



## BEHAVIOUR OF COLD-FORMED STEEL BUILT-UP CLOSED SECTION WITH INTERMEDIATE WEB STIFFENER UNDER BENDING

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### ABSTRACT

In this paper, a study on experimental and numerical investigation of the flexural strength and behaviour of cold-formed steel built-up closed section with intermediate web stiffener is presented. Totally, nine built up beams with various cross section geometries are experimented under simply supported end condition with two point loading. The section geometries are chosen such that all types of buckling modes are met with. A finite element model is developed using ANSYS and verified with experimental results and found to be in good agreement. The material and geometric nonlinearities are included in the finite element model. The results indicate that flange width and depth of intermediate stiffener is significantly affecting the strength and buckling behaviour of the member. The experimental and finite element analysis results are compared with the strength predicted from the North American Iron and Steel Institute Specification for the cold-formed steel structure and suitable recommendations are made based on the results. The accuracy of the proposed design equation is established by comparison with an experimental results reported by other researchers.

**Keywords:** Cold-formed steel; built-up box section; intermediate stiffener; flexural strength; design rules.

### 1. INTRODUCTION

Currently cold-formed steel section has been widely used across many countries in the construction industry. But, it is developing in India now. A cold formed steel section has been utilized in various forms in construction projects. The built-up section is one of the most used cold formed steel sections when single section is no longer sufficient for design

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load. Cold-formed built up section are commonly used as a flexural member or members of roof trusses in the building. The failure modes depend on the dimension/shape and the slenderness ratio of the member. The addition of the intermediate web stiffener to the web can delay the local buckling failure and increase the strength.

De Wolf et al. [1] investigated local and overall buckling behaviour of cold-formed steel box-shaped built-up section. Beshara and Lawson [2] investigated the behaviour of cold-formed steel built-up box section and the test results were compared with the AISI design specification for cold-formed steel structure. Based on the test results, they recommended that the nominal moment capacity of the built-up box section should be considered equivalent to 75% of the combined nominal moment capacities of its components.

Yu and Schafer [3] have done many tests on local buckling of cold-formed steel C, Z section flexural member. Serrette [4] investigated the flexural performance of cold formed steel built-up box section under eccentric and edge loading conditions. Young and Chen [7] discussed the behaviour of cold-formed steel built-up closed section with intermediate stiffener under compression. The flexural behaviour of cold-formed steel C-section with upright, inclined and complex edge stiffeners was discussed by Wang and Zhang [8]. Xu et al. [9] displayed a finite element simulation of the flexural behaviour of cold-formed steel built-up box section subjected to an eccentric loading condition. They offered a modification factor in the current design practice (AISI) for evaluating the flexural strength of the box section when subjected to eccentric loading. Behaviour of cold-formed complex section with intermediate stiffeners was investigated by Chen et al. [11]. The importance of the intermediate stiffener in the compression flanges was discussed by Haidarali and Nethercot [12]. Kankanamge and Mahendran [13] presented a parametric study of cold-formed steel lipped channel beam subject to lateral-torsional buckling using ABAQUS. They discussed the effect of steel grade, thickness, section geometry, and span and also provided relevant information about the maximum and minimum size of lips. They proposed the three design curves, based on the moment capacities. Seo and Mahendran [14] investigated the ultimate strength and behaviour of litesteel flexural members with web opening. Pham et al. [16] discussed the load carrying capacities and behaviour of a series of new innovative complex cold-formed steel C-section in pure bending. Manikandan et al. [17] displayed an importance of edge stiffeners.

