View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by IJRIET (International Journal of Research and Innovation in Engineering Technology)

International Journal of Research and Innovation in Engineering Technology ISSN: 2394 – 4854
Volume: 06 Issue: 11 Pages: 01 – 09

IJRIET

EXPERIMENTAL STUDY ON BEHAVIOUR OF COLD FORMED STEEL LIPPED ANGLE COLUMNS

S. Gayathri[1], N. Moorthi[2], G. Aruna[3]
[1,2]Assistant Professor, Department of Civil Engineering, Paavai Engineering College, Namakkal
E-mail-ID: [1]gayucivil26@gmail.com, [2]moorthi219@gmail.com

Received 28 January 2019, Revised 03 April 2020, Accepted 07 April 2020
Available online 09 April 2020

Abstract

This article reports the experimental work on the behavior of cold formed steel lipped angle columns performed with pinned end conditions under axial compression. In this work three different types of equal and unequal plain and lipped angle sections were chosen with a total of 12 specimens. The column lengths were taken as 1200 mm. The material properties of these sections were found by conducting Tensile Coupon test. The section geometries were selected in order to take account of all types of buckling modes. The column strengths determined from the experiment was examined with the design strength attained from Direct Strength Method in North American Specification and with the Numerical results (ABAQUS) for Cold formed steel structures. Finally, an appropriate design proposal was suggested for DSM to forecast the ultimate strength of cold formed steel columns.

***Keywords**:* Cold-Formed steel, Columns, Finite element analysis, Direct Strength method.

1. INTRODUCTION

Cold-formed steel (**CFS**) is the common term for steel products shaped by cold-working processes carried out near room temperature such as rolling, pressing, stamping, bending. Stock bars and sheets of cold formed steel are commonly used in all areas of manufacturing. The uses of these products are easy to handle during construction and transportation. It possesses high strength to weight ratio of building material. Cold formed steel is much durable which provide higher resistance to corrosion which can be recycled and reused. The material thickness for such thin walled steel members generally limits from 0.373 mm to 6.35 mm. often these members are also known as Light Gauge Steel sections.

B. W. Schafer [1] reports that at least three competing buckling modes: local, distortional, and Euler i.e., flexural or flexural- torsional buckling are observed in open cross-section, thin-walled, cold-formed steel columns. Jintang Yan and Ben Young [2] discussed about experimental investigation of cold formed steel channels with complex stiffeners under pure axial compression for fixed ended columns. Ben young and Jintang Yan [3] reported the design and numerical investigations and behaviour of cold-formed lipped channel columns using finite element analysis. S. Narayanan, M. Mahendran [4] studied the behaviour of a series of innovative cold-formed steel columns for distortional buckling. Demeo Yang and Gregory J.Hancock [5] studied the tests performed on lipped channel section columns fabricated from cold-reduced high strength steel of thickness 0.42mm with nominal yield stress 550Mpa.Ben Young and Jintang Yan [6] investigated the design of cold formed steel channels with complex stiffeners using the effective width method in the current design rules of North American Specification and Australian/New Zealand Standard. P.B.Dinis and D.Camotim [7] reports the structural behavior and design of cold-formed steel columns affected by local–distortional coupling interactions of lipped channels to other cross-section shapes such as hat, zed and rack-sections. Ben Young and Ehab Ell body [8] studied the buckling behaviour of equally lipped angle cold formed steel columns. The initial local imperfections, residual stresses, and corner material properties of steel angles have been measured experimentally. Maura Lecce and Kim J. R. Rasmussen [9] described the experimental study of thin-walled stainless steel sections subject to distortional buckling under compression. Ben Young, Ehab Ellobody [10] reported the finite element model (ABAQUS) for the analysis of cold-formed steel lipped angle sections with unequal flange widths.

M. V. Anil Kumar and V. Kalyanaraman [11] investigated the axial compressive strength of the cold-formed steel CFS members with edge or intermediate stiffener is affected by interaction of local, distortional and overall buckling. Ben Young, Nuno Silvestre, and Dinar Camotim [12] reported the results of an experimental investigation involving a set of 26 columns with several cross-section dimensions and yield stresses for distortional mode interaction. Y.Shifferaw, B.W.Schafer [13] presented the post buckling reserve in global buckling observed in tests on cold-formed steel angle columns, for locally slender cold-formed steel lipped and plain angle columns with fixed end boundary conditions. G.Aruna, V.Karthika et.al [14] describes a series of experiments conducted on cold-formed built-up square sections with intermediate flange and web stiffeners under axial compression with hinged end conditions. P.Manikandan and S.Sukumar [15] studied experimental and numerical investigation of the flexural strength and behaviour of cold-formed steel built-up closed section with intermediate web stiffener.

