

Study on Flexural Behaviour of Cold Formed Steel Built-Up I Beams Composed of Two Sigma Sections

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ABSTRACT: Cold formed steel sections are predominantly upgrading the steel construction as it replaces the use of the hot rolled steel sections. Cold formed steel sections (CFS) having many advantageous that it is lighter in weight, high strength and stiffness, high strength to weight ratio and greater flexibility in forming shapes over the hot rolled sections. Though it has the drawback since it undergoes the local and distortional failure as it is being thin walled members. In this paper, the flexural behaviour of CFS built-up I beams have been investigated by combined numerical and theoretical study. The built up I beams were composed of two sigma sections (C sections with longitudinal V stiffener) with cover plates at top and bottom bolted at the flanges of the channel section. The finite element modelling was developed using ABAQUS software for numerical analysis to simulate the behaviour and the strength of the built up I beams with sigma sections. The direct strength method (DSM) was used to find the moment carrying capacity of the built up beams theoretically. Finally, the results from the numerical and theoretical analysis were compared and has showed a reasonable agreement between them.

KEYWORDS: Built up I beams, Cold formed steel beams, Flexural behaviour, Sigma sections, Thin walled members

I. INTRODUCTION

Cold formed steel sections are predominantly upgrading the steel construction as it replaces the use of the hot rolled steel sections. The commonly formed CFS sections are C and Z sections, because of their simple forming but these sections are characterised by certain buckling modes. Built up sections, with the advantage of flexibility in forming different sectional shapes to meet design requirements have been used in a wide range of constructional steel applications. The built-up sections also have huge potential in terms of improved strength and stiffness when compared to single profiles of cold formed steel members as the sections are thin walled members.

The instability phenomena such as local, distortional, lateral torsional buckling and their interactions are the most interesting and complex. These buckling modes are mostly responsible for the ultimate strength of the compression members as they may occur even before parts of the cross section yield. The local buckling failure in thin walled sections can occur under compression, bending or shear loading. Although local buckling occurs at a stress level lower than the yield stress of steel, it does not necessarily represent the collapse of the members. Distortional buckling is a mode of failure where a section changes its cross-sectional shape under compressive stress. Distortional buckling may occur for comparatively short beams. When distortional buckling occurs, the web distorts and the flanges twist and deflect laterally. When I sections are used as beams or beam columns the compression flange is under compressive stress and has a tendency to buckle but it is attached to the tension flange which resists the buckling giving rise to torsion within the beam section. This torsion twists and warps the unrestrained part of beam leading to lateral torsional buckling.

II. LITERATURE REVIEW

Luis Laim (et al) 2013[6] conducted a research study on the structural behaviour of cold formed steel beams with C-, I-, R-, 2R, shaped cross sections at ambient temperature and concluded that the use of hollow sections can increase the load carrying capacity of beams by 1.45 times when compared to the open sections. **Meza et al (2016)**[7] an experimental program was carried out on built up I beams constructed by bolting four pain channels together. Three different connector spacing were used to study their effect on the ultimate capacity of the built up specimens. The tests revealed that by reducing the spacing between connector results in an increase of the ultimate capacity.

Imanfaridmehr et al (2016)[10] investigated the behaviour and design of cold formed steel C-sections with cover plates under bending. Cover plates with three different thickness were used to evaluate the slenderness effects on the performance of the sections installed at top flanges only where it would be predicted to fail by local and distortional buckling. The result explicitly showed that the cover plate reduced the slenderness which resulted in improving buckling capacity. In current scenario, only little work has been carried out on the structural behaviour of built up sections as flexural members. So the proposed work aims to study the structural behaviour and moment capacity of the cold formed steel built up I beams.

III.METHODOLOGY

This paper is entirely split up into the following works. 1) Literature study: Various Studies are being conducted on behavior cold formed steel sections by adopting different sections using available design methods. Some of the literatures which are relevant to this study are collected and studied. 2) The selection of section as per codal provisions. The section dimensions were selected based on North American Specification for the design of cold-formed steel structural member-2012 edition, Euro code 03 and Australian / New Zealand standard code (AS/NZS 4600:2005). 3) A literature about cold-formed steel built-up beams has been selected and their experimental results have been validated with the Finite Element modelling. Moment capacities, load-deflection curvature and failure modes has been validated. 4) A parametric study has been done for the selected section by varying the thickness and the yield stress and 5) the numerical analysis is done using ABAQUS software. 6) The theoretical analysis of these sections are done by Direct Strength. 7) The results from the numerical analysis and the theoretical analysis are compared and discussed.

