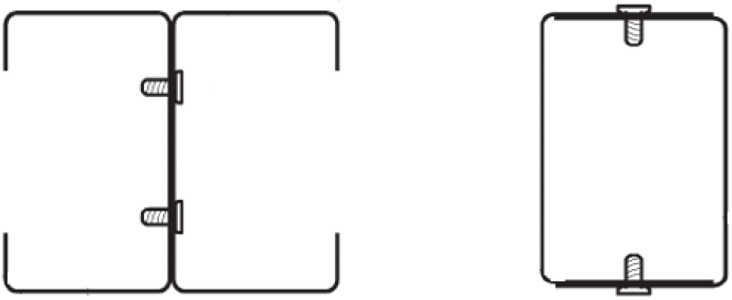


Figure 2.1 Built-up sections of CFS (a) Built-up open sections (b) built-up closed sections (Wang and Young 2015)

### 2.2.1 Types of Cold-Formed Steel

One of the members of Cold-formed steel is individual structural framing is individual structural framing members.

### 2.2.2 Individual Structural Framing Members.

The usual shapes (Yu and LaBoube, 2010) are channels (C-sections), Z-sections, angles, hat sections, I-sections, T-sections, and tubular members. Figure 2.2 shows some of the cold-formed section generally used in structural framing.

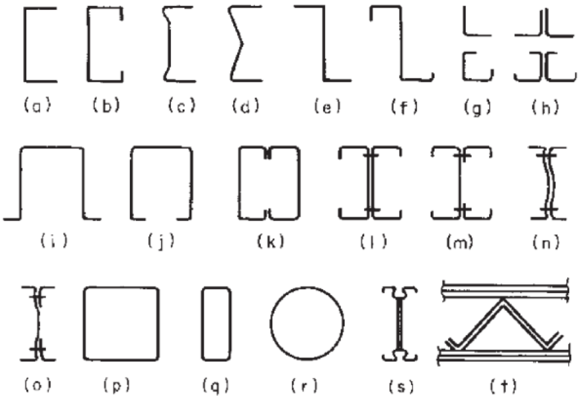


Figure 2.2 Cold-formed sections used in structural framing.

(Yu and LaBoube, 2010)

### 2.2.3 Applications of Cold-Formed Steel

Cold Formed Steel is widely used in buildings, automobiles, equipment, home and office furniture, utility poles, storage racks, grain bins, highway products, drainage facilities, and bridges. Its popularity can be attributed to ease of mass production and prefabrication, uniform quality, lightweight designs, economy in transportation and handling, and quick and simple erection or installation. Cold Formed Steel members have been mainly applied to light steel structure and can be used for whole buildings ( Kulatunga and Macdonald, 2013)

The Cold Formed Steel members offer one of the highest load capacities to weight ratio among the various structural component currently on the market (Mete Güneyisi et al., 2014). Cold-formed steel structural members may lead to a more economic design than hot-rolled steel members as a result of their superior strength to weight ratio and ease of construction (Zhou and Young, 2009).

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., 2014).

CFS is produce with a slender sheet conduct which ready to make an alternate opening gaps at the web. Other than that, cold formed steel is created with many functions such as supply the loads, carry an electric conduct as shown in Figure 2.3. Many structural cold-formed steel members are provided with perforations of different shapes to accommodate electrical, plumbing and heating services (Kulatunga and Macdonald, 2013)

Figure 2.3 Electrical Box and Wiring.

## 2.3 Section sigma

Sigma purlins are now more preferred than the conventional steel sections because of their better performance in resisting loads. These also have higher web stiffness which helps them to carry more loads. These also have shear centre close to the web. In addition, these are light weight and economic. Typical sigma section is shown in Fig 2.4.

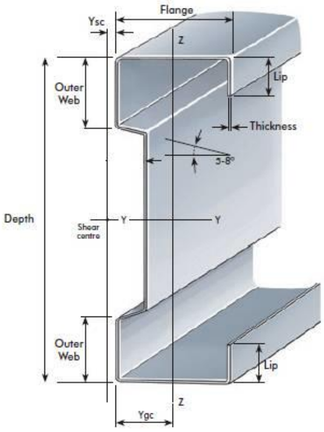


Figure 2.4 Typical view of sigma section. (Anna Green Antony, 2016)

## 2.4 Built – Up Section

Cold-formed steels are especially well known for light structures such as window frames, doors, and others. With technological advances, cool type steel has been introduced in the construction industry(Anbarasu and Venkatesan, 2019). The built-in specimens consisted of two sections that each other deflected. The study used 32 specimens with varying thickness, depth and distance. The specimens were tested using the "Universal Testing Machine" and the end of the specimen will be subjected to pin type support. Specimens will be tested until the specimen fails. Based on the study, local cords will occur first. Local bends often occur between the connection and end of the specimen. In addition, this study found that the distance of the screw connection, the specimen thickness and the depth of the specimen played an important role in the failure load. Figure 2.5 shows the distance of the screw connection**.**

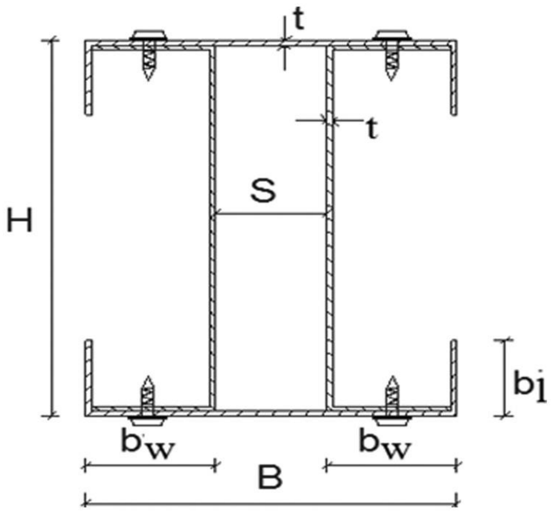


Figure 2.5 Typical built-up column details. (Anbarasu and Venkatesan, 2019)

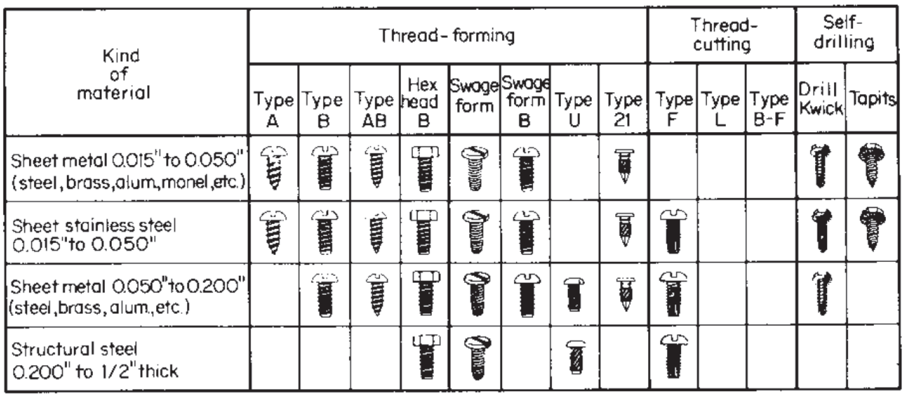
### 2.4.1 Types of connectors.

Connections are required for joining individual members in overall structures. The types of connections (Yu and LaBoube, 2010) generally used in cold-formed steel structures, the design criteria for various types of connections, the requirements to fabricate I- or box-shaped beams and columns by connecting two channels, and the spacing of connections in compression elements. In this experiment the connections that be using such as bolt and screw and also welding at the specimen as sown in Figure 2.6.

Figure 2.6 Screws and welding at the specimen.

### 2.4.2 Screw connections

These screws shall be thread forming or thread cutting as shown in Figure 2.7 and Figure 2.8 with or without a self-drilling point. Screws shall be installed and tightened in accordance with the manufacturer's recommendations.



| Kind of material | Thread-forming | | | | | | | | Thread-cutting | | | Self-drilling | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Type A | Type B | Type AB | Hex head B | Swage form | Swage form B | Type U | Type 21 | Type F | Type L | Type B-F | Drill Kwick | Tapits |
| Sheet metal 0.015" to 0.050" (steel, brass, alum, monel, etc.) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | | | ✓ | ✓ |
| Sheet stainless steel 0.015" to 0.050" | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | | ✓ | ✓ |
| Sheet metal 0.050" to 0.200" (steel, brass, alum., etc.) | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | |
| Structural steel 0.200" to 1/2" thick | | | | ✓ | ✓ | | ✓ | | ✓ | | | | |

Figure 2.7 Type of self-tapping screw. (Yu and LaBoube, 2010)

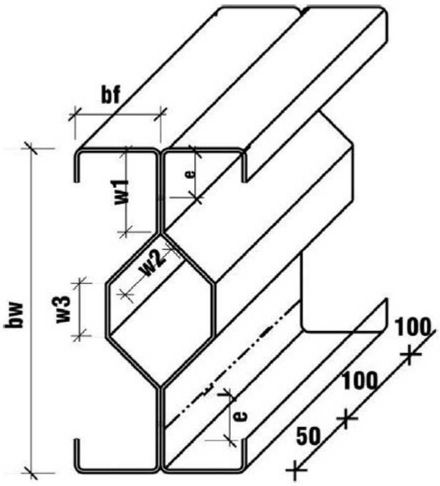


Figure 2.8 Screws arrangement along column specimen.(Abu-Hamd, Abdel-Ghaffar and El-Samman, 2018)

## 2.5 Perforated

Usually cold form steel has hole as shown on Figure 2.9 during column. This case because the hole will affect towards cold type steel nature. ( Kulatunga and Macdonald, 2013) had studied cold type steel structure member that perforated by imposing compression burden. A column has no hole while the rest have hole and the distinguish all five irons is range of between hole with hole and range in hole with post end.