From the literature it is concluded that limited research work exist on the behaviour of cold-formed angle columns. Therefore, present study is investigated by conducting series of experiments on cold-formed steel lipped equal and unequal angle columns by varying the cross section geometry of the sections. The column strengths acquired from the experiments were correlated with the design strength calculated using direct strength method in the North American Specification [16] and Numerical results (ABAQUS) for cold-formed steel structures. In the calculation, combination of local, distortional and flexural buckling modes were observed. And also a design recommendation was proposed to calculate the ultimate strength of cold-formed steel columns.

2. EXPERIMENTAL INVESTIGATION

2.1 Selection of specimens

The specimens of cold formed steel lipped equal and unequal angle columns with pinned end conditions under axial compression were tested. The cross section and dimensions of the angle sections are shown in Fig 1 and Table 1. The section dimensions were determined with the allowable Flat-Width to Thickness ratio (w/t).

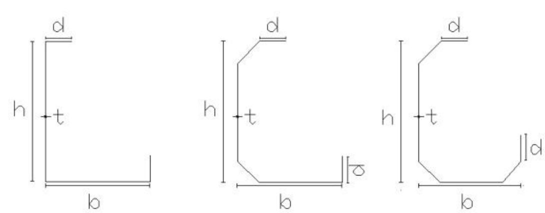


Figure: 1 Cross section of the specimens

Specimen ID	Depth (h) mm	Width (b) mm	lip (d) mm	Degree of inclination (Θ)	Thickness (t) mm	Length (L) Mm
T1 70-15-1200	70	70	15	0	1.6	1200
T2 70-15-1200	70	70	15	45	1.6	1200
T3 70-15-1200	70	70	15	45	1.6	1200
T1 90-15-1200	90	90	15	0	1.6	1200
T2 90-15-1200	90	90	15	45	1.6	1200
T3 90-15-1200	90	90	15	45	1.6	1200
T1 80-50-15-1200	80	50	15	0	1.6	1200
T2 80-50-15-1200	80	50	15	45	1.6	1200
T3 80-50-15-1200	80	50	15	45	1.6	1200
T1 90-60-15-1200	90	60	15	0	1.6	1200
T2 90-60-15-1200	90	60	15	45	1.6	1200
T3 90-60-15-1200	90	60	15	45	1.6	1200

Table: 1 Dimensions of the cross section

12 series of Equal and Unequal steel angle columns were tested. The labelling details of the specimens as follows:

T1, T2, T3 - specifies the types of sections

"T1-70" - width of both legs of type 1 section

"T1-15" - depth of lip of type 1 section

"1200" - length of the specimen

2.2 Material properties

The coupon test was carried out to find the material properties such as Yield Stress (f_y), Ultimate Stress (σ_{ult}), percentage of elongation, etc. The coupon test samples were made according to IS 1608-2005 part I. The obtained material properties are given in the Table 2

Material properties	Coupon test results
Yield stress (f_y)	272 N/mm^2
Ultimate Stress (f_u)	349 N/mm^2
Young's Modulus (E)	2.05x10^5 N/mm^2
Poisson's Ratio (μ)	0.3

Table: 2 Coupon test results

The specimens were made up by press braking operation to the nearest tolerance for the required cross section. The end plates of size 8 mm was placed at mutual ends of the specimen for uniform distribution of load. The Centre of gravity (CG) of the plate was made to coincide with the CG of the fabricated specimen to avoid the eccentric loading on the specimen during the test. The end plates were attached to the specimen by weld connection. Figure 2(a) and (b) shows the fabricated specimens of experimental work.

(a)

(b)

Figure 2(a) and (b) Fabricated Specimens of Equal and Unequal lipped angle columns

2.3 Experimental setup

The 200 tonne capacity loading frame was used for the column tests. At the top and bottom ends of the specimen steel end plates were welded. The spherical ball arrangements were placed in between the end plates to accomplish hinged end condition at supports. The hydraulic jack was utilized to apply the load axially. To predict the axial shortening and lateral deformation of the column one of the dial gauge was placed at the bottom end plate and other dial gauge was placed at the mid height of the specimen. Figure 3 shows the experimental setup of the column.