IV. SECTION AND ITS PROPERTIES

As per European standards (EN-1993-1-3) for the design of cold-formed steel structural members, the flat b/t limits are available for single section only. Based on the single section, suitable Built-Up section is selected. The figure Fig 1 shows the labelling of the section. The section dimensions were selected based on North American Specification for the design of cold-formed steel structural member-2012 edition, Euro code 03 and Australian / New Zealand standard code (AS/NZS 4600:2005). The figure Fig. 2. a, b, c, below shows the Section details considered for Study. Table 1 shows the geometric details of selected sections.

Material Properties:

- Yield strength (Fy) is 250, 350 & 450 N/mm²
- Young's Modulus (E) is 2.1 x 10⁵ N/mm²
- Poisson's Ratio is 0.3
- Material model – Elastic-Perfectly plastic.

Member Properties:

- Thickness of section (t) is 1.0, 1.5 and 2.0mm
- Length of the specimen is 2000mm with constant moment span of 666 mm.
- End condition is simply-supported.

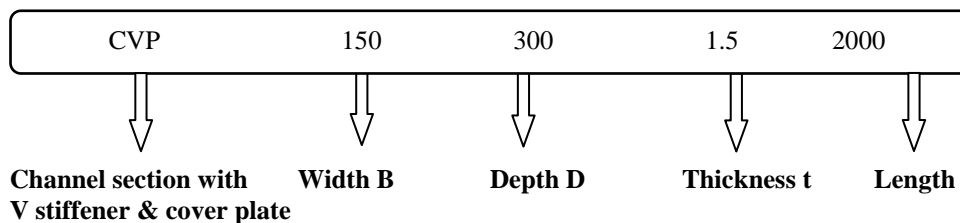
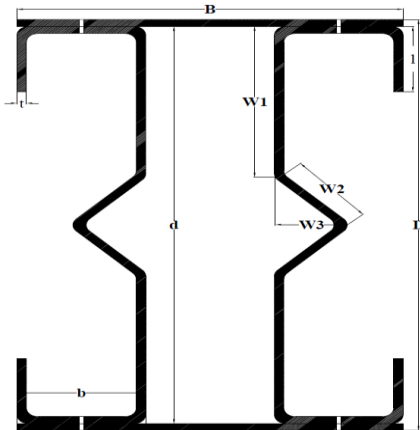


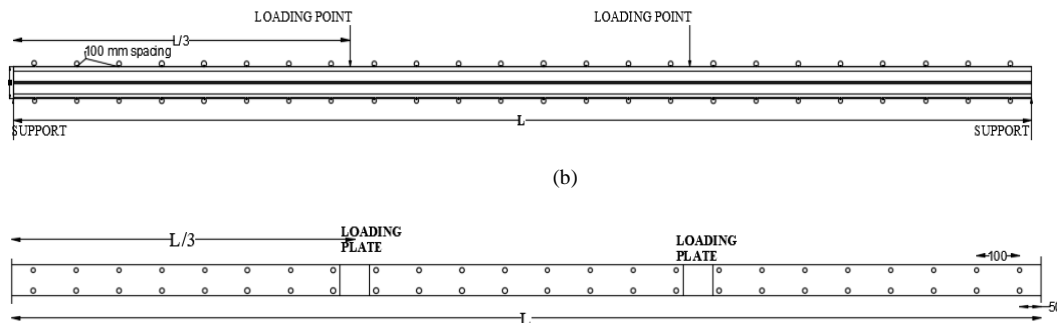
Fig. 1. Labelling of the specimen



(a)

Table 1. Dimensions of the built up I beam composed of sigma section selected for study

Section Name CVP-B-D	Overall dimension		Channel dimension W3=0.5b				
	Flange B	Web D	Flange b	Web	W1	W2	Lip l
	mm	mm	mm	mm	mm	mm	mm
CVP-150X300	150	300	50	297	123.50	35.36	20



(b)

(c)

Fig. 2. (a) Cross section of the selected section (b) Longitudinal side view of the section (c) Top view of the section showing the loading points