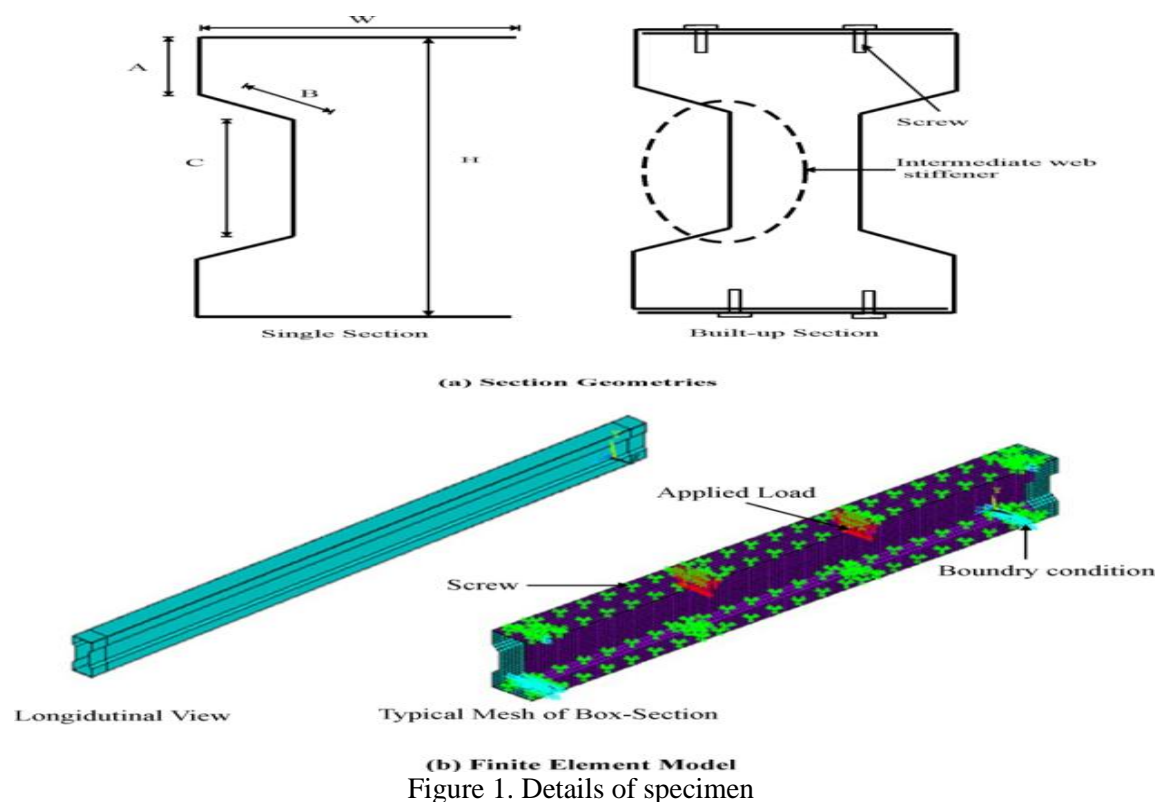
The flexural strength of a cold-formed steel section in bending is generally improved by the presence of the intermediate web stiffener and edge stiffeners. However, for webs with relatively large depth-to-thickness ratio, the local buckling occurs on the web. The structural efficiency of such webs can be improved by adding an intermediate stiffener longitudinally in the middle of the web. From the literature, it is observed that the intermediate web stiffener is a key factor that influences the flexural behaviour and strength of the member. However, not much research has been done on the flexural behaviour of a built-up closed section. Therefore, the flexural behaviour of cold-formed steel built-up closed section with intermediate web stiffener is chosen in this study as shown in Fig. 1a. The objective of the present research is to examine the strength and flexural behaviour of the cold-formed steel built-up closed section with intermediate web stiffener under pinned end condition with two point loading. To simulate the behaviour of the section, a finite element model is developed using finite element analysis software ANSYS [10]. The results obtained from the experiment and numerical analyses are compared the design strength calculated by using the

North American Iron and Steel Institute Specification (AISI: S100-2007 [6]) for cold-formed steel structure.

## 2. EXPERIMENTAL PROGRAMME

### 2.1 Selection of section

The cross-sectional dimensions are fixed based upon the limitations given in the draft of AISI specification. Table 1 shows the cross-sectional dimension of the specimens and the nomenclature defined in Fig. 1a. All the specimens had a length 2300 mm. Built-up closed section consists of two identical C-channel section with intermediate web stiffener and channels are connected at their flanges using self tapping screws with a spacing of 100 mm.



### 2.2 Description of experimental setup

All the sections are fabricated from the locally available 2 mm thick cold rolled mild steel sheet with a yield stress of 270 MPa and young's modulus of 210 GPa. The test specimens are labelled according to their flange width and depth of the sections from B1-B9 as shown in Table 1. All the beams are tested in a loading frame of a capacity of 200 kN under a simply supported end conditions with two point loading. The applied load or reaction forces are applied by means of bearing bearing plate. Lateral restraints are provided at the ends of the beam. A data acquisition system is used to record the applied load and deflection at regular intervals during the test. All the specimens are tested up to the failure.

