

# Structural Behaviour of Web Stiffened Cold Formed Steel Built up Beams

Shiva Sankari J<sup>1</sup>, Amali D<sup>2</sup>

P.G. Student, Department of Civil Engineering, Government College of Engineering, Salem, Tamil Nadu, India<sup>1</sup>

Assistant Professor, Department of Civil Engineering, Government College of Engineering, Salem, Tamil Nadu, India<sup>2</sup>

**ABSTRACT:** The structural performances of the cold formed steel have been widely investigated over the past few decades. The most complex within this field are the instability phenomena such as distortional, local and lateral distortional buckling and their interaction thereof. The cold formed steel built-up sections have huge potential in terms of improve strength and stiffness, especially compared to single profiles. This work represents the structural behavior of cold formed steel built up beams with web stiffener. Intermediate web stiffeners were used to improve the buckling strength. The built up section is formed by placing two web stiffened channels and a cover plates at the top and bottom connected by using self- tapping screws as fasteners to the flanges of the channel sections. The buckling strength of the selected sections were investigated numerically using finite element software ABAQUS. The parametric study has been carried out by varying depth to breadth ratio and thickness. The results obtained from the numerical analysis were compared with the results predicted by using direct strength method in accordance with the North American Specification (AISI-S100:2007) and has showed a reasonable agreement. Thus, also it is concluded that the web stiffened sections will improve the flexural capacity by reducing the slenderness of the elements.

**KEYWORDS:** cold formed steel built up beams, web stiffener, structural behaviour

## I. INTRODUCTION

The structural performances of the cold formed steel have been widely investigated over the past few decades. The most complex within this field are the instability phenomena such as distortional, local and lateral distortional buckling and their interaction thereof. The cold formed steel built-up sections have huge potential in terms of improve strength and stiffness, especially compared to single profiles. Cold-formed steel sections such as C-sections with or without lips, I-sections, Z-sections, angle sections and tubular are normally used as flexural members. When single sections are failed to provide sufficient resistance for the design loads, built-up sections are used as flexural members.

Thin sheet steel products are extensively used in building industry, and range from purlins to roof sheeting and floor decking. These thin steel sections are cold-formed, i.e. their manufacturing process involves forming steel sections in a cold state (i.e. without application of heat) from steel sheets of uniform thickness.

This work represents the structural behaviour of cold formed steel built up beams with web stiffener. The built up section is formed by placing two web stiffened channels and a cover plates at the top and bottom connected by using self- tapping screws as fasteners to the flanges of the channel sections. The buckling strength of the selected sections were investigated numerically using finite element software ABAQUS.

A numerical parametric study is carried out by varying depth to breadth ratio and thickness of the section. Theoretical study is carried out by using direct strength method in accordance with the North American Specification (AISI-S100:2007). The results obtained from the numerical analysis were compared with the results predicted by using direct strength method.

## II. GEOMETRIC DETAILS OF SECTION

In this thesis, the built up section is formed by placing two web stiffened channels and a cover plates at the top and bottom which is connected by using self- tapping screws as fasteners to the flanges of the channel sections. 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. A numerical parametric study is carried out by varying depth to breadth ratio (D/B) of 1.25, 1.5 and 2.0 and thickness is varied about 1.5, 2.0 and 2.5 of the section. Labelling indicates outside dimensions of section with all values in mm, For example, in specimen VC-200-80-1.5, the first term 200 indicates the overall depth(D) of the section, 80 indicates the outer width(b) of the channel section and the last term 1.5 indicates thickness(t) of plate in mm respectively. Cover plates are provided through out the length of the specimen at the top and bottom of the section. Stiffener is provided at the web of the

channel. The channel is stiffened at the middle at an angle 45 with a horizontal length of 0.25b, where b is the width of the flange. The specimens were modelled for a span of 2000mm with a connector spacing of 100 mm that connects the cover plate to the flanges of the web stiffened channels at both top and bottom of the built up section. Figure 1 and 2 shows the cross section view and side view of the proposed built up section and the table 1 shows the geometrical details of the selected section for the study.

The cross section has been selected by varying the depth to breadth ratio of the section and parametric study is carried out by varying the thickness of the section about 1.5, 2.0 and 2.5 mm