V. FINITE ELEMENT MODELLING AND VALIDATION

Finite element analysis is capable of predicting the ultimate moments and complex failure modes of cold-formed steel structural members. The main purposes of the FE analyses is to examine the accuracy of the method proposed in Section VI for the flexural design of cross-sections. In this study, ABAQUS [1] standard version 6.13 is used as a finite element tool. Detailed geometric and material non-linear FE analyses were performed using ABAQUS [1] to evaluate the flexural behaviour and capacity of the considered section (see Table 1). The two important stages in Abaqus are: Linear analysis (Eigen value buckling analysis) and Non-Linear buckling analysis.

The analysis have been done in the following procedure. The section was created based on the centre line dimensions. The material properties like young’s modulus, Poisson’s ratio, yield stress were defined and assigned to the sections. Then sections were assembled together using part instance. The section was converted into a finite element model by using mesh module. The reference points and constraints were created at both the ends. Then the boundary conditions were defined at both the ends based on the support condition. Unit load was applied at reference point. Then the Eigen value buckling analysis was performed and deformed mode shape was obtained. Geometrical (local) imperfection was considered for the deformed shape and fed as an input for the non-linear analysis.

For validation process, the numerical model and the experimental results obtained from the test results given by - *Luís Laímet al (2013)*[6] were used. The validation has been done using ABAQUS [1] software. The section used for numerical model and simulations taken from the selected literature. The numerical investigation of the tested specimen is done using software and the results were obtained. It is observed that reasonable agreement has been achieved between both results. The FE modelling approach has been validated. The comparison between the moment capacities of the tested specimens, and those computed by the finite element analysis are presented in Table 2 and showed a reasonable agreement between the finite element results and FEM results given in the literature. Thus the adopted FEM procedure has been validated.

Table 2 – Comparison of FEM results with experimental results from the literature

Section taken for validation	Ultimate Moment capacity arrived using ABAQUS $[Mu]_{FEM}(kNm)$	Ultimate Moment capacity taken from experimental results of literature $[Mu]_{EXP}(kNm)$	$[Mu]_{EXP}/[Mu]_{FEM}$
I-250-1.5-3000	9.63	10.03	1.041

VI.PARAMETRIC STUDY

In this thesis, the verified FE model was used to perform an extensive parametric study using ABAQUS 6.13. The aim of the parametric study is to understand the different buckling behavior of the cold-formed steel built-up I beams. For the selected cross section dimensions, three different yield stress were considered for parametric study. The thickness of the specimen varies from 1.0, 1.5 and 2.0 mm. All of the beam specimens were modelled under four-point bending with the pin-to-pin length of 2000mm and constant moment span of 666 mm. The numerical study has been conducted for 9 specimens with varying parameters and the yield strength and the details of the section properties are given in the section IV. The specimen were analysed under four point bending configuration. The built up beams have a distance between the end supports of 2000mm. the specimen was loaded at two points, a distance of 666 mm apart and 667mm from the end supports. The spacing between the connectors along the span was 100 mm at the flanges for all the specimens.

