SHEAR BEHAVIOUR OF PERFORATED COLD-FORMED STEEL SECTION

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SCHOOL OF CIVIL ENGINEERING
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By

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Title:

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Disertasi ini membentangkan kajian berangka pada kelakuan ricih sistem rangka keluli rumah mampu milik menggunakan keratan berlubang. Kos keluli yang tidak stabil mengakibatkan kos untuk membina rumah tidak stabil. Keratan keluli berlubang mempunyai berat yang lebih rendah daripada keluli yang biasa. Hal ini menyebabkan berat bahan pembinaan lebih ringan dan lebih murah. Walau bagaimanapun, lubang pada web keluli akan mengurangkan rintangan ricih sistem rangka keluli. Objektif kajian ini adalah untuk menentukan keupayaan ricih keratan berlubang dengan pembukaan web di bawah pembebanan ricih. Objektif kedua adalah untuk mengkaji kesan pembukaan lubang pada web kepada kapasiti ricih. Ketiga, pengurangan berat keratan berlubang dan akhir sekali untuk mencadangkan satu optimum keratan berlubang berdasarkan keputusan yang diperolehi daripada perisian LUSAS. Keratan keluli berlubang dijangka mempunyai pengurangan kos kerana bahannya telah dikurangkan oleh kawasan berlubang. Beban ricih kritikal daripada sistem rangka keluli biasa diperolehi dengan menggunakan perisian Staad Pro menurut Eurocode Standard. Keputusan yang diperolehi akan dibandingkan dengan keratan keluli berlubang. Analisis nilai eigen turut dilakukan dan keputusannya dibandingkan dengan keratan tanpa lubang. Keratan keluli optimum bagi kelakuan ricih telah ditentukan daripada keputusan dengan berbanding keratan tanpa lubang dengan kapasiti ricih dan peratusan pengurangan berat. Keratan keluli lubang dengan 8 bukaan berlian dipilih dengan peratusan kapasiti lengkokan ricih yang berbeza daripada bahagian tanpa lubang adalah 33.02% dan 48.18% dengan bukaan bulatan.

ABSTRACT

This dissertation presents a numerical study on the shear behaviour of steel framing system using perforated section. The unstable cost of steel causing cost to construct housing become unstable thus resulting in other choices of materials for construction. Perforated steel section has lower volume of steel, which cause the weight to decrease and cheaper in construction. However, perforation in steel will decrease shear resistance of steel framing system. The objective of this study is to investigate the shear behaviour of perforated steel section comparing to unperforated section in steel framing system. Perforated steel sections have lower volume of steel material as a result of perforated area. Critical shear loading from common steel framing system is obtained using Staad Pro software according to Eurocode Standard. The shear loading then transferred to model in LUSAS to perform finite element analysis. The results obtained were compared to the steel section without perforation. Eigenvalue analysis was performed and the results were compared by using eigenvalue as structure capacity. Optimal steel section for shear behaviour was determined from the results. The perforated sections were compared with unperforated section for shear capacity and percentage of volume reduction. Perforation steel section with 8 diamond openings was selected with percentage of shear buckling capacity difference from unperforated section about 33.02% and 48.18% with circle openings.

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LIST OF SYMBOLS AND ABBREVIATIONS

M	Mass
V	Volume
Ø	Diameter of openings
D	Depth of section
q_s	Shear capacity reduction factor = $\frac{\boldsymbol{Vnl}}{\boldsymbol{Vv}}$
d_{wh}	Depth of web openings
E	Young's Modulus
G	Shear Modulus
c/c	Centre to centre
FEA	Finite element analysis
QSL8	Quadrilaterial semiloof curved thin shell element
TSL6	Triangular semiloof curved thin shell element
UB	Universal Beam (Steel)
T_{ri}WP	Triangular steel beam web profile
LCB	Lipped channel beam

CHAPTER 1

INTRODUCTION

1.1 Background

In developing country such as Malaysia, the population is increasing in a remarkable pace. To sustain huge population, construction of housing must be fast and affordable. Low cost housing has become major construction development in our country to sustain large population. To take this construction field into the next level, a lot of advance methods have been introduced. In conventional low cost housing construction that using in-situ concrete, labour, and formwork need to be prepared. By using steel framing structure, precast and prefabricated formworks, housing construction has become faster, cheaper and cleaner compared to concrete frame structure. Steel members become popular with its economical design for low cost housing structure. Besides, steel structures can be erected very easily and faster than other structures and can be used soon after their erection compare to concrete structure which required curing period.

Perforated steel section is steel member with holes for various benefits such as air circulation, better mechanical and electrical services installation. Nowadays, perforated section has come in various of shape of hole, size, gauges, type of material, the shape configuration, size of web opening and distance of opening from the support which all have different impact on the structural performance. The openings in the web will reduce the shear area of the section significantly (Tsavdaridis and Mello, 2009). A lot of researchers have set their eyes on steel I-section beams with perforated section by conducting research over the past few years. Common perforated steel sections are castellated section (with hexagonal openings), and cellular beams (with circular section) perforated beam (Tsavdaridis et al., 2015).

Perforated steel section is a better choice for some construction but the choice only can be made after determining the failure of the specimens as steel often fail under the combined action of shear, moment and buckling. The presence of an opening in the web of the beam alters the stress distribution within the member and also influences its collapse behaviour. The shear transferred across sections with large openings have to be considered carefully due to the loss of proportion of the web and it is a better practice to locate the large opening remote from the high shear zones of a beam (Lawson, 1987). Therefore, the efficient design of steel sections with web openings has become one of the challenging research in designing modern structures. The provision of perforating web openings in beams has become a common engineering practice, to eliminates the probability of a service engineer cutting holes subsequently in inappropriate locations causing structure failure. Introduction of openings in the web will decrease the stiffness of the beams causing in larger deflections than the conventional beams with solid webs. This is due to the structure are subjected to high shear and heavy distortion of the web opening causing high deformation of the section (Tsavdaridis and Mello, 2011). Based on various study, the presence of web openings in beam will decrease the strength of steel plate girder (Hamoodi and Gabar, 2013). The more the perforation sizes present, the more the shear strength will decrease (Chan et al., 2013). Shear behaviour of beams with perforation openings is more complicated because their shear strengths are significantly reduced by the presence of web openings (Keerthan and Mahendran, 2013). The shear capacity of such beam is greatly influenced by the depth of the web opening (Darehsouri et al., 2013).

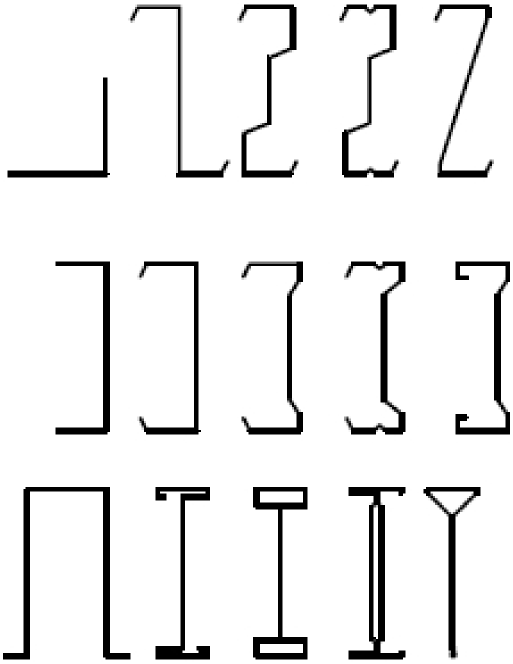
Despite all that, perforated steel section can greatly reduce the cost as compared to regular steel section without perforated section due to the reduction in weight and volume. Besides, the fabrication cost of the perforated steel section can be reduced to the price where it can be compete with open-web steel joists (Zaarour and Redwood, 1996). In addition, the design of perforation can improve the behavior of the connections by enhancing their ductility, rotational capacity and their energy dissipation capacity (Tsavdaridis et al., 2014).