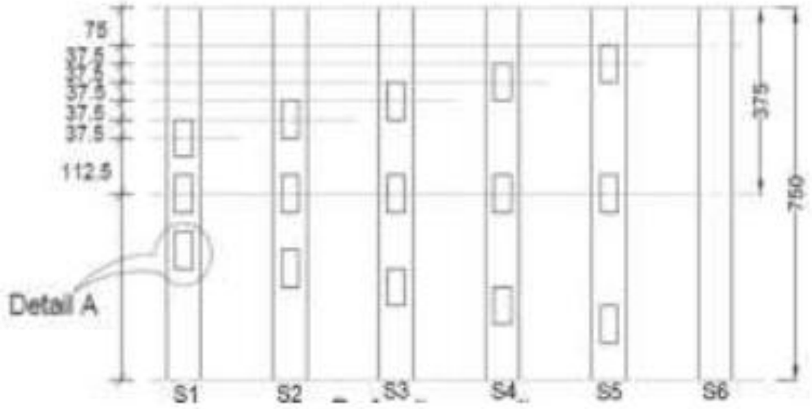


Figure 2.9 Six column member with different features . ( Kulatunga and Macdonald, 2013)

## 2.6 Advantage and Disadvantage of Built-Up Section

Advantages of Built-up sections:

i. More versatile since you are not limited to the shapes in the catalogue

ii. These could be produced in a built-up form much more quickly and potentially contributing better to the domestic economy

iii. High strength to weight ratio is achieved in cold rolled products.

iv. As compared with thicker hot rolled shapes, more economical design can be achieved for relatively light loads and/or short spans.

v. Cold formed steel built-up sections are commonly used as compression members to carry heavier loads.

vi. High load-carrying capacity, smaller blank size, less weight.

vii. Higher strength and better resistance against out-of-plane movement

Disadvantages of Built-up sections:

i. They have low fire resistance.

ii. The Unit price is high.

iii. It is difficult to connect them.

iv. They have to be assembled very carefully.

## 2.7 Previous Research Paper

### 2.7.1 Study on Cold Formed Steel Sigma Sections and the Effect of Stiffeners

Research done by (Anna Green Antony, 2016) cold-formed steel sections are currently widely used as primary framing components and secondary structural systems. They are used as purlins and side rails or floor joist, and after that in the building envelops. The geometry can significantly influence the stability response of cold-formed steel members and their failure patterns. The section selected for the study is CFS sigma section. The behaviour of the sigma section and the effect of providing stiffeners are studied. Providing stiffeners can influence the ultimate load of the section. In this paper, inclined and transverse stiffeners are provided at the flange and their effect on the ultimate load is studied.

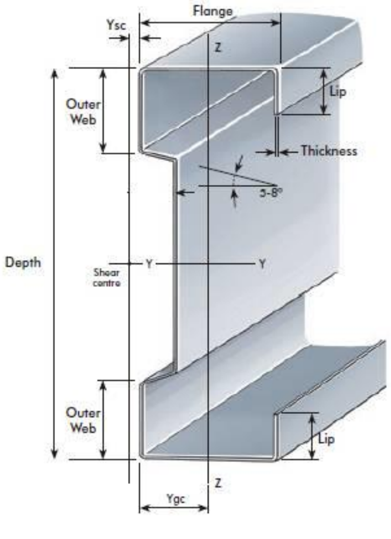


Figure 2.10 Typical view of sigma section (Anna Green Antony, 2016)

### 2.7.2 Behaviour of cold-formed steel built-up I-section columns composed of four U-profiles

Research done by (Anbarasu and Venkatesan, 2019) shows work reports numerical results concerning the cold-formed steel built-up I-section columns composed of four U-profiles under axial compression. A finite element model is developed by using the software program ABAQUS. The developed model includes geo- metric, material nonlinearities and geometric imperfections. The finite element model was verified against the experimental results reported in the cold-formed steel built-up open section columns. In the parametric study, the sections are analysed with several cross-sectional dimension ratios and lengths, in order to assess their influence on the buckling behaviour and ultimate strength of cold-formed steel built-up I-section columns. After presenting and discussing the numerical parametric results, the article shows that the current direct strength method in the North American Specification for cold-formed steel compression members design curve fails to predict adequately the ultimate strength of some of the columns analysed and addresses the modification proposed on current direct strength method curves, providing improved predictions of all the numerical ultimate strength available. The proposed method is also assessed by reliability analysis.

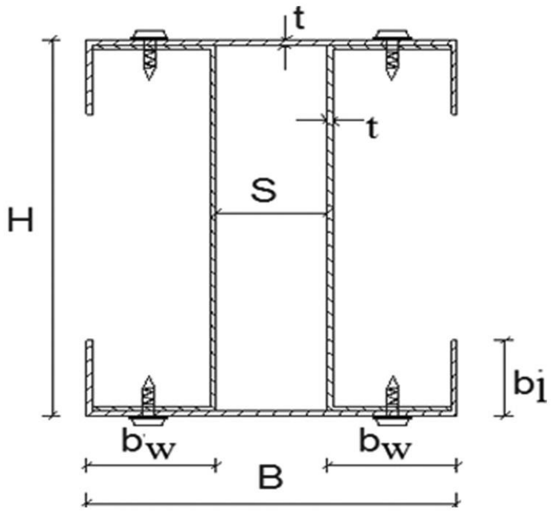


Figure 2.11 Typical built-up column details (Anbarasu and Venkatesan, 2019).

### 2.7.3 Investigation of cold-formed steel structural members with perforations of different arrangements subjected to compression loading

Research done by (Kulatunga and Macdonald, 2013) an investigation of cold-formed steel sections subjected to compression loading was undertaken using Finite Element Analysis to study the effects of perforation positions on the load capacity of column members of lipped channel cross-section. For this purpose, a finite element model was developed using ANSYS and its accuracy was verified using experimental and theoretical results. The study showed that the ultimate load of the lipped channels under compression varied greatly with the perforation position as shown in Figure 2.7. Comparisons of the finite element results and the test results are also made with existing design specifications, and conclusions are drawn on the basis of the comparisons.

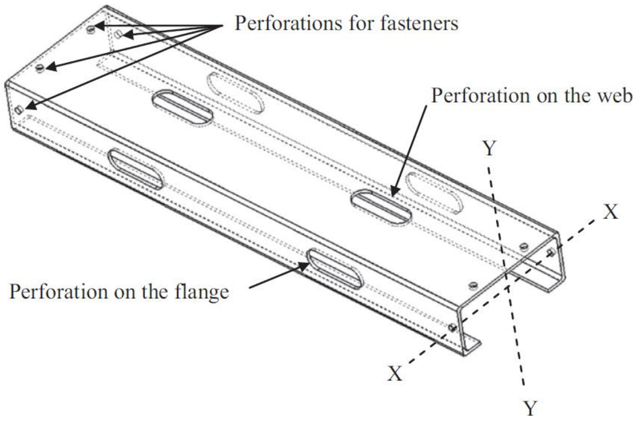


Figure 2.12 Channel section with perforations. (P. Kulatunga and Macdonald, 2013)

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This chapter will explain about the process and method that involved in the experimental test on shot column. The process is started with the setting up of the specimen by placing the transducer. After that, the specimen that been selected is placing on the Universal Testing Machine (UTM). Then, the transducer is put by placing near at the specimen until it touched the specimen to get the data in the laptop. The data in the laptop show the reading of the transducer 1, transducer 2 and transducer 3 while the data from computer will show the loading along the test is occur. Next, the loading rate will be set up at the machine. When the specimen is already set up, the Universal Testing Machine (UTM) will compress the specimen until the machine stop by the user according to displacement value study.

Research study by (Lue, Yen and Liu, 2006) and (Young and Chen, 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. Six specimens had been used where all specimens have different position of openings. The thickness and length of the specimens used are consistent to get an accurate result and to do comparisons.