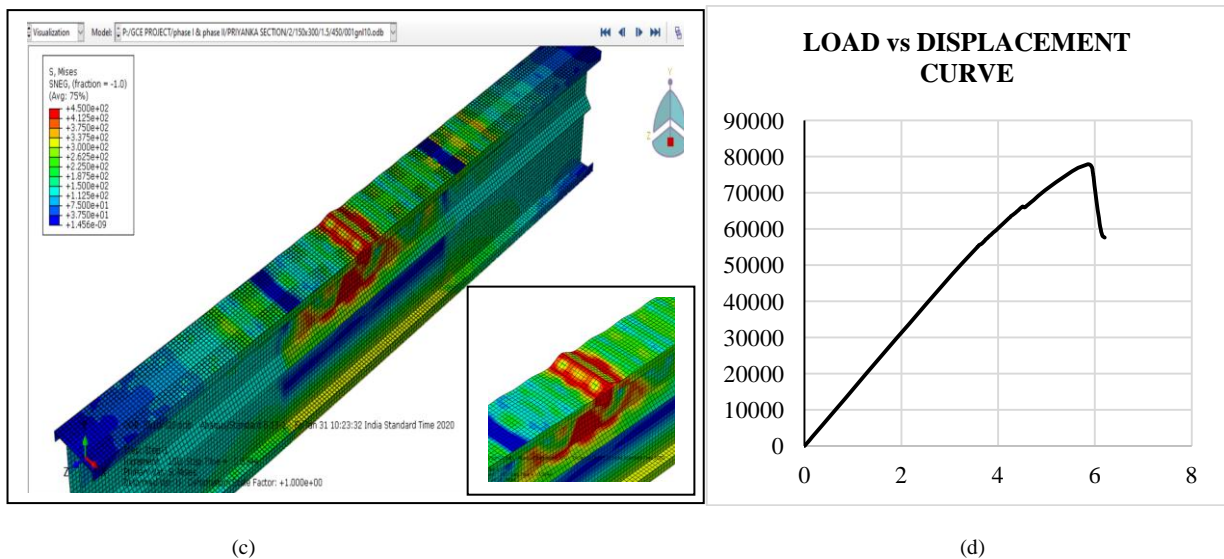
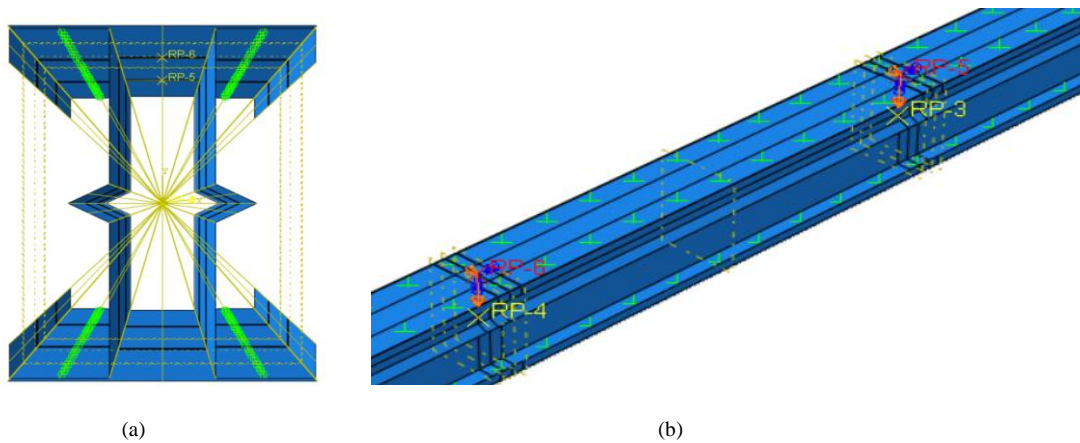


Fig. 3. (a) Cross section of the section showing ABAQUS model with constraints (b) Longitudinal view of the section showing the loading points and application of loads (c) Local buckling failure from the Non-linear analysis result (d) The load- Displacement curve from the ABAQUS.



In ABAQUS [1], the length of the beam was along z axis and the x-y axis plots the cross section. 1, 2 and 3 (U1, U2, U3) represent translations, whereas 4, 5 and 6 (UR1, UR2, UR3) represent the rotations along x, y and z directions, respectively. At pinned end support, 1, 2, 3 and 6 were restrained, whereas in roller end support, 1, 2 and 6 were restrained. Unit load was applied at reference point. Eigen buckling analysis was done and the modes of failure is identified. A geometric imperfection of 0.34t is provided during Nonlinear Analysis. The numerical analysis for the selected sections were done and the resultant load obtained and the moment carrying capacity of each sections are calculated. A graph was plotted between the load and displacement. From this graph, the ultimate load is taken and the ultimate moment capacity (in Nmm) calculated are given in the Table 3.

Table 3 – Numerical analysis results for cross section CVP 150x300

S.no	SECTION BXD	THICKNESS t (mm)	STRESS (N/mm ²)	ULTIMATE LOAD (N)	MOMENT (Nmm) M _{FEA}
1	CVP 150x300	1	250	27508.2	1.8339E+07
2			350	34918	2.3279E+07
3			450	39788.7	2.6526E+07
4		1.5	250	47386.5	3.1591E+07
5			350	63115.5	4.2077E+07
6			450	77921.4	5.1948E+07
7		2	250	79219.4	5.2813E+07
8			350	99722.4	6.6482E+07
9			450	107979	7.1986E+07

VII. THEORETICAL ANALYSIS

After completion of Numerical analysis, Finite element modelling results were compared with theoretical results by Direct Strength Method (DSM method). The moment carrying capacity of the built-up beams composed of two sigma sections with cover plates at top and bottom subjected to local buckling is evaluated. DSM method requires section properties for modelled specimens. To obtain section properties, analysis was done using CUFSM software.