Table 1: Details of test specimen

Specimen ID	Dimensions (mm)		Depth - H (mm)		
	Flange Width(w)	Depth (H)	A	B	C
B1	80	190	35	15	90
B2	100	190	35	15	90
B3	130	190	35	15	90
B4	80	240	35	15	140
B5	100	240	35	15	140
B6	130	240	35	15	140
B7	80	290	35	15	190
B8	100	290	35	15	190
B9	130	290	35	15	190

### 3. NUMERICAL ANALYSIS

The finite element models are based on the centre line dimensions of the cross-section. In the finite element model, material and geometric non linearity ( $L/1000$  [13]) are included, but residual stress and the rounded corners of the section are not modelled. Finite element analysis consists of two phases. The first is known as eigen value elastic buckling analysis that estimates probable buckling mode and load of the specimen. The second is known as nonlinear buckling analysis (static analysis with large displacement) using line search option. The specimen is modelled using 4-node shell 181 element with six degrees of freedom at each node. From the mesh convergence study, an optimal mesh size  $10 \times 10$  mm is used for the study. A typical finite element is illustrated in Fig.1b. In this study, the coupling option is used where the connection is necessary [5, 9, and 17]. Stress-strain relationships are described by a bilinear stress-strain curve with a tangent modulus is  $2E4\text{MPa}$  and Poisson's ratio is 0.3.

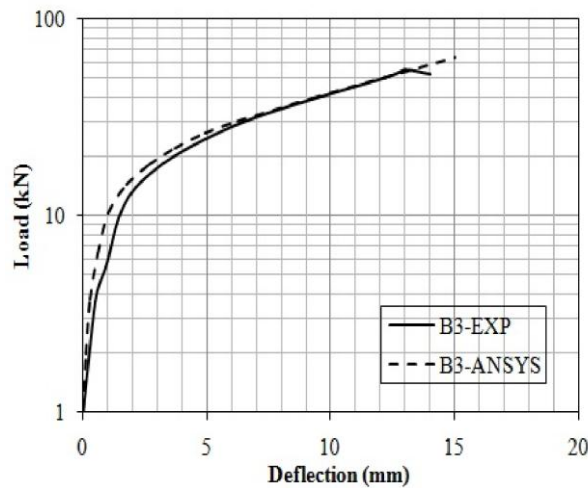


Figure 2. Load deflection curve-B3

#### 4. DISCUSSIONS AND ANALYSIS OF RESULTS

The flexural strength is determined by the change in slope of the log of the load deflection curve [15] and the results are presented in Table 2. For example, the load-deflection curve and failure modes for some of the specimens are illustrated in Fig. 2 and Fig. 3 respectively. Local buckling, flexural bending, lateral torsional buckling, web buckling and interaction between these buckling modes are observed in the test and verified numerically. For the specimens with section depth of 190 mm, Specimens B1, B2 and B3 are failed by flexural bending and with further applying of load, the local buckling is occurring at the compression flange with progressive of loading, the compression flange to buckle outwards forming a bow shape and their flexural strength are 31%, 34% and 20% of the yield strength respectively. For specimens with section depth of 240 mm, Specimens B4 (Fig. 3) and B5 fails by lateral torsional buckling while specimen B6 is failed by local buckling. The flexural strength is 31 % of the yield strength in the case of B4, 32% of the yield strength in the case of B5 and 20% of the yield strength in the case of B6. For specimens with section depth of 290 mm, Specimens B7, B8 and B9 are failed by web buckling and flexural strength is 22%, 24% and 21 % of the yield strength respectively. The failure is initiated by local buckling of the web plate with further progressive of loading, web buckling occurred at both supports.