The result of the performance and behaviour between cold-formed steel E or sigma section and the position of openings with the axial load applied to the cold-formed steel column were obtained by using the experimental study at the laboratory. The experimental investigation was aimed at studying to study about series of column test on the effect of openings and position of opening on built-up sigma section cold-formed.

## 3.2 Experimental Investigation

Built-up cold-formed steel sigma sections subjected to compression loading were considered in the investigation. The flow chart of the experiment as shown in Figure 3.1.

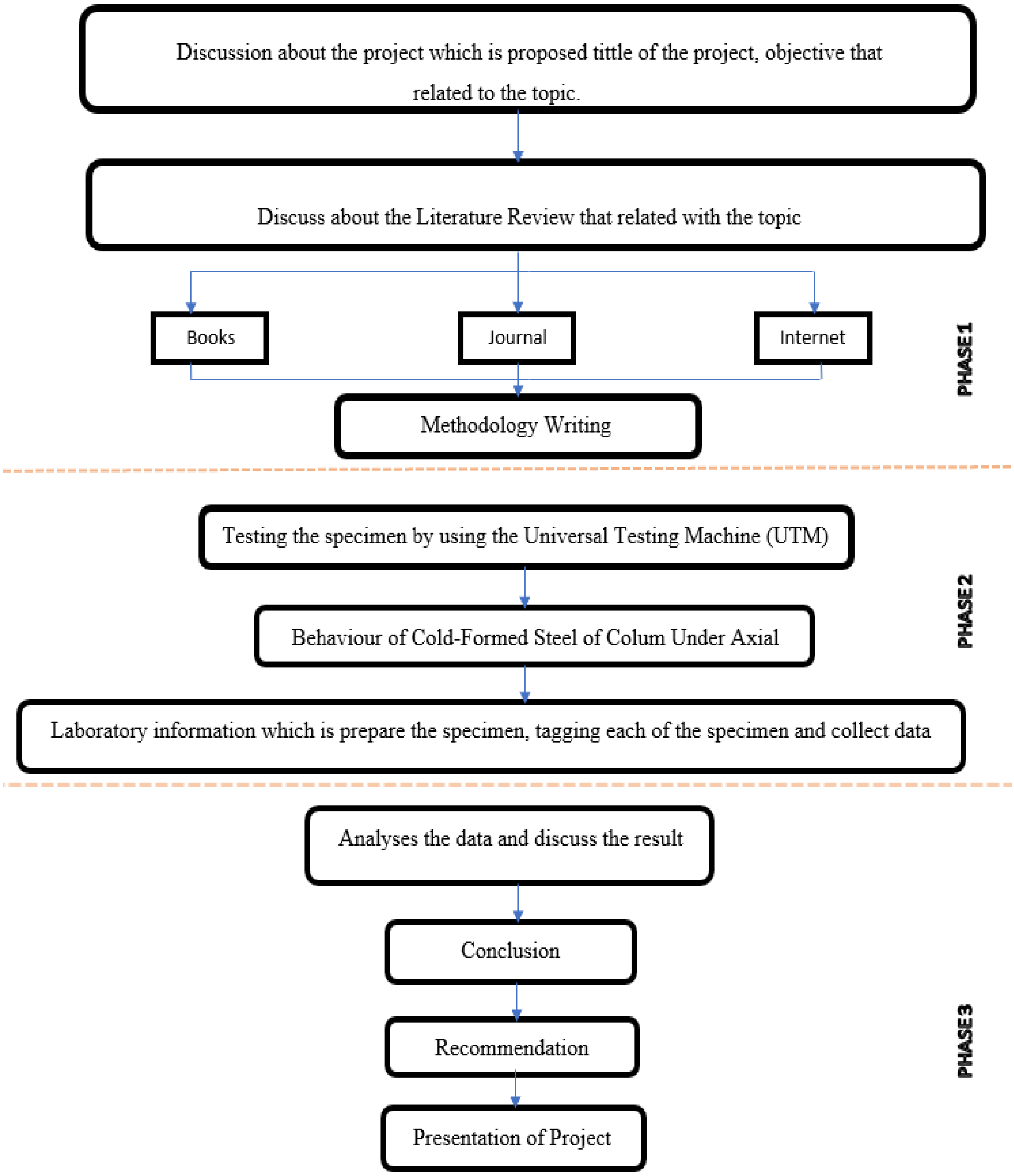


Figure 3.1 Project of flow chart.

### 3.3 Material selection.

Short The cold-formed steel was brake -pressed from steel plate cold rolled common (SPCC) cold rolled sheet which is standard of Japanese Industrial standard (JIS). Cold-reduced carbon steel sheet and strips having the material grade and designation defined in JIS G 3141. The tensile strength of the SPCC steels is must be at least 270 MPa. Before forming, the cold-formed sections were then cut to specified column length. Four column of sigma section 103-2.0 and four column of sigma section 203-2.0 profile as shown in Figure 3.2 and Figure 3.3 have been tested. The cold-formed sigma profile was specially designed with edge and web stiffeners in order to enhance the local buckling stress of a section. The testing of specimens is labelled such that BE103-2.0-A1 and BE203-2.0-A1.

Figure 3.2 BE103-2.0

Figure 3.3 BE203-2.0

### 3.4 Section parameter

The parameters of the typical sigma-section cold-formed and their magnitudes are shown in Table 3.1.

Table 3.1 Measured specimen

| Specimen | Thickness (mm) | Height (mm) | Specimen size (mm) |
|---|---|---|---|
| BE103 | 2.0 | 600 | 103 |
| BE203 | 2.0 | 600 | 203 |

All the samples for specimen 203 and 103 have 600 mm height and the tracks were made of material 2.0mm thick. An inelastic buckling mode was expected during the test.

### 3.5 Operation Set-up and Loading

Universal Testing Machine (UTM) and three transducers as shown in Figure 3.4 will be use to conduct in this experiment. The series of Cold-Formed E section with various position of openings as shown in Figure 3.5 will be used in this experiment. UTM Machine will read the displacement of each of specimen along the test is occur and the loading rate that will be used is 0.5 mm per minute. After the test is complete, the data will be formed as a graph which is loading vs displacement. While the transducer will take the displacement reading. The specimen will support by plate at bottom and above as shown in Figure 3.6 and Figure 3.7. While at the Universal Testing Machine, there is a support at the machine that will support the specimen as shown in Figure 3.8 and Figure 3.9. Other than that, Data logger (Strain Measurement) as shown on Figure 3.10 will be used to read the data for transducer.

Figure 3.4 Transducer at specimen.

Figure 3.5 Series of Cold-Formed E section

Figure 3.6 Support at the bottom of specimen.

Figure 3.7 Support at the above of specimen.

Figure 3.8 Bearing plate at the top

Figure 3.9 Bearing plate at the bottom.

Figure 3.10 Data logger (Strain Measurement)

## 3.6 Schematic Diagram

The diagram of the specimens and machines used are describe by drawing. All dimensions are in millimetre (mm). The cross section of specimen BE103 and specimen BE203 as shown in Figure 3.11 and Figure 3.17. The column lengths, cross- section dimensions, and perforation areas were kept constant, having a thickness of 2.0mm and specimen length is 600 mm. Detail dimension of specimen as shown in Figure 3.12 - Figure 3.21. While in Figure 3.22 shows a schematic drawing of transducers position and in Figure 3.23 shows a Universal Testing Machine (UTM) and transducers set-up.