The experimental procedure was done under hinged end conditions and the load was distributed axially at the CG of the specimen. Distortional buckling and interaction of local and distortional buckling were observed.

Figure: 3 Test Setup

3. NUMERICAL ANALYSIS

Finite Element Analysis (FEA) is an accurate and extensible technique used to assess the performance of the structure, mechanism under different loading conditions. ABAQUS 6.1 software was used to evaluate the modes of failure and ultimate load of the test specimens. The buckling analysis consists of Eigen buckling analysis and nonlinear buckling analysis.

3.1 Modeling of the specimen

The angle sections were modeled using shell element. The numerical models were discretized with the reduced integration four-noded doubly curved shell element and it has five degrees of freedom per node (S4R5). The mesh size for the shell elements was 10 mm x 10 mm (length by width). Figure 4 shows the meshing of the section.

Figure: 4 Meshing of the section

3.2 End conditions

The FEM simulation was carried out by making the boundaries as hinged ends. The modeling of hinged ended boundary conditions were adopted by restraining the transitional degree of freedom in the three directions x, y, and z and also along z-axis at the bottom ends, where at the top translation in x and y directions and rotation concerning z-axis were restrained. This is due to the load applied at the apex of the column.

3.3 Application of load

MPC constraint available in ABAQUS software was used for applying load to the column. At the top, axial compressive load is applied in the geometric centroid of the section and it is distributed uniformly throughout the ends of the specimen. At first, MPC was created by connecting the center node to the edge of the section through edge nodes shown in Figure 5. They were connected by using rigid beams. The load was applied using the modified RIKS method available in ABAQUS library. Linear analyses (Elastic Buckling analyses) were performed firstly to evaluate the critical load and its corresponding buckling modes. Nonlinear analyses were carried to observe the ultimate load by taking imperfection value equal to 0.94 times the metal thickness and L/1000 for distortional and global mode respectively

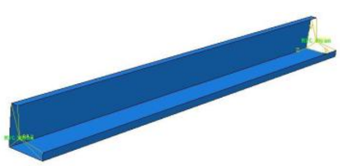


Figure: 5 MPC constraints of the section

3.4 Geometric Imperfection

In the FEM, Elastic bucking analysis was used to include the geometric imperfections. The geometric imperfections were included by using a linear perturbation analysis, in order to establish probable buckling modes (eigenmode) of the column. The Eigen mode was then scaled by a factor (scale factor) to obtain a perturbed mesh of the column for the non-linear analysis.

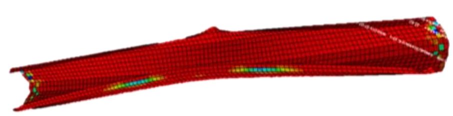
3.5 Material Behavior Modeling

The first stage of the numerical simulation is a linear analysis in which there is a linear relationship between the applied loads and the response of the structure. In this analysis, the stiffness of the structure remained unchanged. Hence, only the density, Young‘s modulus and Poisson‘s ratio defined the material properties. However, the second stage of the numerical simulation is a non-linear analysis in which the stiffness of the structure changed as it deformed.

4. TEST RESULTS

The experimental results of cold-formed steel plain and lipped angle columns are presented in Table 3.Local buckling, distortional buckling, flexural buckling and interaction of these buckling were observed during the test. Figure 6(a) & (b) and Figure 7(a) & (b) shows the failure modes of Equal angle T3 70-15-1200 and Unequal angle T2 90-60-15-1200 specimen. Axial load vs Axial shortening for various sections are shown in Figures 8 to 11.