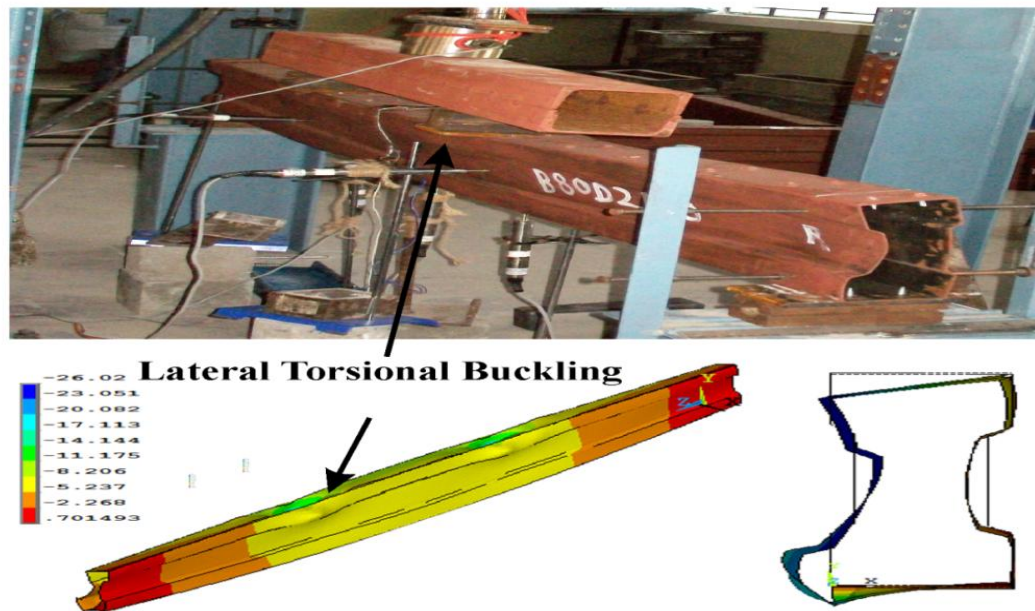


Figure 3. Lateral torsional buckling of specimen--B4

##### 4.1 Effect of depth variation

From the Figure 4, it is observed that, the  $M_{EXP}/M_y$  ratio increases with an increase in the  $h/t$  ratio and  $M_{EXP}/M_y$  ratio is reduced by increasing the  $w/t$  ratio. Because of the increasing size of an intermediate web stiffener, web buckles at the support. The flexural strength increases with an increase in depth of intermediate stiffener.

#### 4.2 Effect of flange width variation

From the Figure 5, it is observed that, the  $M_{EXP}/M_y$  ratio increases with an increase in flange width of the section ( $w$ ) and  $M_{EXP}/M_y$  ratio is reduced by increasing the  $h/t$  ratio. Because of the increasing flange width of the section, local buckling occurred at the flanges.

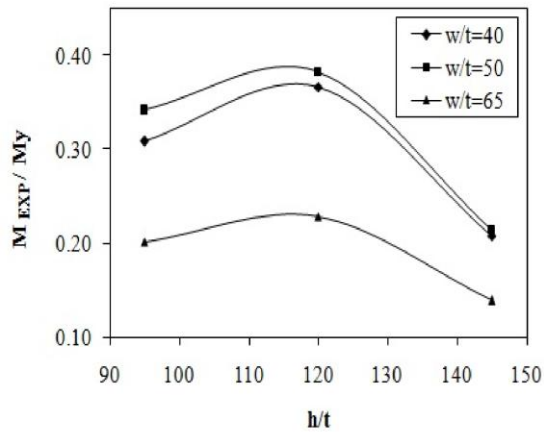


Figure 4. Effect of depth variation

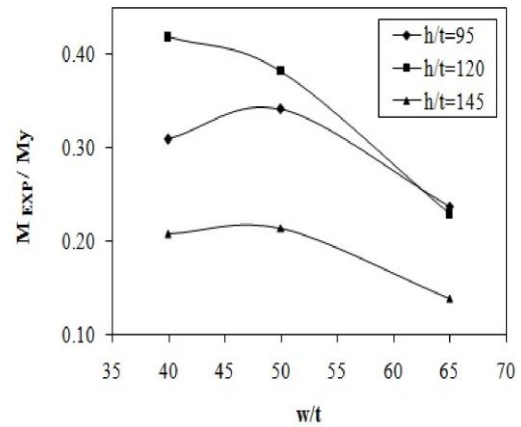


Figure 5. Effect of flange width variation

Table 2: Comparison of results

Specimen ID	Flexural Strength (kN.m)			$\frac{M_{ANSYS}}{M_{EXP}}$	$\frac{M_{AISI}}{M_{EXP}}$	Failure Mode
	Experiment ( $M_{EXP}$ )	ANSYS ( $M_{ANSYS}$ )	AISI ( $M_{AISI}$ )			
B1	6.64	7.10	9.66	1.07	1.45	BF
B2	8.70	9.01	11.45	1.04	1.32	BF
B3	7.48	8.05	7.67	1.03	1.21	BF
B4	11.88	11.83	12.75	1.14	1.23	BF+LTB
B5	12.80	12.11	15.04	0.95	1.17	BF+LTB
B6	9.39	10.14	12.84	1.08	1.37	LB
B7	7.40	7.67	10.67	1.04	1.44	WB
B8	8.94	9.93	12.53	1.11	1.40	WB
B9	7.08	8.31	10.58	1.17	1.49	WB
Mean				1.07	1.34	
Standard Deviation				0.07	0.17	