1.2 Steel Framing System

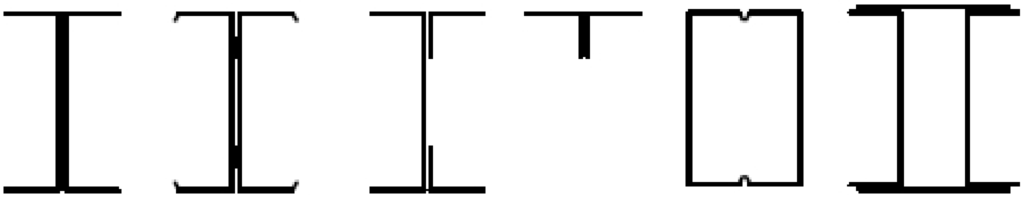
There is various building technique in current construction world today. Steel framing system is considered one of the most important construction technique as it has abundant benefits. Comparing to concrete structure, steel framing structure is obviously lighter which can solve other important factors of construction such as construction period and transportation cost. Steel structure require no formwork to build. It is easy to fabricate and mass-produce steel frame within a short time scale. The steel members can be easily replaced, assembled and disassembled. Various benefits enable rapid construction of structure which provide better construction technique to build housing or structure in disaster area where immediate accommodation has to be provided for disaster victims.

1.3 Cold-Formed Steel

Cold-formed steel is produced by rolling or pressing the steel to form steel sheets in relatively low temperature comparing to hot-rolled which require about 900˚C. Cold-formed steel provide a better surface finish, concentricity, and straightness when compared to hot rolled. This lead to easier structure buildability as cold-formed steel are more precise and easier to handle. Cold-formed Plain Channel steel section can be screwed directly on almost everywhere and perforated to allow better space utilisation. Furthermore, cold-formed steel can be formed into various shape easily by bending, cutting or grinding. Figure 1.1 shows the type of cold-formed steel shapes.



a) Single open sections



b) Open built-up sections

c) Closed built-up sections

Figure 1.1: Type of cold-formed steel shapes (ECCS Eurocode Design Manuals)

1.4 Problem Statements

The price of concrete has remained relatively stable with slight increase trend but the price of steel remained unstable throughout the years. However, the cost for a concrete framing system has increase almost comparable with the cost of a steel framing system. For economical solution, most of construction method has to be cost effective by selecting appropriate construction materials according to the cost of the materials.

Steel framing system can be enhanced by making openings at the web surface of steel beam producing perforated steel section. The section will reduce the raw material required in fabrication process as there are voids in the section. By using perforated steel framing system, raw material can be minimized as the volume of steel decreases. This inherently means that the cost of steel will be decreased as the volume decreased. The proposed section is expected to have equal or slightly lesser shear capacity comparing to the section without openings.

However, the shear behaviour of beams with perforation openings are significantly reduced by the presence of web openings (Keerthan and Mahendran, 2013). Finite element analysis is performed to analysis the proposed section to study and investigate the engineering behaviours and performance of proposed section with openings under shear loading.

1.5 Objectives

The objectives of this research are:

1. To study the shear behaviour of cold-formed steel framing system
2. To study the shear behaviour of perforated Plain Channel steel section for steel framing system

1.6 Scope of Study

This research is carried out to investigate the shear behaviour of cold-formed steel framing system under shear loading by using finite element analysis. The finite element analysis is carried out by utilizing LUSAS Finite Element Analysis software to determine the shear capacity of the proposed section. Sufficient amount of proposed models will be developed and one model of ordinary cold-formed steel section without opening is developed to compare and investigate the effect of web openings on the shear capacity and volume reduction of perforated steel section. The numerical model was limited to the correlation of variables such as opening size, opening edge distance, opening spacing, amount of opening with shear capacity and volume reduction. The model was based on single storey steel frame house loading. The section chosen was Bluescope Plain Channel LC15230 steel section with 152 x 51 with 3 mm thickness specification. This research focused only on the shear behaviour of cold-formed steel section with openings by finite element analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The use of perforated steel beams has resulted in longer span floors. Perforated steel become popular due to its utilization of space and coordination with other buildings function. Steel structure with web openings in the span are now common in modern structure. With the reduction in the volume of steel, the cost of their fabrication has been reduced to the level where for certain applications they may be competitive with other materials. Throughout the decade, researchers have tried to investigate the optimum shape of web opening in perforated steel sections, to understand the stress distribution in the vicinity of the web openings, and to identify the its structural behaviour under different types of loading. The aim is to obtain optimum web opening area for the various type of services, whilst maintaining the minimum possible self-weight for different types of loading.

2.2 Previous Research

Tsavdaridis and D’Mello (2011) conducted excellent research comprising experimental study and finite element analysis to investigate and compare the engineering behaviour of perforated steel beams with web openings. Five irregular shaped beam openings were included to investigate the mode of failure and load strength of the web-post between two adjacent web openings. Seven beam were tested and all the beams have the same 1.7m span and the position of web post in relation to the reactions so the moment-shear ratio (M/V) could be found. The experiment conducted using widely available UB457×152×52 of steel with grade S355. The diameter of opening, d_o, which equal to

0.7h was adopted so that the depth of the web openings is low enough in order to prevent Vierendeel effects prior to web-post buckling failure in perforated sections with relatively thin webs. This setting will ensures that the constant shear forces are generated and hence web-post buckling failure can occur. Finite element analyses were conducted on steel perforated beams with various web openings and compared with the experimental results. The finite element model was validated using the experiments in order to be used for the parametric study. The research established that the specimens failed under a combined action of shear and moment. High deformation was observed accompanied by heavy distortion of the web opening. Web-post buckling occurred at loads slightly in excess of that at which deformations were first noticed. In the case novel elliptical web openings were used, the critical openings length was narrower and hence the Vierendeel capacity was high. Besides, when narrow elliptical web openings are chosen, the capacity only gradually increases as Vierendeel bending is not critical. Figure 2.1, 2.2 and 2.3 show the behaviour of web.