6 (a)

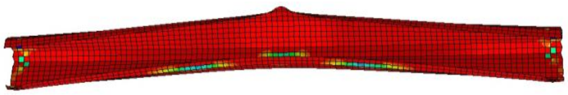


6 (b)

Figure 6 (a) and 6 (b): Comparison of Exp & FEM failure modes for EQUAL Angle T3 70-15-1200

 ISSN: 2394 – 4854
Pages: 01 – 09

7 (a)



7 (b)

Figure 7 (a) and 7 (b): Comparison of Exp & FEM failure modes for UNEQUAL Angle T3 90-60-15-1200

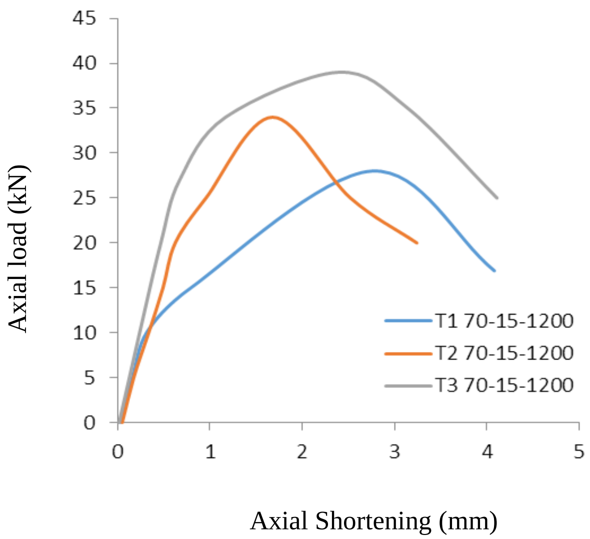


Figure: 8 Axial load vs. axial shortening curves for 70-15-1200 series

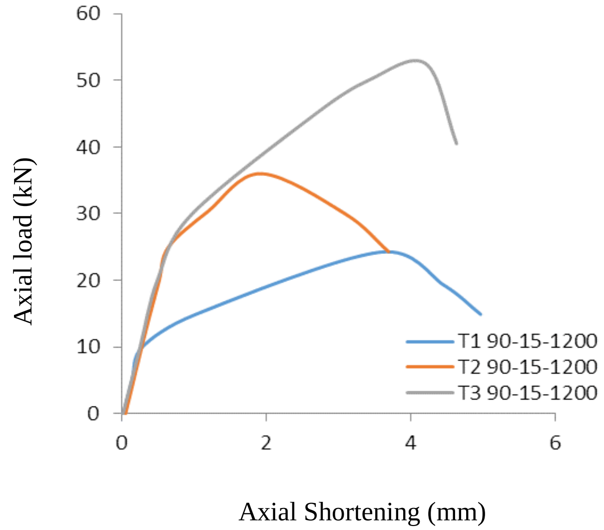


Figure: 9 Axial load vs. axial shortening curves for 90-15-1200 series

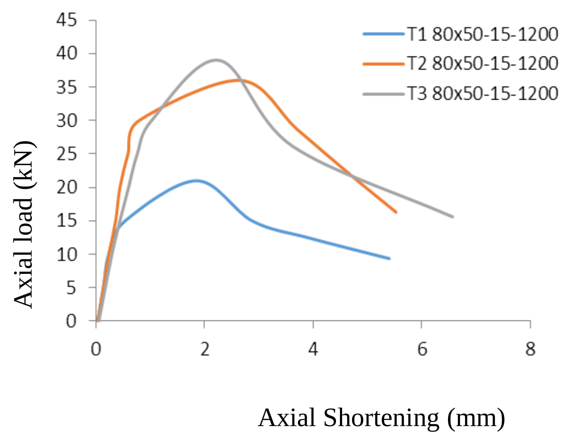


Figure: 10 Axial load vs. axial shortening curves for 80x50-15-1200 series

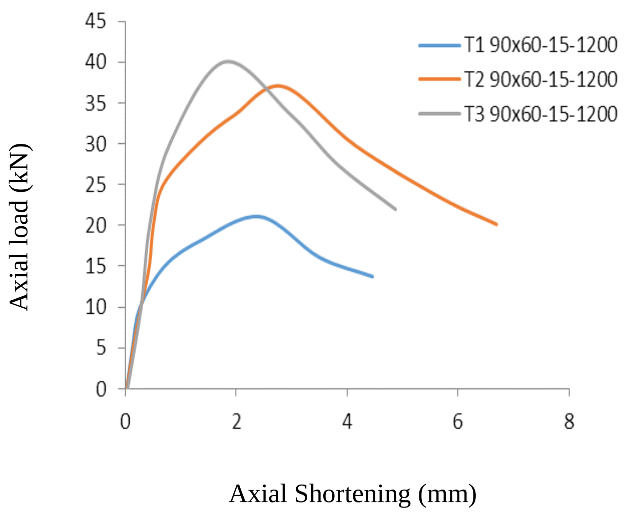


Figure: 11 Axial load vs. axial shortening curves for 90x60-15-1200 series

Specimen ID	Experiment		Numerical		Theoretical	P_{EXP} / P_{DSM}	P_{EXP} / P_{FEA}
	P_{EXP} (kN)	Failure modes	P_{FEA} (kN)	Failure modes	P_{DSM} (kN)		
T1 70-15-1200	28	D	31.04	D	27.56	1.01	0.90
T2 70-15-1200	34	D+F	37.12	D+F	33.67	1.01	0.91
T3 70-15-1200	39	D+F	42.23	D+F	40.56	0.96	0.92
T1 90-15-1200	33	D	36.54	D	32.23	1.02	0.91
T2 90-15-1200	41	D+F	42.49	D+F	38.54	1.06	0.97
T3 90-15-1200	44	D+F	46.47	D+F	40.78	1.07	0.95
T1 80-50-15-1200	21	L+D	23.13	L+D	19.28	1.07	0.91
T2 80-50-15-1200	36	L+D	34.54	L+D	34.78	1.03	1.05
T3 80-50-15-1200	39	D	42.89	D	37.54	1.03	0.90
T1 90-60-15-1200	24	L+D	26.65	L+D	21.58	1.11	0.92
T2 90-60-15-1200	41	L+D	38.26	L+D	42.21	0.97	1.07
T3 90-60-15-1200	43	D	46.34	D	41.58	1.03	0.93
					Mean	1.03	0.96

Table: 3 Comparison of experimental strength with design strength

5. DESIGN RULES

The design strength was calculated by Direct strength Method (DSM) in AS/NZ Specification 4600:2005 for Cold-formed Steel sections. The nominal axial strength of the column is minimum value among the following three equations such as Flexural, Torsional, or Flexural-Torsional Buckling.