(BF-bending failure , LB-local buckling , LTB-lateral-torsional buckling, WB-web buckling )

## 5. THEORETICAL ANALYSIS

The results obtained from the experiment ( $M_{EXP}$ ) and finite element analysis ( $M_{ANSYS}$ ) are compared with the design strength calculated by using the AISI specification ( $M_{AISI}$ ) for the cold-formed steel structure; results are listed in Table 2. The mean and standard deviation of  $M_{ANSYS}/M_{EXP}$  are 1.07 and 0.07 respectively. The average  $M_{AISI}/M_{EXP}$  ratio equals 1.34 with

a standard deviation of 0.17. The  $M_{\text{AISI}}/M_{\text{EXP}}$  ratio (Table 2) is all greater than unity except for one or two cases, which shows that the AISI specification over estimates the flexural capacity of built-up closed section. Therefore, a new design expression is proposed in this study (Equ.1). The regression analysis [9, 17] is conducted, the flexural strength ( $M_{\text{EXP}}$ ) is plotted against the nominal strength ( $M_{\text{AISI}}$ ) calculated according to the current design practice, as shown in Fig.6.

$$M_{\text{DESIGN}} = 0.91 M_{\text{AISI}} - 4.703 \quad (1)$$

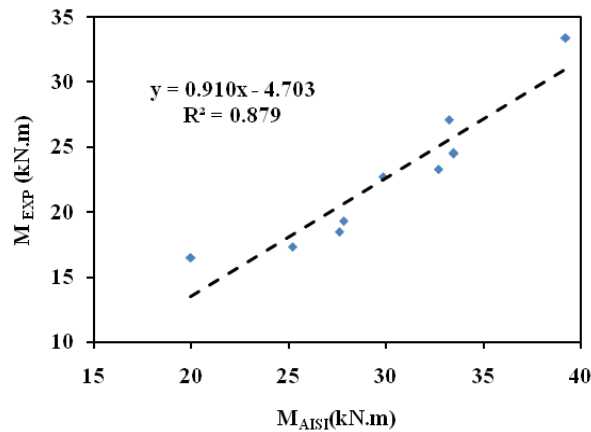


Figure 6.  $M_{\text{EXP}}$  versus  $M_{\text{AISI}}$  ( $h/t$  ratio  $\leq 150$ )

The accuracy of the proposed design equation (Equ.1) is further established by comparing the flexural strength of built-up box section (Beshara and Lawson [2]) by other researchers as listed in Table 3 and the results are compared well with test results.

Table 3: Verification of the design expression results

Particulars of specimen	Experimental strength- kN-m( $M_{\text{EXP}}$ )	Design strength- kN-m ( $M_{\text{DESIGN}}$ )	$\frac{M_{\text{DESIGN}}}{M_{\text{EXP}}}$
CSS stud – track flange screws	17.35 <sup>[2]</sup>	15.53	0.90
CSS stud – TSB track flange screws	17.45 <sup>[2]</sup>	15.05	0.86
CSS stud – rim- track lip screws	17.14 <sup>[2]</sup>	15.53	0.91
CSS stud – TSB track- lip screws	17.41 <sup>[2]</sup>	15.05	0.86
CSS stud – TSB track- lip screws	16.13 <sup>[2]</sup>	15.05	0.93

## 6. SUMMARY AND CONCLUSIONS

A series of flexural test on cold-formed steel built-up closed section have been performed. The flexural strength obtained from the experiment and finite element analysis is compared with the nominal strength calculated by using the North American Iron and Steel Institute Specification for the cold-formed steel structure. The proposed design expression is verified with the test results from the literature.



The following conclusions are drawn from the present investigation.

- Design of cold-formed steel built-up closed beams requires consideration of local, distortional, bending, web buckling and lateral-torsional buckling.
- The intermediate web stiffener has a significant effect on the strength and behaviour of the flexural member.
- The flexural strength increases with an increase in depth of intermediate stiffener.
- Similarly, the flexural strength increase with an increase in the flange width and it is reduced by the increasing flange width.
- The finite element analysis can be used with a high level of confidence in predicting the load capacity of the flexural member.
- The proposed design expression is reasonably predicting the flexural strength of the cold-formed steel built-up closed section with intermediate web stiffener.

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