DIRECT STRENGTH METHOD

Model calculation of CVP-150-300-1.5-2000 specimen for 450 MPa Yield stress is shown below as per DSM in accordance with North American Specification (AISI-S100:2012). Using CUFSM software, geometric properties and elastic instabilities of the models were found.

Lateral-Torsional Buckling Strength

If $M_{cre} < 0.56 M_y$, $M_{ne} = M_{cre}$

If $2.78M_y \geq M_{cre} \geq 0.56 M_y$, $M_{ne} = 10M_y [1 - (10M_y / 36M_{cre})] / 9$

If $M_{cre} > 2.78M_y$, $M_{ne} = M_y$

Where M_{cre} = Critical elastic lateral-torsional buckling moment
= 831.30 kNm

$M_y = S_f F_y$, where S_f = Section modulus
 $M_y = 74.92$ kNm
 $M_{ne} = 74.92$ kNm



Local Buckling Strength

Critical elastic local buckling moment determined by analysis, M_{cr1}

If $\lambda_1 < 0.776$, $M_{nl} = M_{ne}$

If $\lambda_1 > 0.776$, $M_{nl} = [1 - 0.15(M_{cr1}/M_y) 0.4] (M_{cr1} / M_y) 0.4 M_{ne}$

$\lambda_1 = (M_{ne}/M_{cr1})0.5$

$=0.636$

$M_{nl} = 59.89 \text{ kNm}$

$M_n = 59.89 \text{ kNm}$

The buckling Strength of the specimen (M_n) is taken as the minimum of the values of Lateral Torsional Buckling Strength (M_{ne}) and Local Buckling Strength (M_{nl}) as per DSM method.

VIII. RESULT AND DISCUSSION

The numerical study of the cold formed steel built-up I beams has been done using the two sigma sections with cover plates at top and bottom flanges. The results of non-linear numerical analysis indicated local buckling failure in modelled specimens. The local buckling moment as per DSM in accordance with North American Specification (AISI-S100:2012) is studied. The predicted strengths found by existing DSM equation is found to be conservative for the cross section considered in the study with a mean of 0.84. The results of the parametric study by varying the thickness of the material and the yield stress for the built up I beam is shown below in Table 4.

Table 4 – Comparison of numerical results with the theoretical results

S.no	SECTION BXD	THICKNESS t (mm)	STRESS (N/mm2)	λ_1	M_{FEA}	M_{DSM}	M_{FEA}/M_{DSM}
					kNm	kNm	
1	CVP 150x300	1.00	250	1.241	18.339	20.714	0.885
2			350	1.469	23.279	25.809	0.902
3			450	1.665	26.526	30.366	0.874
4		1.50	250	0.818	31.591	40.282	0.784
5			350	0.967	42.077	50.627	0.831
6			450	1.097	51.948	59.892	0.867
7		2.00	250	0.615	52.813	66.536	0.794
8			350	0.745	66.482	80.051	0.830
9			450	0.825	71.986	95.236	0.756
						MEAN	0.84

IX. CONCLUSION

In thesis, the load carrying capacity and failure modes of built up sections have been studied numerically. Modelling using ABAQUS software and analysis procedure was studied. For validation, a Non-linear finite element analysis was developed and verified against the experiment results from the literature. The FE model includes the material model proposed by Luis Laím [6]. Upon validation of FE model, the numerical studies were conducted to investigate the structural response of the selected built up I beams composed of two sigma sections with cover plates. Parametric study was done on the selected section based on three yield stresses and three thickness. Thus there becomes a total 9 sections for the numerical analysis and the results are interpreted. The theoretical study was done using Direct Strength method. Comparison of FEM and DSM result is done. The predicted strengths found by existing DSM equation is found to be

conservative for the cross section considered in the study with a mean of 0.84. Also it is found that the longitudinal stiffeners and the cover plates at top and bottom could reduce the slenderness of the elements and thus improving the sectional capacity.

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