The nominal axial strength is,

$$\begin{cases} \text{For } \lambda_c \leq 1.5 \\ P_{ne} = (0.658\,\lambda c^2)\, P_y \\ \text{For } \lambda_c > 1.5 \\ P_{ne} = \left(\frac{0.877}{\lambda^2}\right) P_y \\ \text{Where } \lambda c = \sqrt{P_y / P_{cre}} \\ P_y = A_g F_y \end{cases} \quad (1)$$

Local buckling

The nominal axial strength is,

$$\begin{cases} \text{For } \lambda_l \leq 0.776 \\ P_{nl} = P_{ne} \\ \text{For } \lambda_l > 0.776 \\ P_{nl} = \left[1 - 0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne} \end{cases} \quad (2)$$

$$\text{Where, } \lambda_l = \sqrt{P_{ne} / P_{crl}}$$

Distortional buckling

The nominal axial strength is,

$$\begin{cases} \text{For } \lambda_d \leq 0.561 \\ P_{nd} = P_y \\ \text{For } \lambda_d > 0.561 \\ \left[1 - 0.25\left(\frac{P_{crd}}{P_y}\right)^{0.6}\right]\left(\frac{P_{crd}}{P_y}\right)^{0.6} P_{ne} \\ \text{Where, } \lambda_d = \sqrt{P_y / P_{crd}} \end{cases} \quad (3)$$

P_{crd} = Critical elastic distortional column buckling load

6. RESULTS AND DISCUSSIONS

The strength obtained from DSM was slightly unconservative.The linear analysis carried out between P_{EXP} and P_{DSM} is shown in Figure 12.The mean value P_{EXP} / P_{DSM} is 1.039 and P_{EXP} / P_{FEA} is

0.961.The relationship between the strength acquired from the experiment (P_{EXP}) and the strength calculated in accordance with the direct strength method (P_{DSM}) is y = 0.957x + 2.488 with R-squared value of 0.966. From this analysis, it was shown that a new design equation is proposed to calculate the compressive strength of lipped angle columns.

