AN EXPERIMENTAL STUDY ON FRP STRENGTHENED COLD FORMED STEEL BUILT-UP CHANNEL SECTION

G. Sangavi[1], M.C. Sundarraja[2]

[1]PG Student, Department of Civil Engineering, Thiagarajar College of Engineering, Tamilnadu
[2]Assistant Professor, Department of Civil Engineering, Thiagarajar College of Engineering, Tamilnadu

---***---

Abstract - *Carbon fiber reinforced polymer (CFRP) materials are used for the purpose of increasing the stiffness, durability and load bearing capacity of concrete and steel members. In this project, the sectional behaviour of CFRP strengthened cold formed steel (CFS) lipped column section are studied using design rules as per Indian Standard codes and experimental analysis. The analytical results obtained by designing with and without wrapping of CFRP are evaluated with experimental results. The experimental analysis is carried out to investigate the failure modes and maximum load bearing capacity of column sections, which are externally bonded with CFRP strips under loading condition. In this work, most common type of symmetric sections i-e built-up column channel sections with lipped channels with bolted and spot-weld connection are investigated. The strength of the column obtained from this experiment is compared with the design strengths obtained using effective width method for control cold formed steel sections and CFRP wrapped sections. Finally, the research work summarizes the numerical and experimental recommendations for cold formed steel column sections using CFRP composites.*

Key Words: Cold formed steel built up channel section, carbon fiber reinforced polymer strip, compression loading condition.

1. INTRODUCTION

Two types of structural steel members are being used, namely hot rolled steel and cold formed steel in the construction industry. The use of cold formed steel (CFS) for buildings and structures is now a day's popular in India. The design and behaviour of hot rolled steel member are well developed, whereas the cold formed steel member behaviour and design is not developed fully. Cold formed steel lipped channel sections are used as purlins, beams and columns. They are produced commercially by roll forming and press break method for the use of structural applications and also manufactured by spot-welding for the use in automotive, aeronautical and other general applications. The different buckling modes such as local buckling, distortional buckling, and overall buckling are occurred in the lipped channel beams and columns. Distortional buckling is the highly influencing mode on the section. Above all, the CFS sections offer versatility and flexibility in producing a variety of cross-sectional shapes, which are obtained by bending relatively thin sheets using either a cold rolling or a press-braking process at room temperature [1] typically from grade 250 or 450MPa steel. The flexibility of the manufacturing process in obtaining various shapes means that there is a great potential for CFS sections to be optimized to meet specific objectives and there by bringing practical benefits to both manufacturers and structural designers. Due to the typical large flat width to thickness ratios, the CFS sections are inherently susceptible to local, distortional and global buckling, resulting in a complex optimization process. Varies studies on the optimization of CFS elements have been done which are limited to standard cross-sections such as lipped channel beams and channel columns and hat, I and Z sections [2-5].

In recent years, there have been a number of studies related to CFS with different shapes carried out. Recent research by Jun et al. [1] on optimization of CFS cross section to increase the load carrying capacity, leading to more efficient and economical structural systems by using effective width method adopted in EC3. Helder et al. [2] carried a study on the buckling behaviour of compressed single, built-up and two closed built-up cold formed steel columns by considering two end-support conditions, pin-ended and fix-ended. The obtained results were compared with the design predictions of EN-1993-1-3:2004 and AISI S100-07. They inferred that the design predictions is good for pin-ended lipped channel columns and for build-up columns, the increasing number of profile may lead to unsafe design prediction, Mehran Zeynalian et al. [3] studied the behaviour of CFS truss connections for maximum load carrying capacity and load deformation behaviour and investigated the main factors contributing to the ductile response of the CFS truss connections in order to suggest recommendations for connection designs and improvement for any risk of brittle failure. M.A. El Aghoury et al. [4] conducted an investigation on the strengthening of a battened beam-column composed of four slender cold formed angles members and their failure modes are analyzed under biaxial loading condition by creating a nonlinear finite element model to study the axial-bending interaction curves for short, medium and long beam-columns for designing reliable design code rules. W.F. Maia et al. [5] carried experimental and numerical investigation of CFS double angle member under concentric and eccentric axial compression by using battened plates which significantly increases the strength of the system especially for members under eccentric compression and they inferred that the strength remains constant after a certain number of batten plates that are connected and after a minimum batten plates width is reached and Mohamed Dabaon et al. [6]

investigated on the nonlinear behaviour and design of built-up CFS battened columns. The built-up columns were pin-ended and consisted of two CFS channels placed back-to-back and were connected using batten plates. The nonlinear 3-D finite element models were also developed to simulate the structural performance of the axially loaded columns.