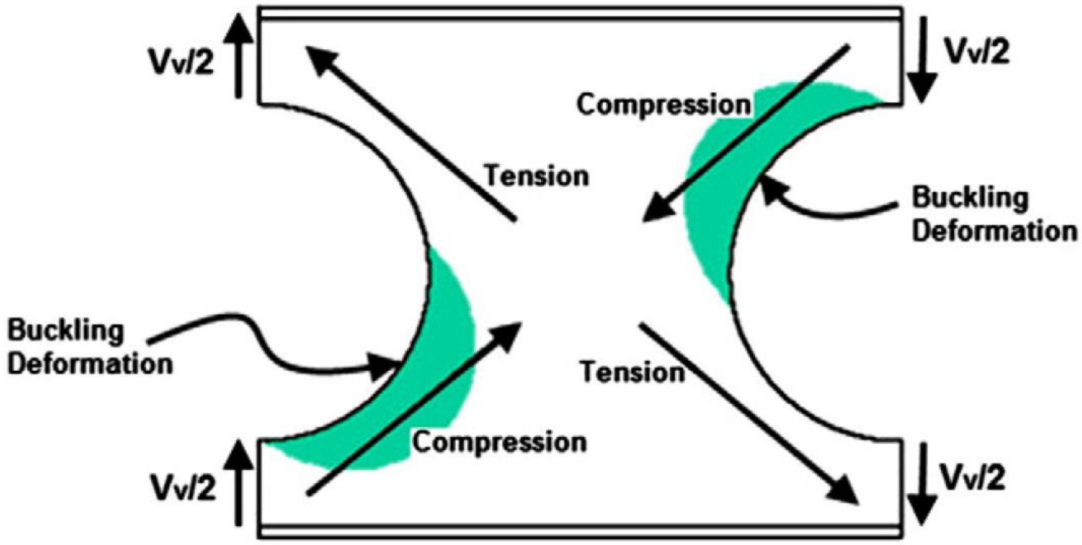


Figure 2.1: Typical web-post behaviour (Tsavdaridis and D’Mello, 2011)

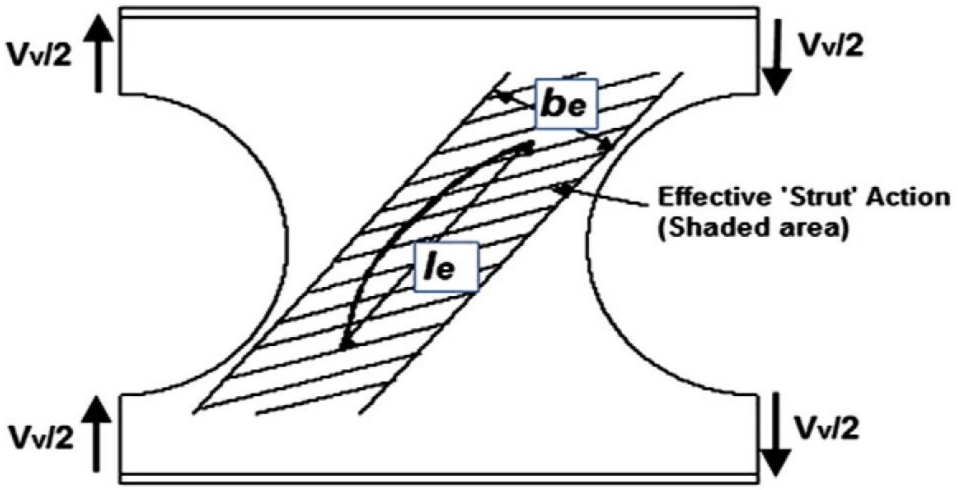


Figure 2.2: ‘Strut’model of web-post buckling (Tsavdaridis and D’Mello, 2011)

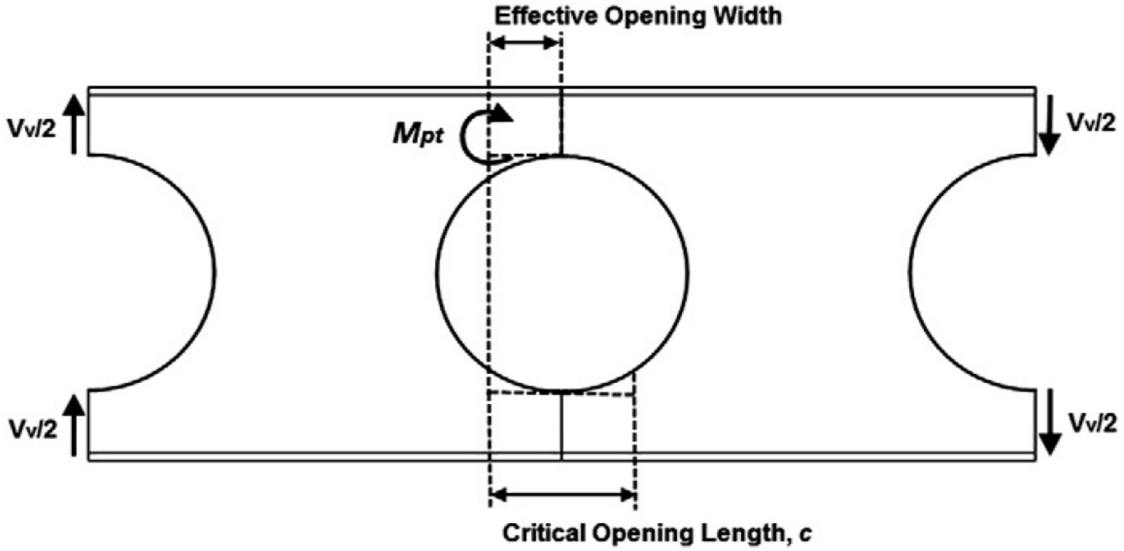


Figure 2.3: Effective opening width and critical opening length of circular web opening (Tsavdaridis and D’Mello, 2011)

Tsavdaridis and D’Mello (2009) conducted research to investigate and compare the behaviour of perforated steel beams with different shape configurations and sizes of web openings. Finite element method employed to simulate the structural behaviour of the proposed section. Eleven types of forms were chosen to compare the efficiency of the various shapes of web openings, six of these are being standard configurations including elongated web openings, whilst other five were elliptical. This study have selected beams UB457×152×52, UB457×152×82, UB610×229×101 and UB610×229×140. The analyses were conducted with a simply supported beams consisting of 5m span under uniformly distributed load. The finite element analysis found that the opening depth, critical length and the web opening shape can strongly affect the structural performance of the perforated sections. Perforated sections with vertical and rotated elliptical web openings performed better in terms of stress distribution compared to circular and hexagonal web openings. The study concludes that the different standard and non-standard web opening configuration showed that the shapes and sizes of the web openings affect the ‘Vierendeel’ mechanism. Figure 2.4 shows the geometric configuration of web openings.

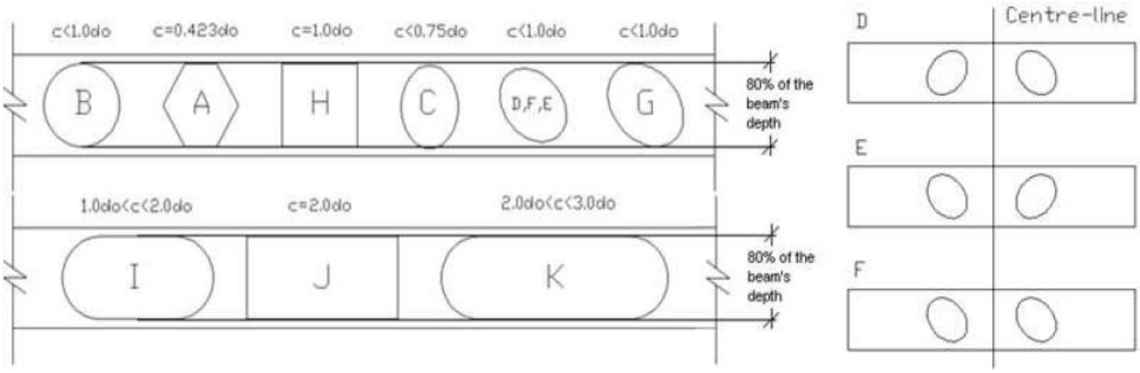


Figure 2.4: Geometric configuration of web openings and rotated elliptical web opening (Tsavdaridis and D’Mello, 2009)