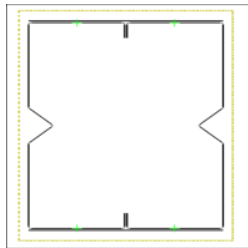


Figure 1 Cross Section Of Built Up Beam

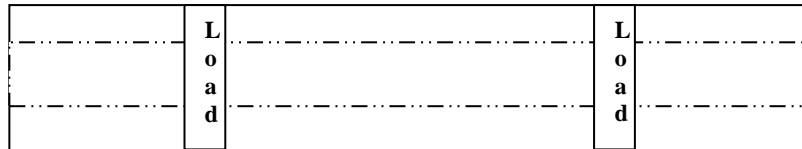


Figure 2 Specimen side view

S No	D/B Ratio	Section	Web (mm)	Flange (mm)	Thickness (mm)	Lip (mm)
1	1.25	VC-200-80-1.5	197	160	1.5	20
2		VC-200-80-2.0	196	160	2.0	20
3		VC-200-80-2.5	195	160	2.5	20
4	1.5	VC-180-60-1.5	177	120	1.5	20
5		VC-180-60-2.0	176	120	2.0	20
6		VC-180-60-2.5	175	120	2.5	20
7	2.0	VC-200-50-1.5	197	100	1.5	20
8		VC-200-50-2.0	196	100	2.0	20
9		VC-200-50-2.5	195	100	2.5	20

Table 1 Geometric Details Of Selected Sections

### III. VALIDATION OF FINITE ELEMENT MODEL

Finite element analysis is capable of predicting the ultimate moments and complex failure modes of cold-formed steel structural members. In this research, ABAQUS standard version 6.13 is used as a finite element tool. Nonlinear analysis results including the ultimate moment and moment-rotation curves are compared with corresponding experimental results. Comparison of results from nonlinear analysis thus enabled a complete validation of the numerical model. For validation of numerical model, experimental results obtained from the test results reported by R. Senthilkumar, T.S. Sunil, P. Jayabalan (2019) were used.

The validation has been done using ABAQUS software. In this paper the ultimate strength of cold formed steel hollow flange channel beams which has the failure modes of local, distortional and lateral torsional buckling under uniform bending.

A numerical parametric study has been carried out by varying flat width thickness ratio, depth of the beam, depth of the hollow flange and length of the beam. The finite element model results were compared with the AS/NZS 4600:2005 code for cold formed steel structures. The material properties like young's modulus, poissons ratio and yield stress considered as per the experimental results given in Anapayan et al. (2011a). All the beams are modelled for simply supported conditions. The applied load is transferred through 10 mm thick plate of 25 × 130 mm, which is modelled as a rigid body.

The load is applied at the shear centre, which acts as the rigid body reference node and transfers the load to the beam. Two-point loading applied at points one-fourth of the span is called quarter point loading. It develops uniform moment in the span between the two point loads. For modelling the hollow flange channel beam, general purpose shell element S4R5 (4-noded doubly curved thin shell element with reduced integration). Thus the adopted FEM procedure has been validated. The comparison of the experimental and finite element analysis, failure mode of specimen 200X75X2 is chosen, shown in Fig (2) and Fig (3). It is observed that reasonable agreement has been achieved between both results.

The comparison between the ultimate moment 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 test results. Hence, the adopted FEM procedure has been validated

Section	Span (mm)	M <sub>u,Exp</sub> (KNm)	M <sub>u,FEA</sub> (KNm)	M <sub>u,Exp</sub> /M <sub>u,FEA</sub>
250X75X2	3000	34.13	33.95	1.005
300X60X2	3500	17.17	17.18	0.999
300X60X2	4000	18.09	17.95	1.007

Table 2 comparison of FEM results with test results

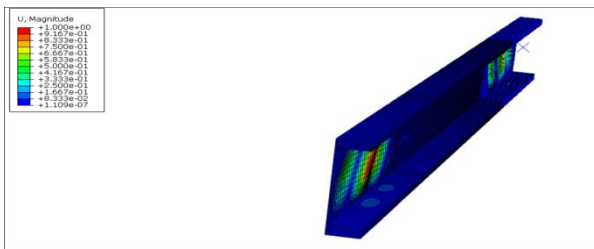


Figure 2 Linear buckling Analysis - 200X75X2

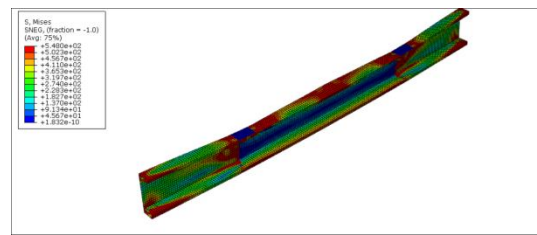


Figure 3 Non Linear buckling Analysis - 200X75X2

#### IV. DEVELOPMENT OF FINITE ELEMENT MODELS

##### 1. Finite Element Models

Finite Element Analysis is one of the common methods used to analyse static and dynamic, numerical method for solving engineering problems by mathematical equations. One of the purposes using finite element method is to predict the performance of design, understand the physical behaviours of a modal and identify the weakness of the design accurately to obtain the safety. Finite element analysis is capable of predicting the ultimate moments and complex failure modes of cold-formed steel structural members. In this research, ABAQUS standard version 6.13 is used to simulate the flexural behaviour of built up beams. For this purpose, appropriate material properties, initial geometric imperfections are used.