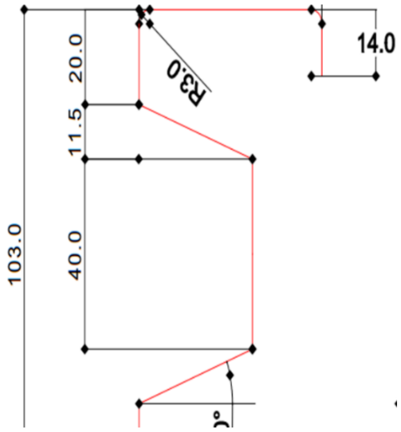


Figure 3.11 Cross Section of specimen BE103-2.0

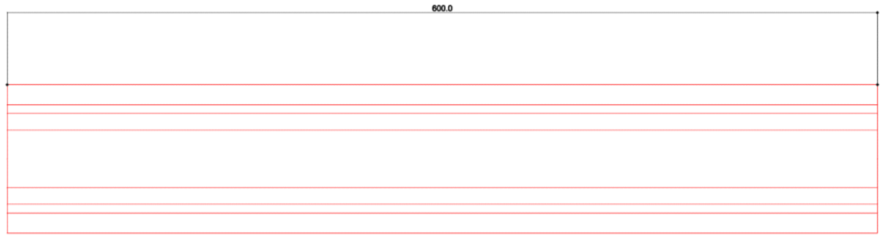


Figure 3.12 Schematic diagram of Specimen BE103-2.0-A1

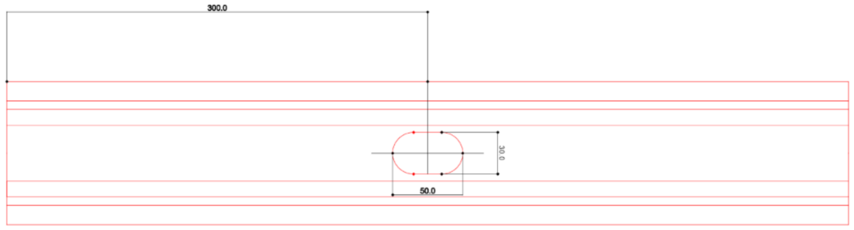


Figure 3.13 Schematic diagram of Specimen BE103-2.0-A2

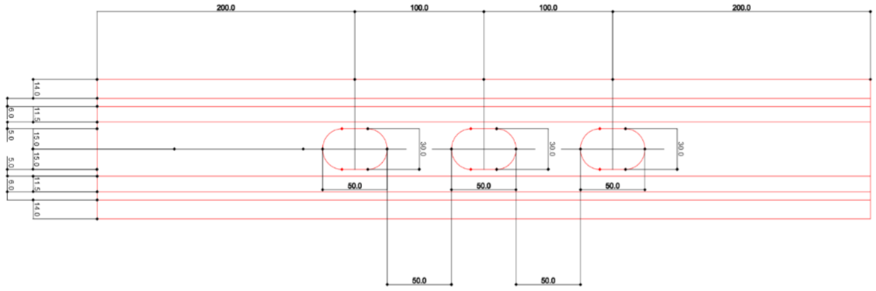


Figure 3.14 Schematic diagram of Specimen BE103-2.0-A3

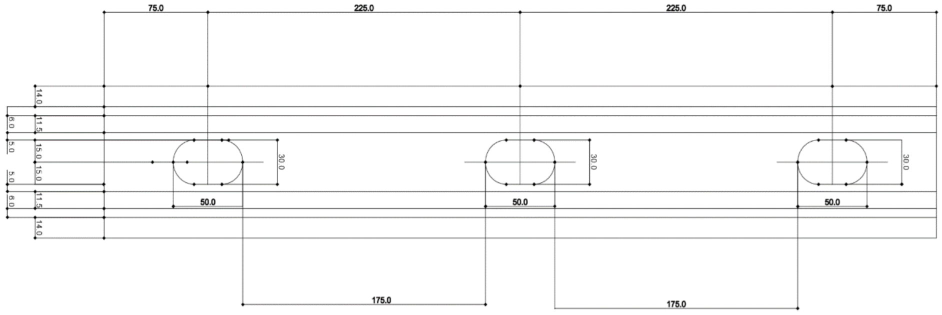


Figure 3.15 Schematic diagram of Specimen BE103-2.0-A4

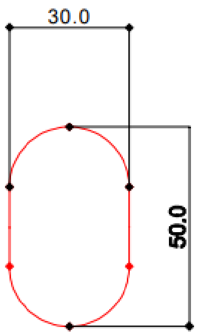


Figure 3.16 Schematic diagram for opening

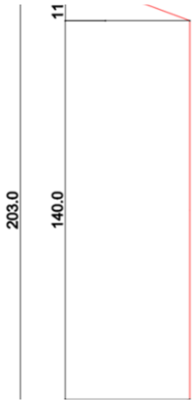


Figure 3.17 Cross Section of Specimen BE203-2.0

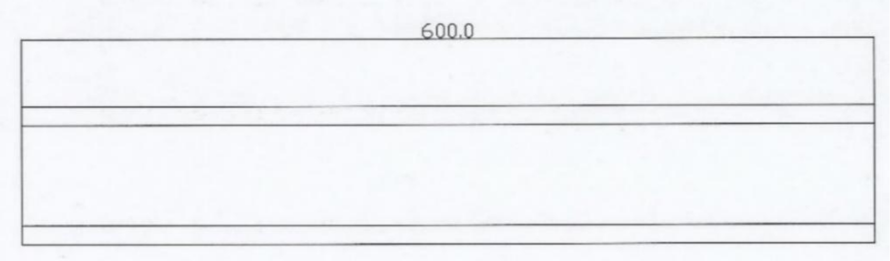


Figure 3.18 Schematic diagram of Specimen BE203-2.0-A1

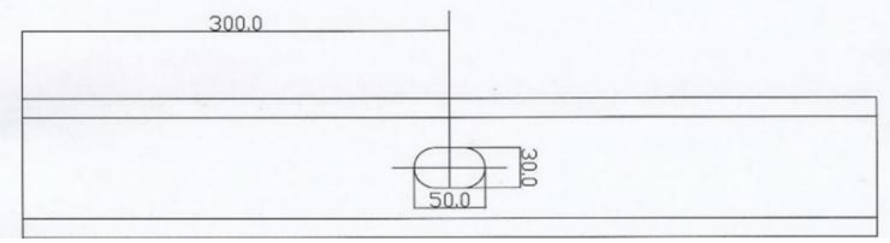


Figure 3.19 Schematic diagram of Specimen BE203-2.0-A2

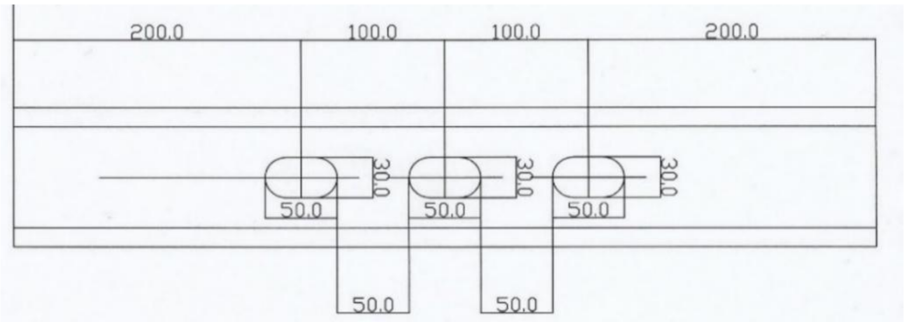


Figure 3.20 Schematic diagram of Specimen BE203-2.0-A3

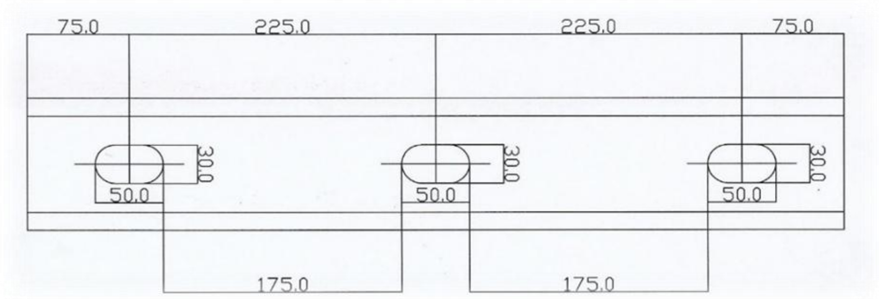


Figure 3.21 Schematic diagram of Specimen BE203-2.0-A4

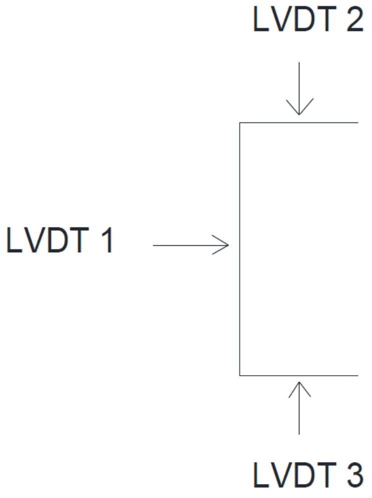


Figure 3.22 Schematic drawing of transducers position

Figure 3.23 Universal testing machine and transducers set-up.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

This chapter discuss about the result that were obtained after the testing for each specimen is done. After the testing is done, the value of vertical displacement for each specimen had been taken. During the experiment, three transducers were placed at the specimen which is transducer one at the upper of the support while the others two which is transducer two and three is located at the both side of the flange of column. Other than that, the mode of failure for each sigma section can be determined after the experiment is done. The aim of this experiment is to determine the maximum value for each specimen and also to determine the mode of failure which is buckle or distort at flange or web. The size of opening for each sigma section during experiment was kept constant. Displacement for each sigma section also keep constant which is 6mm. The graphical method for each sigma section is presented as a result to give more understanding and better visualize. The discussion for every graph of each sigma section also been carried in this chapter. Research study by (Lue, Yen and Liu, 2006) and (Moen, Christopher D, 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.

### 4.2 Ultimate load versus Displacement, T1.

The result and data will be presented as a graph of Load versus Displacement, T1 for specimen sigma section BE103 and BE203. For specimen sigma section BE103 and BE203 have same thickness which is 2.0mm. From the graph and table, it will show the maximum value for each specimen sigma section and the value of Displacement, T1.