Keerthan and Mahendran (2013) conducted few experimental studies on the shear behaviour and strength of cold-formed steel members such as lipped channel beams and LiteSteel beam with openings. Cold-formed lipped channel beams (LCB) are frequently used as flexural members such as floor joists and bearers. 32 shear tests were conducted to investigate the shear behaviour of LCBs with web openings and 32 models were developed using the measured material and geometric properties. Finite element analysis results were compared with the corresponding experimental data. The results showed that finite element models were able to predict the ultimate shear capacity of LCBs. The study concluded that the AS/NZS 4600 (SA, 2005) design equations are conservative for LCB sections with small web openings but not conservative with large openings. In addition, Shan et al.'s (1997) design equation are very conservative for shear capacity of LCBs with web openings. Equations shown below was proposed design equations for the shear capacity of LCBs with web openings (Keerthan and Mahendran, 2013). It was found that the equations (1), (2) and (3) predicted the shear capacity reduction factors agreed with the finite element analysis and experimental shear capacity reduction factor.

$$q_s = 1 - 0.6\left[\frac{d_{wh}}{d_1}\right] \qquad 0 < \frac{d_{wh}}{d_1} \le 0.30$$

equation (1)

$$q_s = 1.215 - 1.316\left[\frac{d_{wh}}{d_1}\right] \qquad 0.30 < \frac{d_{wh}}{d_1} \le 0.70$$

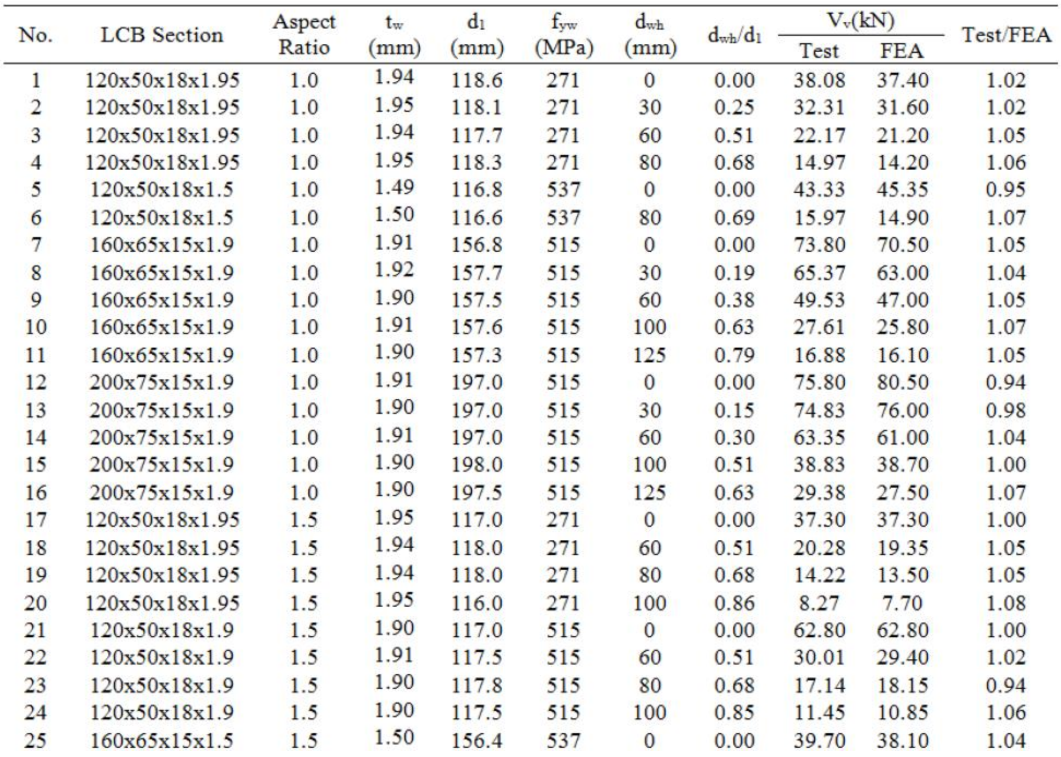
equation (2)

$$q_s = 0.732 - 0.625\left[\frac{d_{wh}}{d_1}\right] \qquad 0.70 < \frac{d_{wh}}{d_1} \le 0.85$$

equation (3)

q_s = shear capacity reduction factor = V_{nl}/V_v, d_{wh} = depth of web openings
d_1 = clear height of web

Keerthan and Mahendran (2013) also carried out the validation of finite element analysis of LCBs with web openings subjected to shear. Thirty-two models were developed using the measured material and geometric properties in experiments. Figure 2.5 shows a summary of the FEA results of applied load and a comparison of these results with the corresponding experimental results. The mean of the ratio of test to FEA applied loads were 1.02. This indicated that the finite element models developed in the study were able to predict the ultimate shear capacity of LCBs. These data also indicated a good agreement between the results from FEA with the experiments and confirmed the adequacy of the developed finite element models in predicting the ultimate loads, deflections and failure modes.



No.	LCB Section	Aspect Ratio	t_w (mm)	d_1 (mm)	f_{yw} (MPa)	d_{wh} (mm)	d_{wh}/d_1	V_v(kN) Test	V_v(kN) FEA	Test/FEA
1	120x50x18x1.95	1.0	1.94	118.6	271	0	0.00	38.08	37.40	1.02
2	120x50x18x1.95	1.0	1.95	118.1	271	30	0.25	32.31	31.60	1.02
3	120x50x18x1.95	1.0	1.94	117.7	271	60	0.51	22.17	21.20	1.05
4	120x50x18x1.95	1.0	1.95	118.3	271	80	0.68	14.97	14.20	1.06
5	120x50x18x1.5	1.0	1.49	116.8	537	0	0.00	43.33	45.35	0.95
6	120x50x18x1.5	1.0	1.50	116.6	537	80	0.69	15.97	14.90	1.07
7	160x65x15x1.9	1.0	1.91	156.8	515	0	0.00	73.80	70.50	1.05
8	160x65x15x1.9	1.0	1.92	157.7	515	30	0.19	65.37	63.00	1.04
9	160x65x15x1.9	1.0	1.90	157.5	515	60	0.38	49.53	47.00	1.05
10	160x65x15x1.9	1.0	1.91	157.6	515	100	0.63	27.61	25.80	1.07
11	160x65x15x1.9	1.0	1.90	157.3	515	125	0.79	16.88	16.10	1.05
12	200x75x15x1.9	1.0	1.91	197.0	515	0	0.00	75.80	80.50	0.94
13	200x75x15x1.9	1.0	1.90	197.0	515	30	0.15	74.83	76.00	0.98
14	200x75x15x1.9	1.0	1.91	197.0	515	60	0.30	63.35	61.00	1.04
15	200x75x15x1.9	1.0	1.90	198.0	515	100	0.51	38.83	38.70	1.00
16	200x75x15x1.9	1.0	1.90	197.5	515	125	0.63	29.38	27.50	1.07
17	120x50x18x1.95	1.5	1.95	117.0	271	0	0.00	37.30	37.30	1.00
18	120x50x18x1.95	1.5	1.94	118.0	271	60	0.51	20.28	19.35	1.05
19	120x50x18x1.95	1.5	1.94	118.0	271	80	0.68	14.22	13.50	1.05
20	120x50x18x1.95	1.5	1.95	116.0	271	100	0.86	8.27	7.70	1.08
21	120x50x18x1.9	1.5	1.90	117.0	515	0	0.00	62.80	62.80	1.00
22	120x50x18x1.9	1.5	1.91	117.5	515	60	0.51	30.01	29.40	1.02
23	120x50x18x1.9	1.5	1.90	117.8	515	80	0.68	17.14	18.15	0.94
24	120x50x18x1.9	1.5	1.90	117.5	515	100	0.85	11.45	10.85	1.06
25	160x65x15x1.5	1.5	1.50	156.4	537	0	0.00	39.70	38.10	1.04

Figure 2.5: Comparison of ultimate shear capacities of LCBs from finite element analysis and experimental tests (Keerthan and Mahendran, 2013)

(Hasan, 2017) studied the efficiency of I beam steel section with perforated corrugated web profile. Three hundred and eighty-four models of Triangular Web Profile (TriWP) have been studied to investigate four types of loading conditions such as bending, lateral torsional buckling, torsion and shear deformation using finite element analysis. The study has conducted in 2 stage to determine the structural efficiency of each models.