##### 2. Description

The Material Properties used

- Yield strength ( $f_y$ ) is 250 N/mm<sup>2</sup>
- Young's Modulus of elasticity (E) is  $2.1 \times 10^5$  N/mm<sup>2</sup>
- Poisson's Ratio is 0.3
- Material model – Elastic-Perfectly plastic

All the beams are modelled for simply supported conditions. The numerical models were discretised with the reduced integration four-noded shell element with reduced integration was selected from the ABAQUS element library. This element uses three translational and three rotational degrees of freedom at each node (S4R). The specimens were modelled for a span of 2000mm with a connector spacing of 100 mm that connects the cover plate to the flanges of the web stiffened channels at both top and bottom of the built up section. In the FE model, four points bending was adopted in order to study the bending moment capacity. Two vertical loads were applied at two points with a constant moment span of  $667(L/3)$  mm. Simply supported boundary conditions and load application were simulated to the maximum precision to reproduce experimental setup. In ABAQUS, 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. Eigen buckling analysis was done and geometric imperfection of  $0.34t$  is provided during Nonlinear Analysis.

Figure 4 and 5 shows the modeling of specimen, boundary and loading conditions applied in finite element modelling. Two vertical loads were applied at two points with a constant moment span of (L/3) mm.

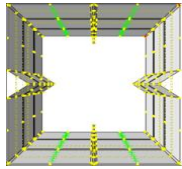


Fig 4 Modelling Specimen

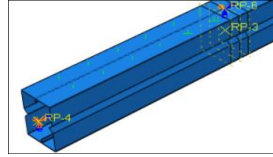


Fig 5 Boundary Conditions and Loading

The static non-linear analysis to determine the ultimate moment carrying capacity ( $M_u$ ) of built up section is carried out using ABAQUS for various parameters and results are given in Table 3. The deformation mode of 180x60x1.5 are shown in figure (6). Figure(7) shows the force displacement curve obtained from finite element analysis which shows the ultimate load carrying capacity of specimen 180-60-1.5

S.No	D/B Ratio	Section	Yield Stress( $F_y$ ) N/mm <sup>2</sup>	Moment Carrying Capacity ( $M_{FEA}$ ) kNm
1	1.25	200x80x1.5	250	23.285
		200x80x2.0	250	34.9753
		200x80x2.5	250	44.3442
2	1.5	180x60x1.5	250	17.4326
		180x60x2.0	250	21.622
		180x60x2.5	250	32.7311
3	2	200x50x1.5	250	19.438
		200x50x2.0	250	25.0672
		200x50x2.5	250	32.4058

Table 3 Ultimate Moment Carrying Capacity ( $M_{fem}$ ) Using Finite Element Analysis