#### 4.2.1 Ultimate load versus Displacement, T1 BE103-2.0.

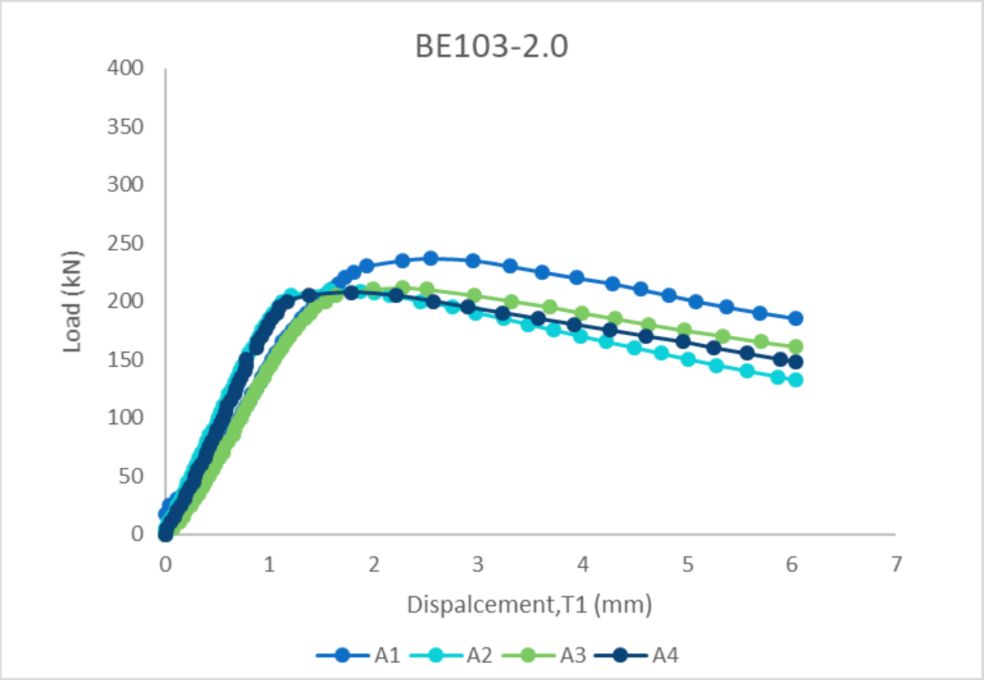


Figure 4.1 Load versus Displacement,T1 BE103-2.0

Figure 4.1 shows Load versus Displacement, T1 for specimen BE103-2.0. Based on the figure above, it shows that specimen BE103-2.0-A1 has the highest graph among the others specimen. This is because specimen with no opening will give the highest value of Load rather than specimen that have opening. The second highest graph is specimen BE103-2.0-A2. Theoretically, the graph of specimen BE103-2.0-A3 should less than BE103-2.0-A2. This is because due to the number of opening of specimen A3 is more than specimen A2. But, according to the figure 4.2, it shows that graph of specimen BE103-2.0-A3 is higher than graph of specimen BE103-2.0-A2. This is because of the error that happen during the test and also during the welding work at the specimen at the lab. While for the specimen BE103-2.0-A4, the graph is the lowest among the other three specimens for BE103-2.0. Specimen BE103-2.0-A4 has the lowest graph because number of opening is more than the others three specimen and also the opening is closer to the support.

Table 4.1 Load and Displacement,T1 specimen BE103-2.0

| **Specimen** | **Ultimate Load (kN)** | **Displacement, T1 (mm)** |
|---|---|---|
| A1 | 236.61 | 2.541 |
| A2 | 209.44 | 1.574 |
| A3 | 211.28 | 2.272 |
| A4 | 207.70 | 1.783 |

Table 4.1 shows the value of Load and the value of the Displacement, T1for sigma BE103-2.0. Theoretically, specimen with no hole will have the maximum value rather than with opening. From the table above, it shows that specimen BE103-2.0-A1 has the highest value among the others three specimen which is 236.61 kN. The second highest is specimen BE103-2.0-A2 which is 209.44 kN. The value of load (kN) for specimen A3 should less than specimen A2. But according to the table above, the maximum value for specimen A3 is higher than the maximum value of specimen A2. This is because there is error during the set-up of the specimen at the lab.

### 4.2.2 Ultimate load versus Displacement, T1 BE203-2.0.

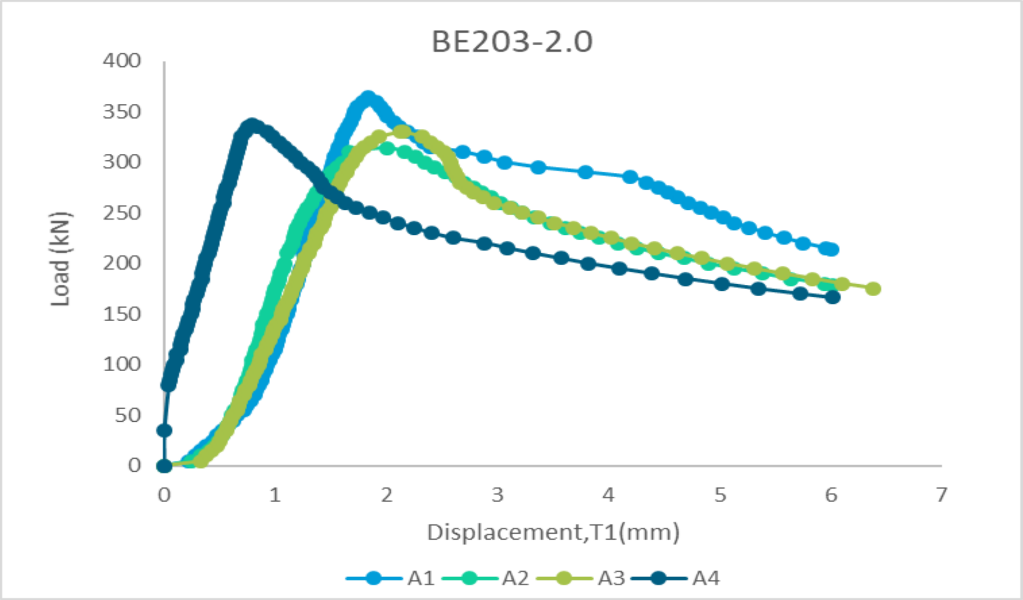


Figure 4.2 Load versus Displacement,T1 BE203 2.0

Figure 4.2 shows the Load versus Displacement, T1 graph for specimen BE203-2.0 sigma section. According to the graph 4.1, it shows that specimen A1 is highest among the specimen A2, A3, and A4. This is because specimen A1 doesn't have any opening rather than specimen A2, A3 and A4. The lowest graph should be the sigma section BE203-2.0-A4 due to the number of opening and also due to the position opening that closer to the support. But according to the graph, it shows that the lowest graph is happen at specimen A2. This is because of the error that happen during set-up specimen at the lab and also during the welding work of the specimen. This error will affect the reading of specimen and prevent from get the exactly result.

Table 4.2 Load and Dispalcement,T1 BE203-2.0

| **Specimen** | **Ultimate Load (kN)** | **Displacement, T1 (mm)** |
|---|---|---|
| A1 | 364.30 | 1.837 |
| A2 | 314.20 | 2.003 |
| A3 | 330.31 | 2.149 |
| A4 | 337.63 | 0.790 |

Table 4.2 shows the result for specimen sigma section BE203-2.0. From the table it shows that specimen BE203-2.0-A1 has the highest value of Load among the specimen A2, A3 and A4 which is 364.30 kN. While the value of Displacement for specimen A1 is 1.837mm. Specimen BE203-2.0-A1 has the maximum value among the others because A1 specimen is made with no hole. Theoretically, specimen BE203-2.0-A4 should has the lowest value of load (kN) because the number of opening at specimen A4 is more than specimen A2 and A3. Other than that, the opening of specimen A8 is closer to the support. But according to the table 4.2, the value of ultimate load for specimen BE203-2.0-A4 is higher than specimen A2 and A3. This is due to error during the set-up of specimen at the machine and also during the welding work of the specimen.

## 4.3 Mode of failure.

After the testing at specimen is done, it will show mode of failure for each specimen. Mode of failure will be started during the compression test at specimen is conducted. In this chapter the failure of mode and the changes of steel columns of each specimen for BE103-2.0 and BE203-2.0 were studied.