In recent years there have been a number of studies related to strengthening of steel structures with carbon fiber reinforced polymer (CFRP) fabrics, particularly in the field of thin-walled steel structures. Recent research on the strengthening of CFS structures with FRP by G. Teng et al. [7] discussed the interpretation of existing research on fiber reinforce polymer (FRP) strengthened steel structures, including surface preparation for adhesive bonding, selection of a suitable adhesive, bond behaviour between FRP and steel and its appropriate modeling. The flexural strengthening of steel beams, fatigue strengthening of steel structures, strengthening of thin-walled steel structures against local buckling, and strengthening of hollow or concrete-filled steel tubes through external FRP confinement are also carried out by him. Kent A et al. [8] studied the stiffness and linear behaviour of FRP materials to provide bracing against web or flange local buckling. The experimental research is aimed at demonstrating the feasibility of using small quantities of FRP to provide cross-sectional stability through the bonding of FRP strips to flange elements of the cross-section, thereby increasing the critical load of the member and facilitating the manifestation of a well-formed and stable hysteretic response of the member under cyclic loading. Nuno Silvestre et al. [9] investigated the structural behaviour of CFRP- strengthened CFS lipped channel columns more specifically and it addressed the applicability of the provisions of Eurocode3 (EC3) and the AISI Specification (AISI-DSM, direct strength method), to estimate their load-carrying capacity. Joyson Silva et al. [10] presented the finite element analysis results of CFRP strengthened hot rolled steel columns devoting special attention to buckling and load-carrying capacity of columns. In this study, an Indian Standard (IS) section was used as a column and CFRP sheet was used as a strengthening material. The CFRP bonded with CFS by using cera epoxy agent and the CFRP is placed at various members of the column at web and flange portion. The ultimate loading capacity was obtained both analytically and experimentally under axial loading condition. The results of the wrapped columns were compared with the controlled columns.

1.1 Objectives

1. To investigate the buckling behaviour of the strengthened cold formed steel built-up channel section with CFRP strips.
2. To study the enhancement in load bearing capacity under axial loading condition.
3. To study the deformation and modes of failure of the columns.
4. To validate the analytical results with the experimental results.

1.2 Material properties

Cold formed steel

The light gauge steel sections are cold formed steel. They are produced by cold forming process which is under room temperature and made up of high speed and pressure in rolling form. The properties are shown in Table 1.

Table 1 – Material Properties of CFS

Specification	Grade	Yield Strength MPa	Poisson Ratio	Thickness mm	Length mm	Width mm
SAIL	CR3D	240	0.3	2	2500	1250

Carbon fiber reinforced polymer

Carbon fiber is a polymer made up of pure carbon known as graphite fiber and it's an extremely strong and light weight which contains carbon atoms bonded together. The material specifications are given in Table 2.

Table 2 – Material Properties of CFRP

Specification Grade	Elastic modulus kN/mm²	Tensile strength N/mm²	Density g/cm³	Thickness mm	Weight g/m²
MBrace Unidirectional CF 240 (230 gsm)	240	3800	1.7	0.117	200

Adhesive bonding

Epoxy resin is used as the bonding agent between steel and carbon fibers. The product details are shown in Table 3.

Table 3 – Properties of Adhesive Agent

Grade	Pull out strength N/mm²	Grunting Time
CERA Bond EP	80 (7 days)	30 - 60 minutes

2. EXPERIMENTAL INVESTIGATION

2.1 Specimen fabrication

In this study, 24 specimens of channel section were fabricated as per IS 811-1987 from 100 x 80 x 15 x 2 having the yield strength of 240 N/mm^2. They have same material property and thickness. In this, two different length specimens CH5 (500mm) and CH4 (400mm) of each 6 built-up sections have been used. For each built-up section, two channel sections were connected using 8.8 Grade bolt and by 7cm spot welding. Two end plates of thickness 6mm were welded on both sides of the section for load distribution..

2.2 Description of specimens

Cold formed sheet cutting are made under press break method to attain the describable shape and fabrication are done with standard size as per IS 811-1987 which are shown in Table 4.