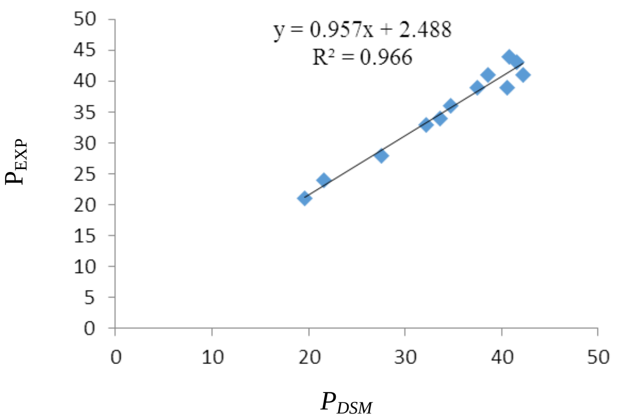


Figure: 12 P_{EXP} versus P_{DSM} curve

7. CONCLUSION

This detailed report describes the critical strength and buckling behavior of cold formed steel lipped and stiffened angle columns. Twelve series of equal and unequal angle columns were tested under hinged support conditions. Tensile coupon test were performed to attain the material properties of the specimens. Distortional buckling and interaction of distortional and flexural buckling modes were noticed during the experiment. The acquired experimental results were matched with Finite element analysis ABAQUS and design strengths based on North American Specifications (AISI S100:2007) for cold-formed steel structures. It is shown that DSM is consistent and rather unconservative. Finally, a new design equation was suggested to compute the optimum compressive strength of lipped angle columns.

References

[1] B. W. Schafer, “Local, Distortional, and Euler Buckling of Thin-Walled Columns”, Journal of Structural Engineering, Vol. 128, No. 3, March 1, 2002.

[2] Jintang Yan and Ben Young, “Column Tests of Cold-Formed Steel Channels with Complex Stiffeners”, Journal of Structural Engineering, Vol. 128, No. 6, June 1, 2002.

[3] Ben young and Jintang Yan, “Channel columns undergoing local, distortional and overall buckling”, Journal of Structural Engineering, Vol. 128, No. 6, June 1, 2002.

[4] S. Narayanan and M. Mahendran, “Ultimate Capacity of Innovative Cold-formed Steel Columns”, Journal of on structural Steel Research, Vol. 59, No.4, pp. 489-508, 2003.

[5] Demeo Yang and Gregory J.Hancock, “Compression Tests of high strength steel channel columns with interaction between local and distortional buckling”, Journal of Structural Engineering, Vol. 130, No. 12, December 1, 2004.

[6] Ben Young M.ASCE and Jintang Yan, “Design of Cold- Formed Steel Channel Columns with Complex Edge Stiffeners by Direct Strength Method”, Journal of Structural Engineering, Vol. 130, No. 11, November 1, 2004.

[7] P.B.Dinis, D.Camotim “Cold-formed steel columns undergoing local–distortional coupling: Behavior and direct strength prediction against interactive failure”, Computers and Structures, October 28, 2014.

[8] Ben Young and Ehab Ell body, “Buckling Analysis of Cold-Formed Steel Lipped Angle Columns”, Journal of Structural Engineering, Vol. 131, No. 10, October 1, 2005.

[9] Maura Lecce and Kim J. R. Rasmussen, “Distortional Buckling of Cold-Formed Stainless Steel Sections: Experimental Investigation”, Journal of Structural Engineering, Vol. 132, No. 4, April 1, 2006.

[10] Ben Young and Ehab Ellobody, “Design of cold-formed steel unequal angle compression members”, Thin walled structures, 2007.

[11] M. V. Anil Kumar and V. Kalyanaraman, "Evaluation of Direct Strength Method for CFS Compression Members without Stiffeners", Journal of Structural Engineering, Vol. 136, No. 7, July 1, 2010.

[12] Ben Young, Nuno Silvestre, and Dinar Camotim, "Cold-Formed Steel Lipped Channel Columns Influenced by Local-Distortional Interaction: Strength and DSM Design", Journal of Structural Engineering, Vol. 139, No. 6, June 1, 2013.

[13] Y.Shifferaw and B.W.Schafer, "Cold-formed steel lipped and plain angle columns with fixed ends", Thin walled structures 2014.

[14] G. Aruna, S.Sukumar and V. Karthika, "Study on cold-formed steel built-up square sections with intermediate flange and web stiffeners", Asian Journal of Civil Engineering 2015.

[15] P.Manikandan and S.Sukumar, "Behavior of cold-formed steel built-up closed Section with intermediate web stiffener under bending", Asian Journal of Civil Engineering 2016.

[16] NAS – 2001 "North American specification for the design of cold – formed steel structural members".