### 4.3.1 Mode of failure BE103-2.0

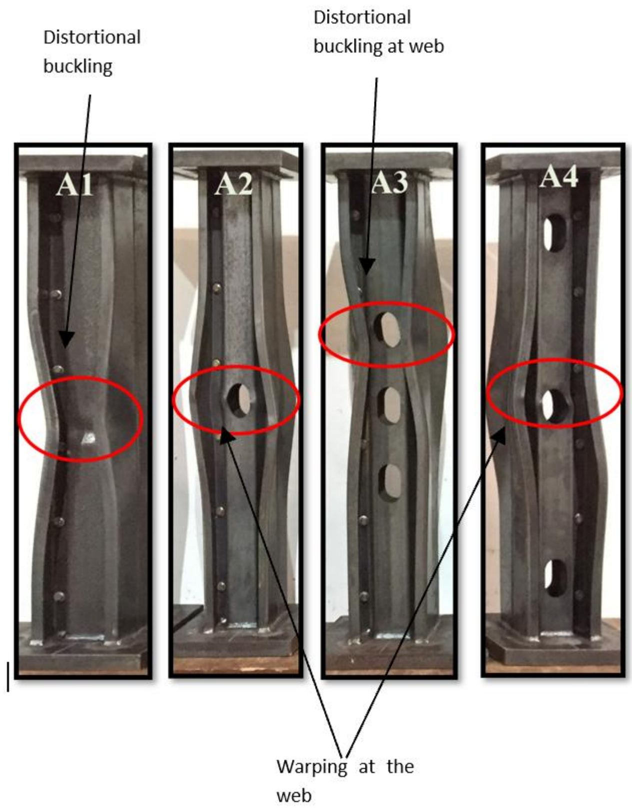


Figure 4.3 Front view failure mode BE103-2.0

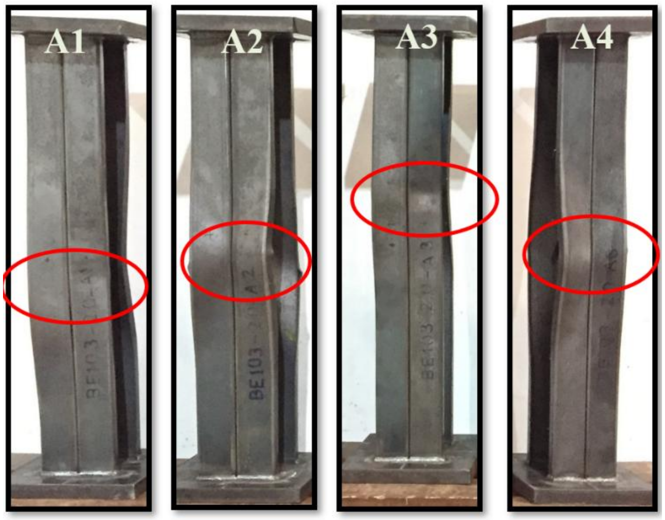


Figure 4.4 Side view failure mode BE103-2.0

From Figure 4.3, it shows that sigma section A1 at front side happen a distortional buckling at the middle of the specimen and also at the lip of the specimen. Sigma section of A1 is the only one specimen that made up with no opening. While from the Figure 4.4 at the side view, specimen A1 happen a warping buckling at the back of the specimen due to the compression.

Specimen A2 column has the longest of the opening from the support but has the lowest distance between openings. From the Figure 4.3, there is mode of failure happen which is distort at the web of the specimen. From the front side based on Figure 4.3, there is a change happen of the shape which is distort buckling behaviour that happen at the lip of the specimen.

Specimen A3 happen a distortional buckling behaviour at the top of the opening. It can be seen that the distort behaviour happen at web specimen A3 and also at flip side at right and left of the specimen. From the Figure 4.4 at the side view, the sigma section specimen A3 happen a change of the shape which is the flange distort inward due to the compression at the specimen.

The specimen A4 has the shortest distance of the opening from the support but has the longest distance between openings. From the Figure 4.3, it shown from the specimen that the column failed at the middle of the opening and it can be seen that the flange warping outward due to compression. The web of column had buckle outward and this show that the specimen A4 experienced distortional buckling.

For the summary, specimen A1, A2 and A4 went through a failure at the middle of the specimen while specimens A3 went through a failure at the top opening. The columns for this experiment experienced local and distortional buckling. Distortional buckling behaviour happened at specimen A1 and A3. Warping behaviour happened at specimen A2 and A4. This failure mode can be seen where the flange and web buckle at the same time.

### 4.3.2 Mode of failure BE203-2.0

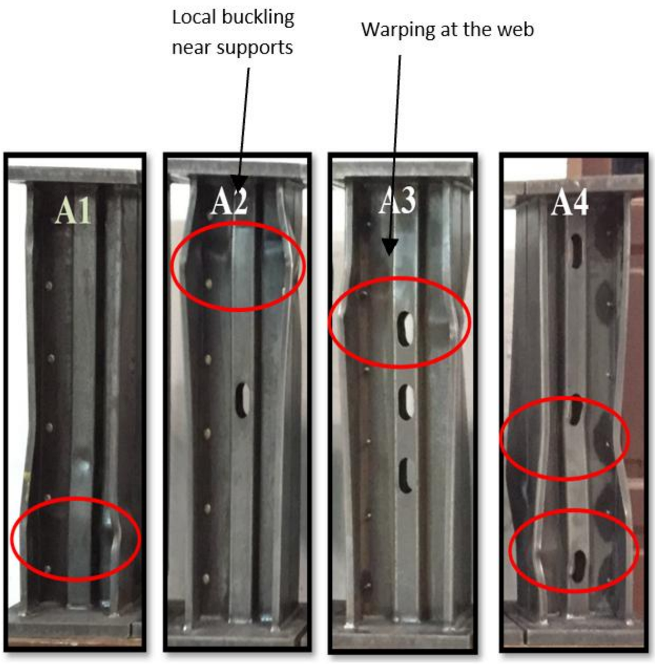


Figure 4.5 Front view failure mode BE203-2.0

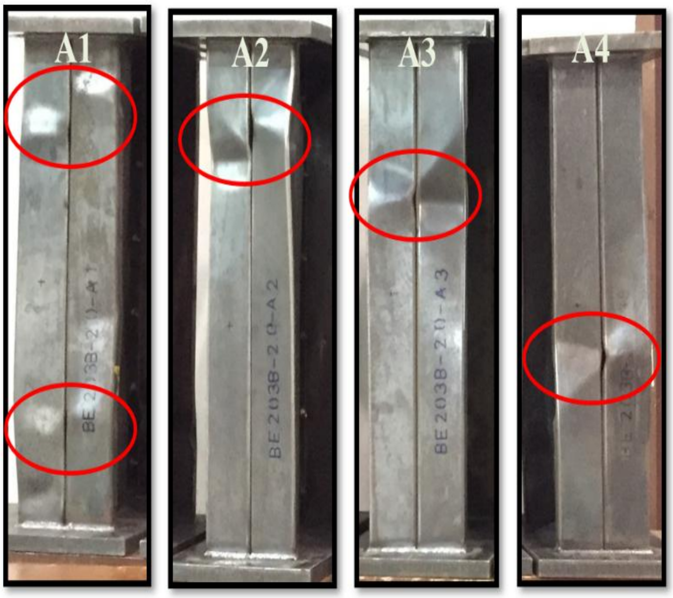


Figure 4.6 Side view failure mode BE203-2.0

For specimen sigma section A1, the column without opening at front side happen a distortional buckling mode at lip of the specimen. While at the side view, can be seen there is local buckling happen at the flange of the specimen. Local buckling behaviour can be seen at specimen A1 where there is a wave appeared at the flange of the specimen as be seen in Figure 4.5. The wavelength appeared at the beginning of the stage of compression at the bottom of the column and the wavelength continue to appear until the column failed as shown in Figure 4.5.

From Figure 4.5, specimen sigma section A2 has the longest distance of opening compare to the others specimen sigma section. But at the same time specimen sigma section A2 also has the lowest distance between opening compare to the others specimen sigma section. At specimen A2, from the front side there is distortional buckling mode that happen at the top of the specimen. While at side view, at the back of the flange experienced a distort inward and warping buckling behaviour at the front of the flange.

Specimen A3 is the second longest distance of the opening of the sigma section. The specimen A3 is the first specimen that happen a warping and distort buckling behaviour at the opening. From Figure 4.4, it can be seen specimen A3 happen warping front and also distort at lip of the specimen due to the compression. At the side view of the column also experienced change of shape where there is a distort buckling behaviour at the back and front of the flange.

From the Figure 4.4, it shows that specimen A4 happen a distort buckling behaviour at the middle of the opening and also at the lip of the specimen. Other than that, at the bottom opening of the specimen, there is distortional buckling behaviour happen at the specimen. While at left lip specimen it shows that there is happen a distort and at the right side of lip it happens warping buckling behaviour.

# CHAPTER 5

# CONCLUSION

## 5.1 Introduction

After the result and discussion is done there are several conclusions can be made which is:

a) Different ultimate load can be seen from different specimen.

b) Specimen without opening have a higher ultimate load compared to the specimen with opening.

c) The deformation of peak load for the short column was less sensitive to the presence of openings, exhibit a mixed local-distortional failure mode.

d) The experimental test conducted in this study have shown that increasing of the numbers of web openings results a considerable decreasing of the column axial compressive strength compared to reference columns with no web openings.

e) The presence of opening at the web of steel columns composed of thin walled cold formed sections (CFS) will increase the possibility of local buckling failure at the locations of openings.