Table 4– Specimen Details

Specimen	Web mm	Flange mm	Lip mm	Thickness mm	Length mm	Area cm²
CH5	100	40	15	2	500	3.86
CH4	100	40	15	2	400	3.86

To identify the specimens, they were designated as per length and the wrapping style such as, CH5-0A, CH5-0B, CH5-0C (without CFRP of length 500mm) CH5-1A ,CH5-1B, CH5-1C (with CFRP of length 500mm) CH4-0A, CH4-OB, CH4-0C (without CFRP of length 400mm) CH4-1A, CH4-1B, CH4-1C(with CFRP of length 400mm) and they are shown in Figure 1.

Figure 1 – Channel section with CFRP

2.3 Surface preparation for bonding

For wrapping the CFRP, the specimens were rubbed using emerald sheet and steel wire mess for developing rough surface to increase the bonding behaviour between CFS and CFRP with adhesive agent.

2.4 Experimental setup

In this study, the CFS columns were tested under compression in the column tester machine of capacity 200Tonne. Each specimen was placed under support condition with one end fixed and another end pinned conditions. The loads were applied using hydraulic jack and monitored using 200Tonne load cell. In this, the axial loading and displacement were observed using 16 channels data locker system by connecting the Linear Voltage Displacement Transducer (LVDT) to the specimens in the axial direction. The experimental setup was shown in Figure 2.

Figure 2 – Experimental setup

3. ANALYTICAL STUDY

3.1 Design prediction

The column under axial loading condition with one end fixed and other end pinned support, the allowable load is calculated using IS-801 1975 by effective width method which is given in Table 5.

Table 5 – Design Prediction

Span length (mm)	L
Yield strength (N/mm²)	F_y
Section Properties (As per IS 811)	
Depth (mm)	h
Width (mm)	b
Lip (mm)	c
thickness(mm)	t
Area of cross section (mm²)	A
Radius of corner (mm)	R
Modulus of Elasticity(N/mm²)	E
Effective Length (mm)	KL
Flat width of flange (mm)	w_f
Flat width of web (mm)	w_w
Flat width of Lip (mm)	w_l
r_{min}	$\sqrt{I_y/A}$
Effective Area (mm²)	A_{eff}
Slenderness ratio	λ
Moment of Inertia (mm⁴)	I_y
Ratio	(w/t)
Partially effective condition - web is stiffened Element	
Calculation of form factor (clause 6.1.1)	$Q' = (A_{eff} * F_c)/(A*F)$
Calculation of slenderness constant	$Cc = \sqrt{(2 * \pi^2 * E)} / F_y$
Allowable bending stress (clause 6.6.1.1)(kgf)	F_a
Allowable load (kN)	**Pu**

3.2 Confined Elastic Modulus calculation

The elastic modulus of the CFRP with CFS is determined from the modular ratio concept [8] which is as follows.

Tt = Tcf + Tcfs
Ecfrp = (Ecfs . Tcfs + Ecf .Tcf)/ Tt

Where,

Ecfrp – Elastic modulus of the strengthened section
Ecfs – Elastic modulus of CFS
Ecf – Elastic modulus of carbon fiber
Tt – Total thickness
Tcf – Fiber thickness
Tcfs – CFS thickness

4. RESULTS AND DISCUSSION

The design capacity of the built-up channel section are calculated according to IS 801-1975 and are presented in Table 6. The design values are calculated using the Effective width concept. They are compared with the maximum capacity obtained from the experimental result under compression loading condition, which are given in Table 6.

The failure modes are observed from the experimental results of specimens without CFRP and with CFRP. The modes of failure are discussed below. The experimental results were noted based on the loading and displacement data and are shown in the Graph 1 & Graph 2.

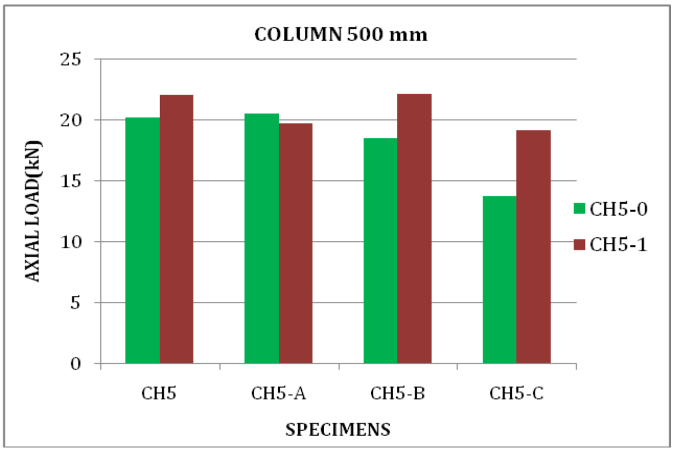
Modes of failure

In this, two types of failure were observed under axial loading namely local and distortional buckling which are shown in Figure 3. In this, the web portion bulges and inward and outward buckling were observed in the flange and lip portions. In the strengthened CFRP specimens, the local buckling and the flange portion buckling were reduced compared to the control specimen without CFRP.