When the perforation size increases, the percentage of weight reduction also increases thus increases structural efficiency. It was found that with the perforation of diamond in shape and 0.4D in size showed the lowest torsional rotation and lowest deflection under torsional and bending loading conditions respectively. It showed the highest shear buckling capacity and highest buckling moment resistance under shear and lateral torsional buckling loading conditions. Therefore, the highest value of structural efficiency and most efficient perforation shape, size and layout were identified.

In stage 2, web and flange thickness were increased under the same span length and constant flange and web depth, the value of deflection and torsional rotation of model decreased under bending and torsional loading conditions, respectively. Furthermore, shear buckling capacity of model was found to increase in shear loading condition and the value of moment buckling resistance also increased under loading causing lateral torsional buckling. Besides, it was found that increase in span length of model results in higher deflection, lower moment buckling resistance, higher torsional rotation and lower shear buckling capacity.

Eldib (2009) carried out a comparative investigation into the behaviour of trapezoidal and curved corrugated steel webs using finite element analysis. The model conditions were set by modelled the connection between the corrugated web and, flanges and stiffeners as simply support boundary conditions as shown in Figure 2.6 to gain the lower shear capacity of the web. The finite element model for trapezoidal web with flanges and stiffeners were also carried out as it represented experimental tests carried out by other researchers. The study shows that flanges and stiffeners produce a small effect on the shear buckling parameter, which can be ignored. Therefore, the proposed approach of finite element analysis using only a corrugated web plate to minimize the computational efforts and the proposed boundary conditions was adopted throughout the study. Both models with or without flanges and stiffeners were studied and analysed. It is found that the maximum difference between the two finite element models due to the presence of stiffeners and flanges and also due to bending stresses is about 3%, which was an ignored error. Thus, the proposed finite element model for corrugated webs without flanges and stiffeners using the proposed boundary conditions can be used to estimate the shear buckling parameter of corrugated steel webs with negligible errors.

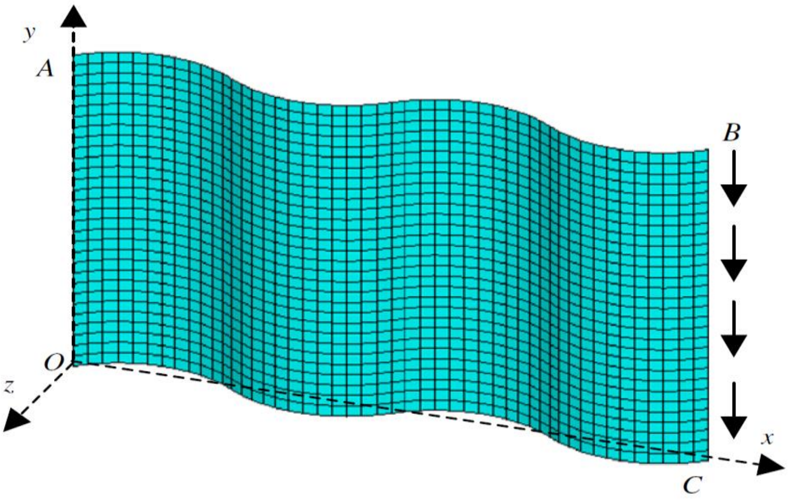


Figure 2.6: Boundary condition of finite element model (Eldib, 2009)

2.3 Summary

This chapter summarised previous research conducted on shear behaviour of steel structural elements, behaviour of steel structural elements with openings, study on cold-formed steel section and finite element method. It was found that finite element method is definitely a reliable method to predict shear buckling capacity of cold-formed steel section by utilising eigenvalue buckling analysis.

Perforation on steel section has many benefits on construction field today. However, unpredictable and uncertainties can still occur around the openings. Therefore, a thorough finite element analysis was conducted to ascertain the claim.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter present description of the research methodology. There are two stages in this methodology. First stage is to study basic single storey cold-formed steel framing system according to Eurocode 3. Stage 1 focus on the design of basic single storey cold-formed steel frame structure. Allowable load and specification by Eurocode 3 is applied. Staad.Pro software was then performed structural analysis and design check. Figure 2.1 shows the structure design using Staad.Pro. A suitable cold-formed section is chosen for this steel frame structure. From the structural analysis, maximum and critical shear force was recorded.

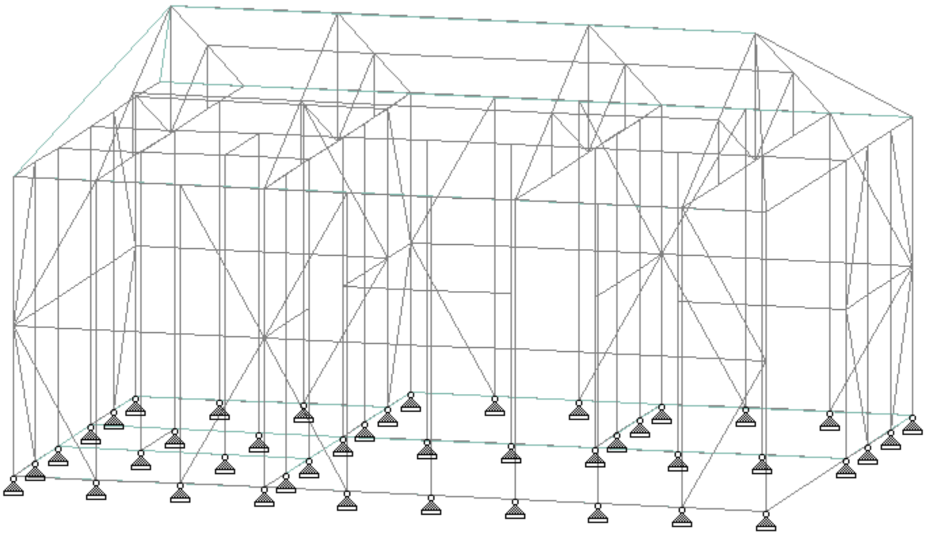


Figure 3.1: Structure design using Staad.Pro

In the stage 2, finite element analysis was performed using LUSAS software. The section selected was analysed based on shear behaviour.

3.2 Finite Element Analysis

Finite element analysis (FEA) is a type of computerized method for analysing and predicting the behaviour of a physical system with respond to the real-world forces. Finite element analysis can analyse whether the product will fail to withstand its designated condition. Finite element analysis is a process of discretize geometrical model into a large number of elements and using mathematical equations to help predict the behaviour of each element. The behaviours then sum up and combined to obtain the whole picture of the behaviours of the actual object.