## 5.2 Recommendation

a) Distortional buckling can be prevented by increasing the web depth, but failure due to local buckling will likely to occur.

b) Using Finite Element software to validate.

c) Use different types opening such as circular, rectangular, oval, or rectangle.

d) Increase the number of the opening at the specimen.

e) Use slenderness column

f) Use different shape of the specimen such as Z-shape, plain C-section and the others.

g) Change to beam specimen.

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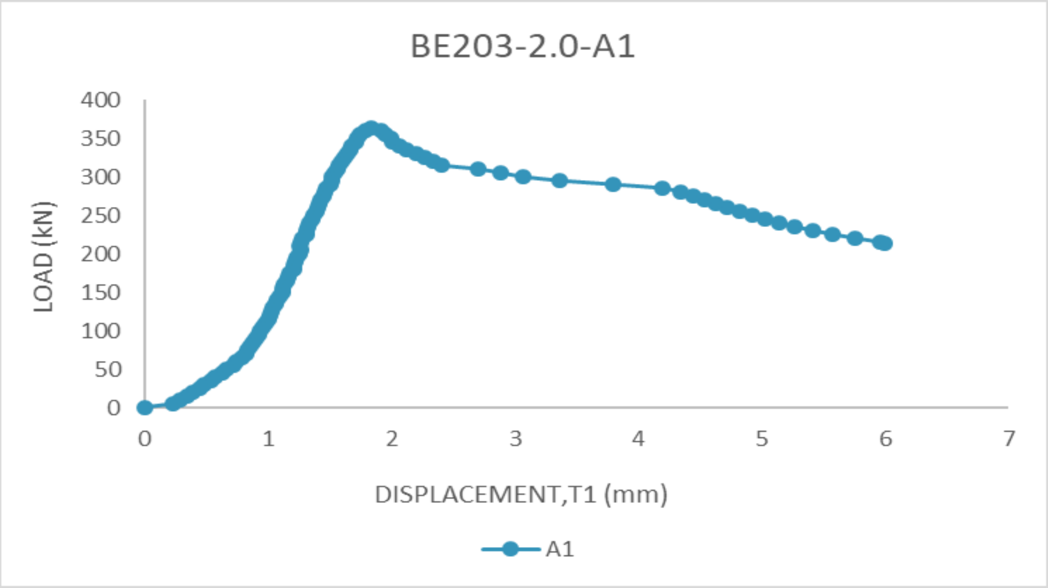
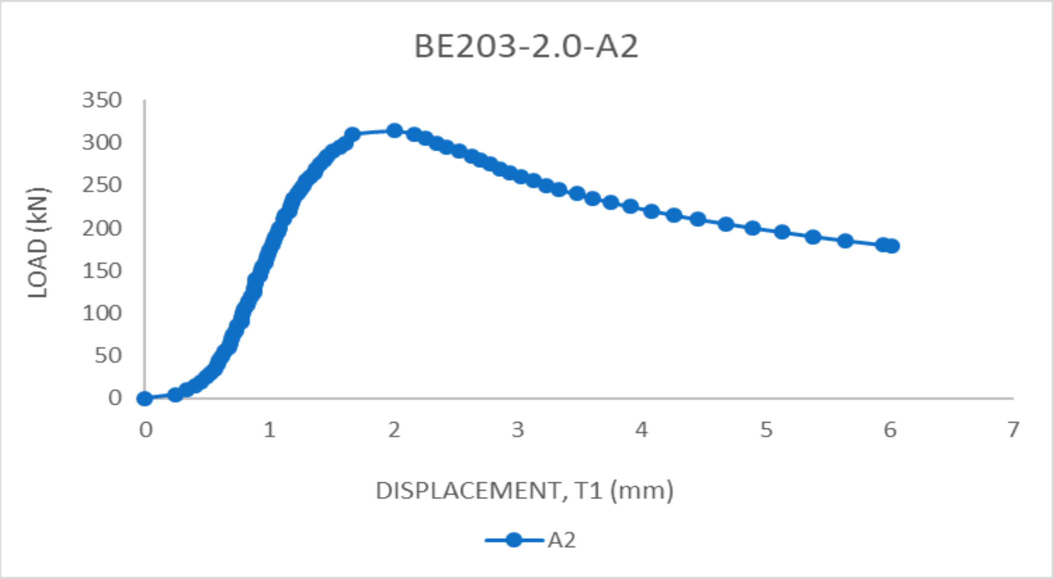
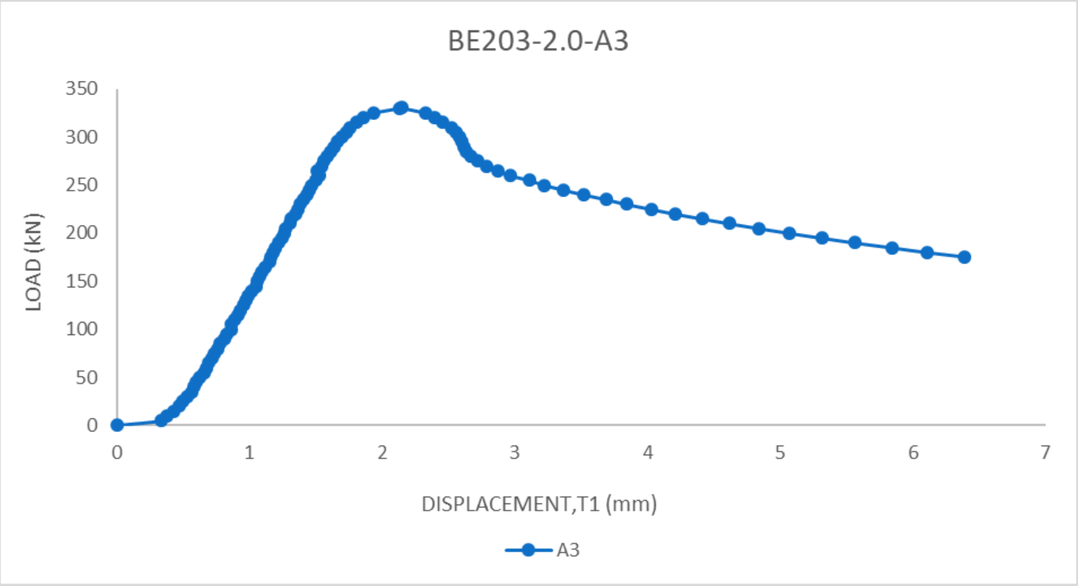
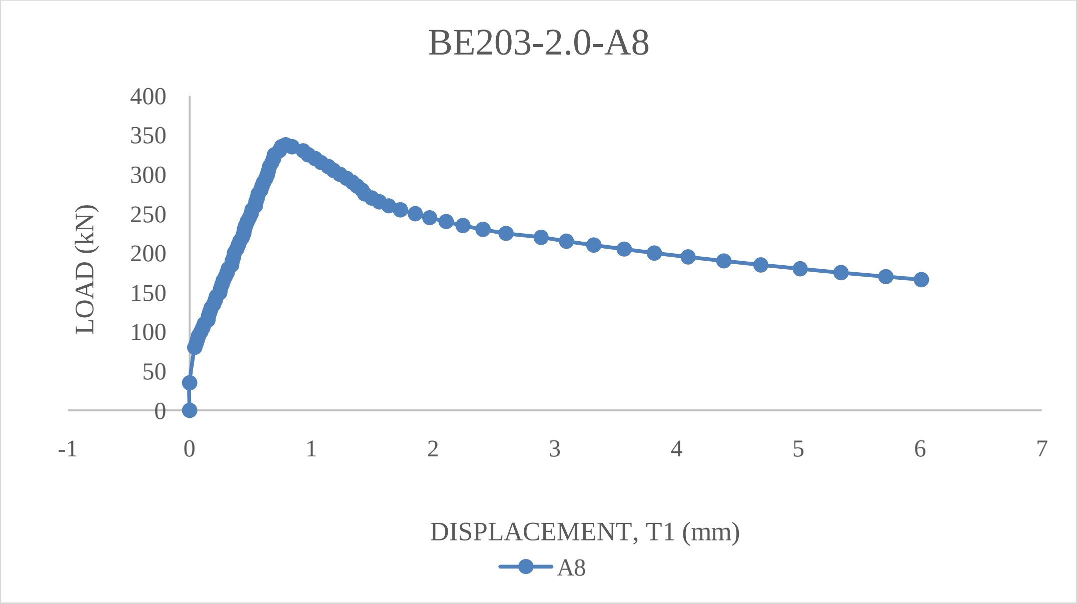
# APPENDIX A
# GRAPH OF SPECIMEN BE203-2.0