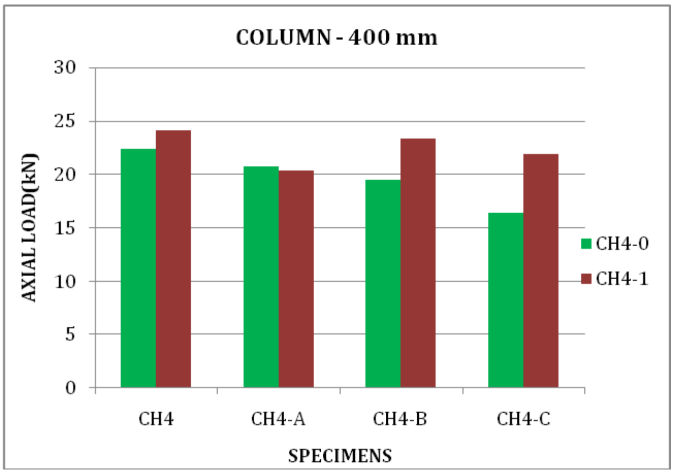
Figure 3 – Failure – Local Distortional buckling

Axial loading capacity comparison

The ultimate capacity of the 12 specimens is given in Table 6. The load carrying capacity of the strengthened column was increased by externally bonded CFRP. The column CH4 carried more loading capacity than the column CH5. The loading capacity of the two different sample sections is shown in Graph 1 & Graph 2.



Graph 1 – Loading Capacity - 500 mm Channel



Graph 2 – Loading Capacity - 400 mm Channel

Table 6 – Comparison of analytical and experimental results

Sample	Specimen	Length of the column (mm)	By Analytical solution as per IS 801:1975 (kN)	By Experimental using LVDT (kN)
Cold formed channel section without CFRP	CH5-0A	500	20.16	20.5
	CH5-0B			18.5
	CH5-0C			13.7
	CH4-0A	400	22.39	20.7
	CH4-0B			19.5
	CH4-0C			16.4
Cold formed channel section with CFRP	CH5-1A	500	22.02	19.7
	CH5-1B			22.1
	CH5-1C			19.1
	CH4-1A	400	24.14	20.4
	CH4-1B			23.3
	CH4-1C			21.9

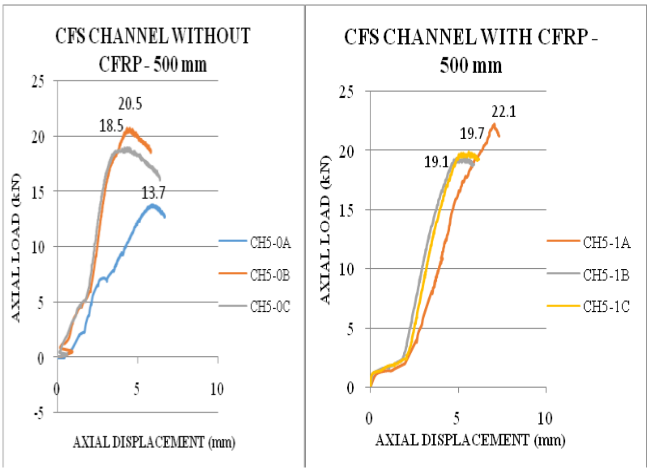
Debonding of CFRP wrapping

For some specimens the adhesive was not good enough to attain the ultimate capacity due to the bonding parameters and wrapping of fiber. In some specimens, the capacity has not been increased as much as the design due to the fiber orientation and adhesive agent. The debonding effect is shown in Figure 4