This research was conducted using LUSAS finite element software to develop models for finite element analysis using perforated section. The shear behaviour is assessed by obtaining the shear buckling capacity of the section proposed. The volume reduction represents the saving in raw materials. The variables are the size of opening, shape of opening, spacing between opening, position of opening and arrangement of opening. All proposed section models were compared to control model which is a normal steel framing section. All models have a constant span of 1000mm.

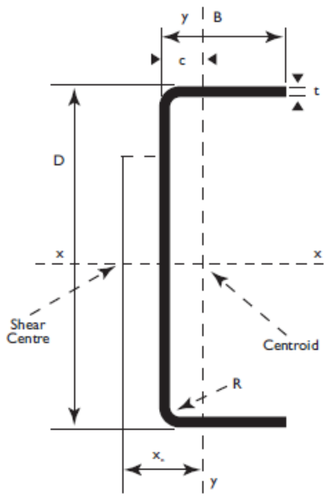
3.3 Model Attributes

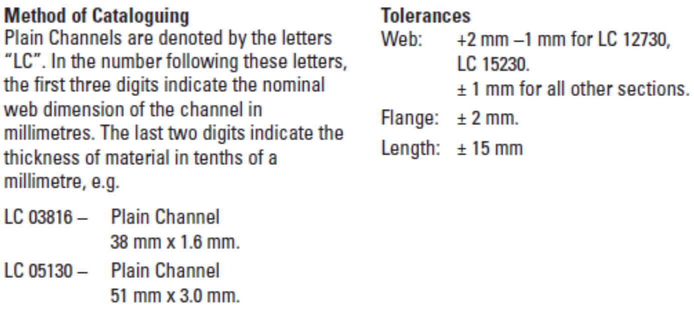
Model attribute data are required to set for defining the properties of the model in LUSAS.

The models were constructed using point, line and surface for further analysis.

3.3.1 Geometry

The geometry of the proposed model can be referred to Bluescope Lysaght Plain Channel Steel Section LC15230. The catalogue is shown in Figure 3.2.

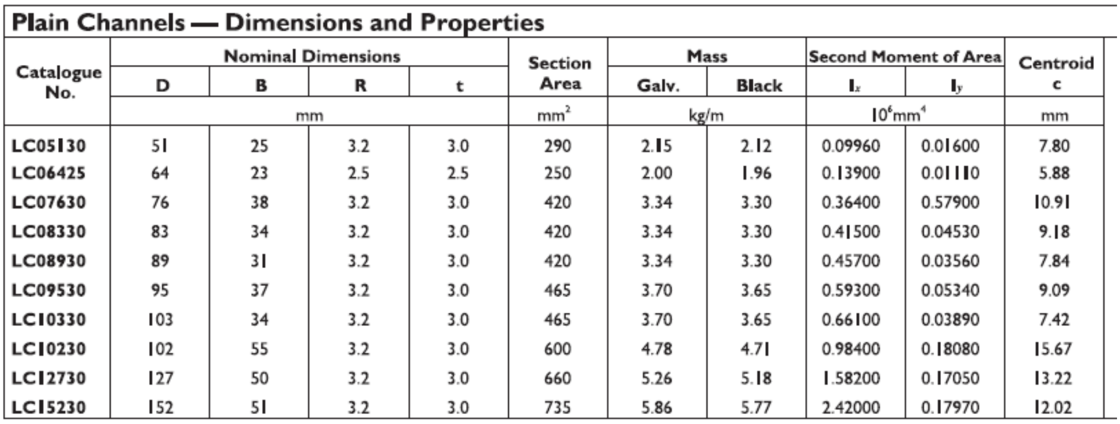



Method of Cataloguing
Plain Channels are denoted by the letters "LC". In the number following these letters, the first three digits indicate the nominal web dimension of the channel in millimetres. The last two digits indicate the thickness of material in tenths of a millimetre, e.g.

LC 03816 –	Plain Channel 38 mm x 1.6 mm.
LC 05130 –	Plain Channel 51 mm x 3.0 mm.

Tolerances

Web:	+2 mm –1 mm for LC 12730, LC 15230. ± 1 mm for all other sections.
Flange:	± 2 mm.
Length:	± 15 mm


Plain Channels — Dimensions and Properties

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

Figure 3.2: Section properties of cold-formed plain channel steel section (Bluescope Lysaght Plain Channel Section Catalogue)

3.3.2 Shear Loading Conditions

Support and loading positon as shown in Figure 3.3 was adopted from Hasan (2017); Eldib (2009); Nie et al. (2013); Hamoodi & Gabar (2013). The symbols of ABCD are presenting the location of the end nodes of the model. The support conditions for the model consist of pinned support at left side end i.e. AB. It is constrained in x, y and z translation for pinned supported end. Meanwhile, along AC, CD and BD, the supports are constrained in x and y translation. A concentrated load was exerted vertically (in the z-axis) to simulate a pure shear loading condition where the shear force due to applied concentrated load will be carried by the web. According to Hasan (2017), the flanges are replaced with simple support boundary condition for conservative consideration and models with or without flanges showed no changes in eigenvalue buckling and buckling modes.

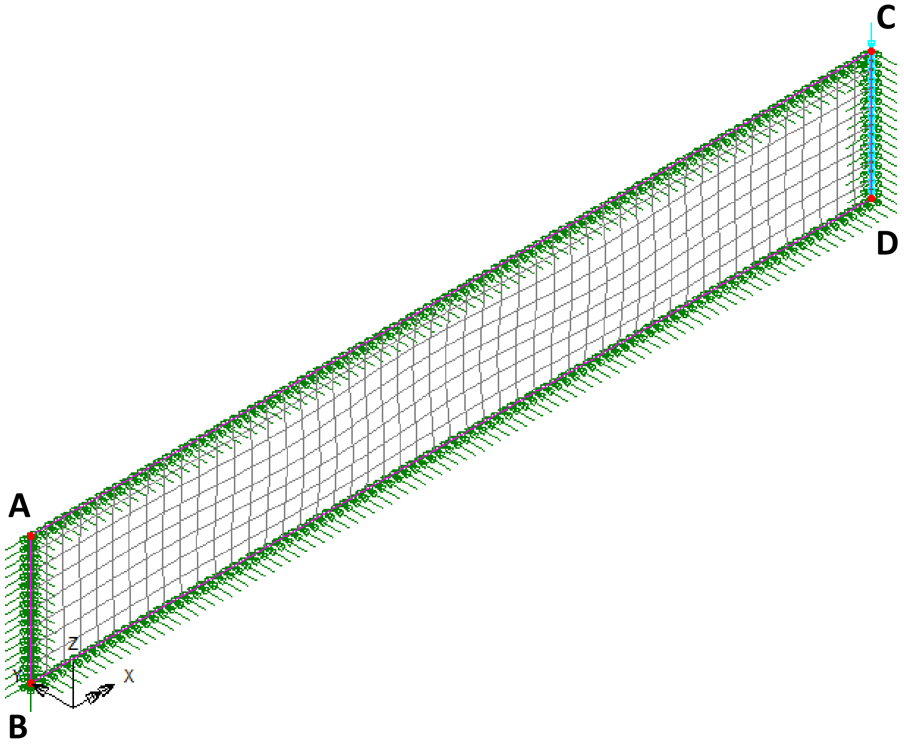


Figure 3.3: Support and loading position of model for shear loading condition

3.3.3 Material Properties

Material assigned to the model is steel with the Young’s Modulus of 200000 N/mm^2 which is the average value for steel. The Poisson ratio used in this study is 0.3 for all the models. In this study, eigenvalue shear buckling and deformation are considered.