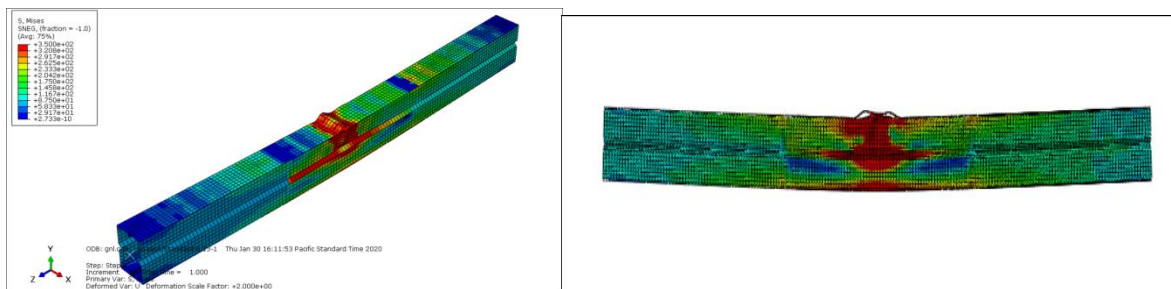


Figure 6 Deformation mode-180x120x1.5 from Non Linear Analysis

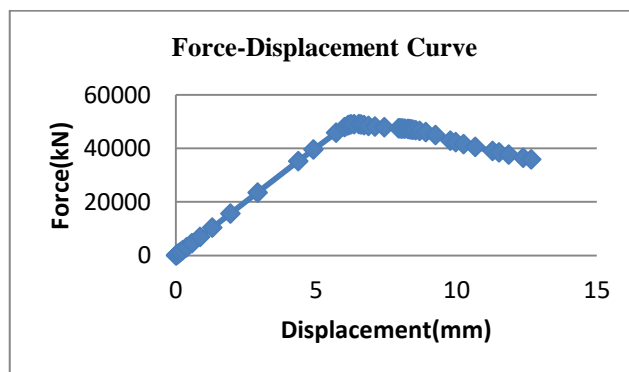


Figure 7 Force-Displacement Curve

## V.THEORETICAL ANALYSIS

Direct Strength Method includes the interaction between adjacent elements and makes the calculations simpler in obtaining the bending strength of complex cross-sections. Shorter half-wave length buckling modes such as local and distortional may interact with long half-wave length modes such as lateral-torsional buckling. The interactions between the buckling modes are also considered in this method. Design procedure based on DSM was incorporated in the North America and Australian/New Zealand Standard for Cold-Formed Steel Structures. This method has been used successfully to predict the distortional buckling strength of flexural and compression members. Direct strength method is based on the linear elastic stability analysis. Here, elastic instability modes are determined (local, global and distortional buckling mode) and then based on the reduction factors for the corresponding buckling curves, the predictable strength of CFS is calculated. After completion of Numerical analysis, Finite element modelling results were compared with theoretical results by DSM method. DSM method requires section properties for modelled specimens. To obtain section property, analysis was done using CUFSM software. Model calculation of VC-200-80-1.5-2000 specimen for 250 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.

## a) Lateral-Torsional Buckling Strength

$$M_{cre} < 0.56 M_y$$

$$M_{ne} = M_{cre}$$

$$2.78 M_y \geq M_y \geq 0.56 M_y$$

$$M_{ne} = 10 M_y [1 - (10 M_y / 36 M_{cre})] / 9$$

$$M_{cre} > 2.78 M_y$$

$$M_{ne} = M_y$$

$$M_y = S_x F_y = 29.57 \text{ kNm}$$

$$M_{ne} = 29.572 \text{ kNm}$$

## b) Local Buckling Strength

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

$$\lambda_1 < 0.776$$

$$M_{nl} = M_{ne}$$

$$\lambda_1 > 0.776$$

$$M_{nl} = [1 - 0.15 (M_{cr1} / M_y)^{0.4}] (M_{cr1} / M_y)^{0.4} M_{ne}$$

$$\lambda_1 = (M_{ne} / M_{cr1})^{0.5} = 0.476$$

$$M_{nl} = 30.77 \text{ kNm}$$

## c) Distortional Buckling Strength

Critical elastic Distortional buckling moment determined by analysis,  $M_{crd}$

$$\lambda_d < 0.673$$

$$M_{nd} = M_{ne}$$

$$\lambda_d > 0.673$$

$$M_{nd} = [1 - 0.22 (M_{crd} / M_y)^{0.5}] (M_{crd} / M_y)^{0.5} M_{ne}$$

$$\lambda_d = (M_{ne} / M_{crd})^{0.5} = 0.476$$

$$M_{nd} = 30.09 \text{ kNm}$$

$$M_n = 29.572 \text{ kNm}$$



The buckling Strength of the specimen (Mn) is taken as the minimum of the values of Torsional Buckling Strength (Mne), Local Buckling Strength (Mnl) and Distortional Buckling (Mnd) Strength as per DSM method. Table 4 shows the parametric results obtained from finite element analysis and direct strength method.

S.No	D/B ratio	section	Yieldstress( $f_y$ ) N/mm <sup>2</sup>	M <sub>FEA</sub> kNm	M <sub>FEA</sub> /M <sub>DSM</sub> kNm
1	1.25	200x80x1.5	250	23.285	0.77373
		200x80x2.0	250	34.9753	1.163122
		200x80x2.5	250	44.3442	1.481014
2	1.5	180x60x1.5	250	17.432	0.835137
		180x60x2.0	250	21.622	1.005958
		180x60x2.5	250	32.7311	1.557392
S.No	D/B ratio	section	Yieldstress( $f_y$ ) N/mm <sup>2</sup>	M <sub>FEA</sub> kNm	M <sub>FEA</sub> /M <sub>DSM</sub> kNm
3	2	200x50x1.5	250	19.438	0.884717
		200x50x2.0	250	25.0672	1.144814
		200x50x2.5	250	32.4058	1.487603

Table 4 Parametric Study Results

VI. SUMMARY AND CONCLUSION

- In this thesis, The built up section which is formed by placing two web stiffened channels and a cover plates at the top and bottom connected by using self- tapping screws as fasteners to the flanges of the channel sections to form a closed section was analysed. The load carrying capacity and failure modes of built up section have been studied numerically. Finite element modelling is done by using the ABAQUS software and analysis procedure was studied.
- Parametric study was done on sections based on depth to breadth ratio and thickness. These are the section analysed using ABAQUS software.
- The results of non-linear numerical analysis indicated lateral torsional buckling failure in all modelled specimens.
- Theoretical study was done using Direct Strength method in accordance with the North American Specification (AISI-S100:2007). Comparison of FEM and DSM result is done. The buckling behaviour of the beam is studied and the Ultimate moment is determined. Thus, also it is concluded that the web stiffened sections will improve the flexural capacity by reducing the slenderness of the elements.

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