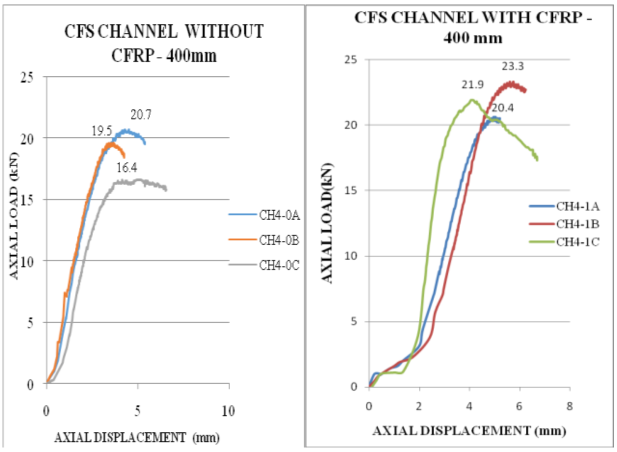
Figure 4 – Debonding

Load Vs Axial Deformation

The result for the load and the corresponding deformation of the 12 specimens were shown in Graph 2 &3. The graph illustrates that the load carrying capacity does not attain the strength as per design prediction for some specimens. The CFRP fabrics have enhanced the load carrying capacity specimens when compared to control columns. The displacement of the strengthened section not showed much variation than that of the control sections.



Graph 1 - 500 mm Channel section



Graph 2 - 400 mm Channel section

5. CONCLUSIONS

The advantages of using CFRP strips in cold formed steel channel section column were investigated with two different parameters such as effective wrapping of CFRP and its orientation. Based on the test results of 12 columns, the following conclusions have been drawn.

1. The columns with length 400 mm showed more effect on load bearing capacity rather than 500 mm length column after wrapping CFRP strip on the web and flange portions.

2. By placing CFRP, the percentage of load carrying capacity of CH5-1 and CH4-1 sections were increased 7.2 % and 11.4 % when compared with the specimens CH5-0 and CH4-0 which are not wrapped by CFRP.

3. The local distortional buckling failure mode of the CFRP specimen does not showed the effect on ductility performance though with the presence of the CFRP layers.

4. On some specimens, the adhesive property was not enough to give full bonding strength and due to this the peeling of strip was observed.

5. Based on the experimental results an analytical model was proposed to determine the load carrying capacity and reduction in deformation of the CFRP strengthened cold-formed double open channel section.

ACKNOWLEDGEMENT

I thank the faculty members of structural engineering laboratory of Thiagarajar College of Engineering for completing this work more successfully.

REFERENCES

[1] Jun Ye, Iman Hajira souliha, Jurgen Becque and Kypros Pilakoutas (2016) "Development of more efficient cold-formed steel channel sections in bending" Thin walled structures 101 (1-13)

[2] Hélder D.Craveiro, João Paulo, C.Rodrigues and LuísLaím (2016) "Buckling resistance of axially loaded cold-formed steel columns" Thin-Walled Structures 106-358–375

[3] Mehran Zeynalian , Adele Shelley and H.R. Ronagh (2016) "An experimental study into the capacity of cold-formed steel truss connections" Journal of Constructional Steel Research 127 - 176–186

[4] M.A. El Aghoury , A.H. Salema, M.T. Hanna and E.A. Amoush (2015)"Strength of cold formed battened columns subjected to eccentric axial compressive force" Journal of Constructional Steel Research 113-58–70

[5] W.F. Maia , L.C.M. Vieira, B.W. Schafer and M.Malited (2016) "Experimental and numerical investigation of cold-formed steel double angle members under compression" Journal of Constructional Steel Research 121-398–412

[6] Mohamed Dabaon, Ehab Ellobody and Khaled Ramzy(2015) "Nonlinear behaviour of built-up cold-formed steel section battened columns" Journal of Constructional Steel Research 110-16–28.

[7] J.G. Teng , T. Yu and D and Fernando (2012) "Strengthening of steel structures with fiber-reinforced polymer composites". Journal of Constructional Steel Research 78-131–143

[8] Kent A. Harries, Andrew J. Peck and Elizabeth J. Abrahamb (2009)"Enhancing stability of structural steel sections using FRP". Thin-Walled Structures 47- 1092–1101

[9] Nuno Silvestre, Dinar Camotim, and BenYoung (2009). "On the use of the EC3 and AISI specifications to estimate the ultimate load of CFRP-strengthened cold-formed steel lipped channel columns" Thin-Walled Structures 47-1102–1111

[10] Joyson Silva P and Dr. P Jayabalan(2013). "Finite element analysis of CFRP strengthened hot rolled steel column". International Journal of Conceptions on Mechanical and Civil Engineering. Vol. 1-ISSN: 2357 – 2760