3.3.4 Model Meshing

Meshing describes the element type and discretisation on the model geometry. The type of meshing use in all the models is thin shell. The order of interpolation of the meshing used is quadrilateral (QSL8). They are ideal for analysing flat and curved 3 dimensional shell structures where the transverse shear effects do not influence the solution. Aspect ratio is one of the important consideration in meshing. Element size used was 20mm which was obtained from convergence study conducted.

3.4 Procedure

The research work flow is as shown in Figure 3.4.

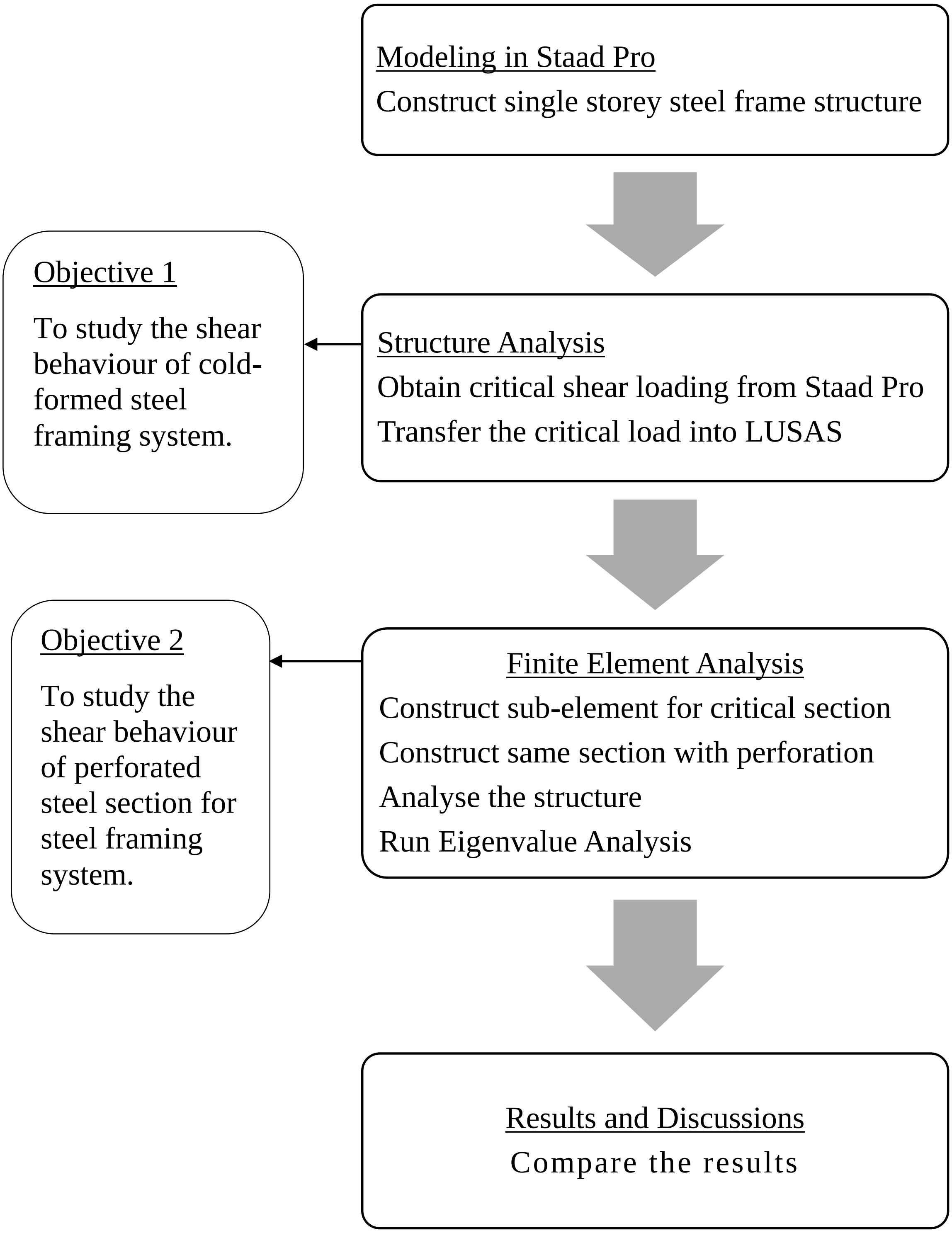


Figure 3.4: Research flow chart

3.5 Finite Element Analysis Procedure

The finite element analysis work flow is as shown in Figure 3.5.