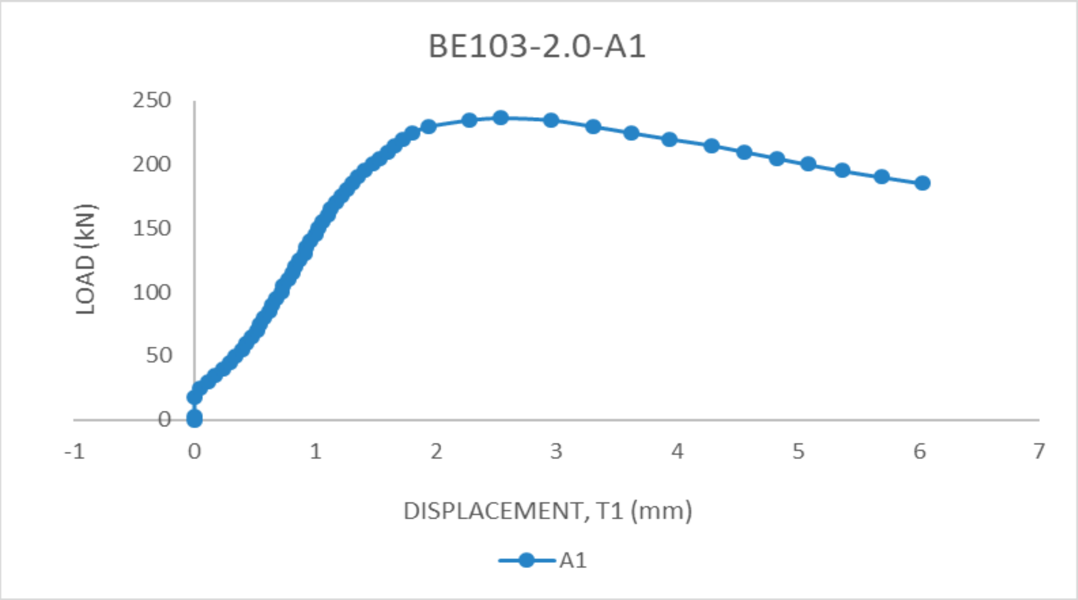


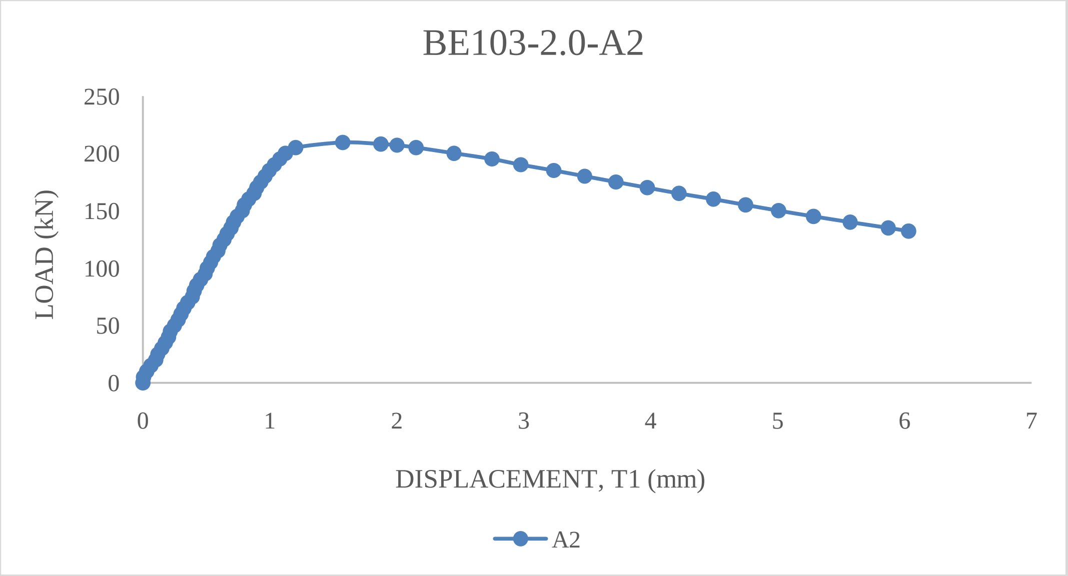


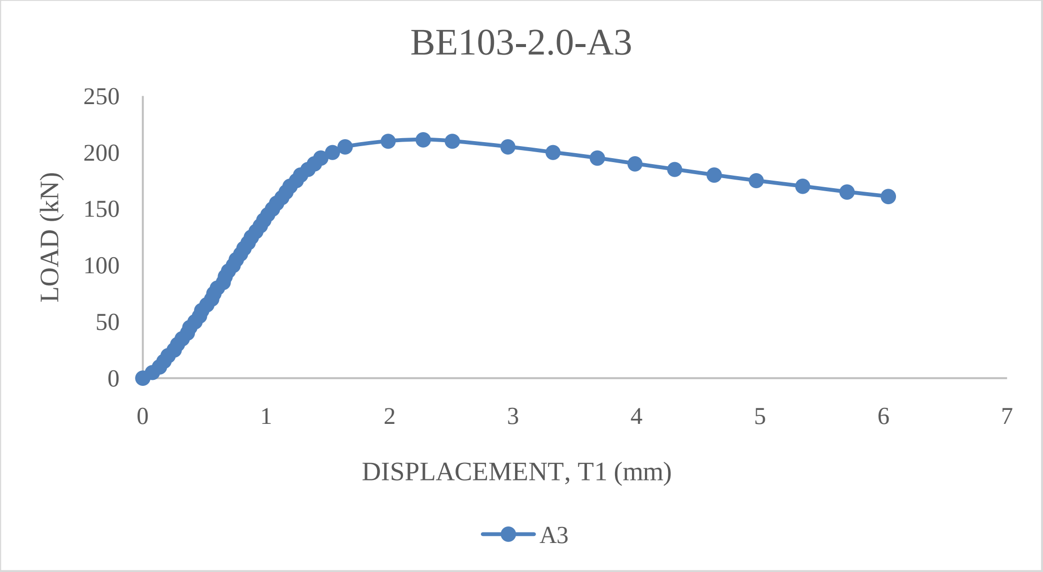

BE203-2.0-A3
LOAD (kN)
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
DISPLACEMENT,T1 (mm)
A3

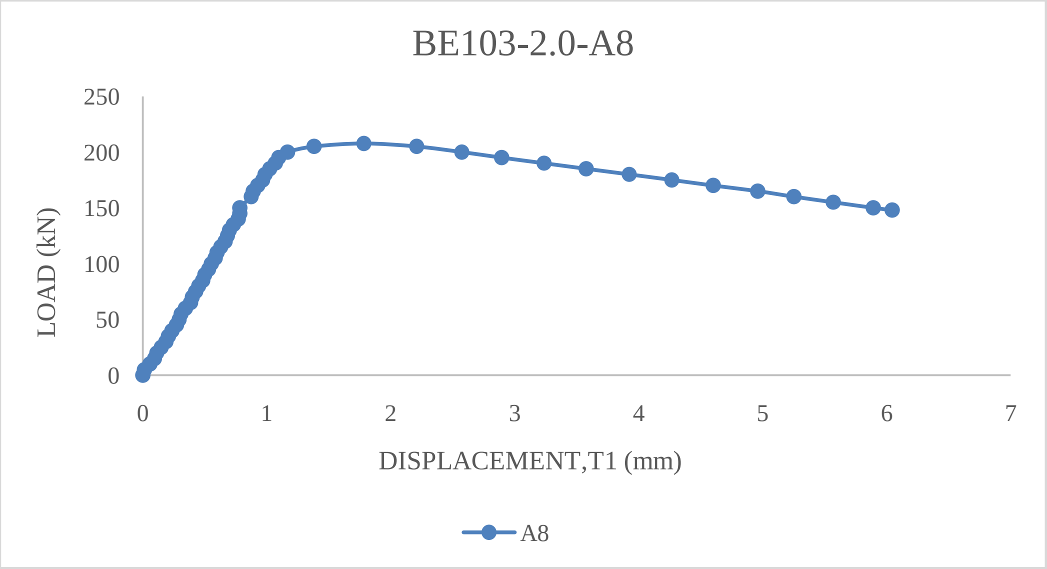

BE203-2.0-A8
LOAD (kN)
400
350
300
250
200
150
100
50
0
-1
0
1
2
3
4
5
6
7
DISPLACEMENT, T1 (mm)
A8

## GRAPH OF SPECIMEN BE203-2.0






BE103-2.0-A3
LOAD (kN)
250
200
150
100
50
0
0
1
2
3
4
5
6
7
DISPLACEMENT, T1 (mm)
A3


BE103-2.0-A8
LOAD (kN)
250
200
150
100
50
0
0
1
2
3
4
5
6
7
DISPLACEMENT,T1 (mm)
A8