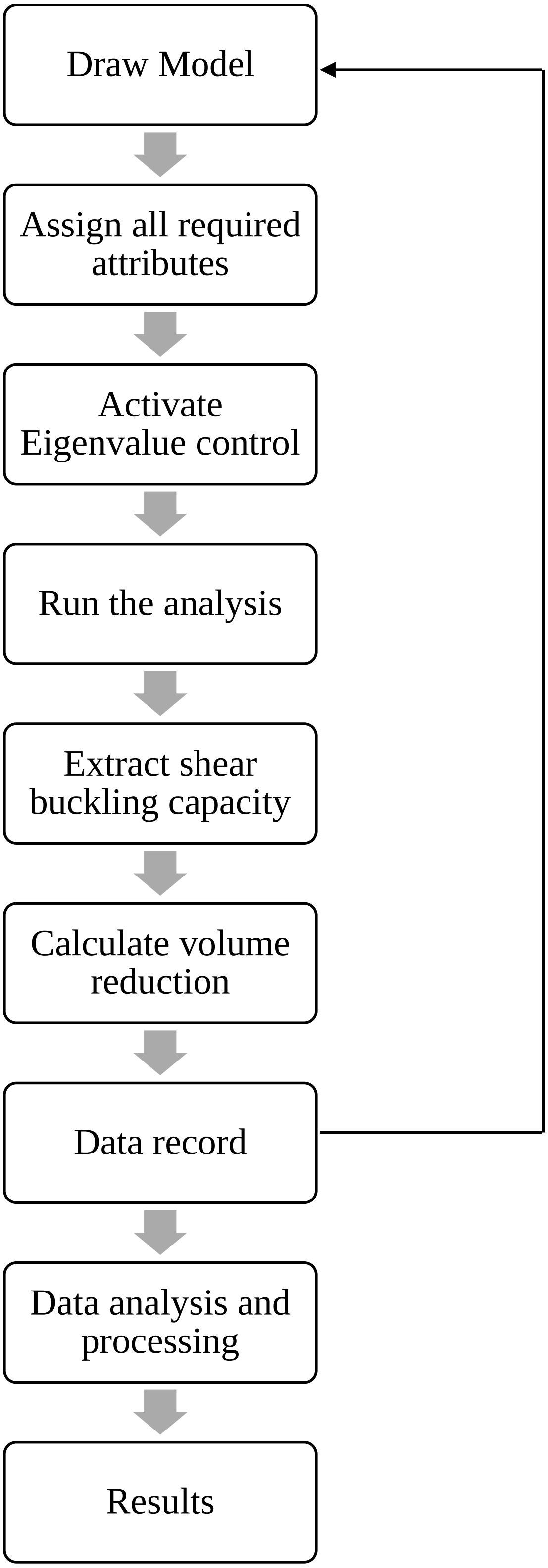


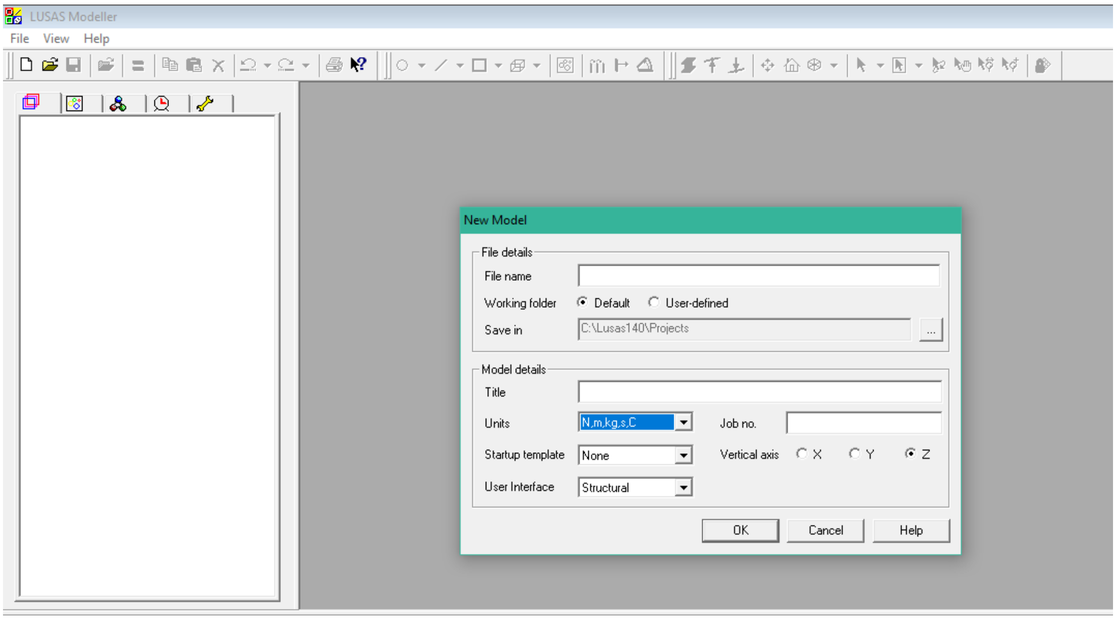
Figure 3.5: Research flow chart

3.6 Detailed LUSAS Modelling Procedure

The detailed procedure for modelling a proposed section by LUSAS is as outlined below:

1. Create a new model as shown in Figure 3.6.1.

    - File > New
    - Key in file name and model title
    - Set the units as N, m, kg, s and C
    - Select z-axis as the vertical axis



File details

File name

Working folder ● Default ○ User-defined

Save in C:\Lusas140\Projects

Model details

Title

Units N,m,kg,s,C

Job no.

Startup template None

Vertical axis ○ X ○ Y ● Z

User Interface Structural

Figure 3.6.1: ‘New model’ window

2. Define the origin point as shown in Figure 3.6.2 and Figure 3.6.3.

    - Geometry > Point > Coordinates
    - Check on ‘3 columns’ for Grid style
    - Key in (0,0,0) and click ’OK’

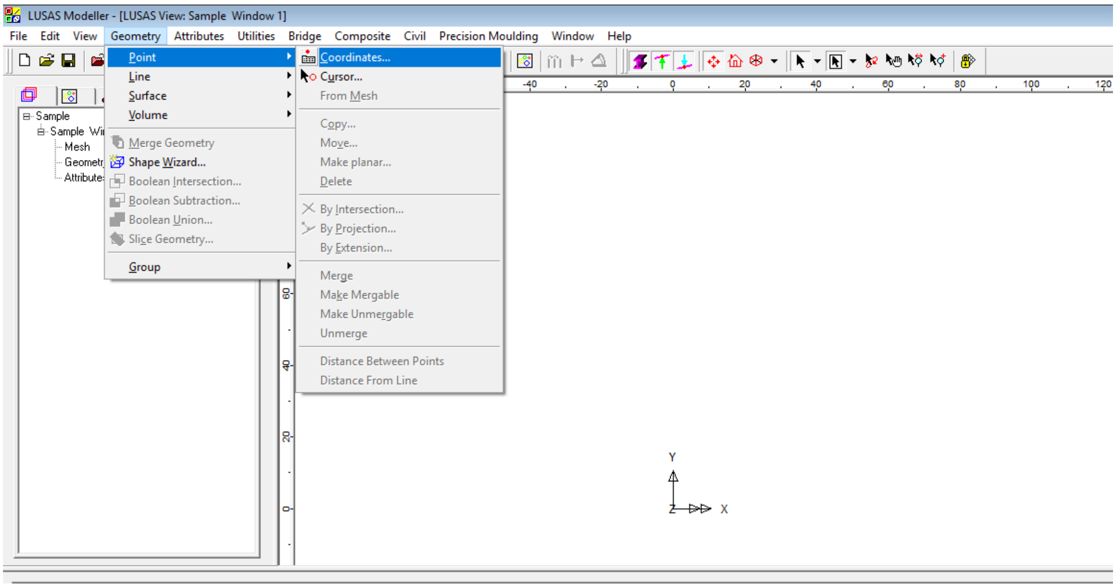
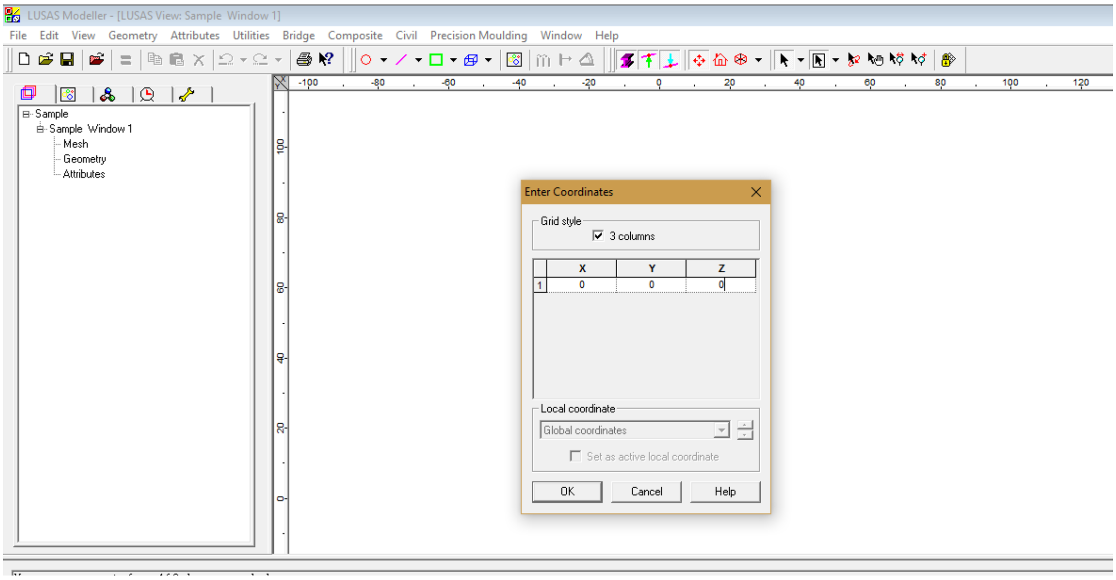


Figure 3.6.2: Coordinate option in LUSAS



Grid style: ☑ 3 columns

	X	Y	Z
1	0	0	0

Local coordinate: Global coordinates

☐ Set as active local coordinate

Figure 3.6.3: Coordinates input table

3. Copy, transform and create surface from origin point as shown in Figure 3.6.4 and Figure 3.6.5.
    - Using the point created, translate using points to create model
    - Form lines from the points defined
    - Create surface from the connecting lines
    - From the surface, define and create hole